SURFACE VEHICLE STANDARD

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On-Board System Requirements for LTE-V2X V2V Safety Communications

RATIONALE

This SAE Standard is the first edition of on-board system requirements for V2V safety communications using LTE-V2X Sidelink. It provides information necessary to build interoperable systems that support select safety applications, which rely on the exchange of basic safety messages.

TABLE OF CONTENTS

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1. SCOPE

This SAE Standard specifies system requirements for an on-board vehicle-to-vehicle (V2V) safety communications system for light vehicles and public safety vehicles[1], including standards profiles, functional requirements, and performance requirements. The system is capable of transmitting and receiving the SAE J2735-defined basic safety message (BSM) over a PC5 Sidelink V2X (mode 4) communications link as defined in ETSI Release 14[2,3]. The system uses Institute of Electrical and Electronics Engineers (IEEE) 1609 standards for network and transport layer communciations, as well as security.

1.1 Purpose

This standard addresses the on-board system needs for ensuring that the exchange of BSMs in V2V safety communications using LTE-V2X Sidelink provides the desired interoperability and data integrity to support the performance of the envisioned safety applications.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2735 V2X Communications Message Set Dictionary

SAE J2945/1 On-Board System Requirements for V2V Safety Communications

SAE J2945/5 Service Specific Permissions and Security Guidelines for Connected Vehicle Applications

2.1.2 ETSI/3GPP Publications

The references to ETSI documents in this section refer to ETSI transposition of specific 3GPP techincal specifications available from 3GPP Mobile Competence Centre, c/o ETSI, 650, route des Lucioles, 06921, Sophia Antipolis Cedex, France, www.etsi.org. The equivalent 3GPP documents are listed in brackets below.

Please note that this report incorporates certain ETSI/3GPP specifications by reference. ESSENTIAL IPRs (Intellectual Property Rights) have been declared to ETSI. All information statements and licensing declarations of ESSENTIAL IPRs received by ETSI are publicly available via the ETSI IPR Online Database found at https://ipr.etsi.org/DynamicReporting.aspx.

The following list of of documents are from the ETSI Release 14 set of standards and are referred to in the body of this document by their document number (e.g., ETSI TS 136 321, which is equivalent to 3GPP TS 36.321):

ETSI TS 136 201 Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description v14.1.0 (Release 14) [3GPP TS 36.201]

ETSI TS 136 213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, V14.2.0 (Release 14) [3GPP TS 36.213]

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[1] See 3.1 for the definition of light vehicle and public safety vehicle. Other vehicle classes and trailers will be addressed in future revisions of this standard, or in other standards within the SAE J2945 family of standards. These revisions or additional standards are expected to be compatible with the requirements of this standard and may define additional capabilities beyond the requirements for light vehicles.

[2] Hereafter in this document, whenever the terms “LTE-V2X,” “Sidelink,” or “PC5” are used separately or in any combination, they refer to ETSI Release 14 PC5 Sidelink (mode 4) communication. External documents may also refer to this technology as cellular-V2X or C-V2X.

[3] ETSI Release 15 allows for cyclic delay diversity, which is optional in this specification.

ETSI TS 136 321 Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification, V14.2.1 (Release 14) [3GPP TS 36.321]

ETSI TS 136 322 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification, V14.1.0 (Release 14) [3GPP TS 36.322]

ETSI TS 136 331 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification, V14.14.0 (Release 14) [3GPP TS 36.331]

ETSI TS 123 285 Architecture enhancements for V2X services, V14.9.0 (Release 14) [3GPP TS 23.285]

ETSI TS 123 303 Proximity-based services (ProSe); Stage 2, V14.1.0 (Release 14) [3GPP TS 23.303]

These documents may reference other related ETSI documents.

2.1.3 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

The following list of of documents are from the IEEE 1609 set of standards and are referred to in the body by their IEEE document number (e.g., 1609.2):

IEEE Std 1609.2-2016 IEEE Standard for Wireless Access in Vehicular Environments - Security Services for Applications and Management Messages (as amended by IEEE Std 1609.2aTM-2017 and IEEE Std 1609.2bTM-2019)

IEEE Std 1609.3-2020 IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services

IEEE Std 1609.12-2019 IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifier Allocations

2.2 Related Publications

Refer to section 2.2 of SAE J2945/1.

3. TERMS AND DEFINITIONS

3.1 Definitions

Definitions unique to this document are included here. Refer also to section 3.1 of SAE J2945/1.

3.1.1 LAYER 2 ADDRESS

The 24-bit destination layer-2 ID.

NOTE: This definition is changed from SAE J2945/1.

3.1.2 CRITICAL EVENT CONDITION

When an event that corresponds to a critical event flag occurs, or when a public safety vehicle (police, fire, or ambulance) is engaged in an emergency response.

NOTE: The inclusion of emergency response as a critical event condition is supplemental to the SAE J2945/1 definition of a critical event condition. Requirements in SAE J2945/1 that apply when a critical event flag is set also apply to a public safety vehicle engaged in an emergency response.

3.1.3 PUBLIC SAFETY VEHICLE

Class 2, 3, or 5 police, fire, and ambulance vehicles, as defined by FHWA.

3.1.4 EMERGENCY RESPONSE

When a police, fire, or ambulance vehicle's light bar or siren is in use and it includes DF_EmergencyDetails in its BSM.

3.2 Abbreviations and Acronyms

The abbreviations and acronyms cited below are terms used in this standard.

3GPP	Third Generation Partnership Project
ASN.1	Abstract Syntax Notation One
BSM	Basic Safety Message
CBR	Channel Busy Ratio
CFR	Code of Federal Regulations
CR	Channel Occupancy Ratio
DE	Data Element
DF	Data Frame
DVI	Driver Vehicle Interface
ECU	Electronic Control Unit
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access
FCC	Federal Communications Commission
GHz	Gigahertz
GNSS	Global Navigation Satellite System
HARQ	Hybrid Automatic Repeat Request
HV	Host Vehicle
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
IPv6	Internet Protocol Version 6
ITT	Inter-Transmit Time
km/h	Kilometers per Hour
LTE	Long Term Evolution
LTE-V2X	Long Term Evolution - Vehicle-to-Everything (also known as cellular-V2X or C-V2X)

MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MHz	Megahertz
OBE	Onboard Equipment
OFDM	Orthogonal Frequency Division Multiplexing
PC5	ProSe Communications 5
PDB	Packet Delay Budget
PER	Packet Error Ratio
PDCP	Packet Data Convergence Protocol
PDCP SN	Packet Data Convergence Protocol Sequence Number
PGK	ProSe Group Key
PICS	Protocol Implementation Conformance Statement
PPPP	ProSe Per Packet Priority
PRB	Physical Resource Block
PSSCH	Physical Sidelink Shared Channel
PSCCH	Physical Sidelink Control Channel
PSID	Provider Service ID
PTK	ProSe Traffic Key
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RSRP	Reference Signal Receive Power
RSSI	Received Signal Strength Indicator
RF	Radio Frequency
RLC	Radio Link Control
RLC UM	Radio Link Control Unacknowledged Mode
RP	Radiated Power
RSE	Roadside Equipment
RSSI	Received Signal Strength Indicator
RV	Remote Vehicle

SCMS	Security Credential Management System
SPS	Semi-Persistent Scheduling
STCH	Sidelink Traffic Channel
3D	Three-Dimensional
TX	Transmit
UE	User Equipment[4]
USIM	Universal Subscriber Identity Module
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WAAS	Wide Area Augmentation System
WSM	WAVE Short Message
WSA	WAVE Service Advertisement
WSMP	WAVE Short Message Protocol

3.3 Requirement Numbering Convention

Each requirement in this standard is tagged with a requirement number of the form:

<Subsection Number>-V2V-< Category Abbreviation>-<Subcategory Abbreviation>-<Number>

For example, if the requirement number is 6.5.2-V2V-SECPRIV-BSMSIGN-005, the subsection is 6.5.2, the category is Security and Privacy, the subcategory is BSM signing, and it is requirement number 5 in the subcategory. Table 1 identifies the sections in this standard and the corresponding subsections and abbreviations that are used. The abbreviation is also in parentheses following each section heading in this standard. The requirement numbering convention applies to both mandatory and optional features.

[4] In this document, the terms UE and OBE are used interchangeably. user equipment could also be a transmitting device or receiving device depending on the context.

Table 1 - Requirement numbering abbreviations

Section	Subsection	Category	Category Abbreviation	Subcategory	Subcategory Abbreviation
6.1	6.1.1	Standards Profiles	STD	ETSI PC5 V2X	ETSI
	6.1.2			IEEE 1609.2	1609.2
	6.1.3			IEEE 1609.3	1609.3
	6.1.5			IEEE 1609.12	1609.12
	6.1.6			SAE J2735	SAE J2735
6.2	6.2.1*	Positioning and Timing	POSTIM	Position Determination	POSDETER
	6.2.2*			Wide Area Augmentation System	WAAS
	6.2.3*			Coordinate System and Reference	COORDSYSREF
	6.2.4*			System Time Coordination	SYSTIMCOORD
6.3	6.3.1	BSM Transmission	BSMTX	BSM Contents	BSMCONT
	6.3.2			Channel and Data Rate	CHDATARATE
	6.3.3			First BSM after Startup and Generation Timing	GENTIM
	6.3.4			Priority Settings	PPPP
	6.3.5			Minimum Transmission Criteria	MINTX
	6.3.6			Data Element Accuracy	DATAACC
	6.3.7			Data Persistency	DATAPERSIST
	6.3.8			BSM Scheduling and Congestion Control	CONGCTRL
6.4	6.4.1	RF Performance	RFPERF	Minimum TX RF Performance and Signal Strength	TXSS
	6.4.2			Receive Sensitivity	RXSENS
6.5	6.5.1	Security and Privacy	SECPRIV	ID Randomization	IDRAND
	6.5.2			BSM Signing	BSMSIGN
	6.5.3			Certificate Change	CERTCHG
	6.5.4			BSM Verification	BSMVERIFY
	6.5.5			Certificate Revocation	CERTREV
6.6	6.6.1*	Security Management	SECMGMT	Bootstrap: Enrollment and Initialization Processing	ENINIT
	6.6.2*			Certificate Loading	CERTLOAD
	6.6.3*			Certificate Storage	CERTSTORE
	6.6.4*			CRL Loading	CRLLOAD
	6.6.5*			Secure Hardware	SECHW
	Appendix C	Service Specific Permissions	SSP	Emergency Vehicles	EV

* These subsections refer to SAE J2945/1.

4. V2V SAFETY SYSTEMS CONCEPT OF OPERATIONS AND SYSTEM DESCRIPTION

This section provides a high-level description of the V2V safety concept of operations and system description. Section 4.1 provides an overview of the system, and 4.2 provides the system description for V2V safety features.

4.1 V2V System Overview

V2V safety communications are designed to exchange basic safety information among vehicles for driver assistance by supporting detection of imminent crash threats and alerting the driver. V2V communications use PC5 V2X radios to transmit BSMs that include a subset of the available data frames and elements in SAE J2735. Onboard safety applications use the information about the host vehicle (HV) and remote vehicles (RVs) to detect potential crash threats and alert the driver. Messages can be used for additional purposes, but only the scenarios described herein were used to develop this standard. For the purposes of the crash scenarios described herein, the HV and RV terminology is used to identify which vehicle is receiving and acting on BSMs (HV), and the set of vehicles from which BSMs are being received (RVs).

V2V communications can enable improved safety system effectiveness by complementing or providing an alternative to self-contained sensors such as radar, lidar, or camera systems. V2V communications provide the vehicle and driver with 360-degree awareness and can detect potential threats at a greater distance than other types of sensors, as well as detecting potential threats to some degree even under non-line-of-sight or low visibility conditions. This enables the driver to receive alerts earlier and have more time to take action to avoid crashes.

Because vehicles need to trust messages from each other, security is essential to protect messages from attacks such as spoofing, alteration, or replay that could cause false alerts or suppress true alerts. In addition, driver privacy is protected appropriately, so the system does not disclose identifying information about the driver, or allow for easy tracking. All BSMs are sent with a signature that enables the receiving vehicle to verify the message. Broadcast information that could potentially be used to identify and track drivers is anonymous and randomized, and other system security measures are also incorporated to protect privacy appropriately.

Figure 1 illustrates the components of the V2V system and its interfaces. An infrastructure-based security credential management system (SCMS) is responsible for generating and delivering the security certificates that are used in the message verification process. The SCMS can also revoke certificates that cannot be trusted (e.g., the associated device may have been tampered with or is misbehaving) by placing them on a certificate revocation list (CRL) that the SCMS distributes to supporting or participating systems. Section 6.6 in this standard describes the services provided by the SCMS.

The V2V onboard equipment (OBE), which is the on-board vehicle-to-vehicle (V2V) safety communications system defined in this standard (hereafter referred to as the system), typically consists of multiple subsystem components, which may be discrete or integrated depending on the implementation. Figure 1 illustrates the following subsystems within the system:

- PC5 radio subsystem: Transmits and receives BSMs. The OBE can include one or more LTE-V2X radio subsystems and still comply with this standard, as long as it meets the performance requirements herein.
- Positioning subsystem: The subsystem that includes a global navigation satellite system (GNSS) receiver and provides vehicle position, heading, speed, and time information. The system may augment and enhance positioning using additional information and components, which are not shown in Figure 1. Examples of these are speed data from the CAN bus, dead reckoning sensors and optical/camera based systems.
- OBE control processor electronic control unit (ECU): Executes software that generates BSMs for transmission according to the requirements in this standard.
- Antennas: Support radio frequency (RF) links for the PC5 radio and GNSS receiver.

Systems (OBE) communicate amongst themselves using the PC5 radio subsystem as an interface. The system can interface to a safety application ECU that detects threats and issues alerts through a driver-vehicle interface (DVI). The DVI can provide visual, audio, and/or haptic alerts. The OBE can also interface with the vehicle controller area network (CAN) bus to obtain vehicle status information. The safety application ECU, CAN bus and DVI are outside the scope of this standard.

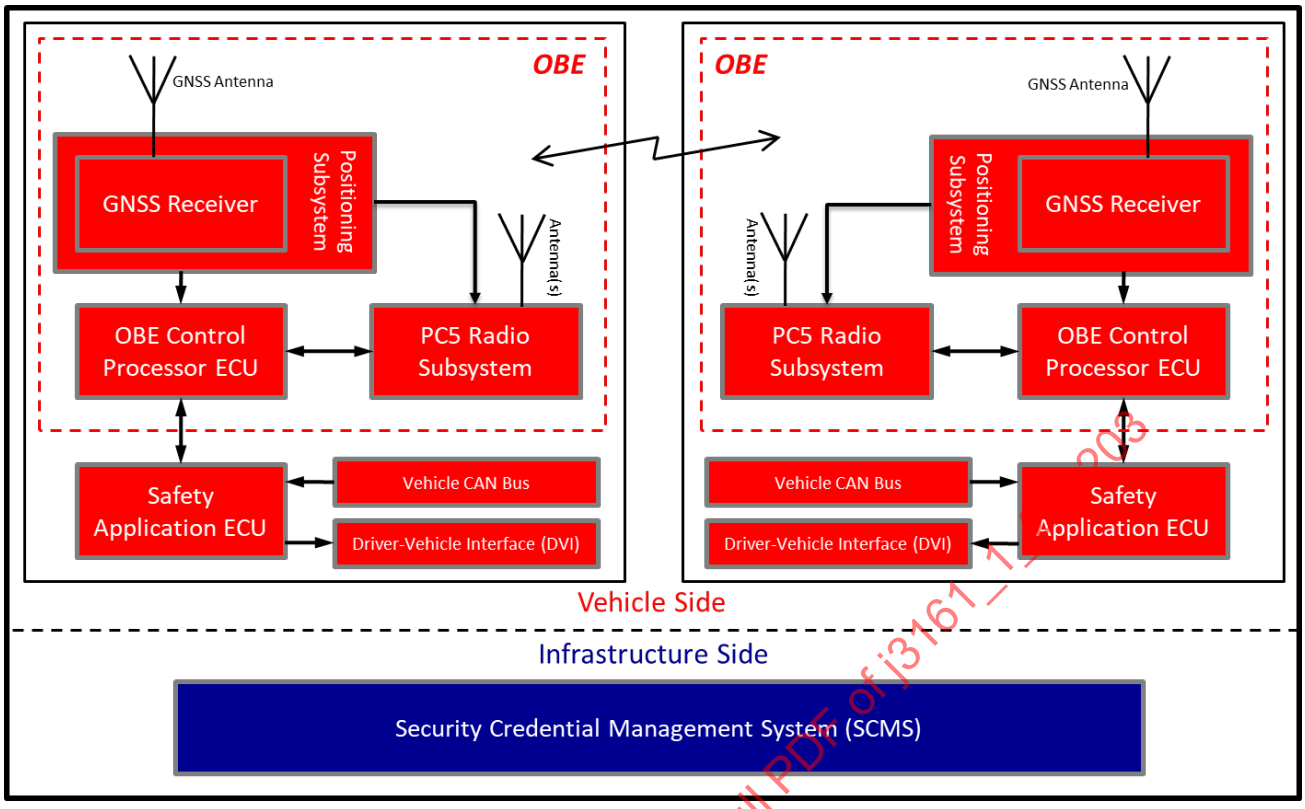

Figure 1 - On-board V2V system

4.2 V2V Safety Features

The V2V safety features used as the conceptual basis for development of V2V safety communications standards were originally developed for a DSRC based interface, as defined in SAE J2945/1. Therefore, the entirety of section 4.2 of SAE J2945/1 is hereby incorporated by reference.

This document additionally includes support for information transmitted by public safety vehicles engaged in an emergency response (police and fire vehicles and ambulances). This feature allows additional information to be included in the BSM (e.g., light bar and siren information), which enables other vehicles and local infrastructure to be informed of the presence of public safety vehicles engaged in an emergency response.

5. INTERFACE DESCRIPTION

5.1 V2V Over-the-Air Data Description

5.1.1 Basic Safety Message Exchange

Refer to section 5.1.1 of SAE J2945/1. This document also includes support for public safety vehicles to include details related to emergencies in their BSM (i.e., use of DF_EmergencyDetails in the BSM).

5.1.2 Positioning

Refer to section 5.1.2 of SAE J2945/1.

5.1.3 Security and Privacy

5.1.3.1 Signing and Verification Algorithm

Refer to section 5.1.3.1 of SAE J2945/1. Note that this document also includes support for service specific permissions to be used in the certificates of public safety vehicles.

5.1.3.2 BSM Signature and Certificate Transmission

Refer to section 5.1.3.2 of SAE J2945/1.

5.1.3.3 BSM Verification

Refer to section 5.1.3.3 of SAE J2945/1.

5.1.3.4 SCMS

Refer to section 5.1.3.4 of SAE J2945/1.

5.1.3.5 Privacy

Refer to section 5.1.3.5 of SAE J2945/1

5.1.4 Startup and Shutdown

Refer to section 5.1.4 of SAE J2945/1.

5.1.5 Mapping to the V2V Over-the-Air Data

Refer to section 5.1.5 of SAE J2945/1. This document also includes data frames and elements that support public safety vehicles engaged in an emergency response so that vehicles can notify a driver of a nearby emergency vehicle. These extra data frames and elements are shown in Table 2

Table 2 - Mapping data elements and frames for emergency vehicle notification

V2V Safety Message BSM Contents	Emergency Vehicle Notification
DF_SpecialVehicleExtensions DF_EmergencyDetails DE_SirenInUse DE_LightbarInUse DE_MultiVehicleResponse DF_SupplementalVehicleExtensions DF_VehicleClassification DE_BasicVehicleRole	Required for: Target Classification Threat Assessment

5.1.6 PC5 Radio Pre-Configuration

The PC5 radio pre-configuration parameters are defined in Table 3.

5.2 System Interfaces

This section provides an overview of the system interfaces. Section 6 provides the detailed requirements for these interfaces.

5.2.1 Vehicle-to-Vehicle Communications Interface

The system interfaces to other vehicles (systems) by transmitting and receiving BSMs in addition to other supporting V2X messages and their applications.

- The format and contents of the BSM are compliant with SAE J2735.
- The BSM is transmitted over the LTE-V2X interface as a wireless access in vehicular environments (WAVE) short message (WSM) using the WAVE short message protocol (WSMP) specified in IEEE 1609.3 without IEEE 802.3 ethertype. Note that several optional fields available in the WSMP header are not applicable to this document (see 6.1.3 for details).

- BSMs are transmitted in LTE band 47 using UARFCN 55140 with a 20 MHz channel width. This corresponds to 5905 to 5925 MHz; this is Channel 183 using the IEEE 802.11 designations.
- BSM security is compliant with IEEE 1609.2.
- The over-the-air interface is compliant with ETSI Release 14 and optionally some features of Release 15.[5]
- The WSM provider service ID (PSID) is set as specified in IEEE 1609.12.

Section 6.1 of this standard profiles the applicable requirements from each of these standards.

5.2.2 System to SCMS Communications Interface

Refer to section 5.2.2 of SAE J2945/1.

5.2.3 System to Positioning Subsystem Interface

Refer to section 5.2.3 of SAE J2945/1.

6. MINIMUM REQUIREMENTS

6.1 Standards Profiles (STD)

6.1.1 ETSI

This section specifies the requirements from ETSI Release 14 to support V2V operation as specified in this document. In general, the scope of communications capabilities used by this document is limited to “non-operator managed” [ETSI TS 123 285] V2X Sidelink communications. A universal subscriber identity module (USIM) and radio access network (RAN) infrastructure are not required to implement the functionality specified in this document.

- The PC5 radio subsystem shall implement the user equipment (UE) as specified in the ETSI Release 14 set of technical specifications to the extent necessary to support V2X Sidelink communications [ETSI TS 136 321, 136 201]. [6.1.1-V2V-STD-ETSI-001]
- For V2V safety communications, the PC5 radio subsystem shall use V2X Sidelink communications, as specified in ETSI Release 14 [ETSI TS 136 321]. There is no infrastructure or serving cell. The radio subsystem is assumed to be pre-authorized for the region in which it operates, which in the case of SAE J3161/1 is the United States. [6.1.1-V2V-STD-ETSI-002]

NOTE: UE has no serving cell means the system does not require a cellular communications infrastructure. Autonomous resource selection using mode 4 is implemented by selecting resource blocks for transmission based on energy sensing of resource blocks (RBs) already in use and priority associated with the information in those RBs [ETSI TS 136 213].

- For V2V safety communications, the PC5 radio subsystem shall use the UE procedure for determining subframes and resource blocks for transmitting PSSCH and reserving resources for Sidelink transmission mode 4 [ETSI TS 136 213, 136 321]. [6.1.1-V2V-STD-ETSI-003]
- The 3-bit SDU-type field in the ETSI PDCP header shall be set to 011, indicating non-IP. The 16-bit PDCP-SN-size shall be used. PGK identity, PTK identity, and PDCP SN shall be set to 0. [6.1.1-V2V-STD-ETSI-004]
- The V2X message family encoding shall be set to the value of 00000001 indicating IEEE 1609 [6.1.1-V2V-STD-ETSI-005]

[5] As noted in Section 1, cyclic delay diversity as defined in Release 15 is optional in this specification.

- The PC5 radio subsystem shall use RLC UM (unacknowledged mode) and the 5-bit RLC SN size. UM window size shall be set to 0. HARQ reordering is not applicable for STCH reception. [6.1.1-V2V-STD-ETSI-006]

- The 4-bit V field in the ETSI MAC header shall be set to 0011, indicating a 24-bit DST field. [ETSI TS 136 321] [6.1.1-V2V-STD-ETSI-007]

- The 24-bit destination layer-2 ID in the ETSI MAC header shall be set to all 1s for BSMs. [ETSI TS 136 321]. [6.1.1-V2V-STD-ETSI-008]

- The 24-bit source layer-2 ID in the 3GPP MAC header shall be set to a random value at startup and periodically reset as described in 6.5.1. [6.1.1-V2V-STD-ETSI-009]

- The PC5 radio subsystem shall use the preconfiguration parameters as specified in Table 3. Parameters not included in Table 3 are not used on a PC5 interface that transmits BSMs according to this document. [ETSI TS 136 213, 136 321]. [6.1.1-V2V-STD-ETSI-0010]

- The maximum EIRP shall be +33 dBm and the nominal conducted power should be set to +20 dBm for light-duty vehicles, as measured at the antenna port of the OBE. While there are ETSI references to maximum TX power later in this document, these values should be considered nominal[6]; devices are allowed to use more or less than the nominal power to compensate for cable losses and antenna gain/loss, as long as regulatory constraints are met. [6.1.1-V2V-STD-ETSI-0011][7,8]

- Packets shall be transmitted using one of two methods. [6.1.1-V2V-STD-ETSI-0012]

    - Semi persistent scheduling (SPS) method.

    - Event-based transmission (commonly known as one-shot transmissions):

        - Event-based BSM transmissions are sent either with ProSe packet priority (PPPP) = 2 or 5. Event-based BSMs with the critical event flag set and BSMs generated by a public safety vehicle engaged in an emergency response are sent using PPPP = 2. SPS-based flows for other BSM transmissions are always sent with PPPP = 5.

        - Both type of flows need to adhere to PDB values as defined.

- Packet delay budget (PDB) is defined as the maximum delay that a packet can tolerate once it is received by the modem from an application stack and is generally based on the priority of the packet generated. PDB shall be set according to the following rules [6.1.1-V2V-STD-ETSI-0013]:

    - For priority 5, PDB is set to 100 ms irrespective of SPS or event-based flows.

    - For priority 2, PDB is set to 50 ms irrespective of SPS or event-based flows.

- The configuration specified below details limits on the relevant parameters for transmission of a payload. If a packet is large and does not fit using the maximum allowable MCS and sub-channel limits, then UE can choose an option between segmentation or dropping the packet as per rules described in ETSI TS 136 321 section 5.14. Additionally, if the choice is to segment the packet, then the segmentation procedure as defined in ETSI TS 136 322 needs to be followed. It is not expected that non-public safety BSMs will require segmentation, however.

Preconfiguration parameters provide a wide variety of parameters that configure the behavior of the LTE-V2X radio. These parameters are split into multiple areas and each set of parameters configure a specific area including but not limited to channel bandwidth, maximum transmit power, limits on modulation and coding schemes, priority handling, limits on sub-channel sizes and number of subchannels and lastly channel busy ratio and channel access limits (CR-limit).

[6] This document retains the ETSI terminology for consistency with referenced ETSI specifications.
[7] See 6.4.1 for additional information on power levels.
[8] For emergency vehicles, the maximum total radiated power may be allowed to increase to a higher value, subject to regulatory constraints.

Table 3 can be effectively broken down into six sets of parameters:

1. General parameter set.
2. Common RX and TX pool configuration set.
3. Channel busy ratio (CBR) configuration set.
4. Priority-based configuration set.
5. Speed-based configuration set.
6. RSRP-based exclusion parameter set.

6.1.1.1 General Parameter Set - Index Elements from 1 to 13

This set of parameters configure high level parameters.

- Maximum number of supported frequencies for this particular configuration.
- Frequency of operation.
- Overall maximum transmit power.
- Configured channel bandwidth.

6.1.1.2 Common RX and TX Pool Configuration Set - Index Elements from 14 to 21

This set of parameters configure general transmission and reception pool configurations.

- Maximum number of RX and TX pool configurations.
- Subframe bitmap for configuration of subframes enabled for LTE-V2X communication.
- Sub-channel configuration: Size of each sub-channel, number of subchannels, and start resource block of the subchannel
- Maximum transmit power for the configured transmit pool. This cannot exceed the maximum configured power in general parameter set 1.
- Type of synchronization source.

6.1.1.3 Channel Busy Ratio (CBR) Configuration Set - Index Elements from 22 to 31

This set of parameters configure CBR levels and transmission parameters based on CBR levels.

- RSSI[9] threshold above which a sub-channel will be considered occupied for channel busy ratio calculation.
- Maximum number of CBR (channel busy ratio) configurations based on CBR levels.

[9] If measured in a single subchannel, RSSI is the power in that subchannel; if measured across multiple subchannels, RSSI is the linear average of the power in those subchannels.

- For each channel busy ratio configuration, these parameters apply:
  - CR-limit: Maximum number of subchannels that can be used in 1 second for a given CBR.
  - Minimum and maximum MCS that can be used.
  - Minimum and maximum number of sub-channels that can be used.
  - Retransmission setting.

6.1.1.4 Priority-Based Configuration Set - Index Elements from 32 to 39

This set of parameters configure various priority configurations.

- Maximum number of priority configurations.
- For each priority configuration it further allows configuration of the below elements:
  - Default CBR configuration to be used when there is no CBR measurement available.
  - A mapping from measured CBR range to a CBR configuration to be used when CBR measurement is available.

6.1.1.5 Speed-Based Configuration Set - Index Elements from 40 to 42

This set of parameters configure transmission parameters based on speed threshold.

The final transmission parameters are chosen based on a combination of speed based and congestion based parameter sets.

- Configuration of a speed threshold.
- Parameters within each set of speed configurations include:
  - Minimum and maximum MCS.
  - Minimum and maximum number of sub-channels.
  - Retransmission configuration.
- There are two sets of transmission parameters:
  - The first set of parameters needs to be used when speed is above the configured threshold.
  - The second set of parameters needs to be used when speed is below the configured threshold.
- Speed threshold of 120 km/h is used to select between the parameter sets.

6.1.1.6 Resource Selection Procedure - Index Elements from 43 to 54

There are two methods of channel access in LTE-V2X: (1) semi-persistent scheduling (SPS), and (2) event-based (one-shot) transmission.

1. A transceiver can use sensing-based SPS algorithm to reserve the channel and transmit periodic data. In this scheme, the transmitter senses the channel for 1 second (referred to as the “sensing window”) and selects a set of SPS subchannels for the first transmission after the resource reselection. In subsequent 100 ms intervals it might transmit a BSM using the same selected subchannels (an “SPS transmission”), it might transmit a BSM using a different set of subchannels selected using the one-shot scheduler, or it might not transmit at all. When it performs resource reselection, it initiates a resource reselection counter (ResourceReselectionCtr) to a random number selected uniformly over the range SPSCtrMin to SPSCtrMax. When it makes an SPS transmission, it decrements ResourceReselectionCtr. When a BSM is ready to be transmitted with SPS, if ResourceReselectionCtr is zero, the transmitter either selects new SPS subchannels (with probability 0.2) or re-uses the existing set of SPS subchannels (with probability 0.8). A new ResourceReselectionCtr value is randomly chosen in both cases.

2. Half-duplex and reselection of reserved resources in SPS flow may cause repetitive packet collision when the transmitter uses SPS flow for periodic packet transmission. To protect against these collisions, LTE-V2X uses one-shot transmissions along with SPS flows to avoid the repetitive packet collision.

3. For this purpose, the transmitter uses another counter for one-shot transmission (OneShotCtr) along with ResourceReselectionCtr. OneShotCtr is chosen uniformly between OneShotCtrMin and OneShotCtrMax. After each packet transmission using SPS flow (or retransmission if HARQ is enabled), both ResourceReselectionCtr and OneShotCtr are decremented by 1.

   When the OneShotCtr becomes 0 and ResourceReselectionCtr is not equal to zero, the transmitter skips the SPS flow and the transmission is made using the one-shot transmission. For this transmission, the PPPP of the one-shot resource grant transmission shall be the same as the PPPP of the SPS resource grant based transmission defined in 6.3.4. [6.1.1-V2V-STD-ETSI-0014]

   After the one-shot transmission, OneShotCtr will be set to a new random number. The ResourceReselectionCtr is not decremented if a one-shot transmission is made.

   When ResourceReselectionCtr becomes 0 and OneShotCtr is not equal to 0 the transmitter determines whether the current resources are going to be kept using the probResourceKeep-r14. If the device keeps the current resources, then only ResourceReselectionCtr is reset to another random number between SPSCtrMin and SPSCtrMax. If, however, the resources are not going to be kept and the transmitter decides to select other resources, both ResourceReselectionCtr and OneShotCtr will be set to new random values after selecting the new resources.

   If both ResourceReselectionCtr and OneShotCtr become 0 simultaneously, the transmitter shall (1) transmit the next packet using one-shot transmission, (2) then determine whether the current SPS resources are going to be kept using the probResourceKeep-r14, (3) based on the decision selects new resources or keeps the current resources, and (4) reset both counters.

   The resource selection for the one-shot transmission interleaved with SPS transmissions as defined above is based on the same PPPP and PDB as the associated SPS. The resources used for one-shot and SPS transmission respectively are always non-overlapping and determined through a separate selection procedure.

Configuration parameters include:

- Resource reservation period.
- Probability of selecting a new resource during resource reselection.
- Number of resources after which resource reselection is to be triggered.

- RSRP exclusion threshold.
  - Payloads received on the resources with measured RSRP below this threshold will not be excluded.
  - Payloads received on the resources with measured RSRP equal or above this threshold will be excluded.
  - There are four thresholds for two priorities (P1 and P2)[10]
    - When a payload with priority P1 needs to be transmitted and payloads with P1 are being received.
    - When a payload with priority P1 needs to be transmitted and payloads with P2 are being received.
    - When a payload with priority P2 needs to be transmitted and payloads with P1 are being received.
    - When a payload with priority P2 needs to be transmitted and payloads with P2 are being received.

NOTE: Preconfiguration refers to the operating parameters that are specifically set in the PC5 radio for V2V operation without the use of infrastructure. For this specification, only operation without use of infrastructure is supported, i.e., the parameters cannot be updated dynamically. Parameters not present are not applicable to this document or are optional according to ETSI TS 136 331 ASN.1. Changing the preconfiguration parameters will require a revision of this document. Detailed parameters can be found in Section A.10.

- The pre-configuration parameter T2 shall be set to 20 ms for CBR ≤ 0.25; for CBR in the range 0.25 < CBR < 0.65, T2 is set to min (PDB-10, 50 ms) and beyond that is set to PDB-10. T2 has to be a minimum of 20 ms. It cannot take values below 20 ms.[11] [6.1.1-V2V-STD-ETSI-0015]

Table 3 - LTE-V2X PC5 pre-configuration requirements

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
1	maxFreqV2X-r14	1	Maximum number of carrier frequencies for which LTE-V2X Sidelink communication can be configured.
2	profile0x0001-r12	FALSE	Legacy from D2D, not applicable to LTE V2X.
3	profile0x0002-r12	FALSE	Legacy from D2D, applicable to for LTE V2X.
4	profile0x0004-r12	FALSE	Legacy from D2D applicable to LTE V2X.
5	profile0x0006-r12	FALSE	Legacy from D2D, applicable to LTE V2X.
6	profile0x0101-r12	FALSE	Legacy from D2D, applicable to LTE V2X.
7	profile0x0102-r12	FALSE	Legacy from D2D, applicable to LTE V2X.
8	profile0x0104-r12	FALSE	Legacy from D2D, applicable to LTE V2X.
9	carrierFreq-r12	55140 (5915 MHz)	ARFCN-ValueEUTRA-r9b (Channel 183 in IEEE 802.11).
10	maxTxPower-r12	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Maximum allowed transmission power (same as P-Max, which is an ETSI standards parameter). This is the maximum conducted transmit power into the antenna, e.g., not including any antenna gain. For light-duty vehicles, maxTxPower-r12 may be set to a nominal value of 20 dBm. For public safety vehicles, maxTxPower-r12 may be set as high as 33 dBm (note that the total radiated power also cannot exceed 33 dBm).[12]
11	sl-bandwidth-r12	N100	Total number of RBs across 20 MHz (N100 = 100).

[10] Corresponding to two different priority (PPPP) values.
[11] T2 is the maximum value of the resource selection sensing window.
[12] The +33 dBm limit is used only by a public safety vehicle engaged in an emergency response, which is a critical event condition. This limit may also be subject to rules established by regulatory authorities.

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
12	tdd-ConfigSL-r12	None	Configuration specifying TDD Uplink Downlink configuration in case applicable. This is used for the case LTE Sidelink is deployed in the same channel as LTE Uplink in a TDD band in order to protect LTE Base station Uplink reception. Not currently applicable for LTE-V2X since there is no LTE network deployed in 5.9 GHz spectrum, hence set to none.
13	reserved-r12	0000000000000000000	
14	maxSL-V2X-RxPoolPreconf-r14	1	Maximum number of RX resource pools for V2X Sidelink communication. In this case, it is set to one pool only.
15	sl-Subframe-r14	11111111111111111111 11111111111111111111	Indicates the subframe bitmap indicating resources used for Sidelink communication. The bit map is repeated to infinity to represent time. Each bit corresponds to one subframe (1 ms). Bit 1 means that the corresponding subframe can be used for LTE-V2X communication. Set to all 1s, which mean all subframes are available for LTE-V2X communication. Bitmap length is a factor of 10240.
16	adjacencyPSCCH-PSSCH-r14	TRUE	Indicates whether a UE always transmits PSCCH and PSSCH in adjacent RBs (indicated by TRUE). This parameter appears only when a pool is configured such that a UE transmits PSCCH and the associated PSSCH in the same subframe.
17	sizeSubchannel-r14	N10	Indicates the number of PRBs of each subchannel in the corresponding resource pool. The value n5 denotes five PRBs, n6 denotes six PRBs, and so on. Here the subchannel size is ten PRBs.
18	numSubchannel-r14	n10	Indicates the number of subchannels in the corresponding resource pool. The value n5 denotes five subchannels, n6 denotes six subchannels, and so on. Here there will be ten subchannels in the resource pool.
19	startRB-Subchannel-r14	0	Indicates the lowest RB index of the subchannel with the lowest index.
20	dataTxParameters-r14	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Same as P-max.
21	syncAllowed-r14	GNSS	Indicates the allowed synchronization reference(s) which is (are) allowed to use the configured resource pool. In this case, it is a GNSS sync source.
22	threshS-RSSI-CBR-r14	9	Indicates the S-RSSI threshold for determining the contribution of a sub-channel to the CBR measurement. Value 0 corresponds to -112 dBm, value 1 to -110 dBm, value n to (-112 + n*2) dBm, and so on. Value 9 means -94 dBm per subchannel.
23	maxSL-V2X-CBRConfig2-r14	2	Maximum number of CBR range configurations in pre-configuration for LTE-V2X Sidelink communication congestion control. There is one common entry for SL-CBR-Levels-Config-r14 for both priorities (2 and 5).
24	maxCBR-Level-r14	2	Maximum number of CBR levels. There are two CBR levels in this case.
25	SL-CBR-Levels-Config-r14	65, 100	Indicates CBR thresholds. Value 0 corresponds to 0, value 1 to (0.01 aka 1%), value 2 to 0.02, and so on. Here the two CBR levels are 0.65 and 1.

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
27	maxSL-V2X-TxConfig2-r14	2	Maximum number of TX parameter configurations in pre-configuration for V2X Sidelink communication congestion control. In this case there are two levels. The number of CBR based TX parameter configurations equals to the number of CBR levels.
NOTE 1: Entries 28 and 29 are part of SL-CBR-PSSCH-TxConfig-r14 index 0. This applies to PPPP 2 and 5 with CBR < 0.65.			
28	cr-Limit-r14	10000	CR-limit for CBR < 0.65 and PPPP 2 and 5. Indicates the maximum limit on the occupancy ratio on a sub-channel basis. Value 0 corresponds to 0, value 1 to 0.0001, value 2 to 0.0002, and so on (i.e., in steps of 0.0001) until value 10000, which corresponds to 1. The period of CR-limit is 1 second. With ten subchannels every ms, one will have a maximum of 10000 subchannels every 1000 ms. Setting a CR-limit to 10000 is equal to no restriction. This is the first of two SL-CBR-PSSCH-TxConfig-r14 entries
29	tx-Parameters-r14	Table 4	PSSCH transmission parameter for CBR < 0.65.
NOTE 2: Entries 30 and 31 are part of SL-CBR-PSSCH-TxConfig-r14 index 1. This applies to PPPP 2 and 5 with CBR ≥ 0.65.			
30	cr-Limit-r14	400	CR-limit for CBR ≥ 0.65 and PPPP 2 and 5. Indicates the maximum limit on the occupancy ratio on a sub-channel basis. Value 0 corresponds to 0, value 1 to 0.0001, value 2 to 0.0002, and so on (i.e., in steps of 0.0001) until value 10000, which corresponds to 1. The period of CR-limit is 1 second. With ten subchannels every ms, one will have a maximum of 10000 subchannels every 1000 ms. Setting a CR-limit to 10000 is equal to no restriction. This is the second of two SL-CBR-PSSCH-TxConfig-r14 entries. CR-limit is 4% for CBR > 0.65 and PPPP 2 and 5.
31	tx-Parameters-r14	Table 5	PSSCH transmission parameter for CBR ≥ 0.65.
NOTE 3: Entries 32 to 35 are preconfigured parameters for the first priority class.			
32	priorityThreshold-r14	2	This configuration is for PPPP of 2 (critical event flag set).
33	defaultTxConfigIndex-r14	1	Indicates the PSSCH transmission parameters to be used by the UEs which do not have available CBR measurement results, by means of an index to the corresponding entry in tx-ConfigIndexList. Value 0 indicates the first entry in tx-ConfigIndexList. Value 1 indicates the second entry in tx-ConfigIndexList. In this case, if the UE does not have available CBR measurement results, use the parameters in entries 30 and 31.
34	cbr-ConfigIndex-r14	0	Indicates the CBR ranges to be used by an index to the entry of the CBR range configuration in cbr-RangeCommonConfigList.

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
35	tx-ConfigIndexList-r14	0, 1	Indicates the list of the PSSCH transmission parameters and CR limit by the indexes to the entries of the configurations in sl-CBR-PSSCH-TxConfigList. Each index in tx-ConfigIndexList sequentially maps to each CBR range indicated by cbr-ConfigIndex. In this case, the UE will use the first configuration with index 0, i.e., entries 28 and 29, when CBR < 0.65; the UE will use the second configuration with index 1, i.e., entries 30 and 31, when CBR ≥ 0.65 See notes 1 and 2.
NOTE 4: Entries 32 to 36 are preconfigured parameters for the second priority class			
36	priorityThreshold-r14	5	Same as above. This configuration is for PPPP of 5.
37	defaultTxConfigIndex-r14	1	Same as above. This configuration is for PPPP of 5
38	cbr-ConfigIndex-r14	0	Same as above. This configuration is for PPPP of 5
39	tx-ConfigIndexList-r14	0, 1	Same as above. This configuration is for PPPP of 5
NOTE 5: There are two applicable entries in SL-CBR-PPPP-TxPreconfigList-r14, one for each PPPP (2, 4, 5, and 7); only PPPP = 2 and PPPP = 5 are used. The other entries are ignored. Refer to Table B.7 in ETSI TS 103 613.			
40	thresUE-Speed-r14	kmph 120	Indicates UE speed threshold; kmph 120 means 120 km/h.
41	parametersBelowThres-r14	Table 6	PSSCH transmission parameter when speed is below threshold.
42	parametersAboveThres-r14	Table 7	PSSCH transmission parameter when speed is above threshold.
43	restrictResourceReservationPeriod-r14	V1	Indicates which values are allowed for the signalling of the resource reservation period in PSCCH. V1 -> 100 ms, which means that the next resource in the same SPS flow will occur after exactly 100 ms at the same PRBs.
44	probResourceKeep-r14	v0dot8	Indicates the probability with which the UE keeps the current resource when the resource reselection counter reaches zero for sensing based UE autonomous resource selection (refer to ETSI TS 136 321). V0dot8 means UE keeps the current resource with probability 0.8 and reselect to a new resource with probability 0.2.
45	sl-ReselectAfter-r14	n6	Indicates the number of consecutive skipped transmissions before triggering resource reselection for V2X Sidelink communication (refer to ETSI TS 136 321).
46	SL-ThresPSSCH-RSRP-List-r14	Entries 47 to 50	This information element is essentially an 8*8 matrix (64 elements). It is an 8*8 table of transmitting packet priority versus receiving packet priority and RSRP exclusion threshold that needs to be added for any of those combinations. In this case, the parameter is a sequences of 64 entries, out of which four entries are configured with value listed below from 47 to 50.

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
47	SL-ThresPSSCH-RSRP-List-r14(19)	2 (-126 dBm per RE)	Value 0 corresponds to minus infinity dBm, value 1 corresponds to -128dBm, value 2 corresponds to -126 dBm, value n corresponds to (-128 + (n-1)*2) dBm, and so on; value 66 corresponds to infinity dBm. This is used when a payload with priority 2 needs to be transmitted and the SCI of payload with two was received Calculation of index element - 2X8+2+1 = 19 1 RE is 1 OFDM tone in 1 OFDM symbol. The RSRP is calculated as the averaged received power over REs that carry reference signal of data channel (PSSCH).
48	SL-ThresPSSCH-RSRP-List-r14(22)	11 (-108 dBm per RE)	Calculation of index element. This is used when a payload with priority 2 needs to be transmitted and the SCI of payload with fove was received. 2X8+5+1 = 22
49	SL-ThresPSSCH-RSRP-List-r14(43)	2 (-126 dBm per RE)	Calculation of index element. This is used when a payload with priority 5 needs to be transmitted and the SCI of payload with two was received. 5X8+2+1 = 43
50	SL-ThresPSSCH-RSRP-List-r14(46)	11 (-108 dBm per RE)	Calculation of index element. This is used when a payload with priority 5 needs to be transmitted and the SCI of payload with five was received. 5X8+5+1 = 46
51	SPSCtrMin	5	Minimum SPS flow counter value for ResourceReselectionCtr.
52	SPSCtrMax	15	Maximum SPS flow counter value for ResourceReselectionCtr.
53	OneShotCtrMin	2	Minimum one-shot counter value for OneShotCtr.
54	OneShotCtrMax	6	Maximum one-shot counter value for OneShotCtr.

Table 4 - PSSCH transmission parameter for CBR < 0.65

Index	Pre-Configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
1	minMCS-PSSCH-r14	0	Minimum MCS index allowed.
2	maxMCS-PSSCH-r14	31	Maximum modulation index (MCS) allowed. Actual values used for each speed profile are defined elsewhere. Note: If a packet is large and does not fit using the maximum MCS then UE can choose an option between segmentation, event based, or dropping the packet as per rules mentioned in ETSI TS 136 321 section 5.14. Additionally, if the choice is to segment the packet then segmentation procedure as defined in ETSI TS 136 322 needs to be followed.
3	minSubChannel-NumberPSSCH-r14	2	Indicates the minimum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
4	maxSubchannel-NumberPSSCH-r14	10	Indicates the maximum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
5	allowedRetxNumberPSSCH-r14	n1	Indicates the allowed retransmission number for transmissions on PSSCH (refer to ETSI TS 136 213). The value n0 indicates no retransmission for a transport block allowed; the value n1 indicates that the UE performs one retransmission for a transport block.
6	maxTxPower-r14	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Same as P-max.

Table 5 - PSSCH transmission parameter for CBR ≥ 0.65

Index	Pre-configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
1	minMCS-PSSCH-r14	0	Minimum MCS index allowed.
2	maxMCS-PSSCH-r14	31	Maximum modulation index (MCS) allowed. Actual values used for each speed profile are defined elsewhere. Note: If packet is large and does not fit using the maximum MCS then UE can choose an option between segmentation, event based, or dropping the packet as per rules mentioned in ETSI TS 136 321 section 5.14. Additionally, if the choice is to segment the packet, then the segmentation procedure as defined in ETSI TS 136 322 needs to be followed.
3	minSubChannel-NumberPSSCH-r14	2	Indicates the minimum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
4	maxSubchannel-NumberPSSCH-r14	10	Indicates the maximum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
5	allowedRetxNumberPSSCH-r14	n1	Indicates the allowed retransmission number for transmissions on PSSCH (see ETSI TS 136 213). The value n0 indicates no retransmission for a transport block allowed; the value n1 indicates that the UE performs one retransmission for a transport block.
6	maxTxPower-r14	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Same as P-max.

Table 6 - PSSCH transmission parameter for speed <120 km/h

Index	Pre-configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
1	minMCS-PSSCH-r14	5 (QPSK)	Minimum MCS index that should be used.
2	maxMCS-PSSCH-r14	11 (16QAM)	Maximum modulation index (MCS) that should be used. Note: MCS 8, 9, 10 are excluded. Note: If packet is large and does not fit using the maximum MCS, then UE can choose an option between segmentation, event based, or dropping the packet as per rules mentioned in ETSI TS 136 321 section 5.14. Additionally, if the choice is to segment the packet, then segmentation procedure as defined in ETSI TS 136 322 needs to be followed.
3	minSubChannel-NumberPSSCH-r14	2	Indicates the minimum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
4	maxSubchannel-NumberPSSCH-r14	10	Indicates the maximum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
5	allowedRetxNumberPSSCH-r14	n1	Indicates the allowed retransmission number for transmissions on PSSCH (refer to ETSI TS 136 213). The value n0 indicates no retransmission for a transport block allowed; the value n1 indicates that the UE performs one retransmission for a transport block.
6	maxTxPower-r14	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Same as P-max.

Table 7 - PSSCH transmission parameter for speed ≥120 km/h

Index	Pre-configuration Parameter (ETSI Information Element)	Value	Explanation of Information Elements
1	minMCS-PSSCH-r14	0 (QPSK)	Minimum MCS index that should be used.
2	maxMCS-PSSCH-r14	7 (QPSK)	Maximum modulation index (MCS) that should be used. Note: If packet is large and does not fit using the maximum MCS then UE can choose an option between segmentation, event based, or dropping the packet as per rules mentioned in ETSI TS 136 321 section 5.14. Additionally, if the choice is to segment the packet then segmentation procedure as defined in ETSI TS 136 322 needs to be followed. Note that segmentation is not expected for BSMs because of their relatively small size.
3	minSubChannel-NumberPSSCH-r14	2	Indicates the minimum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
4	maxSubchannel-NumberPSSCH-r14	10	Indicates the maximum number of sub-channels which may be used for transmissions on PSSCH (refer to ETSI TS 136 213).
5	allowedRetxNumberPSSCH-r14	n1	Indicates the allowed retransmission number for transmissions on PSSCH (refer to ETSI TS 136 213). The value n0 indicates no retransmission for a transport block allowed; the value n1 indicates that the UE performs one retransmission for a transport block.
6	maxTxPower-r14	Light-duty vehicles: 20 dBm Public safety vehicles only: 33 dBm	Same as P-max.

6.1.2 IEEE 1609.2 (1609.2)

Refer to section 6.1.2 of SAE J2945/1.

6.1.3 IEEE 1609.3 (1609.3)

This section specifies the requirements from IEEE 1609.3 to support V2V over LTE-V2X. Using the PICS from IEEE 1609.3, the profile for transmitting BSMs is provided in this section. Items marked “Y” in the “support” column correspond to requirements, and items marked “N” do not correspond to requirements. In some cases a value associated with the requirements is included. Items marked “N/A” in the “support” column are not applicable to V2V over PC5. See 6.1.2 for further description regarding how to interpret an IEEE PICS.

- The PC5 radio subsystem shall comply with the items marked “Y” in the “support” column in Table 8 to support WSMs over PC5. Items marked “N” are not used. If values are specified in the table, the items are set as stated. [6.1.3-V2V-STD-1609.3-001]

NOTE: The LLC is not used with PC5, because the PC5 PDCP header (and non-IP type in the case of WSMP) provides the equivalent functionality.

Table 8 - IEEE 1609.3 requirements (PICS Proforma)

Item	Feature	Value	Reference	Status	Support
N1	**DATA PLANE**		—	—	
N1.1	LLC		5.2	M	N[13]
N1.1.1	LLC extensions for WSMP		7.5	N1.3:M	N[12]
N1.2	IPv6		5.3, 6.4	O1	N/A
N1.2.1	Use stateless configuration		6.4	O	N/A
N1.2.2	IP readdressing		6.4.2	M	N/A
N1.2.3	Send IP datagrams		5.3	O2	N/A
N1.2.4	Receive IP datagrams		5.3	O2	N/A
N1.2.4.1	Receive by link-local address		6.4	M	N/A
N1.2.4.2	Receive by global address		6.4	M	N/A
N1.2.4.3	Receive by host multicast addresses		6.4	O3	N/A
N1.2.4.4	Receive by router multicast addresses		6.4	O3	N/A
N1.2.5	UDP		5.4	O	N/A
N1.2.6	TCP		5.4	O	N/A
N1.2.7	Other IETF protocols	( )[a]	5.4	O	N/A
N1.3	WSMP		5.5	O1	Y
N1.3.1	WSM reception		5.5.3	O4	Y
N1.3.1.1	Check WSMP version number	( )[b]	5.5.3, 8.3.2	M	Y (Version = 3)
N1.3.1.2	Check subtype field	( )[r]	5.5.3, 8.3.2	M	Y (Subtype = 0 or 1)
N1.3.1.3	Check TPID field	( )[s]	5.5.3, 8.3.2	M	Y (TPID = 0)
N1.3.1.4	WAVE info elem extension field		8.1.1	M	Y
N1.3.1.5	Deliver message based on address info (PSID)		5.5.3	M	Y
N1.3.2	WSM transmission		5.5.2	O4	Y
N1.3.2.1	Insert WSMP version number		8.3.2	M	Y (Version = 3)
N1.3.2.2	Insert address info (PSID)		8.3.3	M	Y
N1.3.2.3	Outbound message size	( )[c]	5.5.2	M	Y (at least 1400 bytes)
N1.3.2.4	Transmit channel number		8.3.4.2	O	N[14]
N1.3.2.5	Transmit data rate		8.3.4.3	O	N[12]
N1.3.2.6	Transmit power used		8.3.4.4	O	N[12]
N1.3.2.7	Channel load		8.3.4.5	O	N[12]
N1.3.2.8	Insert subtype features	( )[r]	8.3.2	M	Y (Subtype = 0 or 1)
N1.3.2.9	Insert TPID features	( )[s]	8.3.2	M	Y (TPID = 0)
N2	**MANAGEMENT PLANE** Note: The management plane features are not shown in this table because they are for V2I exchanges and N/A to PC5.		—	—	

[a] List protocols supported.
[b] List version numbers supported.
[c] Enter maximum WAVE short message length.
[d] List version numbers supported.
[e] List any other WSA header WAVE information elements processed on reception.
[f] Enter maximum number of service info instances processed on reception.
[g] List any other service info segment WAVE information elements processed on reception.
[h] Enter maximum number of channel Info Instances processed on reception.
[i] List any other channel info segment WAVE information elements processed on reception.
[j] List any other WAVE routing advertisement WAVE information elements processed on reception.
[k] List any other WSA header WAVE information elements supported on transmission.
[l] Enter maximum number of service info instances supported on transmission.
[m] List any other service info segment WAVE information elements supported on transmission.
[n] Enter maximum number of channel info instances supported on transmission.
[o] List any other channel info segment WAVE information elements supported on transmission.
[p] List any other WAVE routing advertisement WAVE information elements supported on transmission.
[q] List any other MIBs supported.
[r] List Subtype values supported.
[s] List TPID values supported.

[13] The LLC only applies to the IEEE 802 family of protocols.
[14] This field is not applicable to PC5 and is not included in the WSMP header for transmissions compliant with this document.

6.1.4 IEEE 1609.4

This section is included for consistency with SAE J2945/1 section numbers. IEEE 1609.4 does not apply to this document; the system uses a single channel (see 6.1.1).

6.1.5 IEEE 1609.12 (1609.12)

This section specifies the requirements from IEEE 1609.12 to support V2V operation, as described in 6.1.

Table 9 - IEEE 1609.12 requirements

1609.12 Clause	Title (1609.12 Clause)	Required for	Requirement
4	WAVE Identifiers		
4.1.x	Provider service identifier (PSID)	V2V	The system shall set the PSID value to the value assigned to “vehicle-to-vehicle safety and awareness” (hex 20). [6.1.4-V2V-STD-1609.12-001]

NOTE: The LLC 802.2 is not used with LTE-V2X; therefore, ethertype is not present. WSMP is transmitted directly over PC5 by setting the V2X message family encoding information element.

6.1.6 SAE J2735 (J2735)

SAE J2735 requirements included here (Table 10) are supplemental to SAE J2945/1. Note that this document allows DE_TimeConfidence to be added to the BSM per Appendix B. For all other SAE J2735 requirements, refer to section 6.1.6 of SAE J2945/1.

Table 10 - SAE J2735 supplemental requirements

Title (SAE J2735 Clause)	Requirement
Data Frames (Public Safety Vehicles Only)	For BSMs generated by public safety vehicles (ambulance, fire, or police) that support the emergency response feature, the system shall conform to the following data elements (see 6.3.6.20). [6.1.6-V2V-STD-J2735-46] Service specific permissions (SSPs) are required to send BSMs containing these data frames (see Appendix C).
Data Frame: DF_SpecialVehicleExtensions	The system shall conform to DF_SpecialVehicleExtensions, as specified. [6.1.6-V2V-STD-J2735-47]
Data Frame: DF_EmergencyDetails	The system shall conform to DF_EmergencyDetails, as specified. [6.1.6-V2V-STD-J2735-48]
Data Frame: DF_SupplementalVehicleExtensions	The system shall conform to DF_SupplementalVehicleExtensions, as specified. [6.1.6-V2V-STD-J2735-49]
Data Frame: DF_VehicleClassification	The system shall conform to DF_VehicleClassification, as specified. [6.1.6-V2V-STD-J2735-50]
Data Elements	Note: DE_TimeConfidence may be added to the BSM per Appendix B.
Data Element: DE_TimeConfidence	The system shall conform to DE_TimeConfidence, as specified. [6.1.6-V2V-STD-J2735-51]
Data Elements (Public Safety Vehicles Only)	For BSMs generated by public safety vehicles (ambulance, fire, or police) that support the emergency response feature, the system shall conform to the following data elements (see 6.3.6.20). [6.1.6-V2V-STD-J2735-52] Service specific permissions (SSPs) are required to send BSMs containing these data elements (see Appendix C).
Data Element: DE_SSP_Index	The system shall conform to the ASN.1 definition of DE_SSP_Index, as specified. This data element is required to be included according to SAE J2735, but for implementations conformant to this document it is always set to zero and ignored upon receipt. [6.1.6-V2V-STD-J2735-53]
Data Element: DE_SirenInUse	The system shall conform to DE_SirenInUse, as specified. [6.1.6-V2V-STD-J2735-54]
Data Element: DE_LightbarInUse	The system shall conform to DE_LightbarInUse, as specified. [6.1.6-V2V-STD-J2735-55]
Data Element: DE_MultiVehicleResponse	The system shall conform to DE_MultiVehicleResposne, as specified. [6.1.6-V2V-STD-J2735-56]
DE_BasicVehicleRole	The system shall conform to DE_BasicVehicleRole, as specified, with the limitation that only values police (12), fire (13), and ambulance (14) are permitted. [6.1.6-V2V-STD-J2735-57]

6.1.7 Regulatory (Informative)

At the time of publication of this document, band use was under review by the FCC, and a waiver request had been submitted to the FCC by LTE-V2X industry stakeholders to enable use of PC5 on the channel proposed herein. Refer to CFR Title 47 Parts 90 and 95 and FCC NPRM Docket 19-138 for the most up to date information.

NOTE: Regulatory domains outside the United States may be subject to different regulatory requirements.

6.2 Positioning and Timing Requirements (POSTIM)

Refer to section 6.2 of SAE J2945/1.

6.3 BSM Transmission Requirements (BSMTX)

6.3.1 BSM Contents (BSMCONT)

Refer to section 6.3.1 of SAE J2945/1. For public safety vehicles, additional optional features beyond SAE J2945/1 are supported (see 6.3.6.20). Only public safety vehicles engaged in an emergency response shall use DF_EmergencyDetails. [6.3.1-V2V-BSMTX-BSMCONT-007] SSPs are used to support this requirement (Appendix C).

6.3.2 Channel and Data Rate

For a given packet size, multiple (MCS, RB) combinations are possible for the configuration provided in 6.1.1.

The following are a set of guiding principles showing how to select the MCS and number of RBs for a given packet size for an SPS transmission:

- The packet size used for making the reservation is at least the 90th percentile of the expected packet size range.
- Reserve at least two subchannels.
- Minimize the number of subchannels in use.
- A minimum MCS of 5 is recommended. Lower MCSs may still be used if the data fits within two subchannels at that lower MCS. Lower MCSs may also be used if, in the below tables, the packet fits within the same number of RBs at that lower MCS.
- MCS 8, 9, and 10 shall not be used.
- Do not reserve RBs that occupy a number of subchannels in the range of more than 50% to less than 100% of the total subchannels per subframe.
- Beyond the maximum supported packet size, segment the packets

The following tables list the mapping between packet size and (MCS, RB) pairs for 20 MHz bandwidth at low and high speeds per the above recommendations for SPS transmissions. All packet sizes and and transport block sizes are in bytes. Note that basic safety messages for ordinary passenger vehicles (not including public safety vehicles) will always have a transport block size of less than 389 bytes; the other table entries are included for other types of messages..

Table 11 - 20 MHz low speed (<120 km/h)

Packet Size	≤193	194-233	234-277	278-389	390-421	422-597	598-775	776-1063	1064-1239	1240-1479	1480-2124
MCS	5	6	7	11	7	11	11	11	6	7	11
RB	18	18	18	18	27	27	36	48	96	96	96
Transport Block Size	193	233	277	389	421	597	775	1063	1239	1479	2124

Table 12 - 20 MHz high speed (≥120 km/h)

Packet Size	≤193	194-233	234-277	278-293	294-349	350-421	422-469	470-549	550-621	622-749	750-1063	1064-1239	1240-1479
MCS	5	6	7	5	6	7	6	7	6	7	5	6	7
RB	18	18	18	27	27	27	36	36	48	48	96	96	96
Transport Block Size	193	233	277	293	349	421	469	549	621	749	1063	1239	1479

For event-based transmissions used for transmitting BSMs carrying critical events (see 6.3.4), Tables 11 and 12 are used with the following exceptions for speeds below 120 km/h:

Table 13 - 20 MHz low speed exceptions for event-based transmissions (<120 km/h)

Packet Size	278-2293	294-3349	350-4421
MCS	5	6	7
RB	27	27	27
Transport Block Size	293	349	421

6.3.3 Generation of the First BSM after System Device Startup and Generation Timing (GENTIM)

Refer to section 6.3.3 of SAE J2945/1.

6.3.4 ProSe Per Packet Priority (PPPP) Settings

- The system shall set the PPPP [ETSI TS 123 285, 123 303] to five for BSMs with no critical event flags. BSMs are sent using SPS. [6.3.4-V2V-BSMTX-PPPP-001]

NOTE: If the SPS cannot accommodate the size of the most recent BSM, the SPS is adjusted according to ETSI specifications [ETSI TS 136 321].

- The system shall set the PPPP [ETSI TS 123 285, 123 303] to two for BSMs that include one or more critical event flags and BSMs that include DF_EmergencyDetails. The BSMs sent with the event flag set do not use SPS and are sent as event-based (one-shot) packets. These event based transmissions need to be sent with PPPP of 2 and must adhere to PDB limits as defined for this priority. [6.3.4-V2V-BSMTX-PPPP-002]

6.3.5 Minimum Transmission Criteria (MINTX)

Refer to section 6.3.5 of SAE J2945/1. Note that the supplemental requirements in Table 10 do not change the minimum transmission criteria. BSMs can be transmitted without any data frame/data elements in Table 10, regardless of whether the public safety vehicle is engaged in an emergency response.

6.3.6 Data Element Accuracy (DATAACC)

6.3.6.1 DE_DSRC_MessageID

Refer to section 6.3.6.1 of SAE J2945/1.

6.3.6.2 DE_MsgCount

Refer to section 6.3.6.2 of SAE J2945/1.

6.3.6.3 DE_TemporaryID

Refer to section 6.3.6 of SAE J2945/1.

6.3.6.4 DE_DSecond

Refer to section 6.3.6.4 of SAE J2945/1.

6.3.6.5 DE_Latitude and DE_Longitude

Refer to section 6.3.6.5 of SAE J2945/1.

6.3.6.6 DE_Elevation

Refer to section 6.3.6.6 of SAE J2945/1.

6.3.6.7 DF_PositionalAccuracy

Refer to section 6.3.6.7 of SAE J2945/1.

6.3.6.8 DE_Speed

Refer to section 6.3.6.8 of SAE J2945/1.

6.3.6.9 DE_TransmissionState

Refer to section 6.3.6.9 of SAE J2945/1.

6.3.6.10 DE_Heading

Refer to section 6.3.6.10 of SAE J2945/1.

6.3.6.11 DE_SteeringWheelAngle

Refer to section 6.3.6.11 of SAE J2945/1.

6.3.6.12 DF_AccelerationSet4Way

Refer to section 6.3.6.12 of SAE J2945/1.

6.3.6.13 DF_BrakeSystemStatus

Refer to section 6.3.6.13 of SAE J2945/1.

6.3.6.14 DF_VehicleSize

Refer to section 6.3.6.14 of SAE J2945/1.

6.3.6.15 DE_VehicleEventFlags

Refer to section 6.3.6.15 of SAE J2945/1.

6.3.6.16 DF_PathHistory

Refer to section 6.3.6.16 of SAE J2945/1.

6.3.6.17 DF_PathPrediction

Refer to section 6.3.6.17 of SAE J2945/1.

6.3.6.18 DE_ExteriorLights

Refer to section 6.3.6.18 of SAE J2945/1.

6.3.6.19 DE_TimeConfidence

- If the DF_VehicleSafetyExtensions data frame includes DE_TimeConfidence (see Appendix B), the system shall set DE_TimeConfidence to the 95% confidence level (per SAE J2735) of the time represented by DE_DSecond. [6.3.6-V2V-BSMTX-DATAACC-051]

6.3.6.20 Public Safety Vehicles Engaged in Emergency Response.

Refer to SAE J2735 for structure of the data frames and data elements used in the following requirements.

- If the emergency response feature is supported, DF_SpecialVehicleExtensions shall be included when a public safety vehicle is engaged in an emergency response. [6.3.6-V2V-BSMTX-DATAACC-052]

- If the emergency response feature is supported, DF_EmergencyDetails shall be included when a public safety vehicle is engaged in an emergency response. [6.3.6-V2V-BSMTX-DATAACC-053]

- If the emergency response feature is supported, DF_SupplementalVehicleExtensions shall be included when a public safety vehicle is engaged in an emergency response. [6.3.6-V2V-BSMTX-DATAACC-054]

- If the emergency response feature is supported, DF_VehicleClassification shall be included when a public safety vehicle is engaged in an emergency response. [6.3.6-V2V-BSMTX-DATAACC-055]

- If the emergency response feature is supported, DE_SSP Index shall be set to zero and included when a public safety vehicle is engaged in an emergency response. [6.3.6-V2V-BSMTX-DATAACC-056]

- If the emergency response feature is supported, and the siren is on, DE_SirenInUse shall be included and set to in use. [6.3.6-V2V-BSMTX-DATAACC-057]

- If the emergency response feature is supported, and the light bar is on, DE_LightbarInUse shall be included and set to in use. [6.3.6-V2V-BSMTX-DATAACC-058]

- If the emergency response feature is supported, DE_MultiVehicleResponse shall be included and set to unavailable (if unknown), single vehicle or muti vehicle. [6.3.6-V2V-BSMTX-DATAACC-059]

- If the emergency response feature is supported, DE_BasicVehicleRole (police (12), fire (13), or ambulance (14); only one of these three enumerated values shall be used; refer to SAE J2735). [6.3.6-V2V-BSMTX-DATAACC-060]

- A public safety vehicle not engaged in an emergency response shall not include DF_Emergency Details in its BSM. [6.3.6-V2V-BSMTX-DATAACC-061]

6.3.6.21 Additional Data Elements

The system shall not include any additional data elements or data frames in transmitted BSMs beyond those included in 6.1.6 of this document. [6.3.6-V2V-BSMTX-DATAACC-062]

On reception, the system shall be capable of ignoring unused data frames/elements. [6.3.6-V2V-BSMTX-DATAACC-063]

6.3.7 Data Persistency (DATAPERSIST)

Refer to section 6.3.7 of SAE J2945/1.

6.3.8 BSM Scheduling and Congestion Control (BSMCONGCTRL)

This section specifies the requirements for scheduling BSMs and congestion control in LTE-V2X. See Section A.8 for additional implementation details of the congestion control algorithm.

- The system shall generate BSMs using the congestion control algorithm defined in 6.3.8.1 through 6.3.8.8. Those Sections use the following computational threshold and intervals (see 6.3.8.1): vPERSubInterval, vPERInterval, and vTxRateCntrlInt. The relationship between those intervals is shown in Figure 2. [6.3.8-V2V-BSMTX-CONGCTRL-001]

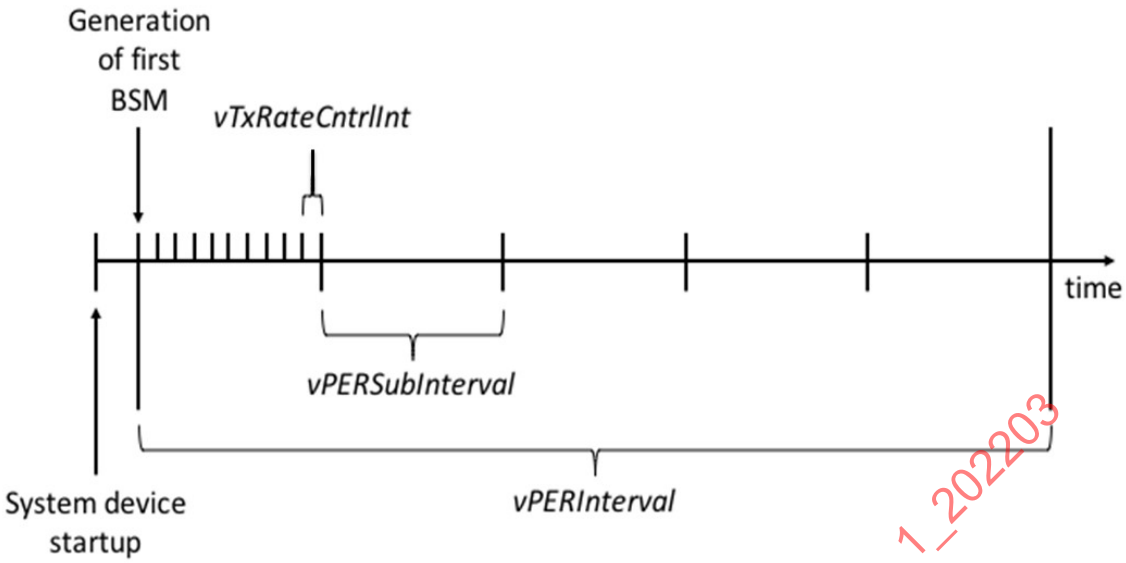

Figure 2 - Relationship between computational intervals: vPERSubInterval, vPERInterval, and vTxRateCntrlInt

The calculations corresponding to a given computational interval are always performed at the end of that computational interval, and k denotes a given instance of that interval. The calculations use inputs collected during the given interval and are written as a function of k. For example, if F represents a specific function, F(k) is a computation using inputs collected during the k^{th} instance of the interval (also referred to as the k^{th} interval).

6.3.8.1 Inputs

This section defines the inputs that are used by the congestion control algorithm.

Packet error ratio (PER), channel quality indicator (Π), and vehicle density in range (N) are calculated at the end of the k^{th} instance of vPERSubInterval as follows:

- PER: The PER is calculated between a pair of vehicles—the host vehicle (HV) and a given remote vehicle (RVi). The system calculates the sliding-window PER over the interval, vPERInterval, at the end of the k^{th} instance of vPERSubinterval as follows:

  Let δ_k be the k^{th} instance of vPERInterval, and w_k be the k^{th} instance of vPERSubInterval. In Figure 3, the duration of δ_k is n times the duration of w_k, where n denotes the number of subintervals within δ_k. At the end of w_k, the number of missed BSMs and the total number of expected BSMs during the corresponding interval δ_k are calculated for RV_i. The PER, $PER_i(k)$, for RV_i during δ_k is computed as follows:

$$PER_i(k) = \frac{number\ of\ missed\ BSMs\ from\ RV_i\ during\ [w_{k-n+1}, w_k]}{total\ expected\ BSMs\ from\ RV_i\ during\ [w_{k-n+1}, w_k]} \quad \text{(Eq. 1)}$$

  where:

  $k \geq n$

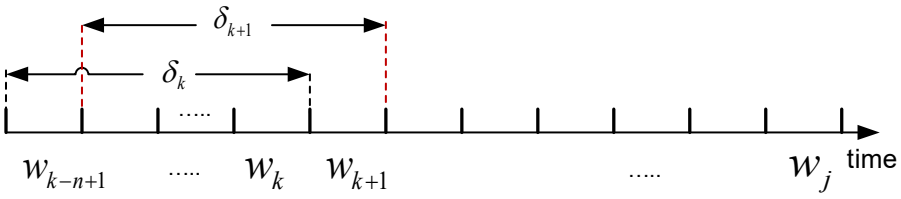

Figure 3 - Sliding window

PER is calculated using the DE_MsgCount data elements contained in the BSMs for each RV from which two or more BSMs were received during δ_k. The number of expected BSMs for a given RV is one plus the difference between the values of DE_MsgCount in the last and first BSMs received from that RV within δ_k. The number of missed BSMs for the RV is the difference between the number of expected BSMs and the number of received BSMs from the RV within δ_k. When calculating the number of expected and missed BSMs from a given RV, the modulus of the DE_MsgCount data element is accounted for based on the range of DE_MsgCount as defined in SAE J2735.

If only one packet is received from a given RV during δ_k, the PER corresponding to that RV is undefined and not used in PER calculations for δ_k. Refer to section A.8.3 of SAE J2945/1 for examples of special PER calculation cases.

An RV is within vPERRange if the last BSM received from that RV during w_k contains a 2D position within vPERRange of the HV's most recent 2D position reference as of the time when PER is calculated. If a BSM is not received from that RV during w_k the RV is not within vPERRange.

- Channel quality indicator (Π): Π(k) is calculated at the end of wk as the average of PER(k) for all RVs within vPERRange and for which PER(k) is calculated, with the following constraint:

$$\text{If } (\Pi(k) > \text{vPERMax}),\quad \Pi(k) = \text{vPERMax} \qquad \text{(Eq. 2)}$$

where:

PER(k) for a given RV, RV_i, is $PER_i(k)$ from Equation 1

- Vehicle density in range (N): The HV (system) calculates N(k) at the end of wk as the number of unique RVs within vPERRange (an RV is determined to be unique if it has a unique DE_TemporaryID included in its BSM).

6.3.8.2 Calculate Tracking Error

Refer to section 6.3.8.2 of SAE J2945/1.

6.3.8.3 Calculate Transmission Probability

Refer to section 6.3.8.3 of SAE J2945/1.

6.3.8.4 Calculate Maximum Inter-Transmit Time (Maximum BSM Generation Interval)

Refer to section 6.3.8.4 of SAE J2945/1.

6.3.8.5 Transmission Decision

Refer to section 6.3.8.5 of SAE J2945/1.

6.3.8.6 Schedule Transmission

Refer to section 6.3.8.6 of SAE J2945/1. Note that vTxRand is set to zero in this document (see Section 7).

6.3.8.7 Calculate Radiated Power

Section 6.3.8.7 of SAE J2945/1 is not applicable to this document.

For BSMs that correspond to critical event conditions wherein a public safety vehicle is engaged in an emergency response, the maximum radiated power is vRP = 33 dBm.[15] For all other BSMs, the nominal radiated power used to send BSMs is vRP = 20 dBm.

NOTE: Conducted power is determined according to 6.4.1, and conducted power may be limited to less than P-max depending on antenna gain.

6.3.8.8 Generate BSM and Schedule Next BSM Generation

Refer to section 6.3.8.8 of SAE J2945/1, with the exception that for this document RandOffset is always zero.

6.4 RF Performance Requirements (RFPERF)

This section describes the minimum transmit RF performance of the LTE-V2X system (6.4.1) as well as minimum receiver sensitivity (6.4.2). Together, these sections assure that the performance of the overall system is adequate to support basic safety use cases.

6.4.1 Minimum TX RF Performance and Signal Strength (TXSS)

Section 6.4.1 of SAE J2945/1 describes the radiated power and transmit power accuracy requirements for DSRC.[16] Some vehicles have been designed assuming the SAE J2945/1 standard and OEMs may choose to retain the existing antenna configurations in those vehicles and install an LTE-V2X system which would use that same antenna configuration. Implementations using these existing antenna configurations are strongly encouraged to perform analysis to assess conformance to this standard.

For new designs, the following section defines the minimum transmit RF performance requirements; it takes into account realistic deployment scenarios and design constraints while assuring a minimum level of signal coverage around the vehicle, including some elevation angles. While omnidirectional coverage is the goal, this section acknowledges that a true omnidirectional pattern is not generally feasible in realistic vehicles, so it proivdes guidance on how to trade off the antenna performance in practical designs. The goal is not to dictate the exact antenna design to OEMs (including the number and geometry of antennas) but rather to give requirements that assure a level of uniformity between vehicles. It is important to note that use of multiple antennas is optional; use of a single antenna is allowed so long as these requirements are met.

- The LTE-V2X system shall comply with the linear average TX signal strength (TXSS) and minimum 70% coverage values around the vehicle as given in Table 15, where $TxSS_{min}$ = 15 dBm and azimuthal zones are as defined in Figure 4. The method for determining TX signal strength is also given below. For each zone, data points which are on the edge of two zones shall be included in the calculations for both zones. [6.4.1-V2V-RFPERF-TXSS-001]

The linear average, as used in Table 14, is defined as the average value of the TX signal strength over the solid angle represented by the range of the given zone's azimuthal angles and the given range of elevation angles, which is then converted from linear units to dB units.

- Within this document, the only polarization considered for TX signal strength and far-field antenna gain is linear vertical.

- The free space[17] far-field antenna gain and EIRP for an individual antenna is considered to be from the geometric center of that antenna on the vehicle.

- 70% coverage is defined as 70% of the measured data points within the azimuthal zone and range of elevation angles must be above the given threshold.

[15] Subject to regulatory limits.
[16] This standard describes minimum signal strength requirements, which can be related to radiated power.
[17] Refers to a far-field antenna pattern in free space as opposed to, for example, a far-field antenna pattern over a ground plane beneath the vehicle.

The step sizes of the signal strength angular positions in the diagram used to determine compliance with Table 14 shall be no greater than 2 degrees in the azimuth and 1 degree in elevation. [6.4.1-V2V-RFPERF-TXSS-002]

Table 14 - Minimum linear average TX signal strength around vehicle (70% coverage)

Zone	Linear Average TX Signal Strength at horizon [θ = 89 to θ = 91 degrees] (dBm)	70% Coverage for TX Signal Strength at horizon [θ = 89 to θ = 91 degrees] (dBm)	Linear Average TX Signal Strength below horizon [θ = 90 to θ = 96 degrees] (dBm)	Linear Average TX Signal Strength above horizon [θ = 90 to θ = 84 degrees] (dBm)
Front Zone	$TxSS_{min}$	$TxSS_{min}$ - 3 dB	$TxSS_{min}$ - 3 dB	$TxSS_{min}$ - 3 dB
Side Zones[18]	$TxSS_{min}$ - 6 dB	$TxSS_{min}$ - 9 dB	$TxSS_{min}$ - 9 dB	$TxSS_{min}$ - 9 dB
Rear Zone	$TxSS_{min}$	$TxSS_{min}$ - 3 dB	$TxSS_{min}$ - 3 dB	$TxSS_{min}$ - 3 dB

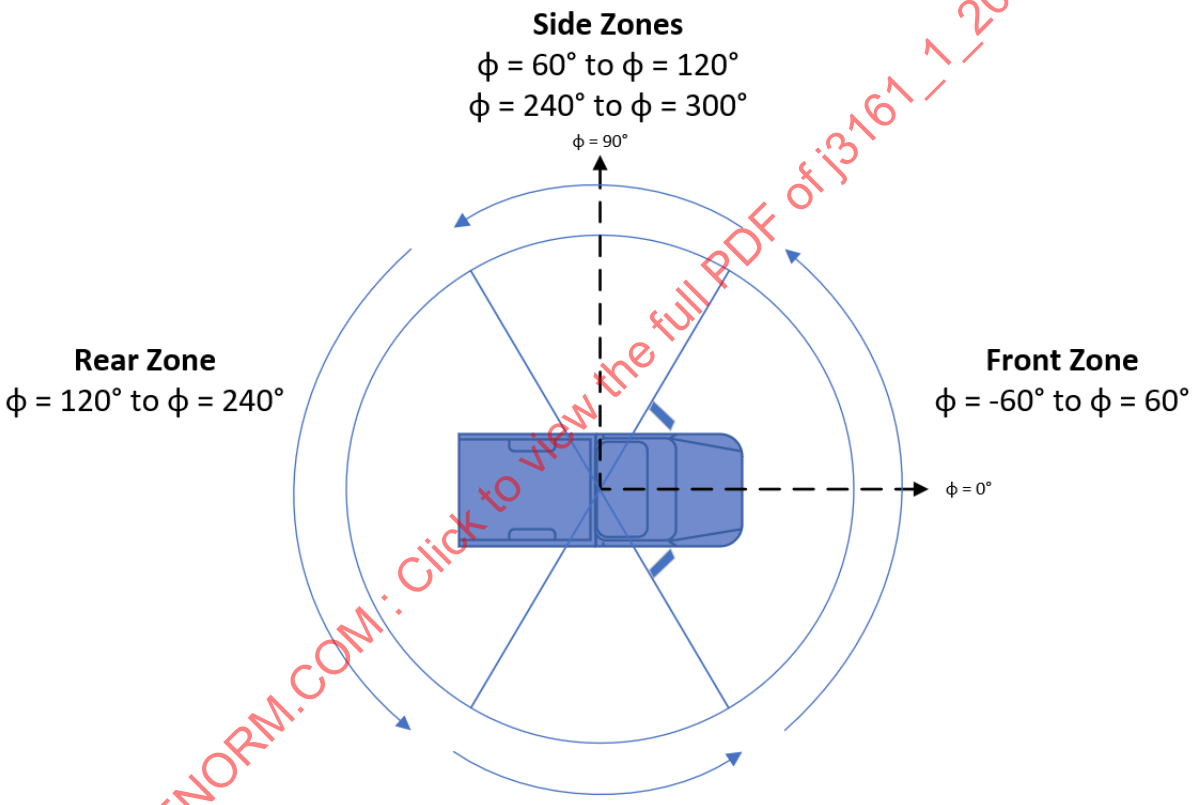

Figure 4 - Definition of TX signal strength zones

[18] While it is recommended that vehicles transmit at a level in the side zones that are comparable to the front and rear zones, the relaxations given in the table reflect the possible presence of unavoidable nulls. In such case, the BSM link may not close at 300 m for all azimuth angles and may have occasional link dropouts during NLOS IMA operations (such as a blind corner approach). This is an acknowledgement that many on-vehicle antenna configurations cannot achieve uniform coverage. If there are unavoidable regions around the vehicle with lower antenna gain, they should be directed towards these side zones while still exceeding the values in this table.

TX signal strength:

In a single TX antenna system:

$$\text{Tx Signal Strength}(\theta, \Phi) = \text{Tx Signal Strength}_{Ant1}(\theta, \Phi) \quad \text{(Eq. 3)}$$

In a TX diversity system:

$$\text{Tx Signal Strength}(\theta, \Phi) = \text{Tx Signal Strength}_{Diversity}(\theta, \Phi) \quad \text{(Eq. 4)}$$

In case of two antenna TX diversity:

$$\text{Tx Signal Strength}_{Diversity}(\theta, \Phi) = \text{Max}(TxSS_1(\theta, \Phi), TxSS_2(\theta, \Phi)) + \text{Diversity Gain}(TxSS_1(\theta, \Phi) - TxSS_2(\theta, \Phi)) \quad \text{(Eq. 5)}$$

where:

diversity gain = is an empirically defined function as explained below

TX signal strength of an individual antenna:

$$\text{TxSignal Strength}_{Ant1}(\theta, \Phi) = TxSS_1(\theta, \Phi) = EIRP_{Ant1}(\theta, \Phi) + f_{\text{height factor}}(h_1) \quad \text{(Eq. 6)}$$

$$\text{TxSignal Strength}_{Ant2}(\theta, \Phi) = TxSS_2(\theta, \Phi) = EIRP_{Ant2}(\theta, \Phi) + f_{\text{height factor}}(h_2) \quad \text{(Eq. 7)}$$

EIRP:

$$EIRP_{Ant1}(\theta, \Phi) = \text{Tx Power}_{port1} - \text{cable and connector loss}_{Ant1} + \text{free space far field antenna gain}_{Ant1}(\theta, \Phi) \quad \text{(Eq. 8)}$$

$$EIRP_{Ant2}(\theta, \Phi) = \text{Tx Power}_{port2} - \text{cable and connector loss}_{Ant2} + \text{free space far field antenna gain}_{Ant2}(\theta, \Phi) \quad \text{(Eq. 9)}$$

TX diversity gain function:

As noted at the beginning of this section, use of two or more antennas for spatial diversity is optional but strongly recommended. If implemented, diversity can add additional gain in the signal strength equation above. The exact type of diversity employed is an implementation choice and can introduce varying amounts of diversity gain. Note that if multiple antennas are transmitting simultaneously, regulations may require measurement of total radiated power, and there may be constraints on the power each antenna is allowed to radiate in order to keep total radiated power within limits.

The TX diversity gain function is a measure of the system gain introduced by an OBU's TX diversity implementation. This function is determined experimentally for each C-V2X OBU over a range of TX signal imbalances.

Antenna height function:

This standard does not specify the height or configuration of the antennas. The equations above introduce a variable to allow for gains or losses due to the height of the antenna. The antenna height function, $f_{\text{height factor}}(h)$, normalizes the height of the antenna on vehicle to a nominal value of h_n = 1.5 m (higher than 1.5 m is typically positive, lower than 1.5 m is typically negative). If the antenna is placed at a height other than 1.5 m on the vehicle, use the appropriate test methodology or transmission model to apply an offset needed to account for the performance differences between that antenna height and an antenna height of 1.5 m.