ITS AMERICA

Beyond 5.9 V2X Deployment Plan

This document provides an analysis of the current landscape and future outlook of Vehicle-to-Everything (V2X) communication technologies outside of 5.9 GHz direct V2X. By examining the definitions, architectures, and functional deployments that comprise this "Beyond 5.9" ecosystem, this document provides insights and guidance for a broad array of stakeholders navigating the complexities of V2X deployment and adoption. The adoption of a diverse, multi-pronged approach to our V2X communications ecosystem will create a foundational baseline that will allow the U.S. to set the standard for creating more expansive, flexible, and interoperable V2X systems at scale. Through widespread V2X deployment, we can achieve improvements in roadway safety and make meaningful progress toward Vision Zero, while fostering a smarter and more efficient transportation system that is safer for all road users.

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Introduction

Vehicle-to-Everything (V2X) communications describe the exchange of digital information between vehicles and the world around them. V2X communications encompass a broad array of communication types, including connections between vehicles and other vehicles (V2V), pedestrians (V2P), infrastructure (V2I), and other networks (V2N). This array of connections enables a whole new range of roadway safety solutions and automotive features, thereby opening the door for a paradigm change in the automotive space and broader transportation industry. V2X technologies are anticipated to play an integral role in the continued improvement of automotive transportation and infrastructure in the 21st century, by enhancing safety, traffic efficiency, and environmental impacts in the short term, and by laying a critical foundation for the continued proliferation of advanced technologies such as autonomous vehicles and smart, connected infrastructure in the future.

All wireless digital communications – including those envisioned within the umbrella of V2X – are delivered over the radio frequency spectrum. In the United States, regulatory policy and rulemaking in this spectrum is overseen by the Federal Communications Commission (FCC), which allocates specific spectrum bands for various communication purposes. Since 1998, the FCC has designated the 5.9 GHz spectrum for V2X communications, which is expected to facilitate high-throughput, low-latency, near real-time communication among numerous assets on the road. Operating in the designated band for automotive safety, C-V2X (cellular vehicle-to-everything) technology over 5.9 GHz (also known as "direct V2X"), will remain a crucial focus in discussions surrounding V2X.

However, over time, complementary end-to-end V2X solutions that utilize segments of the radio frequency spectrum outside of the 5.9 GHz frequency band have emerged or could be developed. These solutions, such as cloud-based, network-supported V2X applications harnessing Long-Term Evolution (LTE) and 5G networks, as well as U-NII Band and mmWave, present new possibilities to deploy and enhance V2X technologies on a broad scale. The practical implementation of many of these V2X solutions beyond the 5.9 GHz band has already been demonstrated through deployments by infrastructure owner-operators (IOOs), fleet managers, and consumer vehicles across the country. ITS America believes that the United States must encourage a holistic approach to V2X communications, both inside the 5.9 band and beyond it.

These direct and networked V2X solutions provide an opportunity for all industry stakeholders to increase the dependability, robustness, and scale of V2X applications by leveraging connectivity across a broad array of approaches, reflecting both the diverse requirements of individual states and communities as well as the relative strengths and benefits of each segment of spectrum. The adoption of a diverse, multi-band approach to our V2X communications ecosystem will create a foundational baseline that will allow the U.S. to set the standard for creating more expansive, flexible, and interoperable V2X systems at scale.

This document provides an informed analysis of the current landscape and future outlook of V2X communication technologies outside of 5.9 GHz direct V2X. By examining the definitions, architectures, and functional deployments that comprise this "Beyond 5.9" ecosystem, this document provides insights and guidance for a broad array of stakeholders navigating the complexities of V2X deployment and adoption.

Networked V2X

Networked V2X refers to the ability for vehicles, infrastructure, and other users and assets on the road to exchange data with one another using network-based systems, outside the 5.9 GHz band. Utilizing networked V2X, vehicles can communicate with each other and the environment around them over the same type of networks that enable other modern connected technologies, such as cell phones.

When the FCC first set aside the 5.9 GHz band of spectrum for V2X communications in 1998, policymakers understood that dedicated spectrum was essential for near real-time vehicular communications due to the technical limitations of cellular networks and centralized data processing systems. Since that time, significant technological advancements in network performance and cloud computing – driven in large part by the widespread adoption of cell phones – have transformed the capabilities of network-based solutions in the V2X space. Modern LTE and 5G networks now provide high enough reliability and low enough latencies for a wide range of V2X use cases, while cloud platforms can increasingly ensure timely data analysis and dissemination. Furthermore, the emergence and integration of edge computing – another product of the cloud revolution – brings data processing closer to the source, further reducing response times and latency. While these developments in network capabilities in no way diminish the need for dedicated spectrum – indeed many use cases in the transportation industry require it – networked V2X provides new opportunities to deliver V2X applications.

Common Networked V2X Architectures

Cellular-Supported V2X

While networked V2X systems can technically leverage any kind of network for communication, the most common example of networked V2X today involves vehicles using cellular networks – 4G LTE (Fourth Generation) or 5G (Fifth Generation) – to enable a variety of V2X use cases. In these systems, infrastructure, vehicles, and users wirelessly send and receive information to and from external systems and platforms over cellular networks. These systems and platforms can include public or private data exchanges, safety-enhancing applications, and other endpoint devices. By utilizing cellular networks for communication, networked V2X systems can accomplish a growing array of V2X use cases on any vehicle or asset that has cellular connectivity that meets the technical requirements of the given platform and use case.

Network Edge

V2X can be further enhanced through the utilization of Network Edge, which seeks to minimize latency and feedback loops in networked V2X systems by deploying cloud data centers and endpoint devices much closer to the vehicles and infrastructure using the network. This approach consists of physically relocating computing resources and software applications from centralized cloud data centers – which are typically located in geographically distributed locations – to the network's "edge," which is near the connected vehicles and assets themselves. Network Edge can be further enhanced with architectures such as Mobile Edge Computing (MEC), in which data processing and storage occur closer to the 5G base station, thereby reducing network hops and their corresponding latency impacts. By processing data on local servers or even within vehicles themselves, networked V2X communications can begin to approximate the real-time responsiveness once thought only possible over dedicated spectrum.

Primary Distinctions Between Direct V2X and Networked V2X

Both direct V2X and networked V2X offer industry stakeholders viable pathways for achieving specific V2X use cases and outcomes, but each approach is distinct with unique benefits, constraints, and other considerations. Understanding their differences is essential for optimizing their respective applications in enhancing road safety and efficiency.

Intermediate Nodes vs. Direct Connection

A fundamental distinction of networked V2X is that, unlike direct V2X, it requires information to travel through intermediate nodes before reaching its final destination. Any communication from a vehicle or asset connected through networked V2X must, by definition, first pass through some kind of intermediary network, system, or platform before reaching another vehicle or asset with which it seeks to communicate. Historically, the additional time required for this passage of information through a network has effectively prevented V2X applications from being deployed effectively through this method, as the additional latency created the potential for data to take too long to reach its destination in a timely manner. However, the remarkable evolution and advancement of cellular networks and cloud-based computing have significantly reduced these latency concerns, enabling a wide number of V2X applications to be achievable over modern networks. This, in turn, reduces the barriers to adoption for those V2X capabilities in vehicles and infrastructure by using the network-supported platforms with which vehicles and assets already connect.

Long Range vs. Short Range

Another key distinction between direct V2X and networked V2X is the types of use cases for which each approach is best suited. Direct V2X communications offer unparalleled speed and responsiveness by eliminating the need for data to traverse intermediary points such as a cloud. In the case of direct V2X, information flows directly from one point to another without delay, making it ideal for split-second scenarios on the road where immediate action is needed to prevent collisions or emergencies. In contrast, networked V2X systems will always inherently come with some degree of delay – even if that delay is increasingly reduced by improvements in network connectivity – as data passes through the cloud, potentially hindering the rapid transmission of critical information in particularly time-sensitive situations. Consequentially, networked V2X is currently best suited for “long reach” V2X applications, such as delivering alerts and warnings to drivers about road conditions and hazards that they are likely to approach in 30-60 seconds, while direct V2X is currently the only suitable solution for applications with sub-second communication requirements like imminent collision prevention and pedestrian avoidance.

Network Coverage Requirements

Network coverage requirements vary between direct V2X and networked V2X communication systems. Direct V2X communications utilize C-V2X technology, which uses the PC5 Interface to enable direct interaction between vehicles and other road users. In the PC5 Interface, a vehicle or roadway asset (referred to as a UE, or User Equipment) communicates directly with another UE over a direct channel, without any requirement for communication with a base station. In contrast, most networked V2X communications operate on traditional cellular networks or edge-supported local networks, using cellular connectivity over the Uu Interface, which defines communication between UE and a base station. This communication enables equipped vehicles and roadway assets to send and receive information through the network in the same way that information is transmitted between cell phones and other mobile devices.

While participation in direct V2X requires vehicles and assets to be equipped with C-V2X technology, participation in networked V2X only requires vehicles and assets to be equipped with everyday cellular connectivity and be operating in an area with appropriate network coverage.

Security and Authentication

One of the pillars of any V2X service or application is security. In direct V2X, the authentication and secure transfer of information between vehicles and other roadway assets is achieved through hardware-based certificates within what is known as the Security Credential Management System (SCMS). The SCMS provides a common set of security policies that can be relied upon to provide critical security functions in the ad-hoc networks created by directly communicating equipment. The interconnected nature of networked V2X, in which data enabling V2X travels through intermediate and unique systems and platforms, fundamentally requires a different approach to security that brings a distinct set of benefits and tradeoffs. Security in networked V2X is achieved through compliance with the unique requirements of each platform through which information is passed. For instance, every automaker that operates a cloud platform to deliver services to network-connected vehicles is responsible for the security and integrity of its platform and the data it ingests, and automakers must maintain rigorous and robust requirements for suppliers that connect with their platform. V2X applications and service providers that serve as originators or intermediaries of V2X data must meet these requirements to deliver data for V2X services, while also ensuring the security and resilience of their own systems. In this way, the technological security and authentication requirements for networked V2X are delivered and enabled through these intermediary nodes.

Benefits of Networked V2X

Network Infrastructure Already in Deployment

One of the great benefits of networked V2X is the vast potential for implementing V2X solutions which utilize the existing cellular networks already in deployment, enabling any cellular-connected vehicle, asset, or piece of infrastructure to connect and communicate with one another via this robust national infrastructure. Vehicles equipped with 4G LTE or 5G technology can leverage this connectivity to achieve V2X use cases and applications almost anywhere with sufficient cellular network connectivity. This significantly improves the prospect of rapidly delivering certain V2X applications, in comparison to other communications methods. With their established network reliability, expanding coverage, and continual improvements in data throughput, LTE networks provide a robust foundation for expanding connectivity and enabling networked V2X deployments by IOOs, automakers, and fleet operators, including public safety and municipal fleets. Furthermore, concerns regarding cellular network congestion are being addressed through ongoing evolution and improvements in LTE and 5G networks. Solutions such as network slicing, dedicated bandwidth allocations, and optimizations can ensure reliable and efficient V2X communications over LTE. Additionally, the transition of most cellular devices to 5G networks over time is likely to enhance V2X capabilities in the transportation ecosystem by providing higher data speeds, reducing latency, and increasing capacity for simultaneous connections.

Automotive Connectivity Already in Deployment

According to Wards Intelligence, there are approximately 134 million connected vehicles on North American roads today, representing 36% of all consumer vehicles.[1] By 2035, the fleet of connected consumer vehicles is anticipated to exceed 305 million. This rapid expansion of connected vehicles is due to the prioritization of connected services in vehicles by automakers. As of 2023, approximately two-thirds of all cars sold in North America came with embedded connectivity, and a growing number of automakers today offer cloud-based connected services as a standard feature on vehicles.[2]

To date, this connectivity has primarily been leveraged to provide services related to safety and security, maintenance, remote access, multimedia, and navigation, but the exciting potential of harnessing this same connectivity for interoperable communication between vehicles, infrastructure, and other roadway assets provides a transformative step towards enhancing safety and other benefits for the entire transportation system. Furthermore, the nature of modern cloud-connected cars offers the ability for automakers to provide over-the-air (OTA) updates, delivering new functionality to vehicles even after they are manufactured and deployed on the road. Network connectivity also enables remote updates and maintenance of V2X systems, allowing for the deployment of new features, bug fixes, and security patches without necessarily requiring vehicles to be physically serviced. In this way, networked

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[1] Available via Wards Intelligence https://wardsintelligence.informa.com/wi967779/global-connected-vehicle-forecast-2024--2035

[2] Cloud-based connected services are standard in the vehicle market today, see McKinsey & Company, ABI research, Stellantis Media - Uconnect Newsroom (stellantisnorthamerica.com), Bluelink | MyHyundai (hyundaiusa.com);

V2X offers the promising opportunity to bring the benefits of V2X to millions of vehicles already on the road today, enabling a faster adoption and speed to market for automakers.

Interoperability By Design

With all V2X, interoperability is essential, as it is intended to enable individual vehicles to communicate and exchange information with other road users and the road infrastructure. Interoperability in any V2X exchange necessitates careful system design such that data navigating across multiple systems and networks can be well-defined and properly recognized throughout all exchanges. For example, with direct V2X, communication is broadcast directly between vehicles and assets over a short range, and interoperability is envisioned as an ideal state where any device that complies with an application standard can participate in those V2X exchanges. This interoperability also requires conformity to a common set of lower layer communication protocols. By contrast, networked V2X can leverage clouds and involve mobile network operators (MNOs) with different coverage, quality of service, and enterprise arrangements. In these exchanges, interoperability manifests differently, occurring between distinct V2X service providers and users as service-level interoperability in which information passes between proprietary systems that do not require design conformity and operation at lower communication layers. While those V2X end actors do need to interoperate as well with network edge devices at the lower layers, this exchange typically happens over well-established cellular or Wi-Fi network protocols, so it is not a point of emphasis.[3] As a result, in designing and deploying end-to-end networked V2X solutions, interoperability must be directly defined into the systems and applications that transmit data between independent systems and assets. Implementation of nationwide interoperability with these considerations is paramount to the end-to-end promise of the V2X system of systems described in this document.

Ideal V2X Applications in a Networked Model

For decades, V2X stakeholders and practitioners in the United States envisioned a transportation ecosystem in which V2X applications would be enabled, supported, and delivered through a single technological approach (direct V2X over the 5.9 GHz band). Operating under this assumption, numerous distinct V2X applications have been identified and defined by the V2X community, from imminent vehicle and pedestrian collision prevention to emergency vehicle and work zone notifications. The emergence of networked V2X as a viable approach for achieving V2X outcomes provides stakeholders with a new option for deployment that complements direct V2X but raises intriguing questions around the suitability of various V2X applications for a given approach. While there is no definitive division of which V2X applications are best achieved over direct V2X versus networked V2X,[4] a general framework

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[3] Interoperability between cellular networks has been a longstanding function and tradition of cellular network operation in the United States, already providing seamless communication between any cellular-connected devices and assets regardless of carrier.

[4] As an example of a similar but distinct analysis of this topic, reference ITS America's *Future of V2X in 5.9 GHz Report*, which identifies suitable modalities of communication (direct V2X or networked V2X) for each V2X application. Available at: https://itsa.org/wp-content/uploads/2024/05/ITS-America-Future-of-V2X-in-5.9-GHz-Report.pdf.

of analysis can provide automakers and transportation agencies with a starting point for determining which strategies should be utilized for specific applications.

Framework of Analysis

V2X applications and services can be broadly divided into two categories: safety-related services designed to ensure the protection and wellbeing of road users, and convenience services that offer quality-of-life improvements to transportation users such as saving time, reducing effort, or providing ease of access to various road assets. Safety-related services can be further subdivided based on a vehicle's temporal proximity to a life-threatening situation as either "safety enhancing" or "safety critical" as shown in Figure 1.

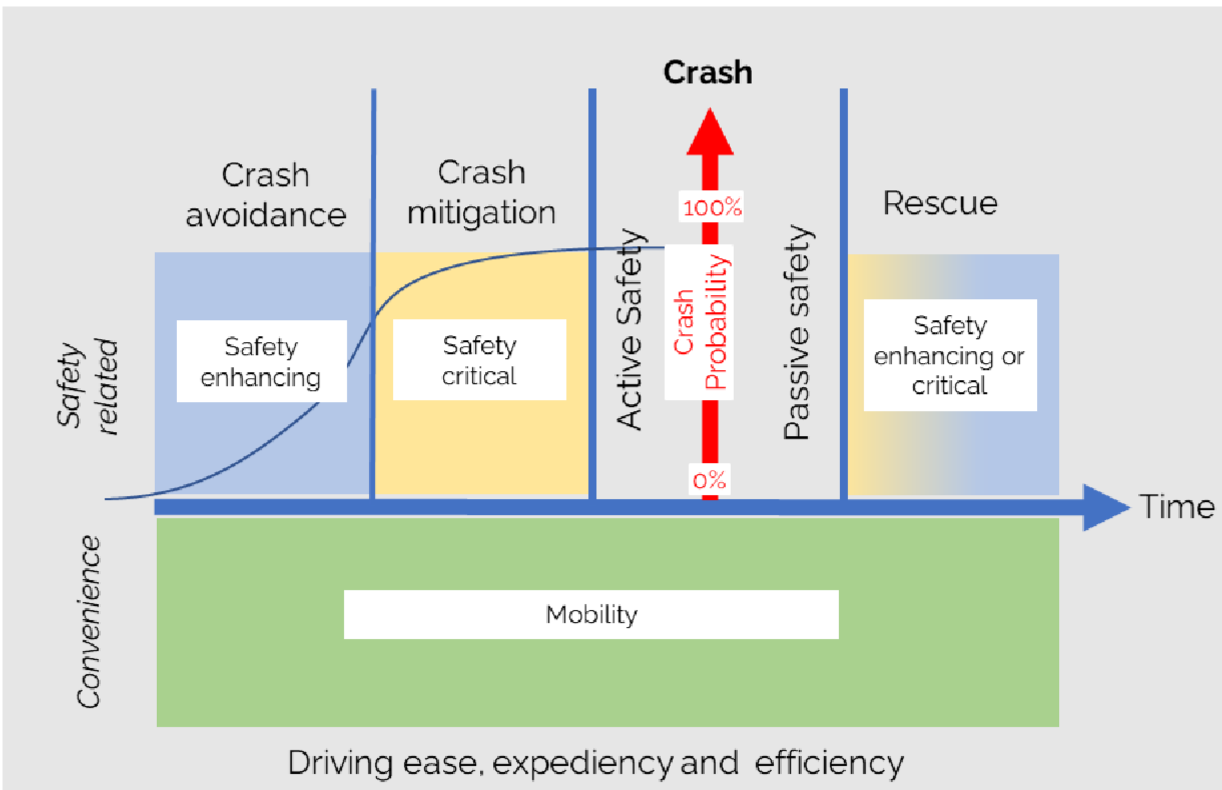

Figure 1: V2X Service Typology

These services are explored in further detail below:

A. Safety Critical Services

Safety critical services improve the safety of road users by mitigating collisions. Services that support rescue operations following a collision, such as 9-1-1, may also be deemed safety critical. Such services operate in a regime immediately preceding a vehicle collision while there is still sufficient time for intervention or immediately following the collision. The operating timeframe for such services is fractions of a second.[5] The service delivers notifications to the vehicle operator (human or automated) in the form of warnings through vehicle collision avoidance systems, which can be integrated with ADAS.

B. Safety Enhancing Services

Safety enhancing services improve the safety of road users through collision prevention. Such services provide timely and relevant information to the driver when there is ample opportunity to avoid a collision or upcoming hazard. The operating timeframe for such services is in the order of many seconds to possibly minutes. Drivers are made aware of the hazard through some vehicle interface, such as the infotainment system or instrument cluster. These notifications are distinct from ADAS and are not necessarily tethered to any vehicle automation, though they can be used to inform or complement such systems.

C. Mobility Services

Mobility services deliver non-emergency information to vehicle occupants through vehicle infotainment systems during normal vehicle operations when the driver and vehicle are not at risk of a collision or hazard. Through monitoring the driving and vehicle operation, mobility services such as eco-approach and departure can enhance travel efficiency through applications and features that improve traffic flow, reduce energy consumption, and reduce transit time, while also contributing to a reduction in congestion that often leads to unsafe roadway conditions.

The key differentiator between these various types of V2X services is ***service risk,*** which in this context can be defined as the likelihood of a V2X service failure and the significance or magnitude of its consequence. The concept of risk is explored and defined across many transportation industry practices such as Failure Modes and Effects Analysis (FMEA), Automotive Safety Integrity Level (ASIL), Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems (IEC 61508), and similar frameworks in related industries. In the most rudimentary form, risk is just a product of severity and probability of service failure.

The distinct nature of these three V2X service categories is reflected in the significant difference in requirements that are necessary for a given service to be viable. Generally, these three service categories carry different levels of acceptable service risk:

- Safety Critical V2X Services – **high** risk
- Safety Enhancing V2X Services – **medium** risk
- Mobility V2X Services – **low** risk

Higher service risks carry more rigorous requirements and necessitate stronger adherence to legal, regulatory, and standards (industry and enterprise specific) practices.

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[5] In this use, the “operating timeframe” for a V2X service is defined as the time period just prior to initiating a V2X-enabled evasive maneuver. If the vehicle is operated by a human, the operating timeframe must contemplate the typical reaction time of the driver, which inevitably reduces the overall temporal budget for detecting, communicating, and acting on the perceived hazard. Contemporary ADAS systems, which can detect, transmit and process information utilizing onboard sensors and networks in 100s of milliseconds or faster, provide a reference benchmark.

The consequence of service failure in V2X corresponds directly with service classifications in self-evident ways. By definition, the failure of Mobility Services will not lead to loss of life (the most precious of value metrics); in contrast, the failure of Safety Critical services carries much more risk because the services operate in relation to imminent roadway hazards. Gauging the likelihood of service failure is more complex, given the range of factors and variables that contribute to the successful functioning of a given V2X service, but can fundamentally be understood as the reliability of information delivery. In V2X, reliability is measured through three information delivery characteristics:

1. Success Rate
   The mean and variance of the proportion of sent V2X messages that are successfully received by the recipient within the operating timeframe of the service.[6] This characteristic is often expressed alternatively as "delivery failure rate."

2. Latency
   The mean and variance of the elapsed time between sending and receiving a V2X message. Lower latency is associated with higher information relevance, and smaller variance reflects more reliable delivery.

3. Ubiquity
   The proportion of localities where two roadway entities (e.g. vehicles, infrastructure assets, and pedestrians) that may be involved in a potentially precarious situation have access to the necessary technology, infrastructure, and/or applications to electronically communicate, whether directly or indirectly.

High success rate, low latency, and high ubiquity correspond to higher service reliability, which subsequently implies a lower probability of service failure. Consequently, V2X technologies that feature such characteristics are most appropriate for high-risk Safety Critical services. Similarly, V2X technologies that have lower reliability – whether in low or unpredictable delivery success rate, higher or unpredictable latency, or low ubiquity – are more appropriate for low-risk services (Mobility Services). The minimum requirements for V2X services are summarized below.

Service Type	Failure Consequence	Success rate	Latency	Ubiquity
Safety critical	High	High	Low	High
Safety enhancing	Medium	Medium	Medium	Medium
Mobility	Low	Low	High	Low

These requirements are best understood as the minimum conditions for a V2X solution to be appropriate for a given service. In other words, a more capable solution could be used to deliver a low-risk service, but other practical considerations may diminish its viability. For example, the solution may be costly, or the technology may not be available at the penetration rate required to make it practical.

[6] Note that "time to incident," which distinguishes safety critical from safety enhancing services, can also be expressed in terms of distance from a given hazard for a given vehicle speed. As a result, communication range is sometimes referenced as a requirement under certain assumptions about vehicle speed to simplify conformance testing.

However, the reverse is not possible – a less reliable solution cannot be used for high-risk services. Simply put, safety of life must never be compromised. This fact is reinforced by legal and regulatory constraints (e.g., FMVSS requirements) imposed on the transportation industry to ensure that the public is protected. Moreover, development of products for safety critical services follows industry practices that adhere to rigorous standards and guidelines to ensure that consumer products are designed and built with the maximum possible reliability.[7]

Applications Achievable in Networked V2X

Given that networked V2X utilizes cellular networks to enable V2X applications and services, a consideration of cellular network characteristics and functionality can provide insight into the role that networked V2X can play in the broader V2X ecosystem. In the United States, cellular networks are undergoing constant improvement and expansion; as such, any declarative determination of their capabilities is temporary to a degree, and likely to change as time passes. Nevertheless, an analysis of contemporary cellular networks offers a valuable perspective on the role that they can play in supporting and achieving V2X deployment. Contemporary cellular networks can be characterized as follows:

Characteristics	Rating	Rationale
Success Rate	High	Most cellular networks deployed today are rigorously designed, built, tested, and maintained in order to deliver information reliably. Sometimes this is done at the expense of higher latency. For example, certain network protocols include acknowledgement and retransmission of information in order to ensure delivery, at the expense of added latency.
Latency	Medium	Modern network technology is demonstrably capable of delivering information with low average latency and variance. However, deployed networks feature a wide range of service capabilities reflecting the diversity of carriers and installed technology, and which can be employed by specific traffic classes. Deployment of such traffic class capabilities is essential for enabling highly reliable low-latency services while maintaining wide scale support for the broader population. As a result, the expected average latency and variance in practice can vary, with medium being predominant.[8]
Ubiquity[9]	Medium	Most of the United States today benefits from some kind of cellular network coverage, driven in part by the rapid growth of cell phone

[7] Examples of this are ISO 26262 (functional safety), UNECE 1556/166 (vehicle cybersecurity) and the SAE family of V2X standards including J3161, J2945, J2735. For a good summary of applicable SAE standards see https://5gaa.org/united-states-vehicle-to-infrastructure-communications-day-one-deployment-guide/

[8] We note that this characterization is an assessment of capability when a network is available and endpoints are equipped with the appropriate technology. Coverage and availability is reflected in the ubiquity metric.

[9] Network capability is evolving rapidly. The introduction of hybrid (non-terrestrial) solutions, such as fixed wireless backhaul and low earth orbiting satellites, are likely to significantly alter and expand network coverage even further, and therefore should be monitored with some care. This analysis assumes purely terrestrial capability.

		adoption by consumers in the last 30 years. While there are still rural areas nationwide that lack robust coverage, ongoing national efforts to expand network coverage to these areas are continuously reducing the portion of communities not covered. The requirement for V2X coverage to be achieved by vehicles on the road regardless of the road user's cellular carrier introduces some complexity into this characteristic, as coverage by distinct carriers must intersect for V2X communications to be maximally effective. Nevertheless, the longstanding fundamentally interoperable nature of all cellular network coverage in the United States means that network ubiquity for the purposes of V2X can be assessed in the medium range.

Using the framework of analysis outlined previously, it can be surmised that V2X applications and services in the "Mobility Services" and "Safety Enhancing" categories are achievable today in networked V2X. Networked V2X can address a broad array of V2X applications and scenarios within the Safety Enhancing category in which information is delivered to vehicle operators about upcoming Safety Critical scenarios that may be outside of the line of sight, including:

- Active emergency vehicle incidents ahead
- Active emergency vehicles approaching
- Active construction and work zones ahead
- Active municipal vehicles (snow plows, school buses, etc.)
- Vulnerable road user activity at intersections and crosswalks
- Vehicles driving the wrong way
- Dangerous weather and roadway conditions

V2X applications within the Mobility Services category are also appropriate for networked V2X, including:[10]

- Parking
- Transit signal priority (public and commercial)
- Electronic payments (e.g., tolls)
- Traveler information
- Improved travel time reliability

As stated previously, the continuously evolving nature of cellular networks and technology in the United States means that the universe of V2X applications and services achievable through networked V2X is only likely to expand over time. Indeed, the fact that these applications were not achievable over networked V2X as recently as a decade ago demonstrates the significant impact that continuous

[10] A good resource for information regarding mobility services is the Connected Vehicle reference implementation reference architecture, which is available at https://local.iteris.com/cvria/html/applications/applications.html.

improvement in network capabilities can have on the V2X ecosystem. As such, industry stakeholders in the future should regularly assess the functional capabilities and sophistication of cellular networks on an ongoing basis to identify opportunities for expansion of networked V2X into more advanced applications.

Networked V2X Deployment Examples

Today, there are many communities across the country leveraging some form of networked V2X to achieve safer outcomes on roadways. In the past, the primary obstacle to V2X deployment at scale has been the challenge of getting various stakeholders – from automakers and IOOs to individual fleet operators – to adopt and leverage the necessary technology. Now, the broad accessibility of network connectivity has created a national ecosystem of networked V2X applications, solutions, and deployments, demonstrating this approach's transformational opportunities. To further illustrate the effectiveness and practicality of networked V2X, we briefly highlight examples of successful networked V2X solutions already in deployment.

Digital Alerting

In May 2023, global automaker Stellantis released its new Emergency Vehicle Alert System on nearly 1.8 million vehicles across North America.[11] The system integrates the automotive's cloud infrastructure with a commercial digital alerting platform from HAAS Alert called Safety Cloud, enabling the delivery of V2X safety notifications into Jeep, Dodge, Chrysler, and RAM consumer vehicles from emergency vehicles, municipal vehicles, work zones, and tow trucks.[12] These notifications – called digital alerts – are delivered to drivers through the infotainment screen approximately 30 seconds in advance of a Stellantis vehicle approaching an alerting vehicle or hazard, providing the driver with a potentially lifesaving advance warning ahead of unexpected situations on the road. To broadcast these alerts, fleet operators and agencies equip their vehicles with the service, either with an aftermarket transponder device or through an integration with a Safety Cloud partner. Currently, more than 3,500 fleets and agencies are equipped to deliver alerts to Stellantis vehicles, distributed nationally in every U.S. state as well as in Canada. Safety Cloud is available as an activatable service through more than 50 companies including telematics providers like Samsara and Geotab, fleet connectivity solutions like Cradlepoint, and emergency vehicle equipment manufacturers such as Pierce, Rosenbauer, Seagrave, and Whelen. Connected infrastructure manufacturers, including Applied Information, Tapco, Wanco, and SolarTech also offer digital alerting integrations, expanding the service capability to warn drivers about pedestrian crossings, work zones, wrong way drivers, and more. Safety Cloud alerts are also distributed on navigation platforms such as Waze and Apple Maps, providing notifications regardless of the age or type

[11] See https://www.stellantis.com/en/news/press-releases/2023/may/safely-aware-industry-leading-v2x-activation-equips-1-8-million-stellantis-vehicles-with-emergency-vehicle-alert-system.

[12] EVAS alerts are a standard safety feature included with Stellantis' connected services platform uConnect, which comes included with new vehicle purchases at no cost for a ten-year period as of this writing. The alerts are available on model year 2018-and-newer Jeep, Dodge, Chrysler, and RAM vehicles.

of vehicle being operated. For an example of a fleet's deployment of Safety Cloud, see the published use case of DC Fire and EMS in the *ITS Technology Use Case Library* published by ITS America.[13]

Traveler Information Messages

One of the most widely known examples of networked V2X in ITS is real-time traveler and navigation information delivered through smartphone apps such as Waze, Apple Maps, Google Maps, and similar applications. The power and utility of this information is derived directly from the comprehensive and growing dataset of connected transportation assets (roads, POIs, events, traffic stops and signals, etc.) that IOOs and other stakeholders generate and aggregate on cloud platforms for distribution. The information is geolocated and delivered to devices in vehicles based on their relative position through cellular networks. These applications have been adapted and improved continuously to minimize distraction and are typically delivered in vehicles' central stacks through embedded platforms such as Android Auto and CarPlay, enabling their safe use in a way that effectively achieves V2X outcomes without requiring native vehicle functionality.

Freight and Transit Signal Priority

Freight Signal Priority (FSP) systems aim to streamline the flow of freight transportation in urban areas. By giving priority to freight vehicles at signalized intersections, FSP systems look to enhance efficiency, minimize delays, and promote sustainability. This emphasis on improving freight movement is particularly important in regions serving as significant logistics and distribution hubs, where efficient freight transportation is crucial for economic growth. Similarly, Transit Signal Priority (TSP) systems are used to improve the efficiency of public transportation, particularly buses and trams. By reducing delays for public transit vehicles and improving the overall transit system reliability, TSP can incentivize and encourage broader utilization of transit systems by the public. TSP systems often utilize GPS technology and cellular communication to track bus locations and enable them to request priority at traffic signals. TSP systems have been deployed by several public transportation authorities including the New York City Transit Authority, the City of Portland, the San Francisco Municipal Transportation Agency, the Los Angeles Metro, and King County Metro Transit in Seattle.[14] This V2X application – coordinated communication between vehicles and roadway infrastructure – is an example of a Mobility Service that is not related to safety, but nevertheless improves transportation functionality for all participants.

Data Exchanges

In recent years, a growing number of states, cities, and Federal initiatives have launched data exchanges for connected vehicles and V2X services. Data exchanges are essentially data feeds – typically operated by IOOs – that aggregate information about roadway conditions into a single authoritative source that

[13] Available at https://itsa.org/wp-content/uploads/2024/05/Use-Case-Library-Final_DI-Week.pdf.
[14] See https://www.gtt.com/project/new-york-mta-signal-priority/; https://blog.trimet.org/2022/09/08/transit-signal-priority-101-technology-keeps-buses-out-of-traffic/; https://www.sfmta.com/sites/default/files/reports-and-documents/2023/02/bus_transit_signal_priority.pdf; https://www.itskrs.its.dot.gov/2008-b00544; and https://kingcounty.gov/en/dept/metro/about/data-and-reports/-/media/depts/metro/schedules/ready-when-you-are/tsp-policies-and-strategies-7-22-2021.pdf.

can then be shared and disseminated to other systems, platforms, and applications. One well-known example of this is the WZDx (Work Zone Data Exchange) initiative that was formally launched to the public by the Federal Highway Administration (FHWA) in 2023. The WZDx initiative provided states with a standardized data format for describing, sharing, and distributing timely information about work zones and roadway construction to navigation platforms and OEMs. Multiple states, including Arizona and Michigan, have subsequently used the WZDx format to create publicly accessible feeds for work zone data, which can be freely utilized by transportation stakeholders to map active work zones for the purposes of digital alerting, rerouting, and more. These feeds are harnessed via networked V2X, leveraging cloud-to-cloud communication between the IOOs that manage them and the external systems that integrate the data into their platforms.

Deployment Guidance for Networked V2X

ITS America believes that the United States must encourage, facilitate, and support the deployment and adoption of networked V2X capabilities. To this end, we have developed a set of recommended actions, initiatives, and efforts designed to achieve this outcome. Our recommendations target five key stakeholder groups: Federal Agencies and Policymakers, Public Fleet Operators, Infrastructure Owner-Operators, and Automakers. These groups play vital roles in shaping a synchronized, efficient, and safe transportation network. Actionable guidance is provided for each group, and as we delve into the specifics for each group, stakeholders are encouraged to view these recommendations not as isolated directives but as interconnected pieces in a larger vision, propelling the United States towards a transformative transportation future with a thriving V2X ecosystem.

Federal Agencies and Policymakers

For Federal agencies and policymakers, we recommend:

- Include Networked V2X in V2X Programs: Historically, all Federal efforts and programs for deploying V2X on American roads have been focused on direct V2X over the 5.9 GHz band. While protecting this band for V2X purposes and successful direct V2X deployment remains an urgent national priority, the emergence of networked V2X provides the United States with an opportunity to prevent countless collisions, injuries, and deaths in a much shorter period of time. Moving forward, we recommend that any and all Federal programs related to V2X deployments explicitly include interoperable networked V2X solutions as an eligible use of funds. Providing stakeholders with the opportunity to deploy networked V2X alongside direct V2X solutions will bring V2X capabilities sooner to millions of vehicles already on the road today.

- Fleet Modernization Fund: To fortify the safety and efficacy of public services, a dedicated fund should be established to equip all public safety and emergency vehicles with cellular connectivity for networked V2X accessibility alongside direct V2X capabilities. Additionally, incorporation of digital alerting capabilities as an eligible funding activity in this category can further drive immediate adoption and deployment of V2X applications, providing lifesaving benefit to communities and road users.

- Federal Fleet Standards: Policymakers should explore the development and implementation of a Federal mandate requiring all Federal fleet vehicles to have basic LTE or 5G cellular connectivity by 2030 alongside direct V2X capabilities. Such connectivity will enable the activation and utilization of networked V2X across these fleets. In addition to ensuring efficient intercommunication among Federal assets and maximizing their operational efficiency, this will spur the adoption and ongoing development of LTE- or 5G-based V2X applications among automakers while also driving adoption downstream to state and local fleets.

- Research on the Impact of Digital Alerts on Distracted Driving: A significant number of V2X applications and services are predicated on delivering information about roadway conditions and hazards to human-operated vehicles, and the adoption of networked V2X functionality on millions of vehicles today is already conditioning drivers to expect more connectivity and communication between their vehicles and the world around them. There is very little Federal research or guidance on the impact of these notifications on driver behavior, despite the requirement for entities like State Highway Safety Offices to assert and demonstrate the efficacy of technologies like networked V2X when seeking Federal funds for deployment. By funding targeted research into how digital alerts and similar V2X notifications affect driver situational awareness, focus, and safety, the Federal government can more effectively require IOOs, OEMs, and other stakeholders to deploy and integrate these capabilities into the transportation ecosystem.

- Add V2X-Supported Safety Services into NCAP: The New Car Assessment Program (NCAP) provides critical guidance and standards for automakers in the manufacturing and selling of vehicles, and NCAP sets clear expectations of safe vehicle functionality and operations on American roadways. The National Highway Traffic Safety Administration (NHTSA) should incorporate functions, services, and applications into NCAP that can be achieved or delivered through networked and direct V2X, such as digital alerting, to better signal support to automakers for V2X deployment in vehicles.

- Mandating V2X in Automated Vehicle (AV) Fleets: Federal policymakers should require AV fleets to ingest all available networked and direct V2X data and roadway safety data from public agencies and fleets in any city where they are deployed to enhance safety and efficiency of AV operations. By integrating autonomous systems with existing V2X infrastructure and data systems, AVs can enhance their situational awareness, enabling them to make informed decisions and adapt their behavior accordingly. Additionally, this integration will enable AVs to proactively anticipate and respond to dynamic traffic conditions, road closures, crashes, and other incidents, ultimately reducing the likelihood of crashes and improving overall traffic flow.

- Clarify and Expand Digital Alerting Eligibility: Federal funding for digital alerting is already included in Section 405 of the National Priority Safety Program, providing a critical flow of dedicated funds to states for the purposes of deploying networked V2X on emergency vehicles and similar assets. This grant is jointly administered by FHWA and NHTSA at the Federal level and by the State Highway Safety Offices at the state level. Digital alerting should be formally expanded as an eligible technology and solution beyond Section 405(h) to Section 405(e) – which encompasses Distracted Driving – and Section 402 for improving driver behavior and reducing deaths and injuries from motor vehicle-related crashes.

- Work Zone Safety Fund: To enhance the safety and efficacy of work zones, dedicated funding should be allocated to allow subcontractors to retrofit key work zone assets or equipment with cellular connectivity. This would be pivotal in fostering connectivity and enabling networked V2X communications in work zones. Additionally, this funding could support the installation and integration of these new technologies, ensuring their effective utilization.

Public Fleet Operators

Public fleet operators are a critical stakeholder group for the proliferation of V2X in the United States. Many of the V2X applications envisioned by the broader connected transportation ecosystem are designed with these fleets in mind, from emergency vehicle and school bus notifications to warnings for snowplows, transit vehicles, and other publicly owned and operated vehicles. In this way, it is critical for public fleet operators to leverage networked V2X in ways that support the widescale adoption of V2X in consumer vehicles. For Public Fleet Operators we recommend:

- Equipping all public safety and emergency vehicles with cellular connectivity for networked V2X accessibility, enabling communication between vehicles and infrastructure and improving response times and overall safety on the roads.

- Collaborating with IOOs and transit authorities to deploy V2I functionality on vehicles, such as transit signal priority systems, to enhance transportation efficiency and reduce congestion.

Infrastructure Owner-Operators

V2I applications and services are another critical component of a thriving and robust V2X ecosystem. While networked V2X reduces the burden of infrastructure deployment for V2X services and applications, it still requires action on behalf of IOOs to enable the critical V2I use cases that are expected to facilitate improved traffic flow, reduced risk of collision, and lifesaving protection for vulnerable road users. For Infrastructure Owner-Operators we recommend:

- Equipping cellular connectivity alongside direct V2X capabilities on all infrastructure assets, traffic signals, and roadway assets for remote operation and monitoring, data ingestion and generation, and cross-communication over networked V2X.

- Allocating funds for upfitting work zone assets with cellular connectivity to enhance safety and efficiency on roadways.

- Implementing robust data exchange programs in states and municipalities to provide a more robust and sophisticated data ecosystem for networked V2X applications.

Automakers

For the vast majority of road users, V2X functionality is experienced and delivered within their personal passenger vehicle. As such, any true progress in V2X requires adoption, engagement, and support from automakers. Networked V2X removes many of the equipment and business barriers that previously served to delay the rollout of direct V2X over the 5.9 GHz band. Given that most automakers today manage connected vehicle platforms for millions of vehicles, there has never been a stronger opportunity for OEMs to take direct action to connect their platforms to networked V2X solutions for safer roads and vehicles. For Automakers we recommend:

- Incorporating networked V2X capabilities as a complement to direct C-V2X to enable V2X applications and services on the millions of network-connected vehicles already deployed today.

- Equipping AVs with networked and direct V2X capabilities so they can communicate with other vehicles and infrastructure over existing cellular networks, allowing for smoother traffic flow and improved decision-making processes.

Direct V2X Outside of the 5.9 GHz ITS Band

This section explores deployment options for direct V2X communications in bands other than the 5.9 GHz ITS band. ITS America has documented that the 30 MHz 5.9 GHz band has too little capacity to support the full suite of V2X applications.[15] The U.S. Department of Transportation and industry organizations such as the Car2Car Communications Consortium and the 5G Automotive Association have provided detailed analyses of the spectrum needs of applications supporting Vulnerable Road User (VRU) safety, cooperative perception and maneuvers, and other services in support of automated driving.[16] We also foresee the emergence of additional cooperative automated driving applications that utilize large amounts of data, such as high-definition map dissemination and raw sensor data sharing.

As shown in the previous section, a growing number of V2X services and applications can be supported by networked V2X. Research is ongoing to determine if other applications – especially those that require very low latency, very high bit rates, and/or use of free spectrum – are well-suited for direct V2X communications outside the 5.9 GHz band. While these approaches may not be practical today, these non-5.9 GHz technologies have potential to be practical in the future as technology continuously evolves. This section explores two specific options that are being considered for the longer term: V2X in midband U-NII spectrum and V2X in 60 GHz millimeter wave spectrum. It also briefly discusses the prospect for eventually augmenting the 5.9 GHz band with additional dedicated ITS spectrum.

U-NII V2X

Definition and Characteristics of U-NII Bands

The Federal Communications Commission (FCC) has created eight Unlicensed National Information Infrastructure (U-NII) bands in the 5 GHz and 6 GHz spectrum, as illustrated in Figure 2 below. These include the U-NII-3/U-NII-4 bands (5.725-5.895 GHz) and the U-NII-5 band (5.925-6.425 GHz), which are, respectively, just below and above the 5.9 GHz ITS band (5.895-5.925 GHz). In particular, when the FCC reduced the ITS band from 75 MHz to 30 MHz in the "First Report and Order" against the wishes of ITS America, USDOT, and other automotive stakeholders, the FCC reallocated that 45 MHz to create the U-NII-4 band (5.850-5.895 GHz).[17]

[15] *The Future of V2X: 30 MHz Application Map*, ITS America, January 27, 2021. https://itsa.org/wp-content/uploads/2021/01/ITS-America-30-MHz-Application-Map-1-27-21.pdf

[16] Comments of US DOT, ET Docket No. 19-138, March 9, 2020
Comments of the Car2Car Communications Consortium, ET Docket No. 19-138, March 9, 2020
Comments of the 5G Automotive Association, ET Docket No. 19-138, March 9, 2020

[17] "Use of the 5.850-5.925 GHz Band," FCC Final Rule, Federal Register pp. 23281-23299, May 3, 2021. The first R&O restricts U-NII-4 usage to indoor access points and their clients. The FCC has proposed to allow outdoor U-NII-4 usage in a second R&O, which ITS America opposes (see Comments of the Intelligent Transportation Society of America, June 2, 2021, ET Docket No. 19-138). This deployment plan does not consider using U-NII-4 for V2X.

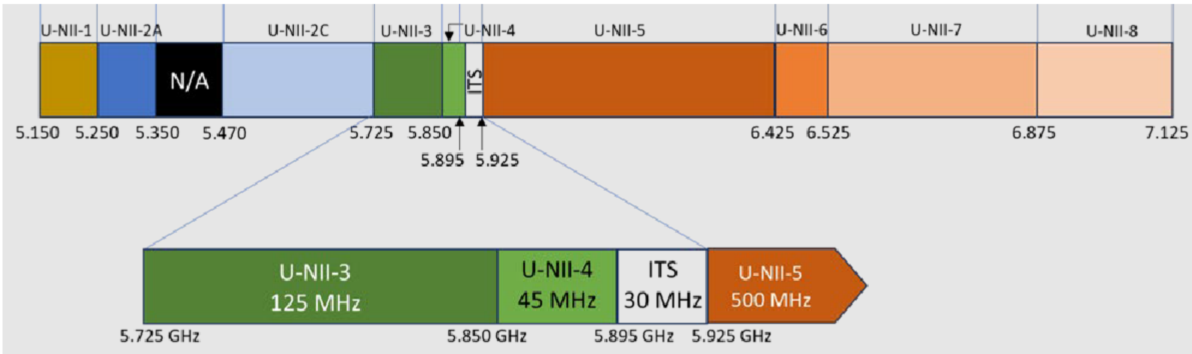

Figure 2: U-NII Bands

Devices using U-NII bands operate under Part 15 of the FCC's Code of Federal Regulation Title 47 (47 CFR 15), which includes an important prohibition on causing "harmful interference" to licensed users, such as 5.9 GHz V2X devices.

U-NII bands are generally shared by devices using various technologies, the most common of which is IEEE 802.11, referred to as Wi-Fi in this document. Therefore, any plan to use U-NII bands for direct V2X must consider the impact of sharing with Wi-Fi, and the fact that the U-NII V2X devices have no regulatory protection from Wi-Fi interference.

U-NII V2X Application Considerations

When considering which V2X applications are best suited to be supported in a U-NII band, it is important to note that the radio frequency characteristics of the U-NII bands are relatively similar to those of the 5.9 GHz band (for example, with respect to propagation and fading), due to the fact that both U-NII and ITS occupy midband spectrum. This suggests that applications that would have been candidates for use in the 30 MHz ITS band if there were more capacity, or in the previous 75 MHz ITS band, could be researched as candidates for applications in a U-NII band.

Other considerations in configuring U-NII V2X communications include:

1. Which U-NII band to use for V2X
2. Message traffic and harm that applications may pose to safety services in the 30 MHz
3. Application resilience to same-channel Wi-Fi interference
4. Cost of OEM and IOO adoption
5. When and where the applications will be active
6. Which lower layer V2X technology is best suited for a U-NII band

1. Which U-NI band

While there are some regulations common to all U-NII bands, such as the "no harmful interference rule," each band also has unique rules and constraints. Considering band-specific constraints, and avoiding adjacency to the ITS band, the U-NII-3 band might be suited to supporting U-NII V2X, given the considerations listed above and most specifically the consideration of harm to the safety services delivered in the ITS band. Furthermore, to mitigate interference with Wi-Fi operation, additional research would be useful in determining how to best align U-NII V2X channels with the U-NII-3 Wi-Fi channel plan in such a manner to fit within the six considerations listed previously. A notional approach is shown in Figure 3 below.

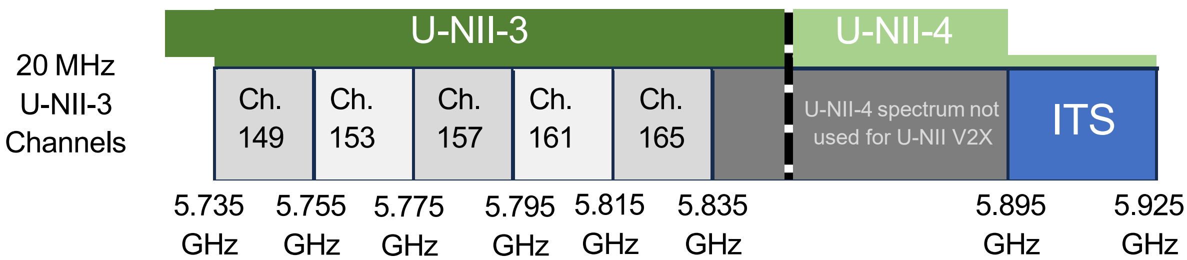

Figure 3: Wi-Fi Channelization of U-NII-3 Band

2. Message Traffic and Harmful Interference to Safety Services

High V2X message traffic in U-NII bands adjacent or near-adjacent to the ITS spectrum can, in effect, "spill over" and create noise for safety services delivered in the ITS spectrum. Therefore, the specific applications that could be delivered in U-NII should be carefully considered. There is a well-documented risk of harmful interference from Wi-Fi transmissions to 5.9 GHz V2X communications, and transportation stakeholders (including ITS America) have previously criticized FCC rules for insufficient protection of 5.9 GHz V2X. We note two favorable facts for U-NII V2X, however, which significantly reduce risk that U-NII V2X would harmfully interfere with 5.9 GHz V2X:

- As shown in Figure 3, a guard band of 60-140 MHz exists between the U-NII-3 channels and the lower edge of the 5.9 GHz ITS band (5.895 GHz). Potential interference in any of the channels shown in Figure 3 will be reduced over the 60-140 MHz of separation. This contrasts with Wi-Fi use in the U-NII-4 and U-NII-5 bands, which have no guard band to the 5.9 GHz ITS band.

- U-NII V2X transmissions in U-NII-3 will likely use no more than 1/10 of the transmission power that Wi-Fi transmissions are permitted to use in any of the U-NII bands. That means that even before taking the advantage of the guard band into account, potential interference from U-NII V2X devices would be significantly lower than interference from Wi-Fi.

Nevertheless, it is imperative that any use of U-NII bands for V2X rigorously protect 5.9 GHz V2X as required by FCC rules.

3. Interference Resilience

Operation in a U-NII band requires acceptance of whatever interference is present. In particular, the U-NII bands are generally attractive to Wi-Fi systems. As such, V2X applications that are relatively robust to lost packets may be better suited to U-NII bands than applications that are very sensitive to packets being lost. It is important to note that Wi-Fi message traffic in U-NII-3 is generally high and unpredictable.

4. Cost of Adoption

We assume that an Onboard Unit (OBU) or Roadside Unit (RSU) that supports direct V2X with a single channel of communication will do so in the 20 MHz channel of the 5.9 GHz ITS band (5.905-5.925 GHz). An OBU or RSU that supports a second channel of V2X communications for additional applications – whether in the 10 MHz channel of the 5.9 GHz band or in one of the U-NII channels – will very likely incur additional equipment costs, such as for a radio chipset, antenna, processor, and cabling.

5. When and Where

Even if Wi-Fi systems are the primary source of interference concerns within a U-NII band, we know that Wi-Fi activity is not uniform across space and time. Wi-Fi activity may be more intense in urban areas, for example, and less intense around roads and highways in rural settings. Wi-Fi activity may be more intense during daylight hours near businesses, and in evening hours near residential areas. V2X systems can be configured to take advantage of Wi-Fi usage patterns or could monitor Wi-Fi activity for more dynamic control. For example, garage operations where data is offloaded from parked vehicles might be attractive. However, V2X deployers should investigate mobility applications to understand if and how traffic might affect delivery of safety messages in the ITS band.

Of particular concern is Wi-Fi usage within a vehicle that is also engaged in direct V2X communications in the 5.9 GHz band and/or in a U-NII band. Interference that vehicular Wi-Fi imparts on V2X in the same or neighboring vehicles can persist for long periods of time, seriously degrading the V2X system; both U-NII-based V2X and, importantly, 5.9 GHz V2X would be impacted. However, if a Wi-Fi system is embedded in a vehicle at the time of manufacture, the automaker can ensure that it does not use the U-NII-3/4 band. For example, an embedded vehicular Wi-Fi system could use 2.4 GHz, or the U-NII-1 band (5.150-5.250 GHz), which are spectrally far removed from both 5.9 GHz V2X and U-NII-3 V2X. But it is possible that passengers will bring U-NII-3/4 Wi-Fi devices into a vehicle, and these could potentially interfere persistently with V2X systems operating in U-NII-3 and/or 5.9 GHz. It is difficult to say how likely this passenger-initiated in-vehicle interference scenario is to occur. ITS America and other industry associations are seeking to disallow U-NII-4 operation with these types of devices.

6. Which Lower Layer Protocol?

The nature of Wi-Fi interference in the same channel, which is relevant for U-NII V2X, is different from Wi-Fi interference in adjacent spectrum, which is relevant for V2X in the dedicated 5.9 GHz band. There is very little a 5.9 GHz V2X system can do about Wi-Fi energy that leaks into the 5.9 GHz band, which is why the automotive community strongly urges the FCC to impose tight leakage regulations on Wi-Fi systems in adjacent U-NII-3/4 and U-NII-5 bands. Regarding users within the same channel, however, there is an opportunity to use channel access protocols to mitigate potential interference. There are a variety of lower layer V2X protocols and channel widths that have been standardized by 3GPP and IEEE. Some of these may coexist better with Wi-Fi than others. This plan recommends that ITS stakeholders study the effects of Wi-Fi interference on same-channel U-NII V2X for different lower layer V2X protocols.

Example U- NII V2X Use Case: Sensor Data Sharing (Cooperative Perception)

The loss of sufficient dedicated spectrum is a significant obstacle for IOOs that wish to share sensor information deployed in their roadways in a reliable manner. The availability of U-NII band spectrum represents a potential solution and could be researched further.

Cooperative Perception messages generated from IOO sensor infrastructure could be broadcast over U-NII spectrum, complementing the 30 MHz dedicated in the ITS 5.9 GHz band. These messages can be signed by the RSU and authenticated by the OBU receivers using the usual SCMS-issued credentials. Messages can also be encrypted with a secret key, shared only with devices enrolled in SCMS, if desired.

P3Mobility has developed an implementation of the above concept, which allows a Wi-Fi-enabled RSU to redirect Sensor Data Sharing Messages (SDSMs) to its Wi-Fi radio interface for U-NII transmission. The RSU can choose a specific U-NII channel dynamically, based on measured traffic volume and signal strength of detected traffic (RSSI). The current SDSM channel can be advertised in WAVE Service Advertisements (WSAs) to OBUs listening to the 5.9 GHz band. In this way, if the volumes and RSSI of neighboring U-NII traffic reach pre-configured thresholds for interference, the RSU can dynamically change to a less congested U-NII spectrum channel or be switched back to using the C-V2X protocol in the dedicated 5.9 GHz band. Also, in times and places where the cooperative perception service is not available, the Sensor Data Sharing Provider Service Identifier (PSID) will not appear in WSAs.

Direct V2X in 60 GHz Millimeter Wave Band

Definition and Characteristics of Millimeter Wave

Signals in the 30-300 GHz range are often referred to as millimeter wave (mmWave) signals because their wavelengths range from 10 mm to 1 mm. The ITU, which regulates some aspects of frequency usage globally, refers to the mmWave range as the Extremely High Frequency band. The use of mmWave communication for V2X is an active research topic at present. While deployment of mmWave for stationary communication is commercially available, and real-world tests have shown the potential of mmWave for moving vehicles, mmWave V2X is not expected to be commercially viable within the next few years. Nevertheless, we include mmWave V2X in this deployment plan because of its longer-term potential for achieving very high data rate communication for vehicles.

There are several bands within the mmWave range. The so-called 60 GHz band, which actually spans from 57 to 71 GHz, is available for unlicensed mmWave communication and is of particular interest for V2X applications. Both IEEE and 3GPP have specified mmWave versions of their respective protocols; the commercially available IEEE 802.11 version is known as WiGig and operates in channels that are 2160 MHz wide, more than ten times wider than the largest channel available in the U-NII-3/4 band.

Perhaps the most important difference between 60 GHz and 5 GHz is that in the 60 GHz band, the signal strength decays much more rapidly with distance. This characteristic has several implications, including:

- The mmWave signal is usually focused on a narrow beam and sent directionally to just one other device, whereas 5 GHz signals – including 5.9 GHz V2X and U-NII V2X – are usually broadcast in 360 degrees for all devices within range to hear. Research into mmWave V2X has shown that communication range for I2V with a moving vehicle can reach 200 meters at greater than 1 Gbps, and for V2V with two moving vehicles a data rate of greater than 100 Mbps can be achieved.[18]

- There are several beam management functions that a mmWave device must support, which are not needed in 5 GHz. This increases complexity and reduces the chance of reaching a non-line-of-sight (NLOS) recipient.

- However, narrow beams means that mmWave transmissions are less likely to interfere with other transmissions in the same vicinity, allowing a higher degree of spatial reuse of spectrum than in the broadcast case.

- mmWave antennas are smaller than 5 GHz antennas and are often implemented as small antenna arrays for improved performance, though costs can be higher.

Europe has already allocated one mmWave channel (63.72-65.88 GHz) for ITS. This channel is aligned with the WiGig channel plan. No official ITS designation exists for U.S. mmWave spectrum, but existing FCC regulations permit use of the band for V2X just like any other unlicensed device. As in Europe, it would make sense to adopt mmWave V2X channels aligned with the WiGig channel plan.

These wider channels illustrate the primary attraction of mmWave communication – high bit rates. Whereas a typical midband V2X channel can support on the order of 10 Mbits per second shared among all users, a 2160 MHz mmWave channel can support hundreds or thousands of Mbits per second.

Millimeter Wave V2X Application Considerations

V2X applications that are well-suited for mmWave communication are those that are consistent with the two main characteristics noted above: very high bit rates and point-to-point communication over ranges up to 200 meters (i.e., a single recipient for each transmission). Those characteristics are quite different from the typical midband (U-NII or 5.9 GHz) V2X application. In that sense, mmWave V2X can be viewed as entirely complementary with 5.9 GHz V2X and does not replace 5.9 GHz V2X. Applications that are frequently mentioned as motivating mmWave V2X include:

[18] See, for example: "Bulk sensor data sharing using millimeter wave V2X for enhanced safety and comfort in mobility", M Irie, GWY Huang, MSH Cheng, K Takahashi, Proceedings of 2018 Asia-Pacific Microwave Conference and "A real-time high-definition vehicular sensor data sharing system using millimeter wave V2V communications," CH Wang, T Shimizu, H Muralidharan, A Yamamuro, Proceedings of 2020 Vehicular Networking Conference.

- **Raw sensor data sharing.** Raw sensor data includes image data and point cloud data that has not yet been processed to extract features or classified objects. One can imagine that if a vehicle can fuse raw sensor data from its own sensors with raw sensor data from another device (with a different perspective on a scene), the resulting fused sensor data could provide a richer view of the surrounding environment.

- **High-definition (HD) map data**. As the name implies, high-definition map data requires large storage and is best communicated at high bit rates like those available in the mmWave band. HD map data can be important for supporting advanced automated driving.

The Future of Dedicated (Licensed) V2X Spectrum

In 2021, the FCC promulgated rules that repurposed 45 MHz of the 5.9 GHz band, reducing the ITS band from 75 MHz to 30 MHz and designating the 45 MHz from 5.850-5.895 GHz as the unlicensed band U-NII-4. The reverberations of that rulemaking are still being felt by the ITS community.

One of the primary motivations for this Beyond 5.9 GHz Deployment Plan is to demonstrate that options for V2X communications exist outside of the curtailed 30 MHz ITS band. Specifically, the plan addresses networked V2X already in deployment today, while also sharing future research ideas in Unlicensed-Band V2X and Millimeter Wave V2X.

As important as these alternatives are, it is equally important to note that they are not a substitute for adequate licensed (i.e., protected) V2X spectrum. The transportation industry is united on the need for additional, licensed spectrum and its importance to the future of V2X communications. In November 2020, the FCC adopted a Further Notice of Proposed Rulemaking (FNPRM) for a 2nd Report & Order defining rules in the 5.9 GHz band. This FNPRM included the following statements and questions:[19]

> *"We seek comment on whether, notwithstanding our determination that current safety-of-life services can continue to operate using 30 megahertz of spectrum, we should consider allocating additional spectrum for ITS applications. For what purposes would additional spectrum be needed? ... Should we determine that additional spectrum is needed to provide advanced ITS applications, what spectrum band(s) should we consider?"*

[19] Use of the 5.850-5.925 GHz Band, First Report & Order, Further Notice of Proposed Rulemaking, & Order of Proposed Modification, 35 FCC Rcd 13440 (2020), paragraphs 52-53.

ITS stakeholders responded unequivocally to these questions, uniformly indicating that more mid-band ITS spectrum should be allocated by the FCC. ITS America believes the record before the Commission overwhelmingly demonstrates the need for at least 40 MHz of additional mid-band spectrum for V2X. ITS America supports the robust effort by all stakeholders – which include the FCC, NTIA, and USDOT – to identify additional spectrum resources for ITS practitioners to enable deployment of critically important advanced V2X services for VRU safety, cooperative automation, and high efficiency roadway transportation. There is a demonstrated need for greater transportation safety, and V2X communications are a critical tool toward reaching Vision Zero on U.S. roads.

Conclusion

This deployment plan documents promising opportunities for V2X communications well into the future and proposes concrete deployment recommendations for networked V2X outside the 5.9 GHz band. By offering actionable guidance to Federal Agencies and Policymakers, Public Fleet Operators, Infrastructure Owner-Operators, and Automakers, ITS America hopes to advance the deployment of all V2X communications technologies at scale, providing immense safety benefits to the traveling public. Notwithstanding networked V2X opportunities, ITS America continues to advocate that government stakeholders, including the FCC, work to identify and allocate additional licensed ITS spectrum that complements the 30 MHz 5.9 GHz band.

It is our hope that this document provides valuable insight and guidance for those wishing to deploy "Beyond 5.9" and educates the broader ITS community about the opportunities and challenges within the entire V2X ecosystem.

The Beyond 5.9 Deployment Plan was developed by the ITS America Beyond 5.9 Working Group in conjunction with the ITS America V2X and Connected Transportation Committee.

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