A Vision for Dynamic Spectrum Use

Events surrounding the use of spectrum dedicated to Intelligent Transportation Systems (ITS) have made it clear that the ITS community cannot expect to have access to enough spectrum in a dedicated band to satisfy the needs of all the ITS services for which the community had planned and has started to deploy. Furthermore, changes in telecommunications technology requires existing and newly deployed applications to have a plan for when the communications technology evolves, and existing communications services are no longer offered (i.e., the discontinuance of 3G chipsets and 3G service).

Dynamic spectrum use allocates available spectrum resources to applications based on as-needed, near-real time (or slower) machine-to-machine requests, using automated systems. In other words, the participants in the telecommunications ecosystem decide the communications resources to be used to accomplish a given information exchange. This is somewhat similar to the telecom-carrier 'network slicing' solution, but dynamic spectrum allocation is not tied to a particular provider.

What is the Problem?

Many ITS services have been conceptually defined assuming access to dedicated wireless spectrum; specifically, they would have access to communications channels in the 5.9 GHz range using wireless access in vehicular environments (**WAVE**), a communication technology employing broadcast ad hoc communications, known as Vehicle-to-Everything (V2X) communications. In the early days of V2X communications (2000-2019), the underlying radio technology was based on Dedicated Short Range Communications (DSRC—a Wi-Fi derivative); with a change in Federal Communications Commission (FCC) decision-making in 2019, the technology was required to change to a 4G-derivative known as LTE-V2X (with a presumption that this might migrate to a 5G New Radio (NR)-V2X technology at some point in the future, adding an additional capability to interface with and utilize networked communications to augment ad hoc communications).

A critical feature of V2X communications using dedicated spectrum is the interoperability associated with how it was designed by industry, as well as the latency achieved in complex traffic conditions with rapidly moving vehicles (it adjusts for effects like Doppler or multipath) and a highly variable conditions (i.e., pedestrians with V2X devices versus trucks versus passenger cars, etc.). With technical interoperability, any make or model of device can "hear" and understand each other. With its short range and latency, threats and hazards can be identified, processed, and an alert provided to drivers to prevent crashes, among other benefits.

Using these and other technical features and requirements, the V2X application and service developed since 2000 are well documented through government-sponsored research (e.g., ConOps and Requirements documents), ITS standards (e.g., the SAE J2945/X series) and ITS architecture (e.g., the Architecture Reference for Cooperative and Intelligent Transportation or ARC-IT). However, even though most of the V2X technology followed a systems engineering process, the assumption of access to dedicated wireless media suitable for local point-to-point low latency communications underpinning so many applications (e.g. collision avoidance using Basic Safety Messages (BSMs), pedestrian safety using Personal Safety Messages (PSMs)) means that the interfaces defined within those standards, even the use cases espoused in the ConOps portions of the standards, must be revised to address the differences between LTE-V2X and DSRC. Further, since the amount of dedicated spectrum was reduced from 75 MHz to 30 MHz by the FCC in 2019, the dedicated spectrum will not be available to many of the V2X applications.

What is the Opportunity?

At this time, with the advancements in communications technologies options beyond the early V2X communications have become more mature and accessible in contrast. Cellular-based wireless technologies have increased significantly in performance since many of these initial concepts were developed. IEEE 802.11 (Wi-Fi standard) has also evolved a great deal, predominantly utilizing existing and new unlicensed broadband spectrum for implementations such as Wi-Fi 6.

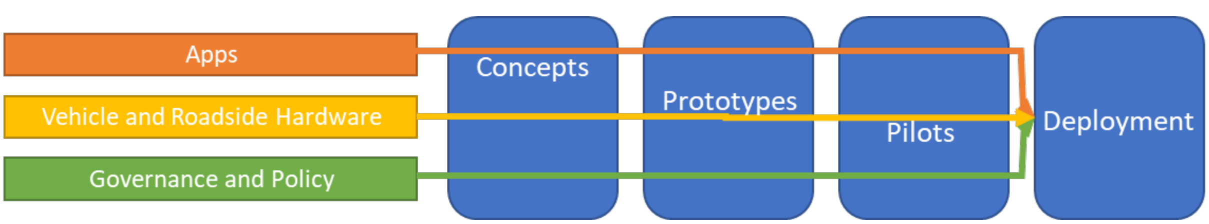
With these changes and given the inadequacy of spectrum in the 5.9 GHz band to support new cooperative and automated applications that are being tested and just beginning to emerge, the US DOT and ITS stakeholders believe that there needs to be other ways of achieving safety, mobility and other V2X benefits using media outside the dedicated spectrum, but carrying forward the latency, interoperability, and other critical features of V2X communications.

A systematic assessment of “what access layer technologies make sense where” may lead to a clearer deployment plan than what exists today. It may also lead to some near-term deployments if services are identified that can operate on existing infrastructure. Some services may be able to use multiple media, which is an opportunity for more widespread deployment, while acknowledging a slight complexity that must be managed. This notion that multiple media offerings for a given information exchange increase complexity should not be considered a barrier, as simple Internet devices and smart phones do this commonly (typically through the installation of multiple radios tuned to different parts of the spectrum).

The Current Situation

Connected Vehicle technology has always been envisioned as a means to deliver ITS services that benefit vehicle operators and passengers. When originally conceived (circa 2000), Internet access was generally available only from fixed points. Thus, the original concepts were focused on the use of previously unused spectrum in the 5.9 GHz range to provide a means for transportation users to interact directly.

Pilots and tests were conducted, and then once the kinks were ironed out, regulation was planned to provide a level playing field for automotive deployers, encouraging a ubiquitous, vehicle-based set of ITS services.



This did not happen, given the uncertainty introduced by FCC’s decision-making.

As time passed, communications technology continued to evolve. Wireless Internet access is now generally available in most transportation environments around the country. Most personal devices and vehicles include high speed Internet access through proprietary commercial cellular networks. Use of 5.9 GHz spectrum for ITS is now more in doubt, as it lies adjacent to a Wi-Fi band that is widely used in residential and commercial indoor applications; the allocation of spectrum to ITS has been challenged; the technology intended for ITS called into question and possibly made impractical through regulation, while regulation of vehicle-centric deployment has not materialized.

Considering this information, it would be wise to examine the ITS services envisioned for connected vehicle technologies and ascertain if these services might be viable using communications technology other than those based on dedicated spectrum and direct communications between participants as originally envisaged.

One complication lies in how communications path assignments are managed in application specifications. Many current application specifications, including the current SAE J2945/X series, specify the communications path in the standard. To be standards conformant, an application must use the path defined in the standard. This practice of specifying the media layer in the technical specification is inflexible: it requires changes in the standard and conformance testing to modify.

Enhancements to the Current Situation

The fundamental proposed research is to *enable ITS applications to use any available and suitable communications mechanism at any time*. This enablement requires three things:

1) **Understanding information exchange performance requirements in context of the applications involved in the exchange.** Types of requirements will mostly be related to timeliness and trustworthiness.
2) **Understanding the performance capabilities of available communications mechanisms.** These must describe timeliness-related characteristics of the media, ability to satisfy trustworthiness requirements, and scalability.
3) **Enabling dynamic selection of communications paths to perform information exchanges.** While identifying alternative methods for data delivery could enable new variations of existing application specifications, a more robust approach would be to simultaneously enable that choice to happen dynamically, in the operational environment. This way, the communications environment can be leveraged on an as-available basis; additionally, a dynamic approach, where media selection is not specified in the application specification, but rather performance requirements are, enables a life-cycle opportunity where applications might evolve in tune with communications capabilities without requiring a wholesale rewrite of standards and specifications.

Research Approach

Matching information exchanges to communications technologies that might support them can be done using ARC-IT as the basis for analysis. The focus will be on information flow triples (source + destination + flow) that involve a mobile participant; a set of analytical tools will be developed to characterize the performance requirements for each such triple. Similarly, a communications technology performance capabilities framework will be developed and populated. Then, an analysis to map communications technology to triples will be performed, and scalability will be explored by developing baseline deployment scenarios (triples, communications technologies in support of “day 1” ITS services) and running simulation experiments.

A Methodology for Communications Technology Use

First, determine the viability and appropriateness of the dynamic communications path assignment technique. This means:

1) Identifying the information exchanges for which this approach has value/makes sense, and
2) Identifying the communications technologies/information exchange pairings, and
3) Validating that the approach scales through likely deployment scenarios

Second, develop the mechanism for dynamic communications path assignment.

Schema to model the performance requirements of information provision will be added to ARC-IT. Initial analysis suggests a set of necessary information flow characteristics as described in Table 1.

Table 1: Information Flow Characteristics

Characteristic	**Description**
Availability	Avoidance of unacceptable delay in obtaining authorized access to information
Carrying positioning information	If the information flow carries positioning information
Communication range	Minimum Euclidian distance from the sender where a receiver expects to be able to receive information with a 95% confidence
Confidentiality	Assurance that information is accessible only to those authorized to have access
Coverage	Geographic area over which the receiver expects to be able to exchange data
Data Integrity	Assurance that the consistency of data is guaranteed
Data rate	Maximum amount of data that needs to be transmitted in a specified amount of time, typically expressed as bits per second
Delay jitter	Difference in delay between successive packet arrivals (of the same flow) at the egress of the network
End to End Latency	The time that it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination

Characteristic	Description
Fixed or wireless	If the communication is fixed or wireless
Kind of multicast communication	Point to point, or
	Point to Multipoint, or
	Broadcast
Purpose of Communications	If it is vehicle-to-vehicle communications (V2V) through onboard units (OBUs), vehicle-to-infrastructure communications (V2I) typically using a roadside unit (RSU), vehicle-to-device (V2D) communications (e.g., for vehicle-to-pedestrian (V2P) or vehicle-to-wheelchair or other means of transport), or vehicle-to-everything (V2X) communications
Data Packet size	Maximum size of data packet required over this triple
Regularity	If transmissions occur at regular intervals

Similarly, schema to model the performance of wireless communications technology will also be added to ARC-IT. Initial analysis suggests a set of necessary communications technology performance characteristics, as described in Table 2.

Table 2: Communications Technology Performance Characteristics

Characteristic	Description
Availability	Avoidance of unacceptable delay in obtaining authorized access to information
Communication range	Maximum Euclidian distance from the sender where a communication can take place with a message reception rate of more than 95 %
coverage	Geographic area included within the range of, or covered by, a wireless radio system
Data rate	Maximum amount of data that can be transmitted in a specified amount of time, typically expressed as bits per second
Delay Jitter	Difference in delay between successive packet arrivals (of the same flow) at the egress of the network
End to End Latency	The time that it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination
Fixed or wireless	If the communication is fixed or wireless
Kind of multicast communication	Point to point, or
	Point to Multipoint, or
	Broadcast

Characteristic	Description
Scalability	To how many nodes can the communication be established without significant degradation, or
	Performance characteristics, which indicates that a system is capable of keeping the level of performance while increasing the number of participating ITS-S
Sensitivity to environment conditions (only for wireless)	If the communication link is vulnerable to environment conditions (e.g., fog)
Sensitivity to the presence of obstacles (only for wireless)	If the communication link is vulnerable to the presence of obstacles (e.g., building at a cross section)
Spectrum occupancy	If it uses a portion of spectrum shared with other wireless services or if it uses dedicated spectrum
Synchronicity	If it is a synchronous or asynchronous communication
Data Packet limitation	If there is a limit for sending data with a single transmission

Many characteristics between the information flow triples and communications technology characteristics schema are the same or similar; depending on the simulation engine used, some of the communications characteristics may be able to be simplified.

These schemas will be reflected in a new ARC-IT database linked to existing ARC-IT 9.2 databases, and the analysis and simulations performed with the intent of learning at minimum:

- What technologies are appropriate for each information flow triple
- Relative ranking of such technologies
- Scalability of various technologies in support of realistic deployment concepts.

Re-imagine ITS Discovery

Discovery as a process is commonly used in various IoT-related protocols. IoT discovery is typically associated with the concept of ‘data discovery’, as many IoT protocols (e.g., MQTT, DDS) abstract the communications layer and instead provide a ‘databus’ to the developer. Communications still occur of course, but the minutiae of connection and such are abstracted out by the middleware protocol. While handing off discovery to a middleware protocol is an attractive option from a “lets get deployed now” perspective, it would be naive to assume this approach as a total, scalable solution for a complex transportation environment. Prior testing (see ISO TR 23255) suggests that IoT protocols struggle in some communication environments, particularly when congested. Furthermore, the lack of visibility into the underlying communications media makes diagnosis difficult. Thus, it is incumbent upon the community at large to realistically characterize information flow performance requirements as described herein but also to acknowledge that in some cases an IoT protocol may be an appropriate and elegant solution to information exchanges.

ARC-IT content recognized IoT protocols as of version 9.0 (e.g., see OASIS AMQP over wireless at https://www.arc-it.net/html/comm/solution91088.html) , and notes that in nearly every case, no profile exists whereby an IoT protocol could be obviously and easily used—implementers have to build their own. Use of one or more protocols would be facilitated by the development of such profiles, but that is another task entirely.

In order to dynamically match available communications with application information exchange requirements, we not only need the ARC-IT-based analysis, but a way to communicate the relevant information to connected vehicle environment participants on an as-needed basis. Users need to be able to answer questions related to problems such as:

1) How does the Transportation Information Center (TIC) find the data it needs to serve travelers? and how does the traveler find the TIC that has the information he needs?
2) What access-layer technologies are appropriate for a given information exchange?

Conceptual Architecture

One way this might be accomplished is with development of an "ITS Registration and Discovery Service," based on a support capability described in ARC-IT but with additional features as outlined here. A conceptual architecture depicting the critical components and how they interact is presented in Figure 1:

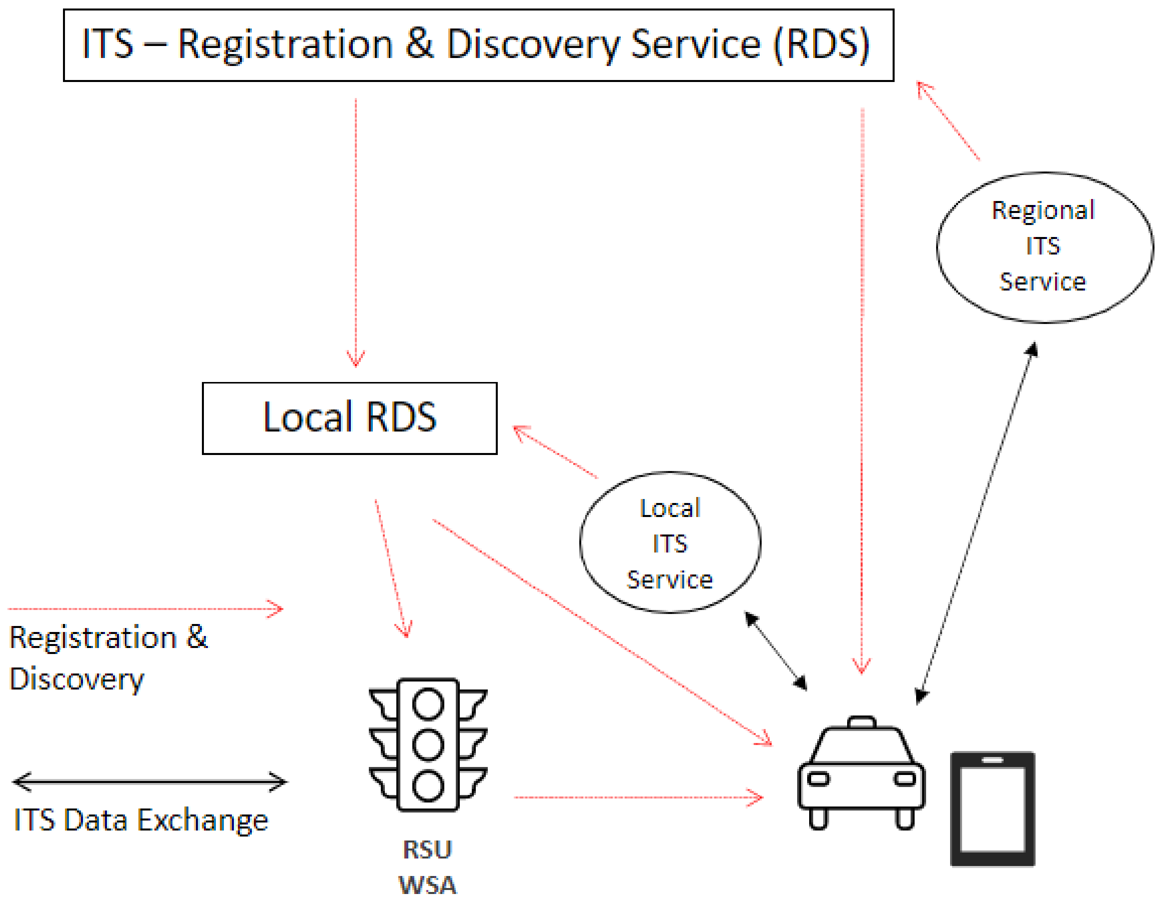


Figure 1: ITS Registration and Discovery System (RDS)

Registration and Discovery: These show the paths by which services register with RDS components and ITS mobile users interact with RDS components.

ITS Data Exchange: These are the actual data exchanges (e.g., provision of probe data from a mobile entity, or provision of traveler information from an information provider to a mobile entity).

Regional ITS Service refers to a service offered over an area that spans multiple transportation Infrastructure Owner Operator (IOO) jurisdictions. For example, traveler information services offered via 511 or Internet are typically regional ITS services.

Local ITS Service refers to a service offered over an area entirely contained with one IOO's jurisdiction. Typically, this will be services that operate using short-range communications services, such as LTE-V2X or Wi-Fi.

ITS-RDS: An ITS Registration and Discovery Service can be patterned after the Internet's Domain Name Service (DNS). It is national in scope and maintains a database of ITS service offerings and identifies mechanisms for receiving those services.

ITS applications and service offerings would be associated with a unique identifier and be specified in such a way that the user of the ITS RDS knows how to access the service. For example, the service offering might be 'traveler information' and the associated access mechanism something like "accessed at [Internet IP address] following a [specified protocol]." Service offerings might have multi-dimensional granularity by time, space, provider, cost, or other factors. In some cases, the ITS-RDS might know that such a service exists, but not how to access it, in which case it would forward or redirect the requester to the local-RDS.

Local-RDS: The local-RDS knows what the ITS-RDS does not regarding services offered in a particular jurisdiction. The local-RDS is not national in scope but performs as a cloud/edge-based service that provides the same kind of information that the ITS-RDS does. Other differences lie in operations and maintenance, where the local-RDS could be maintained by a local jurisdiction, and that it is focused on identifying services and access methods that are under the control of that local jurisdiction.

RSU-WSA: The Wave Services Advertisement issued by a Roadside Unit (RSU) will direct mobile participants to the local-RDS or ITS-RDS and will also advertise any other services provided by that RSU.

System-Wide Impacts

Use of this system comes with a few other changes to the traditional environment:

1) Transition to a specification of performance requirements instead—let the participating device determine the access method using the system above. Today, standards typically specify the access technology for a given information exchange. Of course, some applications could still be pre-previsioned on a particular channel (e.g., V2V basic safety messages (BSMs) will be broadcast on channel 183 using LTE-V2X).
2) Never use proprietary or shared (e.g., unlicensed) spectrum to meet a safety-centric user need.
3) Avoid requiring use of cellular technology to satisfy safety-related interfaces that go between infrastructure owner-operators and mobile participants.
4) Provide both a cellular and short-range path when time criticality is not a concern and deployment of short-range infrastructure would be co-incident to existing infrastructure (e.g., adjacent to a traffic signal controller).
5) Some of the services should be made secure to support authentication and integrity. Confidentiality is not so important in this context unless some services are for specific categories of vehicles (e.g., police). If an ITS service or an RDS service is tampered with and it provides false

information, this could be a problem for road transportation authorities, which is why integrity, authentication and availability are so important.

6) Participating devices (e.g. OBUs) would have to be built with this approach in mind. As smartphones can already do much of what is described here, a smartphone connected to a vehicle as a plug-in or nomadic device may work as an interim solution. As transportation infrastructure typically has a 10-20 year lifespan, and communications technologies may be made obsolete within that lifespan, phone-based options may provide long-term viability.

To ensure interoperability with the ITS-RDS concept, additional research may be needed on “translation protocols” that help ensure that messaging in one part of the spectrum can be “heard” and understood by devices in other parts of the spectrum.

Conclusion

By pursuing this research, development and testing, US DOT and industry partners expect that there may be future paths to achieving V2X benefits outside of the currently allocated 30 MHz of spectrum. As analysis proceeds, this paper may be updated with recent results.