

IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture

IEEE Vehicular Technology Society

Sponsored by the
Intelligent Transportation Systems Committee



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Intelligent Transportation Systems Committee
of the
IEEE Vehicular Technology Society

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Abstract: The wireless access in vehicular environments (WAVE) architecture and services necessary for WAVE devices to communicate in a mobile vehicular environment are described in this guide. It is meant to be used in conjunction with the family of IEEE 1609 standards as of its publication date. These include IEEE Std 1609.2™, IEEE Standard Security Services for Applications and Management Messages; IEEE Std 1609.3™, Networking Services; IEEE Std 1609.4™, Multi-Channel Operation; IEEE Std 1609.11™, Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS); IEEE Std 1609.12™, Identifiers; and IEEE Std 802.11™ in operation outside the context of a basic service set.

Keywords: dedicated short range communications, DSRC, IEEE 1609.0™, OBU, onboard unit, Provider Service Identifier (PSID), roadside unit (RSU), WAVE, WAVE service advertisement, WAVE Short Message, WAVE Short Message Protocol, wireless access in vehicular environments, WSA, WSM, WSMP

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Introduction

This introduction is not part of IEEE Std 1609.0™-2019, IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture.

This document is a revision of IEEE Std 1609.0-2013, modified to be compatible with, and in alignment to the 1609 family of standards that underwent major revisions during 2015. The revisions resulted in the publishing of IEEE Std 1609.2-2016, IEEE Std 1609.3-2016, IEEE Std 1609.4-2016, and IEEE Std 1609.12-2016.

This revision has also been modified to reflect a more up to date current state of Connected Vehicle programs and activities and progress in the US. Department of Transportation (USDOT) ITS program in general.

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1. Overview

A wireless access in vehicular environments (WAVE) system is a radio communication system intended to provide seamless, interoperable services to [users of a transportation system](#). These services include [intelligent transportation system \(ITS\) services](#) ~~those~~ recognized by the [Architecture Reference for Cooperative and U.S. National Intelligent Transportation \(ARC-IT\) Systems \(ITS\) architecture](#) and many others contemplated by the automotive and transportation infrastructure industries around the world. [Specifically, the WAVE system provides](#) ~~, such as~~ communications between vehicles and infrastructure, and communications among vehicles. This guide provides an overview of the system, its components, and its operation. It is intended to provide a context within which to better understand the content of the related IEEE WAVE standards documents, which include IEEE Std 1609.2-~~2013~~TM, IEEE Std 1609.-~~2010~~TM, IEEE Std 1609.4TM, ~~2010, IEEE P1609.6TM [B19],^{1,2}~~ IEEE Std 1609.1-~~2010~~TM, and IEEE Std 1609.12TM, as well as IEEE Std 802.1-~~2012~~TM [stations communicating outside the context of a Basic Service Set (BSS), or OCB]. ¹³

The term dedicated short range communications (DSRC) is sometimes used in the U. S. to refer to radio spectrum or technologies associated with WAVE. For example, U. S. Federal Communications Commission (FCC) documents ([FCC ET Docket No.98-95, RM-9096 \[B15\]](#)) ~~[B6]~~ allocate spectrum to “mobile service for use by DSRC systems operating in the Intelligent Transportation System (ITS) radio service,” and the Society of Automotive Engineers (SAE) has specified messages in SAE J2735 “for use by applications intended to utilize the 5.9 GHz dedicated short range communications for wireless access in vehicular environments.”² Outside the U. S., DSRC may refer to [alternate a distinct radio technologies, such as M5 defined in ISO 21215 \[B50\], G5 defined in ETSI 302 663 \[B8\], or similar technologies](#) ~~technology operating at 5.8 GHz, used, e.g., for electronic fee collection.~~

¹³Information on references can be found in Clause 2.

²⁴The numbers in brackets correspond to those of the bibliography in Annex [A](#) ~~G~~.

²~~Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE SA Standards Board at the time this publication went to press.~~

1.1 Scope

This guide describes the architecture and operation of a WAVE system based on IEEE 1609 standards and IEEE Std 802.11-~~2012~~.

1.2 Aspects of a WAVE system

1.2.1 Introduction

ISO/IEC 42010:2007 [B55 B28] is a recommended practice for architectural description of software-intensive systems, and defines several aspects of any system: an environment or context, stakeholders who typically have interest in or concerns relative to the system, and one or more missions. These aspects are addressed in 1.2.2 through 1.2.5.

1.2.2 Environment

As its name suggests, the WAVE system as presently envisaged is designed to meet the communication needs of mobile elements in the transportation sector. While in many of the usage scenarios at least one of the devices engaged in WAVE communications is expected to be associated with a vehicle, other devices, both fixed and portable (e.g., roadside and pedestrian) are envisaged as well.

1.2.3 Stakeholders

This document is intended to be a useful reference for any of the direct stakeholders including the following:

- Government agencies, ~~and e.g.,~~ national, ~~and~~ state, ~~and local~~ road operators (~~e.g., USDOT NHTSA, FHWA, FMCSA, FTA, and others, see 4.6~~)
- Vehicle designers and original equipment manufacturers.
- Aftermarket equipment makers

— Developers of applications and related standards-

— [Testing and certification groups](#)

Indirect stakeholders include anyone who uses or is otherwise affected by the intelligent transportation systems [\(ITS\)](#) built using the WAVE standards.

1.2.4 Mission

The WAVE standards enable the development of interoperable low-latency, low overhead WAVE devices that can provide communications in support of transportation safety, efficiency, and sustainability, and that can enhance user comfort and convenience.

1.2.5 [Architectural representations](#) ~~Views~~

This document presents several architectural representations, ~~or views~~. These include a device [representation](#) ~~view~~ (~~see~~, e.g., [see](#) 4.3.3.2 and 4.3.3.3), a protocol [representation](#) ~~view~~ (~~see~~, e.g., [see](#) 5.3.1), and a standards [representation](#) ~~view~~ (~~see~~, e.g., [see](#) 4.3.3.1).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies. Additional, non-essential references may be found in the bibliography in Annex [A](#) ~~G~~.

IEEE Std 802.11-~~2012~~, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. [3](#), ~~4~~, ~~5~~

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IEEE Std 1609.3-~~2010~~, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) — Networking Services.

IEEE Std 1609.2-~~2013~~, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) — Security Services for Applications and Management Messages.

IEEE Std 1609.4-~~2010~~, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) — Multi-Channel Operation.

IEEE Std 1609.11-~~2010~~, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) — Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS).

IEEE Std 1609.12, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) — Identifiers ~~Identifier~~ Allocations.

SAE J2735-~~2009~~, Dedicated Short Range Communications (DSRC) Message Set Dictionary. ⁵⁶

3. Definitions, abbreviations ~~abbreviation~~, and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. Normative references listed in Clause 2, and the *IEEE Standards Dictionary Online* ~~or IEEE Std 802.11-2012~~ should be consulted for terms not defined in this clause. ⁶⁷

⁵⁶SAE publications are available from the Society of Automotive Engineers, ~~400 Commonwealth Drive, Warrendale, PA 15096, USA~~ (<http://www.sae.org/>).

⁶⁷*IEEE Standards Dictionary Online* ~~subscription~~ is available at: <http://dictionary.ieee.org>.
~~http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html~~

advertised ~~application~~-service opportunity: A resource consisting of a service channel (SCH) within geographic and temporal bounds, intended for support of a service as indicated by the transmission of a WAVE service advertisement (WSA) with *Service Info* and *Channel Info* referring to that ~~application~~-service and SCH. *See also: [unadvertised service opportunity](#)*.

certificate: *See: [digital certificate](#)*.

certificate authority (CA): *[An entity that issues certificates to entities that are entitled to them. \[from IEEE Std 1609.2\]](#)* ~~An authority trusted to issue digital certificates.~~

certificate chain: *[An ordered set of certificates such that each certificate \(except for the top\) was issued by the certificate above it in the list \[from IEEE Std 1609.2\].](#)* ~~A top-to-bottom ordered list of digital certificates such that each certificate other than the top one is issued by the one above it in the chain.~~

control channel (CCH): A radio channel limited by the WAVE standards to the exchange of management frames and WAVE Short Messages *[\[from IEEE Std 1609.3\]](#)*. *See also: [service channel \(SCH\)](#)*.

cryptomaterial handle: *[A reference to a private key and the associated public key or certificate, used to indicate to the secure data service that the referenced key should be used in a particular operation \[from IEEE Std 1609.2\].](#)*

data plane: *[A component of the abstract architecture containing entities that exchange user data \[from IEEE Std 1609.3\].](#)*

~~**cryptomaterial handle (CMH)**: A reference used by entities outside WAVE Security Services to refer to private keys and associated public key material stored within WAVE Security Services.~~

digital certificate: *[A digitally signed document binding a public key to an identity and/or a set of permissions \[from IEEE Std 1609.2\].](#)* *Syn: [certificate](#), [security certificate](#)*. ~~A set of communication protocols defined to carry application and management data. The data plane provides protocol stack(s) for the transfer of data through a device for transfer over the air.~~

~~**digital certificate:** An electronic document that binds information about an entity to a public key owned by the entity (i.e., a key to which the entity knows the corresponding private key), along with a cryptographic proof that the binding statement is made by a trusted authority (known as the issuer).~~

EtherType: A 2-octet value, assigned by the IEEE Registration Authority, which provides context for interpretation of a data field of a frame (protocol identification) [from IEEE Std 802]. ~~The Ethernet Type field defined in IETF RFC 1042, used to identify the higher layer protocol above logical link control.~~

guard interval: A time interval at the start of each time slot, during which devices using alternating channel access do not transmit [from IEEE Std 1609.4].

~~**application:** A higher layer entity:~~ An abstract entity, typically implemented in software, that resides above the WAVE protocols in the protocol stack, and ~~that~~ may make use of WAVE communication services [from IEEE Std 1609.3] facilities.

higher layer ~~application~~ service: An abstract entity, A service involving an exchange of data, generally provided by a higher layer entity on one WAVE device to a similar entity on another WAVE device, using WAVE communications [from IEEE Std 1609.3]. Syn: service.

~~**higher layer entity:** An entity, such as an application, that resides above the WAVE protocols in the protocol stack and may make use of WAVE communication services.~~

management plane: A component of the abstract architecture containing functions that manage the entities in the data plane [from IEEE Std 1609.3]. ~~A collection of functions performed in support of the communication functions provided by the data plane, but not directly involved in passing application data. The management plane may employ lower layers of the data plane to transfer management information between devices.~~

Networking Services: The A collection of management plane and data plane functions at the network ~~layer~~ and transport ~~layers~~ layer, as specified in IEEE Std 1609.3, supporting Wireless Access in Vehicular Environments (WAVE) communications [from IEEE Std 1609.3].

OCBActivated: [Indicates communication outside the context of a basic service set as specified in IEEE Std 802.11 \(by setting *dot11OCBActivated* to TRUE\) \(i.e., used for WAVE operation\) \[from IEEE Std 1609.4\].](#)

onboard equipment (OBE): A collection of vehicle-mounted equipment including an onboard unit (OBU).

onboard unit (OBU): A WAVE device that can operate when in motion and supports the information exchange with roadside units ([RSUs](#)) or other OBUs.

participant: A WAVE device that is tuned to a channel for the purpose [of](#) accessing an (advertised or unadvertised) ~~application~~-service opportunity.

provider: [Advertiser of a Wireless Access in Vehicular Environments \(WAVE\) service \[from IEEE Std 1609.3\]. See also: user; Wireless Access in Vehicular Environments](#) ~~A WAVE device that transmits a (WAVE) Service Advertisement (WSA), containing Service Info indicating an advertised application-service opportunity, and is a participant in that advertised application-service opportunity. See also: User.~~

Provider Service Context (PSC): A field ~~within the WAVE Service Advertisement (WSA),~~ associated with a Provider Service Identifier (PSID) containing supplementary information related to the ~~application~~-service. The internal format of the PSC is [PSID](#) dependent [\[from IEEE Std 1609.3\].](#) ~~on the PSID value with which it is associated.~~

Provider Service Identifier (PSID): An identifier of [a higher layer](#) ~~an application~~-service provided by a higher layer entity [\[from IEEE Std 1609.12\].](#)

roadside equipment (RSE): A collection of roadside equipment including a roadside unit (RSU).

roadside unit (RSU): A WAVE device that operates only when stationary and supports information exchange with onboard units (OBUs).

root certificate: [A self-signed certificate that can be used as a trust anchor to verify other certificates \[from IEEE Std 1609.2\].](#) ~~A digital certificate that is issued by itself, i.e., that is verified using the public key contained in the certificate rather than a public key contained in a different certificate.~~

~~**root certificate authority:** A certificate authority that holds a root certificate.~~

secure data exchange entity (SDEE): [An entity that uses IEEE Std 1609.2 services to secure any communications \[from IEEE Std 1609.2\].](#) ~~A higher layer entity, such as an application, that originates or receives secured data plane protocol data units (PDUs.)~~

security certificate: [See: digital certificate.](#)

service: [Syn: higher layer service.](#)

service channel (SCH): Any channel that is not the control channel [\[from IEEE Std 1609.3\]. See also: control channel \(CCH\).](#)

sync interval: [A repeating time interval comprised of one time slot 0 interval followed by one time slot 1 interval \[from IEEE Std 1609.4\]. See also: time slot 0; time slot 1.](#)

time slot 0: [A recurring time interval during which a device using alternating channel access will tune to one channel \(nominally the CCH\) and outside of which the device will tune to another channel \(nominally an SCH\) \[from IEEE Std 1609.4\]. See also: time slot 1; sync interval.](#)

time slot 1: [A recurring time interval during which a device using alternating channel access will tune to one channel \(nominally an SCH\) and outside of which the device will tune to another channel \(nominally the CCH\) \[from IEEE Std 1609.4\]. See also: time slot 0; sync interval.](#)

trust anchor: [A certificate whose validity does not depend on the validity of other certificates \[from IEEE Std 1609.2\].](#) ~~Any digital certificate which can be trusted on its own merits, i.e., without ensuring that it is part of a certificate chain up to an already trusted issuer.~~

unadvertised ~~application~~-service opportunity: A resource consisting of a channel within geographic and temporal bounds, intended for support of [a an-application](#)-service, where no WSA with *Service Info* and *Channel Info* referring to that ~~application~~-service and channel is transmitted. [See also: advertised service opportunity.](#)

user: A WAVE device that monitors received WAVE Service Advertisements (WSAs) for an advertised ~~application~~-service opportunity of interest [\[from IEEE Std 1609.3\]](#). See also: **provider**; [Wireless Access in Vehicular Environments \(WAVE\) Service Advertisement \(WSA\)](#).

user priority: A [value](#) ~~priority level~~ assigned to a packet that is ready for transmission, which determines its treatment at the medium access control (MAC) layer [\[from IEEE Std 802.11\]](#).

[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~~ ~~operating~~ outside the context of a basic service set [\[from IEEE Std 1609.3\]](#). ~~outside the context of a(n IEEE 802.11) basic service set (OCB))~~.

[Wireless Access in Vehicular Environments \(WAVE\) Management Entity \(WME\):](#) A set of management functions ~~required to provide~~ ~~providing~~ WAVE Networking Services [\[from IEEE Std 1609.3\]](#).

[Wireless Access in Vehicular Environments \(WAVE\) Routing Advertisement \(WRA\):](#) IPv6 network configuration information broadcast as part of a WAVE Service Advertisement [\(WSA\)](#) [\[from IEEE Std 1609.3\]](#).

[Wireless Access in Vehicular Environments \(WAVE\) Service Advertisement \(WSA\):](#) A [data structure that may include](#) ~~management message type, containing information including~~ the announcement of the availability of [higher layer services](#) [\[from IEEE Std 1609.3\]](#). ~~an application service~~.

WAVE Short Message (WSM): A packet consisting of ~~a WSM data and a WAVE Short Message Protocol~~ (WSMP) header [and WSM Data](#) [\[from IEEE Std 1609.3\]](#).

WAVE Short Message Protocol (WSMP): [The protocol specified in IEEE Std 1609.3 that minimizes communications overhead](#) [\[from IEEE Std 1609.3\]](#). ~~protocol for rapid exchange of messages in a rapidly varying radio frequency (RF) environment where low latency may also be an important objective~~.

3.2 Abbreviations and acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADU	application data unit
AES	Advanced Encryption Standard
AES-CCM	AES in Counter mode with CBC MAC
ANPRM	advance notice of proposed rule making
AP	access point
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
BSM	basic safety message
BSMD	Basic Secured Managed Domain
BSS	basic service set
CA	certificate authority
CALM	communications access for land mobiles
CAM	cooperative awareness message
CBC	cipher block chaining
CCH	control channel
CEN	Comité Européen de Normalization, European Committee for Standardization
CMH	cryptomaterial handle
CMS	Cryptographic Message Syntax

COER	Canonical Octet Encoding Rules
COC	Certificate Operating Council
CRACA	certificate revocation authorizing certificate authority
CRL	certificate revocation list-
CV	connected vehicle
CVNGCE	Connected Vehicle—Next Generation Certification Environment
CVRIA	Connected Vehicle Reference Implementation Architecture
DENM	decentralized environmental notification message
~~DNS~~	~~domain name system~~
DOT	Department of Transportation
DSRC	dedicated short range communications
DTLS	Datagram Transport Layer Security
ECDSA	elliptic curve digital signature algorithm
ECIES	elliptic curve integrated encryption scheme
EDCA	Enhanced Distributed Channel Access
EFC	electronic fee collection
EPD	EtherType Protocol Discrimination
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FMVSS	Federal Motor Vehicle Safety Standard

FNTF	Fast Networking and Transport Layer Protocol
FSAP	Fast Service Announcement Protocol
GPS	global positioning system
ICMPv6	Internet Control Message Protocol for IPv6
IEEE-RA	IEEE Registration Authority
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPSec	Internet Protocol Security
IPv6	Internet Protocol version 6
ISO	International Organization for Standardization
ITS	intelligent transportation systems
ITS-AID	ITS application
ID ITS-PN	ITS port number
ITS-S	ITS station
ITS-SU	ITS station units
IV	initialization vector
LDM	local dynamic map
LLC	logical link control
LPD	LLC Protocol Discrimination
LSAP	link service access point

~~LSI-S~~	~~local service indicator for security~~
MAC	medium access control (in IEEE Std 802.11)
MAC	message authentication code (in IEEE Std 1609.2)
MAP	Map Data
MIB	management information base
MLME	MAC sublayer management entity
MLMEX	MLME extension
NHTSA	National Highway Transportation Safety Administration
NPRM	notice of proposed rule making
~~MTU~~	~~maximum transmission unit~~
OBE	onboard equipment
OBU	onboard unit
OCB	outside the context of an a(n IEEE Std 802.11) basic service set
OEM	original equipment manufacturer
OFDM	orthogonal frequency division multiplexing
OID	object identifier
OSI	open systems interconnect
P2PCD	peer-to-peer certificate distribution
PDU	protocol data unit
PHY	physical layer

[PICS](#) [Protocol Implementation Conformance Statement](#)

[PKCS](#) [Public Key Cryptography Specification](#)

[POC](#) [proof of concept](#)

~~PLME~~ ~~physical layer management entity~~

PSC Provider Service Context

PSID Provider Service Identifier

PSSME Provider Service Security Management Entity

~~QC~~ ~~quality control~~

RF radio frequency

RFC Request for Comments

[RSA](#) [Rivest-Shamir-Adleman](#)

RSE roadside equipment-

RSU roadside unit

[SAE](#) [Society of Automotive Engineers](#)

SAP service access point

SCH service channel

[SCMS](#) [Security Credential Management System](#)

SDEE secure data exchange entity

[SDO](#) [standards development organization](#)

[SDS](#) [Secure Data Service](#)

SE	systems engineering
SHA-2	Secure Hash Algorithm 2
SME	Station Management Entity
SPAT	signal phase and timing
SPDU	secured protocol data unit
SSME	Station Security Management Entity
SSP	service specific permissions
STA	station
SUT	system under test
TCI	test command interface
~~SNAP~~	~~Subnetwork Access Protocol~~
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TMC	Traffic Management Center
TP	test purposes
TSS	test suite structures
UDP	User Datagram Protocol
UMTRI	University of Michigan Technology Research Institute
UP	user priority
UPER	Unaligned Packed Encoding Rules

~~U.S.~~	~~United States of America~~
UTC	Coordinated Universal Time
V-DTLS	Vehicular-Datagram Transport Layer Security
V-HIP	Vehicular-Host Identity Protocols
V2D	vehicle-to-hand-held device
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VII	vehicle infrastructure integration
VIIC	Vehicle Infrastructure Integration Consortium
VSA	vendor specific action
VSC	vehicle safety communications
VST	Vehicle Service Table
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

4. Introduction to relevant activities, systems, ~~Relevant~~ standards, and terminology usage

4.1 Overview of intelligent transportation systems (ITS) and Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) ~~Systems and the National ITS architecture~~

This subclause provides a brief context for the WAVE standards, and includes information on related activities.

~~Intelligent Transportation Systems (ITS)~~ are being developed throughout the world. The United States ITS program was created by Congress in the Intermodal Surface Transportation Efficiency Act of 1991, and is administered by the U. S. Department of Transportation ([USDOT](#)). The program uses advanced electronics to improve traveler safety, decrease traffic congestion, facilitate the reduction of air pollution, and conserve vital fossil fuels.

ITS improve transportation safety and mobility and [enhance](#) ~~enhances~~ productivity through the use of advanced communications and information systems technologies. ITS encompass a broad range of fixed and mobile communications-based information and electronics technologies. When integrated into the transportation system's infrastructure, and into vehicles themselves, these technologies relieve congestion, improve safety, and enhance productivity.

One of the key initiatives within the U. S. ITS program is the [ARC-IT \[B1\]](#). [ARC-IT is a reference architecture and National ITS Architecture. The National ITS Architecture is the definitive framework that will guide deployment of intelligent transportation systems in the U.S. for the next 20 years or more. The latest version of the National ITS Architecture is Version 7, the details of which can be found at: <http://www.its.dot.gov/arch>. The National ITS Architecture](#) provides a common framework for planning, defining, and integrating intelligent transportation systems. [ARC-IT reflects the contributions of a broad cross-section of the ITS community \(e.g., transportation practitioners, systems engineers, system developers, technology specialists, consultants\) over many years. ARC-IT, previously called the National ITS Architecture, was first developed in 1996 and has been updated many times over the years to reflect changes in technology and define new ITS services. ARC-IT includes content from the Connected Vehicle Reference Implementation Architecture \(CVRIA\), which until now was the repository of all connected vehicle architecture-related material. The architecture has been renamed in recognition of these major revisions to content and underlying structure. ARC-IT is expected to guide deployment of ITS in the US for the next 20 years or more. See Annex H for a discussion of terminology usage within, and a more detailed description of, ARC-IT.](#) ~~The architecture defines the following:~~

- ~~= Functions (e.g., gather traffic information or request a route) that are required for ITS.~~
- ~~= Physical entities or subsystems where these functions reside (e.g., the field or the vehicle).~~
- ~~= Information flows and data flows that connect these functions and physical subsystems together into an integrated subsystem.~~

~~This architecture guide focuses on the physical entities or subsystems of an ITS architecture, for example the U.S. National ITS Architecture. The National ITS Architecture describes a physical representation (though not a detailed design) of how the system provides the required functionality. Four categories of subsystems are identified: Travelers (e.g., Remote Traveler Support, Personal Information Access), Centers (e.g., Traffic Management, Emergency Management), Vehicles, and Field (e.g., Roadway Payment, Parking Management). The roadside unit (RSU) exists in the "Field" area, and the onboard unit (OBU) exists in the "Vehicle" area. The WAVE communications provide vehicle-vehicle communications and field-vehicle communications.~~

4.2 ASTM and the Federal Communications Commission (FCC)

Pursuant to the Transportation Equity Act for the 21st Century, the US. FCC, in consultation with the US. DOT, allocated the 5.850–5.925 GHz band to DSRC in October 1999 (see 5.6). On November 7, 2002, the FCC adopted a Notice of Proposed Rule Making (NPRM) seeking comment on proposed DSRC service rules in the 5.9 GHz band, and on December 17, 2003, it adopted the DSRC service rules.

To promote the widespread use and evaluation of intelligent vehicle-highway systems technology, the ~~Commission in the~~ DSRC Report and Order FCC 03-[324-2004 \[B16\]](#) ~~0324 [B7]~~ adopted the ASTM E2213–03 Standard (ASTM-DSRC) [[B2](#) ~~B4~~], which was supported by most commenters and which had been developed under an accredited standard setting process. To achieve interoperability, allow open eligibility, and encourage the development of a market for equipment that [meets](#) ~~will meet~~ the needs of public safety DSRC licensees, the rules adopted by the FCC require all DSRC operations in the 5.9 GHz band to comply with the ASTM-DSRC standard. [The ASTM-2213-2003 standard \[B2\] describes the physical \(PHY\) layer \(e.g., carrier sense multiple access operation, power spectral density, adjacent channel interference\) and medium access control \(MAC\) layer protocols that are based on IEEE Std 802.11.](#)

DSRC roadside units ([RSUs](#)) (i.e., communication units that are fixed along the roadside) are licensed under Part 90 Subpart M of the FCC rules (“Intelligent Transportation Systems Radio Service”). RSU licensees receive non-exclusive geographic-area licenses authorizing operation on [70](#) ~~seventy~~ of the [75 MHz](#) ~~seventy-five megahertz~~ of the 5.9 GHz band. [Onboard units \(OBUs\)](#) are licensed by rule under new Subpart L of Part 95 of the FCC rules; OBU operation is not geographically restricted by FCC license.

The FCC has defined three levels of priority for operation in the 5.9 GHz band. Safety of life and property has the highest priority. The second highest priority is public safety, which consists of State and Local Government agencies (non-Federal), which includes groups such as first responders, highway maintenance, State and Local Departments of Transportation, and Public Transit. Also included are authorized groups (usually with a memorandum of agreement) such as private ambulance services and volunteer fire departments. The lowest level of priority are private service providers, which includes all commercial services.

For more information pertaining to the DSRC Service, visit the FCC website <https://www.fcc.gov/dedicated-short-range-communications-dsrc-service>.

After ASTM 2213-2003 [B2] was published, standardization of the PHY and MAC was moved to the IEEE 802.11 Working Group. Improvements to the standard were made resulting in the amendment IEEE Std 802.11p-2010, which was subsequently incorporated into the base standard, IEEE Std 802.11. The FCC rules need to be updated to incorporate the improved standard. Equipment currently being used in testbeds and other deployments that have government funding are operating under an experimental National Telecommunications and Information Administration (NTIA) license and are compliant with IEEE Std 802.11 and the IEEE 1609 family of standards.

~~Since 2003, work has continued on IEEE standards for the 5.9 GHz band, making the FCC reference to the ASTM DSRC standard obsolete. It is currently expected that equipment deployed in the 5.9 GHz band in the U. S. will be compliant to the IEEE 1609 family of standards and IEEE Std 802.11-2012.~~

4.3 IEEE standards

4.3.1 Trial-use WAVE standards—historical

In 2006 and 2007, a set of IEEE 1609 standards were adopted for trial-use. The trial-use standards were used to demonstrate and prove the WAVE architecture and protocols, with the resulting lessons learned fed back into full-use standards published in 2010 and beyond (see Annex F for an overview of field trials, and 4.3.3 for a description of subsequent standards). These IEEE 1609 trial-use standards, which were developed for use with IEEE Std 802.11p (now [incorporated into](#) IEEE Std 802.11-~~2012~~; see 4.3.2), are depicted in Figure 1 and described following [the figure](#).

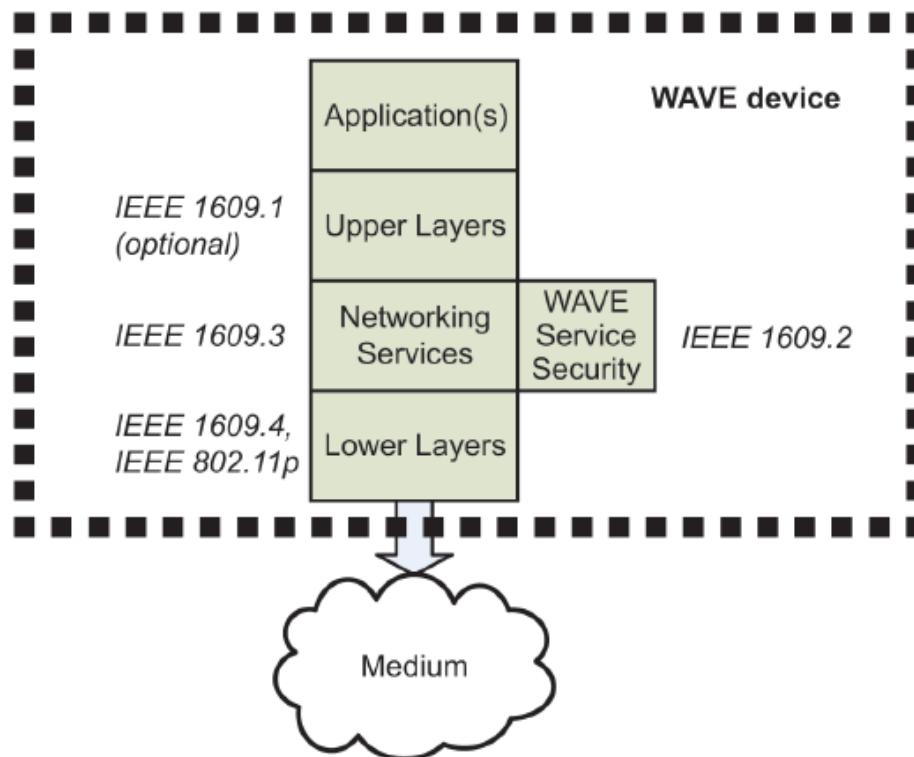


Figure 1—Trial-use standards

IEEE Std 1609.4TM-2006 [B32 B18] specified extensions to the IEEE Std 802.11-2012 MAC layer for multi-channel operations, for example e.g., operating alternately on the control channel and one of several service channels. It was superseded by IEEE Std 1609.4TM-2010 [B33], and has since been superseded by IEEE Std 1609.4TM-2016 [B34] -2010.

IEEE Std 1609.3TM-2007 [B29 B17] specified networking services required for operation of a WAVE system. It employs the standard IPv6 protocol, introduces a WAVE Short Message Protocol (WSMP), and provides a collection of management functions supporting ~~WAVE~~-services available on WAVE devices. It was superseded by IEEE Std 1609.3TM-2010 [B30], and has since been superseded by IEEE Std 1609.3TM-2016 [B31]. ~~1609.3-2010.~~

IEEE Std 1609.2TM-2006 [B26 B16] collected the security processing requirements necessary for WAVE system operation. It was superseded by IEEE Std 1609.2TM-2013 [B27], and has since been superseded by IEEE Std 1609.2TM-2016 [B28] -2013.

IEEE Std 1609.1TM-2006 [B25 B15] Resource Manager was found unnecessary for WAVE standardization~~system-operation~~; it has been withdrawn and no revision is planned.

4.3.2 IEEE Std 802.11

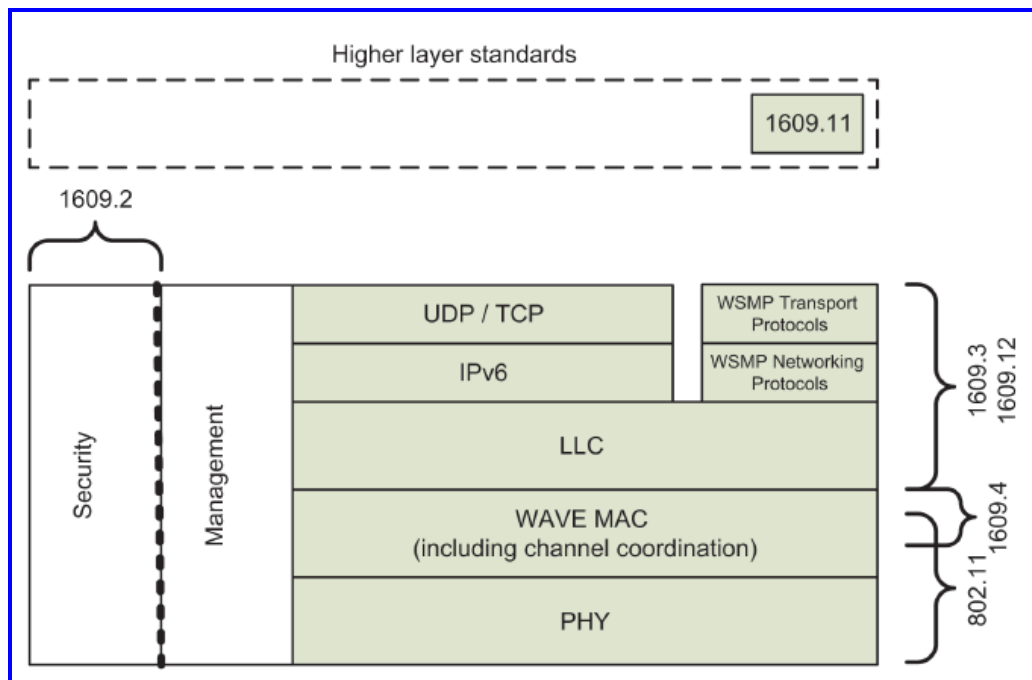
IEEE Std 802.11-2012 specifies one ~~medium access control~~-(MAC layer)-~~sublayer~~ and several ~~physical layers~~-(PHYs) to provide wireless connectivity among fixed, portable, and moving access points (APs) and stations (STAs) within a local area. IEEE Std 802.11pTM-2010 [B21 B12], ~~now incorporated in IEEE Std 802.11-2012,~~ standardized a ~~small~~-number of extensions ~~to IEEE Std 802.11-2012 for operating outside the context of a basic service set (OCB, i.e., with the dot11OCBAActivated parameter set to true), that is,~~ supporting the types of communications ~~vehicular~~ scenarios required for WAVE system operation, including OCB (i.e., when dot11OCBAActivated is true). When operating OCB, certain services are disabled in a WAVE network. These include the IEEE Std 802.11 authentication, association, and data confidentiality services, which take too much time and do not allow the fast access and low latency communications required of a dynamic mobile environment. IEEE Std 802.11p-2010 [B12] ~~also standardized the 5.9 GHz~~ [B21] was incorporated into the IEEE Std 802.11 base standard in 2012. IEEE Std 802.11 was subsequently updated in 2016.

[IEEE Std 802.11](#) uses the orthogonal frequency division multiplexing (OFDM) PHY (5.850 GHz to 5.925 GHz in the US, 5.855 GHz to 5.925 GHz in Europe), [and amends the](#) channel bandwidths, operating classes, transmit power classification, transmission masks, and the alternate channel and alternate adjacent channel rejection requirements [needed for a WAVE network](#).

4.3.3 Full-use WAVE standards

4.3.3.1 IEEE 1609 standards

Full-use WAVE standards are ~~in the process of being~~ published as illustrated in Figure 2 and are described in the following subclauses. These are the standards that are reflected in the descriptions throughout this document. Differences between trial-use and full-use standards are summarized in Annex F.



[\(New\)](#)

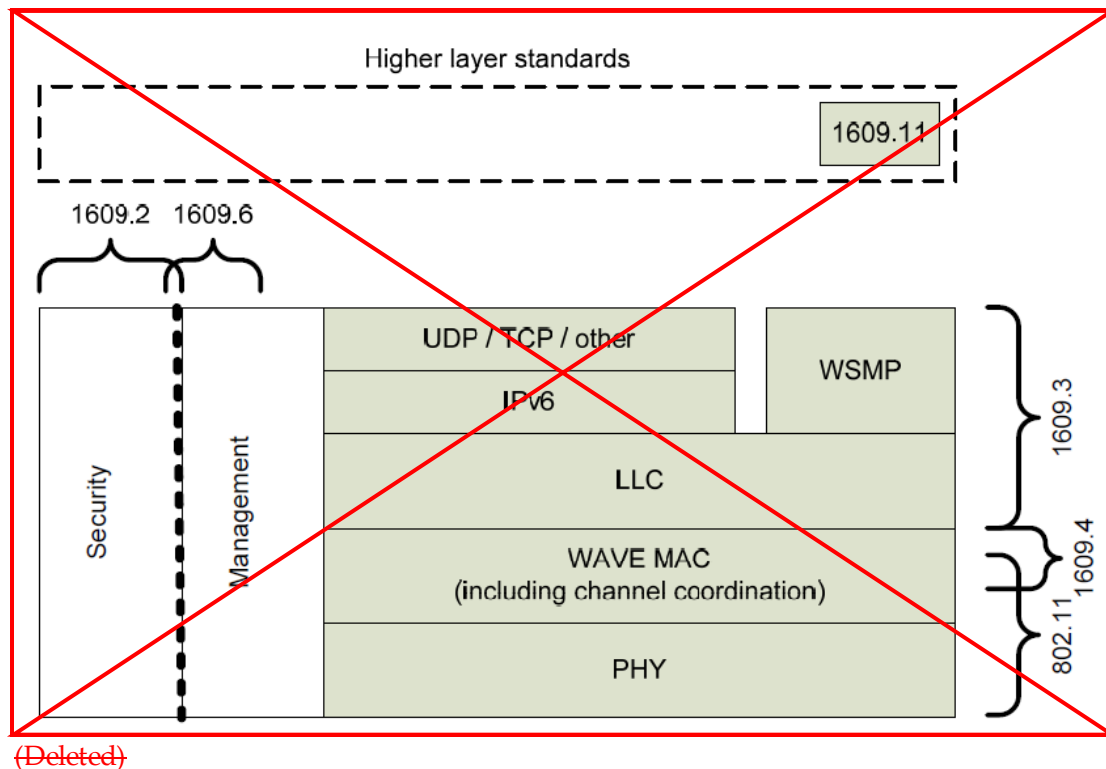


Figure 2—Full-use standards

IEEE Std 1609.4-2010 (Multi-Channel Operations) specifies extensions to the IEEE [Std 802.11](#) MAC layer protocol and includes the following features:

- Channel [coordination](#) ~~timing~~ and [routing](#), [multi-channel synchronnization](#) ~~switching~~
- Use of IEEE [Std 802.11](#) facilities [e.g., channel access, Enhanced Distributed Channel Access (EDCA)] outside the context of a BSS
- Use of IEEE [Std 802.11](#) ~~Vendor Specific Action and~~ Timing Advertisement frames in a WAVE system
- MAC-layer readdressing in support of pseudonymity
- [Management information base \(MIB\) maintenance \(contains configuration and status information\)](#)

IEEE Std 1609.3 (Networking Services) includes the following features:

- WSA transmission and monitoring, channel access assignment
- WSMP
- Use of the local link control (LLC) sublayer and EtherType Protocol Discrimination (EPD)
- ~~– WAVE Service Advertisements and channel scheduling~~
- ~~– WAVE Short Message Protocol~~
- Use of Internet Protocol version 6 (~~protocols, e.g., LLC~~ and IPv6), including streamlined IPv6 configuration
- ~~Exchange~~ Delivery of ~~specific~~ general management information between WAVE devices ~~over the air interface~~
- MIB maintenance (contains configuration and status information)

IEEE Std 1609.2-~~2013~~ (Security Services for Applications and Management Messages) specifies communications security for WAVE Service Advertisements and WAVE Short Messages and additional security services that may be provided to higher layers.

~~IEEE P1609.5 (Communication Manager) is an open project for addressing network management requirements.~~

~~IEEE P1609.6 (Remote Management Services), in development, includes over the air management and alias features.~~

IEEE Std 1609.11-~~2010~~ (Over-the-Air Electronic Payment Data Exchange Protocol for ITS) is the first application-level IEEE 1609 standard and specifies a payment protocol referencing ISO standards. An example use case illustrating electronic fee collection is provided in DE.2.

IEEE Std 1609.12 (~~Identifiers -2012 (Identifier Allocations)~~) records the allocations of some Provider Service Identifier (PSID) allocation decisions made by the IEEE 1609 working group, and other identifiers used by the WAVE standards, including object identifier (OID), Ether Type, and Management ID. PSID usage and encoding rules are also described.

Other WAVE standards may be developed in the future to specify higher layer, for example, or application layer, features.

4.3.3.2 “WAVE device” and standards conformance

The IEEE 1609 standards include the concept of a WAVE device, which is defined as a device that is conformant to the following:

- IEEE Std 1609.3~~-2010.~~
- IEEE Std 1609.4~~-2010.~~
- IEEE Std 1609.12
- IEEE Std 802.11~~-2012~~, operating outside the context of a basic service set~~.~~
- IEEE Std 1609.2 (when sending secured WSAs or using 1609.2 certificates)

For IEEE Std 1609.3 conformance, a device implements at least the following ~~high-level~~ features:

- LLC sublayer
- ~~— LLC and Subnetwork Access Protocol (SNAP) — see 5.3.~~
- IPv6 or WSMP_L or both. ~~A conformant device is able to at least send or receive over one of the protocols.~~
- Transmit or receive, or both

For IEEE Std 1609.4 conformance, a device implements at least the following features:

- OCBActivated communication (as specified in IEEE Std 802.11)

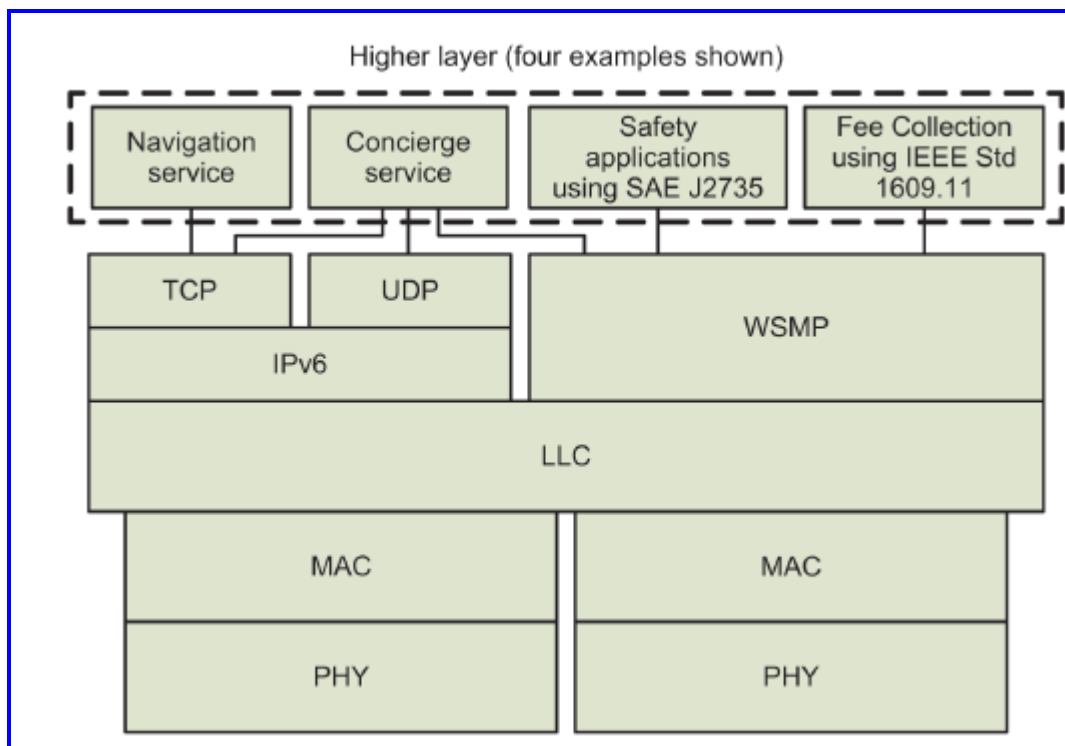
- Transmit or receive, or both.
- EDCA and user priority when transmitting.

Each [of the](#) WAVE protocol [standards IEEE Std 1609.2, ~~standard \(including~~ IEEE Std 1609.3-2010, IEEE Std 1609.4-2010, and IEEE Std 1609.11-2010](#) includes an annex containing a Protocol Implementation Conformance Statement (PICS). The PICS references each major feature specified in the standard, with an indication of whether the feature is mandatory, optional, or conditional on the presence of some other feature. An implementer of WAVE devices may use the PICS to indicate which features are supported by an implementation; a procurer of WAVE devices may employ the PICS to indicate the features required for a particular deployment. A tester may use the PICS as a checklist against which to verify conformance. See Annex [C](#) ~~B~~ for a discussion of certification.

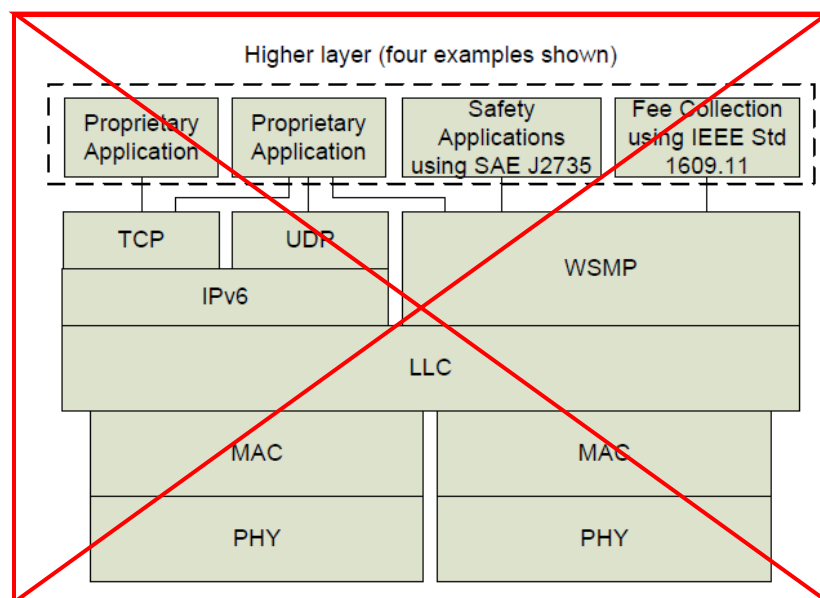
[Note that the definition of a “WAVE device” as described above does not preclude the device from including any other radios, protocol stacks, or other communications technology \(e.g., IEEE 802.x, 3G/4G/LTE cellular, Bluetooth\), and makes no assumptions about its internal architecture.](#)

4.3.3.3 WAVE device configuration

Figure 3 illustrates an example of a device with two radios, running four applications operating above the WAVE communication protocols.



(New)



(Deleted)

Figure 3—Example WAVE device configuration

4.4 SAE DSRC standards

SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary comprises a set of messages, data frames, and data elements intended for ~~both~~ vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (the roadside) (V2I⁷) safety exchanges. It includes specifications of each message, as well as explanatory usage text required to properly understand and implement that message. Informative annexes explain the operational concepts of several of the safety applications.

[SAE is developing a family of standards, which includes guidance for the use of systems engineering \(SE\) and generic DSRC interface requirements content. The parent document is SAE J2945 201712, Dedicated Short Range Communication \(DSRC\) Systems Engineering Process Guidance for SAE J2945 201712](#)

[Documents and Common Design Concepts™ \[B63\]. SAE has recently published SAE J2945/1, On-Board System Requirements for V2V Safety Communications \[B62\] to specify system requirements for an on-board vehicle-to-vehicle safety communications system for light vehicles, including standards profiles, functional requirements, and performance requirements. The system is capable of transmitting and receiving the SAE J2735-defined basic safety message \(BSM\) over a WAVE system.](#)

~~SAE is also developing J2945 DSRC Minimum Performance Standards to specify the minimum communication performance requirements of the SAE J2735 DSRC message sets and associated data frames and data elements.~~

IEEE 1609 WAVE and SAE DSRC standards are developed cooperatively; ~~several PSID values have been allocated for use with DSRC messages.~~ WAVE systems deployed in the U. S. are expected to use the SAE J2735 message set for safety applications. See [DE.1](#) for a use case for collision avoidance using this message set.

⁷[The terms vehicle-to-infrastructure \(V2I\) and infrastructure-to-vehicle \(I2V\) are often used interchangeably, and sometimes written as V2I/I2V. This guide uses the V2I variant throughout.](#)

4.5 Terminology use in WAVE and related standards

4.5.1 General

As of this writing, the terminology used in ITS related standards is relatively new, and usage of terms has not yet stabilized. In conjunction with the efforts to harmonize IEEE 1609 standards with those of ISO (specifically ISO 21217 [B51] and related standards and technical specifications), there is an ongoing effort in building consensus regarding how terminology should be used and how terms should be defined. The following provides some historical context and information helpful to understanding subsequent detailed discussions regarding terminology usage.

4.5.2 Historical perspective

In IEEE Std 1609.0™-2013 [B24], some changes were made to the terminology used to define and describe the PSID and its use in layers above the transport layer. Terms such as “application-service” were introduced, with the objective to be more flexible in describing what occurs above the WSMP protocol. These changes eventually made their way into the most recently published IEEE Std 1609.3™-2016 [B31] and IEEE Std 1609.12™-2016 [B35] versions.

Additionally, international standards groups introduced terminology to describe the ITS station architecture. For example, terms such as service, application object, application class, application, application process, and numerous other terms are defined in ISO standards. In some cases, the terminology used in these standards does not exactly align with terminology used in IEEE 1609 standards. The inconsistencies in terminology usage in the aforementioned IEEE and international standards, which have significant overlap, has been a source of confusion to many.

Other standards organizations (e.g., SAE) and various programs that use standards have introduced new terminology into their lexicons. For example the ARC-IT reference architecture uses some terminology that is unique to that project (see Annex H).

Harmonization of terminology is an ongoing process that is being undertaken to bring additional clarity to ITS standards. As a part of this effort, this revision of IEEE Std 1609.0 introduces some simplified terminology, and also clarifies terminology usage over various standards and the projects that use them. Important parallels as well as distinctions are noted. In clauses that follow, this guide discusses specific topics related to terminology usage in a structured way. Terminology within the context of various standards and projects are discussed separately, and also correlated where possible.

See 5.10.4 for a detailed discussion of PSID and related terminology, in all of its known uses and contexts.

4.5.3 Use of the term “service” in WAVE standards

The term “service” is widely used when describing systems and software architectures, and can refer to different concepts depending on context. Within the WAVE standards we use the term in two contexts, and they are illustrated as follows:

- In layered protocol architectures, the term *service* may be used to describe functionality provided to one layer from the layer below. Concepts within IEEE 1609 standards that use the term *service* in this manner include:
 - *Service access points (SAPs)*
 - *Service primitives (describes interfaces across SAPs)*
 - *Data plane services*
 - *Management plane services*
 - *Networking services*
 - *Security services*

- In service oriented software and communications systems architectures, the term *service* may be used to describe functionality provided between peer devices communicating over a network. IEEE 1609 standards describe services as being provided and used between higher layer entities operating on WAVE devices. These are also sometimes referred to as *higher layer services*. Concepts within IEEE 1609 standards that use the term *service* in this manner include:
 - Provider Service Identifier (PSID)
 - Provider Service Context (PSC)
 - WAVE Service Advertisement (WSA)
 - Service opportunity, service channel
 - Provider service request, user service request (i.e., the object of the word *service* is a higher layer service)

4.5.4 Use of the term “application” in WAVE standards

The term “application” is another term that is widely used but may have different meanings depending on the context in which it is used. For example a client *application* running on a laptop computer typically presents a GUI displayed on a monitor, and uses a keyboard and mouse as input devices. Another example is an “app” running on a smart phone using a touchscreen. These are examples that are very familiar to a wide variety of users. In these examples, the term application has meaning that is understood in the context of laptops and smartphones.

Within the ITS community, the term “application” has many different implications. Within ISO, the term ITS *application* is used to reference an instantiation of an ITS service (i.e., a specific design of how an intelligent transportation system provides functionality to a user of the transportation system). In the community focused on avoiding collisions between vehicles, the term is used to refer to logic that is used to avoid collisions in particular scenarios: for example, Forward Collision Warning, Left Turn Warning, and Intersection Movement Assist are referred to as different *applications* even though they use the same data and sensor input — in other words, the concept of an *application* is in some sense tied to the real-world outcome.

In the 1609 WG, the PSID is often discussed in terms of being related to *application* activities, but it is associated not with outcomes but with successful interoperability over particular interfaces. Examples include successful delivery of BSMs to a BSM-consuming entity on the receiving WAVE device, or successful authentication (via 1609.2 certificates) of data that is input to a decision, or successful advertisement of and establishment of a tolling session via a WSA.

It is important to note that although the term “application” is often used in informal discussions of activity using the IEEE 1609 standards, the IEEE 1609 standards do not specify a system architecture or behavior above the transport layer. The WAVE standards to date describe these operations in a generic manner, using terms such as higher layer entity, service, and several permutations of the term application, for example, application-service and application area. This has been a source of confusion to readers of the standards, and the source of much discussion within the 1609 Working Group and other Standards Development Organizations (SDOs).

Operations that occur in higher layers are, of course, essential to the overall usefulness of any communications system. Furthermore, the higher layers and the usage of the term “application” are defined within other standards and technical specifications that are related to the WAVE standard, for example, ISO 17419 [B48].

This document attempts to disambiguate the usage of terms within their respective standards, and draw parallels where appropriate to facilitate understanding of the overall ITS strategy around the world. This writing of IEEE Std 1609.0 simplifies the definition of terms that are expected to be reflected in future updates of IEEE Std 1609.3.

[Planned future updates to IEEE Std 1609.3 are expected to use the term “service” rather than the term “application” \(and its permutations\). However, as IEEE Std 1609.0 does address and describe behavior above the transport layer, this document uses the term “application” generically as is appropriate to convey a good understanding of the WAVE system’s intended use.](#)

4.6 Related standards and organizations

4.6.1 Organizations ~~and projects~~

Each organization listed below includes some aspect of ITS or communications in its charter, and may be of interest to WAVE stakeholders. Annex [E](#) ~~D~~ has a link to a list of international ITS standards.

American Association of State Highway and Transportation Officials (AASHTO): AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 [US](#) ~~United~~ states, the District of Columbia, and Puerto Rico. It represents five transportation modes: air, highways, public transportation, rail, and water. Its primary goal is to foster the development, operation, and maintenance of an integrated national transportation system.

ASTM International ~~l~~: ASTM International, formerly the American Society for Testing and Materials, develops and delivers test methods, specifications, guides, and practices that support industries and governments worldwide.

[Crash Avoidance Metrics Partners \(CAMP\): CAMP is a consortium of automobile original equipment manufacturers \(OEMs\) working to develop technology that helps vehicles avoid crashes.](#)

European Committee for Standardization (CEN): CEN is a major provider of European Standards and technical specifications. These standards have a unique status since they also are national standards in each of its member countries.

European Telecommunications Standards Institute (ETSI): ETSI produces globally applicable standards for information and communications technologies including fixed, mobile, radio, broadcast, Internet, aeronautical, and other areas.