Testing Long-Term Evolution Vehicle-to-Everything (LTE-V2X) Radio Performance Capabilities within the 5.9 GHz Safety Band

Jonathan B. Walker, P.E., Ph.D.
Chief of Policy, Architecture, Knowledge Transfer
U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office

Jeff Bellone, ITS Systems Engineer
U.S. Department of Transportation, Volpe National Transportation Systems Center

U.S. Department of Transportation

Goal and Objectives

- **Goal: To discuss the USDOT's approach to testing LTE C-V2X devices on a large scale from a radio performance (RF) perspective.**
- **Objectives:**
  1. Background
  2. Test Goals -> Test Objectives -> Test Progress -> Test Approach
  3. Controlled Track Testing -> Controlled Track Test Parameters
  4. Interference Testing
  5. Real-World Environment
  6. Assessment Metrics
  7. Analysis Questions
  8. Resources Informing Test Approach

Background

- **On May 3, 2021, the Federal Communications Commission (FCC) published in the Federal Register a First Report and Order (R&O) that became effective on July 2, 2021. The R&O reallocated 45 MHz of the 5.890 to 5.950 GHz spectrum ("Safety Band") to unlicensed Wi-Fi uses.**
  - The FCC shifted the vehicle-to-everything (V2X) communications technology in the remaining 30 MHz. **FCC chose 4G long-term evolution V2X (or LTE-V2X)**, which is part of an emerging cellular V2X (C-V2X) set of technologies.
  - The "guard band" that had existed between the lower end of the original Safety Band and the unlicensed Wi-Fi band has been removed, **raising concerns about potential out-of-band emissions (OOBE) from unlicensed Wi-Fi** operating just below the new (30 MHz) V2X band (5.895 to 5.925 GHz).
  - The FCC proposes to **remove the priority for the safety-of-life and public safety messages**, raising concern over how such messages may be affected by other V2X messages or by unlicensed Wi-Fi transmissions.

Test Goals

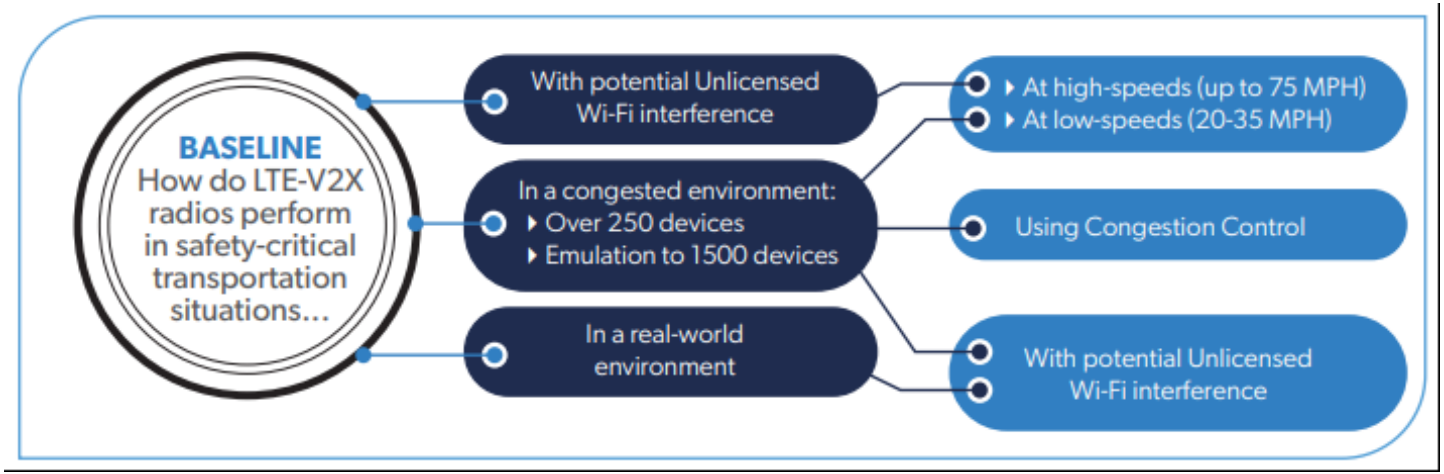
- **Safety is a mission requirement for U.S. DOT. With changes to both the allocation and technology, testing is necessary to understand what can and cannot be performed in the public interest; including safety, mobility, and environmental sustainability (among others).**
  - Testing to assess the radio performance and communications quality of LTE-V2X technology under the new FCC rules and within **test scenarios that mimic both typical and challenging crash avoidance conditions** – the type of conditions that result in some of the most common crashes.
  - Testing to examine the radio environment and V2X performance in **congested conditions** (with hundreds of V2X devices transmitting within reception range of each other).
    - **250+ devices** transmitting and receiving within 300 meters range
    - Emulation of **1000+ vehicles** transmitting and receiving within 300 meters range

Test Approach

- **Test set-ups allow testing of complex and challenging transportation conditions that commonly result in crashes; in a safe, controlled environment with vehicles moving at high speeds; varying speeds; and with line-of-site blockages; and collection of signal and basic safety message (BSM) data.**
- **Test Methodology includes the following:**
  - **Laboratory Device Performance Characterization** to quantify the baseline performance of the devices for comparison to performance under test conditions
  - **Device/System Integration Testing** to ensure that all systems (including data collection systems and test command and control systems) are operating correctly with properly calibrated measurement equipment
  - **Controlled Track Testing** using two basic scenarios that can scale to over 250 LTE-V2X transmitting and receiving devices (with an ability to emulate up to 1500 devices), including moving vehicles and generation of unlicensed Wi-Fi transmissions
  - **Small-Scale Real-World Testing** to gather data on communications under conditions such as typical reflectivity and obstructions that complicate the RF environment (i.e., buildings, overpasses)

Test Objectives

- **Test LTE-V2X communications under varying conditions. Each test case helps to assess the effects of each factor on the performance of LTE-V2X radios in a transportation setting.**



Test Progress

- **U.S. DOT has compressed a typical three-year test period into one year in response to the implementation timelines for new spectrum allocations in the FCC R&O.**
  - In 2020, U.S. DOT released a **Broad Agency Announcement** to procure test devices.
  - **Laboratory characterization** of devices proceeded from August 2020 through May 2021.
  - **Testing is underway** at various partner facilities
    - **Laboratory and small-scale testing** at FHWA's Turner-Fairbank Highway Research Center and National Telecommunications and Information Administration (NTIA's) ITS Boulder facilities.
    - **Controlled track testing** at the decommissioned Naval Air Base (NAB) in Willow Grove, PA and at the Summit Point Motor Sports Park in Summit Point, WV
    - **Real-World environment testing** at a U.S. DOT Connected Vehicle Pilot Site: Tampa-Hillsborough Expressway Authority (THEA) in Tampa, FL

Controlled Track Testing

- Broken into two scenarios, **measuring line of sight (LOS) and non-line of sight (NLOS) performance** situations not previously addressed by industry testing
- Assess variations in communications between and among **vehicles operating up to and over 75 MPH** while surrounding onboard units (OBUs) are stationary (e.g., similar to idling traffic at an intersection) because LTE-V2X technology uses different modulations based on vehicle speed
- Using each device's own settings based **on SAE J3161/1 parameter settings**, including use of the 20 MHz Channel 183 and an operational **congestion mitigation algorithm**
- Over **10 roadside units (RSUs)** set to transmit MAP (intersection geometry) messages, using larger (approximately 14,00 byte) MAP messages
- Evaluate performance with and without **Unlicensed Wi-Fi transmissions**

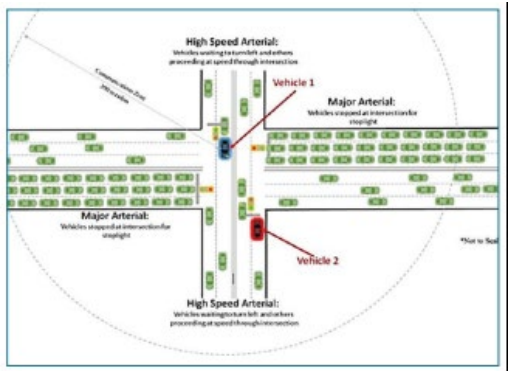


Figure 1: Test Track Scenario 1 Set-up

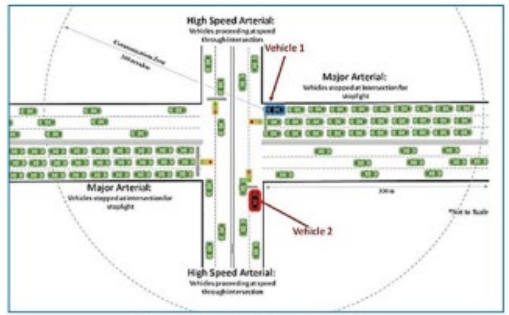


Figure 2: Test Track Scenario 2 Set-up

Controlled Track Test Parameters

- More details on the test parameters can be found at https://www.transportation.gov/V2XTestSummary

Scenario 1 Parameters

Scenario 1 LTE-V2X and Line-of-Sight/NLOS Test Parameters and the Range of Variations:

Number of OBUs	250+
Number of RSUs	10+
Payload	365 Byte (V2V) / 1400 Byte (I2V)
Hybrid Automatic Repeat Request (HARQ)	ON
LTE-V2X Channels	183 (for both OBUs and RSUs)
LTE-V2X Transmit Power	20 dBm
Obstructing Vehicle	YES / NO
High-Speed Vehicle Congestion Mitigation	ON / OFF
High-Speed Vehicle Transmit Time Interval (TTI) Setting	AUTOMATIC / 100 ms
250+ Stationary Devices Congestion Mitigation	ON / OFF
250+ Stationary Devices TTI Setting	AUTOMATIC / 100 ms / 300 ms / 600 ms

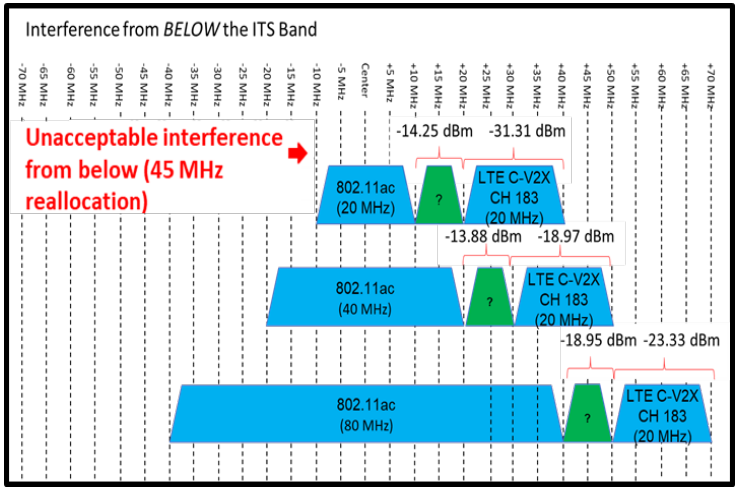
Scenario 2 Parameters

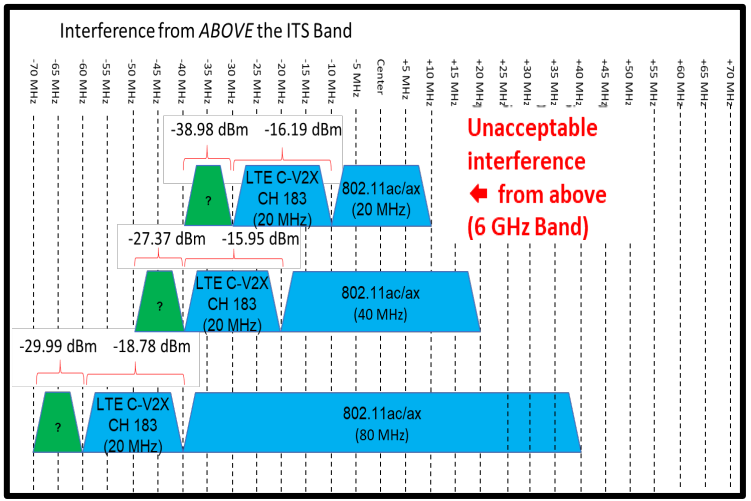
Scenario 2 Test Parameters and Variations:

Number of LTE-V2X OBUs	250+
Number of LTE-V2X RSUs	10+
Payload	365 Byte (V2V) / 1400 Byte (I2V)
HARQ	ON
LTE-V2X Channels	5.915 MHz-183 (for both OBUs and RSUs)
LTE-V2X Transmit Power	20 dBm
High-Speed Vehicle Congestion Mitigation	ON
High-Speed Vehicle TTI	AUTOMATIC
250+ Stationary Devices Congestion Mitigation	ON / OFF
250+ Stationary Devices TTI Setting	AUTOMATIC / 50 ms / 100 ms / 600 ms
Unlicensed Wi-Fi Channel	OFF / 5.885 MHz (CH 177) / 5.895 MHz
Unlicensed Wi-Fi Effective Isotropic Radiated Power (EIRP)	OFF / 13 dBm /33 dBm / Max OOBE

Interference Testing

- Testing **the impact of Unlicensed Wi-Fi transmissions** operating above and below the newly allocated channel (183) for LTE-V2X communications.





Real-World Environment

- **Using a Connected Vehicle Pilot site in Tampa, Florida as a real-world location for communications performance testing. The data set will allow for a fuller understanding of the propagation performance of LTE-V2X technologies outside of controlled conditions.**
  - Testing in an environment that offers **buildings and reflectivity**, as well as urban canyon effects, **overpasses**, foliage and weather variation, among **other typical conditions**.
  - **Interference testing** to compare performance in different conditions (i.e., weather, time of day) as a baseline and then in the target area where unlicensed Wi-Fi interference will be generated.

Figure 3: Test Track Scenario 3 Set-up

Number of LTE-V2X OBUs / RSUs	3 OBUs, 1 RSU
Payload	365 Byte (V2V) / 1400 Byte (I2V)
HARQ	ON
LTE-V2X Channels	CH 183
LTE-V2X Transmit Power	20 dBm
Unlicensed Wi-Fi Channel	20 MHz channel centered at 5.895 MHz / Also in the next adjacent channel CH177 Unlicensed Wi-Fi
Unlicensed Wi-Fi EIRP	OFF / 13 dBm / 33 dBm / Max OOBE

Assessment Metrics

PACKET ERROR RATE

The ratio of packets received to packets sent, over a window of time.

INTER-PACKET GAP

The time between successive packets received.

CONSECUTIVE PACKETS MISSED

The number of times at least two consecutive packets are missed.

TRANSMIT TIME INTERVAL

The time between successive packets sent.

CHANNEL BUSY RATIO

The amount of time the channel is busy.

Analysis Questions

- **Analysis of the test data is anticipated to address the following questions:**
  - **LTE-V2X Device Performance:** What are the operational characteristics and how do they support V2V and V2I ad hoc communications? Can LTE-V2X remain operational with loss of GPS and thus loss of ability to “sync” with all surrounding devices to divide up/reserve the available spectrum resource blocks?
  - **Scalability/Congestion:** Are there LTE-V2X technology performance gaps in high-density scenarios? How stable and consistent are the LTE-V2X ad hoc environments as more devices are added?
  - **Interference and Understanding the Usability of the 30 MHz at 5.895 – 5.925 GHz:** Are any mitigations required to prevent harmful interference from unlicensed Wi-Fi out-of-band emissions (OOBE) above and below the Safety Band?
  - **Safety Performance:** What is the potential for LTE-V2X radio performance to meet crash-imminent safety communications requirements in a non-network connected mode under varying average and challenging traffic, interference, and spectrum conditions?

Resources Informing Test Approach

- **Transportation community questions and concerns:**
  - March 2020 filing: https://ecfsapi.fcc.gov/file/10313251510165/5.850-5.925%20GHz%20Band%2C%20ET%20Dkt%20No.%2019-138.pdf
  - November 2020 filing: https://www.fcc.gov/ecfs/filing/1109637413744
  - State/Local DOT and OEM filings
- **U.S. DOT test/interference studies that identify effects of unlicensed Wi-Fi in adjacent/ second adjacent channels that we assume will have a similar effect on LTE-CV2X:**
  - Industry: https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/v2v-cr_dsrc_wifi_baseline_cross-channel_interference_test_report_pre_final_dec_2019-121219-v1-tag.pdf
  - U.S. DOT analysis using FCC measurements: https://www.transportation.gov/sites/dot.gov/files/2020-03/Analysis%20%20of%20FCC%20Phase%20I%20Sharing%20Report_V02_04%2011MARCH2020.pdf
  - U.S. DOT DSRC-UNII Sharing Study (Phase 2 of a 3-Phase Study with FCC and NTIA): https://www.transportation.gov/research-and-technology/us-dot-spectrum-sharing-test-report-effects-unlicensed-national-information
  - Industry study on in-vehicle UNII on LTE-CV2X transmissions: https://ecfsapi.fcc.gov/file/109091489219757/5GAA%209.9.20%20Ex%20Parte%20w%20Attachment%20(Final).pdf
- **Previous DSRC testing:**
  - https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication
  - https://www.campllc.org/publications/

For More Information

- **Technical Contacts:**
  - **ITS Joint Program Office**, Jonathan B. Walker, P.E., Ph.D. (Jonathan.B.Walker@dot.gov), Chief of Policy, Architecture, and Knowledge Transfer
  - **Federal Highway Administration**, John Harding (John.Harding@dot.gov) Connected/Automated Vehicles and Emerging Technologies Team Leader, Office of Operations
  - **National Highway Traffic Safety Administration**, Bob Kreeb (Robert.Kreeb@dot.gov), Chief of Electronic Systems Safety Division\
  - **OST-R/Volpe National Transportation Systems Center**, Suzanne Sloan (Suzanne.Sloan@dot.gov), Principal Technical Advisor, Technology Innovation and Policy
  - **OST-R/Volpe National Transportation Systems Center**, Jeff Bellone (Jeffrey.Bellone@dot.gov), Systems Engineer
- **U.S. DOT Safety Band Website:**
  - www.transportation.gov/content/safety-band
- **U.S. DOT ITS Program's Emerging and Enabling Technologies Website:**
  - www.its.dot.gov/research_areas/emerging_tech/index.htm