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IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Networking Services

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IEEE Vehicular Technology Society

Developed by the
Intelligent Transportation Systems Committee



IEEE Std 1609.3™-2020
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(Revision of
IEEE Std 1609.3-2016)

IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Networking Services

Developed by the

Intelligent Transportation Systems Committee
of the
IEEE Vehicular Technology Society

Approved 4 December 2020

IEEE SA Standards Board

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Abstract: Services to WAVE devices and systems are provided. Layer 3 and layer 4 of the open system interconnect (OSI) model and the Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) elements of the Internet model are represented. Management and data services within WAVE devices are provided.

Keywords: IEEE 1609.3™, Provider Service Identifier (PSID), WAVE Service Advertisement (WSA), WAVE Short Message (WSM), Wireless Access in Vehicular Environments (WAVE)

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PDF: ISBN 978-1-5044-7275-3 STD24544
Print: ISBN 978-1-5044-7276-0 STDPD24544

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Introduction

This introduction is not part of IEEE Std 1609.3™-2020, IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Networking Services.

A WAVE system is a radio communications system intended to provide seamless, interoperable services to users of a transportation system. These services include Intelligent Transportation System (ITS) services recognized by the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) [B1][1] and many others contemplated by the automotive and transportation infrastructure industries around the world. Specifically, the WAVE system provides communications between vehicles and infrastructure, communications among vehicles, and potentially communication among other devices. Networking Services provides services to WAVE devices and systems. Layer 3 and layer 4 of the open system interconnect (OSI) model and the Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) elements of the Internet model are represented. Management and data services within WAVE devices are provided. Network Services is but one component in the overall WAVE architecture, which is described in IEEE Std 1609.0™.

[1] The numbers in brackets correspond to those of the bibliography in Annex A.

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1. Overview

1.1 General

A wireless access in vehicular environments (WAVE) system is a radio communication ~~communications~~ system intended to provide seamless, interoperable services to users of a transportation system. These services include ~~those recognized by the U.S. National~~ Intelligent Transportation System ~~Systems~~ (ITS) services recognized by the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) and many others contemplated by the automotive and transportation infrastructure industries around the world. Specifically, the WAVE system provides~~. These services include~~ communications between vehicles and infrastructure ~~roadside units, vehicles and other vehicles~~, and ~~perhaps~~ communications among vehicles ~~other WAVE devices~~. WAVE Networking Services provide management services and data delivery services between WAVE devices. Networking Services is but one component in the overall WAVE architecture, which ~~includes IEEE Std 1609.2™,[1] IEEE Std 1609.4™, and IEEE Std 802.11™. The WAVE architecture~~ is described in IEEE Std 1609.0™[1].

[1] Information on references can be found in Clause 2.

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Aspects of the WAVE architecture specifically related to the use of IEEE Std 802.11™ as the underlying wireless communication technology are incorporated in various places throughout this document. The IEEE Std 802.11–specific aspects are identified and marked as such, and Annex M has been added to include aspects specifically related to the use of LTE-V2X as the underlying wireless communication technology.

1.2 Scope

The scope of this standard is to define services, operating at the network and transport layers, in support of wireless connectivity among vehicles, roadside devices, and Intelligent Transportation Systems (ITS) devices. The scope also includes aspects of the corresponding architecture related to the use of lower layer underlying wireless communication technologies ~~vehicle-based devices, and between fixed roadside devices and vehicle-based devices using the 5.9 GHz Dedicated Short Range Communications/Wireless Access in Vehicular Environments (DSRC/WAVE) mode~~.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals is *required to*).[2, 3]

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals is *recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals is *permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals is *able to*).

[2] The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

[3] The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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~~1.2 Purpose~~

~~WAVE Networking Services represent layer 3 (networking) and layer 4 (transport) of the open system interconnect (OSI) communications stack. The purpose of this standard is to provide addressing and routing services within a WAVE system, enabling multiple stacks of upper layers above WAVE Networking Services and multiple lower layers beneath WAVE Networking Services. Upper layer support includes invehicle applications offering safety and convenience to users.~~

1.4 System overview

The system described in this standard supports high-rate, low-latency communications between WAVE devices. Generic Internet Protocol version 6 (IPv6) traffic is supported, ~~(not Internet Protocol version 4),~~ as well as a specialized WAVE Short Message service, although a given device might not support both protocols. Additional Internet Protocols (IP) may also be supported. When IEEE Std 802.11™ is used as the underlying wireless communication technology, A control channel provides a common channel for signaling. Both IP data and ~~is restricted to service channels;~~ short message data may be sent on either type of channel. Higher layer entities benefiting from the WAVE communications can reside on the WAVE devices or reside on devices located on other networks connected to these devices. A more complete description of a WAVE system is provided in IEEE Std 1609.0.

1.5 Applicability

WAVE Networking Services support wireless communications between ~~any and~~ all WAVE devices. These devices may be mobile, portable, or stationary. The mobile devices include vehicles operating at high speeds on open highways. A common characteristic of WAVE systems is the need for extremely low communications latency (measured in milliseconds) from initially encountering a device that provides services to completing a set of data transfers.

This standard is consistent with the vehicle-to-roadside and vehicle-to-vehicle communications needs of various ITS architectures. Its intent is to enable interoperability and robust safety/public safety communications among these WAVE devices.

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1.6 Conformance

Per the *IEEE Style Manual* [B5 ~~B1~~], this standard includes normative and informative information. Normative text may describe mandatory or optional features. A mandatory feature may have optional as well as mandatory components. For example, a mandatory message may have optional fields. An optional feature may have components that are mandatory if the feature is supported. For example, an optional message might require a certain field. Additionally, a feature may be conditional on support of another feature. For example, if A is supported, at least one of B or C must be supported.

In this standard, features are designated as mandatory, optional, or conditional in the introduction to the subclause specifying the feature. The designation applies to the requirements found in the subclause itself as well as any subordinate subclauses, unless otherwise indicated. The word *shall*, when applied to a component of an optional feature, indicates that the component is mandatory if the feature is supported, i.e., conditional on support for the feature. The protocol implementation conformance statement (PICS) in Annex D summarizes the features and their components.

1.7 Document conventions

Unless otherwise noted, conventions follow those in IEEE Std 802.11, including conventions for the ordering of information within data items as specified in Clause 8 of this standard.

Numbers are decimal unless otherwise noted, except Internet Protocol (IP) addresses, which are hexadecimal per the conventions defined in Internet Engineering Task Force (IETF) RFC 4291 ~~2373~~. Numbers preceded by 0x indicate hexadecimal numbers, so that 0xFF is equivalent to "FF hexadecimal." Numbers preceded by 0b are binary. Numbers preceded by 0p are p-encoded (see IEEE Std 1609.12™).

Words referring to data items that are defined as either a field in an interface primitive, a field in an over-the-air message, or a data item in the management information base (MIB) are written in italics.

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Unless otherwise noted, references to a MIB refer to the WME MIB specified in Annex B.

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.

ATIS.3GPP.24.301V14100-2019, Universal Mobile Telecommunications System (UMTS); LTE; 5G; Non- Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3 (3GPP TS 24.301 version 14.10.0 Release 14).

ATIS.3GPP.24.386V1440-2019, LTE; User Equipment (UE) to V2X control function; protocol aspects; Stage 3 (3GPP TS 24.386 version 14.4.0 Release 14).

ATIS.3GPP.36.211V14120-2019, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.12.0 Release 14).

ATIS.3GPP.36.212V14100-2019, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (3GPP TS 36.212 version 14.10.0 Release 14).

ATIS.3GPP.36.213V14120-2019, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (3GPP TS 36.213 version 14.12.0 Release 14).

ATIS.3GPP.36.214V1440-2018, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements (3GPP TS 36.214 version 14.4.0 Release 14).

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ATIS.3GPP.36.321V14110-2019, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (3GPP TS 36.321 version 14.11.0 Release 14).

ATIS.3GPP.36.322V1410-2017, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification (3GPP TS 36.322 version 14.1.0 Release 14).

ATIS.3GPP.36.323V1450-2018, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification (3GPP TS 36.323 version 14.5.0 Release 14).

ATIS.3GPP.36.331V14120-2019, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (3GPP TS 36.331 version 14.12.0 Release 14).

ATIS.3GPP.36.101V14150-2020, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.15.0 Release 14).

IEEE Std 802®, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.[4, 5] ~~[2, 3, 4]~~

IEEE Std 802.11™, 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.

[4] ~~[2]~~ IEEE publications are available from The Institute of Electrical and Electronics Engineers~~, 445 Hoes Lane, Piscataway, NJ 08854, USA~~ (https://standards.ieee.org/).

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

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

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

~~IETF RFC 768, User Datagram Protocol.[5]~~

~~IETF RFC 793, Transmission Control Protocol.~~

~~IETF RFC 2460, Internet Protocol, Version 6 (IPv6) Specification.~~

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~~[5] IETF publications are available from the Internet Engineering Task Force, IETF Secretariat, c/o Association Management Solutions, LLC (AMS), 48377 Fremont Boulevard, Suite 117, Fremont, CA 94538 (http://www.ietf.org).~~

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ISO/IEC 8802-2:1998, ~~[IEEE Std 802.2™], IEEE Standard for~~ Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 2: Logical Link Control.[6]

ISO/IEC 8825-2, Information technology—ASN.1 encoding rules: Specification of Packed Encoding Rules (PER).

SAE J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary.[7]

Unicode, Inc., The Unicode Standard, http://www.unicode.org.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[8]

assertion by Wireless Access in Vehicular Environments (WAVE) Service Advertisement (WSA) signer: A mechanism that allows an appropriately authorized WSA signer to indicate a high level of assurance that certain material contained in the WSA is correct.

NOTE—This term is used in this document in the verb form *asserted by SA signer*.

[6] ISO~~/IEC~~ publications are available from the International Organization for Standardization ~~ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland~~ (https://www.iso.org/) and. ~~ISO/IEC publications are available in the United States from~~ the American National Standards Institute~~, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA~~ (https://www.ansi.org/).

[7] SAE publications are available from the Society of Automotive Engineers~~, 400 Commonwealth Drive, Warrendale, PA 15096, USA~~ (https://www.sae.org/).

[8] *IEEE Standards Dictionary Online* ~~subscription~~ is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page ~~ieeexplore.ieee.org/xpls/dictionary.jsp~~.

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~~**application:** A higher layer entity that may make use of WAVE communication facilities.~~

~~**application-service:** 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.~~

control channel (CCH): The default ~~A radio~~ channel on which Wireless Access in Vehicular Environments (WAVE) Service Advertisements (WSAs) are transmitted ~~limited by the WAVE standards to the exchange of management frames and WAVE Short Messages~~. *See also:* **service channel (SCH)**.

data plane: A component of the abstract architecture containing entities that exchange user data.

EtherType: A 2-octet value, assigned by the IEEE Registration Authority, that ~~which~~ provides context for interpretation of a data field of a frame (protocol identification). (~~See~~ IEEE Std 802™ ~~1609.12~~)

hexadecimal representation: The representation of a sequence of octet values in which the values of the individual octets are displayed in order from left to right, with each octet value represented as a two-digit hexadecimal numeral, and with the resulting pairs of hexadecimal digits separated by hyphens. The order of the hexadecimal digits in each pair, and the mapping between the hexadecimal digits and the bits of the octet value, are derived by interpreting the bits of the octet value as a binary numeral using the normal mathematical rules for digit significance. (~~From~~ IEEE Std 802®)

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

higher layer service: An abstract entity, 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. *Syn:* **service**.

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ITS port number: Transport layer protocol address element in Intelligent Transport Systems (ITS) used to identify source and destination of an entity above the open system interconnect (OSI) transport layer.

Long Term Evolution–based vehicle-to-everything (LTE-V2X): Vehicle-to-everything (V2X) sidelink communications protocols specified by 3GPP (releases 14 and 15).

managed Wireless Access in Vehicular Environments (WAVE) device: A WAVE device that supports management through the use of an IEEE 1609 standards-defined management information base (MIB).

management plane: A component of the abstract architecture containing functions that manage the entities in the data plane.

Networking Services: The collection of management plane and data plane functions at the network and transport layers specified in this standard, supporting Wireless Access in Vehicular Environments (WAVE) communications.

notification: An indication of an event of interest, sent from a management entity to a higher layer entity.

null-networking: A network layer protocol that does not utilize network layer addresses.

provider: Advertiser of a Wireless Access in Vehicular Environments (WAVE) ~~application~~ service. *See also:* **user**; **Wireless Access in Vehicular Environments (WAVE) Service Advertisement**.

Provider Service Context (PSC): A field associated with a Provider Service Identifier (PSID) containing supplementary information related to the ~~application~~ service. The internal format of the PSC is PSID dependent.

Provider Service Identifier (PSID): An identifier of a Higher layer service provided by a higher layer entity ~~an application area~~. (~~See~~ IEEE Std 1609.12™)

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Proximity Services (ProSe) Per-Packet Priority (PPPP): A measure of packet priority used in Long Term Evolution–based vehicle-to-everything (LTE-V2X).

pseudonymity: A property wherein an entity's permanent or long-lived identities, and its long-term patterns of behavior, cannot be deduced from its network traffic and are only observable by appropriately authorized parties.

service: *Syn:* **Higher layer service**.

service channel (SCH): Any channel that is not the control channel. *See also:* **control channel (CCH)**.

sync interval: A repeating time interval composed ~~comprised~~ of one time slot 0 interval followed by one time slot 1 interval. *See also:* **time slot 0**; **time slot 1**. (~~See~~ IEEE Std 1609.4™)

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

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

Timing Advertisement frame: A specific management frame used to carry timing information. (See IEEE Std 802.11™.)

Transport Protocol Identifier (TPID): Identifier contained in the Wireless Access in Vehicular Environments (WAVE) Short Message Protocol (WSMP) WSMP-N-Header, which selects a WSMP-T- Header type.

user: A WAVE device that monitors received WAVE Service Advertisements (WSAs) for an advertised ~~application~~ service opportunity of interest. *See also:* **provider; Wireless Access in Vehicular Environments (WAVE) Service Advertisement**.

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user priority (UP): A value assigned to a packet that is ready for transmission, which determines its treatment at the medium access control (MAC) layer. (See IEEE Std 802.11.)

Wireless Access in Vehicular Environments (WAVE) device: A device that is compliant with 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.

Wireless Access in Vehicular Environments (WAVE) medium access control (MAC): A WAVE MAC is a medium access control sublayer conformant to IEEE Std 1609.4.

Wireless Access in Vehicular Environments (WAVE) Management Entity (WME): A set of management functions required to provide WAVE Networking Services.

Wireless Access in Vehicular Environments (WAVE) Routing Advertisement (WRA): IPv6 network configuration information broadcast as part of a WAVE Service Advertisement.

Wireless Access in Vehicular Environments (WAVE) Service Advertisement (WSA): A data structure that may include the announcement of the availability of Higher layer ~~application~~ services.

Wireless Access in Vehicular Environments (WAVE) Short Message (WSM): A packet consisting of a WSMP header and WSM Data.

Wireless Access in Vehicular Environments (WAVE) Short Message Protocol (WSMP): The protocol specified in IEEE Std 1609.3 ~~this standard~~ that minimizes communications overhead.

3.2 Acronyms and abbreviations

ACI	access category index
ACM	admission control mandatory
AIFSN	arbitration interframe space number
AM	Acknowledged Mode
ASCII	American Standard Code for Information Interchange

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AS	Access Stratum
ASN	Abstract Syntax Notation
CBR	channel busy ratio
CCH	control channel
DNS	domain name system
ECIES	Elliptic Curve Integrated Encryption Scheme
EDCA	enhanced distributed channel access
EIRP	effective isotropic radiated power
EPD	EtherType protocol discrimination
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPv6	Internet Protocol version 6
ITS	Intelligent Transportation Systems
LLC	logical link control
LSAP	link service access point
LTE-V2X	Long Term Evolution–based vehicle-to-everything
MAC	medium access control (IEEE 802®) or Media Access Control (3GPP)
MIB	management information base
MLME	medium access control (MAC) sublayer management entity

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MLMEX	medium access control (MAC) sublayer management entity extension
NAS	Non-Access Stratum
OSI	open system interconnect
PDB	packet delay budget
PDCP	Packet Data Convergence Protocol
PHY	physical layer
PICS	protocol implementation conformance statement
PPPP	Proximity Services (ProSe) Per-Packet Priority
PSC	Provider Service Context
PSID	Provider Service Identifier
RCPI	received channel power indicator
RF	radio frequency
RFC	Request for Comments
RLC	Radio Link Control
RRC	Radio Resource Control
SAE	SAE International ~~Society of Automotive Engineers~~
SAP	service access point
SCH	service channel
STA	station
TA	Timing Advertisement (frame)

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TCP	Transmission Control Protocol
TXOP	transmission opportunity
TPID	Transport Protocol Identifier
UDP	User Datagram Protocol
UM	Unacknowledged Mode
V2X	vehicle-to-everything
WAVE	Wireless Access in Vehicular Environments
WGS	world geodetic system
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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4. General description

4.1 Overview

Wireless Access in Vehicular Environments (WAVE) provides a communication protocol stack optimized for the vehicular environment, employing both customized and general-purpose elements. Figure 1 and Figure 2 depict the protocol stack reference model and the Scope of this standard when IEEE Std 802.11™ is used as the underlying wireless communication technology. More generalized depictions, as well as similar figures for when Long Term Evolution–based vehicle-to-everything (LTE-V2X) is used as the underlying wireless communication technology, are included in Annex M ~~as shown in Figure 1 and Figure 2~~. IEEE Std 1609.0™ provides a description of the WAVE system architecture and operations.

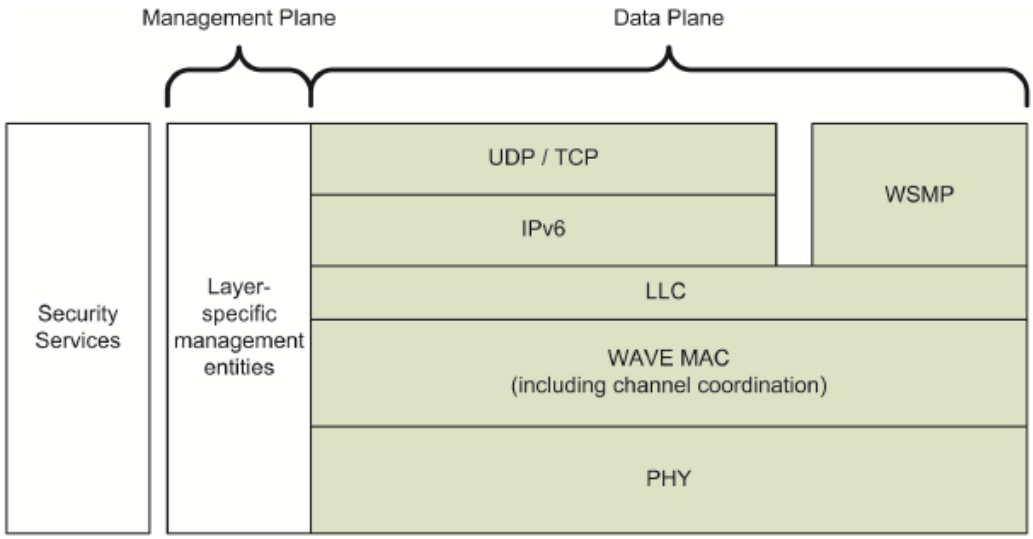


Figure 1—WAVE reference model

WAVE Networking Services are ~~is~~ specified in this standard and consist ~~consists~~ of network and transport layer services and the associated management plane entity (WAVE Management Entity [WME]) as shown by the dashed lines in Figure 2. These are introduced in 4.2 and 4.3 and specified in Clause 5 and Clause 6.

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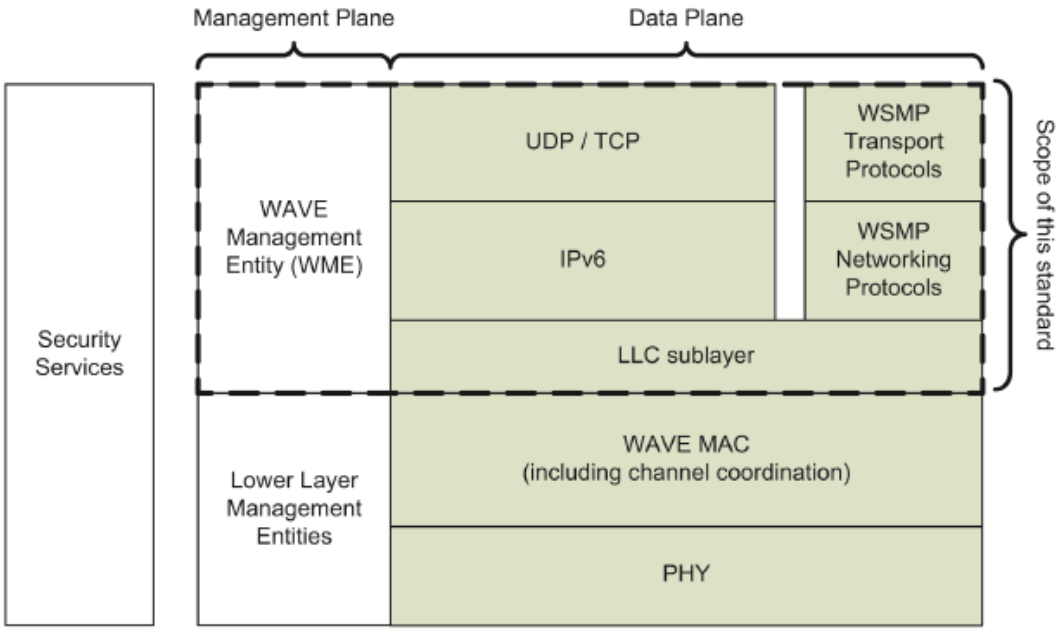


Figure 2—Scope of this standard

At minimum, a WAVE device implements at least the following features specified in this standard (see Annex D).

— Logical link control (LLC) sublayer (only required for IEEE 802.11-based devices)

— Internet Protocol version 6 (IPv6), WAVE Short Message Protocol (~~or~~ WSMP), or both

— Transmit, ~~or~~ receive, or both

Also see IEEE Std 1609.0 for additional descriptive information about WAVE devices.

4.2 Data services

Data plane components of WAVE Networking Services are specified in Clause 5 and consist of the following, not all of which may be present in a given device:

— Logical Link Control (LLC) (only required by IEEE 802.11-based devices)

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Networking Services includes the LLC sublayer~~,~~ for ~~both~~ IPv6 and WSMP traffic~~.~~

— IPv6~~,~~ and transport layer protocols such as User Datagram Protocol (UDP) and Transmission Control Protocol (TCP)

  Networking Services accepts data from higher layers for transmission over the Internet Protocol (IP) stack and delivers received IP data to higher layers

— WSMP

  Networking Services accepts data from higher layers for transmission over the WAVE Short Message Protocol (WSMP) and delivers received WAVE Short Message (WSM) data to higher layers. WSMP is designed to provide both network and transport layer protocols.

WSMP is used to transport WAVE Service Advertisements (WSAs) as requested by the WAVE Management Entity (WME).

4.3 Management services

Management plane components of WAVE Networking Services are specified in Clause 6 and consist of the following functions performed by the WAVE Management Entity, not all of which may be present in a given device[9]:

— Service requests and channel access assignment

  The WME processes service requests from higher layer entities, provides service channel access to satisfy service requests, and causes WAVE Service Advertisements and Timing Advertisements to be transmitted.

— WAVE Service Advertisement monitoring

[9] In systems that do not use dedicated short range communications (DSRC), these management services may be replaced by equivalent functionality specific to the physical medium (see Annex M).

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The WME monitors and verifies services advertised by other WAVE devices for use by higher layer entities and management functions.

— IPv6 configuration

The WME configures the local IP protocol stack using data received from other WAVE devices.

— Management information base (MIB) maintenance

The WME maintains a MIB containing configuration and status information.

5. Data plane

5.1 General

~~This~~ Clause 5 specifies the components of the Networking Services data plane, which are optimized for air interface efficiency and low latency in support of vehicular applications. WSMP is specified in this standard. For WSMs, the channel, time slot, transmit power, data rate, and channel load may be set by higher layers on a per-message basis when using IEEE Std 802.11 as the underlying wireless communication technology. Networking Services also specifies the use of the Internet Protocol IPv6 and supports transport protocols such as UDP and TCP. For IP datagrams, the channel, transmit power, and data rate to be used are stored in a transmitter profile. A Networking Services implementation shall support ~~either~~ IPv6, ~~or~~ WSMP, or both. WSMP and IPv6 are each selected by registered EtherType values.

WSMP uses subtyping to distinguish various features related to networking. WSMP provides networking protocol functions via the WSMP-N-Header. Different networking protocol features are indicated by different values of the *Subtype* field (see Table 20 ~~22~~). WSMP provides transport protocol functions via the WSMP-T-Header. Different transport protocol features are indicated by different values of the Transport Protocol Identifier (*TPID*) field (see Table 21 ~~23~~).

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Figure 3 and Figure 4 illustrate the flow of information associated with IP and WSMP, respectively, when using IEEE Std 802.11 as the underlying wireless communication technology. Equivalent figures corresponding to the use of LTE-V2X as the underlying wireless communication technology are included in Annex M. The primitives defined for exchanging information between the data plane components are described in Clause 7 and Annex M. Note that the service primitives representing the interfaces between WSMP or IPv6 and the LLC, and between the LLC and medium access control (MAC)/physical layer (PHY), can be provided by implementation-specific functionality unique to the physical interface. In this subclause the layer descriptions below WSMP and IPv6 typically apply to IEEE 802.11-based devices.

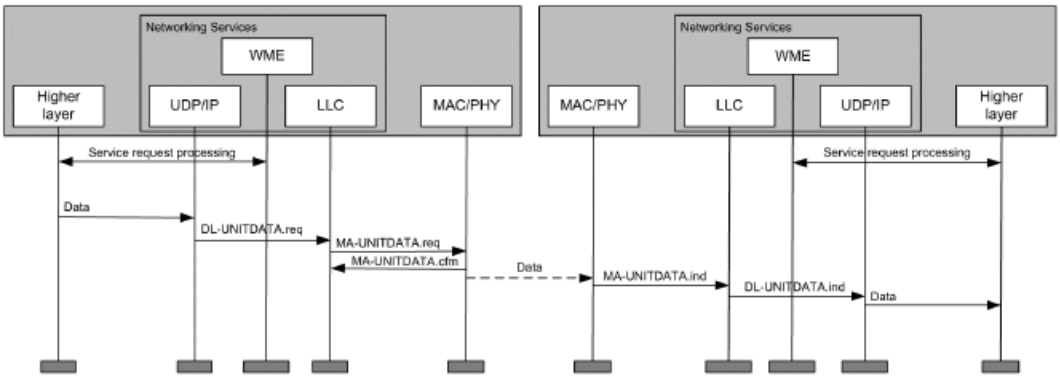


Figure 3—IP data flow

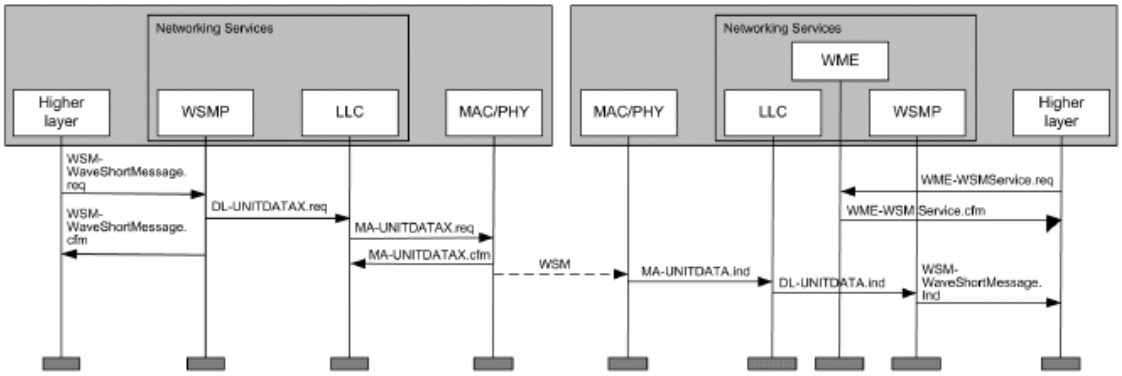


Figure 4—WSMP flow

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5.2 Logical link control for devices using IEEE 802.11

5.2.1 General

A Networking Services implementation shall use EtherType protocol discrimination (EPD) in the LLC sublayer as described in IEEE Std 802, using an EtherType in the LLC sublayer header *Type*[10] ~~9~~ field (see Figure 5 and Figure 33 ~~28~~). The LLC sublayer header consists solely of a 2-octet field that contains an EtherType that identifies the higher layer protocol. To allow higher layer control of WSM transmit parameters, the link service access point (LSAP) has been extended for WSM as specified in 7.5.

NOTE 1—See M.2.2 for equivalent information when using LTE-V2X as the underlying wireless communication technology.

NOTE 2—As the LLC sublayer header is not a part of the WSM header, the ASN.1 definition for *Type* is not specified in this standard.

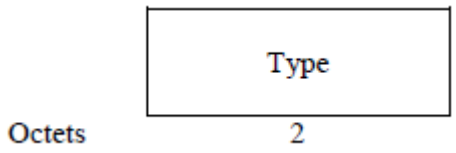


Figure 5—LLC sublayer header type field

5.2.2 Processing on transmit

When IPv6 requests transmission of a packet (via DL-UNITDATA.request), the LLC sublayer sets the *Type* field to EtherType value 0x86DD, and passes the data to the lower layers using the MA-UNITDATA.request primitive. Similarly, when WSMP requests transmission of a packet (via DL-UNITDATAX.request), the LLC sublayer sets the *Type* field to EtherType value 0x88DC and passes the data to the lower layers using the MA-UNITDATAX.request primitive.

[10] ~~9~~ The *Type* field specified herein is one of the options for the *Length*/*Type* field described in IEEE Std 802.

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5.2.3 Processing on receive

When the LLC sublayer receives a MAC service data unit (MSDU) via an MA-UNITDATA.indication primitive, it reads the *Type* field containing the EtherType and extracts the packet. If the EtherType value is 0x86DD, the LLC sublayer delivers the packet to IPv6. If the EtherType value is 0x88DC, the LLC sublayer delivers the packet to WSMP. In either case, the packet is delivered to the higher layer via the DL-UNITDATA.indication. If the EtherType field contains a value other than 0x88DC or 0x86DD, no further processing is required.

5.3 Internet Protocol version 6

Support for IPv6 is conditionally mandatory as specified in 5.1. An IPv6 implementation shall comply with IETF RFC 8200 ~~2460~~. Related features defined in other RFCs are specified in 6.4. When using IEEE Std 802.11 as the underlying wireless communication technology, IP traffic is sent and received through the LLC sublayer as specified in 5.2.

5.4 Other IP-based protocols

WAVE devices may implement any Internet Engineering Task Force (IETF) protocol. Examples of commonly used IETF protocols follow:~~are UDP (IETF RFC 768) and TCP (IETF RFC 793).~~

— UDP (IETF RFC 768 [B6]) and TCP (IETF RFC 793 [B9]).

— IPv4 (IETF RFC 791 [B7]). WAVE devices may implement IPv4 for use by applications. Fast setup of IPv4 is not specified in this standard, however traditional discovery mechanisms, such as Internet Control Message Protocol (ICMP) (IETF RFC 792 [B8]), Ethernet Address Resolution Protocol (IETF RFC 826 [B10]), and ICMP Router Discovery Messages (IETF RFC 1256 [B11]) may be used.

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— Neighbor Discovery for IP version 6 (IPv6) (IETF RFC 4861). While a mechanism to support fast setup of IPv6 is provided (i.e, using the WAVE Routing Advertisement [WRA], see 8.2.5), other discovery mechanisms specified by IETF protocols may be used, see 6.4. If the IPv6 field included in a WSA indicates an IPv4 address (see 8.2.3.6.3), fast setup is not available.

5.5 WAVE Short Message Protocol (WSMP)

5.5.1 General

Support for WSMP is conditionally mandatory as specified in 5.1. Delivery of a received WSM to a higher layer entity is determined by the WSMP header *Address Info* field. In this version of the standard, the *Address Info* field shall contain a *Provider Service Identifier* (*PSID*), see 8.1.4. Future versions of this standard may support other types of addressing methods such as ports, see 8.3.2.2 and 8.3.3.2. A WSM may be accepted by one or more destination devices, depending on the type of MAC-level addressing used (e.g., individual or group). Note that MAC addresses may be changed for pseudonymity, see 6.4.2 ~~as specified in IEEE Std 1609.4~~.

Within a receiving device, the message will be delivered by WSMP to any higher layer entities with interest in the ~~application~~ service opportunity associated with the *PSID*. Interest is indicated via the WSM service request procedure specified in 6.2.2.2 ~~1~~.4. Higher layer entities take responsibility for message signing and authentication (per IEEE Std 1609.2™) and for providing the channel information for transmission. The WSM format is specified in 8.3.

WSMP is also used to send and receive WSAs. From the standpoint of WSMP, the WME may be considered as a higher layer entity.

NOTE—This standard does not specify the attributes of the abstract Higher layer entity, which might be considered as an application, a service, a process, a protocol, or any software-based entity residing above the WSMP transport layer.

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5.5.2 WSM transmission

On receipt of a WSM-WaveShortMessage.request from a higher layer entity, WSMP shall calculate the length of the WSMP header and verify that the length of that WSMP header combined with the accompanying *WSM Data* is less than the value of the WME MIB parameter *WsmMaxLength*. Upon successful verification of *WsmMaxLength*, WSMP shall generate the WSMP header per the format specified in 8.3 for inclusion in a DL-UNITDATAX.request. Upon failed verification of *WsmMaxLength*, the WSM is not passed and the failure is indicated via the WSM-WaveShortMessage.confirm. The DL-UNITDATAX.request applies when using IEEE Std 802.11 as the underlying wireless communication technology, and some of the parameters of the service primitive apply only to IEEE 802.11-based devices. See Annex M for equivalent information when using LTE-V2X as the underlying wireless communication technology.

DL-UNITDATAX.request parameters are set as follows:

source_address	Set to the IEEE Std 802.11 *dot11StationID* for the WAVE interface.
destination_address	Set to the *Peer MAC Address* from the WSM-WaveShortMessage.request.
data	Set as described in the subsequent discussion.
priority	Set to the *User Priority* from the WSM-WaveShortMessage.request.
service class	May be set to QoSAck or QoSNoAck per IEEE Std 802.11.
Channel Identifier	Set to the *Channel Identifier* from the WSM-WaveShortMessage.request.
Time Slot	Set to the *Time Slot* from the WSM-WaveShortMessage.request.
Data Rate	Set to the *Data Rate* from the WSM-WaveShortMessage.request.
TxPwr_Level	Set as described in the subsequent discussion.
Channel Load	Set to the *Chanel Load* from the WSM-WaveShortMessage.request.

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Expiry Time Set to the *Expiry Time* from the WSM-WaveShortMessage.request.

The *data* parameter consists of a WSM, which is formed from the WSMP header (which includes the WSMP-N-Header and the WSMP-T-Header) and the *WSM Data* from the WSM-WaveShortMessage.request, as described in 7.3.2.

Transmit Power Level, received in the WSM-WaveShortMessage.request, is converted to *TxPwr_Level* in the DL-UNITDATAX.request as follows. *TxPwr_Level* is set to the index of the highest value of IEEE Std 802.11 MIB *Dot11PhyTxPowerEntry* that does not exceed *Transmit Power Level*. If there is no such value, then the WSM-WaveShortMessage.request should be rejected.

5.5.3 WSM reception

On receipt of a DL-UNITDATA.indication from the LLC sublayer, WSMP evaluates the *WSMP Version* field in the WSMP-N-Header. If a WAVE device receives a WSM with *WSMP Version* set to an unsupported value, no further processing is required (see 8.3.2.1).

WSMP then evaluates the WSMP-N-Header *Subtype* field and processes the WSMP-N-Header as indicated in 8.3.2. WSMP then evaluates the *TPID* field and processes the WSMP-T-Header as indicated in 8.3.3. After the headers have been processed, WSMP delivers the received *WSM Data* to the destination higher layer entity or entities, with the destination entity determined by the *PSID* and the MIB *WsmServiceRequestTable*. Higher layer entities are notified via the WSM-WaveShortMessage.indication primitive (see 7.3.4).

If a WAVE device receives a WSM in which the *Subtype* equals any value other than 0, or in which *TPID* equals any values other than 0 or 1, then no further processing of the message is required.

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6. Management plane

6.1 General

The following subclauses specify the networking functions associated with the management plane. The primitives for exchanging information between the WME and other internal functional entities are described in Clause 7. Use of the WME-Notification.indication primitive (e.g., notifying a higher layer entity that a service request has been matched to a ~~an application~~ service opportunity, or that a channel has been assigned) is not explicitly specified, but it is left as a choice for implementers.

Networking Services management functions provide the means to control transmit parameters (e.g., data rate and power) of data plane traffic; the data rates and power levels for transmitting management frames are specified in IEEE Std 1609.4™.

Some of the management plane functionality described in Clause 6 only applies when using IEEE Std 802.11 as the underlying wireless communication technology. In particular, the use of various channel access options as described in subclause 6.2 is written primarily based on the expected use of IEEE Std 802.11 for a variety of services distributed across multiple 10 MHz channels. By contrast, LTE-V2X is expected to support a variety of services on a single 20 MHz channel. See Annex M for additional information when using LTE-V2X as the underlying wireless communication technology.

6.2 Service requests and channel access assignment

6.2.1 General

The WME accepts service requests of several types from higher layer entities. Channel access allows higher layers to exchange data on a designated channel. Channel access options include continuous access (on control channel [CCH] or service channel [SCH]), alternating access (between CCH and SCH, or two SCHs), and immediate SCH access (see IEEE Std 1609.4). To satisfy service requests, the WME may provide access to channels and may cause WSAs and Timing Advertisement messages to be periodically transmitted. Providing channel access entails causing the device transceiver to be tuned to a specific channel during one or more time slots, via requests to the MAC sublayer management entity (MLME).

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For convenience, two WAVE device roles are defined. The provider role is assumed by a device transmitting WAVE Service Advertisements (WSAs) indicating its availability for data exchange on one or more channels. The user role is assumed by a device monitoring for received WSAs, with the potential to participate in a data exchange on any channel. A WAVE device may assume one, both, or neither role.

The various service request types, an indication of whether or not a channel assignment occurs, and the messages automatically generated are summarized in Table 1.

Table 1—Service request summary

Service request type	Reference	Primary purpose	Results in channel assignment?	Message generation
Provider	7.4.2.2	WAVE service advertisement/SCH participation	yes	WSM containing WSA
User	7.4.2.4	Service availability notification/SCH participation	yes	none
WSM	7.4.2.6	Received message delivery	no	none
Channel	7.4.2.8	Channel participation	yes	none
Timing Advertisement	7.4.2.10	Time distribution	yes	Timing Advertisement (TA) frame

To facilitate the specification, a distinction is made between single-physical layer (PHY) devices and multi-PHY devices (see IEEE Std 1609.4). A single-PHY device is a WAVE device not capable of simultaneous operation on multiple radio channels. A multi-PHY device is a WAVE device capable of simultaneous operation on multiple radio channels. A switching device has at least one PHY that is capable of switching between channels (e.g., SCH and CCH). Depending on the characteristics and usage of the WAVE device at a given time, it might support any of several channel usage models, including the following:

— Operation only on the CCH or only on an SCH (e.g., by a single-PHY device). See Figure 6(a).

— Alternating operation on CCH and SCH, or on SCH and another SCH, in time slot 0 and time slot 1, respectively (a switching device). See Figure 6(b).

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— Simultaneous operation on CCH and one or more SCHs (by a multi-PHY device).

— Simultaneous operation on multiple SCHs (by a multi-PHY device).

The capabilities of the WAVE device may be considered by the WME in assigning channel access to satisfy requested services. Several examples of channel access (applicable to a single-PHY WAVE device) are illustrated in Figure 6. The first option (a) shows continuous operation on the CCH or the SCH. The second option (b) shows alternating operation on the CCH and an SCH during time slot 0 and time slot 1, respectively, where SCH access is provided based on a request from a higher layer. Switching between two SCHs is also possible. The third option (c) shows a variation where SCH access is provided on an immediate basis for an indefinite or configured duration at the request of the higher layer. Networking Services may make channel access assignments based on the service requests described in this subclause, resulting in any of the following:

— Alternating operation with CCH access during time slot 0, and SCH access during time slot 1. Alternating operation with multiple SCHs during both time slots 0 and 1 is also possible.

— Immediate channel access during time slots 0 and 1.

— Channel access during time slot 0 and/or time slot 1 (used, for example, to override immediate channel access in support of user service requests).

Examples of information flows associated with channel access under different scenarios are shown in Annex E.

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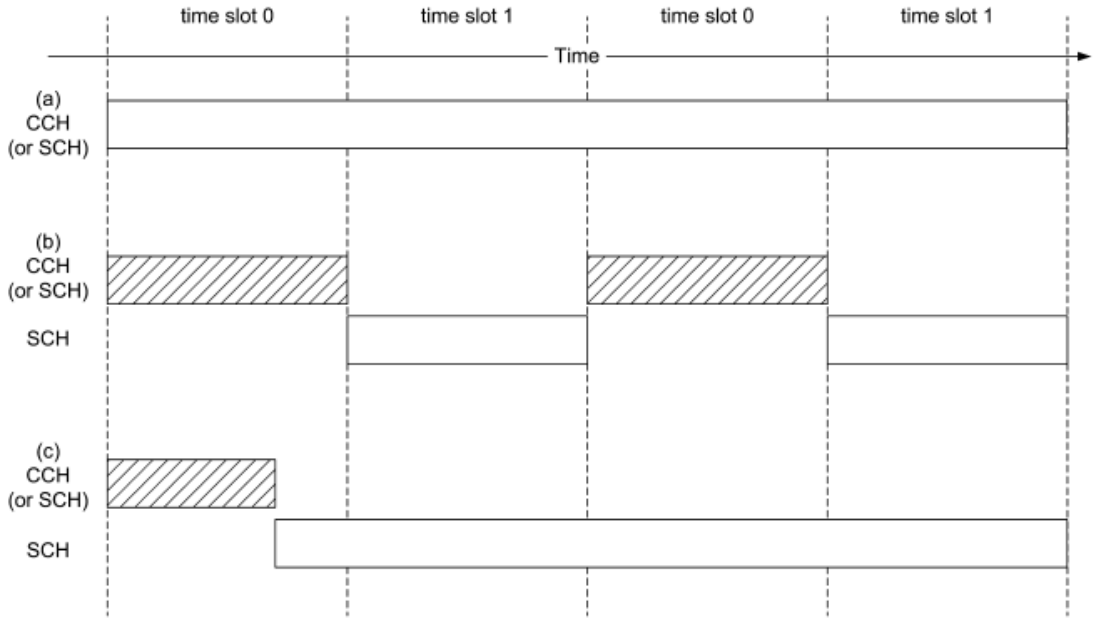


Figure 6—Channel access options: (a) continuous, (b) alternating, and (c) immediate

6.2.2 Service requests

6.2.2.1 General

This subclause generally describes internal device operation; therefore, the features specified here are optional. The WME maintains information about requested and available services for use in determining channel access assignments. Requested ~~application~~ service information is maintained in the MIB *ProviderServiceRequestTable*, *UserServiceRequestTable*, *WsmServiceRequestTable*, and *ChannelServiceRequestTable*. Service requests may be made through the WME service access point (SAP) as described in 7.4, or via other mechanisms (e.g., preloaded MIB information for static services).

Figure 7 illustrates service request information flow via service request primitives.

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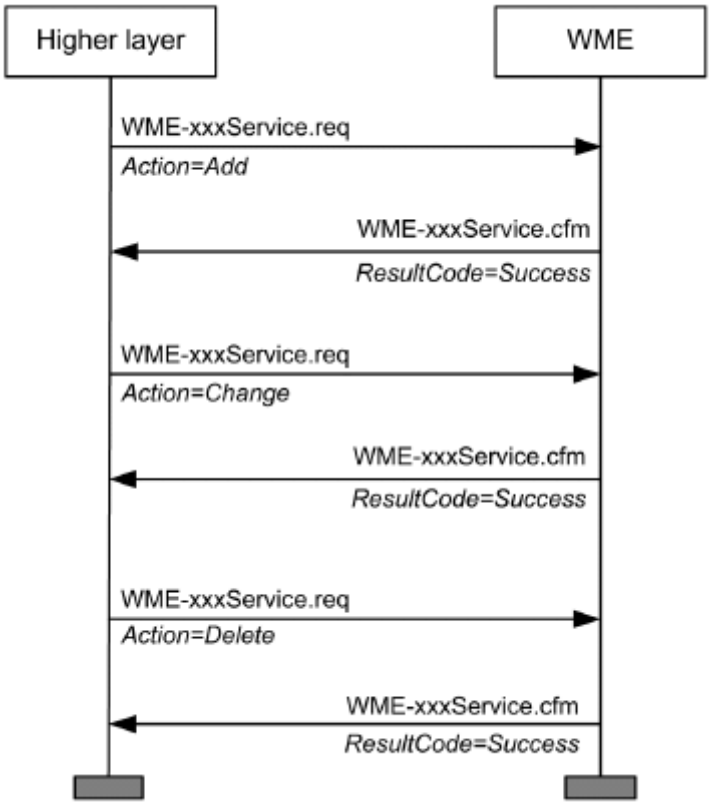


Figure 7—Service request information flow

6.2.2.2 Adding service requests

6.2.2.2.1 General

A service request may be of the form WME-ProviderService.request, WME-UserService.request, WME-WSMService.request, WME-ChannelService.request, or WME-TimingAdvertisementService.request as described in 7.4.

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6.2.2.2.2 Provider service request

A provider service request indicates to the WME that a higher layer wishes to have WSAs generated on its behalf and SCH access provided. WSAs may be transmitted on any channel (i.e., CCH or SCH) and during any time slot. WSAs are nominally sent on the CCH during time slot 0. Acceptance of a WME-ProviderService.request results in the population of a corresponding *ProviderServiceRequestTableEntry* in the MIB and consideration of the service request in determining channel access assignments. The device sending the WSA performs the provider role; a device accepting the WSA performs the user role.

The WME may receive requests from multiple higher layer entities, each requesting to advertise services with sufficiently differing requirements such that it may be useful to build multiple unique WSAs. A device may transmit multiple WSAs, each containing different content, e.g., unique WSA frames may be transmitted at different rates, have different services identified within them, or contain different security information. One unique WSA may be terminated while other WSAs continue to be transmitted. To facilitate this feature, WSA frames containing different content shall be uniquely identified by the provider using the *WSA Identifier* (see 8.2.2.4). The WME may group requests from higher layer entities requesting similar requirements. A device receiving WSA frames may use *WSA Identifier* as described in this subclause. The criteria for what constitutes different content is implementation dependent.

A *PSID* value representing "IPv6 routing" in a *Service Info Segment* indicates available Internet access using the parameters found in the accompanying WRA, on the channel associated with the *Service Info Segment*.

In addition to advertising ~~application~~ service opportunities, the provider service request may be used to advertise local CCH or SCH channel configuration information (e.g., enhanced distributed channel access [EDCA] parameter set) in the WSA. In this case, there may or may not be ~~application~~ service information in the WSA.

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6.2.2.2.3 User service request

A user service request indicates to the WME that a higher layer entity has an interest in ~~application~~ service opportunities meeting specific criteria. The request indicates the action to be taken when the WME recognizes such available services, including assigning channel access. Acceptance of a WME-UserService.request results in the population of a corresponding *UserServiceRequestTableEntry* in the MIB and in consideration of the service request in determining channel access assignments.

6.2.2.2.4 WSM service request

A WSM service request indicates to the WME that a higher layer entity wishes to receive WSMs addressed to a particular *PSID*. Acceptance of a WME-WSMService.request results in the population of a corresponding *WsmServiceRequestTableEntry* in the MIB and causes Networking Services to deliver any received *WSM Data* with matching *PSID* to the requesting higher layer entity. See 7.4.2.6.

6.2.2.2.5 Channel service request

A channel service request indicates that a higher layer entity requires ongoing channel access to a specific channel during particular time slots (see IEEE Std 1609.4), e.g., for WSM activity or for WSA reception. Acceptance of a WME-ChannelService.request results in the population of a corresponding *ChannelServiceRequestTableEntry* in the MIB and in consideration of the service request in determining channel access assignments.

The channel request indicates the desired channel and whether it applies to time slot 0, time slot 1, or both. A channel service request indicating time slot 0 does not affect decisions to assign channel access during time slot 1, but it can be used to prevent assigning SCH *ImmediateAccess* (see 6.2.3) during time slot 0 based on implementation-specific information.

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6.2.2.2.6 Timing Advertisement service request

A Timing Advertisement service request indicates to the WME that another entity wishes to have Timing Advertisement frames transmitted on its behalf and, possibly, channel access provided. Acceptance of a WME-TimingAdvertisementService.request results in the consideration of the service request in determining channel access assignments and in generating TA requests to the MLME.

6.2.2.3 Changing service requests

Upon receipt of any service request with *Action* equal to Change, the corresponding ~~application~~ service information is updated in the MIB and in the WME channel access assignment function. Changing of an ongoing WAVE Service Advertisement is covered in more detail in 6.2.4.2.2.

6.2.2.4 Deleting service requests

Upon receipt of any service request with *Action* equal to Delete, the corresponding ~~application~~ service information is removed from the MIB and from the WME channel access assignment function. Additional processing is specified in 6.2.3.6 and 6.2.4.4.

6.2.3 Channel access assignment

6.2.3.1 General

Each of the features specified in the subclauses of 6.2.3 are optional. Networking Services assigns local radio channel resources in support of service requests. This includes assigning radio resources to ~~particular~~ channels to provide data communication opportunities for the requesting entities. The primitive exchanges related to channel access assignment for provider and user service requests are illustrated in Figure 8 and described here and in more detail in the following subclauses. Additional flows are depicted in Annex E.

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The following example illustrates a typical scenario where a channel-switching user device monitors the CCH for WSAs during time slot 0 and participates in ~~application~~ service opportunities during time slot 1. This scenario can be considered part of a rendezvous arrangement that allows service providers and potential service users to communicate in a predefined channel and time slot about available services. Other channel- switching scenarios are also valid.

In Figure 8, the provider WME initiates WSA broadcasts on the CCH and provides SCH access, followed by user communications with the provider on the SCH. The provider WME first submits the WSA data to be signed via the Sec-SignedData.request. The provider WME then initiates WSA broadcasts over WSMP on the CCH via the WSM-WaveShortMessage.request, and alternating SCH access via the MLMEX-CHSTART.request. The user, monitoring the CCH receives the WSA via the WSM-WaveShortMessage.indication, verifies it via Sec-SecureDataPreprocessing.request and Sec-SignedDataVerification.request, recognizes a ~~an application~~ service opportunity of interest, and begins alternating SCH access via the MLMEX-CHSTART.request. In each case, if the ~~application~~ service employs IP, the MLMEX-REGISTERTXPROFILE.request is also used. Subsequently higher layer traffic may be exchanged between the devices on the SCH.

The status of each ~~application~~ service (e.g., satisfied or not) is maintained in a status field in its request table in the MIB.

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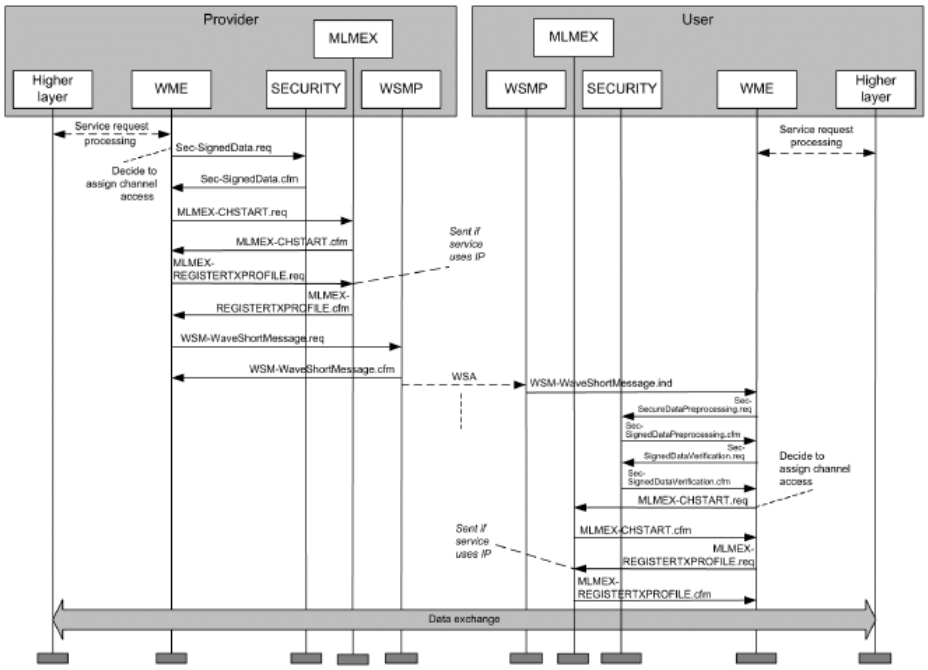


Figure 8—Example information flow for channel access assignment

6.2.3.2 Channel access assignment algorithm

This standard does not specify an algorithm for channel access assignment. The following criteria should be considered by algorithm developers:

— Number of channels that can be simultaneously accessed by the device's radio equipment

— Service requests (6.2.2)

— Available services (6.3.3) matching user service requests

— The relative priorities of the requested services

— The *Channel Access* of the ~~application~~ service, i.e., the time slots during which it is active

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In general, the access assignment algorithm may give precedence to requests with higher priority. Channel service requests with a higher priority may take precedence over lower priority assignments that would interfere with ongoing channel operation. For example, SCH access in support of a user service request may be assigned but without the requested *ImmediateAccess*. Any prioritization of service requests, based on configuration information or information received from the requesting higher layer, is not specified in this standard.

Other factors may be considered, such as the following:

— The geographic proximity to the transmitter of the WSA

— Link quality associated with the transmitter of the WSA

— ~~Application~~ service duration

After channel access has been assigned, certain events such as the following should cause the assignment to be ended. Refer to 6.2.3.6:

— ~~Application~~ service has been deleted (6.2.2.4 ~~3~~)

— User service request no longer matching an available ~~application~~ service opportunity (6.3)

— Need to satisfy a service request with higher priority

— Loss of lower layer synchronization indicated by receipt of MLMEX-CHEND.indication per IEEE Std 1609.4

— Other factors, such as poor *Link Quality* (6.3.4)

6.2.3.3 Assignments in support of provider service requests

When service channels are assigned to fulfill provider service requests, in addition to generating a series of WSAs for transmission via WSMP as specified in 6.2.4.2, the WME triggers MAC sublayer processing by sending an MLMEX-CHSTART.request to start service channel access.

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If the WME-ProviderService.request includes *IPv6 Address*, indicating a need for IPv6 communications, the WME also sends a MLMEX-REGISTERTXPROFILE.request. Refer to Figure 8.

MLMEX-CHSTART.request parameters are set as follows:

Channel Identifier — This defines the channel assigned. Set to the channel indicated by the MIB *ProviderChannelInfoTableEntry*.

Time Slot — The time slot (0 or 1) in which the access is to be provided. Set based on the MIB *ProviderServiceRequestTableEntry ChannelAccess*.

OperationalRateSet — Not used.

EDCA Parameter Set — If present, insert values from MIB *ProviderChannelInfoTableEntry* associated with the channel.

ImmediateAccess — Set to 0.

MLMEX-REGISTERTXPROFILE.request parameters are set as follows:

Channel Identifier — Set equal to *Channel Identifier* in the MLMEX-CHSTART.request.

Adaptable — From the MIB *ProviderChannelInfoTableEntry* associated with the channel.

TxPwr_Level — Set to the index of the highest value of IEEE Std 802.11 MIB *Dot11PhyTxPowerEntry* that does not exceed the MIB *ProviderChannelInfoTransmitPowerLevel*. If there is no such value, then the provider service request should be rejected.

Data Rate — From the MIB *ProviderChannelInfoTableEntry*.

6.2.3.4 Assignments in support of user service requests

Channel access is assigned by the WME, e.g., to satisfy a user service request when the WME detects a suitable match between a MIB User*AvailableServiceTableEntry* and a *UserServiceRequestTableEntry*. When channel access is assigned to satisfy a user service request, the WME sends an MLMEX-CHSTART.request, with parameters set as follows. Refer to Figure 8.

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