5GAA Automotive Association

V2X Functional and Performance Test Procedures – Selected Assessment of Device to Device Communication Aspects

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Introduction

This document captures planning information necessary to prepare a comparative communication performance assessment of vehicle to vehicle (V2V) radio technologies such as Cellular V2X (C-V2X) On-Board Unit (OBU) and Dedicated Short Range Communications (DSRC)/Intelligent Transport Systems (ITS)-G5 OBU devices.

DSRC has been the primary technology for V2X and is supported by a large body of research addressing a variety of topics from the lower-level communications platform to higher-level applications and their associated evaluation. DSRC is based on standards (e.g. IEEE 802.11p, SAE J2735, and SAE 2945/x) that have been defined explicitly to support V2X technologies and in particular imminent safety applications.

C-V2X is a recently standardized 3GPP technology. Prototype devices and chipsets are currently under development, thus soon permitting physical testing of C-V2X and providing the first opportunity to evaluate performance of the new radio stack. It is the purpose of the test specification described herein to recommend evaluation of C-V2X prototypes based on the knowledge acquired during the development of DSRC. As such, the procedures documented herein were, to the extent feasible, extracted from the previous DSRC testing and evaluation projects conducted primarily at the Crash Avoidance Metrics Partnership (CAMP) over the last decade.

1 Scope

As the first known physical in-vehicle evaluation of C-V2X, the test specification focuses on communications performance. It is presumed that much of the higher-layer research and development for DSRC is directly portable to C-V2X and thus does not require independent validation. For example, the testing described will implement the same or similar message structures and payload - that have been well established for DSRC or ITS-G5 V2X. Whilst conducting the tests for the purpose of comparing C-V2X and 802.11p based V2X-communications, the higher layers will not be changed. This also means that the messages exchanged during the tests are either the Cooperative Awareness Message (for the European ETSI ITS G5 stack) or the Basic Safety Message (for the DSRC used in the United States of America).

In addition to the communications-layer testing, we have included rudimentary application-level testing to provide assurance that C-V2X system functions as intended and to identify unforeseen issues with the higher layer integration. It is expected that through testing, researchers will gain insights into the operations of C-V2X that may guide additional research questions and perhaps suggest required design improvements.

It is also important to note that this test specification does not represent a complete duplication of the entire work performed by CAMP and/or others on the development of DSRC. Rather, this is a targeted effort that reflects a specific set of tests that are believed to be critical towards evaluating the efficacy of C-V2X communication technology within the V2V application space. Within this set of tests, applying identical methods from DSRC to C-V2X may not be feasible in all instances. This will be indicated in the respective description of test procedures.

While the first version of this document focuses on V2V testing, upcoming versions will also include V2I, V2P, V2N.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

[1] CAMP VSC2 Consortium, "Vehicle Safety Communications – Applications (VSC-A) Final Report: Appendix Volume 1: System Design and Objective Test," NHTSA Publication, 2011

[2] CAMP VSC3 Consortium, *"Vehicle-to-Vehicle Safety System and Vehicle Build for Safety Pilot (V2V-SP) Final Report, Volume 2 of 2: Performance Testing,"* NHTSA Publication, 2014

[3] CAMP VSC3 Consortium, "Interoperability Issues of Vehicle-to-Vehicle Based Safety System Project (V2V-Interoperability) Phase 2 Final Report Volume 1: Communications Scalability for V2V Safety Development," NHTSA Publication 2015

[4] CAMP VSC3 Consortium, "Interoperability Issues of Vehicle-to-Vehicle Based Safety System Project (V2V-Interoperability) Phase 2 Final Report Volume 2: Communications Scalability for V2V Safety Analysis," NHTSA Publication 2015

[5] CAMP VSC6 Consortium, "Vehicle-to-Vehicle Communications Research (V2V-CR) Project Design Specifications Document," VSC6 Internal Document 2016

[6] SAE International®, *"Surface Vehicle Standard - On-Board System Requirements for V2V Safety Communications,"* J2945TM/1, Issued 2016-03.

3 Abbreviations

3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
AP	Access Point
API	Application Program Interface
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
BSM	Basic Safety Message
BW	Bandwidth
CAMP	Crash Avoidance Metrics Partnership
CB	Channel Busy
CBP	Channel Busy Percentage
CBR	Channel Busy Rate, Channel Busy Ratio
CCA	Clear Channel Assessment
CPU	Central Processing Unit
CSV	Comma-separated values
C-V2X	Cellular V2X
DSRC	Dedicated Short Range Communication
DUT	Device Under Test
EEBL	Emergency Electronic Brake Lights
EIRP	Equivalent Isotropically Radiated Power
FCW	Forward Collision Warning
FTP	File Transfer Protocol
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
HTTPS	HTTP Secure
HV	Host Vehicle
HW	Hardware
IA	Information Age
IEEE	Institute of Electrical and Electronics Engineers
IMA	Intersection Movement Assist
IPG	Inter-Packet Gap
ITS-G5	Intelligent Transportation Systems Access Layers at 5 GHz
KPI	Key Performance Indicator
LOS	Line-of-Sight
LTE	Long-Term Evolution
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MH-LOS	Multi-Lane Highway Line-of-Sight
MIMO	Multiple-Input and Multiple-Output
NHTSA	National Highway Traffic Safety Administration
OBU	On-Board Unit
OS	Operating System

OTA	Over-the-Air
PC	Personal Computer
PER	Packet Error Rate
PHY	Physical
PSD	Power Spectral Density
PSID	Provider Service Identifier
PSCCH	Physical Sidelink Control Channel
PSCH	Primary Synchronization Channel
PSSCH	Physical Sidelink Shared Channel
RB	Resource Block
RDP	Radiation Density Pattern
REF	Reference Device
RF	Radio Frequency
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RV	Remote Vehicle
RX	Receive
S-RSSI	Sidelink RSSI
SAE	Society of Automotive Engineers
SD	Secure Digital
SINR	Signal to Interference plus Noise Ratio
SoI	Signal of Interest
SPS	Semi-Persistent Scheduling Sidelink
SW	Software
TME	Test and Measurement Equipment
TTI	Transmission Time Interval
TX	Transmit
UE	User Equipment
USB	Universal Serial Bus
UTC	Coordinated Universal Time
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2V-CR	Vehicle-to-Vehicle Communications Research
V2V-I	Vehicle-to-Vehicle Interoperability
V2V-SP	Vehicle-to-Vehicle Safety Pilot
V2X	Vehicle-to-X
VSC	Vehicle Safety Consortium
VSC-A	Vehicle Safety Communications – Applications

4 Overview

4.1 Approach

The series of tests defined when executed will allow for comparison between V2V radio technology while also enabling development, calibration, and validation of simulation models used for analyzing a broader set of scenarios. The overall test execution approach is documented below as an interconnected work flow presented in **Figure 1**. This is presented in Preparation, Execution, Analysis, and Evaluation. This test specification focuses on the Preparation and Execution stages of the workflow. The data captured will inform the simulation, which then enables the broad evaluation of C-V2X.

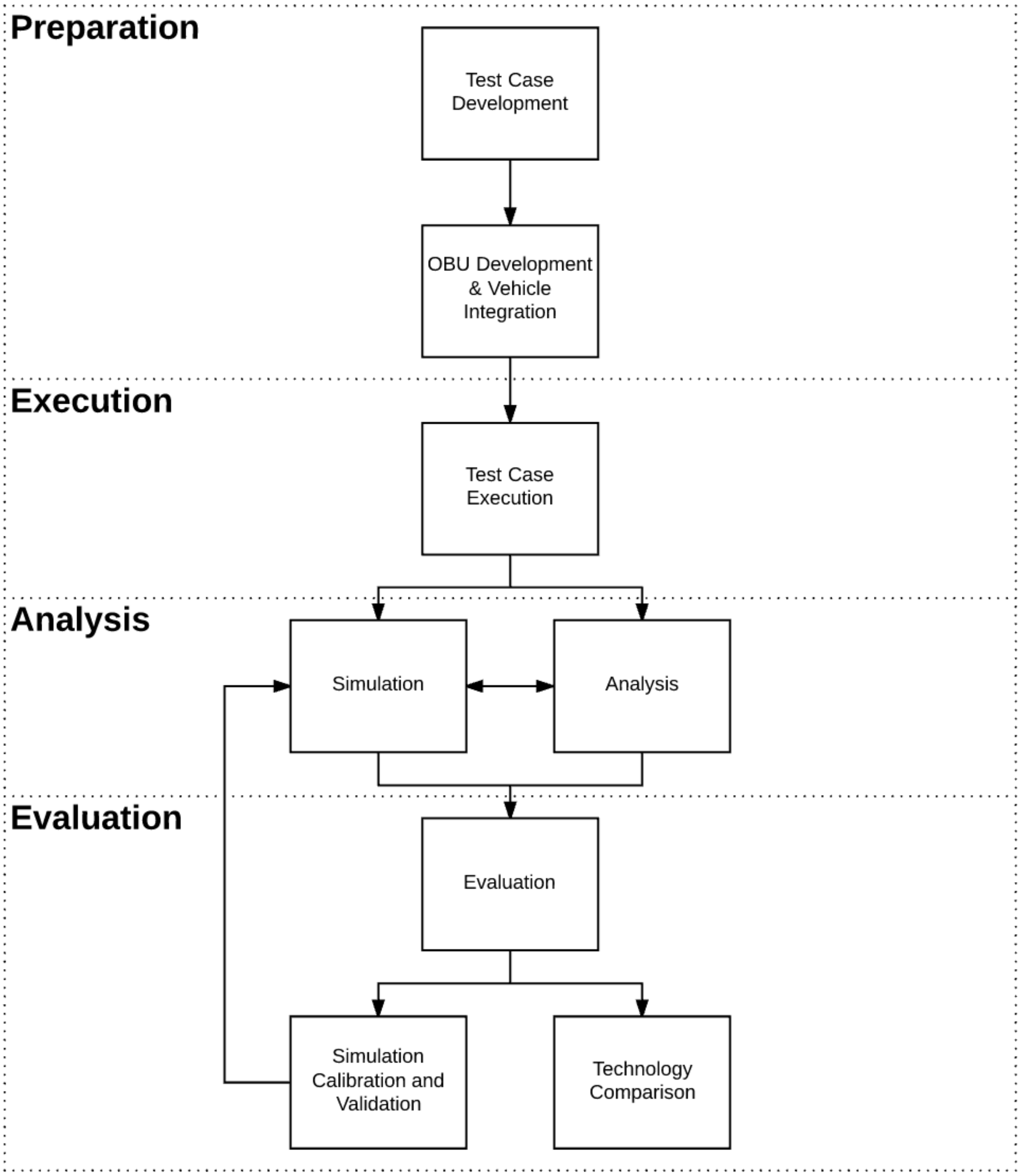


Figure 1: Workflow

4.2 Assumptions

The following assumptions have been made in the development of this document. Any deviation from these assumptions must be discussed and accepted with the data collection and analysis teams prior to inclusion in the testing.

- The DSRC OBU is expected to meet applicable standards, particularly the most recent versions of standards as defined in Section 6.2.1
- The C-V2X OBU is expected to meet applicable standards, particularly the most recent version of standards as defined in Section 6.2.1
- Both V2V devices will be capable of either logging the necessary data or interfacing and providing data to a data acquisition system for data logging. Any impairments of the measurement setup should be considered. All measurement points should be clearly documented.
- Test track or other facilities will be available for the testing specified
- C-V2X OBU communicates directly V2V (Device-to-Device) using 3GPP R14 Mode 4 and does not rely on cellular network infrastructure (edge or otherwise) to communicate safety messages between other Cellular OBUs (not including security functions which are not within the scope of this test specification)
- C-V2X OBU will operate at the same communication frequency (5.9 GHz), b/w (10 MHz), channel (172), maximum allowed transmit power level (e.g. 20 dBm) for C-V2x and DSRC) and message transmit frequency (10Hz) as a DSRC OBU to ensure that the device performance measures of interest can be compared equally to DSRC/ITS-G5. Although the test procedures described within this document are centered around the 5.9 GHz band, methodologies can be used in different frequency bands.
- C-V2X and DSRC OBUs will utilize the same antenna which exhibits a uniform propagation pattern as well as the same diversity configuration. Chapter 9.1.5 gives details about antenna characterization tests.
- Message payloads will be populated with meaningful data to enable application tests (i.e. BSM based data frames) and be identical for DSRC and C-V2X
- All vehicles integrated with OBUs will be the same make and model within a set of tests with antennas mounted at the apex of the vehicle to minimize the influence of vehicle chassis line-of-sight occlusion
- Only the DSRC and Cellular OBU device under test (DUT) will be transmitting in the allocated 5.9 GHz frequency band in the open laboratory and test track environments to ensure that the data collected in the test environments is not influenced by external factors
- GNSS receivers used for C-V2X and DSRC/ITS-G5 OBUs shall have similar performance (e.g. update rate 10 Hz), particularly timing information.

Radio level tests, with the exception of those related to congestion control, are applicable to both DSRC as well as ITS-G5. Any tests that involve the higher layer protocol stack would be dependent on the specific protocol stack which is different for various regions. The higher layer tests described in the present version of this document focus on the US stack.

5 Performance Measures of Interest

The sections below provide the applicable performance measures to assess the OBUs communication and congestion control performance. Details regarding data elements, data logging and data export requirements needed to derive these measures are detailed in the Requirements section.

5.1 Packet Error Rate (PER) [4]

The PER is the ratio, expressed as a percentage, of the number of missed packets at a receiver from a particular transmitter and the total number of packets queued at that transmitter.

A sliding window PER is used to smooth out the sudden fluctuations and obtain an approximate average of the data. The PER is calculated using the sequence number contained in each message, and is calculated between a receiving Host Vehicle (HV) and a transmitting Remote Vehicle(s) (RV). The PER is calculated and plotted against time.

Let δ be the PER interval that is divided into w sub-windows as shown in Figure 2. The width of w is normally set to 1 second. In Figure 2, $\delta = n * w$, where *n is normally set to a 5 second PER value*. At the end of each sub-window interval w , the number of missed packets and the number of transmitted packets are calculated for that sub-window. The PER is calculated at the end of each δ for the last n sub-windows as follows.

$$PER_{j-n+1} = \frac{missed\ seq\ \#\ from\ vehicle\ i\ during\ [w_{j-n+1}, w_j]}{total\ seq\ \#\ from\ vehicle\ i\ during\ [w_{j-n+1}, w_j]} \quad (1)$$

Where $j \geq n$

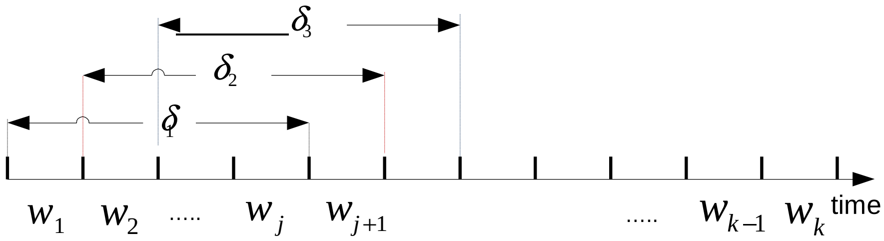


Figure 2: Sliding Window [4]

Note that PER is undefined if the DSRC receiver does not receive at least 2 BSMs (PER is 100%) in a δ window. Also, note that the PER metric in this case includes:

- Packet loss due to packets that were dropped from the transmit queue because a newer BSM arrived in the queue before the previous BSM could be transmitted due to the medium being busy (the DSRC radio's clear channel assessment could not detect that the medium was clear for transmitting before the next packet arrived)
- Packets lost over the air due to collisions or insufficient signal strength

5.2 Inter-Packet Gap (IPG) [4]

The IPG is the time, calculated at the receiver and expressed in milliseconds, between successive successful packet receptions from a particular transmitter.

Like the PER, the IPG is calculated between the HV and the RV, and represents the IPG seen by the HV with respect to the RV over the entire test run.

Let r_i denote the Coordinated Universal Time (UTC time) at which the ith message from a RV is received by the HV, and r_{i-1} $r_i$denote the UTC time at which the $(n-1)^{th}$ message from the RV was received by the HV, then the IPG_i between the $(i-1)^{th}$ message and the i^{th} message is:

$$IPG_i = r_i - r_{i-1} \quad (2)$$

5.3 Channel Busy Percentage (CBP) [4]

CBP is the ratio, expressed as a percentage, of the time during which the wireless channel is busy (i.e., energy level is higher than the carrier sensing threshold) to the period of time over which CBP is being measured.

CBP is calculated periodically over a pre-defined windowed monitoring period referred to as ‘ChanBusyIntvl’. The ChanBusyIntvl for DSRC is expected to be set to 100 ms.

CBP can be determined using the clear channel assessment busy fraction defined in the IEEE 802.11p standard as follows:

$$CBP = \frac{(100 \times Duration\ Channel\ Indicated\ as\ Busy)}{ChanBusyIntvl} \quad (3)$$

Note that CBP is a DSRC specific metric and C-V2X utilizes Channel Busy Ratio (CBR). Note also that CBP includes channel busy time due to both carrier sensing and energy detection, but it does not include virtual channel busy time based on the Network Allocation Vector defined in IEEE 802.11.

5.4 Channel Busy Ratio (CBR)

Channel busy ratio (CBR) measured in subframe n is defined as follows:

- For PSSCH, the portion of sub-channels in the resource pool whose S-RSSI measured by the UE exceed a (pre-)configured threshold sensed over subframes [n-100, n-1];
- For PSCCH, in a pool (pre)configured such that PSCCH may be transmitted with its corresponding PSSCH in non-adjacent resource blocks, the portion of the resources of the PSCCH pool whose S-RSSI measured by the UE exceed a (pre-)configured threshold sensed over subframes [n-100, n-1], assuming that the PSCCH pool is composed of resources with a size of two consecutive PRB pairs in the frequency domain.

Note that CBR is a C-V2X specific metric and DSRC utilizes Channel Busy Percentage (CBP).

5.5 Information Age (IA) [4]

IA represents the time interval, expressed in milliseconds, between the current time at a receiver and the timestamp, applied by the transmitter, corresponding to the data (e.g., position, speed, heading) contained in the most recently received BSM from the transmitter.

IA can be a continuous or sampled variable and for a given transmitter can be calculated in real time, if desired, at the receiver. IA is calculated as follows:

$$IA_{TxRx}(t) = t - t_{TxRx}(k_t) \quad (4)$$

Where:

- k_t is the index of most recent data received up to time *t*
- $t_{TxRx}(k_t)$ is the timestamp corresponding to the data of sample indexed k_t, received from RX at TX

Note that IA:

- Is calculated periodically, normally every 100 ms
- Is lowest when a receiver receives a new BSM from a particular transmitter
- Increases linearly with time, until the receiver receives a new BSM from the transmitter

5.6 Application End-to-End Latency

Application E2E Latency represents the time interval, expressed in milliseconds, between the time instant when the Transmitter application delivers the application layer packet (e.g., BSM) to the lower layers, in particular Medium Access Control (MAC) and Physical Layer (PHY), and the time instant when the application layer packet is received by the application layer at the receiver (before payload decoding).

It is envisioned that when the application layer packet is delivered to the lower layers (through an API) that the application records this time in the Transmitter log file. This is not a requirement however, it simplifies computing the Application E2E Latency. Time information shall be synchronized between units using GNSS time information. Similarly, when the receiver application receives the packet it records this time in the Receiver log file. The Transmitter and Receiver clocks used to read the times when the application layer delivers/receives the packet through the API need to be synchronized. This is critical since the difference between these two quantities represents the Application E2E Latency. It should be noted that there are other ways to record the Application E2E Latency and that the important thing is note when the interval starts and when it ends.

5.7 Relevant measures

In addition to the performance measures of interest, assessment considers the following:

1. Communication properties:
    - Received Signal Strength Indicator (RSSI) for DSRC
    - Reference Signal Received Power (RSRP) for C-V2X
    - Over-the-Air (OTA) Message Size
2. Relative vehicle-to-vehicle kinematic properties:
    - Range
    - Speed
    - Elevation
    - Heading
3. Device performance:
    - Transmit to Receive Message Latency (on PHY MAC layer, methodology needs to be clearly documented)

6 Preliminary Test Configuration Requirements

6.1 Device Interfaces

Figure 3 depicts a generalized OBU interface required to support the test cases defined. Along the left side, are the software stacks where values and configurations are accessible to other computer systems by way of an Application Program Interface (API). In addition, relevant data can also be logged to a file that resides either on a local or mountable file system.

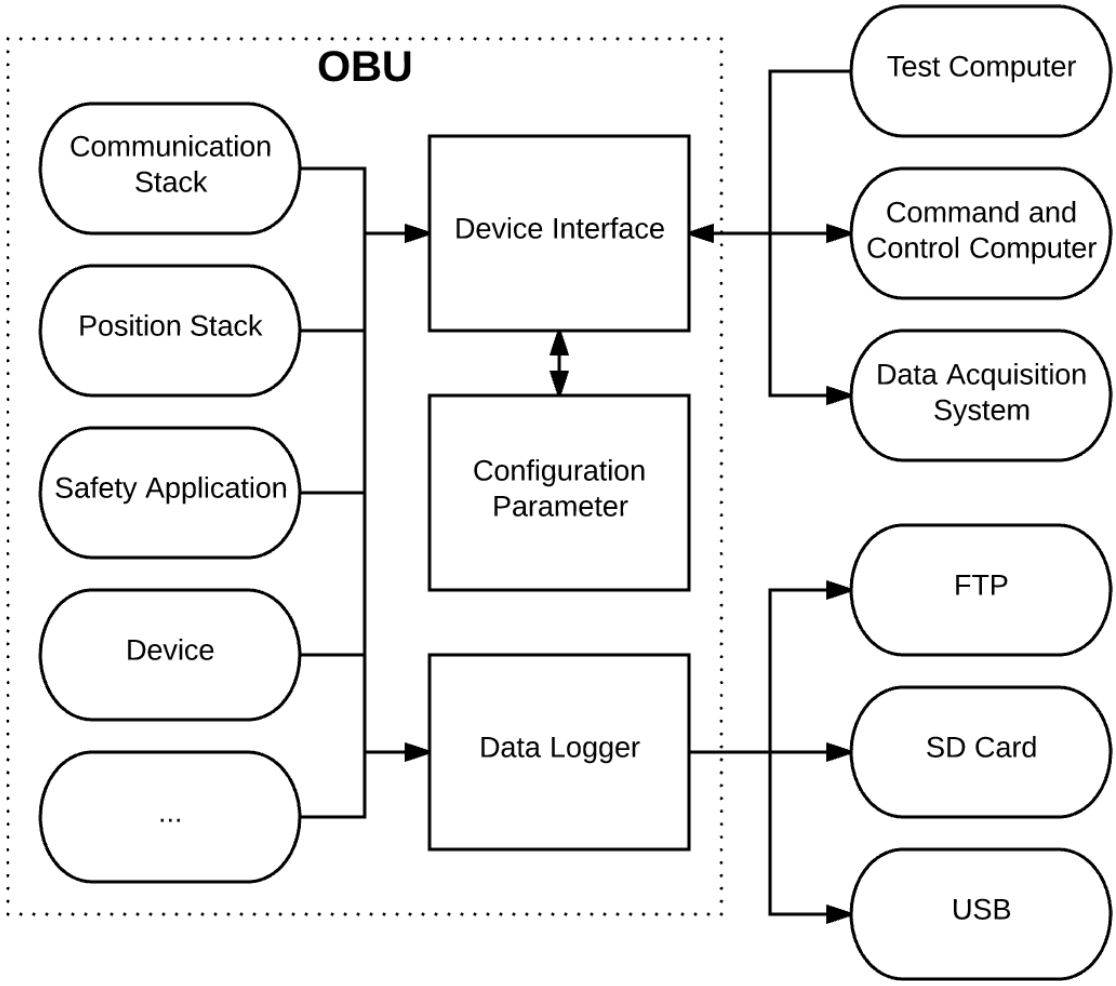


Figure 3: OBU Interfaces

6.2 OBU

To support the execution and analysis of the test cases contained in this document, the following section describes requirements that need to be supported by the DUT OBUs. This section is organized into the following subsections:

1. Device Standards
2. Device Interfaces
3. Variables of Interest and Logging
4. Device Parameter Configuration

6.2.1 Device Standards

The DSRC OBU will comply with all current standards focused on enablement of V2V safety applications highlighted in the following:

- IEEE 802.11p
- IEEE 1609.2
- IEEE 1609.3
- IEEE 1609. 4
- IEEE 1609.12
- SAE J2735
- SAE J2945/1

The Cellular OBU will comply with all current standards focused on enablement of V2V safety applications highlighted in the list below. Exceptions are detailed where applicable:

- 3GPP R14
- IEEE 1609.2
- IEEE 1609.3
    - Exception of WSA channel switching
- IEEE 1609.12
- SAE J2735
- SAE J2945/1
    - Priority levels from 2945/1 map to 2 of the 8 priorities supplied by underlying 3GPP PC5 radio

6.2.2 Device Interfaces

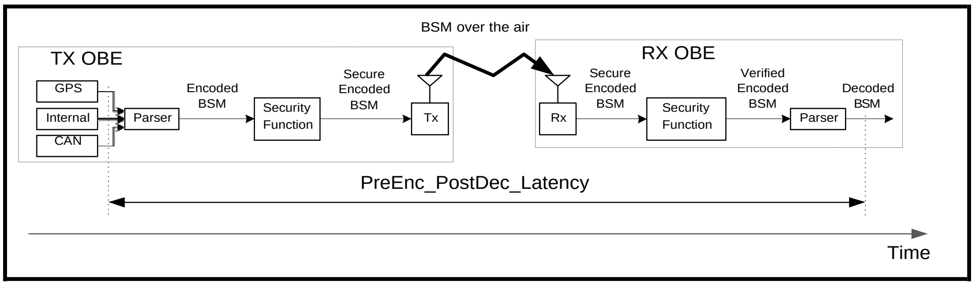
Interfaces for logging, DUT configuration, etc. will be detailed in a later version of this document.

6.2.3 Variables of Interest

Table 1 shows the primary variables of interest used to assist in calculation or direct sampling for the device performance measurements. These are the minimum elements needed to be made available by the device. A complete list of variables developed by CAMP and used for DSRC testing can be referenced in the VSC6 V2V-CR Project for DSRC report [5].

Access to these variables can be made by way of an API where an external device can acquire and store the data. Additionally, access can be made by way of a data logging function that acquires and writes to a test log file (i.e. CSV).

Table 1: Example for Variables of Interest (see [5])

Log Element	Data representation clarification
Time Stamp	Time stamp will be in "year/month/day-hour:min:sec.ms" format. where the following ranges apply: year: 1970-9999, month: 1-12, day: 1-31, hour: 0-23, min: 0-59, sec: 0-59, and ms: 0-999.
Time Stamp in milliseconds	Millisecond format of ‘TimeStamp’ which is the number of milliseconds from 01 Jan 1970 00:00:00 GMT
Pre Encode to Post Decode Latency	Pre-Encoding on Transmit to Post-Decoding on Receive Latency in milliseconds calculated per figure below.  Note: Security function is not in scope for tests defined in this document.
Log record type	MSG_Type indicates record type and it will have one of the following values: RX - received message record TX - transmit message record ST - internal statistics record RXM - per RV periodic records, CC - per HV periodic for CC
Raw Channel Busy	Measurement of the raw channel percent usage 0-no activity on CH 100-completely saturated
Channel Busy Ratio	As defined in Section 5.4
Received Signal Strength Indication	Power granularity is in half dBm units.
Reference Signal Received Power	Defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth.
PLCP Message Length	Number of bytes in the message. This length comes from PLCP header which corresponds to the IEEE 802.11 PLCP Header ‘LENGTH’ field for the appropriate physical layer referred to in [6]
Transmit Power Level	The conducted TX power level at the connector after applying 'MinSectorAntGain_dBi' and 'CLoss_dB' to the calculated RadPwr.
Radiated Power	The Radiated Power level after filtering the Raw RP (Base_RP eq. 9 in J2945/1) should be the actual transmit power level.
Raw Power	The Raw RP value calculated as a function of CBP, f(CBP), eq. 8 in J2945/1.
Packet Transmit Interval	Packet Transmit interval calculated by taking the difference in timestamps between consecutive TX lines.

Unique OBU_ID Alias	The string alias for the OBU from OBU_ID.conf which has a maximum size of 10 characters. If UniqueOBU_Alias can't be identified, then record the Radio MAC which has a maximum size of 17 characters.
Message Sequence Number	Test data frame in part II of BSM
Second Mark	Data representation is per DE_DSecond from SAE J2735
Latitude	Per $GPRMC NMEA format Data representation is NOT per SAE J2735
Longitude	Per $GPRMC NMEA message Data representation is NOT per SAE J2735
Elevation	Height above ellipsoid (HAE) calculated per $GPGGA NMEA message Data representation is NOT per SAE J2735
Speed	In m/s. Data representation is NOT per SAE J2735
Heading	Per $GPRMC NMEA message Data representation is NOT per SAE J2735.
Distance between HV and RV	The distance calculated by the HV 1- Upon receiving a message from RV, record the distance with TXE 2- Record the last calculated distance along with RXM records 3- If the Range value is less than 1, then round it up to 1. 4- If the Range can't be calculated (due to GPS problems, bad antenna, etc.), then log zero to indicate that the Range is Unavailable
Packet Error Rate	Number of received packets during the PER measurement period (vPERInterval). The max value is defined based on the assumption that nodes transmit at most at 10 Hz, and the vPERInterval is 5 sec.
	Number of lost packets during the PER measurement period (vPERInterval). The max value is defined based on the assumption that nodes transmit at most at 10 Hz, and the vPERInterval is 5 sec.
	Actual PER over vPERInterval. This value is calculated via PER(k), eq. 3, from SAE J2945/1.
Inter Packet Gap	Minimum inter packet gap latency between two consecutive received packets from a particular sender during the vPERInterval. The min and max values were defined based on the BSMPartITxInterval_ms
	Maximum inter packet gap latency between the two consecutive received packets from a particular sender during vPERInterval. The min and max values were defined based on the BSMPartITxInterval_ms.
	average inter packet gap latency, calculated in the Inter-Packet latency section, over the measurement period vPERInterval . The min and the max values were defined based on the range of the BSMPartITxInterval_ms.
Event Flag	Event Flag = 1 indicates the presence of at least one event. Event Flag = 0 indicates that all events are absent.
Tracking Error	HV's estimate of RV's error in tracking HV calculated per section 6.3.8.2 'Calculate Tracking Error' in J2945/1.
Transmit Probability	Packet transmission probability, p(k) per eq. 5 in J2945/1, for the HV based on the tracking error.
Critical Event TX Decision	HV's decision to transmit packet based on Critical Events.
Dynamics Transmit Decision	HV's decision to transmit packet based on Vehicle Dynamics

Max ITT Transmit Decision	HV's decision to transmit packet based on Max ITT
Channel Quality Indicator	The average Packet error rate from all RVs within vPERRange per J2945/1 Π(k) calculation description.
Smooth CBP	Percentage of channel utilization observed by the HV after being smoothened, CBP(k) eq. 2 calculation per J2945/1.
HV Local Position Estimation	Indicates that HV's position estimation is in progress per 'Calculate Tracking Error' section in J2945/1. HVEstimation = 1 Coasting in progress HVEstimation= 0 No coasting in progress
HV Remote Position Estimation	Indicates that HV's Remote estimation is in progress per 'Calculate Tracking Error' section in J2945/1. HVRemoteEstimation = 1 Coasting in progress HVRemoteEstimation = 0 No coasting in progress
Previous TX Result	HV's assumption about its previous transmission, determined per Appendix A.8.1 'Assumption of Latest HV State Information at RVs' in J2945/1. 1 = success 0 = failed
Max ITT	Maximum Inter Transmit Time, Max_ITT(k) calculated per eq. 7 in J2945/1, based on the smoothened vehicle density in range.
Vehicle Density in Range	Number of RV's observed in the PER Range, N(k), per section 'Vehicle Density in Range (N)' in J2945/1.
Smoothened Vehicle Density in Range	Vehicle density after Smoothening the number of RV's, Ns(k) eq. 6 in J2945/1, observed in the PER range.
MsgRate	Message Transmission Rate
BSMUserPriority	Defines the Access Categories being used. Valid values are: 0,3 = AC_BE (Best Effort) 1,2 = AC_BK (Bkgrnd) 4,5 = AC_VI (Video) 6,7 = AC_VO (Voice)
GPS status on whether available or not	Indicates whether a valid GPS positioning solution is unavailable (0) or available (1)
Horizontal dilution of precision	Indicates the HDOP to reflect quality of position solution on the 2-D plane. Set to 0 when GPS is unavailable.
Number of satellites	Identifies the total number of satellites visible to reflect the quality of position solution. Set to 0 when GPS is unavailable.
Safety Alert	Define the triggered safety alert 0 = EEBL 1 = IMA 2 = FCW

6.2.4 Device Parameter Configuration

Provided in **Table 2** below are the minimum configurable variables that may need to be changed to support a given test scenario. A complete list of configurable items developed by CAMP and used for DSRC testing can be referenced in the VSC6 V2V-CR Project for DSRC report.

Generally, the DUT will be configured to the specified standards. The device parameter configuration is needed to support test cases where certain TX characteristics need to be adjusted to generate a form of channel interference.

Table 2: Device Parameter Configuration and default settings

Configurable Item	**Default Value**
TX Power	20 dBm
TX Frequency	10 Hz
TX Channel	172
RX Channel	172
User Priority	5 = BSMs with no Critical Event Flags 7 = BSMs with ≥ 1 Critical Event Flags
Typical Packet Size	150 – 190 bytes *If using BSMs, only configure the pad bytes in the TDF to account for security when security is disabled
Data Rate	Technology specific
Congestion Control	On
Safety Application Alerts	On
Security	Off Note: Security overhead is taken into account in some tests described in this document by adding padding bytes to the messages.

7 Test Cases - Overview

Based off the collection of work performed by CAMP under VSC-A, V2V-SP, V2V-I and V2V-CR programs, the test cases presented in the subsequent sections provide a method in which devices can be objectively evaluated and compared against. In addition, test case analysis and data logs could be used to develop, validate, and/or recalibrate simulation models for the given radio technology.

The collection of test cases is provided in the In-Vehicle Characterization section. Tests to prepare for In-Vehicle Characterization and to perform technology readiness will be performed in the Lab, however, they are not described here. In-Vehicle Characterization are tests designed to evaluate the device: communication range, channel congestion and safety applications in real-world configurations. Provided below is a list of the sections and corresponding test cases:

- Device and Technology Readiness Characterization
    - Basic Bench Cabled RF Tests
    - Congestion Control Lab Tests
    - Adjacent/Non-Adjacent Channel Interference Lab Tests
- In-Vehicle Characterization
    - Test Track
    - Safety Application Demonstration
    - Public Roads

For each individual test case, the format will use a standard template consisting of the following sections:

- Background
- Assumptions
- Setup
- Test Execution
- Unique Tests to be Conducted
- Required Documentation of Results
- Evaluation Criteria
- Estimated time to complete

8 Test Cases - Device Characterization

The following sections focus on test cases that characterize the device's RX/TX, latency and processing performance in a laboratory environment. In particular, the tests described in this section are focused on characterizing the Physical (PHY) and Medium Access Control (MAC) layers of radio technology, including interference scenarios, and on device performance in a high density radio congested environment. Evaluation measures shall reference industry standards, if available, for the given radio technology, such as IEEE 802.11p and SAE J2945/1 for the DSRC and 3GPP R14 / PC5-LTE for C-V2X.

Upon execution and collection of test log data from these test cases, analysis could be used to assist in development and validation of simulation models for the given radio technology.

The guiding principle for a test in general is that it must be applicable and repeatable for different radio technologies.

8.1 Basic Bench Cabled RF Tests

In this section the focus is on test procedures performed in the lab in the cabled RF environment. The test procedures are described as C-V2X test procedures, however, the exact same tests shall be carried out for DSRC.

8.1.1 Cabled Transmission and Reception Test with varying payload sizes

8.1.1.1 Background

The purpose of this test is to verify that C-V2X devices can transmit and receive varying C-V2X messages over PC5 Interface.

8.1.1.2 Assumptions

Operating system time of both the transmitter and receiver box is synchronized to the common clock (e.g., GPS) with an error of no more than 1ms.

8.1.1.3 Setup

This test uses a lab cabled setup as shown in the figure below. A C-V2X Device 2 (receiver) is configured to receive data from C-V2X Device 1 on an ITS band (channel 172) with a Bandwidth of 10 MHz. It is recommended that at least RF shield boxes be used to isolate the devices in terms of RF leakage.

- Settings on the C-V2X Device 1 [Transmit Radio]:
    - Application layer configured to generate messages and deliver to the lower layers with 100 ms periodicity.
    - Varying Packet lengths
        - Smaller packets (150 – 190) bytes for 4 transmit occasions followed by larger (250-300) bytes for one occasion (in a specific test packet size should remain constant). This shall model the expected load when security measures are enabled.
        - Repeat the above data pattern for the duration of the test.
    - Transmit on ITS band Channel 172 with Bandwidth of 10 MHz
    - Appropriate transmit power and attenuation added to ensure DUT input of -50 dBm (when signal is present)

- Settings on the C-V2X Device 2 [Receive Radio]
    - Configured to Receive on the same ITS band (i.e. Channel 172) of 10 MHz bandwidth.
    - Receive Radio in C-V2X will listen on all occasions.
- Data Collection at TX

  - OS Timestamp for each transmitted packet (ITS stack)
  - Sequence number of the transmitted packet (ITS stack)
- Data Collection at RX
  - OS Timestamp for each received packet (ITS stack)
  - Sequence number of the received packet (TS stack)
  - Receive signal power for each received packet

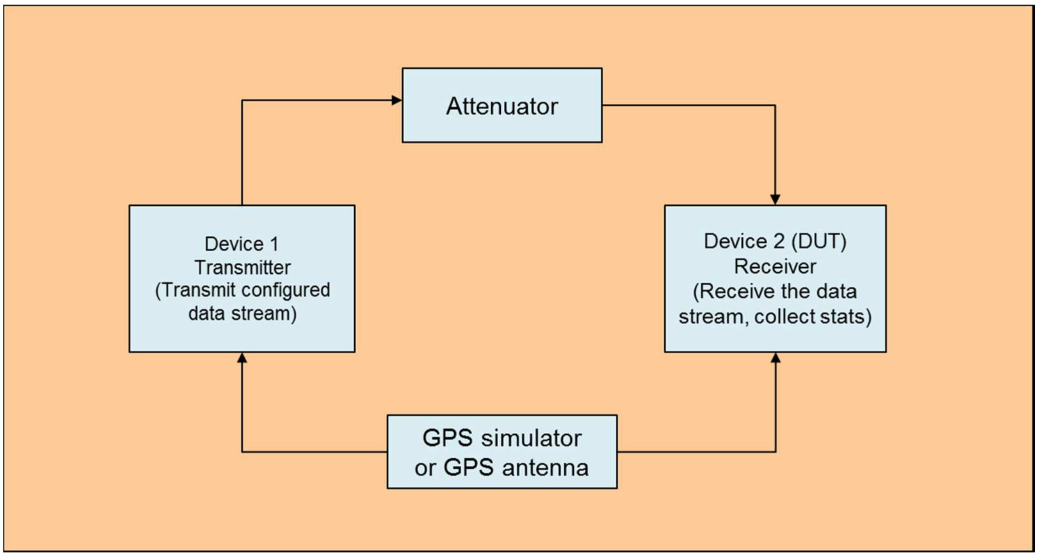


Figure 4: Test Setup

8.1.1.4 Test Execution

1. Configure the Attenuator so that received power on the receiver entity is -50dBm.
2. Configure the Transmit Device with the data stream of interest
   a. Transmit power for the Transmit device remains constant at 20 dBm.
   b. Data Stream is a sample SPS based Transmit Flow of varying payload sizes sent periodically every 100ms.
3. Record the data collected by TX and RX device as mentioned below in a log file
   a. OS Timestamp for each TX/RX packet
   b. Sequence number of the TX/RX packet
   c. Receive signal power for each RX packet

8.1.1.5 Unique Tests to be Conducted

Run this test using:

1. Two (2) C-V2X devices for the test

8.1.1.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table. PER is computed from both the TX and RX data logs. The number of missing (not received) packets is divided by the number of the total packets transmitted. The IPG statistic is computed from the RX logs. The latency is computed from both TX and RX logs.

Table 3: Basic Cabled Tests Documentation

No. of Transmitted pkts/s reported	No. of Received pkts/s reported	Calculated at Receiver	Calculated at Receiver	Calculated at Receiver
C-V2X Transmit Device	**C-V2X Receive Device**	**PER %**	**%age of packets meeting IPG threshold (histogram of IPG)**	**%age of packets meeting Latency threshold (histogram of delay)**

8.1.1.7 Evaluation Criteria

Evaluation criteria is a successful decode of all the payload lengths on RX entity.

8.1.1.8 Estimated Time to Complete

Table 4: Estimated Completion Time

Task	Estimated Time	Notes
Test setup	10 minutes	Assumes basic device setup has taken place
Test execution	30 minutes	Cellular?
Test Analysis	60 minutes	Includes file acquisition, script execution, metric generation and analysis
Total	100 minutes	

8.1.2 Clean Channel Cabled Transmission and Reception Test across power levels

8.1.2.1 Background

The purpose of this test is to verify that C-V2X Devices can transmit and receive C-V2X messages over PC5 Interface at different received powers and assess End to End Statistics.

8.1.2.2 Assumptions

Operating system time of both the transmitter and receiver box is synchronized to the common clock (e.g., GPS) with an error of no more than 1ms.

8.1.2.3 Setup

This test used a lab cabled setup as shown in the figure below. A C-V2X Device 2 (receiver) is configured to receive data from C-V2X Device 1 on the ITS band (Channel 172) with a Bandwidth of 10 MHz. Each C-V2X OBE shall be placed in a RF shielding box to account for possible RF leakage.

- Settings on the C-V2X Device 1 [Transmit Radio]:
    - Application layer configured to generate messages and deliver to the lower layers with 100 ms periodicity.
    - Packet length is constant within the range 150-190 bytes (in a specific test packet size should remain constant).
    - Transmit on ITS band with Bandwidth of 10MHz
    - Appropriate transmit power and fixed attenuation added to ensure DUT input of -50 dBm

- Settings on the C-V2X Device 2 [Receive Radio]
    - Configured to Receive on ITS band (e.g., center frequency 5,860 MHz) and Bandwidth of 10 MHz.
    - Receive Radio in C-V2X will listen on all occasions.
- Data Collection at TX
    - OS Timestamp for each transmitted packet
    - Sequence number of the transmitted packet
- Data Collection at RX
    - OS Timestamp for each received packet
    - Sequence number of the received packet
    - Receive signal power for each received packet

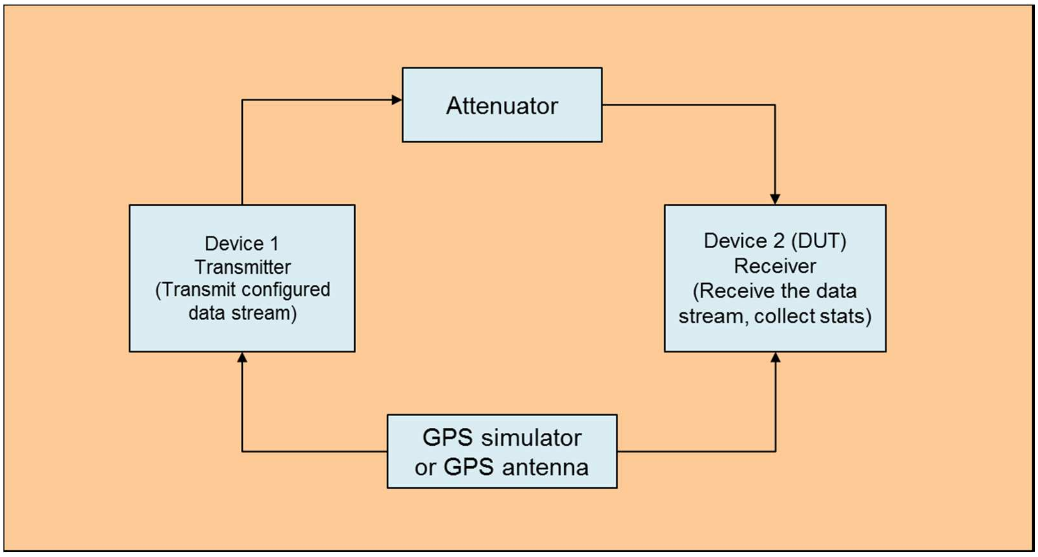


Figure 5: Test Setup

8.1.2.4 Test Execution

1. Calibrate the insertion loss between the two devices by setting the attenuator to 0dB measuring the loss with both cables connected to the attenuator. This value will be the fixed insertion loss of the cables and attenuator setup
2. Calibrate the TX power of C-V2X Device 1 via programming
   a. Transmit power for the transmit device remains constant
3. Adjust overall path loss (insertion loss plus attenuator value) to be 45dB
4. Vary the attenuation in steps of 10 dB
   a. Near sensitivity reduce step size to 1dB
   b. Continue the test till observed PER is 100%
5. Record the Statistics as mentioned below on the C-V2X devices for each path loss setting in a log file:
   a. OS Timestamp for each TX/RX packet
   b. Sequence number of the TX/RX packet
   c. Receive signal power for each RX packet

Note : Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees)

8.1.2.5 Unique Tests to be Conducted

Run this test using:

2. Two (2) C-V2X devices for the test

8.1.2.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table. PER is computed from both the TX and RX data logs. The number of missing (not received) packets is divided by the number of the total packets transmitted. The IPG statistic is computed from the RX logs. The latency is computed from both TX and RX logs.

Table 5: Required Documentation

	No. of Transmitted pkts/s	No. of Received pkts/s	Calculated at Receiver	Calculated at Receiver	Calculated at Receiver	Calculated at Receiver	Calculated at Receiver
Attenuator Value (dB)	**C-V2X Transmit Device**	**C-V2X Receive Device**	**RX signal power**	**PER %**	**CBP (%) for DSRC** **CBR(%) for C-V2X**	**%age of packets meeting IPG threshold** **(histogram of IPG)**	**%age of packets** **meeting Latency threshold** **(histogram of delay)**

8.1.2.7 Evaluation Criteria

Evaluation criteria is a successful decode of all the payload lengths on RX entity.

8.1.2.8 Estimated Time to Complete

Table 6: Completion Time

Task	Estimated Time	Notes
Test setup	10 minutes	Assumes basic device setup has taken place
Test execution	30 minutes	Cellular?
Test Analysis	60 minutes	Includes file acquisition, script execution, metric generation and analysis
Total	100 minutes	

8.1.3 Cabled Transmission and Reception Test with added Channel Impairment

8.1.3.1 Background

The purpose of this test is to verify that C-V2X devices can transmit and receive C-V2X messages over the PC5 Interface with an AWGN Channel Impairment Model being applied between the transmit and receive C-V2X devices.

8.1.3.2 Assumptions

The operating system time of both the transmitter and receiver boxes is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms.

8.1.3.3 Setup

This test uses a lab cabled setup as shown in the figure below. A signal generator (SigGen) is used to generate AWGN in the frequency range of the channel, and Device 2 (receiver) is configured to receive data from Device 1 on this same impaired channel.

- Channel Impairment settings on the Signal Generator (SigGen):
  - Configured to generate AWGN across the entire 10 MHz bandwidth of the channel
- Settings on Device 1 (Transmit Radio):
  - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
  - Packet length of 150 – 190 bytes
  - Transmit on ITS band (Channel 172) with bandwidth of 10MHz
  - Transmit power set at 20 dBm
  - Appropriate fixed attenuation added (“Attenuator” shown in figure) to ensure that Device 1 TX power at DUT input is -50 dBm
- Settings on Device 2 (Receive Radio):
  - Configured to receive on ITS band (Channel 172) with bandwidth of 10 MHz
  - All measurements of receiving side performance are done on this device.

- Data Collection at TX (Device 1):
    - OS timestamp for each transmitted packet
    - Sequence number of each transmitted packet
- Data Collection at RX (Device 2):
    - OS timestamp for each received packet
    - Sequence number of each received packet

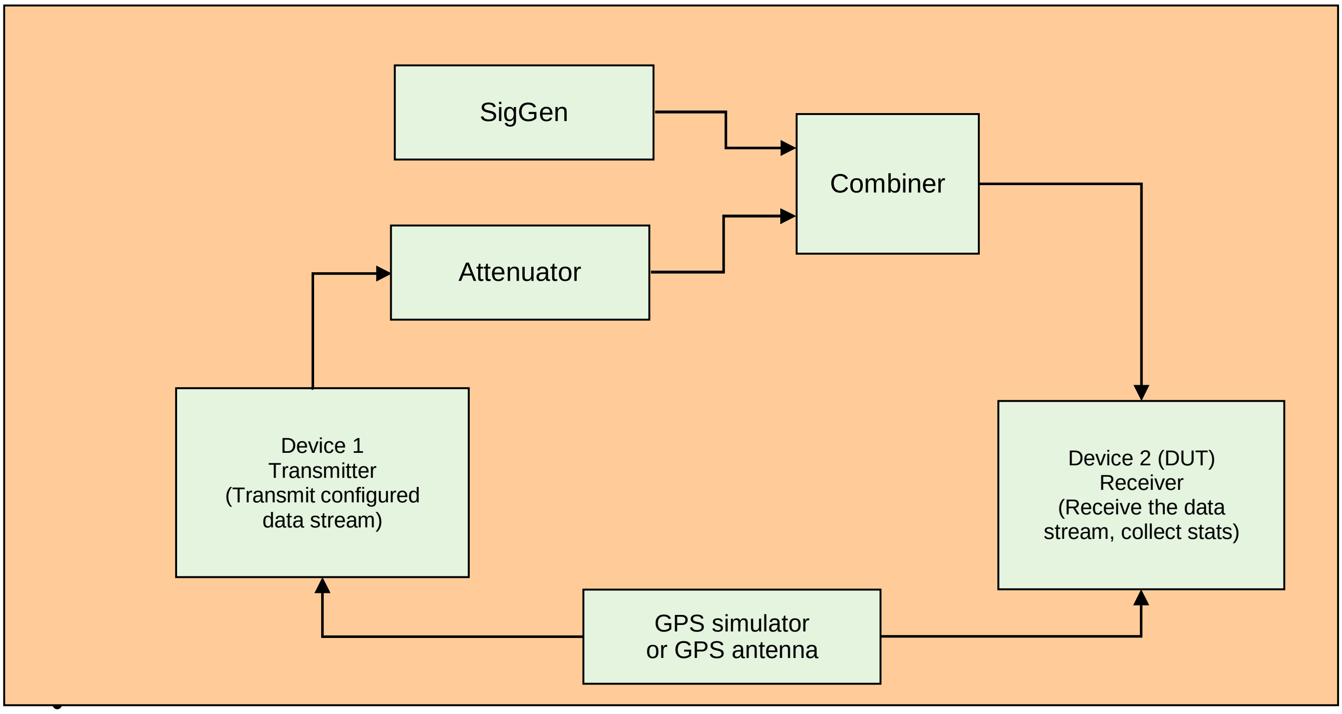


Figure 6: Suggested Test Setup for AWGN Channel

8.1.3.4 Test Execution

Note: Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

1. Configure the Signal Generator to generate AWGN across the entire 10 MHz bandwidth of the channel.
2. Configure the Transmit Device (Device 1) with the data stream of interest:
    a. Transmit power for the Transmit device remains constant at 20 dBm.
    b. Application layer message (e.g. BSM) to be sent periodically every 100ms. Packet length shall be such that there is a one-to-one correspondence between packet and message; the packet size should remain constant throughout the test.
3. Set the Signal Generator to produce zero AWGN power in the channel.
4. Set the Attenuator to an attenuation value such that the receive signal power measured at DUT input is -50 dBm.
5. Adjust the power of the noise produced by the Signal Generator in order to exercise performance across different levels of channel impairment as follows:
    a. Set the Signal Generator to produce -70 dBm/Hz of AWGN power in the channel.
    b. Measure/calculate PER at Device 2.

c. Adjust the Signal Generator to increase the AWGN power in the channel (suggested step size 5 dBm/Hz).

d. Measure/calculate PER at Device 2 (should be greater than before).

e. Repeat steps c and d until PER reaches 100%.

6. Record to a log file the statistics as mentioned below on the Receive Device (Device 2) at every noise power value:

   a. OS Timestamp for each TX/RX packet

   b. Sequence number for each TX/RX packet

8.1.3.5 Unique Tests to be Conducted

Run this test using:

1. Two (2) C-V2X devices for the test

8.1.3.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table.

Table 7: Required Documentation

Signal Generator Setting	**No. of Transmitted pkts**	**No. of Received pkts**	**Calculated at Receiver**	**Calculated at Receiver**	**Calculated at Receiver**
Noise PSD dBm/Hz	**TX Device**	**RX Device**	**PER %**	**%age of packets meeting IPG threshold (histogram of IPG)**	**%age of packets meeting Latency threshold (histogram of delay)**

8.1.3.7 Evaluation Criteria

Evaluation criteria is to assess and compare TX & RX activity of the TX Device and RX Device, respectively, across the noise power range. In addition, the purpose is to measure reported PER values at the RX device in the presence of the injected noise stream.

8.1.3.8 Estimated Time to Complete

Table 8: Completion Time

Task	**Estimated Time**	**Notes**
Test setup		
Test execution		
Test analysis		
Total		

8.2 Congestion Control Lab Test

The following test scenarios are recommended for assessing performance in a radio congested environment (all cases listed here are V2V without network infrastructure coverage):

- V2V congestion control in lab environment: regular BSM broadcast (section 8.2.1)
- V2V congestion control in lab environment: critical BSM broadcast (section 8.2.2)

A full emulation of outdoor/test track large scale testing in a lab environment is not practicable due to the conflicting requirements of space for emulating a full-scale test vs. adding attenuation (for reducing the required physical distances) affecting the behavior of the distributed congestion control algorithm. Therefore, the following approach can be used:

- Perform lab testing as described in this section with devices (antennas) close to each other, without adding additional attenuation, thus creating a highly challenged RF congested environment.
- Identify the limits at which performance severely degrades with congestion control algorithms
    - switched off
    - switched on
- Carefully document in both cases the KPIs and capture the logs from the devices.
- Use the above information as inputs for developing a simulation which would allow scaling up.

The tests are aimed at showing that the congestion control algorithm works well and improves the system performance. In that sense each test described below will be executed first without and then with the congestion control algorithm turned on.

The lab tests are used to identify the practical limits of communication in a congested environment, and so to define the setup (number of devices) for a field/track test. Both test scenarios shall then be repeated in a field/track environment.

8.2.1 V2V Congestion Control in lab environment – Regular BSM broadcast

8.2.1.1 Background

The purpose of this test is to verify that V2V (LTE C-V2X Mode 4 or DSRC)[1] devices can transmit and receive BSM messages in a congestion challenged channel. It is assumed that C-V2X devices will be communicating over the PC5 interface without cellular network assistance (out-of-coverage, Mode 4).

A BSM message should reach 300m to 500m from the transmitter V2V device according to simulations results stated in TR 36.885 and TR22.885.

Therefore, for this consideration, we take a highly challenging scenario, considering an effective communication range of 500m. The following table gives the rough estimate of vehicles that we can fit in this range by considering a normal freeway of five lanes as well as the two widest freeways in the world:

Table 9: Estimated Number of Cars

	Freeway with 5 lanes	Katy Freeway in USA	G4 China
Number of lanes of travel in a single direction	5	26	50
Average vehicle length (m)	5	5	5
Spacing between vehicles (m)	15	15	15
Assumed PC5 communication range (m)	500	500	500

[1] For brevity some parts of this section are specific to C-V2X.

Max number of vehicles to be considered within the communication range of 500m, vehicles travelling in a single direction	250	1300	2500
Max number of vehicles to be considered within the communication range of 500m, vehicles travelling in both directions (i.e. total number of vehicles within 500m of a given DUT)	500	2600	5000

Consequently, in the following lab tests, we start with the equivalent load of 50 devices and increase gradually up to a configurable number N of simulated devices. The value of N should be such that any increase in N would not provide any additional information in terms of behavior of the system and that the behavior for larger values of simulated devices can be extrapolated based on the information measured for values at or below N. The value of N shall be estimated from cross-validated system simulations. The success of the test will also depend on the quality of the match between the lab tests and the system simulation results, which is open to further study.

8.2.1.2 Assumptions

This test case focuses on either DSRC or LTE C-V2X Mode 4 operation where no LTE coverage is available (out-of-coverage).

For C-V2X, the devices are pre-configured with TX and RX resource pools. Resource pools should be configured such that the setup described below is possible.

The operating system time of all devices is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms. This requirement ensures that end-to-end latency between the transmitter and receiver can be measured with an accuracy of 2ms. (This requirement does not relate to the requirement of the PHY layer synchronization.)

All devices operate in the same channel (e.g. channel 172).

8.2.1.3 Setup

There are two alternative setups possible for the lab test:

- Over the air setup, using module/manufacturer provided antennas

- Fully cabled setup, using RF cables and arrays of splitters and combiners to connect all required devices to each other

Both setups have their advantages and disadvantages. An over the air setup is in many aspects closer to actual live environment, however it is to some extent influenced by the particular lab environment in which it is set up. A cabled environment provides a more controlled environment and repeatability, however it is further from real-life behavior of the system and may be even more challenging to set up in larger scale (hundreds of devices).

Neither setup can fully emulate a large scale test with actual vehicles on a test track. Therefore, it is recommended to use lab tests and setups in combination with further simulations, to provide the best inputs for actual field testing.

Note: The following describes only the cabled lab setup:

NOTE: In this setup a number of reference devices are used (sometimes referred to as “REF”), and their purpose is to generate the traffic that will provide the congested environment. In addition, two devices under test (DUT) are used, referred to as DUT1 and DUT2.

In this setup:

- All devices will be cabled up and connected to each other via splitters and combiners.
- Adequate insulation needs to be used to prevent leakages.
- The setup needs to use splitters/combiners that satisfy the requirements in the frequency range of C-V2X operation.

A cabled up test is preferable mainly due to the following reasons:

a. Provides a deterministic way to recreate results and debug scenarios.

b. Provides results that will eventually be useful for comparison and repeatability.

c. Provides deterministic hooks for attenuation between desired devices / set of devices.

Also in the cabled RF environment, the use of the distributed congestion control algorithm will not be fully comparable to an actual live environment, due to the fact that, for a given REF device, the transmission that it receives from other REF devices in its vicinity will generally be more attenuated than it would be in an actual live environment (e.g. the typical 15-20 dB isolation between ports of an RF combiner; e.g. in some cases the variable attenuators between rows "far from DUT" will make the rows seem farther from each other than they would be in an actual live environment). This in turn impacts the performance of the congestion control algorithm and thus the device.

For control of the experiment, either or both of the following might be used:

- External PC/laptop units
- Connection of the modules/devices by wired LAN or 2.4 GHz Wi-Fi to a central control equipment

The OS timestamp of all devices shall be synchronized by a common GPS source.

A diagrammatic description of the setup is provided below. Notes for reading the diagram:

- The devices labelled "UE" are reference devices.
- "VA" stands for "variable attenuator".
- DUT1 and DUT2 are shown as "HV" and "RV", respectively.

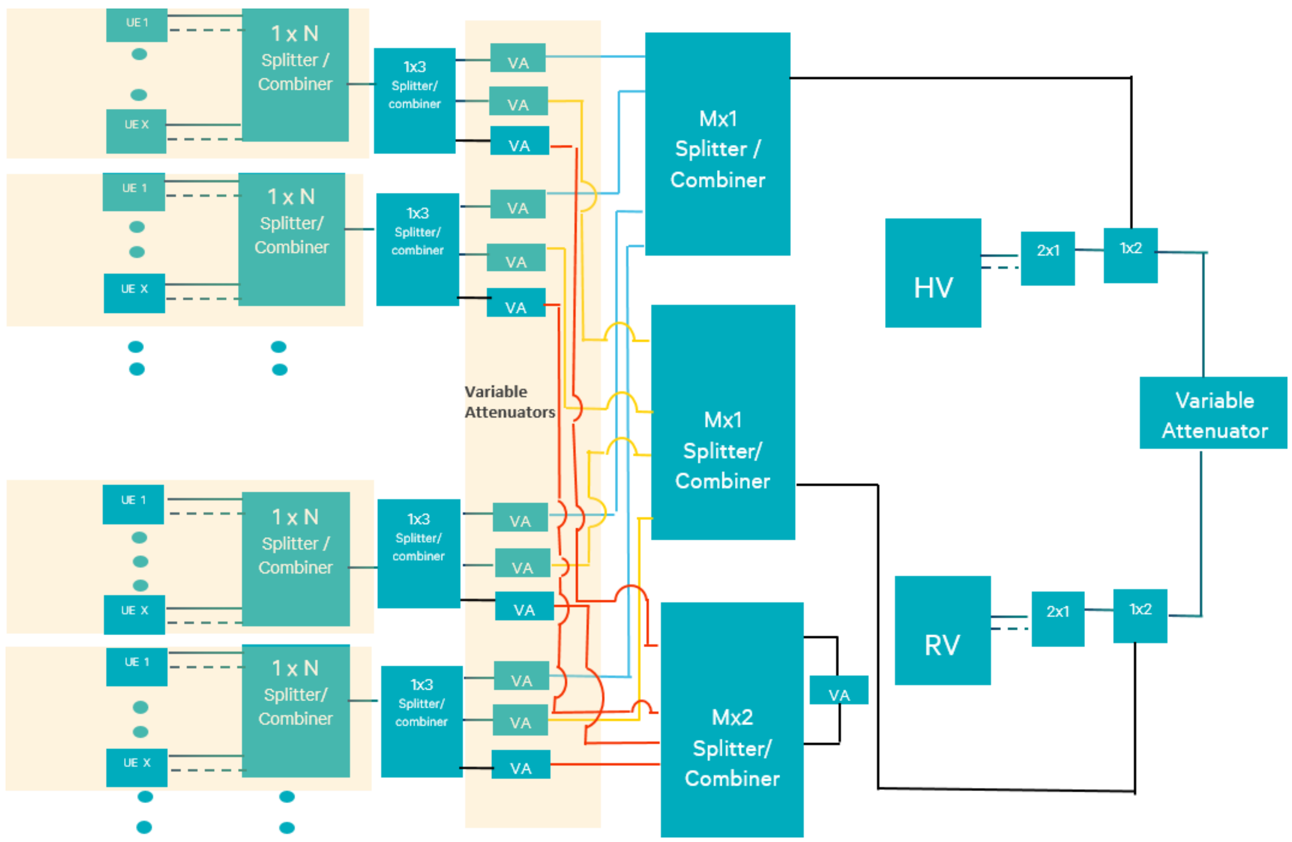


Figure 7: Lab Setup (HV is DUT1 and RV is DUT2)

The setup above can be extended to accommodate a larger number of devices following similar logic, using and cascading more splitters/combiners and attenuators and connecting to the overall grid.

The following settings on the devices are applicable for both over the air and cabled setups.

- Settings on Device 1 (DUT1) and Device 2 (DUT2):
    - Periodic based packet transmit flow with a periodicity of 100ms (in LTE C-V2X an SPS (Semi-Persistent Scheduling) flow shall be configured with periodicity of 100ms)
    - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10MHz; transmitting regular BSM messages
    - Transmit power is controlled by the device, so as to not artificially influence behavior of the congestion control algorithm
    - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
    - Packet length of standard BSM message
    - Using static GPS
- Adjustable attenuator ("Variable Attenuator" at far right side of diagram) is used to simulate different distances between DUT1 and DUT2.

- Settings on the reference devices:
    - Periodic based transmit packet flow with a periodicity and load specified in such a way as to emulate multiple devices (e.g., 5 or 10) using the channel. This can be done in multiple ways:
      (1) Varying the periodicity from 100ms to a smaller value;
      (2) Varying the packet or transmission size (instead of 250-400 bytes multiply by a factor);
      (3) A combination of the two.
      It is important to characterize the load of the reference devices in terms of how much higher load they produce compared to DUTs as well as capture this in system simulations that accompany this lab test.
    - The variable attenuators (in cabled RF setup) will be set depending on the following:
      a) The number of "real" devices each REF device emulates;
      b) The real-world "distance" to be emulated between the specific REF device row and the DUTs, as well as between the REF device rows.
      NOTE: The set of attenuators discuss here is exclusive of the "Variable Attenuator" shown at far right side of diagram.
    - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10MHz; transmitting regular BSM messages
    - Generation of BSM content shall not be synchronized, i.e. each reference device generates its content at a different (random) point in time to avoid synchronization of transmission behavior
    - Transmit power is controlled by the respective devices, so as to not artificially influence behavior of the congestion control algorithm
    - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
    - Packet length of standard BSM message (unless the choice is made to vary the packet size as described in earlier bullet)
    - Using static GPS

- Data Collection at DUT1 and DUT2:
    - OS timestamp for each transmitted packet (ITS stack)
    - Sequence number of each transmitted packet (ITS stack)
    - OS timestamp for each received packet (ITS stack)
    - Sequence number of each received packet (ITS stack)
    - Receive signal power for each received packet
    - All KPIs as listed further in this section

- Data Collection at each reference device:
    - OS timestamp for each transmitted packet (ITS stack)
    - Sequence number of each transmitted packet (ITS stack)
    - OS timestamp for each received packet (ITS stack)
    - Sequence number of each received packet (ITS stack)
    - All KPIs as listed further in this section

8.2.1.4 Test Execution

Overview: With the reference devices creating a congested environment, the PER between the DUTs (DUT1 and DUT2) is observed as the “distance” between them is gradually increased by adjusting the attenuation. This test is repeated with an increasing quantity of reference devices. All of this testing is done first with congestion control disabled and then with it enabled.

1. Setup the test bed as explained above, where the total quantity of reference devices is 50.
2. Set “Variable Attenuator” at far right side of diagram to 0 dB to simulate a short distance between the DUTs.
3. Start transmission at all reference devices (regular BSM broadcast).
4. Start transmission at DUT1 and DUT2 (regular BSM broadcast).
5. Record to a log file the statistics and KPIs as defined in this section for DUT1, DUT2, and the reference devices.
   NOTE: Logging/saving of all KPIs shall be done for at least one reference device. Logging/saving is recommended for all reference devices as far as practicable, for additional analysis.
6. Calculate the PER between the two DUTs at each of DUT1 and DUT2.
7. Increase the attenuation at “Variable Attenuator” by 10 dB to simulate an increase in distance between the DUTs.
8. Repeat steps 5 through 7 until the PER between DUT1 and DUT2 reaches 100%.
9. Increase the quantity of reference devices by four, and start transmission (regular BSM broadcast) on these four additional reference devices.
10. Set “Variable Attenuator” at far right side of diagram to 0 dB to simulate a short distance between the DUTs.
11. Repeat steps 5 through 10 until the quantity of used reference devices is “N” as defined in section 8.2.1.1.

8.2.1.5 Unique Tests to be Conducted

Run this test as described in 8.2.1.4 using two C-V2X DUTs and up to N reference devices with special configuration as explained above, so that 100% PER between DUT1 and DUT2 is achieved. The test in 8.2.1.4 shall be run two times as follows:

- All devices (DUT1, DUT2, reference devices) having congestion control switched off
- All devices (DUT1, DUT2, reference devices) having congestions control switched on

8.2.1.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table.

Table 10: Required Documentation

Attenuation value between DUTs (dB)	Number of reference devices	No. of Transmitted pkts		No. of Received pkts		Calculated at Receiver			
		DUT1	DUT2	DUT1	DUT2	PER % at DUT1	PER % at DUT2	%age of packets meeting IPG threshold (histogram of IPG)	%age of packets meeting Latency threshold (histogram of delay)
0	50								
10									
20									
30									
40									
…									
0	54								
10									
20									
30									
40									
…									
0	…								
10									
20									
30									
40									
…									

Additionally, extract the following KPIs from the logs of each DUT and from the logs of at least one reference device with special configuration:

- Channel Busy Ratio (CBR)
- DUT TX power
- BSM Packet transmission rate
- Number of PSSCH resource blocks assigned to DUT
- MCS Range
- PSCCH and PSSCH BLER to capture hidden node scenario

8.2.1.7 Evaluation Criteria

Note: The below stated procedures will be detailed in a later document version.

Evaluation criteria is to assess the performance of V2X in a highly congested environment, including the performance of the distributed congestion control mechanism implemented on the device under test under different values of CBR. For CBR implementation details see: J2945-1, J3161.

Results from this lab test (number of reference devices providing usable PER for usable distance between DUTs) shall be used as an indication for defining the maximum range of number of devices to be used for field test.

This test needs to be accompanied by a detailed system simulation with two models.

The first model shall accurately capture the lab setup:

- Number of DUTs (two)
- Number of reference devices
- Behavior of reference devices
- Attenuation between the pair of DUTs
- Congestion control used in the lab

Part of the evaluation criteria is the match between the lab tests and the system simulation results, without and with congestion control.

The second system simulation model shall provide the justification and validation for using the reference devices. This model shall use the same setup as the lab for the following:

- Number of DUTs (two)
- Attenuation between the pair of DUTs
- Congestion control used in the lab

The difference from the lab setup is that each reference device will be replaced by the actual number of devices that the reference device is emulating. For example, if a reference device emulates the load of 10 regular devices, then in this simulation the reference device will be replaced by 10 distinct regular devices. Each regular device that replaces a specific reference device will be assigned the same attenuation as the original reference device. The results from this simulation shall be compared with the simulation results that use reference devices described above.

8.2.2 V2V Congestion Control in lab – Critical BSM broadcast

Most of the test setup and test steps for this test case, 8.2.2, is the same as for 8.2.1. Therefore, only key differences are described in the following subsections.

8.2.2.1 Background

Same as 8.2.1.1 except for the following:

The purpose of this test is to verify that C-V2X devices can transmit and receive BSM messages, **with critical priority**, over the PC5 interface in a congestion challenged channel.

In the following lab tests, we start with the equivalent load of **20** devices and increase gradually up to N devices.

8.2.2.2 Assumptions

Same as 8.2.1.2

8.2.2.3 Setup

Same as 8.2.1.3 except for the following…

The two devices under test, DUT1 and DUT2, send BSM messages as in 8.2.1.3. While most of the messages are regular BSM messages, a subset of the sent BSM messages are **critical** ones as detailed below. (As in 8.2.1.3 the REF devices provide the congested environment, and they send only regular BSM messages, not critical BSM messages.)

- Settings on Device 1 (DUT1) and Device 2 (DUT2):
  - Same as in 8.2.1.3 except as described below
  - BSM messages are sent according to the same cadence as described in 8.2.1.3. The only difference is that **critical** BSM messages (i.e. priority 7) are sent at random occasions (in place of regular BSM messages) to simulate the event of incident. More specifically:
    - At a random time the device starts sending BSM messages with critical priority instead of regular priority. I.e. instead of sending a regular BSM message once every 100ms, it sends a critical BSM message once every 100ms.
    - The device continues to do this for a total of five seconds.
    - At that point the device reverts to sending the BSM messages with regular priority.

- Adjustable attenuator ("Variable Attenuator" at far right side of diagram in Figure 7):
  - Same as specified in 8.2.1.3

- Settings on the reference devices:
  - Same as specified in 8.2.1.3. This includes the fact that the reference devices will send only regular BSM messages (no critical ones).

- Data Collection at DUT1 and DUT2:
  - Same as specified in 8.2.1.3 with the additions listed below
  - Priority (critical or regular) for each transmitted packet
  - Priority (critical or regular) for each received packet

- Data Collection at each reference device:
  - Same as specified in 8.2.1.3

8.2.2.4 Test Execution

The overall idea of the testing is the same as in 8.2.1.4. The "Overview" from 8.2.1.4 is repeated here:

> With the reference devices creating a congested environment, the PER between the DUTs (DUT1 and DUT2) is observed as the "distance" between them is gradually increased by adjusting the attenuation. This test is repeated with an increasing quantity of reference devices. All of this testing is done first with congestion control disabled and then with it enabled.

The main differences, as compared to 8.2.1.4, are as follows:
a) At random times, BSM messages are sent as critical instead of regular, as previously discussed.

b) Different quantities of reference devices are used.
c) The testing is done until PER reaches 100% for both critical and regular BSM messages.

The following is the complete set of test execution steps.

1. Setup the test bed as explained above, where the total quantity of reference devices is 20.
2. Set “Variable Attenuator” (at far right side of diagram in Figure 7) to 0 dB to simulate a short distance between the DUTs.
3. Start transmission at all reference devices (regular BSM broadcast).
4. Start transmission at DUT1 and DUT2 (BSM broadcast). Normally the BSM messages of a given DUT shall be sent with regular priority, but at times they shall instead be sent with critical priority, according to the following:
   - At a random time the device starts sending BSM messages with critical priority instead of regular priority.
   - The device continues to do this for a total of five seconds.
   - At that point the device reverts to sending the BSM messages with regular priority.

   This period of critical BSM sending shall be repeated, for a total of ten five-second periods of critical BSMs.
5. Record to a log file the statistics and KPIs as defined in this section for DUT1, DUT2, and the reference devices.
   NOTE: Logging/saving of all KPIs shall be done for at least one reference device. Logging/saving is recommended for all reference devices as far as practicable, for additional analysis.
6. Calculate the PER between the two DUTs at each of DUT1 and DUT2.
   NOTE: Do these calculations separately for critical and regular BSM messages.
7. Increase the attenuation at “Variable Attenuator” (at far right side of diagram in Figure 7) by 10 dB to simulate an increase in distance between the DUTs.
8. Repeat steps 5 through 7 until the PER between DUT1 and DUT2 reaches 100%. PER shall be considered separately for critical BSM messages and regular BSM messages.
9. Increase the quantity of reference devices by eleven, and start transmission (regular BSM broadcast) on these four additional reference devices.
10. Set “Variable Attenuator” (at far right side of diagram in Figure 7) to 0 dB to simulate a short distance between the DUTs.
11. Repeat steps 5 through 10 until the quantity of used reference devices is “N” as defined in section 8.2.1.1.

8.2.2.5 Unique Tests to be Conducted

Run this test as described in 8.2.2.4 using two C-V2X DUTs and up to N reference devices with special configuration as explained above, so that 100% PER between DUT1 and DUT2 is achieved for both critical BSM messages and regular BSM messages. The test in 8.2.2.4 shall be run two times as follows:

- All devices (DUT1, DUT2, reference devices) having congestion control switched off
- All devices (DUT1, DUT2, reference devices) having congestions control switched on

8.2.2.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table.

Table 11: Required Documentation

Atten. value between DUTs (dB)	No. of REF devices	No. of Transmitted pkts				No. of Received pkts				Calculated at Receiver					
		DUT1		DUT2		DUT1		DUT2		PER % at DUT1		PER % at DUT2		%age of packets meeting IPG threshold (histo-gram of IPG)	%age of packets meeting Latency threshold (histo-gram of delay)
		Crit. BSM	Reg. BSM	Crit. BSM	Reg. BSM	Crit. BSM	Reg. BSM	Crit. BSM	Reg. BSM	Crit. BSM	Reg. BSM	Crit. BSM	Reg. BSM		
0	20														
10															
20															
30															
40															
…															
0	31														
10															
20															
30															
40															
…															
0	…														
10															
20															
30															
40															
…															

Additionally, extract the following KPIs from the logs of each DUT and from the logs of at least one reference device with special configuration:

- Channel Busy Ratio (CBR)
- DUT TX power
- BSM Packet transmission rate
- Number of PSSCH resource blocks assigned to DUT
- MCS Range
- PSCCH and PSSCH BLER to capture hidden node scenario

8.2.2.7 Evaluation Criteria

The discussion in 8.2.1.7 applies here. In addition the differences for critical BSM vs. regular BSM should be considered.

8.3 Adjacent/Non-Adjacent Channel Interference Lab Test

The following test cases are recommended to be performed. For completeness all recommended interference and co-existence tests are listed below, with a designation of which tests are recommended for (Lab), (Field) or (Both) environments.

- (Lab) External Interference
  - Robustness to external caused in-band interference, at various positions inside the ITS channel, with bandwidths of 200 kHz, 500 kHz, 1 MHz, 2 MHz, 5 MHz (section 8.3.1)
  - Robustness to external caused in-band interference, starting at the guard band of the ITS channel, with bandwidths of 50 kHz, 100 kHz, 200kHz, 300kHz, 400kHz, 500kHz, 600kHz, 700kHz, 800kHz, 900kHz, 1MHz (section 8.3.2)

- (Lab) Intra System Interference Testing
  - Hidden Node Scenario (section 8.3.3)
  - Interference caused by Near-Far Effect (section 8.3.4)

- (Both) Inter System Co-Existence Testing
  - Co-existence with Wi-Fi 80 MHz bandwidth in UNII-3 (section 9.1.3)
  - Co-existing C-V2X with adjacent DSRC carrier (e.g. impact of communication in channel 174 to 172 channel) (section 9.1.4)

  These two test cases are described in detail in the indicated sections of Chapter 9 for a field environment. All of them can also be tested in a lab environment by adapting these sections, where an over-the-air (rather than cabled) testing approach is recommended; the main adaptation is the use of attenuators to simulate physical distance and thus reduce the physical area needed to emulate the real environment.

- Optional: Inter System Co-Existence Testing in same frequency band, same channel
  - As per November 2017 there is no final standards specification for C-V2X sharing the same channel with DSRC. Therefore, this test-case is noted for completeness but not developed in this document version.

While all of the above test cases are relevant for actual deployments, external in-band interference tests are recommended to be performed in a lab environment only, due to the ability to have the environment easily created and fully controlled.

The working assumption for the Inter System co-existence tests is that there should not be significant impact on C-V2X performance in the defined channel under such conditions. Therefore, it is recommended to set up the tests first in a field environment, providing maximum real-environment effects.

In the remainder of this section (8.3) the focus is only on interference test procedures performed in the lab in the cabled RF environment, where interference characteristics will be fully controllable with regards to time domain, frequency domain and amplitude.

External Interference is a term used to define any component in the target frequency spectrum (e.g. channel 172, where the spectrum power density is higher than the calculated thermal background noise) which is not produced by other users employing the same or alternative technologies collocated in the same frequency band (channel).

The variety of external interference sources is almost endless. It may vary depending on the geographical region and RF environment and may have different characteristics in the time and frequency domains. A large number of interferers often share common characteristics and can be roughly classified into the following categories:

a) Noise and Spurious Emissions

b) Jammers and Deliberate Interference

c) Intermodulation and Harmonics

d) Cable Leakage

e) Unlicensed or Wrong Band Operations

Additional information outlining the above categories:

a] Noise and Spurious Emissions

The interference commonly arises from unwanted or spurious transmission effects. Electrical noise sources tend to be from a few KHz to MHz wide and periodic in frequency and/or time. Typical examples are emissions from electric motors, welding equipment, vehicle ignition systems, faulty transformers/ballasts, etc.

Electrical noise shows up as jumps in the noise floor or as a wide, random spectral pattern.

b] Jammers and Deliberate Interference

There are also cases of deliberate interference.

- Deliberate wideband interferers are known as jammers: devices designed to limit or deny the ability to use a certain frequency range by raising the noise floor to a high level (typically around –50 dBm in the affected area). Jammers generate a wide, strong, continuous signal.
- Deliberate narrowband interference is usually unlicensed/pirate analogue modulated voice signals transmitted in licensed bands of cellular technologies.

c] Intermodulation and Harmonics

Harmonics are a normal by-product of almost all RF transmitters. A harmonic is a copy of the fundamental signal appearing at a whole number multiple of the original frequency. In the case of channel 172, a potential interferer may come from frequencies around 2930MHz or from band 1953MHz (which overlaps with Band1 according to 3GPP TS 36.101). The level of harmonics normally decreases as the frequency increases.

Interference due to intermodulation can appear when high-power transmitters share an antenna or feeder line. It is caused by the nonlinear behavior of corroded metals in RF joints, so for C-V2X technology the probability for strong intermodulation interference is lower.

d] Cable Leakage

Cable Leakage occurs when the RF signals used in e.g. cable television systems escape from the shielded cables and devices that carry them. Since the frequencies used in cable television systems can extend up to 1 GHz, there is a small probability that this will affect the C-V2X spectrum.

e] Unlicensed or Wrong Band Operations

This kind of interference is caused by the use of transmitters designed for use in countries/regions with different frequency allocations.

Based on the description above, the variation of external interference sources, the characteristics of interference and the fact that the variety of interference is almost endless, one test case group is defined in general to test the robustness of the system to different characteristics of external interference in a simulated cabled environment, isolated from other external interference.

The test procedures are described as C-V2X test procedures, however, it is straightforward to convert them to another V2X point-to-point radio technology (e.g., IEEE 802.11p).

8.3.1 Cabled Transmission and Reception Test with Simulated External Interference: flat characteristics, constant in time, occupying part of ITS channel (e.g. channel 172)

8.3.1.1 Background

The purpose of this test is to test robustness to external interference which has flat spectrum density, varying bandwidths, and is constant in time.

The goal is to verify that C-V2X devices can transmit and receive C-V2X messages over the PC5 interface with an interference model being applied between the transmit and receive C-V2X devices in order to simulate potential external interference in the system with pre-defined characteristics.

8.3.1.2 Assumptions

The operating system time of both the transmitter and receiver boxes is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms.

The testing environment is isolated from other external interference sources.

Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

8.3.1.3 Setup

This test uses a lab cabled setup as shown in Figure 8. A signal generator (SigGen) is used to model different characteristics of potential interference in a 10 MHz channel bandwidth. Device 2 (receiver), also known as DUT, is configured to receive data from Device 1 on the same impaired channel.

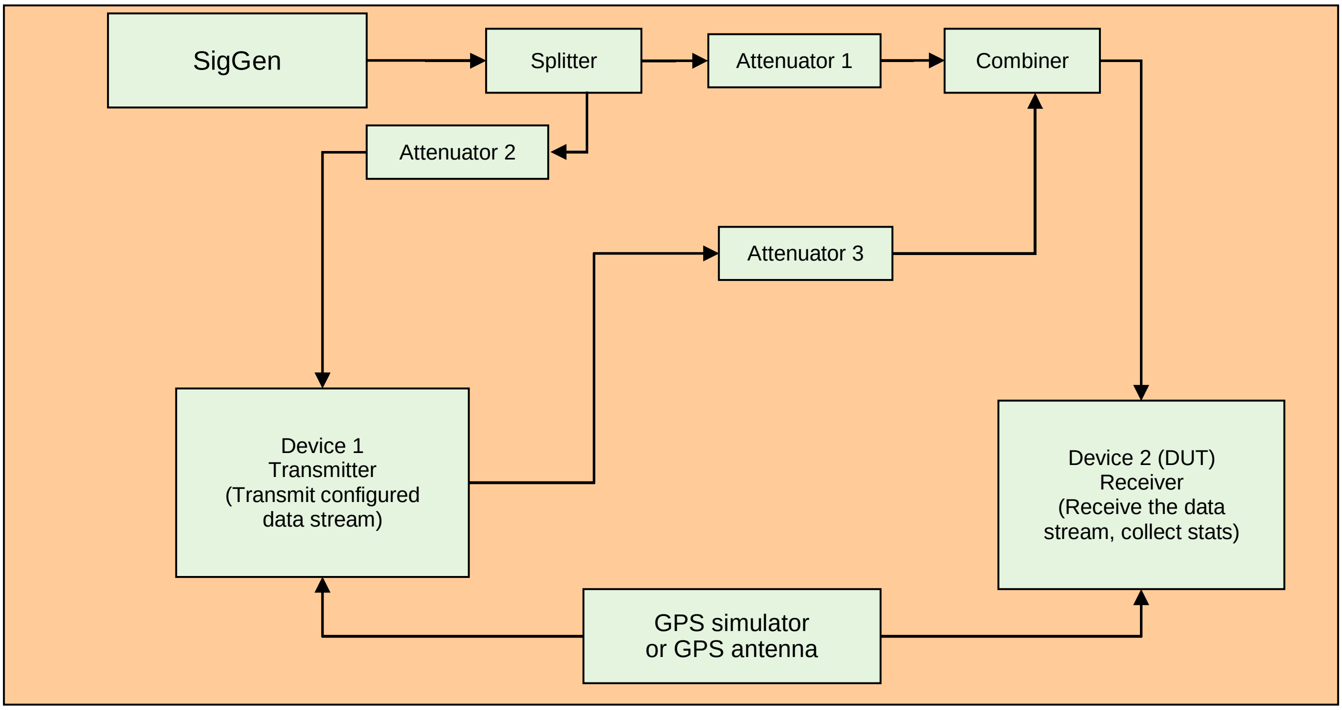


Figure 8: Test Setup

- Channel impairment settings on the Signal Generator (SigGen) are configured to emulate pre-defined interference with the following characteristics:
    - Flat characteristic, constant power spectral density within the predefined bandwidth
    - Bandwidth of the interference signal defined in Table 12 with the center frequency of the signal defined in Figure 9
    - Attenuator 1 is set to ensure that SigGen TX power at DUT input is -40 dBm.

- Testing will be done with the interference source (SigGen) located in two different positions[2]:
    - Interference source close to the RX side (Device 2)
    - Interference source midway between TX side (Device 1) and RX side (Device 2), so that both devices are affected[3]

- Settings on Device 1 (Transmit Radio):

    - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)

    - Packet length of 150 – 190 bytes

    - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10MHz

    - Appropriate transmit power and fixed attenuation added (Attenuator 3) to ensure that Device 1 TX power at DUT input is -50 dBm

[2] SigGen will not be physically moved. Rather, the varying positions of SigGen will be simulated by adjusting Attenuator 1 and Attenuator 2.
[3] Although Device 1 (TX side) does not receive the data stream, its behavior as a transmitter is affected by the signal received from SigGen..

Figure 9: Interference definition in the Channel 172

- Settings on the Device 2 (Receive Radio):
  - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
  - All measurements of receiving side performance are done on this device.
- Data Collection at TX (Device 1):
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet
- Data Collection at RX (Device 2):
  - OS timestamp for each received packet
  - Sequence number of each received packet
  - Receive signal power for each received packet

Table 12: Interference characterization definition

Signal Generator Setting		
Interference Bandwidth [MHz]	**Position Numbers**	**Number of Iterations**
0.2	1, 2, 3	100
0.5	1, 2, 3	50
1	1, 2, 3	25
2	1, 2, 3	10
5	1, 2, 3	10

8.3.1.4 Test Execution

Note: Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

1. Configure the Transmit Device (Device 1) with the data stream of interest: Application layer message (e.g. BSM) to be sent periodically every 100ms. Packet length shall be such that there is a one-to-one correspondence between packet and message; the packet size should remain constant throughout the test.
2. Set the Signal Generator to produce zero power.

3. Set the transmit power for the Transmit device (Device 1) to an appropriate level to fulfill the following requirements.

4. Set Attenuator 3 to an attenuation value such that the receive signal power measured at DUT input is -50 dBm.

5. Set the transmit power for the Transmit device (Device 1) to zero (e.g. by turning the device off).

6. Configure the Signal Generator to generate a pre-defined interference of 200 kHz bandwidth with center frequency defined in Figure 9 as position 1.

7. Set the attenuation values on Attenuator 1 and Attenuator 2 according to the first row of Table 13.

Table 13: Interference source position settings

Interference source position settings		
Interference source	**Attenuator 1**	**Attenuator 2**
Interference source is close to RX device (Device 2). TX device (Device 1) is minimally impacted by interference source.	Setting to achieve that interference power at DUT input is 10dB above Device 1 power at DUT input. I.e. receive signal power (of SigGen) measured at DUT input is -40 dBm.	MAX
Both devices are affected by interference source.	to achieve that interference power at DUT input is 10 dB above Device 1 power at DUT input. I.e. receive signal power (of SigGen) measured at DUT input is -40 dBm.	Setting to achieve that interference power at Device 1 input is same as interference power at DUT input. I.e. receive signal power (of SigGen) measured at Device 1 input is -40 dBm.

8. Set the transmit power for the Transmit device (Device 1) to an appropriate level to fulfill the following requirements.

9. For a time period of 60 seconds, record to a log file the following statistics:
   - For Device 1: OS timestamp for each TX packet, sequence number of each TX packet.
   - For DUT: OS timestamp for each RX packet, sequence number of each RX packet, receive signal power for each RX packet.

10. Repeat step 9 for a total of “n” iterations, according to column “Number of Iterations” of Table 12.

11. Repeat steps 5 through 10 for interference on position 2 from Figure 9.
    (I.e. in step 6 use the center frequency defined in Figure 9 as position 2.)

12. Repeat steps 5 through 10 for interference on position 3 from Figure 9.
    (I.e. in step 6 use the center frequency defined in Figure 9 as position 3.)

13. Repeat steps 5 through 12 for all bandwidth sizes from Table 12.
    (I.e. in step 6 use the bandwidth from column “Interference Bandwidth” from the next row of Table 12.)

14. Repeat steps 5 through 13 for the second set of interference source position settings.
    (I.e. in step 7 set the attenuation values on Attenuator 1 and Attenuator 2 according to the second row of Table 13.

8.3.1.5 Unique Tests to be Conducted

Run this test using:

Two (2) C-V2X devices for the test

8.3.1.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table.

Table 14: Required Documentation

Signal Generator Setting – Interference Bandwidth (MHz)	Signal Generator Setting – Position (i.e. Interference Center Frequency (1, 2, or 3)	SigGen Location (“RX” = close to RX device; “Mid” = halfway between TX and RX Devices)	No. of Transmitted pkts (summed across all 60-second iterations)	No. of Received pkts (summed across all 60-second iterations)	PER %	%age of packets meeting IPG threshold (histogram of IPG)	%age of packets meeting Latency threshold (histogram of delay)
			Measured at TX Device	Measured at RX Device	Calculated at RX Device	Calculated at RX Device	Calculated at RX Device
0.2	1	RX					
0.2	2	RX					
0.2	3	RX					
0.5	1	RX					
0.5	2	RX					
0.5	3	RX					
1	1	RX					
1	2	RX					
1	3	RX					
2	1	RX					
2	2	RX					
2	3	RX					
5	1	RX					
5	2	RX					
5	3	RX					
0.2	1	Mid					
0.2	2	Mid					
0.2	3	Mid					
0.5	1	Mid					
0.5	2	Mid					
0.5	3	Mid					
1	1	Mid					
1	2	Mid					
1	3	Mid					

Signal Generator Setting – Interference Bandwidth (MHz)	**Signal Generator Setting – Position (i.e. Interference Center Frequency (1, 2, or 3)**	**SigGen Location ("RX" = close to RX device; "Mid" = halfway between TX and RX Devices)**	**No. of Transmitted pkts (summed across all 60-second iterations)**	**No. of Received pkts (summed across all 60-second iterations)**	**PER %**	**%age of packets meeting IPG threshold (histogram of IPG)**	**%age of packets meeting Latency threshold (histogram of delay)**
			Measured at TX Device	**Measured at RX Device**	**Calculated at RX Device**	**Calculated at RX Device**	**Calculated at RX Device**
2	1	Mid					
2	2	Mid					
2	3	Mid					
5	1	Mid					
5	2	Mid					
5	3	Mid					

8.3.1.7 Evaluation Criteria

Evaluation criteria is to assess and compare TX & RX activity of the TX & RX devices, respectively, across the various interference scenarios. In addition, the purpose is to measure reported PER values for the RX device with the injected interference stream.

8.3.1.8 Estimated Time to Complete

Table 15: Completion Time

Task	**Estimated Time**	**Notes**
Test setup		
Test execution		
Test analysis		
Total		

8.3.2 Cabled Transmission and Reception Test with Simulated External Interference: flat characteristics, constant in time, starting from guard band occupying part of given ITS channel (e.g. channel 172)

8.3.2.1 Background

The purpose of this test is to test robustness to external interference which has flat spectrum density, varying bandwidths, and is constant in time, where the external interference is starting from the guard band of channel 172.

The goal is to verify that C-V2X devices can transmit and receive C-V2X messages over the PC5 interface with an interference model being applied between the transmit and receive C-V2X devices in order to simulate potential external interference in the system with pre-defined characteristics.

8.3.2.2 Assumptions

The operating system time of both the transmitter and receiver boxes is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms.

The testing environment is isolated from other external interference sources.

Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

8.3.2.3 Setup

This test uses a lab cabled setup as shown in Figure 10. A signal generator (SigGen) is used to model different characteristics of potential interface in a 10 MHz channel bandwidth. Device 2 (receiver), also known as DUT, is configured to receive data from Device 1 on the same impaired channel.

- Channel impairment settings on the Signal Generator (SigGen) are configured to emulate pre-defined interference characterization:
  - Flat characteristic, constant power spectral density within the predefined bandwidth
  - Bandwidth of the interference signal defined in Table 16 with the center frequency of the signal defined in Figure 11
  - Attenuator 1 is set to ensure that SigGen TX power at DUT input is -40 dBm.

- Testing will be done with the interference source (SigGen) located in two different positions[4]:
  - Interference source close to the RX side (Device 2)
  - Interference source midway between TX side (Device 1) and RX side (Device 2), so that both devices are affected[5]

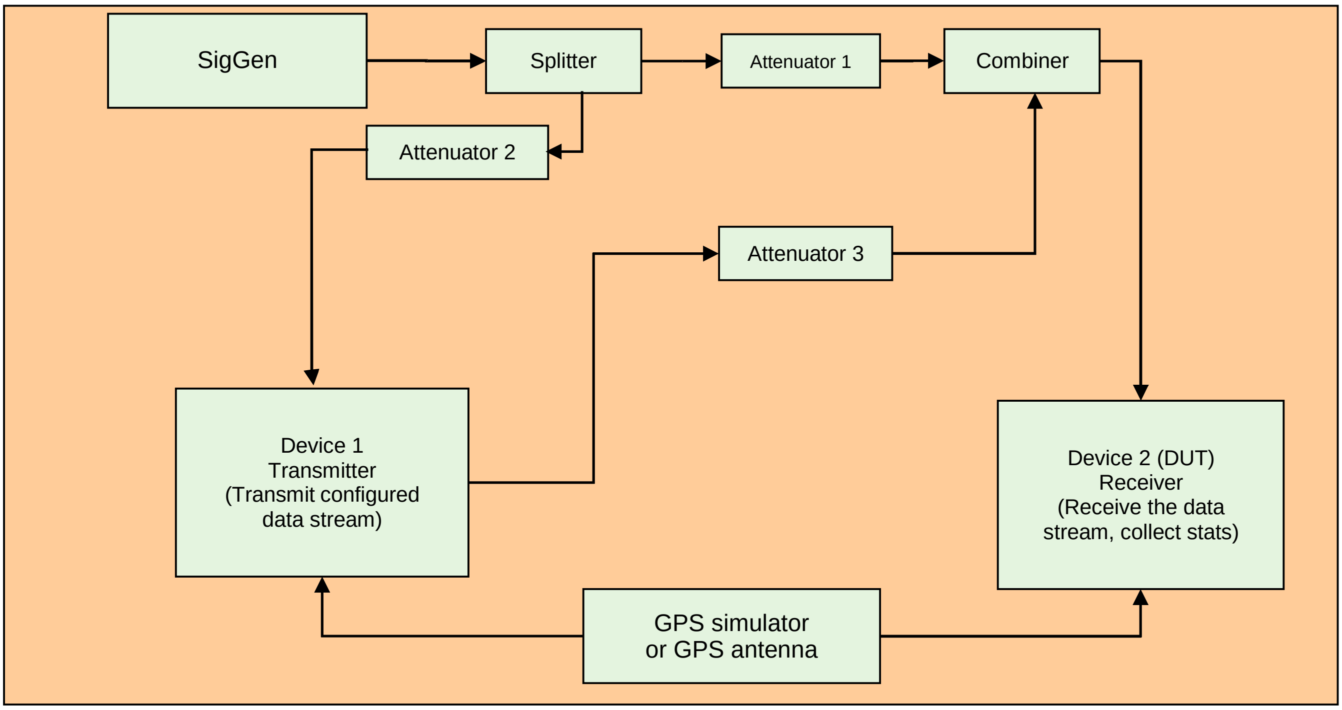


Figure 10: Test Setup

- Settings on Device 1 (Transmit Radio):

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[4] SigGen will not be physically moved. Rather, the varying positions of SigGen will be simulated by adjusting Attenuator 1 and Attenuator 2.

[5] Although Device 1 (TX side) does not receive the data stream, its behavior as a transmitter is affected by the signal received from SigGen..

- SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
- Packet length of 150 – 190 bytes
- Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
- Appropriate transmit power and fixed attenuation added (Attenuator 3) to ensure that Device 1 TX power at DUT input is -50 dBm

Figure 11: Interference position in Channel 172

- Settings on the Device 2 (Receive Radio):
  - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
  - All measurements of receiving side performance are done on this device.
- Data Collection at TX (Device 1):
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet
- Data Collection at RX (Device 2):
  - OS timestamp for each received packet
  - Sequence number of each received packet
  - Receive signal power for each received packet

Table 16: Interference characterization definition

Signal Generator Setting	
Interference Bandwidth [MHz]	**Number of Iterations**
0.05	100
0.1	100
0.2	100
0.3	100
0.4	100
0.5	100
0.6	100

0.7	100
0.8	100
0.9	100
1	100

8.3.2.4 Test Execution

Note: Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees)

1. Configure the Signal Generator to generate a pre-defined interference of 50 kHz bandwidth (subsequently referred to as “Interference_Bandwidth") with a center frequency of (5855MHz + Interference_Bandwidth/2).

2. Set the attenuation values on Attenuator 1 and Attenuator 2 according to the first row of Table 17.

Table 17: Interference source position settings

Interference source position settings		
Interference source	**Attenuator 1**	**Attenuator 2**
Interference source is close to RX device (Device 2). TX device (Device 1) is minimally impacted by interference source.	Setting to achieve that interference power at DUT input is 10dB above Device 1 power at DUT input. I.e. receive signal power (of SigGen) measured at DUT input is -40 dBm.	MAX
Both devices are affected by interference source.	Setting to achieve that interference power at DUT input is 10 dB above Device 1 power at DUT input. I.e. receive signal power (of SigGen) measured at DUT input is -40 dBm.	Setting to achieve that interference power at Device 1 input is same as interference power at DUT input. I.e. receive signal power (of SigGen) measured at Device 1 input is -40 dBm.

3. Set the transmit power for the Transmit device (Device 1) to fulfill requirements stated in Table 17.
4. For a time period of 60 seconds, record to a log file the following statistics:
   - For Device 1: OS timestamp for each TX packet, sequence number of each TX packet.
   - For DUT: OS timestamp for each RX packet, sequence number of each RX packet, receive signal power for each RX packet.
5. Repeat step 9 for a total of "n" iterations, according to column "Number of Iterations" of Table 16.
6. Repeat steps 5 through 10 for all bandwidth sizes from Table 16.
   (I.e. in step 6 use Interference_Bandwidth from column "Interference Bandwidth" from the next row of Table 16.)
7. Repeat steps 5 through 11 for the second set of interference source position settings.
   (I.e. in step 7 set the attenuation values on Attenuator 1 and Attenuator 2 according to the second row of Table 17.)

8.3.2.5 Unique Tests to be Conducted

Run this test using:

Two (2) C-V2X devices for the test

8.3.2.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table.

Table 18: Required Documentation

Signal Generator Setting – Interference Bandwidth (MHz)	Signal Generator Setting – Interference Center Frequency (MHz)	SigGen Location (“RX” = close to RX device; “Mid” = halfway between TX and RX Devices)	No. of Transmitted pkts (summed across all 60-second iterations)	No. of Received pkts (summed across all 60-second iterations)	PER %	%age of packets meeting IPG threshold (histogram of IPG)	%age of packets meeting Latency threshold (histogram of delay)
			Measured at TX Device	Measured at RX Device	Calculated at RX Device	Calculated at RX Device	Calculated at RX Device
0.05	5.880	RX					
0.1	5.905	RX					
0.2	5.955	RX					
0.3	6.005	RX					
0.4	6.055	RX					
0.5	6.105	RX					
0.6	6.155	RX					
0.7	6.205	RX					
0.8	6.255	RX					
0.9	6.305	RX					
1	6.355	RX					
0.05	5.880	Mid					
0.1	5.905	Mid					
0.2	5.955	Mid					
0.3	6.005	Mid					
0.4	6.055	Mid					
0.5	6.105	Mid					
0.6	6.155	Mid					
0.7	6.205	Mid					
0.8	6.255	Mid					
0.9	6.305	Mid					
1	6.355	Mid					

8.3.2.7 Evaluation Criteria

Evaluation criteria is to assess and compare TX & RX activity of the TX & RX devices, respectively, across the various interference scenarios. In addition, the purpose is to measure reported PER values for the RX device with the injected interference stream.

8.3.2.8 Estimated Time to Complete

Table 19: Completion Time

Task	Estimated Time	Notes
Test setup		
Test execution		
Test analysis		
Total		

8.3.3 Hidden Node Scenario

8.3.3.1 Background

The purpose of this test is to assess the performance of a C-V2X device during a resource collision scenario (hidden node phenomenon). The hidden node scenario is mainly reproducible with a highly congested environment. An example is with OBUs that are located at opposite edges of one OBU's communication range. Those devices cannot sense each other and can transmit on the same subframe to the OBU in the middle which will produce a collision at the latter.

8.3.3.2 Assumptions

Lab setup with cabled or over-the-air RF environment: The test case is specified with a cabled environment in sections 8.3.3.3-8.3.3.7, but it can also be adapted to an RF laboratory environment.

This test case focuses on Mode 4 operation where no LTE coverage is available.

Devices are pre-configured with TX and RX resource pools. TX resource pools configuration should be identical (same TTI and RB configuration). (NOTE: The goal is to make the devices send at the same TTI (same 1ms) and using the same amount of resource blocks (in the frequency domain). Also the number of TTIs and RBs available should be as small as possible in order to get collisions in a small amount of iterations since a given device selects one of the available resources randomly.)

The operating system time of all the transmitter and receiver boxes is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms.

All devices operate in the same channel (e.g. 172).

8.3.3.3 Setup

Three C-V2X devices are considered with the setup described in the diagram below.

- Settings on Device 1 (DUT1):
  - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
  - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10MHz
  - Packet length of 150 – 190 bytes
  - Transmit power set at 20 dBm initially

- Settings on Device 2 (DUT2):
    - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
    - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
    - Packet length of standard BSM message
    - Transmit power set at 20 dBm initially

- Settings on Device 3 (DUT3):
    - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
    - All measurements of receiving side performance are done on this device.

- Data Collection at DUT1:
    - OS timestamp for each transmitted packet
    - Sequence number of each transmitted packet

- Data Collection at DUT2:
    - OS timestamp for each transmitted packet
    - Sequence number of each transmitted packet

- Data Collection at DUT3:
    - OS timestamp for each received packet
    - Sequence number of each received packet
    - Receive signal power for each received packet

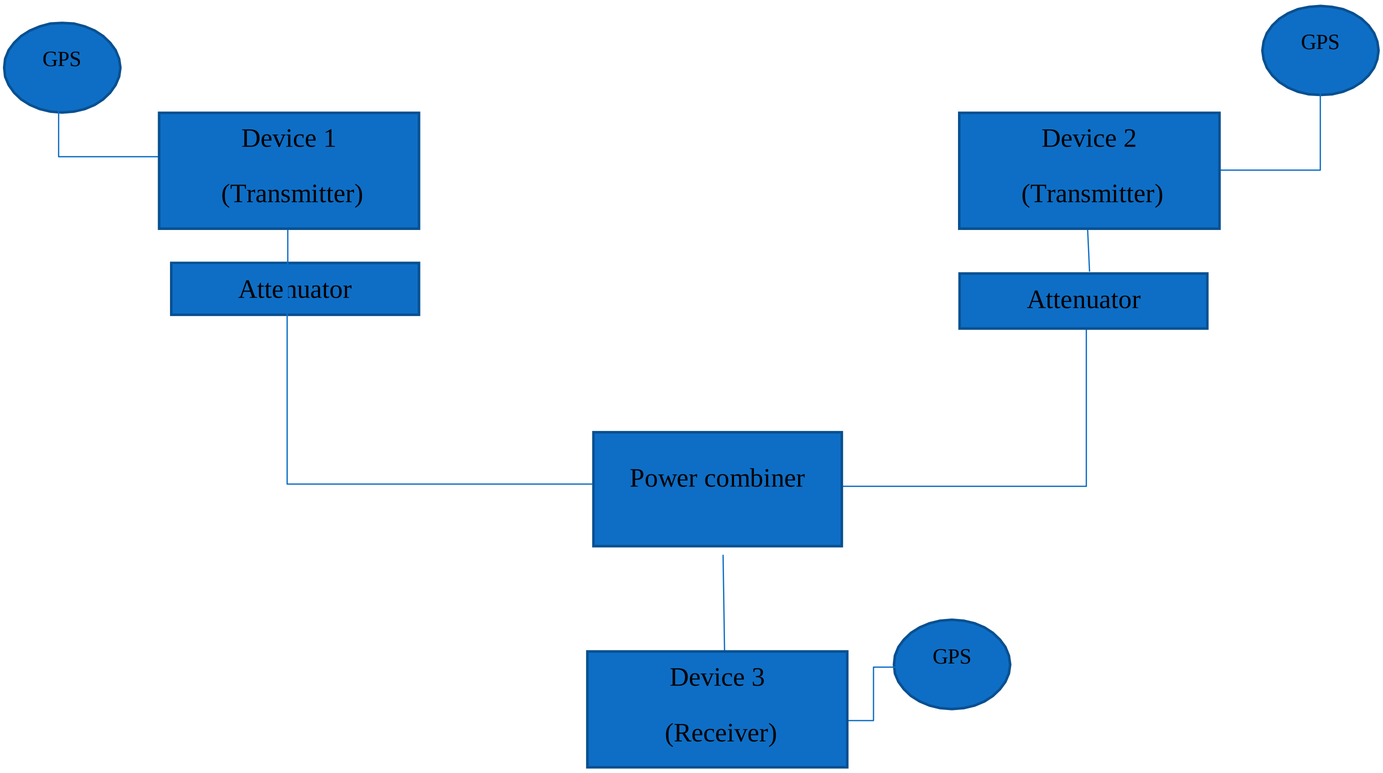

Figure 12: Hidden Node Scenario Test Setup

8.3.3.4 Test Execution

Note: Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

1. Configure Device 1 so that the transmit power fulfills the below stated requirements (this will remain constant throughout the test).

2. Configure Device 2 so that the transmit power fulfills the below stated requirements (this will remain constant throughout the test).

3. Calculate the insertion loss between Device 1 and Device 3 by setting Attenuator 1 to 0dB and then measuring the loss between Device 1 and Device 3 with all cables in place. This value will be the fixed insertion loss of the cables/attenuator/combiner setup for these devices.

4. Adjust the setting of Attenuator 1 to yield an overall path loss (insertion loss plus attenuator value) of 45dB between Device 1 and Device 3.

5. Calculate the insertion loss between Device 2 and Device 3 by setting Attenuator 2 to 0dB and then measuring the loss between Device 2 and Device 3 with all cables in place. This value will be the fixed insertion loss of the cables/attenuator/combiner setup for these devices.

6. Adjust the setting of Attenuator 2 to yield an overall path loss (insertion loss plus attenuator value) of 45dB between Device 1 and Device 3.

7. Power up Device 3.

8. Record the statistics as mentioned below on all the C-V2X devices for a period of 10 minutes:

    a. Device 1 and Device 2:
    - OS timestamp for each TX packet
    - Sequence number of each TX packet

   b. Device 3:
      - OS timestamp for each RX packet
      - Sequence number of each RX packet
      - Receive signal power for each RX packet

9. Repeat step 8 for a total of 10 executions.

8.3.3.5 Unique Tests to be Conducted

Run this test using:

1. Three (3) C-V2X devices.

8.3.3.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table (one row per ten minute test).

Table 20: Required Documentation

	No. of Transmitted pkts (total for the 10 min test)		**No. of Received pkts (total for the 10 min test)**		**PER % Calculated at Receiver (Device 3)**	
Execution #	**Transmit Device 1**	**Transmit Device 2**	**Received at Device 3 from Device 1**	**Received at Device 3 from Device 2**	**For Packets from Device 1**	**For Packets from Device 2**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Measured Insertion Loss, Device 1 to Device 3 (dB)			**Attenuator 1 Value (dB)**			
Measured Insertion Loss, Device 2 to Device 3 (dB)			**Attenuator 2 Value (dB)**			

8.3.3.7 Evaluation Criteria

Evaluation criteria is to assess the performance in a collision challenged environment through assessment of colliding TTIs and RBs.

8.3.4 Near-Far Effect

8.3.4.1 Background

The purpose of this test is to assess the performance of C-V2X devices under the scenario in which a device receives a signal from two or more transmitters with different power levels. The power difference may occur even for two nearby transmitters, when one of them is obstructed. The problem becomes critical when a critical message is received with low power (example: obstructed vehicle behind the receiver vehicle), but the one received with high power (a transmitting vehicle at close proximity to the receiver vehicle) is containing only a regular event.

8.3.4.2 Assumptions

Lab setup with cabled or over-the-air RF environment. The test case is specified with a cabled environment in sections 8.3.4.3-8.3.4.7, but it can also be adapted to an RF laboratory environment.

This test case focuses on Mode 4 operation where no LTE coverage is available.

Devices are pre-configured with TX and RX resource pools. TX resource pools configuration should be identical (same TTI and RB configuration). (NOTE: The goal is to make the devices send at the same TTI (same 1ms) and using the same amount of resource blocks (in the frequency domain). Also the number of TTIs and RBs available should be as small as possible in order to get collisions in a small amount of iterations since a given device selects one of the available resources randomly.)

The operating system time of all the transmitter and receiver boxes is synchronized to a common clock (e.g., GPS) with an error of no more than 1ms.

All devices operate in the same channel (e.g. 172).

8.3.4.3 Setup

Three C-V2X devices are considered with the setup described in the diagram below.

- Settings on Device 1 (DUT1):
  - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalentto setting a periodic stream at 100ms period for other technologies)
  - Transmit BSM messages with regular priority
  - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
  - Packet length of standard BSM message

- Settings on Device 2 (DUT2):
  - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
  - Transmit BSM messages with regular priority, but some BSM messages with critical priority are interspersed, as follows:
    - Critical events are sent at random occasions during the test. Minimum five messages for each attenuation level setting.
  - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
  - Packet length of standard BSM message

- Settings on Device 3 (DUT3):
  - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz

  - All measurements of receiving side performance are done on this device.

- Data Collection at DUT1
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet

- Data Collection at DUT2
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet

- Data Collection at DUT3
  - OS timestamp for each received packet
  - Sequence number of each received packet
  - Receive signal power for each received packet

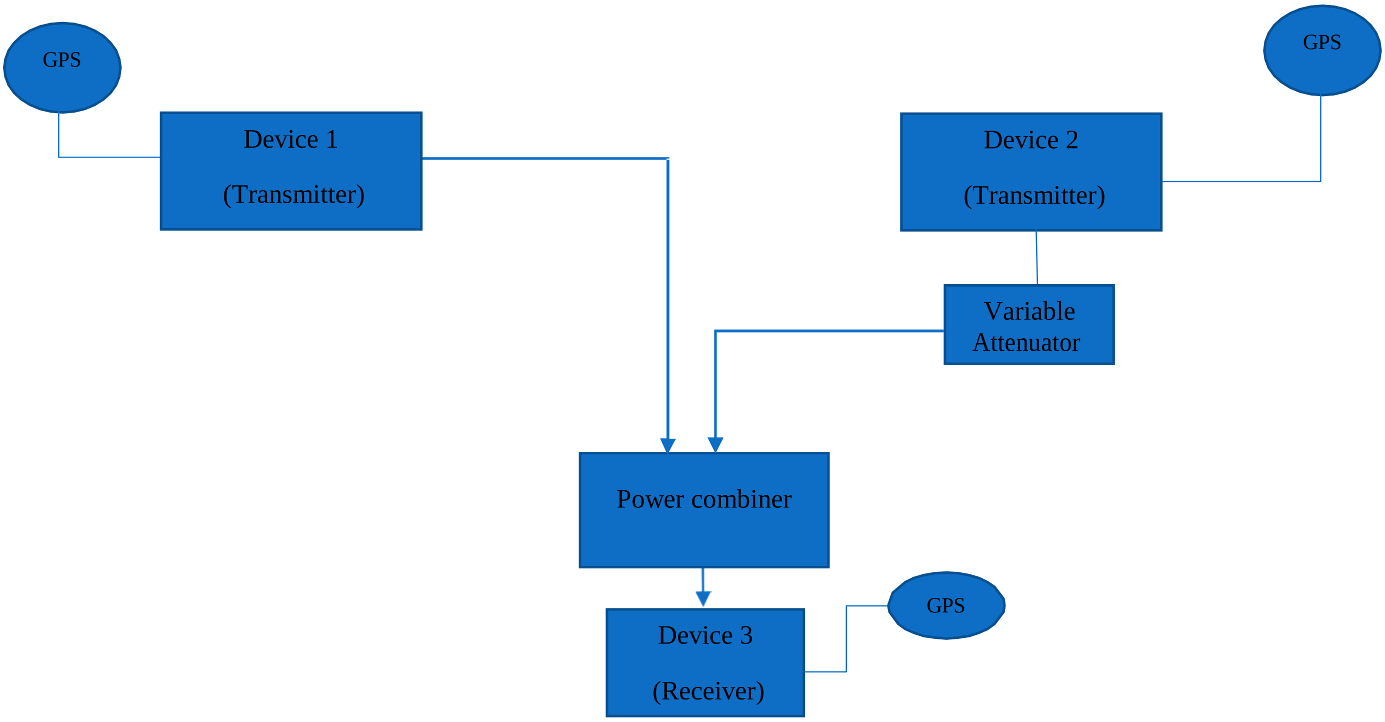

Figure 13: Near-Far Effect Test Setup

Note: For an equivalent test for near far effect, please see 3GPP 36.101, chapter 14.4.

8.3.4.4 Test Execution

Note: Tests should be conducted at room temperature (21 degrees Celsius +/- 5 degrees).

1. Power off Device 2.

2. Set the TX power of Device 1 so that the input power at Device 3 is -50 dBm. Record this TX power setting.
3. Power off Device 1.
4. Set the attenuation on Variable Attenuator to 0dB.
5. Power on Device 2 and set the TX power of Device 2 so that the input power at Device 3 is -50 dBm. Record this TX power setting.
6. Power on Device 1 and set the TX power of Device 1 to the value determined in Step 2.
7. Record the statistics as mentioned below on all the devices for a period of 10 minutes:
   NOTE: On Device 2, send some BSM messages with critical priority at random points during this 10 minutes. A minimum of five BSM messages shall be sent as critical.
   a. Device 1 and Device 2:
      - OS timestamp for each TX packet
      - Sequence number of each TX packet
   b. Device 3:
      - OS timestamp for each RX packet
      - Sequence number of each RX packet
      - Receive signal power for each RX packet
8. At Device 3, calculate the PER for packets sent by Device 1, as well as the PER for packets sent by Device 2.
9. Increase the attenuation on Variable Attenuator by a certain increment.
   - In the first few iterations, use five dB as the increment.
   - In later iterations, as the PER (observed in step 9) approaches 100%, use one dB as the increment.
10. Repeat steps 7 through 9 until the PER for packets sent by Device 2 reaches 100%.

8.3.4.5 Unique Tests to be Conducted

Run this test using:

Three C-V2X devices.

8.3.4.6 Required Documentation

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following table (one row per ten minute test).

Table 21: Required Documentation

Attenuator Value (dB)	No. of Transmitted pkts (total for the 10 min test)		No. of Received pkts (total for the 10 min test)		PER % Calculated at Receiver (Device 3)	
	Transmit Device 1	Transmit Device 2	Received at Device 3 from Device 1	Received at Device 3 from Device 2	For Packets from Device 1	For Packets from Device 2
0						
5						
10						
…						
Device 1 TX Power (dBm)						
Device 2 TX Power (dBm)						

8.3.4.7 Evaluation Criteria

Evaluation criteria is to assess the performance in terms of PER during near far scenario through assessment of colliding TTIs and adjacent RBs.

9 Test Cases – In-Vehicle Characterization

The following sections describe test cases to characterize in-vehicle device in terms of signal strength of the received signal as a function of distance and other environment dependent variables. In particular, the tests described in this section are focused on characterizing the impact of the environment on the PHY layer of radio technology. Evaluation measures shall reference industry standards, if available, for the given radio technology, such as IEEE 802.11p and SAE J2945/1 for the DSRC and 3GPP R14 / PC5-LTE for C-V2X.

Upon execution and collection of test log data from these test cases, analysis could be used to assist in calibrating the simulator's PHY channel model for the given radio technology. It should be noted that the channel model would change when the physical environment changes.

Prior to executing a field test described in Chapter 9, the radio band shall be checked for unwanted interferers (i.e. through connecting the car antennas to a spectrum analyzer.

9.1 Test Track

9.1.1 Ranging

9.1.1.1 Background

The following tests the performance characteristics of the radio technology in a dynamic outdoor environment over the full range communications. It will additionally provide the signal propagation data necessary to determine if a re-calibration and/or enhancement, based on occluded LOS, of the communications simulator is required.

Objective: Verify communication range under LOS and NLOS conditions.

Hypothesis: When the receive signal power is at or below sensitivity the PER of the short BSM-like periodic messages will start to degrade.

Scenario: A stationary and a moving vehicle (SV, MV) exchange BSM-like messages while MV is performing loops on a straight 2-lane road

Condition: Vary the transmit power of both devices

9.1.1.2 Assumptions

This set of tests is performed under "open sky" assumptions.

9.1.1.3 Setup

Following is the setup for this test:

- Hardware
  - Two (2) devices under test w/ internal or external GPS receiver
    - Each device has an external GPS antenna
    - Each device has an external communications antenna
    - Low loss cable (e.g., LMR200) to connect the device to the communications antenna
    - Other cable to connect to GPS antenna
  - Two (2) identical vehicles
    - Communications antenna placed at the apex of the vehicle roof
    - If the GPS antenna is in a housing separate from the communications antenna, place the GPS antenna on the vehicle roof such that it does not impede the forward and rearward communication path of the communications antenna

    Note: The Chapter 9.1.5 Antenna Characterization Tests details antenna requirements.

- Two (2) LOS blocking objects
  The size of the blocking object should be comparable in size to a typical light commercial (i.e. length 5.5 m (+/- 0.5m), height 2.5 m (+/- 20 cm), width 2 m (+/- 20 cm), vehicle or shipping containers.

Note: Because the shape of the LOS blocking objects affect the obstruction of the transmission, the detailed information of the LOS blocking objects should be provided with the test results.

- Device Configuration Setup
  - Both devices set up for receive and transmit capability
  - Each device configured for the standard 10 Hz transmit rate
  - GPS antenna offsets configured for each device
  - Each device configured to support logging

Note: Message size to be recorded.

- Environment
  - Test track which supports the SAE J2945/1 ‘Open Sky Test Conditions’ criteria.

9.1.1.4 Test Execution

The following steps should be performed for this test:

1. Stage the vehicles as shown in Figure 14 below
2. Power on devices
3. Ensure devices loaded with proper configuration (verify configuration file and make sure TX power is fixed)
4. Start the test on the devices and ensure
   a. The moving vehicle device is transmitting and receiving
   b. The static vehicle device is transmitting and receiving
   c. Both devices are logging

   Note: GPS initialization required. Moving the vehicle prior to testing may be required (i.e. to get correct heading data). Logging of transmitted messages is required for later data analysis.
5. As an initial assessment, drive the moving vehicle at a speed in which 500 samples are obtained per range step of 25 m. Notate the speed and follow that speed per steps 7-8.
6. Capture and record a full UTC timestamp

This will be used as the start time for the test to be used for calculating any metrics.

7. Slowly drive the moving vehicle away from the static vehicle at notated speed until it exceeds the communication range of the device
8. Slowly drive the moving vehicle back toward the static vehicle at notated speed until the range is close to 0 m
9. Repeat steps 5 to 7 ten times with the same speed
   Note: The number of repetitions may depend on MV velocity and transmission frequency.
10. Stop the test
11. Transfer log files for analysis
12. Ensure that a minimum of 500 samples per 25 m range bin are recorded
13. Repeat steps 1-10 with a LOS blocker as depicted in Figure 14 below and then again as in Figure 15 below.

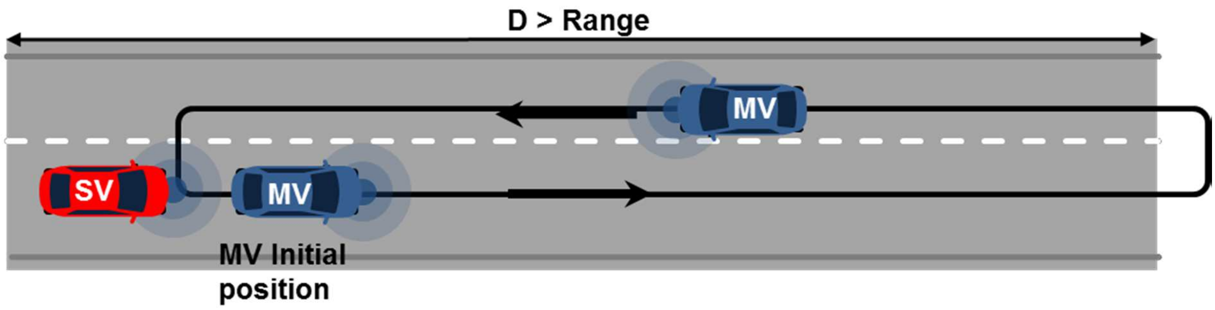

Figure 14: Ranging Setup

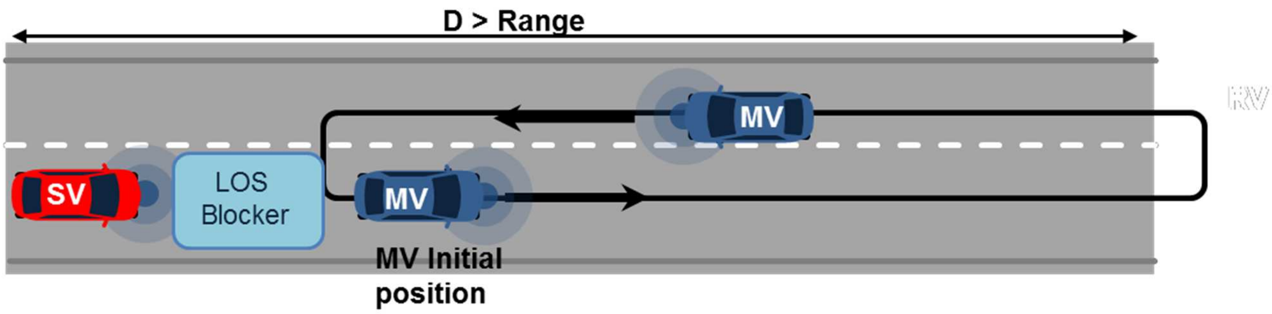

Figure 15: Ranging LOS Blocker Setup

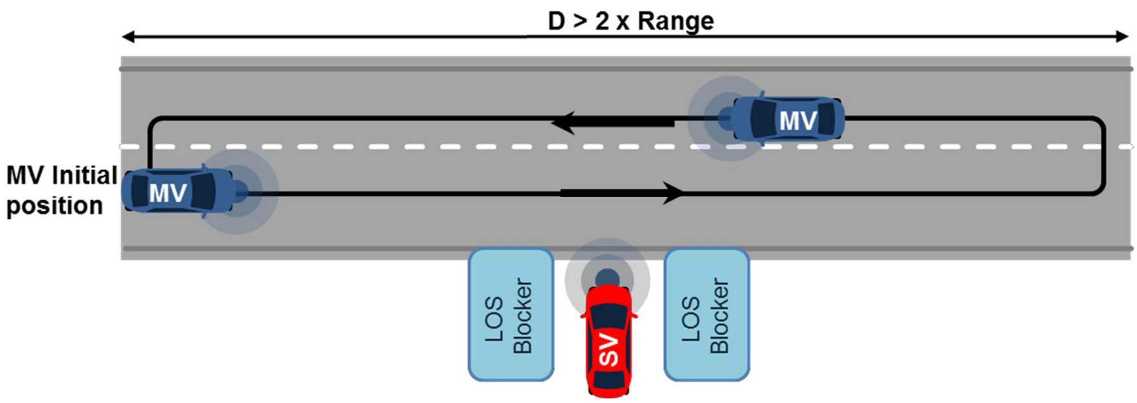

Figure 16: Ranging LOS Blocker Intersecting Setup

9.1.1.5 Unique Tests to be Conducted

Run this test two times using:

1. Two (2) V2X devices of the same type (C-V2C, DSRC or other) for one test
    a. Clear LOS
    b. Occluded LOS
        i. Approach/Depart
        ii. Intersecting
2. Repeat the test using the second transmit power setting (10 dBm)

9.1.1.6 Required Documentation

Following is the required documentation for this test:

- Plot of PER vs Range
- Plot of PER vs RSSI (DSRC)
- Plot of PER vs RSSI/RSRP (C-V2X)
- Plot of RSSI vs Range (DSRC)
- Plot of RSSI/RSRP vs Range (C-V2X)
- Plot Latency vs. Range
- Antenna characteristics

9.1.1.7 Evaluation Criteria

Compare performance between radio technologies based on the plots defined in the required documentation section. In addition, provided below are the evaluation criteria for DSRC in the clear LOS configuration.

The maximum Communication Range for each technology should be based on reaching at least 10% PER or less at the Maximum Distance.

Table 22: Ranging Evaluation Criteria

Metric	Evaluation Criteria	Notes
PER vs Range	≤ 10 % For all TX – RX ranges (it may be beneficial to set up the test range until ~100% PER is reached, e.g. 1000 m as a start)	PER should be evaluated across all ranges

9.1.1.8 Estimated Time to Complete

Table 23: Completion Time

Task	Estimated Time	Notes
Test setup	60 minutes	Done once per test type
Test execution	60 minutes	Per device type, test parameters (e.g., power setting)
Test Analysis	60 minutes	Includes file acquisition, script execution, metric generation and analysis
Total	180 minutes	

9.1.2 Congestion Control Field Test: Multi-Lane Line-of-Sight Highway (MH-LOS) [2]

For V2V applications to be effective and reliable, devices must be able to withstand a congested channel due to many radio devices communicating in a real-world environment. An example of this is a multi-lane highway traffic jam during rush hour in a major urban city. To support large-scale deployment of V2V safety communications, the communication system must be scalable to the extent that there is a reasonable expectation that the system will function and units communicate correctly in this challenging environment. This test allows for evaluation of the radio's ability to handle an increasing channel load by capturing PER, IPG, CBP/CBR, IA and device performance.

Upon execution and collection of test log data from these test cases, analysis could be used to assist in calibrating the simulator's channel congestion control model for the given radio technology.

The test procedure provided below has been adapted from the assessment of the DSRC device and can be referenced in V2V-Interoperability Project - Phase 2 Final Report Volume 1 [2].

9.1.2.1 Background

The following test will assess the transmit protocols between the same-technology V2X devices (DSRC or C-V2X) in an outdoor environment with clear LOS over the full range communications in the presence of a high density of simulated vehicles in a MH-LOS configuration.

Provided in the background subsections below are details regarding key items from the DSRC tests performed by CAMP.

9.1.2.2 Creating Channel Congestion by Emulation

To ensure that the channel is congested, the following strategy can be deployed to emulate as many vehicles as possible by the device. Note that the examples below are just used for illustration and further tuning can be used to obtain exact scaling:

- OBUs mounted to a cart which can hold K OBUs as shown in Figure 17 (for K=3)
  - The traffic environment assumed 5m for the vehicle length, and 1.5 vehicle lengths (i.e., 7.5m) for the space between vehicles
  - Each cart was intended to represent K vehicles comprising an 11m wide (i.e., 3 lanes) by 25m long area in the case when K=6.
- Each OBU was configured to emulate M OBUs by increasing their BSM TX rate to M x 10 Hz
  - At M-times BSM TX, each K-OBU cart performed virtually as K x M OBUs
  - Ensure that BSM generation is not synchronized, i.e. BSMs are generated at different points in time for each simulated vehicle
- Figure 18 shows the cart-to-vehicle equivalency, using a M-times TX rate (M=10), for thirty (K=3, M=10) vehicles comprising an 18m (i.e., 5 lanes) by 75m long area.

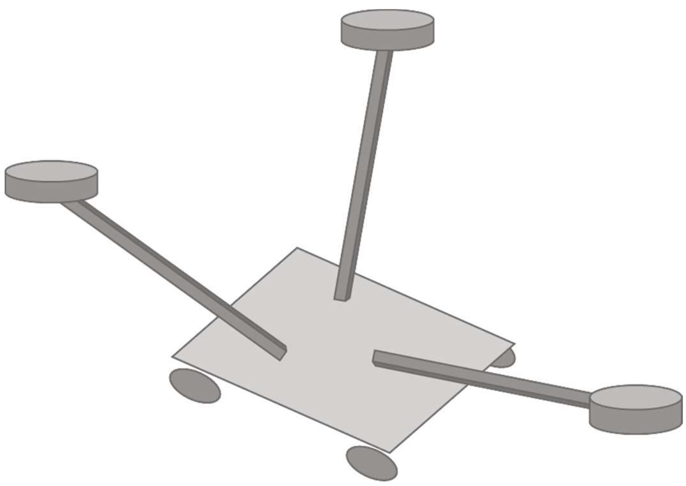

Figure 17: Static Cart – Example with 3 OBUs.

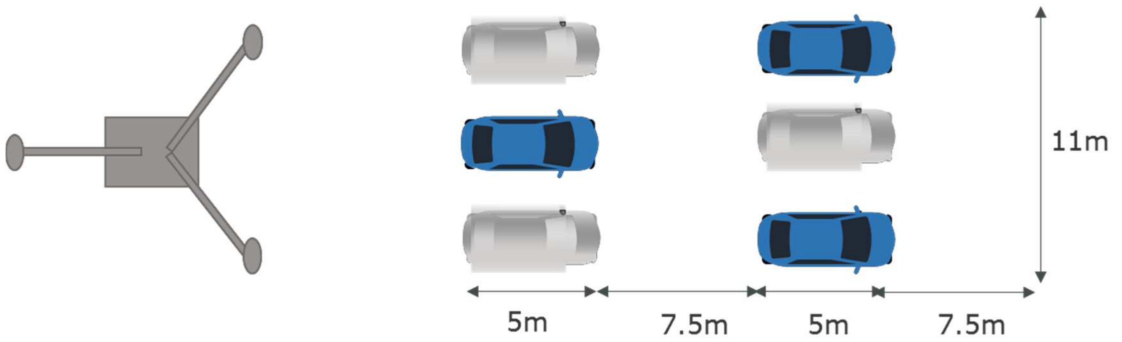

Figure 18: Cart to Vehicle Equivalency for three Vehicles

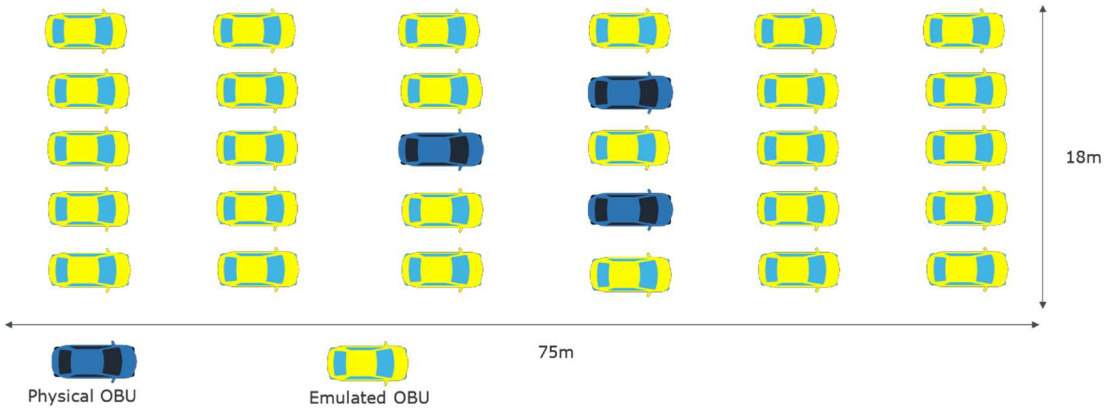

Figure 19: Cart to Vehicle Equivalency for Thirty Emulated Vehicles

9.1.2.3 Static OBU Cart Deployment

In this section a large scale test is described based on the building blocks explained in the previous section. The ideas are borrowed from [2], [3], and [4]. To ensure that the channel is congested across a wide range to allow for vehicle dynamics in a multi-lane highway line of sight (MH-LOS) environment, the following strategy can be deployed to emulate as many vehicles as possible by the device across a wide range:

- Per Figure 20 the carts can be placed in two rows on each side of a straight track and evenly spaced within each row (i.e., 75m from cart-to-cart within a given row), over a distance of 1200m.
  - The 75m cart-to-cart spacing is representative of the number of vehicles (e.g., 30) that could be expected to occupy that space within a heavily congested bumper-to-bumper vehicle traffic environment.
  - Row of carts are staggered by 37.5m from its adjacent row to obtain an even distribution of the channel communications.
  - Depending on the width of the test track the distance between adjacent rows of carts can be modified.
- With K OBUs per each of the N carts (KxN physical OBUs) and a M-times TX rate this allowed approximately K x M x N static OBUs to be emulated comprising twenty lanes of bumper-to-bumper traffic as shown in Figure 21.

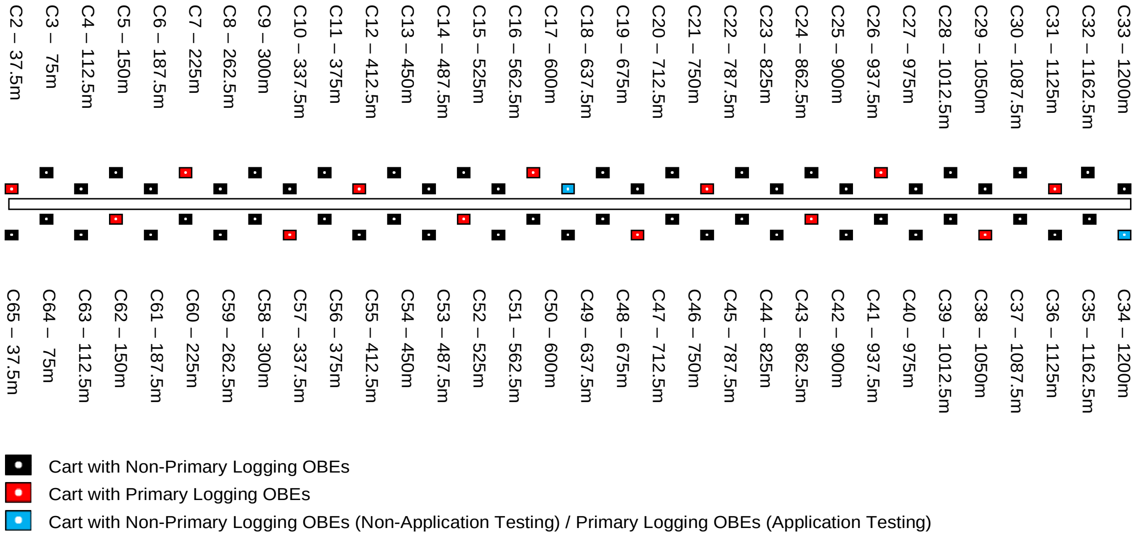

Figure 20: 400 OBU Testing – Static Cart Deployment [2]

Figure 21: Five-Times Transmit Rate Emulation Vehicle Density [2]

9.1.2.4 Hidden Node

The hidden node phenomenon may result from OBUs deployment location in the field. In this phenomenon, OBUs on opposite ends of the field test are outside of each other's transmission range and unable to hear from each other. Therefore, they experience different channel conditions and can get out of synch from a channel idle perspective. This may cause them to access the channel at the same time causing their transmissions to collide from the perspective of the OBUs in the middle.

In order to replicate this, data analyzed from the ranging test should be used to determine the maximum length of pod deployment, this way the devices in the middle of the test track will be subjected to the hidden node phenomenon.

9.1.2.5 Command and Control

To ensure testing was efficient, repeatable, and correct, communication with each of the OBUs from a single point needs to be developed ([2], [3], [4]).

9.1.2.6 Assumptions

It is assumed that the ability of the OBU to increase the TX frequency of the radio device to emulate multiple devices, effectively creates a level of channel congestion.

The placement of carts is at a range that creates the hidden node phenomenon.

9.1.2.7 Setup

Following is the setup for this test:

- Hardware
  - Command and Control System
    - Ability to adjust and verify configuration parameters across all OBUs
    - Ability to gather test data logs from all pods
  - TBD (n) OBU emulator carts (this depends on the number of devices per cart)
    - Each device has GPS antenna and communications antenna
    - Low loss cable (e.g., LMR200) to connect the device to the communications antenna
    - Other cable to connect to GPS antenna
    - Ability to execute command and control requests
  - Four (4) devices under test w/ internal or external GPS receiver
    - Each device has GPS antenna
    - Each device has communications antenna
    - Low loss cable (e.g., LMR200) to connect the device to the communications antenna
    - Other cable to connect to GPS antenna
  - Four (4) equivalent sedan-like vehicles
    - Communications antenna placed at the apex of the vehicle roof
    - If the GPS antenna is in a housing separate from the communications antenna, place the GPS antenna on the vehicle roof such that it does not impede the forward and rearward communication path of the communications antenna
- Device Configuration Setup
  - DUT configured for transmit and receive capability
  - DUT configured for 10 Hz transmit rate
  - DUT configured to support logging
  - DUT configured to a given TX protocol
  - OBU emulator TX rate stepped in intervals to emulate up to 2000 devices
- Environment
  - Test track which supports the SAE J2945/1 ‘Open Sky Test Conditions’ criteria.

9.1.2.8 Test Execution

The following steps should be performed for this test:

1. Stage the vehicles and OBU Emulators as shown in the figures below
2. Power on devices
3. Ensure devices loaded with proper configuration
4. Start the test on the devices and ensure
   a. All vehicles are transmitting and receiving

    b. Both devices are logging
5. Start the OBU emulator devices and ensure
    a. All vehicles are transmitting and receiving
    b. Number of devices seen match number of emulated
    c. All devices are logging
6. Capture and record a full UTC timestamp
    a. This will be used as the start time for the test to be used for calculating any metrics.
7. Begin driving the vehicles in a platoon maintaining the distance and travel speed of approximately 40 km/h
8. Repeat steps 5 to 7 two times
9. Stop the test
10. Transfer log files for analysis
11. Increase the OBU emulator TX rates
12. Repeat steps 1-11.

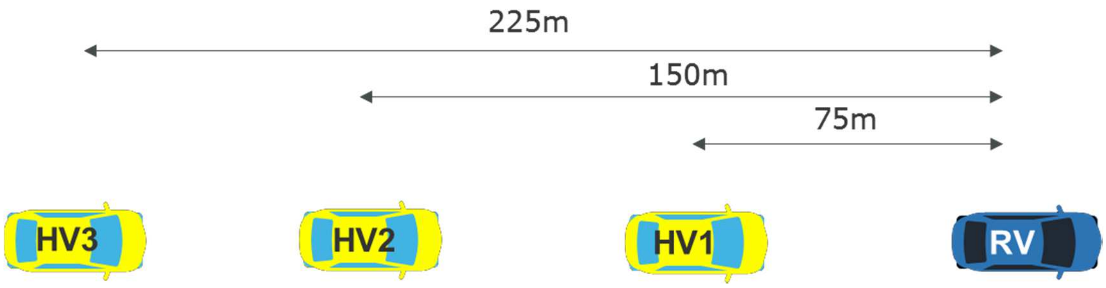

Figure 22: Test Vehicle Configuration – 4-vehicle platoon example [2]

Further information on the initial vehicle platoon placement and the moving diagram of the vehicles can be found in [2], [3], and [4].

9.1.2.9 Unique Tests to be Conducted

1. Set of V2X devices for the other test
    a. Congestion Control Off (Baseline)
    b. Congestion Control (On)
2. Stepped increase of emulated devices, if feasible:
    a. 50
    b. 100
    c. 200
    d. 500
    e. 1000
    f. 1500
    g. 2000

9.1.2.10 Required Documentation

Following is the required documentation for this test per TX protocol and No. of Emulated OBUs:

- Plot of PER vs Time, Range, RSSI/RSRP
- Plot of IPG vs Time, Range, RSSI/RSRP

- Plot of IA vs Time, Range, RSSI/RSRP
- Plot CBP/CBR vs Time, Range
- Plot of RSSI/RSRP vs Time, Range

9.1.2.11 Evaluation Criteria

Compare performance between radio technologies per the required documentation listed above (excl. RSSI).

9.1.3 Co-existence with Wi-Fi 80 MHz bandwidth in UNII-3

9.1.3.1 Background

The purpose of this test is to measure the impact of Wi-Fi with 80MHz bandwidth implemented in the UNII-3 band that is closest to the ITS frequency band (e.g., center frequency 5860 MHz) having a bandwidth of 10 MHz. Based on current standardization the closest channel for the 80MHz Wi-Fi implementation is 155 (5735MHz-5815MHz).

Two options are recommended for testing this scenario:

1. Using actual Wi-Fi AP and Wi-Fi clients
   - Use of one Wi-Fi access point
     - 802.11ac standard
     - Supporting Wave 2 dual stream and minimum 2x2 MIMO
     - Configurable to use 80 MHz UNII-3 spectrum nearest to ITS spectrum
   - Four or more Wi-Fi clients
     - Clients supporting the standards and features provided by the AP
     - Clients performing continuous data transfer; located at near cell, mid cell, and cell edge (for details, see the setup and test execution sections below)
     - More Wi-Fi clients can be added, creating an even more RF challenged environment

2. Using a Wi-Fi signal generator (document the details how traffic is generated)
   - Use of one professional TME
     - Generating RF signal as per 802.11ac standard
     - Configurable to use 80 MHz UNII-3 spectrum nearest to ITS spectrum
     - MIMO support
     - Set at maximum standard-allowed EIRP depending on the region (EU, North America, …)

Both options have their pros and cons; while use of a signal generator provides for a more strictly controlled environment, use of an actual Wi-Fi AP and clients, performing actual data transfers, provides a more realistic environment closer to actual live situations. Therefore it might be advisable to use both approaches along the development and deployment cycle, for example using a Wi-Fi signal generator at the earlier stages of development, and using a Wi-Fi AP and clients at later stages.

Option 1: Wi-Fi AP and Wi-Fi clients

Sections 9.1.3.2 through 9.1.3.8 describe the test procedure for option 1: using actual Wi-Fi AP and Wi-Fi clients transferring data.

9.1.3.2 Assumptions

The testing environment is isolated from external interference sources including other DSRC/C-V2X users. This should be verified with a spectrum analyzer as the first step in test case execution.

9.1.3.3 Setup

This test uses a Wi-Fi Access Point which can support a bandwidth of 80MHz. Wi-Fi implemented on channel 155 should be loaded with Wi-Fi users and create a congested environment.

The test is designed for a minimum of 4 Wi-Fi users/clients which use Wi-Fi to transfer data continuously. The distribution of users should provide different path losses from the AP to the users.

Table 24: Coverage Definitions

Coverage Definitions	Coverage Definitions	RSSI [dBm]
1	Near Cell	Above -50
2	Mid Cell	Between -50 and -70
3	Cell Edge	Between -70 and -90

- Settings on Wi-Fi devices (UE1 through UE4):
  - All devices should initiate and maintain continuous FTP or HTTP/HTTPS download of very large files in order to highly utilize the Wi-Fi network.
  - The devices should be distributed across all categories in terms of Wi-Fi coverage:
    - One device in Near Cell
    - One device in Mid Cell
    - Two devices in Cell Edge Environment
- A spectrum analyzer should be used to verify spectrum characteristics (i.e. spectrum clear of external interference sources) within the ITS band (e.g., center frequency 5,860 MHz and bandwidth of 10 MHz), as well as in Channel 155, throughout the area where the testing will be performed (including the entire test track over which DUT2 will be driven).
- The Wi-Fi AP shall be placed at a height of 3 meters above the ground.
- The Wi-Fi AP shall be placed at the beginning of the test track (see Figure 23).
- The antennas of the UEs shall be at a height of 1.5 meters above the ground.
- The UEs shall be placed along the test track (see Figure 23). The distance of each UE from the AP shall be as defined in the table immediately below (Table 25) and as shown in the figure immediately below (Figure 23). The values of d1, d2, and d3 can be determined with a spectrum analyzer as follows:
  - d1 is the distance at which RSSI of the AP is -50 dBm.
  - d2 is the distance at which RSSI of the AP is -70 dBm.
  - d3 is the distance at which RSSI of the AP is -90 dBm.

Table 25: Wi-Fi UE Positions

User	Coverage Definitions	Distance from AP (d_n)
UE1	Near Cell	d1/2
UE2	Mid Cell	d1+(d2-d1)/2
UE3	Cell Edge	d2+(d3-d2)/2
UE4	Cell Edge	d3 – d3*0.1 (But ensure that sustained Wi-Fi data transfer will still occur at this distance.)

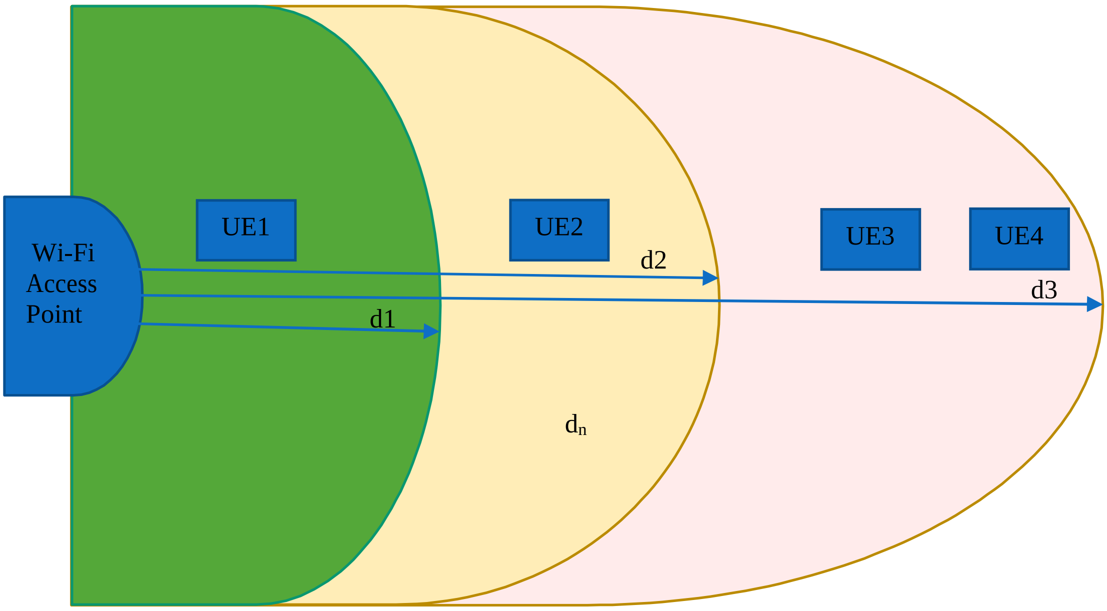

Figure 23: Wi-Fi Coverage Definitions

- Settings on C-V2X devices P1 and DUT2):
  - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
  - Packet length of standard BSM message
  - Transmit on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10MHz; transmitting BSM messages
  - Transmit power is controlled by the C-V2X device
  - Configured to receive on ITS band (e.g., center frequency 5,860 MHz) with bandwidth of 10 MHz
- Data collection at C-V2X devices (DUT1 and DUT2):
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet
  - GPS location for each transmitted packet
  - OS timestamp for each received packet

- Sequence number of each received packet
- GPS location for each received packet
- Receive signal power for each received packet
- All KPIs as listed further in this section

NOTE: It is assumed that the V2x coverage range (shown in Figure 23; pertains to DUT1 and DUT2) is greater than the size of the Wi-Fi network/cell (shown in Figure 23).

9.1.3.4 Test Execution

1. Using a spectrum analyzer verify that the spectrum is clean in Channel 155 as well as in the ITS band while the AP and UEs are turned off. Do this throughout the area where the testing will be performed, including the entire test track over which DUT2 will be driven.
2. Power up the Wi-Fi Access Point.
3. Using a spectrum analyzer to check the RSSI of the Wi-Fi channel at varying locations, calculate the values of d1/d2/d3 (see section 9.1.3.3), and place the four Wi-Fi UEs along the test track at the distances from AP specified in Table 25. Note the locations of the UEs.
4. Power down the Wi-Fi Access Point.
5. Place DUT1/vehicle at a horizontal distance of ~1m from the Wi-Fi AP, with the antennas of DUT1 at 1.5m above the ground.
6. Place DUT2/vehicle next to DUT1/vehicle, with the antennas of DUT2 at 1.5m above the ground.
7. Power up DUT1 and DUT2 and start their transmission of BSM. Note the time.

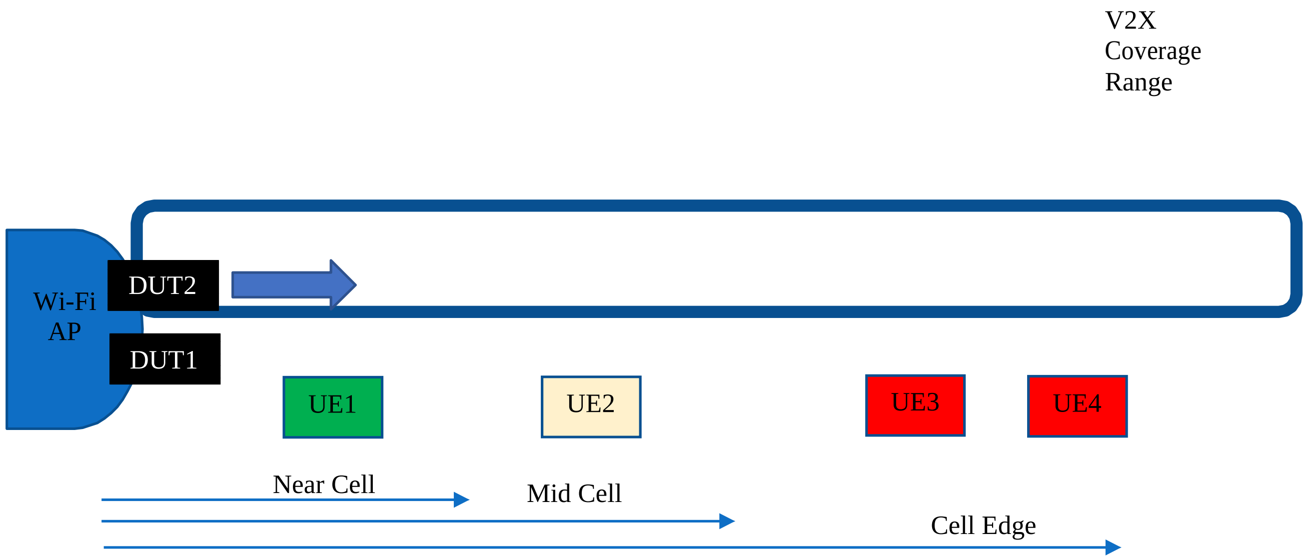

Figure 24: Test Setup

8. Start driving the vehicle with DUT2, starting at a location next to DUT1, moving towards the Wi-Fi cell edge, along the location of the Wi-Fi UEs, at a low speed (25 km/h), and continue moving beyond the Wi-Fi cell edge towards the maximum V2X range (i.e. until V2X PER rises above 50%). Note the time when you start driving DUT2 away from DUT1.
9. Drive the vehicle with DUT2 back towards DUT1 at a low speed (25 km/h) back to the starting position.
   Note the time when you turn around and start driving DUT2 back towards DUT1.
10. Repeat steps 8 and 9 for a total of ten (10) iterations.
11. Transfer the log files of DUT1 and DUT2 for analysis.
12. Power down DUT1 and DUT2. Note the time.

13. Power on the Wi-Fi AP and all four Wi-Fi UEs.
14. Start and maintain continued FTP or HTTP/HTTPS download of very large files at each Wi-Fi UE, from a file server connected to the Wi-Fi AP, in order to highly utilize the Wi-Fi network.
15. Power up DUT1 and DUT2 and start their transmission of BSM. Note the time.
16. Start driving the vehicle with DUT2, starting at a location next to DUT1, moving towards the Wi-Fi cell edge, along the location of the Wi-Fi UEs, at a low speed (25 km/h) towards the maximum V2X range identified in step 8.
    Note the time when you start driving DUT2 away from DUT1.
17. Drive the vehicle with DUT2 back towards DUT1 at a low speed (25 km/h) back to the starting position.
    Note the time when you turn around and start driving DUT2 back towards DUT1.
18. Repeat steps 16 and 17 for a total of ten (10) iterations.
19. Stop the test.
20. Transfer the log files of DUT1 and DUT2 for analysis.

9.1.3.5 Unique Tests to be Conducted

Run this test using:

Four (4) Wi-Fi devices (UE1 through UE4)

One Wi-Fi AP

One spectrum analyzer (which covers 5.9GHz)

Two (2) C-V2X devices and two (2) DSRC devices (DUT1 and DUT2)

9.1.3.6 Required Documentation

In the following table, record the following:

- The boundaries of the different coverage zones of the Wi-Fi cell (determined using the spectrum analyzer).
- The physical positions at which the UEs were actually placed.
- The maximum V2X range (where V2X PER noted at DUT2 rises above 50%).

Table 26: Test Setup Values

Wi-Fi Coverage Zone Boundaries (see Table 25)		Wi-Fi Device Positions		Maximum V2X Range (given as distance from AP in meters)	
Distance Figure	Value (meters)	Device	Distance from AP (meters)		
d1		UE1			
d2		UE2			
d3		UE3			
		UE4			

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following two tables.

Table 27: Test Results - Wi-Fi Off

Testing Results When Wi-Fi AP and UEs Are Powered Off								
DUT1 & DUT2 start sending BSMs (hh:mm:ss):								
Exec. #	DUT2 starts driving away from DUT1 (hh:mm:ss)	DUT2 starts driving back to DUT1 (hh:mm:ss)	No. of Pkts (total for the 10 executions)		PER %	No. of Pkts (total for the 10 executions)		PER %
			TX by DUT1	RX by DUT2	Calc. at DUT2	TX by DUT2	RX by DUT1	Calc. at DUT1
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
Power off of DUT1 & DUT2 (hh:mm:ss):								

Table 28: Test Results - Wi-Fi On

Testing Results When Wi-Fi AP and UEs Are Powered On and in Use								
DUT1 & DUT2 start sending BSMs (hh:mm:ss):								
Exec. #	DUT2 starts driving away from DUT1 (hh:mm:ss)	DUT2 starts driving back to DUT1 (hh:mm:ss)	No. of Pkts (total for the 10 executions)		PER %	No. of Pkts (total for the 10 executions)		PER %
			TX by DUT1	RX by DUT2	Calc. at DUT2	TX by DUT2	RX by DUT1	Calc. at DUT1
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
Power off of DUT1 & DUT2 (hh:mm:ss):								

9.1.3.7 Evaluation Criteria

Plot and evaluate PER based on location, for both DUT1 and DUT2, for both scenarios (Wi-Fi equipment off and on), and assess the differences between the two scenarios.

9.1.3.8 Estimated Time to Complete

Table 29: Completion Time

Task	Estimated Time	Notes
Test setup		
Test execution		
Test analysis		
Total		

Option 2: Wi-Fi signal generator

Sections 9.1.3.9 through 9.1.3.15 describe the test procedure for option 2: using Wi-Fi signal generator.

9.1.3.9 Assumptions

The testing environment is isolated from external interference sources including other DSRC/C-V2X users. This should be verified with a spectrum analyzer as the first step in test case execution.

9.1.3.10 Setup

This test uses a Wi-Fi signal generator TME (Test & Measurement Equipment). This TME needs to support generating an actual 802.11ac Wi-Fi signal with a bandwidth of 80MHz and MIMO. The TME will generate a Wi-Fi signal simulating a fully loaded Wi-Fi Channel 155. Also the TME shall be set at the maximum standard-allowed EIRP depending on the region (EU, North America, …).

- A spectrum analyzer should be used to verify spectrum characteristics (i.e. spectrum clear of external interference sources) within the ITS band (e.g., center frequency 5,860 MHz and bandwidth of 10 MHz), as well as in Channel 155, throughout the area where the testing will be performed (including the entire test track over which DUT2 will be driven).
- Settings on C-V2X devices (DUT1 and DUT2): Same as in section 9.1.3.3.
- Data collection at C-V2X devices (DUT1 and DUT2): Same as in section 9.1.3.3.

9.1.3.11 Test Execution

1. Using a spectrum analyzer verify that the spectrum is clean in Channel 155 as well as in the ITS band while the Wi-Fi TME is turned off. Do this throughout the area where the testing will be performed, including the entire test track over which DUT2 will be driven.
2. Place DUT1/vehicle at a horizontal distance of ~1m from the Wi-Fi TME signal generator, with the antennas of DUT1 at 1.5m above the ground.
3. Place DUT2/vehicle next to DUT1/vehicle, with the antennas of DUT2 at 1.5m above the ground.
4. Power up DUT1 and DUT2 and start their transmission of BSM. Note the time.

Figure 25: Test Setup

5. Start driving the vehicle with DUT2, starting at a location next to DUT1, moving at a low speed (25 km/h) towards the maximum V2X range (until V2X PER rises above 50%).
   Note the time when you start driving DUT2 away from DUT1.
6. Drive the vehicle with DUT2 back towards DUT1 at a low speed (25 km/h) back to the starting position. Note the time when you turn around and start driving DUT2 back towards DUT1.
7. Repeat steps 5 and 6 for a total of ten (10) iterations.

8. Transfer the log files of DUT1 and DUT2 for analysis.
9. Power down DUT1 and DUT2. Note the time.
10. Power on the Wi-Fi signal generator and configure it to generate a Wi-Fi signal simulating a fully loaded Wi-Fi channel.
11. Power up DUT1 and DUT2 and start their transmission of BSM. Note the time.
12. Start driving the vehicle with DUT2, starting at a location next to DUT1, moving at a low speed (25 km/h) towards the maximum V2X range identified in step 5.
    Note the time when you start driving DUT2 away from DUT1.
13. Drive the vehicle with DUT2 back toward DUT1 at a low speed (25 km/h) back to the starting position. Note the time when you turn around and start driving DUT2 back towards DUT1.
14. Repeat steps 12 and 13 for a total of ten (10) iterations.
15. Stop the test.
16. Transfer the log files of DUT1 and DUT2 for analysis.

9.1.3.12 Unique Tests to be Conducted

Run this test using:

One Wi-Fi signal generator TME

One spectrum analyzer (which covers 5.9GHz)

Two (2) C-V2X devices and two (2) DSRC devices (DUT1 and DUT2)

9.1.3.13 Required Documentation

In the following table, record the maximum V2X range (where V2X PER noted at DUT2 rises above 50%).

Table 30: Test Setup Values

Maximum V2X Range (given as distance from AP in meters)

Utilizing the data collected from log files, or observed from any OBU user interface, fill in the following two tables.

Table 31: Test Results - Wi-Fi Off

Testing Results When Wi-Fi Signal Generator Is Powered Off								
DUT1 & DUT2 start sending BSMs (hh:mm:ss):								
Exec. #	DUT2 starts driving away from DUT1 (hh:mm:ss)	DUT2 starts driving back to DUT1 (hh:mm:ss)	No. of Pkts (total for the 10 executions)		PER %	No. of Pkts (total for the 10 executions)		PER %
			TX by DUT1	RX by DUT2	Calc. at DUT2	TX by DUT2	RX by DUT1	Calc. at DUT1
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
Power off of DUT1 & DUT2 (hh:mm:ss):								

Table 32: Test Results - Wi-Fi On

Testing Results When Wi-Fi Signal Generator Is Powered On and in Use								
DUT1 & DUT2 start sending BSMs (hh:mm:ss):								
Exec. #	DUT2 starts driving away from DUT1 (hh:mm:ss)	DUT2 starts driving back to DUT1 (hh:mm:ss)	No. of Pkts (total for the 10 executions)		PER %	No. of Pkts (total for the 10 executions)		PER %
			TX by DUT1	RX by DUT2	Calc. at DUT2	TX by DUT2	RX by DUT1	Calc. at DUT1
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
Power off of DUT1 & DUT2 (hh:mm:ss):								

9.1.3.14 Evaluation Criteria

Plot and evaluate PER based on location, for both DUT1 and DUT2, for both scenarios (Wi-Fi signal generator equipment off and on), and assess the differences between the two scenarios.

9.1.3.15 Estimated Time to Complete

Table 33: Completion Time

Task	Estimated Time	Notes
Test setup		
Test execution		
Test analysis		
Total		

9.1.4 Co-existing of C-V2X with adjacent DSRC carrier

9.1.4.1 Background

The purpose of this test is to measure how C-V2X PC5 communication is impacted by DSRC communication where the two technologies are using adjacent channels. More specifically in this test the C-V2X PC5 technology is using e.g. channel 172 of the ITS band with a center frequency of 5,860 MHz and a bandwidth of 10MHz, and the DSRC technology is using e.g. channel 174 with a center frequency of 5,870 MHz and a bandwidth of 10MHz. This test also envisions swapping of the devices and measuring how DSRC communication is impacted by C-V2X PC5 communication.

A typical use case could be C-V2X vehicles exchanging BSM packets on channel 172 in proximity to DSRC vehicles exchanging IP traffic on channel 174.

9.1.4.2 Assumptions

The testing environment is isolated from external interference sources including other DSRC/C-V2X users. This should be verified with a spectrum analyzer as the first step in test case execution.

9.1.4.3 Setup

Following is the setup for this test:

- A spectrum analyzer should be used to verify spectrum characteristics (i.e. spectrum clear of external interference sources) within the C-V2X ITS band (e.g., channel 172 with a center frequency 5,860 MHz and bandwidth of 10 MHz), as well as in the DSRC channel (e.g., channel 174 with a center frequency of 5,870 MHz and bandwidth of 10 MHz) throughout the area where the testing will be performed.
- Hardware
  The testing will use two C-V2X devices called DUT1 and DUT2, as well as two DSRC devices called DUT3 and DUT4. Each device will be located in a vehicle.
    - Each of the four (4) devices has the following:
        - Internal or external GPS receiver
        - GPS antenna
        - Communications antenna
        - Low loss cable (e.g., LMR200) to connect the device to the communications antenna
        - Other cable to connect the GPS receiver to the GPS antenna
    - The equipment for each device shall be installed in its respective vehicle according to the following:
        - Communications antenna placed at the apex of the vehicle roof
        - If the GPS antenna is in a housing separate from the communications antenna, place the GPS antenna on the vehicle roof such that it does not impede the forward and rearward communication path of the communications antenna.
- Settings on C-V2X and/or DSRC devices (DUT1 and DUT2):
    - SPS (Semi-Persistent Scheduling) based transmit flow with a periodicity of 100ms (Note: equivalent to setting a periodic stream at 100ms period for other technologies)
    - Packet length of standard BSM message
    - Transmit on ITS band (e.g., channel 172 with center frequency of 5,860 MHz) with bandwidth of 10MHz; transmitting BSM messages
    - Transmit power is controlled by the C-V2X device
    - Configured to receive on ITS band (e.g., channel 172 with center frequency of 5,860 MHz) with bandwidth of 10 MHz
- Settings on DSRC and/or C-V2X devices (DUT3 and DUT4):
    - Transmit and receive on e.g., channel 174 with center frequency of 5,870 MHz) with bandwidth of 10MHz
    - Configured to transmit and receive IP traffic
- Settings common to all four devices (DUT1, DUT2, DUT3, DUT4):
    - GPS antenna offsets configured for each device

  - Each device configured to support logging
- Data collection at C-V2X devices (DUT1 and DUT2):
  - OS timestamp for each transmitted packet
  - Sequence number of each transmitted packet
  - GPS location for each transmitted packet
  - OS timestamp for each received packet
  - Sequence number of each received packet
  - GPS location for each received packet
  - Receive signal power for each received packet
  - All KPIs as listed further in this section
- Data collection at DSRC devices (DUT3 and DUT4):
  - Collect data sufficient to be able to calculate PER.

9.1.4.4 Test Execution

1. Using a spectrum analyzer verify that the spectrum is clean in the C-V2X ITS band (e.g., channel 172) as well as in the DSRC channel (e.g. channel 174) while all four DUTs are powered off.
2. Place the 4 DUTs/vehicles at a close distance to each other:
   a. DUT2 vehicle right in front of DUT1 vehicle
   b. DUT3 vehicle next to DUT 1 vehicle; DUT4 vehicle right in front of DUT3 vehicle and next to DUT2 vehicle

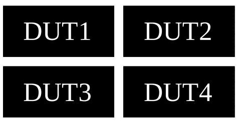

Figure 26: Test Setup

3. Power on DUT1 and DUT2. DUT3 and DUT4 stay powered off, at this stage.
4. Ensure devices are loaded with proper configuration.
5. Start the test on DUT1 and DUT2 and ensure the following:
   a. DUT1 remains stationary.
   b. Both DUTs are transmitting and receiving, standard BSM traffic.
   c. Both DUTs are logging.
6. Drive DUT2 away from DUT1 at the notated speed until PER (between DUT1 and DUT2, measured at DUT1 and DUT2) reaches 100%. Note the maximum distance between DUT1 and DUT2, referring to is as “coverage range”.

Figure 27: Test Setup

7. Slowly drive DUT2 back toward DUT1 at the notated speed until the range is around 1m.
8. Power on DUT3 and DUT4.
9. Start exchange of IP traffic between DUT3 and DUT4 (e.g. continuous HTTP/S or FTP file transfer running between the DUTs).
10. Repeat step 6 while DUT3 and DUT4 remain stationary. Note the distance at which PER (measured at DUT1 and DUT2) reaches 100%.
11. Slowly drive DUT2 back toward DUT1 at the notated speed until the range is around 1m.
12. Perform the following steps iteratively, increasing the distance between DUT3 and DUT4 in steps of 10dB of RSSI decrease, and observing the effect that each new DUT3/DUT4 position has upon the C-V2X coverage range between DUT1 and DUT2.
    NOTE: DUT3 remains stationary at its initial position, and DUT4 is moved in steps.
    a. Drive DUT4 away from DUT3, by a “10 dB” step as measured by a spectrum analyzer[6]; move DUT4 along the same track as DUT2 in step 6.

Figure 28: Test Setup

[6] I.e. drive DUT4 away from DUT3, until the RSSI between DUT3 and DUT4 is 10 dB lower than before.

b. Note the location of DUT4 (i.e. its distance from DUT3).

c. Note the PER between DUT3 and DUT4 (calculate it at both DUT3 and DUT4).

d. Drive DUT2 away from DUT1 at the notated speed along the same path as in step 6 all the way to the "coverage range" (i.e. until the PER between DUT1 and DUT2, measured at DUT1 and DUT2, reaches 100%).

e. Slowly drive DUT2 back toward DUT1 at the notated speed until the range is around 1m.

13. If the PER between DUT3 and DUT4 (see step "c") is less than 100%, then repeat the above steps. Else, stop the test.

9.1.4.5 Unique Tests to be Conducted

Run this test using the following:

Two (2) C-V2X devices operating on e.g. channel 172

Two (2) DSRC devices operating on e.g. channel 174

One spectrum analyzer (which covers 5.9 GHz)

and repeat it with the devices roles swapped, i.e.

Two (2) C-V2X devices operating on e.g. channel 174

Two (2) DSRC devices operating on e.g. channel 172

9.1.4.6 Required Documentation

Utilizing the data collected during the testing, fill in the following table.

Table 34: Required Documentation

Execution #	Setup of DSRC Devices (DUT3 and DUT4)				C-V2X Coverage Range, DUT1-to-DUT4 (distance to reach PER of 100%) (meters)
	Power State	Reduction in RSSI[7] (dB)	Physical distance	PER[8]	
1	Powered Off	N/A	Adjacent		
2	Powered On	N/A	Adjacent		
3	Powered On	10			
4	Powered On	20			
5	Powered On	30			
6	Powered On	40			
7	Powered On	50			
8	Powered On	60			
9	Powered On	70			
10	Powered On	80			
11	Powered On	90			
n	…				

For execution #1, plot PER (measured at DUT1 and DUT2) vs. distance between DUT1 and DUT2.

For execution #2 through n, do the following:

- Plot PER (measured at DUT1 and DUT2) vs. distance between DUT1 and DUT2.
- Observe if the C-V2X coverage range between DUT1 and DUT2 is affected by the traffic between DUT3 and DUT4, with DUT4 at the different locations.
- Observe if the PER between DUT1 and DUT2 is affected by the traffic between DUT3 and DUT4, with DUT4 at the different locations.

9.1.4.7 Evaluation Criteria

To assess the performance of C-V2X in terms of PER and communication range, when there is simultaneous DSRC communication over an adjacent channel.

[7] As compared to RSSI when DUT3 and DUT4 are adjacent
[8] Between DUT3 and DUT4, measured at each of DUT3 and DUT4

9.1.4.8 Estimated Time to Complete

Table 35: Completion Time

Task	Estimated Time	Notes
Test setup		
Test execution		
Test analysis		
Total		

9.1.5 Antenna Characterization Tests

9.1.5.1 Background

Antenna pattern test cover passive antenna element radiation density pattern collection, active antenna diversity verification and an in situ RF system verification. The intent of these tests is to fully verify the radiation characteristics of the Cellular V2X system of the vehicle. Knowledge of the radiation environment through simulation, HIL testing, and similar vehicle performance will be used to augment testing and to replace certification when there is a high level of confidence in the simulation results.

Table 36: Antenna Characterization Process

Simulation/Pre-Test Analysis	
	Environmental Simulation (Ground Bounce, Multipath, Freespace Attenuation)
	On Vehicle Passive Antenna Simulation
	Diversity System Simulation
	Test Parameter Determination
Passive Antenna Test (Radiation Density Pattern)	
	Passive Antenna Patterns
RF System Test	
	Verify Diversity Performance in Limited Set of Data
Post Process/Requirement Verification	

9.1.5.2 Simulation/Pre-Test Analysis

RF and communications simulation has matured to the point where full vehicle and full RF systems analysis can be performed with a resulting accuracy that can exceed that achieved by test. These tools can therefore be used to augment testing. The testing organization must always be aware that the goal is to verify functionally. Requirements validation can be achieved through testing and simulation or even simulation alone the end result is still achieved.

For this test process, simulation will be used to validate system requirement margin prior to test and determine test parameter adequately test the antenna limiting over testing. Of particular importance is determining the diversity performance of the system as this is difficult to evaluate on the vehicle. With the diversity included a link-budget is to be determined that allocates system performance margin between he antennas, receiver and interconnects. This accolated margin is then the requirements that are applied to the antenna system. The link budget shall demonstrate 300 meter of operation with a less than 10% packet error rate.

9.1.5.3 Passive Antenna Test (Radiation Density Pattern)

In the verification of any RF communication system passive antenna verification is performed prior to any system test. This testing is to both be performed at the antenna component level and in the vehicle installed configuration. Both of these measurements are critical as unlike modules, antenna performance is heavily influenced by the structure surrounding the antenna. An antenna designed to work in free space might have performance issues when placed near structure that is of large enough size to influence the antenna performance (sizes greater than 0.1 wavelength for objects within 1-5 wavelengths, sizes greater than .5 wavelength for objects of a greater distance away).

The key parameters that need to be verified both at the component level is the antenna radiation density pattern (RDP), antenna impedance match and antenna efficiency.

RDPs:

RDPs are typically collected in outdoor or anechoic facilities. The parameter measured is realized antenna gain and is defined by as follows:

Realized Gain (dBi)= Directivity (dBi) – Mismatch Loss (dB) – Efficiency Loss (dB)

For component testing, traditional far field facilities are adequate and the antenna size is relatively small. If the antenna is designed to operate on a ground plane the antenna should be measured on a 1 meter diameter circular ground plane. For on vehicle testing either a large anechoic facility or outdoor facility is required. Typically these facilities operate in the nearfield of the antenna and are either true spherical nearfield or compact antenna ranges. Description of these facilities and traditional antenna ranges can be found in *149-1979 IEEE Standard Test Procedures for Antennas* or in facility vendor specification sheets. Ideally, these measurements are to be performed in an indoor facility as the error terms induced by the environment are less. Any facility shall be capable of measuring two orthogonal polarizations, either right hand circular polarization/left hand circular polarization or linear theta/phi polarization. Measuring both polarizations is essential as placement on vehicle can induce cross polarization scatter. The two results of the polarization are to be summed to achieve the total or matched gain.Figure 29 defines the measurement coordinate system and polarization for both vehicle antenna testing and component testing.

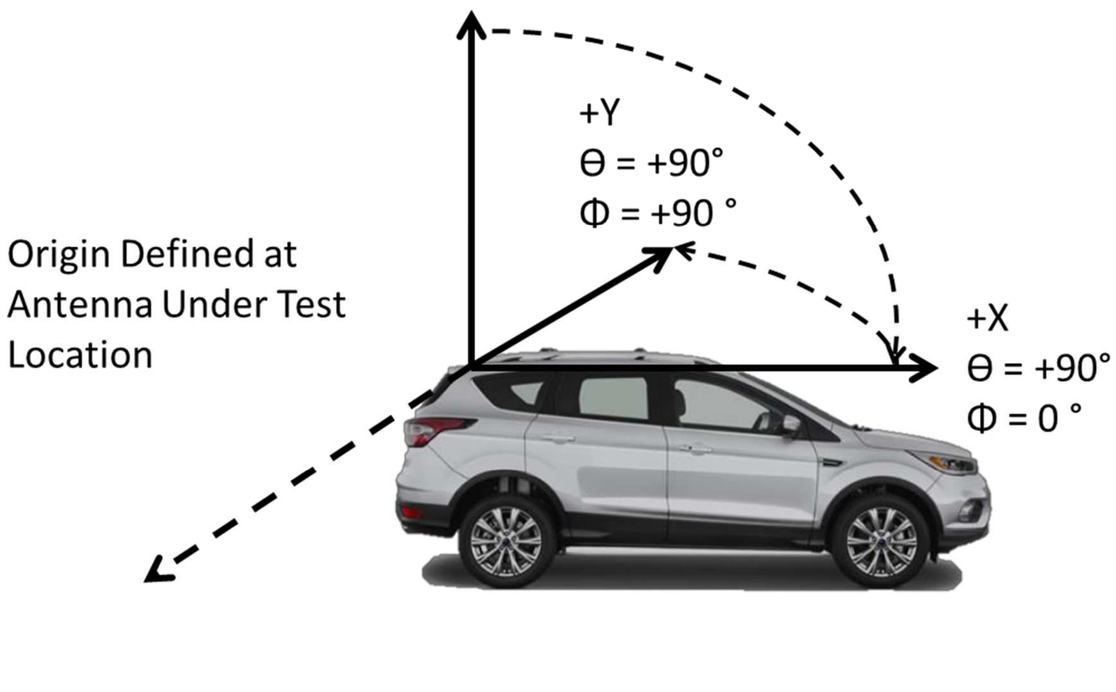

Figure 29: RDP Measurement Coordinate Systems

Note that vehicle testing can be performed on surrogate or sections of vehicle. Simulation can be used to validate these substitutions to determine the error induced by not measuring the entire vehicle or a vehicle. For example a roof antenna may be adequately characterized by fabricating a roof section of the vehicle. Scattering from internal or lower body sections will have very little impact on the pattern. Also, current production vehicle can be used as a surrogate for full vehicle testing. Again, simulation can be used to validate the approximations made on unit under test (UUT).

The size of the test object, frequency, test requirements and measurement system also defines the test pattern measurement density. Larger structures and higher frequencies require denser theta phi collection spacing. In addition traditional spherical nearfield chambers require that the collection density satisfy inquest. Reference the facility supplier documentation for minimum required sampling.

V2X antenna configurations typically involve more than one antenna. The antennas may be measured one at a time or contently if a switch matrix is available. All unused antennas and antenna ports shall be terminated with the correct system impedance.

For passive antenna measurements, the vehicle battery shall be disconnected.

Any integrated amplifier shall be active during testing.

Required test parameters for RDP are summarized in Table 37.

Table 37: RDP Antenna Requirements Summary

Test Parameter	Value/Determination
Polarization	Two orthogonal polarizations (Horizontal and Vertical Preferred)
Theta	80 - 96 Deg minimum, density determined by UUT size, requirement, test system and frequency
Phi	0-360 Deg, density determined by UUT size, requirement, test system and frequency
Vehicle Configuration	Determined By Analysis/Simulation, Battery Disconnected
Multiple Antenna	Terminate all unused antennas
Coordinate System Origin	Centered on Antenna Under Test
Frequency	5855 MHz to 5925 MHz, Minimum Testing Shall Be 5855 MHz, 5890 MHz, and 5925 MHz

Automotive industry typically requires antenna patterns to be expressed as linear average gain and a standard deviation requirement about this value. Linear average gain is the linear magnitude gain averaged over Phi. Reference the antenna performance specifications and/or system performance requirements for actual required values.

Antenna Input Impedance:

Input impedance shall be measured in a vehicle like configuration. This is required as nearby structure influences antenna match. For combined antennas, all other antennas shall be terminated.

Efficiency:

Sufficient antenna pattern (RDP) data shall be collected to determine efficiency. If this is not achievable due to test equipment, simulation may be used to augment test data.

9.1.5.4 Active RF System Test

Active antenna measurements shall be performed in a test setup similar to the facility shown in 9.1.5.3. However, the test shall be run with a C-V2X standard minimum performing radio as the range transceiver that is connected to the antenna. The range transceiver then communicates to the vehicle antenna/C-V2X radio system. Setup is shown in Figure 30.

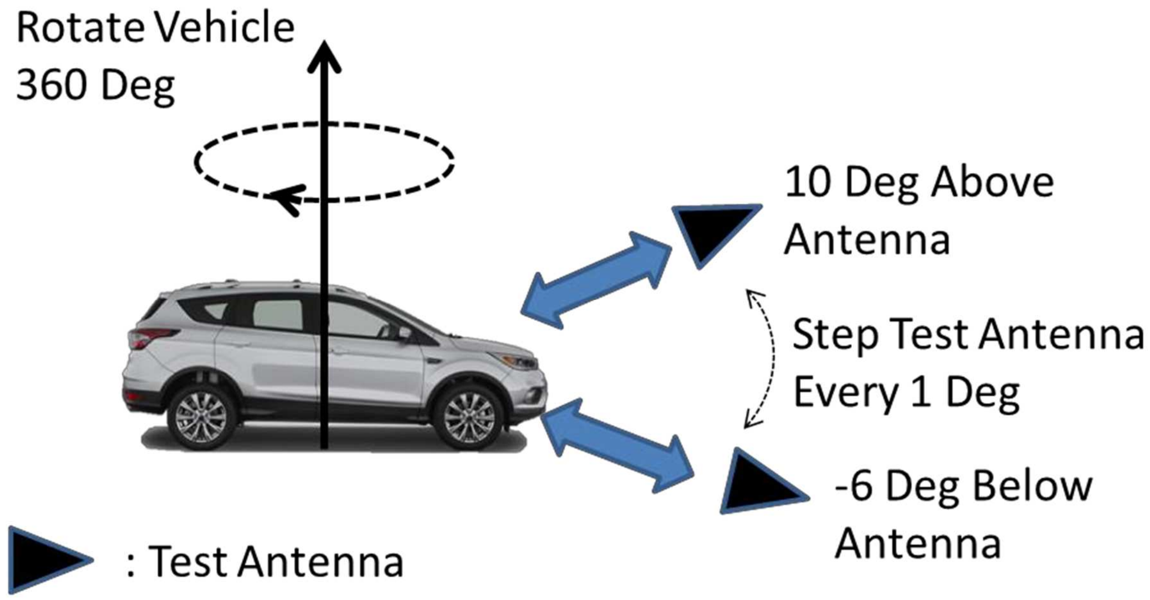

Figure 30: RDP Measurement Coordinate Systems

Attenuation shall be applied to the test antenna to simulate the worst case path loss between two vehicles more than 300 m apart, including worst case ground reflection location. This test will be performed with the vehicle in key on engine running state to simulate EMI interferences. Signal Strength and PER will be collected at each point. Test locations shall be measured as shown in Table 6:

Table 38: Active RF System Test

Test Parameter	Value/Determination
Polarization	Vertical Polarization
Theta	80 - 96 Deg step size of determined from passive antenna testing
Phi	0-360 Deg, step size of determined from passive antenna testing
Dwell Time	1 minute at each location (TBR)
Vehicle Configuration	Key-on/Running
Attenuation	Attenuation due to freespace loss or worst case ground reflection + test antenna gain – test system losses (Determined in pre-test simulation)

Figure of merit for this test shall be packet error rate not to exceed 10% . The vehicle shall demonstrate performance both as a receiver and a transmitter.

9.1.5.5 Post Processing/Requirement Verification

The passive antenna test will primarily be used for antenna performance knowledge and to determine test parameters for the Active RF System Test. The Active RF System Test shows that in a free space environment that the CV2V system meets performance requirements (PER). In addition both tests will show the weakest performing directions of the CV2V system. This knowledge can then be applied to testing in the other sections of this document.

9.2 Safety Application Demonstration

The following test cases are to simply demonstrate device’s ability to repeatedly produce a crash avoidance warning. A detailed evaluation of the safety application is not required given that the latency and other tests have shown no issues, therefore there is no difference between the radio technologies from the safety application perspective. It should be noted that the safety application stack is the same on both the DSRC and C-V2X device.

The test procedure provided below has been adapted from the assessment of the DSRC device defined in VSC-A Project - Final Report: Appendix Volume 1 System Design and Objective Test – Appendix C-2 – Objective Test Procedures and Plan.

Note: The use cases presented in this chapter might need to be revised after 5GAA WG1 confirms urgent use cases.

9.2.1 Emergency Electronic Brake Lights (EEBL) [1]

9.2.1.1 Background

This test is to verify that the EEBL system will issue a warning when the brakes of a vehicle in its forward path and direction of travel have been applied abruptly and the instantaneous braking of the RV exceeds the braking threshold as defined by the application. While the primary objective of the EEBL system is to enhance driver visibility of potential hazards via wireless communication amongst similarly equipped vehicles, this test can be used to verify EEBL performance in the presence of obstructing vehicles and/or adverse weather conditions that obstructs the view of the RV from the HV.

9.2.1.2 Assumptions

Will be performed on closed test track.

Personal performing tests are familiar with the application, application scenarios and has experience executing. Red flags placed at the starting point where the HV and RV begin their maneuver (flags not shown in the figure).

9.2.1.3 Setup

Cones with flags will be placed so the driver of the HV is aware of the vehicle's location in reference to the required maneuvers. These flags will be located by their distance from the starting point for the HV. It is assumed that flags will be placed using a L1 GPS handheld receiver. Alternate methods of flag location can be used. Flag locations are:

- A red flag is placed at the starting point where the HV begins its maneuver (cone HV-A)
- A yellow flag is placed at the point where the RV begins its maneuver (cone RV-A), at least 70 meters from the red flag (the distance is calculated by the headway as required below)
- A green flag is placed at the point where the HV confirms its own position (cone HV-B), at least 650 meters from the red flag
- A checkered flag is placed at the point where the RV starts to decelerate (cone RV-B), at least 70 meters from the green flag (the distance is calculated by the headway as required below)

9.2.1.4 Test Execution

Scenario Specific Initial Conditions

- The RV's deceleration shall occur at 0.4 g or greater and continue decelerating to reach at least 0.5 g or greater
- The headway between the HV and RV should be greater than 3 seconds

Driving Instructions

- The HV stops with its front bumper at the red flag.
- The RV stops with its front bumper at the yellow flag.
- The HV test observer and the RV test observer communicate to each other to start at the same time.
- The HV and RV accelerate to 80 km/h, and maintain this speed in the center lane. the front bumper of RV reaches the checkered flag, the RV decelerates hard and then stops, the RV test observer communicates this to the HV test observer at the same time.
- The HV test observer should confirm his own position when he receives the information, if the HV has not passed the green flag (cone HV-B), headway between the HV and RV is greater than 3 seconds.
- The HV observes the warning and comes to a stop.

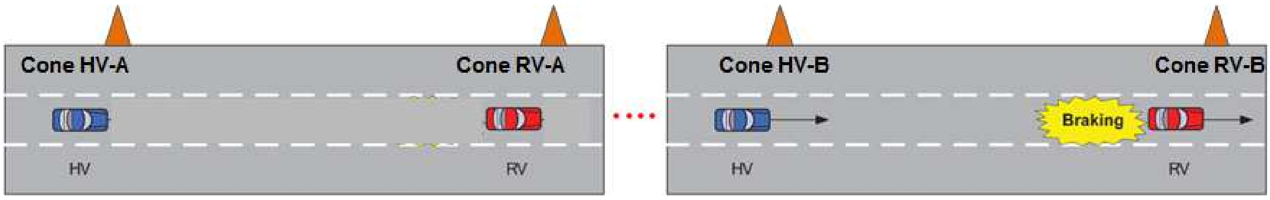

Figure 31: EEBL Setup [1]

9.2.1.5 Unique Tests to be Conducted

Run this test two times using:

1. Two (2) DSRC devices for one test
2. Two (2) C-V2X devices for the other test

9.2.1.6 Required Documentation

All KPI's listed in chapter 5 shall be recorded.

Observation from the test run, fill in the following table:

Table 39: EEBL Required Documentation

Test Run	Successful Alert (Y/N)	HV Speed (km/h)	RV Speed (km/h)
1		80	80
2		80	80
…		80	80
8		80	80

9.2.1.7 Evaluation Criteria

Successful Criteria

- The HV issues a warning to the driver for at least six out of eight test runs.

Unsuccessful Criteria

- The test is Unsuccessful if the warning is not issued for three or more out of eight test runs.

9.2.1.8 Estimated Time to Complete

Table 40: Completion Time

Task	Estimated Time	Notes
Test setup	60 minutes	
Test execution	60 minutes	Cellular
Test execution	60 minutes	DSRC
Test Analysis	30 minutes	Includes file acquisition, script execution, metric generation and analysis
Total	210 minutes	

9.2.2 Forward Collision Warning (FCW) [1]

9.2.2.1 Background

This test begins with the HV traveling on a straight, flat road at 80 km/h. Ahead of the HV, in the same lane, is a single RV stopped in the lane of travel. The test determines whether the countermeasure's required collision alert occurs at the expected range. This test especially explores the ability of the countermeasure to accurately identify stationary in-path targets on a flat, straight road.

9.2.2.2 Assumptions

Will be performed on closed test track.

Personal performing tests are familiar with the application, application scenarios and has experience executing.

9.2.2.3 Setup

Cones with flags will be placed so the driver of the HV is aware of the vehicle's location in reference to the required maneuvers. These flags will be located by their distance from the starting point for the HV. It is assumed that flags will be placed using a L1 GPS handheld receiver. Alternate methods of flag location can be used. Flag locations are:

- A red flag is placed at the starting point where the HV begins its maneuver (cone not shown)
- A yellow flag is placed at the point where the HV reaches the target speed (cone HV-A), at least 650 meters from the red flag
- A white flag is placed at the earliest valid (from the driver's perspective) WARN point (cone HV-B)
- A checkered flag is placed where the HV will make an evasive maneuver by changing lanes if the WARN has failed to occur (cone HV-C) which is positioned at 90 percent of the allowable alert range. At the test speed of 80 km/h, this is 9 meters from HV-B cone
- A green flag is placed at the stopping position for the RV (cone RV-A), at least 800 meters from the red flag

9.2.2.4 Test Execution

Driving Instructions

- The RV begins at the starting point and stops with its rear bumper at the green flag.
- The HV starts accelerating at least 800 meters behind the RV in the same lane to reach a speed of 80 km/h.
- The HV Cruise Control is set at the required speed of 80 km/h.
- The HV Cruise Control shall be engaged at least 150 meters behind the RV.
- The warning will be given at around the nominal warn range (cone HV-B) after which the HV will change lane.
- [Note: If the warning is not given when the HV reaches the checkered flag (cone HV-C), the HV shall make an evasive maneuver by changing lanes and come to a safe stop in the adjacent lane.]

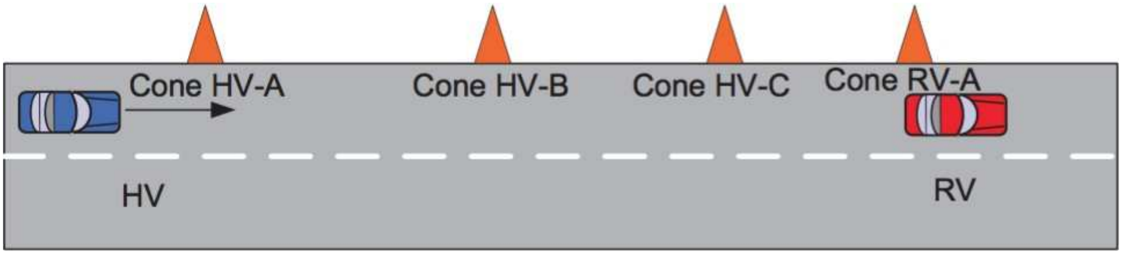

Figure 32: FCW Setup [1]

9.2.2.5 Unique Tests to be Conducted

Run this test two times using:

1. Two (2) DSRC devices for one test
2. Two (2) C-V2X devices for the other test

9.2.2.6 Required Documentation

All KPI’s listed in chapter 5 shall be recorded.

Observation from the test run, fill in the following table:

Table 41: FCW Required Documentation

Test Run	Successful Alert (Y/N)	HV Speed (km/h)	RV Speed (km/h)
1		80	0
2		80	0
…		80	0
8		80	0

9.2.2.7 Evaluation Criteria

Successful Criteria

- The HV issues a warning to the driver for at least six out of eight test runs.

Unsuccessful Criteria

- The warning is missed such that the HV passes cone HV-C and no alert is triggered
- The test is Unsuccessful if the warning is not issued for three or more out of eight test runs.

9.2.2.8 Estimated Time to Complete

Table 42: Completion Time

Task	Estimated Time	Notes
Test setup	60 minutes	
Test execution	60 minutes	Cellular
Test execution	60 minutes	DSRC
Test Analysis	30 minutes	Includes file acquisition, script execution, metric generation and analysis

Task	Estimated Time	Notes
Total	210 minutes	

9.2.3 Intersection Movement Assist (IMA) [1]

9.2.3.1 Background

The objective of this test is to determine whether the alerts will be given for both the HV and the RV when both the HV and the RV are moving toward the intersection. This situation is encountered at uncontrolled intersections.

In this scenario, the HV is stopped with the gear in “drive” and the RV is approaching the intersection at a constant speed of 55 km/h. When the RV passes the INFORM distance and the speed is above 55 km/h, the HV will get an INFORM. No other warning should be given.

9.2.3.2 Assumptions

Will be performed on closed test track.

Personal performing tests are familiar with the application, application scenarios and has experience executing.

9.2.3.3 Setup

Cones with flags will be placed so the driver of the RV is aware of the vehicle’s location with respect to the required maneuvers. These flags will be located by their distance from the stop bar (cone HV-A and cone RV-B) including the offset of the stop bar from the conflict point. It is assumed that flags will be placed using a L1 GPS handheld receiver. Alternate methods of flag location can be used. Flag locations are:

- A green flag is placed at the upper right edge of the intersection box (cone RV-B)
- A red flag is placed at the point where the RV starts its maneuver, 300 meters from the green flag (cone not shown)
- A yellow flag is placed at the point where the RV reaches the target speed, 150 meters from the green flag (cone RV-A)
- A green flag is placed at the stop location of the HV, 1 meter from the lower right corner of the intersection box (cone HV-A)
- A checkered flag where the HV starts to drive toward the intersection 50 meters from cone HV-A (cone not shown)

9.2.3.4 Test Execution

Driving Instructions

The test will be conducted in the following manner:

- The HV will start at the checkered flag and drive toward the intersection. The HV will stop at the green flag (cone HV-A) and park at the stop bar with the front bumper at the outer edge of the stop bar with the gear in “drive.” The driver has a foot on the brake.
- The RV will begin at the red flag, 300 meters from the stop bar
- The RV driver will begin acceleration to the target test speed (speed 50 km/h)
- The RV driver will reach the targeted speed range before the vehicle reaches the yellow flag
- The RV’s driver shall keep the target test speed. Using cruise control set at the target test speed (55, 80 km/h) will help accomplish this.
- The RV driver will continue toward the stop bar at the target velocity

- The test observer in the RV will note behavior of the DVI and record state transitions from “OFF” to “INFORM”
- The test observer in the HV will observe and record if any warning modalities occur
- The driver of the RV will continue at the test speed through the intersection and stop at any point after the intersection
- The driver of the RV will make a controlled stop of the vehicle after passing the intersection box

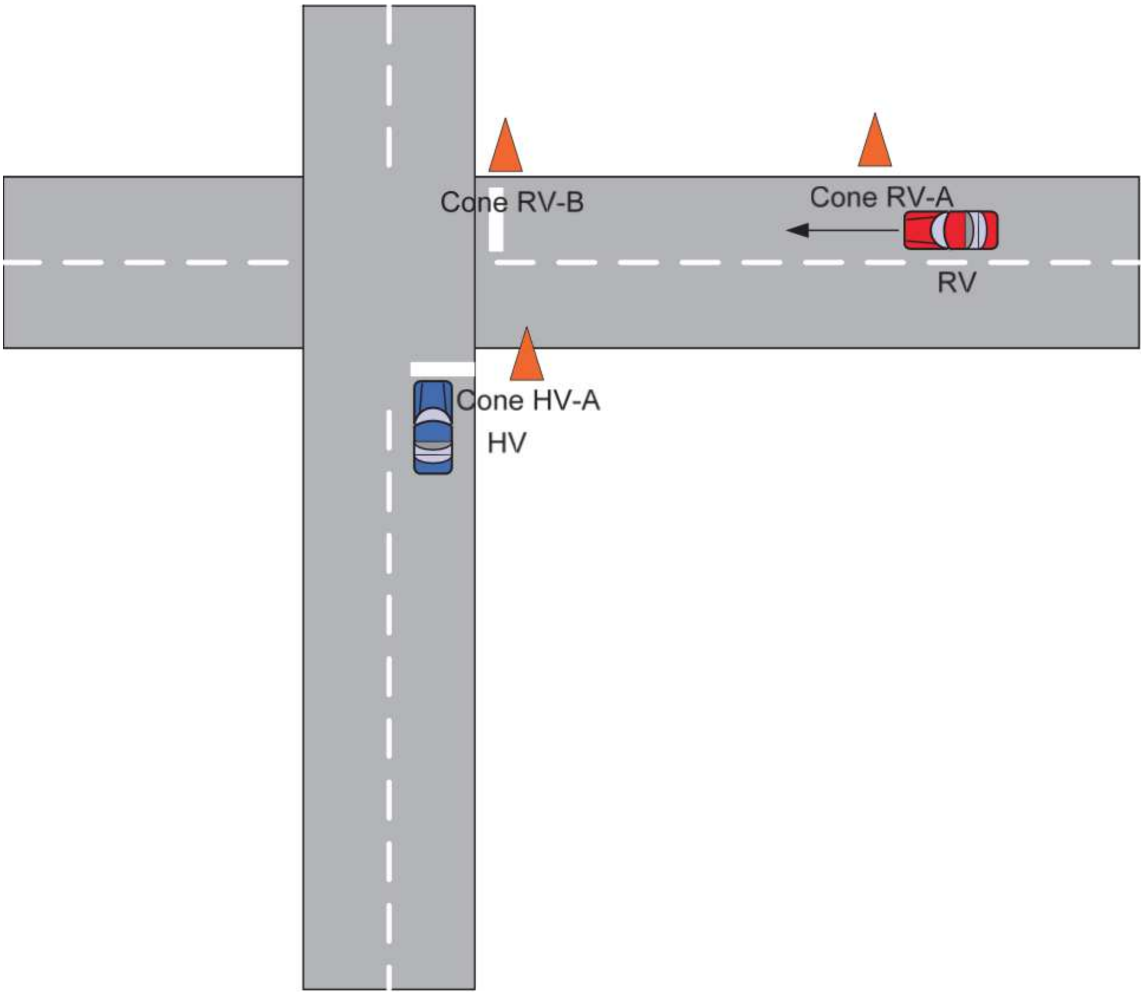

Figure 33: IMA Setup [1]

9.2.3.5 Unique Tests to be Conducted

Run this test two times using:

1. Two (2) DSRC devices for one test
2. Two (2) C-V2X devices for the other test

9.2.3.6 Required Documentation

Observation from the test run, fill in the following table:

Table 43: IMA Required Documentation

Test Run	Successful Alert (Y/N)	HV Speed (km/h)	RV Speed (km/h)
1		0	55
2		0	80

9.2.3.7 Evaluation Criteria

Successful Criteria

- The HV issues a warning to the driver for at least six out of eight test runs.

Unsuccessful Criteria

- The warning is missed such that the HV passes cone HV-A and no alert is triggered
- The test is Unsuccessful if the warning is not issued for three or more out of eight test runs.

9.2.3.8 Estimated Time to Complete

Table 44: Completion Time

Task	Estimated Time	Notes
Test setup	60 minutes	
Test execution	60 minutes	Cellular
Test execution	60 minutes	DSRC
Test Analysis	30 minutes	Includes file acquisition, script execution, metric generation and analysis
Total	210 minutes	

9.3 Public Roads

9.3.1 Platoon

9.3.1.1 Background

The purpose of this testing is to evaluate the device communications performance in various open-road driving environments (e.g., rural, urban). The CAMP Vehicle-to-Vehicle Safety System and Vehicle Build for Safety Pilot (V2V-SP) project performed a similar analysis at six different locations around the U.S. [2]. The purpose of that testing "was to evaluate the performance of the components of the system in various locations, by allowing variation in the time-of-day, location, time-of-year, weather, speed, and road surroundings." Such variations are expected to be minimal, but will be accounted for during analysis and filtered out if necessary. Such variations will not be addressed in this test but rather a subset, focused on different speeds and road surroundings encountered in different driving environments, will be. Unique environments may provide the signal propagation data necessary to enhance the communications simulator.

The test procedure provided below has been adapted from the assessment of the DSRC device defined in V2V-SP Project - Final Report Volume 2 – Performance Testing [2].

9.3.1.2 Assumptions

No special assumptions exist for this test.

9.3.1.3 Setup

Following is the setup for this test:

- Hardware
  - Four (4) devices under test w/ internal or external GPS receiver
    - Each device has GPS antenna
    - Each device has communications antenna
    - Low loss cable (e.g., LMR200) to connect the device to the communications antenna
    - Other cable to connect to GPS antenna
  - Four (4) identical vehicles
    - Communications antenna placed at the apex of the vehicle roof
    - If the GPS antenna is in a housing separate from the communications antenna, place the GPS antenna on the vehicle roof such that it does not impede the forward and rearward communication path of the communications antenna
- Device Configuration Setup
  - Each device configured for transmit and receive capability
  - Each device configured for 10 Hz transmit rate
  - Each device configured to support logging
- Environment
  - An open-road driving route which environmental characteristics that are representative to the statistics of a "typical driver" driving route.

9.3.1.4 Test Execution

The following steps should be performed for this test:

1. Stage the vehicles in a platoon configuration as shown in the figure below
2. Power on devices
3. Ensure devices loaded with proper configuration
4. Start the test on the devices and ensure that all devices are
   a. Transmitting
   b. Receiving each of the other devices
   c. Logging
   Note: Transmission data should be logged as well.
5. Capture and record a full UTC timestamp
   a. This will be used as the start time for the test to be used for calculating any metrics.
6. Drive the route shown in the example figure below in the following manner
   a. Attempt to drive in a single lane formation
   b. Maintain a safe following distance
   c. Vary the distances between the vehicles throughout the drive to obtain samples at different range bins (up to 400m)

7. When arriving at the end destination, stop the test
8. Transfer log files for analysis

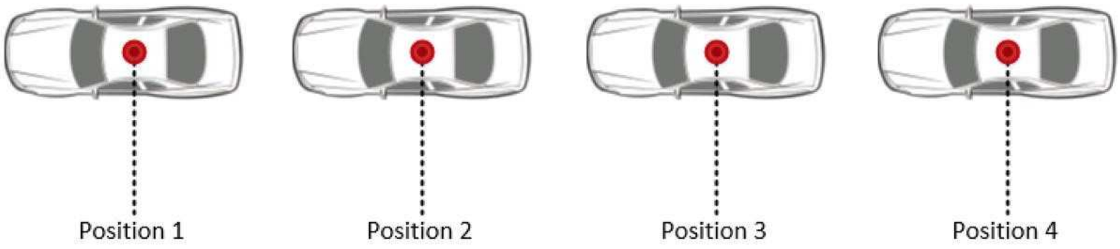

Figure 34: Platoon Setup

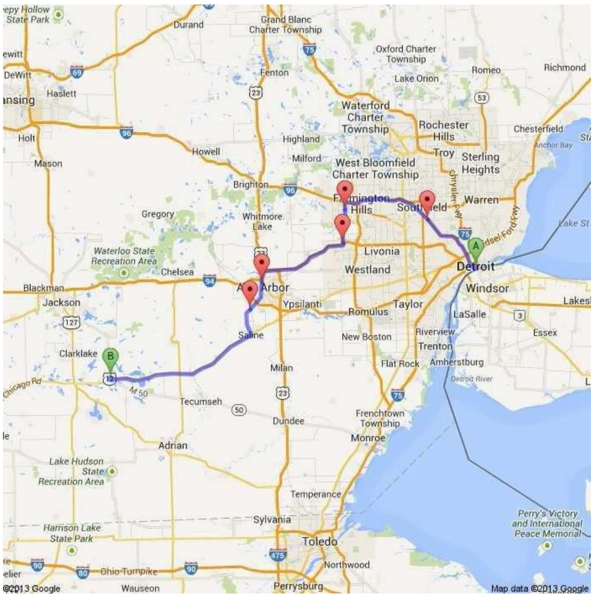

Figure 35: Platoon Route

9.3.1.5 Unique Tests to be Conducted

Run this test two times using the setup itemized below. If executing the test:

1. Four (4) DSRC devices for one test
2. Four (4) C-V2X devices for the other test

9.3.1.6 Required Documentation

Following is the required documentation for this test:

- Plot of PER vs Device-to-Device Range Separation Bin
- Plot of IPG vs Device-to-Device Range Separation Bin
- Plot of RSSI/RSRP vs Device-to-Device Range Separation Bin

9.3.1.7 Evaluation Criteria

Table 45: Platoon Evaluation Criteria

Metric	Evaluation Criteria	Notes
PER vs Device Separation Range	Comparative Analysis	To remove positioning losses from affecting communications performance analysis, consider removing data where devices were not transmitting due to positioning loss.
IPG vs Device Separation Range	Comparative Analysis	
RSSI for DSRC and RSRP for C-V2X vs Device Separation Range	N/A Informative Analysis	RSSI/RSRP data should be retained to aid in determining if a recalibration of the simulation should be performed

9.3.1.8 Estimated Time to Complete

Table 46: Completion Time

Task	Estimated Time	Notes
Test setup	2 hours	
Test execution	4 hours	
Test Analysis	1 day	
Total	~ 2 days	Per performance drive

10 Simulation Scenarios

Simulation scenarios will be detailed in a later version of this document.

Annex A: DSRC OBU Configuration Parameters [5]

Table 47 below provides a list of configuration items identified to support the requirements. For each configuration item, the configuration file parameter name, value range, default range, and required SW release is provided. Note that usage is to provide guidance and additional detail for using the configuration items. Where discrepancies may exist between the configuration item and the requirements that reference the configuration item the requirement takes precedence. [5]

Table 47: Configuration List Parameters for v2vi_OBU.conf [5]

Configuration Item	Values	Default Value	Units	Usage	SW Release
OBU Configuration Items					
MaxRemoteVehicles	1 to 450	450	N/A	Indicates the maximum number of remote vehicles that may be encountered at any given time	Baseline
OBUIDFileName	"string"	OBU_ID.conf	string	File containing a mapping from Ethernet MAC address to 10 character OBU Identifier	Baseline
PreRecFileName	"string"	PreRefFile	String	File that contains the pre-recorded file data to play back Design Guidance: While initial pre-recorded files will be in .csv format that extension will not be included. Specific extensions and paths should be handled outside of the configuration file as required by each OBU implementation.	Baseline
Radio Configuration Items					
EnableTxRx	0 to 3	3	Enum	0 = Both disabled 1 = TX only enabled 2 = RX only enabled 3 = TX and RX enabled	Baseline
802.11p Configuration Items					
TxPwrLevel_dBm	10 to 33	20	dBm	Valid values: 0 to 33 in increments of 1 dBm NOTE: The actual power used and reported elsewhere should be bound within the min/max supported	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
				Only supported if CongestionCntrl == 0 (Disabled)	
TxDataRate_Mbps	6 to 54	12	Mbps	Configuration parameter is twice the actual 10 MHz channel rate (i.e., 12=6Mbps) Configuration parameter is the actual 20 MHz channel rate (i.e., 12=12Mbps) Valid values: 6, 9, 12, 18, 24, 36, 48, 54	Baseline
AC_BK_CWminKVal	1 to 10	4		CWmin = (2^k) – 1 (802.11 Default = 4)	Baseline
AC_BK_CWmaxKVal	1 to 10	10		CWmax = (2^k) – 1 802.11 Default = 10	Baseline
AC_BK_AIFSN	2 to 15	9		(802.11 Default = 9)	Baseline
AC_BE_CWminKVal	1 to 10	4		CWmin = (2^k) – 1 (802.11 Default = 4)	Baseline
AC_BE_CWmaxKVal	1 to 10	10		CWmax = (2^k) – 1 (802.11 Default = 10)	Baseline
AC_BE_AIFSN	2 to 15	6		(802.11 Default = 6)	Baseline
AC_VI_CWminKVal	1 to 10	4		CWmin = (2^k) – 1 (802.11 Default = 3)	Baseline
AC_VI_CWmaxKVal	1 to 10	10		CWmax = (2^k) – 1 (802.11 Default = 4)	Baseline
AC_VI_AIFSN	2 to 15	4		(802.11 Default = 3)	Baseline
AC_VO_CWminKVal	1 to 10	2		CWmin = (2^k) – 1 (802.11 Default = 2)	Baseline
AC_VO_CWmaxKVal	1 to 10	3		CWmax = (2^k) – 1 (802.11 Default = 3)	Baseline
AC_VO_AIFSN	2 to 15	2		(802.11 Default = 2)	Baseline
UP1DropPolicy	1 to 2	2	Enum	If AC_BK TX Queue is full 1 = Drop Newest Packet 2 = Drop Oldest Packet	SW6
UP3DropPolicy	1 to 2	2	Enum	If AC_BE TX Queue is full 1 = Drop Newest Packet 2 = Drop Oldest Packet	SW6

Configuration Item	Values	Default Value	Units	Usage	SW Release
UP5DropPolicy	1 to 2	2	Enum	If AC_VI TX Queue is full 1 = Drop Newest Packet 2 = Drop Oldest Packet	SW6
UP7DropPolicy	1 to 2	2	Enum	If AC_VO TX Queue is full 1 = Drop Newest Packet 2 = Drop Oldest Packet	SW6
MaxUP1QDepth	1 to 100	100	Integer	Max number of messages to hold in the AC_BK UP1 queue	SW6
MaxUP3QDepth	1 to 100	100	Integer	Max number of messages to hold in the AC_BE UP3 queue	SW6
MaxUP5QDepth	1 to 100	1	Integer	Max number of messages to hold in the AC_VI UP5 queue	SW6
MaxUP7QDepth	1 to 100	1	Integer	Max number of messages to hold in the AC_VO UP7 queue	SW6
1609.2 Configuration Items					
SecurityEnable	0 to 2	0	Enum	Enables / Disables the security functionality 0 =Disabled 1 = Enabled-Self Generated Certificates (Same as for Task 3) 2 = Enabled-LCM	Baseline
FailVerGenTime	-2000 to 2000	0	ms	Time to add to Generation Time in security header	Baseline
MessageValidityDuration	0.0 to 255.0	1	Seconds	Duration added to Generation Time to determine message expiry time	Baseline
MessageReplayCheck	0 to 1	0	Boolean	Enables / Disables checking to see if a message is a replayed one when verifying a message 0 = False 1 = True	Baseline
1609.3 Configuration Items					

Configuration Item	Values	Default Value	Units	Usage	SW Release
BSMRXUnsecurePSID	0x00 to 0xEFFFFFFF	0x00	N/A	PSID that should be used when receiving an Unsecure DER encoded BSM (J2735 2009). PSID Length: Valid Vals 1: 00 - 7F 2: 8000 - BFFF 3: C00000 - DFFFFF 4: E0000000 - EFFFFFFF	Baseline
BSMRXUnsecurePSID_PERU_UB	0x00 to 0xEFFFFFFF	0x01	N/A	PSID that should be used when receiving an Unsecure PER Unaligned encoded BSM (J2735 2016). PSID Length: Valid Vals 1: 00 - 7F 2: 8000 - BFFF 3: C00000 - DFFFFF 4: E0000000 – EFFFFFFF	SW6
BSMTXUnsecurePSID	0x00 to 0xEFFFFFFF	0x00	N/A	PSID that should be used when transmitting an Unsecure DER encoded BSM (J2735 2009). PSID Length: Valid Vals 1: 00 - 7F 2: 8000 - BFFF 3: C00000 - DFFFFF 4: E0000000 - EFFFFFFF	200 Unit
BSMTXUnsecurePSID_PERU_UB	0x00 to 0xEFFFFFFF	0x01	N/A	PSID that should be used when transmitting an Unsecure PER Unaligned encoded BSM (J2735 2016). PSID Length: Valid Vals 1: 00 - 7F 2: 8000 - BFFF 3: C00000 - DFFFFF 4: E0000000 - EFFFFFFF	SW6
BSMRXSecurePSID	0x00 to 0xEFFFFFFF	0x10	N/A	PSID that should be used when receiving a Secure DER encoded BSM (J2735 2009). Same valid values as for BSMRX/TXUnsecurePSID	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
BSMRXSecurePSID_PERU_UB	0x00 to 0xEFFFFFFF	0x11	N/A	PSID that should be used when receiving a Secure PER Unaligned BSM (J2735 2016). Same valid values as for BSMRX/TXUnsecurePSID_UB	SW6
BSMTXSecurePSID	0x00 to 0xEFFFFFFF	0x10	N/A	PSID that should be used when transmitting a Secure DER encoded BSM (J2735 2009). Same valid values as for BSMRX/TXUnsecurePSID	200 Unit
BSMTXSecurePSID_PERU	0x00 to 0xEFFFFFFF	0x11	N/A	PSID that should be used when transmitting a Secure PER Unaligned BSM (J2735 2016). Same valid values as for BSMRX/TXUnsecurePSID	SW6
BSMUserPriority	0 to 7	5	N/A	1,2 = AC_BK (Bkgrnd) 0,3 = AC_BE (Best Effort) 4,5 = AC_VI (Video) 6,7 = AC_VO (Voice)	Baseline
BSMEventUserPriority	0 to 7	7	N/A	1,2 = AC_BK (Bkgrnd) 0,3 = AC_BE (Best Effort) 4,5 = AC_VI (Video) 6,7 = AC_VO (Voice)	SW7
1609.4 Configuration Items					
ChannelMode	0 to 2	0	Enum	0 = Continuous Channel 1 = Chan Switch Alternating Forced 2 = Chan Switch Alternating Conditional	Baseline
ContinuousChanNum	172 to 184	172	N/A	Channel number to use when 'ChannelMode' is set to '0' Even channel number applicable to 10 MHz channels Odd channel numbers applicable to 20 MHz channels	Baseline - 10 MHz channels Baseline - 175, 181 20 MHz channels Baseline - Remaining 20 MHz channels

Configuration Item	Values	Default Value	Units	Usage	SW Release
ForcedSerChanNum	172 to 184	182	N/A	Service channel number to switch to when 'ChannelMode' is set to '1' Channel 178 invalid Even channel number applicable to 10 MHz channels Odd channel numbers applicable to 20 MHz channels	Baseline - 10 MHz channels Baseline - 175, 181 20 MHz channels Baseline - Remaining 20 MHz channels
SAE J2735 Configuration Items					
BSMEnabled	0 to 1	1	Boolean	Enables / Disables support for transmitting a BSM 0 = False 1 = True	Baseline
BSMPartITxInterval_ms	10 to 1000	100	ms	BSM Transmit interval valid in 1 msec. increments. Only supported if CongestionCntrl == 0 (Disabled)	Baseline
BSMPart2TxMethod	0 to 2	1	Enum	Controls individual PartII PH, PP, VehStatus attach logic 0 = Part II PH, PP, ExtLights are disabled regardless of individual Part II TX Interval settings 1 = Part II PH, PP, ExtLights are attached with each BSM if individually configured for greater than 0ms TX Interval 2 = Part II PH, PP, ExtLights are attached with each BSM according to their individually configured TX Interval	SW4
FirstBSMTxMaxDelay_ms	10 to 1000	100	ms	First BSM should be transmitted at a random time between startup and this value	

Configuration Item	Values	Default Value	Units	Usage	SW Release
				Supported for CongestionCntrl == 0 or 1	
BSMTxJitter_ms	0 to 5	5	ms	A random ms time value between +/– BSMTxJitter_ms added to the next BSM transmission timing. Only supported if CongestionCntrl == 0 (Disabled)	SW4
BSMTxNoPosAvailable	0 to 1	0	Boolean	Enables / Disables transmitting a BSM if no GPS position (indicated by the 3D fix value) is available 0 = False 1 = True	Baseline
AntAdjX_m	-81.91 to 81.91	0	meters	GPS X antenna offset in meters, defined according to SAE J2735 81.91 = Unavailable	Baseline
AntAdjY_m	-2.55 to 2.55	0	meters	GPS Y antenna offset in meters, defined according to SAE J2735 2.55 = Unavailable	Baseline
HeadingLatchSpeed_km/h	0.0 to 10.0	4	km/h	Speed, in km/h, below which the heading will be latched	Baseline
HeadingUnlatchSpeed_km/h	0.0 to 10.0	5	km/h	Speed, in km/h, above which heading will be unlatched	Baseline
HeadingPersistency	0 to 1	1	Boolean	Enables / Disables persistently storing the heading at shutdown and using on startup 0 = False 1 = True	Baseline
PHTxInterval_ms	0 to 2000	100	ms	Transmit interval, in ms, for PH Part II data frame Must be selected to be a multiple of BSMPartITxRate_ms	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
				If equal to zero PH TX is disabled	
PHAllowableError_m	0.0 to 1.0	1.0	meters	Allowable error, in meters, for selecting concise points	Baseline
PHDistance_m	0 to 300	200	meters	Distance, in meters, for PH concise representation	Baseline
PHChordLength_m	0 to 310	210	meters	Distance, in meters, in which a Path History Point shall be added if one has not been added through normal algorithm processing	Baseline
PHMaxPoints	1 to 23	15	N/A	Max number of path history points to include in path history data frame.	SW7
PPTxInterval_ms	0 to 2000	100	ms	Transmit interval, in ms, for PP Part II data frame Must be selected to be a multiple of BSMPartITxRate_ms If equal to zero PP TX is disabled	Baseline
PPMinSpeed_mps	0 to 2	1	m/s	Minimum speed for PP calculations. Below this speed, PP will report straight path (3276.7m)	
PPMaximumRadius_m	2000 to 3000	2500	m	For any (absolute) radius above this threshold, the PP algorithm will report straight path (3276.7m)	
PPPathIsStraight_m	3276.7	3276.7	meters	Radius, in meters, for considering path to be straight	Baseline
PPStationaryConf	0 to 100	0	N/A		Baseline
PPConfDampFactor	0 to 2	1	N/A		Baseline
PPConfFilterCutoff_Hz	0.33 to 1	1	Hz		Baseline
PPConfLookup_0_0_YawRt … PPConfLookup_0_10_YawRt PPConfLookup_1_0_Conf	[(25,0), (20,10), (15,20), (10,30), (5,40), (2.5,50), (2,60),	Same	N/A	2D table accepts filtered/differentiated yaw rate and outputs confidence (0-100%)	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
… PPConfLookup_1_10_Conf	(1.5,70), (1,80), (0.5,90), (0,100)]				
VehStatusTxInterval_ms	0 to 2000	0	ms	Transmit interval, in ms, for Vehicle Status Part II data frame Must be selected to be a multiple of BSMPartITxRate_ms If equal to zero VehStatus TX is disabled	Baseline
ExtLightTxEnable	0 or 1	1	Boolean	If enabled transmit Exterior Lights status as part of PartII data elements else don't transmit. 0 = False 1 = True	SW7
ASN1EncodeMethod	0 to 1	1	[-]	Indicates the encoding method to be used 0 – SAE J2735 2009 DER 1 – SAE J2735 2016 PER unaligned	
BypassSecurityProc	0 to 1	1	[-]	Indicates if appropriate security processing is needed 0 = False, perform security processing 1 = True, by pass security processing	
BypassASNDecode	0 to 1	1	[-]	Indicates if message decoding is needed or not. 0 = False, perform ASN.1 decoding 1= True, no decoding	
Security Manager Configuration Items					
SecurityVerInterval_S	0 to 60	0	seconds	Interval in seconds for verfying security credentials 0 = disable message verification	200 Unit

Configuration Item	Values	Default Value	Units	Usage	SW Release
SecurityVerJitter_ms	0 to 1000	100	ms	This is intended to add some jitter to the verity interval such that messages from the same OBU are not always the ones verified. A random ms time value is to be added to SecurityVerInterval_S when starting a timer to determine when to verify the next message received.	Baseline
VerFailMsgParseFlag	0 to 1	1	Boolean	Indicates if message processing, parsing, and logging should continue if message verification fails. 0 = False, stop 1 = True, continue	Baseline
CertAutoGenStartup	0 to 2	1	Enum	Determines the functionality for certificate generation at application startup 0 = No Auto Generation 1 = Auto Generation on first application startup 2 = Auto Generation on each application startup	Baseline
NumCertsAutoGen	1 to 20	10	N/A	Indicates the number of certificates that should be auto-generated	Baseline
CertRotateOrRegen	0 to 1	0	Enum	Indicates if the certificates should be rotated or regenerate when the last certificate of a certificate pool becomes invalid due to the need for a certificate change 0 = Rotate 1 = Regenerate	Baseline
CertChangeMin_S	0 to 300	60	seconds	The minimum time in which a certificate should be changed	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
CertChangeMax_S	0 to 600	120	seconds	The maximum time in which a certificate should be changed	Baseline
CertAttachInterval_ms	100 to 1000	100	ms	Interval at which a full certificate needs to be attached to a message Valid values: 100, 200, 300, …,1000 ms	Baseline
RandMAC	0 to 1	0	Boolean	Randomize the radio MAC address with a certificate change. 0 = False 1 = True	Baseline
RandTemporaryID	0 to 2	0	Enum	Randomize the J2735 Temporary ID with a certificate change. - 0 = No randomization. 1 = All bytes randomized. 2 = Randomize upper two bytes	Baseline
FixedTempIDVal	0 to 2	0	Enum	0 = OBU ID fixed ID. 1 = Ethernet MAC. 2 = Radio MAC.	
RandMsgCount	0 to 1	0	Boolean	Randomize the J2735 message count with a certificate change. 0 = False 1 = True	Baseline
BootStrap_LCM	0 to 1	0	Enum	0 = Every startup 1 = One time or when necessary	
CasualMsgRprt	0 to 1	0	Boolean	Support Casual message reporting to the CA. 0 = Disabled 1 = Enabled	Security Integration
CasualRprtMsgCnt	0 to 50	5	N/A	Number of messages contained in the casual message report. Design Guidance:	Security Integration

Configuration Item	Values	Default Value	Units	Usage	SW Release
				If the number of messages is exceeded, delete the oldest message from the report. When the report is sent to the CA, the reporting messages should be removed from internal report.	
CasualMsgPeriod	0 to 3600	60	Seconds	Interval in seconds for selecting a random message to be added to the causal message report	Security Integration
AlrtMsgRprt	0 to 1	0	Boolean	Support alert message reporting to the CA. 0 = Disabled 1 = Enabled	Security Integration
AlrtRprtMsgCnt	0 to 50	5	N/A	Number of messages contained in the alert message report. See CasualRprtMsgCnt Desing Guidance	Security Integration
SuspMsgRprt	0 to 1	0	Boolean	Support suspicious message reporting to the CA. 0 = Disabled 1 = Enabled	Security Integration
SuspRprtMsgCnt	0 to 50	5	N/A	Number of messages contained in the suspicious message report. See CasualRprtMsgCnt Desing Guidance	Security Integration
SuspMsgSpeedThrshld	0 to 360	320	km/h	Speed above which will be considered suspicious driving behavior leading to a message being added to the suspicious message report.	Security Integration
Congestion Control Configuration Items					
CongestionCntrl	0 to 1	1	Boolean	0 = Disabled	SW8
				1= Enabled	SW8
J2945/1 Congestion Control Configuration Items					

Configuration Item	Values	Default Value	Units	Usage	SW Release
vCBPMeasInt	100 to 1000	100	ms	The time window for which the CBP is calculated (ms)	SW8
vPERInterval	1000 to 10000	5000	ms	The time window for which the PER is being evaluated to calculate channel reliability (ms) NOTE: This same interval will be used for calculating the IPG	SW8
vPERSubInterval	1000 to 2000	1000	ms	Used to decide the time interval by which the PER window slides (ms)	SW8
vTxRateCntrlInt	50 to 100	100	ms	This interval used to calculate the transimission rate control interval (ms)	SW8
vCBPWeightFactor	0.0 to 1.0	0.5	N/A	Weight factor used by AR-1 model to filter out the temporal noise.	SW8
vPERRange	0 to 300	100	m	The range of distance from the HV within which RVs are considered for PER calculations (m)	SW8
vPERMax	0.0 to 1.0	0.3	N/A	If congestion control PER is greater than this value then set it to PERMax	SW8
vHVLocalPosEstIntMin	50 to 1000	50	ms	Local Estimator coasts HV position if time from latest GPS update is greater than HVLocalPosEstIntMin and less than HVLocalPosEstIntMax (ms)	SW8
vHVLocalPosEstIntMax	150 to 5000	150	ms	Local Estimator coasts HV position if time from latest GPS update is greater than HVLocalPosEstIntMin and less than HVLocalPosEstIntMax (ms)	SW8
vHVRemotePosEstIntMin	50 to 1000	50	ms	HV Remote Estimator coasts HV position as it perceives the RVs have	SW8

Configuration Item	Values	Default Value	Units	Usage	SW Release
				calculated its position if time from position update from the latest perceived successful transmission is greater HVRemotePosEstIntMin and less than HVRemotePosEstIntMax (ms)	
vHVRemotePosEstIntMax	1000 to 10000	3000	ms	HV Remote Estimator coasts HV position as it perceives the RVs have calculated its position if time from position update from the latest perceived successful transmission is greater HVRemotePosEstIntMin and less than HVRemotePosEstIntMax (ms)	SW8
vTrackingErrMin	0.0 to 1.0	0.2	m	The minimum communications-induced tracking error threshold (m)	SW8
vTrackingErrMax	0.0 to 2.0	0.5	m	The maximum communications-induced tracking error threshold (m)	SW8
vErrSensitivity	1 to 100	75	N/A	Error sensitivity used to calculate transmission probability.	SW8
vDensityWeightFactor	0.00 to 1.00	0.05	N/A	Weight factor used by AR-1 model to filter out the temporal noise in density (used in J2935/1 N(k) calculation)	SW8
vDensityCoefficient	25 to 100	25	N/A	Density Coefficient (used in J2935/1 Max_ITT(k) calculation)	SW8
vMax_ITT	0 to 1000	600	ms	Maximum time allowed between two consecutive transmissions in case of a delay because of high PER.	SW8
vRescheduleTh	0 to 100	25	ms	Reschedule threshold, used in transmission decision (ms)	SW8

Configuration Item	Values	Default Value	Units	Usage	SW Release
vRPMax	10 to 20	20	dBm	The higher threshold for radiated power (dBm)	
vRPMin	10 to 20	10	dBm	The lower threshold for radiated power (dBm)	SW8
vSUPRAGain	0.0 to 1.0	0.5	N/A	Stateful Utilization-based Power Adaptation (SUPRA) gain used to calculate Transmission Power	SW8
vMinChanUtil	0 to 100	50	%	Min channel utilization threshold in percentage.	SW8
vMaxChanUtil	0 to 100	80	%	Max channel utilization threshold in percentage.	SW8
vTxRand	0 to 5	5	ms	Random time offset used in BSM transmission (ms)	SW8
vMaxSuccessiveFail	1 to 5	3	N / A	Used to set a max limit on the number of consectutive failed Bernoulli trials for determining the latest HV state information at the RV	SW8
vRP	10 to 20	15	dBm	The initial value of radiated power for the first BSM after startup (dBm)	SW8
vTxPwrCtrlStep	0.5 to 1	1	dB	Transmit power granularity (dB)	SW8
MinSectorAntGain_dBi	0 to 20	0.0	dB	The lesser of the right and left sector SectorAntGainAvg in dBi as defined in SAE J2945/1	SW8
CLoss_dB	0 to 20	0.0	dB	Total cable and connector losses	SW8
Logging Configuration Items					
LogFileFormat	0 to 2	2	Enum	0 = Disabled 1 = interoperability 2 = scalability	SW1
TxLogEnableFlag	0 to 1	0	Boolean	Support logging of the TX log data 0 = False 1 = True	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
RxLogEnableFlag	0 to 1	0	Boolean	Support logging of the RX log data 0 = False 1 = True	Baseline
StatsLogEnableFlag	0 to 1	0	Boolean	Support logging of the stats log data 0 = False 1 = True	Baseline
CertLogFileFlag	0 to 1	0	Boolean	Support logging the full certificate and corresponding certificate SHA-256 raw data 0 = False 1 = True	Baseline
RXELogEnableFlag	0 to 5	0	Enum	Support logging of the RX log data 0 = Disabled 1 = All_Msg_All_RV 2 = All_Msg_Some_RV 3 = Some_Msg_All_RV 4 = Some_Msg_Some_RV 5= All_Msg_Some_RV_Some_Msg_Rest_RV	SW1
RXMLogEnableFlag	0 to 5	0	Enum	Support logging of the Metrics data per RV 0 = Disabled 1 = All_SubW_All_RV 2= All_SubW_Some_RV 3 = Some_SubW_All_RV 4 = Some_SubW_Some_Rv 5 = All_SubW_Some_RV_Some_SubW_Rest_RV	SW1
TXELogEnableFlag	0 to 1	1	Boolean	Support logging of TX log data 0 = False 1 = True	SW1

Configuration Item	Values	Default Value	Units	Usage	SW Release
CCLogEnableFlag	0 to 1	1	Boolean	Support logging of Congestion Control (CC) data 0 = False 1 = True	SW8
STELogEnableFlag	0 to 1	1	Boolean	Support logging of STE log data 0 = False 1 = True	SW1
STEPeriodicLogging	100 to 10000	100	msec	The time window for STE logging	SW1
RXMPeriodicLogging	1000 t0 10000	1000	msec	The Time window for RXM logging	
LogUnknownRV	0 - 1	0	Boolean	Support logging from unrecognized RVs 0 = false 1 = true	
Subset_RXE_Msg_Cntr	1 – 100	10	[-]	The number of received BSMs since the last logged BSM the HV has to count before logging from the same RV	
Subset_RXM_SubW_Cntr	1 - 10	5	[-]	The number of Sub-windows since last RXM logging the HV has to wait before logging from the RV.	
CPU_Util_Intrvl	0 to 10	5	[%]	The interval over which the CPU_Util is reported	SW1
GPS Interface Configuration Items					
GPSCoasting	0 – 1	1	Boolean	Enabling coasting 0 = false 1 = true For CongestionCntrl == 0 (Disabled) the CC local estimator logic utilizing vHVLocalPosEstIntMin and vHVLocalPosEstIntMax should be used for the coasted position calculation	

Configuration Item	Values	Default Value	Units	Usage	SW Release
GPSTimeOut	0 – 5000	500	msec	The time out for the GPS update	
Test Data Frame Configuration Items					
TDFEnabled	0 to 2	2	Enum	Enables / Disables support for the TDF and configures padding logic 0 = False 1 = True w/ static pad bytes 2 = True w/ variable pad bytes When '1' is selected 'TDFPadBytes1' will always be attachedincluded in the TDF. When '2' is selected 'TDFPadBytes1' will be included in the TDF at 'TDFPad1AttachInt_ms', otherwise 'TDFPadBytes2' will be included in the TDF.	Baseline
TDFPadBytes1	0 to 1000	160	bytes	Number of padded bytes in TDF TDFPad1AttachInt	SW71
TDFPadBytes2	0 to 1000	90	bytes	Number of padded bytes in TDF	SW7
TDFPad1AttachInt_ms	0 to 1000	450	ms	Only valid if TDFEnabled == 2. If the last time BSM sent with TDFPadBytes1 attached is greater then TDFPad1AttachInt_ms then attach TDFPadBytes1 otherwise attach TDFPadBytes2.	SW7
Data Source Configuration Items					
BSMTxDataSource	1 to 5	4	Enum	1 = Live Data 2 = Prerecorded 3 = UDP Source 4 = GPS Only 5 = Hybrid	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
ExtGPSSrcFlag	0 to 1	0	Boolean	Enable receiving the GPS data from an external GPS receiver 0 = For OBUs that support an internal GPS receiver use the internal one. For an OBU that supports only external GPS receiver use that one. 1 = Always use an external GPS receiver for the GPS data regardless or internal / external GPS receiver support.	Baseline
PreRecFileRepEnable	0 to 1	0	Boolean	Support the repeat transmit from a pre-recorded file. 0 = False 1 = True	Baseline
PreRecFileRepDelay_ms	50 to 1000	100	ms	Delay in ms between transmitting the last record from a pre-recorded file and the first record of the pre-recorded file when repeat is enabled.	Baseline
wsm_OBU2pc_ip	”string”	192.168.10.11	String	Static IP address of the test computer	Baseline
wsm_OBU2pc_port	0 to 65535	4200	Number	UDP port to forward OTA packets (OBU -> test computer)	Baseline
wsm_pc2OBU_ip	”string”	192.168.10.255	String	Static IP address of the OBU	Baseline
wsm_pc2OBU_port	0 to 65535	4201	Number	UDP port to forward OTA packets (test computer -> OBU)	Baseline
UDPStreamingMode	0 to 1	0	Boolean	0 = Disabled 1 = Enabled	Baseline
UDPStreamingFormat	0 to 1	1	Enum	This is the format of the data field of the UDP message 0 = Raw Format	Baseline

Configuration Item	Values	Default Value	Units	Usage	SW Release
				1 = Meta Format	
Command and Control UDP Packet Configuration Parameters					
TxUdpPacket	0 to 1	1	Boolean	This is what the OBU will read upon boot-up to enable or disable the UDP packet transmission 0 = disabled 1 = enabled (only when test is running)	SW1
TxUdpPacketFreq	1 to 30	2	Seconds	This is the frequency at which the OBU will transmit the command and control OBU status UDP packet	SW1
TxUdpPacketAddress	String	192.168.48. 7	String	This is the IP address to which the OBUs will send the UDP packets.	SW1
TxUdpPacketPort	0 to 65535	60100	Number	The port to which the UDP packets will be sent	SW1
UdpPktRvRange	0 to 2000	2000	Meters	The range at which the OBU should calculate certain values for the UDP packet that rely on remote OBU data	SW1
RxTxQVal_enum	0 to 3	3	Enum	0 = disabled 1 = Average over reporting interval 2 = Most recent reading since last reporting interval 3 = max reading since last reporting interval	

Change history

Date	Meeting	TDoc	Subject/Comment
2017-11	F2F	P-170142	First draft shared in 5GAA WG3 for discussion
2018-01	TelCo	P-18002	Updated draft shared in 5GAA WG3 for ongoing discussion
2018-02	F2F	P-18013	Updated draft shared in 5GAA WG3 for finalization in F2F meeting in Munich
2018-03	TelCo	P-180038	Version 1 Board approved
2018-05	TelCo	P-180092	Version 1.1 including editorial changes