Designation: E2213 – 03 (Reapproved 2010)

Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications[1]

This standard is issued under the fixed designation E2213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] describes a medium access control (MAC) and physical layer (PHY) specification for wireless connectivity using dedicated short-range communications (DSRC) services. This standard is based on and refers to IEEE Standards 802.11, *Wireless LAN Medium Access Control and Physical Layer Specifications*, and 802.11a, *Wireless LAN Medium Access Control and Physical Layer Specifications High-Speed Physical Layer in the 5 GHz Band*, with permission from the IEEE society. This specification is meant to be an extension of IEEE 802.11 technology into the high-speed vehicle environment. As presented here, this specification contains just enough information to explain the difference between IEEE 802.11 and IEEE 802.11a operating parameters required to implement a mostly high-speed data transfer service in the 5.9-GHz Intelligent Transportation Systems Radio Service (ITS-RS) Band. Potential operations within the Unlicensed National Information Infrastructure (UNII) Band are also addressed, as appropriate.

1.2 *Purpose*—The purpose of this specification is to provide wireless communications over short distances between information sources and transactions stations on the roadside and mobile radio units, between mobile units, and between portable units and mobile units. The communications generally occur over line-of-sight distances of less than 1000 m between roadside units and mostly high speed, but occasionally stopped and slow moving, vehicles or between high-speed vehicles. This specification also offers regulatory bodies a means of standardizing access to the 5.9 GHz frequency band for the purpose of interoperable communications to and between vehicles at line-of-sight distances on the roadway.

1.3 Specifically, this specification accomplishes the following:

1.3.1 Describes the functions and services required by a DSRC and IEEE 802.11 compliant device to operate in a high-speed mobile environment.

1.3.2 Refers to IEEE 802.11 MAC procedures.

1.3.3 Defines the 5.9 GHz DSRC signaling technique and interface functions that are controlled by the IEEE 802.11 MAC.

1.3.4 Permits the operation of a DSRC conformant device within a DSRC communications zone that may coexist with multiple overlapping DSRC communication zones.

1.3.5 Describes the requirements and procedures to provide privacy of user information being transferred over the wireless medium and authentication of the DSRC or IEEE 802.11 conformant devices.

2. Referenced Documents

2.1 *IEEE Standards:*[3]

802.11 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

802.11a Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications—Amendment 1: High-Speed Physical Layer in the 5 GHz Band

2.2 *Federal Document:*

CFR 47 Title 47 on Telecommunication[4]

3. Terminology

3.1 *Definitions*—See IEEE 802.11, Clause 3, in addition to the following information:

3.1.1 *onboard unit (OBU)*—an onboard unit (OBU) is a DSRC transceiver that is normally mounted in or on a vehicle, but which in some instances may be a portable unit. An OBU can be operational while a vehicle or person is either mobile or

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[2] This specification is based on IEEE 802.11, 1999 Edition and IEEE 802.11a, 1999 Edition. This specification explains the DSRC parameters as an extension of the IEEE 802.11 and IEEE 802.11a documents.

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

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stationary. The OBUs receive and contend for time to transmit on one or more RF channels. Except where specifically excluded, OBU operation is permitted wherever vehicle operation or human passage is permitted. The OBUs mounted in vehicles are licensed by rule and communicate with roadside units (RSUs) and other OBUs. Portable OBUs are also licensed by rule. OBU operations in the UNII Bands follow the rules in those bands.

3.1.2 *roadside unit (RSU)*—a roadside unit is a DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand-carried unit is stationary. Furthermore, an RSU operating under CFR 47 Part 90 rules is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate on the Control Channel and Service channels where they do not interfere with a site-licensed operation. A RSU broadcasts data to OBUs or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required.

3.1.3 *private (application)*—implementation of a DSRC service to transfer data to and from individual or business-owned devices to enable business or user data transactions or to improve the efficiency of business data transactions.

3.1.4 *public safety (application)*—implementation of a DSRC service by a government or government sponsored activity as defined in CFR 47 USC section 309(j).

3.2 *Acronyms*—See IEEE 802.11, Clause 4, in addition to the following information:

3.2.1 *BPSK*—binary phase shift keying
3.2.2 *C-MPDU*—coded MPDU
3.2.3 *DSRC*—dedicated short-range communications
3.2.4 *FFT*—Fast Fourier Transform
3.2.5 *GI*—guard interval
3.2.6 *IFFT*—inverse Fast Fourier Transform
3.2.7 *MLME*—MAC sublayer management entity
3.2.8 *OBU*—onboard unit
3.2.9 *OFDM*—orthogonal frequency division multiplexing
3.2.10 *PER*—packet error rate
3.2.11 *PLME*—PHY management entity
3.2.12 *QAM*—quadrature amplitude modulation
3.2.13 *QPSK*—quadrature phase shift keying
3.2.14 *RSU*—roadside unit
3.2.15 *U-NII*—unlicensed national information infrastructure

4. General Description

4.1 This specification defines the Open Systems Interconnection (OSI) Layer 1, physical layer, and Layer 2, medium access control layer for DSRC equipment operating in a two-way or one-way, half-duplex, active mode. The physical layer is a special case implementation of IEEE 802.11a technology and the medium access control layer is the same as the IEEE 802.11 MAC. All references in this specification to IEEE 802.11 MAC concepts are incorporated in the DSRC implementation. This specification establishes a common framework for the physical layer in the 5.850 to 5.925 GHz ITS-RS band. This band is allocated for DSRC applications by the FCC in Title 47, Code of Federal Regulations (CFR), Part 90, Subpart M and by Industry Canada in the Spectrum Management, Radio Standard Specification, Location and Monitoring Service (5.850 to 5.925 GHz), Number TBD.

4.1.1 *General Description of the DSRC and IEEE 802.11 Architecture*—See IEEE 802.11, Clause 5.1.

4.1.1.1 *How Wireless LAN Systems are Different from Wired LAN Systems*—See IEEE 802.11, Clause 5.1.1 and sub-clauses:

4.1.1.2 *How DSRC Systems are Different from IEEE 802.11 Systems:*

(1) This specification defines a medium access control and air interface that enables accurate and valid message delivery with communication units that are primarily mounted in high-speed moving vehicles. These communications may occur with other units that are: (*1*) fixed along the roadside or above the roadway; (*2*) mounted in other high-speed moving vehicles; (*3*) mounted in stationary vehicles; or (*4*) portable or hand-held. Communications may also occur between stationary or low-speed mobile units and fixed or portable units on the roadside or off-the-road, in private or public areas. However, most IEEE 802.11 systems implement communications between stationary units or mobile units moving at low speeds. High-speeds are considered those achieved by the general public and emergency vehicles on North American highways. Low-speeds are considered as walking to running paces.

(2) DSRC devices must be capable of transferring messages to and from vehicles at speeds of 85 mph with a Packet Error Rate (PER) of less than 10 % for PSDU lengths of 1000 bytes and to and from vehicles at speeds of 120 mph with a PER of less than 10 % for PSDU lengths of 64 bytes.

(3) As explained in the definitions, in-vehicle communications units are called on-board units (OBUs). Communication units fixed along the roadside, over the road on gantries or poles, or off the road in private or public areas are called roadside units (RSUs). The DSRC RSUs may function as stations or as access points (APs) and DSRC OBUs only have functions consistent with those of stations (STAs). The common function between all RSUs is that these stationary units control access to the RF medium for OBUs in their communication zone or relinquish control to broadcast data only.

(4) In order to accommodate the more dynamic environment with essentially the same radio technology and provide priority to public safety communications, DSRC uses a different channel access strategy than IEEE 802.11 units and employs additional operating rules. This additional System Management strategy is described primarily in the IEEE Control Channel and Service Channel Standard (under development) Number TBD.

(5) The essence of this strategy is the identification of a control channel and service channels, a system of priority access, and mandatory service channel data transfer time limits while in motion.

(6) DSRC uses a unique Ad Hoc mode. The DSRC Ad Hoc mode is used on all DSRC channels as the default mode of operation. However, it is the only mode of operation on the control channel. In this mode, the BSSID is all zeros and there

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is no distributed beaconing mechanism. An OBU nominally listens on the control channel for messages or application announcements and a data exchange channel assignment, but does not scan. The IEEE 802.11-1999 management frames are received and acknowledged but not acted upon in the DSRC Ad Hoc mode.

(7) RF power, sensitivity, and antenna pattern are intended to be referenced to a standard location on the vehicle. This standard location is intended to be the front bumper of a passenger vehicle or the equivalent on a commercial vehicle. Annex A3 describes the power and antenna calibration factors.

4.2 *Components of the IEEE 802.11 Architecture*—See IEEE 802.11, Clause 5.2.

4.3 *Logical Service Interfaces*—See IEEE 802.11, Clause 5.3.

4.4 *Overview of the Services*—See IEEE 802.11, Clause 5.4.

4.5 *Relationships Between Services*—See IEEE 802.11, Clause 5.5.

4.6 *Difference Between ESS and IBSS LANs*—See IEEE 802.11, Clause 5.6.

4.7 *Message Information Contents that Support the Services*—See IEEE 802.11, Clause 5.7.

4.8 *Reference Model*—See IEEE 802.11, Clause 5.8.

4.9 *Implementation of DSRC Using IEEE 802.11 Architecture Components:*

4.9.1 The DSRC communications are conducted either between RSUs and OBUs, as shown in Figs. 1 and 2, or only between OBUs, as shown in Fig. 3.

4.9.2 The DSRC communications may be routed from or into wide area networks by portals from RSUs, as shown in Fig. 4.

4.9.3 The DSRC communications may be routed between wide area networks and in-vehicle networks by portals from OBUs and RSUs, as shown in Figs. 5-7.

4.9.4 DSRC devices shall implement a DSRC Ad-Hoc mode and initialize to the settings defined in Annex A2 to operate in the ITS-RS band.

5. MAC Operation (IEEE 802.11 and IEEE 802.11a Referenced Paragraphs)

5.1 *MAC Service Definition*—See IEEE 802.11, Clause 6.

5.2 *Frame Formats*—See IEEE 802.11, Clause 7. All of the specifications of IEEE 802.11, Clause 7, are incorporated in this standard in addition to the requirements for a DSRC Ad Hoc mode of operation.

5.2.1 *DSRC Ad Hoc Mode*—DSRC devices shall implement a DSRC Ad Hoc mode of operation. In this mode, only the Control, Data, and Management type fields described below are used. (See IEEE 802.11, Table 1). Within the Control type field, only the RTS, CTS, and ACK subtypes are used. Within the Data type field, only the basic data subtype is used. RTS and CTS shall not be used in the control channel.

5.3 *Authentication and Privacy*—See IEEE 802.11, Clause 8.

5.4 *MAC Sublayer Functional Description*—See IEEE 802.11, Clause 9. All of the specifications of IEEE 802.11, Clause 9, are incorporated in this standard in addition to the requirements for a DSRC Ad Hoc mode of operation.

5.4.1 *DSRC Ad Hoc Mode*—In the DSRC Ad Hoc mode of operation, only three Frame Exchange Sequences, "Data," "Mgmt," and "{RTS - CTS-}[Frag - ACK -] Last - ACK" are used (See IEEE 802.11, Table 21).

5.5 *Multirate Support*—For the 5 GHz PHY, the time required to transmit a frame for use in the Duration/ID field is determined using the PLME-TXTIME.request primitive and the PLME-TXTIME.confirm primitive. The calculation method of TXTIME duration is defined in IEEE 802.11a, Clause 17.4.3.

6. Layer Management

6.1 See IEEE 802.11, Clause 10.

6.2 Add to IEEE 802.11, Clause 10: Remove the references to aMPDUDurationFactor from 10.4.3.1.

6.3 Add to IEEE 802.11, Clause 10:

6.3.1 *PLME-TXTIME.request:*

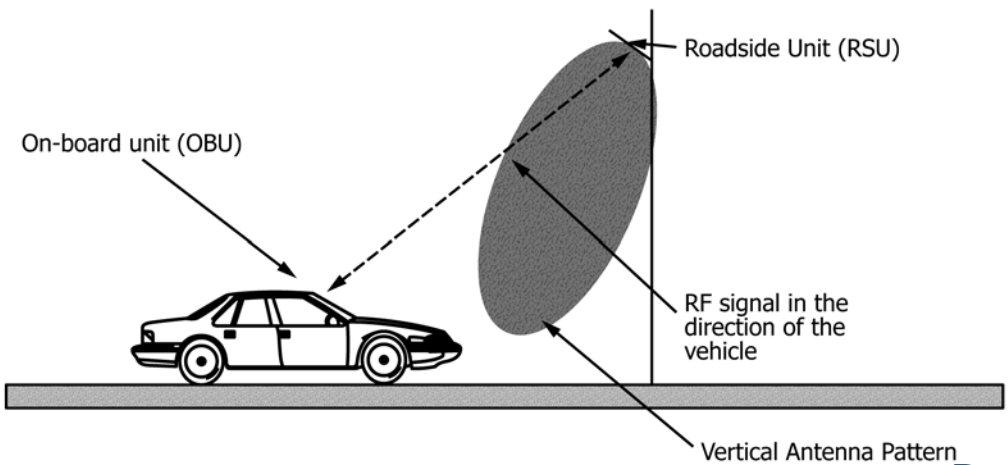

FIG. 1 RSU Communicating With an OBU

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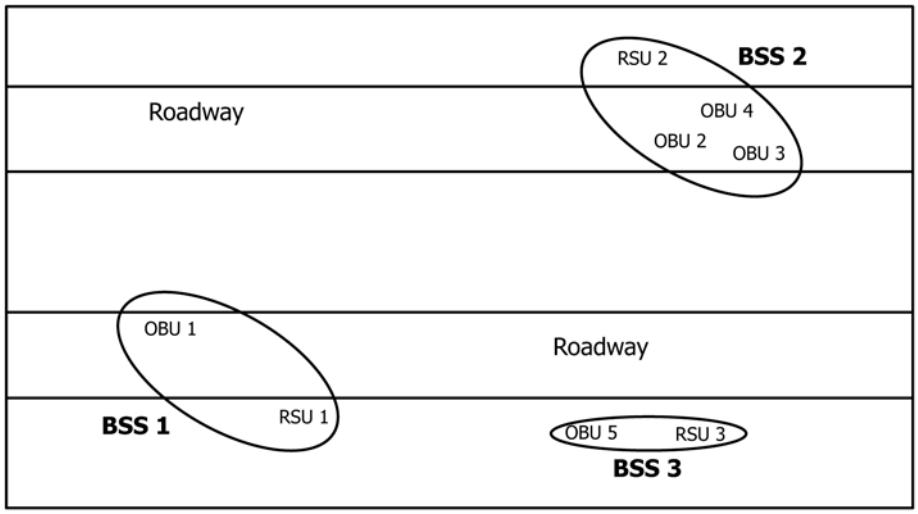

FIG. 2 Basic Service Sets With RSUs and OBUs

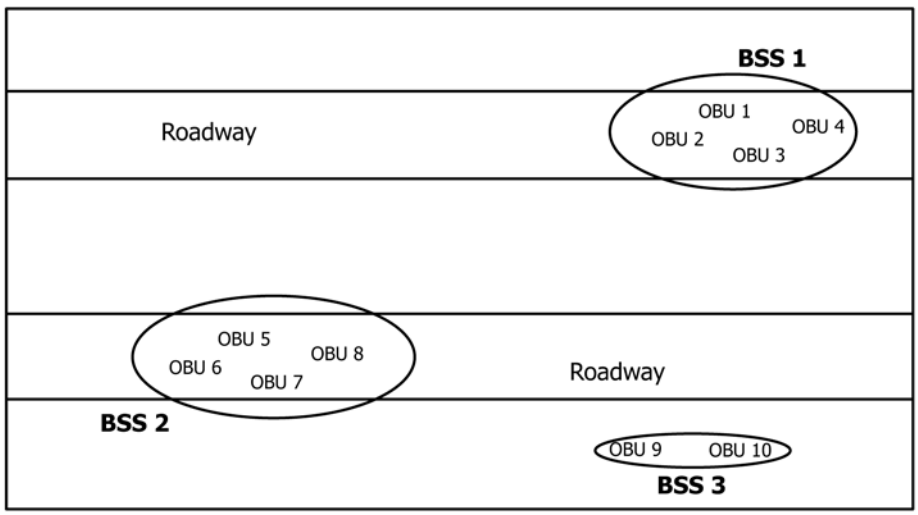

FIG. 3 Basic Service Sets With OBUs Only

6.3.1.1 *Function*—This primitive is a request for the PHY to calculate the time that will be required to transmit a PPDU containing a specified length MPDU, and using a specified format, data rate, and signaling onto the wireless medium.

6.3.1.2 *Semantics of the Service Primitive*—This primitive provides the following parameters: PLME-TXTIME.request(TXVECTOR). The TXVECTOR represents a list of parameters that the MAC sublayer provides to the local PHY entity in order to transmit an MPDU, as further described in IEEE 802.11 Clauses 12.3.4.4 and 17.4 (which defines the local PHY entity).

6.3.1.3 *When Generated*—This primitive is issued by the MAC sublayer to the PHY entity whenever the MAC sublayer needs to determine the time required to transmit a particular MPDU.

6.3.1.4 *Effect of Receipt*—The effect of receipt of this primitive by the PHY entity shall be to generate a PHY-TXTIME.confirm primitive that conveys the required transmission time.

6.3.2 *PLME-TXTIME.confirm:*

6.3.2.1 *Function*—This primitive provides the time that will be required to transmit the PPDU described in the corresponding PLME-TXTIME.request.

6.3.2.2 *Semantics of the Service Primitive*—This primitive provides the following parameters: PLME-TXTIME.confirm(TXTIME). The TXTIME represents the time in microseconds required to transmit the PPDU described in the corresponding PLME-TXTIME.request. If the calculated time includes a fractional microsecond, the TXTIME value is rounded up to the next higher integer.

6.3.2.3 *When Generated*—This primitive is issued by the local PHY entity in response to a PLME-TXTIME.request.

6.3.2.4 *Effect of Receipt*—The receipt of this primitive provides the MAC sublayer with the PPDU transmission time.

6.4 *MAC Sublayer Management Entity*—See IEEE 802.11, Clause 11. All of the specifications of IEEE 802.11, Clause 11, are incorporated in this standard in addition to the requirements for a DSRC Ad Hoc mode of operation and the capability to generate a dynamic MAC address.

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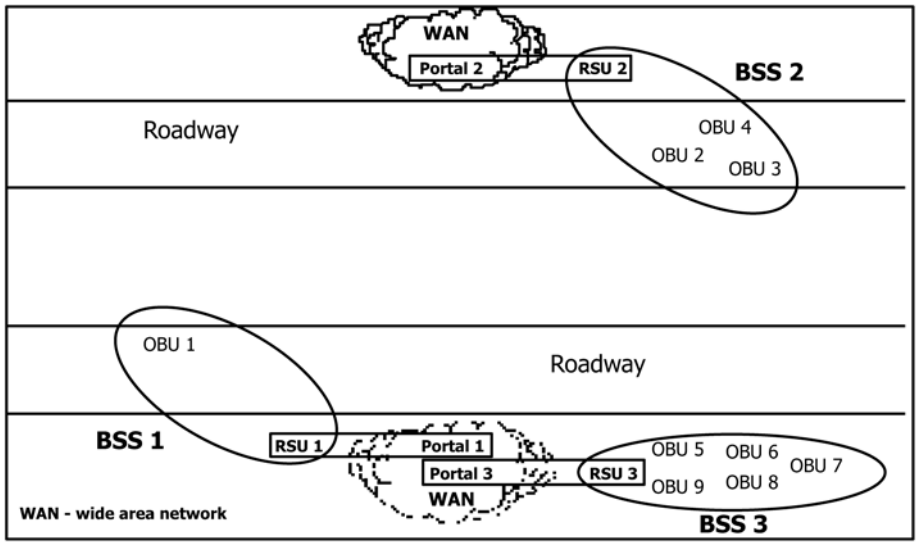

FIG. 4 Connecting OBUs to Wide-Area Networks

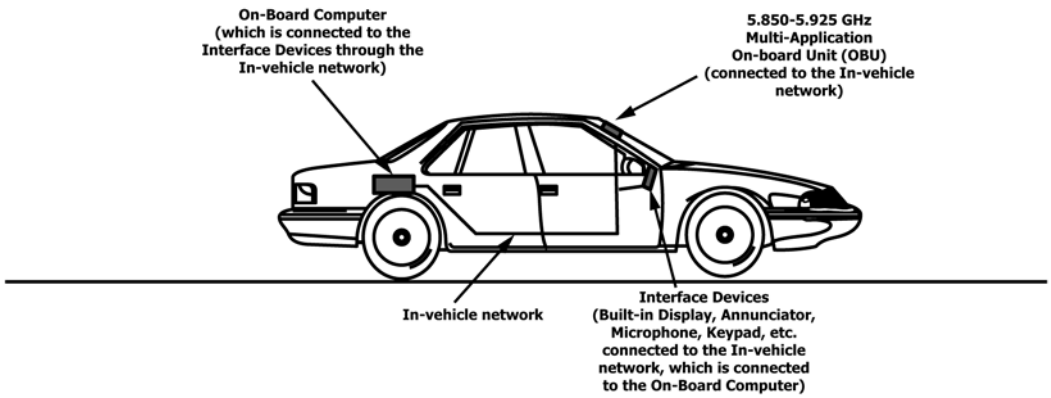

FIG. 5 Connecting an OBU to an In-vehicle Network

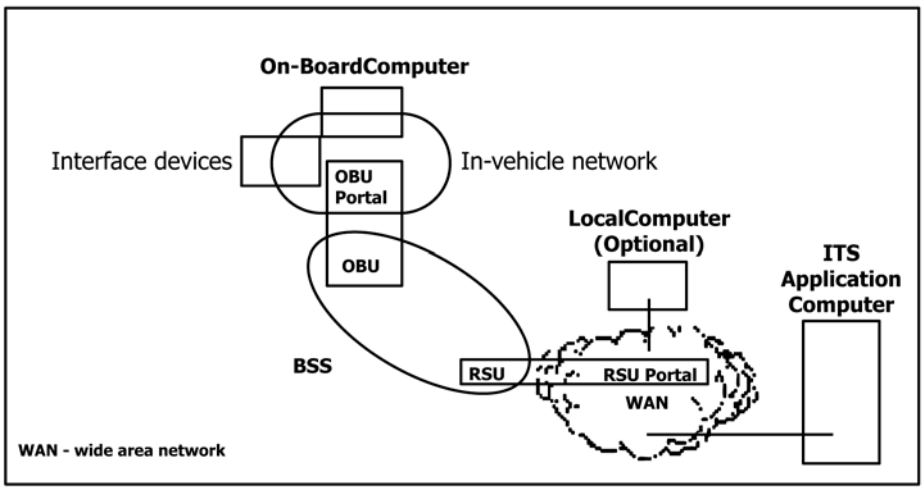

FIG. 6 BSS Connects On-board Computer Through the WAN to the ITS Application

6.4.1 *DSRC Ad Hoc Mode*—In the DSRC Ad Hoc mode of operation the BSSID shall be all zeros, which is a change to the function described in IEEE 802.11, Clause 11.1. There shall be no distributed beaconing mechanism, which is a change to IEEE 802.11, Clause 11.1.2. DSRC devices do not implement the 802.11 scanning function, which is a change to IEEE 802.11, Clause 11.1.3. DSRC devices use the default channel of operation as defined by the Management Information Base of IEEE

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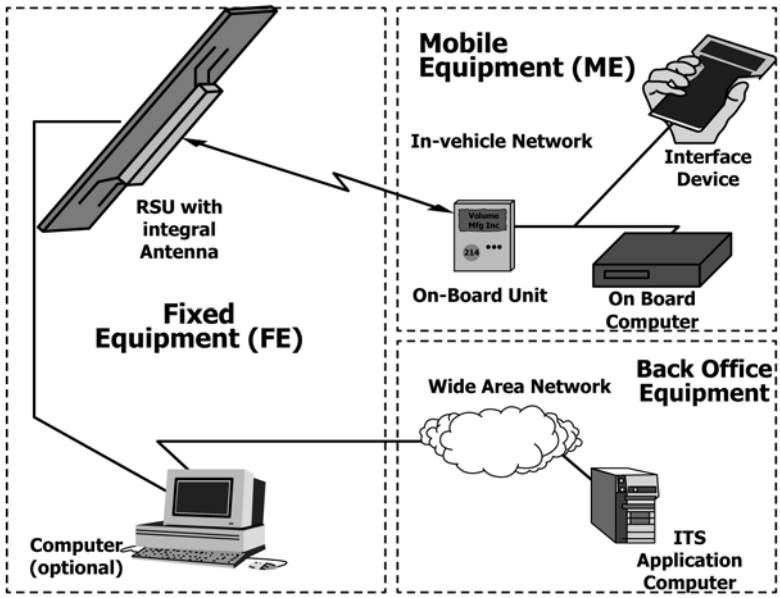

FIG. 7 Connecting a Remote ITS Application to On-board Systems

802.11, Clause 11. In addition, the management frames are received and acknowledged but not acted upon.

6.4.2 *Dynamic MAC Address*—DSRC OBU devices shall implement a mechanism to dynamically generate a random MAC address to be used to control DSRC network access and confidentiality. The MAC address shall be a randomly generated number that minimizes the probability of OBUs generating the same number, even when those OBUs are subjected to the same initial conditions. The new random MAC address shall be generated upon start-up of the device.

6.4.2.1 In the 48 bit MAC address, the individual/group bit shall be set as needed and the Global/Local bit shall be set to local. The remaining 46 bits shall receive the randomized address. The random algorithm shall generate an uncorrelated value. If an OBU ever receives a frame with its own address as the source address, the receiving OBU selects a new MAC address. Duplicate address detection is done during association. If a station that is already associated attempts to reassociate, assume it is a duplicate. A "regenerate MAC address" command shall be sent.

6.4.2.2 One of the following FIPS or ANSI random number generators shall be used: FIPS 186 (DSS) Appendix 3.1 or Appendix 3.2; ANSI X9.31 Appendix A.2.4; or ANSI X9.62-1998 Annex A.4.

7. IEEE 802.11a Section 12 Updates for DSRC

7.1 The following paragraphs define the changes and additions to Clause 12 of IEEE 802.11 to describe the standard as it applies to a DSRC device.

7.2 *DSRC Physical Layer Service Specifications*—See IEEE 802.11, Clause 12. All of the specifications of IEEE 802.11, Clause 12, are incorporated in this standard with the following requirements added for a higher resolution for RSSI measurements and the generation of a random MAC address.

7.2.1 *HRRSSI PHY-SAP Sublayer-to-Sublayer Service Primitives*—PHY-HRRSSI Request and Confirm service primitives shall be added to those identified in IEEE 802.11, Table 25.

7.2.2 *PHY-HRRSSI.request:*

7.2.2.1 *Function*—This primitive is a request by the MAC sublayer to the local PHY entity to lock the AGC and get ready for high resolution RSSI mode.

7.2.2.2 *Semantics of the Service Primitive*—The primitive provides the following parameters: PHY-HRRSSI.request (SWITCH). SWITCH is a parameter that has two values: ON and OFF. When the value is ON, the MAC sublayer requests the PHY entity to enter the high resolution RSSI mode and when the value is OFF, the MAC sublayer request the PHY entity to exit the high resolution RSSI mode.

7.2.2.3 *When Generated*—This primitive will be issued by the MAC sublayer to the PHY entity whenever the MAC sublayer needs to enter or exit the high resolution RSSI mode.

7.2.2.4 *Effect of Receipt*—The effect of receipt of this primitive by the PHY entity will be to lock the AGC and enter the high resolution RSSI mode or unlock the AGC and exit the high resolution RSSI mode.

7.2.3 *PHY-HRRSSI.confirm:*

7.2.3.1 *Function*—This primitive is issued by the PHY sublayer to the local MAC entity to confirm the entering or exiting of the high resolution RSSI mode.

7.2.3.2 *Semantics of the Service Primitive*—The semantics of the primitive are as follows: PHY-HRRSSI.confirm. There are no parameters associated with this primitive.

7.2.3.3 *When Generated*—This primitive will be issued by the PHY sublayer to the MAC entity whenever the PHY has received a PHY-HRRSSI.request from the MAC entity and is ready for high resolution RSSI measurement or out of the high resolution RSSI mode.

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7.2.3.4 *Effect of Receipt*—The receipt of this primitive by the MAC entity will cause the MAC to indicate the received RSSI as a high resolution RSSI or as a normal resolution RSSI.

7.2.4 *RANDOMMAC PHY-SAP Sublayer-to-Sublayer Service Primitives*—PHY-RANDOMMAC generation of a random MAC address request service primitive shall be added to those identified in IEEE 802.11, Table 25.

7.2.5 *PHY-RANDOMMAC.request:*

7.2.5.1 *Function*—This primitive is a request by the MAC sublayer to the local PHY entity to generate a random MAC address using an FIPS or ANSI random number generator.

7.2.5.2 *Semantics of the Service Primitive*—The primitive provides the following parameters: PHY-RANDOMMAC.request.

TABLE 1 TXVECTOR Parameters[A]

Parameter	Associate Primitive	Value
LENGTH	PHY-TXSTART.request (TXVECTOR)	1-4095
DATATRATE	PHY-TXSTART.request (TXVECTOR)	3, 4.5, 6, 9, 12, 18, 24, and 27 (Support of 3, 6, and 12 data rates is mandatory.)
SERVICE	PHY-TXSTART.request (TXVECTOR)	scrambler initialization; 7 null bits + 9 reserved null bits
TXPWR_LEVEL	PHY-TXSTART.request (TXVECTOR)	1-64

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7.2.5.3 *When Generated*—This primitive shall be issued by the MAC sublayer to the PHY entity during start-up or whenever the MAC sublayer requests that the PHY entity regenerate a MAC address.

7.2.5.4 *Effect of Receipt*—The effect of receipt of this primitive by the PHY entity will be to generate an uncorrelated random MAC address.

8. IEEE 802.11a Section 17 Updates for DSRC

8.1 The following paragraphs define the changes in Clause 17 of IEEE 802.11a as modified to describe DSRC device implementations. IEEE 802.11, the IEEE 802.11a Supplement, and the additions or modifications that follow fully describe the standard as it applies to a DSRC device.

8.2 *Introduction—DSRC PHY Specification for the 5 GHz Band—*

8.2.1 This clause specifies the PHY entity for an orthogonal frequency division multiplexing (OFDM) system and additions that have to be made to the base standard in order to accommodate the OFDM PHY. This DSRC radio frequency system is initially intended for the 5.850-5.925 GHz-licensed ITS Radio Services Band, as regulated in the United States by the Code of Federal Regulations, Title 47, Part 90. The OFDM system provides DSRC with data payload communication capabilities of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbit/s. In addition data payload capabilities of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s can be supported in optional channel combinations. The support of transmitting and receiving at data rates of 3, 6, and 12 Mbit/s is mandatory. The system uses 52 subcarriers, modulated using binary or quadrature phase shift keying (BPSK/QPSK), 16-quadrature amplitude modulation (QAM), or 64-QAM. Forward error correction coding (convolution coding) is used with a coding rate of 1/2, 2/3, or 3/4.

8.3 *TXVECTOR Parameters*—The parameters in Table 1[5] are defined as part of the TXVECTOR parameter list in the PHY- TXSTART.request service primitive.

8.3.1 *TXVECTOR DATARATE*—The DATARATE parameter describes the bit rate at which the PLCP shall transmit the PSDU. Its value can be any of the rates defined in Table 1.[5] Data rates of 3, 6, and 12 Mbps shall be supported. Other rates may also be supported.

8.4 *RXVECTOR Parameters*—The parameters listed in Table 2[5] are defined as part of the RXVECTOR parameter list in the PHY- RXSTART.indicate service primitive.

8.4.1 *RXVECTOR RSSI*—The allowed values for the receive signal strength indicator (RSSI) parameter are in the range from 0 to RSSI maximum. This parameter is a measure by the PHY sublayer of the energy observed at the antenna used to receive the current PPDU. The RSSI shall be measured during the reception of the PLCP preamble. The RSSI is intended to be used in a relative manner, and it shall be a monotonically increasing function of the received power. Subsequent to a period of no less than 2 ms after an alert signal, the minimum RSSI resolution should be less than or equal to 0.2 dB and must be accurate to ± 1 dB across the entire operating temperature range within −60 to −30 dBm of the receiving signal range.

8.4.2 *DATARATE*—DATARATE shall represent the data rate at which the current PPDU was received. The allowed values of the DATARATE are 3, 4.5, 6, 9, 12, 18, 24, or 27 Mbps.

8.5 *RATE-dependent Parameters*—The modulation parameters dependent on the data rate used shall be set according to Table 3.[5]

8.5.1 *Timing-Related Parameters*—Table 4[5] is the list of timing parameters associated with the OFDM PLCP.

[5] This table is reprinted with permission from IEEE 802.11a "IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metrolpoitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications—Amendment 1: High-Speed Physical Layer in the 5 GHz Band," Copyright 1999, by IEEE. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.

TABLE 2 RXVECTOR Parameters[A]

Parameter	Associate Primitive	Value
LENGTH	PHY-RXSTART.indicate	1-4095
RSSI	PHY-RXSTART.indicate (RXVECTOR)	0-RSSI maximum
DATARATE	PHY-RXSTART.request (RXVECTOR)	3, 4.5, 6, 9, 12, 18, 24, and 27
SERVICE	PHY-RXSTART.request (RXVECTOR)	null

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TABLE 3 Rate-dependent Parameters[A]

Data Rate, Mbits/s	Modulation	Coding Rate, R	Coded Bits per Subcarrier, N_{BPSC}	Coded Bits per OFDM Symbol, N_{CBPS}	Data Bits per OFDM Symbol, N_{DBPS}
3	BPSK	1/2	1	48	24
4.5	BPSK	3/4	1	48	36
6	QPSK	1/2	2	96	48
9	QPSK	3/4	2	96	72
12	16-QAM	1/2	4	192	96
18	16-QAM	3/4	4	192	144
24	64-QAM	2/3	6	288	192
27	64-QAM	3/4	6	288	216

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TABLE 4 Timing-related Parameters[A]

Parameter	Value
N_{SD}: number of data subcarriers	48
N_{SP}: number of pilot subcarriers	4
N_{ST}: number of subcarriers, total	52 (N_{SD} + N_{SP})
Δ_F: subcarrier frequency spacing	156.25 kHz (=10 MHz/64)
T_{FFT}: IFFT/FFT period	6.4 µs ($1/\Delta_F$)
$T_{PREAMBLE}$: PLCP preamble duration	32 µs (T_{SHORT} + T_{LONG})
T_{SIGNAL}: duration of the SIGNAL BPSK-OFDM symbol	8 µs (T_{GI} + T_{FFT})
T_{GI}: GI duration	1.6 µs (T_{FFT}/4)
T_{GI2}: training symbol GI duration	3.2 µs (T_{FFT}/2)
T_{SYM}: symbol interval	8 µs (T_{GI} + T_{FFT})
T_{SHORT}: short training sequence duration	16 µs (10 × T_{FFT}/4)
T_{LONG}: long training sequence duration	16 µs (T_{GI2} + 2 × T_{FFT})

[A] From IEEE 802.11a. Copyright 1999 IEEE. All rights reserved.

8.5.2 *Discrete Time Implementation Considerations*—See IEEE 802.11a, Clause 17.3.2.5.

8.6 *PLCP Preamble (SYNC):*

8.6.1 The PLCP preamble field is used for synchronization. It consists of 10 short symbols and two long symbols that are shown in Fig. 8 and described as follows. Fig. 8 shows the OFDM training structure (PLCP preamble), where t_1 to t_{10} denote short training symbols and T_1 and T_2 denote long training symbols. The PLCP preamble is followed by the SIGNAL field and DATA. The total training length is 32 µs. The dashed boundaries in Fig. 8 denote repetitions due to the periodicity of the inverse Fourier transform.

8.6.2 A short OFDM training symbol consists of 12 subcarriers, which are modulated by the elements of the sequence *S*, given as follows:

$$S_{-26,\,26} = \sqrt{(13/6)} \times \{0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0,0\}$$

The multiplication by a factor of $\sqrt{(13/6)}$ is in order to normalize the average power of the resulting OFDM symbol, which utilizes 12 out of 52 subcarriers.

8.6.2.1 The signal shall be generated according to the following equation:

$$r_{SHORT}(t) = w_{TSHORT}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} S_k \exp(j2\pi k\Delta_F t)$$

The fact that only spectral lines of $S_{-26:26}$ with indices that are a multiple of 4 have nonzero amplitude results in a periodicity of $T_{FFT}/4$ = 1.6 µs. The interval *TSHORT* is equal to ten 1.6 µs periods (that is, 16 µs). Generation of the short training sequence is illustrated in IEEE 802.11a, Annex G (G.3.1, Table G.2).

8.6.2.2 A long OFDM training symbol consists of 53 subcarriers (including a zero value at dc), which are modulated by the elements of the sequence *L*, given as follows:

$$L_{-26,\,26} = \{1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1\}$$

A long OFDM training symbol shall be generated according to the following equation:

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} L_k \exp(j2\pi k\Delta_F(t - T_{G12}))$$

where:

T_{G12} = 3.2 µs.

Two periods of the long sequence are transmitted for improved channel estimation accuracy, yielding T_{LONG} = 3.2 + 2*6.4 = 16 µs. An illustration of the long training sequence generation is given in IEEE 802.11a, Annex G (G.3.2, Table G.5). The sections of short repetitions and long repetitions shall be concatenated to form the following preamble:

$$r_{PREAMBLE}(t) = r_{SHORT}(t) + r_{LONG}(t - T_{SHORT})$$

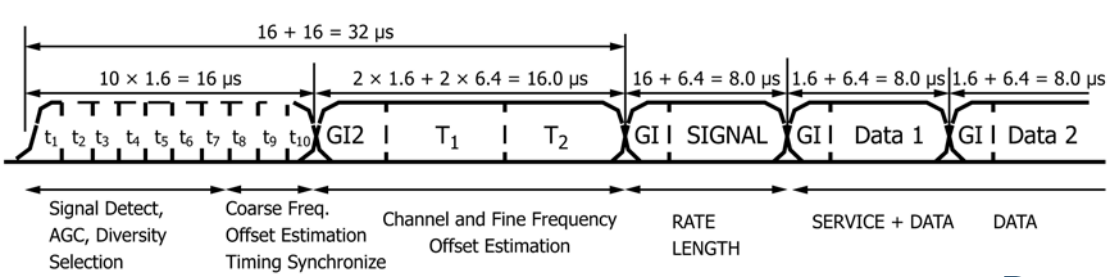

FIG. 8 OFDM Training Structure

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