CV 265: Introduction to IEEE 1609 Family of Standards for Wireless Access in a Vehicular Environments (WAVE)

Table of Contents

1. Module Description

IEEE 1609 family of standards for Wireless Access in Vehicular Environments (WAVE) supports the Dedicated Short Range Communication (DSRC) deployed in conjunction with 5.9 GHz spectrum in a CV environment and suitable for emerging Cellular-Vehicle to Everything (C-V2X) communication alternative. These (WAVE) standards define the wireless interface for CV safety and mobility applications, and networking services so that applications can be interoperable without regard to specific manufacturers, including data storage access mechanisms, device management, and secure message passing.

IEEE 1609 family of standards (WAVE standards) provides (previously unavailable) capability for:

- homogeneous communications interfaces between vehicles (different automotive manufacturers) for secure V2X communication-interoperability and between vehicles and roadside units.
- dynamic ad-hoc communications access capability between vehicles and service providers to support high speed (up to 27 Mb/s) short range (up to 300 meter) and low latency wireless communications required for time-critical safety applications in the CV environment.
- faster processing with the simple Wave Short Message (WSM) and Wave Short Message Protocol (WSMP-a network/transport level protocol) mainly intended for applications that rely on broadcasts messages whereas IP is used for more extensive data exchanges often with host server instead of RSU. Either protocol can be used for time-critical, critical, or non-critical ITS applications.
- WAVE stack also enables low-latency IPv6 connectivity and data exchange to support locally (e.g. at an RSU or remotely hosted TMC applications.)

The intent of this module is to introduce essential technical details of the IEEE 1609 family of standards which defines the architecture, communications model, management structure, security mechanisms and physical access mechanism. The scope includes discussion on the functionality of the WAVE standards as they are used in conjunction with the 5.9 GHz spectrum-based DSRC radio operation and illustrate WAVE protocol stack to show how IEEE 1609 family of standards and other cooperative standards fit together:

- IEEE 1609.0 (Guide)
- The security protocols defined in IEEE 1609.2
- The network-layer protocol defined in IEEE 1609.3 (WSMP), and IPv6 processing for non-critical (supplementary) ITS information.
- Provide extensions to the physical channel access defined in IEEE 802.11 to support the WAVE standards in IEEE 1609.4 (multi-channel operation).

Network engineers, hardware engineers, and application designers supporting CV environment will gain further insight into WAVE standards as they cooperatively define the communications architecture for DSRC-based Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) interactions, and as the basis for the low-latency interface design of WAVE devices such as Onboard Unit (OBU) and Roadside Unit (RSU).

2. Introduction/Purpose

The connected vehicle environment has the potential to transform surface transportation systems such that vehicular crashes will be significantly reduced, operators of the surface transportation systems will have access to more accurate system performance data, travelers will have access to specific traveler information, and will allow the surface transportation systems to be optimized to minimize environmental impacts. This module provides an overall technical understanding of what is required to enable connected vehicle communication for V2X (vehicle to everything).

Figure 1 (slide 18 in the presentation) shows the WAVE protocol stack with pertinent standards to support CV communication, for both DSRC (at present) and LTE-V2X (under preparation) communication alternatives. Note, IEEE standards are under further revisions (beyond 2016 releases) to support CV operation. The diagram does not show higher layer entities that provide service, involving an exchange of data, (e.g. SAE J2735 safety messages) on one WAVE device to a similar entity on another WAVE device, using WAVE communications, using WAVE Protocol (WSMP).

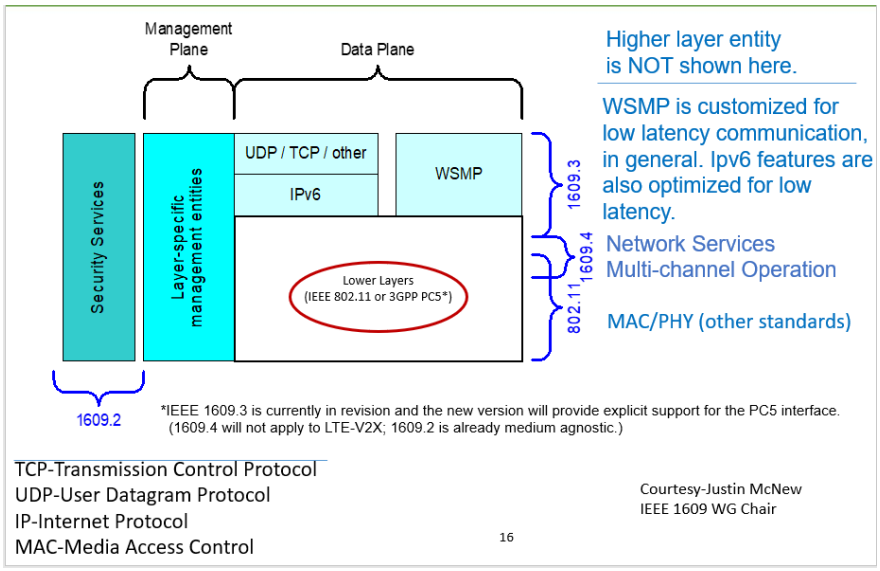

Figure 1: IEEE 1609 WAVE Protocol Stack
Source: Courtesy-Justin McNew, IEEE 1609 Working Group Chair

Note, safety/mobility applications are handled at higher layer and are not shown here. IEEE 802.11 is deployed with DSRC in US IEEE 1609 standards (WAVE).

DSRC based CV implementation will need support of the entire protocol stack in both data plane (a component of the abstract architecture containing entities that exchange user data-messages) and management plane (a component of the abstract architecture containing functions that manage the entities in the data plane), while LTE-V2X may not require IEEE 160.4 multi-channel support. In addition to IEEE 1609.3 modification for PC5 support, IEEE 1609.2.1 is under development to support interfacing to the Security Credential Management System (SCMS). Note, LTE-V2X is the terminology associated with Rel 14-15 of 3GPP. SAE J3161/1, which is the BSM application standard that uses the LTE-V2X interface for V2V safety, is also still in development. Both the 1609.3 revision and J3161/1 are expected be published sometime in 2020.

The following provides a brief description of services provided by 1609.0 family of standards.

IEEE 1609.0 IEEE Guide for WAVE - Architecture standard defines the architecture, operations, and services required for multi-channel WAVE communications in a moving vehicular environment, such as CV and AV. The standard is expected to be used in conjunction with the other standards along with IEEE 802.11p. The standard is active, with the latest version published in 2019.

IEEE 1609.2 IEEE Standard for WAVE Security Services for Applications and Management Messages

This standard defines the secure message formats and processing for use by WAVE devices. The standard describes the methods to secure services for WAVE management messages and application messages. WAVE Internal Security Services consists of secure data service (SDS) and security management.

The SDS operations define the process for creating a security envelope by adding data to unsecured protocol data units (PDUs), transforming them into secured protocol data units (SPDUs). The SDS also describes processing received SPDUs and transforming them into PDUs. The transformation of the data units occurs between two secure data exchange entities (SDEEs). The process occurs by one SDEE invoking a request to process data and the resulting processed data is returned to the invoking SDEE. The security management service defines managing information about certificates using a security services management entity (SSME) to store information related to the certificate data being managed.

WAVE Higher Layer Security Services consists of certificate revocation list (CRL) verification entity (CRLVE) and peer-to-peer certificate distribution entity (P2PCDE). The CRLVE is a service that validates incoming CRLs and updates local stores of certification revocation by invoking the SDS and SSME. Related revocation information is then passed to the SSME for storage.

The P2PCDE enables peer-to-peer certificates. The latest version of the standard is 2016 and is a revision of the IEEE 1609.2-2016.

IEEE 1609.3 - Standard for WAVE - Networking Services

IEEE Std 1609.3 specifies two data plane protocol stacks (sharing a common lower stack at the data link and physical layers)—the standard IPv6 and the WSMP designed for optimized operation in a wireless vehicular environment. WSMs may be sent on any channel. IP traffic is only allowed on SCHs, so as to offload high-volume IP traffic from the CCH. The hexadecimal values indicating IPv6 and WSMP are 0x86DD and 0x88DC, respectively. A proposal to allow IP traffic on control channels may be considered in future revisions of the standards.

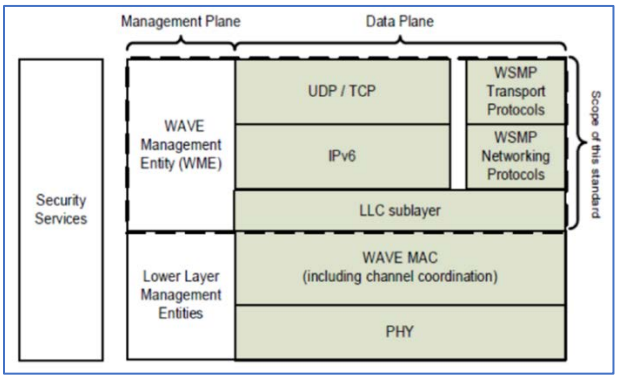

Figure 2 WAVE Network Services Data Planes

The WAVE Networking Services, shown in Figure 2, consists of network and transport layer services and the associated management plane entity, called the WAVE Management Entity (WME). The standard also defines a WAVE specific alternative to Internet Protocol version 6 (IPv6) called WAVE Short Message Protocol (WSMP, a common network/transport layer protocol) and the Management Information Base (MIB) for the WAVE protocol stack. A WAVE device may support one of WSMP or IPv6, or it may support both. Note that WSMP and IPv6 are separate and distinct networking protocols, and one does not depend on the other (e.g., IPv6 frames are not transported over WSMP, or vice versa). (Note that, a WAVE device may also support additional protocols other than WSMP and IPv6, but not within the scope of WAVE standards).

IEEE Std 1609.3 (Networking Services) includes the following:

- WSA transmission and monitoring, channel access assignment
- WSMP
- Use of the local link control (LLC) sublayer and EtherType Protocol Discrimination (EPD)
- Use of Internet Protocol version 6 (IPv6), including streamlined IPv6 configuration Exchange of specific management information between WAVE devices
- MIB maintenance (contains configuration and status information)

IEEE 1609.4 - IEEE Standard for WAVE - Multi-Channel Operation

The purpose of this standard is to enable effective mechanisms that control the operation of upper layer data transfers across multiple channels, without requiring knowledge of physical layer (PHY) parameters and describe the multi-channel operation channel routing and switching for different scenarios.

IEEE Std 1609.4 (Multi-Channel Operations) specifies extensions to the IEEE Std 802.11 MAC layer protocol and includes the following:

- Channel coordination and routing, multi-channel synchronization
- Use of IEEE Std 802.11 facilities [e.g., channel access, Enhanced Distributed Channel Access (EDCA)]
- Use of IEEE Std 802.11 Timing Advertisement frames in a WAVE system
- MAC-layer readdressing in support of pseudonymity
- Management Information Base (MIB) maintenance (contains configuration and status information)

As shown in Figure 3, this standard provides specifications regarding the MAC sublayer functions and services that support multi-channel wireless connectivity between WAVE devices without requiring knowledge of PHY parameters. This standard describes the channel coordination required for WAVE devices to operate over multiple wireless channels, using additional features for “OCBActivated” communication in the MAC sublayer, outside the context of basic service set, as specified by IEEE 802.11. (Ref.19). IEEE 802.11-OCB networks are used for vehicular communications as 'Wireless Access in Vehicular Environments'-Outside the Context of Basic Service (OCB) as per RFC8691.

The IEEE 802.11 MAC layer management entity (MLME) invokes layer management functions using layer management service interfaces. This standard specifies MLME extensions to the IEEE 802.11 sublayer that include channel coordination features and additions to the primitives used for transmitting data to support MAC service data units (MSDU) delivery. The defined primitives are exchanged through services access point (SAP) interactions between the various entities. (Ref.19)

As shown in Figure 3 multi-channel operation, the 1609.4 standard specifies data plane services and management services. Data services consists of: Channel coordination, Channel routing and User priority. Channel coordination describes how the MAC sublayer coordinates device resources so that data packets are transmitted on the proper wireless channel in the correct time slot. Channel routing describes how the MAC sublayer handles inbound and outbound higher layer data, including the routing of data packets to and from a higher layer to the designated channel, and setting parameters (e.g., transmit power) for WAVE transmissions. User priority utilizes the IEEE 802.11 enhanced distributed channel access (EDCA) mechanism to define the use of user priority (UP) and related access category (AC) to support quality of service and accommodate a variety of safety and non-safety applications. The IEEE 1609.4 management services uses the MLME and consists of: Multi-channel synchronization, Channel access, other IEEE 802.11 services, MIB (Management Information Base) maintenance and Readdressing.

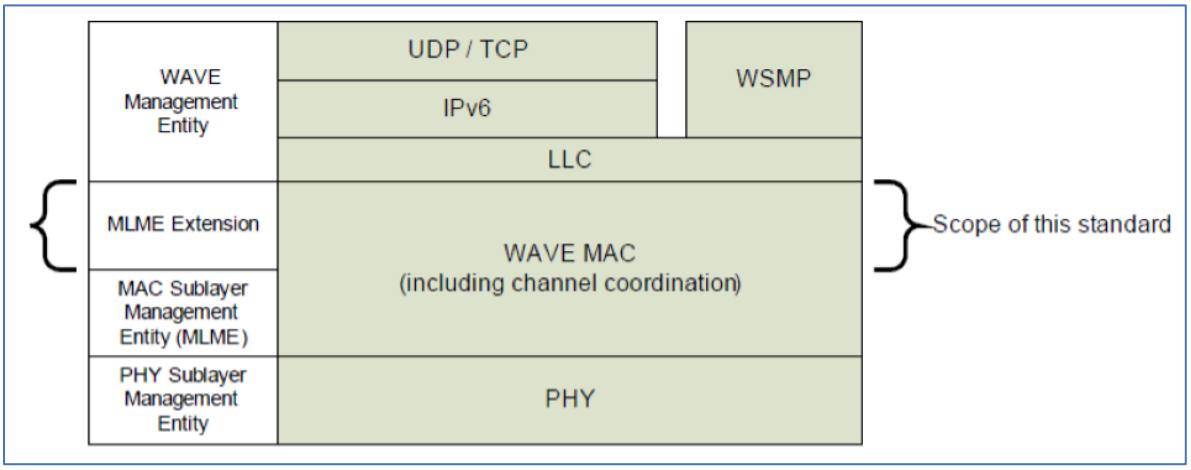

Figure 3 Multi-Channel Operation as per IEEE 1609.4 Standard (2016)

Multi-channel synchronization defines how to use the MLME synchronization function to achieve the aligning time slots among communicating WAVE devices using the MLME using information that may be derived locally or received over the air. The MLME also provides the capability to generate and monitor Timing Advertisement (TA) frames for the distribution of system timing information. Channel access defines the MLME methods to control access to specific radio channel communication requests received from the WME.

When considering other IEEE 802.11 services, the management services defines that the IEEE 802.11 services may be invoked on a per-channel basis using the MLME.

What is channel switching?

IEEE 802.11p (now part of 802.11) is a single channel operation-that is data packets are placed on whichever channel is selected- however, since US DSRC offers seven channels, upper layer IEEE 1609.4 provided multi-channel operations with SCH switching channels mechanism to enable a single radio device to access multi-channels spectrum, bringing WAVE to CV environment.

The MAC sub-layer has an extension that supports channel switching, defined in IEEE 1609.4. One of the seven 10 MHz channels is dedicated as the control channel (CCH 178) while others work as service channels (SCHs). Channel switching allows concurrent access of CCH and SCHs. This is achieved by

dividing each 100 ms into a 46 ms CCH interval and a 46 ms SCH interval, each followed by a 4 ms guard interval.] WAVE device is able to accommodate an architecture that support two channels i.e. Control Channel (CCH) and Service Channel (SCH). These channels provide the multiple channel operation in WAVE and has advantage related to security. The role of CCH is to transmit the WAVE short message and announce the WAVE services whereas the SCH is responsible for application interaction and transmission.

IEEE offers Registration Authority programs or registries which maintain lists of unique identifiers under standards and issue unique identifiers to those wishing to register them. The IEEE Registration Authority assigns unambiguous names to objects in a way which makes the assignment available to interested parties. [https://standards.ieee.org/products-services/regauth/psid/public.html]

The PSID has three use cases: Identify the permissions of the senders of some information, identify available advertised provider services and route messages, sent by advertised provider services to the appropriate user applications. The EtherType identifier is a 2-octet field with values (i.e., networking protocols) assigned by the IEEE Registration Authority and is used to identify the networking protocol employed above the data link layer, such as IPv6 and WSMP.

WAVE Devices

The Roadside Unit (RSU) is a key enabling component of the C-ITS environment - it serves as an interface, also known as vehicle-to-infrastructure (V2I) interface, between connected devices and the roadway infrastructure. The U.S. Federal Communications Commission (FCC), at 47 CFR Part 90 (90.7), defines an RSU as:

A DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand carried unit is stationary. Furthermore, an RSU operating under this part is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate where they do not interfere with a site licensed operation. An RSU broadcasts data to OBUs [Onboard Units] or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required.

Onboard Unit (OBU)

An OBU is a DSRC transceiver that is installed in the vehicle as an OEM item or as ASD-Aftermarket Safety Device as called by CV Pilot projects. An OBU can be operational while a vehicle or person holding it is either mobile or stationary. The OBUs receive and contend for time to transmit on one or more radio frequency (RF) channels. Except where specifically excluded, OBU operation is permitted wherever vehicle operation or human passage is permitted. The OBUs mounted in vehicles are licensed by rule under part 95 of this chapter and communicate with Roadside Units (RSUs) and other OBUs. Portable OBUs are also licensed by rule under part 95 of this chapter. OBU operations in the Unlicensed National Information Infrastructure (UNII) Bands follow the rules in those bands.

3. Reference to Other Standards

The following list summarizes pertinent standards referred in this module and deployed in CV applications. Note, several standards have been revised in recent years and users must deploy latest published versions.

- IEEE 1609.x Wireless Access for Vehicle Environments (WAVE) Family
- IEEE 802.11 (WAVE DSRC (2016)
- SAE J2735 Data Dictionary standard
- SAE J2945.x Interface standards

Completion of key standards/Recommended Practices

- SAE J2945/1 V2V Safety Application
- SAE J2945/2 V2V Awareness Application
- J2945/3 Road weather applications
- J2945/5 Security guidelines for connected vehicle applications
- SAE J2945/9 Vulnerable Road User Application
- Conformance test specifications for SAE J2945/1

Revisions of standards

- SAE J2735 DSRC Message Set Dictionary
- IEEE 1609.2 Security Services for Applications and Management Messages
- IEEE 1609.2.1 Security Credential Management System (SCMS) is pending
- IEEE 1609.3 Networking Services
- IEEE 1609.4 Multi-channel Operation

4. Glossary

The following are additional **descriptions/acronyms** used in the module.

Term	Definition
Application	An application process providing application entity functionality as defined by the ITS reference architecture. For CV applications, SAE J2735 and J2945.X standards are used.
ASD-Aftermarket Safety Device	A connected device in a vehicle that operates while the vehicle is mobile, but which is not connected to the data bus of the vehicle. ASD is a connected device, but not integrated during vehicle manufacture but added after sale. It is installed in a vehicle and is capable of sending and receiving messages over a Dedicated Short-Range Communication (DSRC) wireless communications link. The device has a driver interface, runs V2V and V2I safety applications, and issues audible or visual warnings and/or alerts to the driver of the vehicle.
Basic Safety Message (BSM)	The message containing the core data set transmitted by the connected vehicle for safety-related purposes (vehicle size, position, speed, heading acceleration, brake system status). The message includes an optional extension that can report additional data depending upon events (e.g., anti-

Term	Definition
	lock brakes activated) but the availability of types of extension data varies by vehicle model. The BSM is tailored for low latency; localized broadcast required by V2V safety applications but can be used with many other types of applications.
CCH	Control channel (CCH): A radio channel limited by the WAVE standards to the exchange of management frames and WAVE Short Messages.
Connected Device	Any device used to transmit or receive messages from another device. Within the scope of V2X, we specifically mean those connected devices that are a part of an ITS trust domain, thereby allowing them to transmit and receive messages with other ITS-trusted connected devices. Within the scope of this course (V2V and V2P), we specifically mean those connected devices that are a part of the ITS trust domain established by the SCMS, thereby allowing them to transmit and receive messages with SCMS-trusted connected devices A connected device can be sub-categorized as an OBU or RSU.
CV	Connected Vehicle (CV): a vehicle that has an operational OBU, for transmit/receive messages.
Conformance	A condition that exists when an item meets all of the mandatory requirements as defined by a standard. It can be measured on the standard as a whole, which means that it meets all mandatory (and applicable conditional) requirements of the standard or on a feature level.
Data Plane	The data plane (sometimes known as the user plane, forwarding plane, carrier plane or bearer plane) is the part of a network that carries user traffic. The data plane, the control plane and the management plane are the three basic components of a telecommunications architecture.
Dedicated Short Range Communications	DSRC is a technology for the transmission of information between multiple vehicles (V2V) and between vehicles and the transportation infrastructure (V2I) using wireless technologies using 5.9 GHz spectrum in US.
Higher Layer Entity	An abstract entity, typically implemented in a software, that resides above the WAVE protocols in the protocol stack, and may make use of WAVE communications services.
Interoperability	Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged. [ISO 24765:2017]
Latency	A measure of time delay experienced in a system, the precise definition of which depends on the system and the time being measured. For a data element in this context, latency is the time difference between the time that data value is acquired by the source and the time the message is transmitted.
Management Plane	In computer networking, the management plane of a networking device is the element of a system that configures, monitors, and provides management, monitoring and configuration services to, all layers of the network stack and other parts of the system.

Term	Definition
MAC Address	MAC-Media Access Control: Each device operating in an IEEE 802® network, such as IEEE 802.11, is assigned a MAC (layer 2) address that is used in transferring packets across a data link. Distinct physical interfaces on a device have different MAC addresses, for example, a device with both WAVE and Ethernet physical interfaces have a unique MAC address for each. The MAC address is 48 b. Per IEEE Std 802.11, the source and destination MAC addresses are included in the MAC header of each transmitted frame.
Networking Services	The collection of management plane and data plane functions at the network and transport layers, as specified in IEEE Std 1609.3, supporting Wireless Access in Vehicular Environments (WAVE) communications. For DSRC implementation, these services are supported by WSMP.
On-Board Unit (OBU)	A vehicle-mounted device used to transmit and receive a variety of message traffic to and from other connected devices (other OBUs and RSUs). Among the message types and applications supported by this device are vehicle safety messages, a primary subject of this standard, used to exchange information on each vehicle's dynamic movements for coordination and safety. IEEE defines OBU as: A WAVE device that can operate when in motion and supports the information exchange with roadside units (RSUs) or other OBUs.
OCBActivated	Indicates communication outside the context of a basic service set as specified in IEEE Std 802.11 (by setting dot11OCBActivated to TRUE) (i.e., used for WAVE operation).
OFDM	In telecommunications, orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has is a popular scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL internet access, wireless networks, power line networks, and 4G mobile communications.
PICS	A protocol implementation conformance statement or PICS is a structured document which asserts which specific requirements are met by a given implementation of a protocol standard. It is often completed as a record of formal protocol conformance test results, and some automated testing systems machine-author a PICS as output. A potential buyer or user of the implementation can consult the PICS to determine if it meets their requirements. For example, IEEE 1609.3 standard has an annex D which can be reproduced for intended purpose (other 1609 standards have a similar annex.
Protocol Stack	Protocol stack refers to a group of protocols that are running concurrently that are employed for the implementation of network protocol suite. The protocols in a stack determine the interconnectivity rules for a layered network model such as in the OSI or TCP/IP models. WAVE standards shown together at each layer of OSI form a (DSRC) WAVE stack, for example.

Term	Definition
Public Key Infrastructure (PKI)	A public key infrastructure (PKI) is a set of roles, policies, hardware, software and procedures needed to create, manage, distribute, use, store and revoke digital certificates and manage public-key encryption.
PC5 Interface	A component of a C-V2X communication for Direct Connection (V2V) that does NOT require use of cellular network services, compared to UU interface which does require use of cellular network for V2N communication.
PSID-Provider Service Identifier	A Provider Service Identifier (PSID) is message/application classification; an Organization can request a PSID from IEEE and define and describe how that PSID is to be used. It is part of the WSMPIEEE defines as: An identifier of a higher layer service provided by a higher layer entity [from IEEE Std 1609.12]. The PSID has three use cases: Identify the permissions of the senders of some information; Identify available advertised provider services and Route messages, sent by advertised provider services, to the appropriate user applications. PSID values are assigned and used for BSMs. J2735 has allocated nine PSDI values. PSID is carried by Header of WSM.
Road-Side Equipment (RSE)	Term used to describe the complement of equipment to be located at the roadside; the RSE will prepare and transmit messages to the vehicles and receive messages from the vehicles for supporting the V2I applications. This is intended to include the DSRC radio, traffic signal controller where appropriate, interface to the backhaul communications network necessary to support the applications, and support such functions as data security, encryption, buffering, and message processing. It may also be referred to as the roadside ITS station. When speaking of the DSRC radio alone, the correct term is RSU.
Roadside Unit (RSU)	A connected device that is only allowed to operate from a fixed position (which may in fact be a permanent installation or from temporary equipment brought on-site for a period of time associated with an incident, road construction, or other event). Some RSEs may have connectivity to other nodes or the Internet.
Service (in WAVE)	Generally, in layered protocol architectures, the term service may be used to describe functionality provided to one layer from the layer below. IEEE 1609 standards describe services as being provided and used between higher layer entities operating on WAVE devices-higher layer services.
Security Credential Management System (SCMS)	A public key infrastructure (PKI) approach to security involving the management of digital certificates that are used to sign and authenticate messages that are exchanged among connected devices that might have no direct relationship with each other.
SCH	Service Channel: Any channel that is not the Control Channel 178 in US DSRC.
Vehicle to Infrastructure (V2I)	The exchange of information between a vehicle and a roadside device or centralized equipment to enhance safety, mobility, and sustainability.
Vehicle-to-Pedestrian (V2P)	The exchange of information between a vehicle and a connected device representing a pedestrian or other vulnerable road user to enhance safety, mobility, and sustainability.

Term	Definition
Vehicle-to-Vehicle (V2V)	The exchange of information between vehicles to enhance safety, mobility, and sustainability.
Vehicle-to-Anything (V2X)	The exchange of information between a vehicle one or more connected devices to enhance safety, mobility, and sustainability. The other connected device might be another vehicle, a pedestrian or other vulnerable road user device, a roadside station, or a central system.
WAVE	Wireless Access in Vehicular Environments, a radio communications system intended to provide seamless, interoperable services to transportation users.
WAVE Device	Wireless Access in Vehicular Environments (WAVE) device: A device that is compliant to IEEE Std 1609.3, IEEE Std 1609.4, IEEE Std 1609.12, and IEEE Std 802.11, communicating outside the context of a basic service set.
WLAN	A wireless LAN (WLAN) is a wireless computer network that links two or more devices using wireless communication to form a local area network (LAN) within a limited area. DSRC is based on WLAN with 5.9GHZ spectrum.
WSM	WAVE Short Message is a packet consisting of a WSMP header and WSM Data.
WAVE Short Message Protocol (WSMP)	A low-overhead Network (TransNet) Layer protocol designed for use over DSRC Wave Short Messages (WSM). The protocol specified in IEEE Std 1609.3 that minimizes communications overhead. WSMP acts as a combined protocol at Transport/Network Layer.

5. Acronyms

Acronym	Definition
3GPP	Third Generation Partnership Project
5G NR	Fifth Generation New Radio
ASD	Aftermarket Safety Device (OBU)
BSM	Basic Safety Message
CA	Certificate Authority
C-ITS	Cooperative Intelligent transportation System
CRL	Certificate revocation List
CV	Connected Vehicle
C-V2X	Cellular Vehicle to Everything
DSRC	Dedicated Short Range Communication
HTTPS	Hypertext Transfer Protocol Secure
IEEE	Institute of Electrical and Electronic Engineers
IEEE	Institute of Electronics and Electrical Engineers
ISO	International Organization for Standardization
LLC	Logical Link Control
LTE	Long-Term Evolution (cellular C-V2X technology)

Acronym	Definition
MAC	Medium Access Control (in IEEE Std 802.11)
MLME	MAC sublayer Management Entity
OAI	Over the Air Interface
OBU	Onboard Unit
OCB	Outside the Context of Basic Service
OFDM	Orthogonal frequency division multiplexing
PC5	LTE-V2X Interface, Direct Communication
PHY	Physical Layer
PICS	Protocol Implementation Conformance Statement
PSID	Provider Service Identifier
RSE	Roadside Equipment
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SAP	Service Access Point
SCH	Service Channel
SCMS	Security Credential Management System
SDS	Secured Data Service
SPDU	Secured Protocol Data Unit
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UDP	User Datagram Protocol
UTC	Coordinated Universal Time
Uu	User Equipment to the Universal Mobile Telecommunications Service (UMTS)
V2I	Vehicle-to-Infrastructure
V2N	Vehicle to Network (C-V2X Interface, second component)
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WAVE	Wireless Access in Vehicular Environments
WME	WAVE Management Entity
WRA	WAVE Routing Advertisement
WSA	WAVE Service Advertisement
WSM	WAVE Short Message
WSMP	WAVE Short Message Protocol

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19. I-75 Florida's Regional Advanced Mobility Elements (FRAME)-RSU/OBU Testing, 2018. http://www.cflsmartroads.com/projects/CVAV_D5_Testing.html

7. Study Questions

1. Which of the following is an **incorrect** statement related to WAVE System?
   a) WAVE devices deploy IEEE 1609.3 standard.
   b) WSMP/IP v6, both protocols can be used at network layer.
   c) WAVE Service Advertising (WSA) indicates BSMs on SCH 172.
   d) V2X includes all forms of CV communication services.

2. Which of the following is **NOT** included in the IEEE 1609.3 standard?
   a) WSA (WAVE Service Advertisement)
   b) PSID (Provider Service Identifier)
   c) WSMP (WAVE Short Message Protocol)/IPv6
   d) BSM (Basic Safety Message)

3. Which of the following is an incorrect statement?
   a) IEEE 1609.4 supports channel switching capability.
   b) BSM messages are typically received on SCH 172.
   c) Channel switching operation occurs at Network layer.
   d) Dual radio ensures continuous listening of safety messages.

4. Which of the following is an Incorrect statement?
   a) WAVE supports both WSMP and IPv6 protocols.
   b) Compliant WAVE devices are typically interoperable.
   c) PICS should be included in a CV project specification.
   d) WSA broadcasts opportunity on any channel.

8. Icon Guide

The following icons are used throughout the module to visually indicate the corresponding learning concept listed out below, and/or to highlight a specific point in the training material.

1) **Background information:** General knowledge that is available elsewhere and is outside the module being presented. This will be used primarily in the beginning of slide set when reviewing information readers are expected to already know.

2) **Tools/Applications:** An industry-specific item a person would use to accomplish a specific task and applying that tool to fit your need.

3) **Remember:** Used when referencing something already discussed in the module that is necessary to recount.

4) **Refer to Student Supplement:** Items or information that are further explained/detailed in the Student Supplement.

5) **Example:** Can be real-world (case study), hypothetical, a sample of a table, etc.

6) **Checklist:** Used to indicate a process that is being laid out sequentially.