V2X Technology
Functional and Performance Benchmark Testing
Key Findings
October 2018

Read full report here
Technology Performance Characterization Approach

• Provision for interchangeable DSRC and C-V2X systems.

• Technology agnostic capability assessment procedures documented and harmonized in 5GAA for global consistency.

• Tests conducted with scrupulous control of factors influencing radio wave propagation to ensure fair comparison:
  • Antenna characteristics and placement
  • Vehicle geometry and cabling
  • Location and environmental conditions
  • Power, interference and other settings
Performance Characterization

Ford and Qualcomm conducted testing to compare radio performance of CV2X and DSRC in Ann Arbor and San Diego. Key tests performed:

<table>
<thead>
<tr>
<th>Category</th>
<th>Lab/Cabled Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion</td>
<td>Cabled Congestion Control</td>
</tr>
<tr>
<td>Reliability</td>
<td>Cabled Tx and Rx Tests</td>
</tr>
<tr>
<td></td>
<td>Line-of-Sight (LOS) Range Tests</td>
</tr>
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<td>Interference</td>
<td>Cabled Test with Simulated Co-channel Interference</td>
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<td>Cabled Near-Far Test</td>
</tr>
<tr>
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<td>Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3</td>
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<td>Co-existing of C-V2X with Adjacent DSRC Carrier</td>
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</tbody>
</table>
Congestion Lab Test

**Purpose:**
Assess CV2X ability to manage congestion per SAE 2945/1.

Packet error rate remains below 10% while CBR is ~30% with congestion management.
Cabled Radio Lab Test

**Purpose:**
Measure radio performance under varying receive power conditions.

CV2X outperforms DSRC consistent with simulations.
Line-of-Sight Field Test

**Purpose:**
Assess baseline capability for V2V message exchange in line of sight (LOS).

**Note:** Equivalent transmit power was set at 11dBm for both DSRC and CV2X to fit measured range into the test track (1350m long) and to match the setting in previous tests by the industry.
Line-of-Sight Field Test Results

Stationary vehicle receiving
Moving vehicle transmitting and approaching

Stationary vehicle transmitting
Moving vehicle approaching and receiving

Significant baseline performance advantage consistent with Lab results.
**Intersection Test (Obstructed view)**

**Purpose:**
Assess non-line of sight V2V communication capability.

- 26-ft U-Haul trucks
- Constant speed: 20mph
- U-turn at the end of the test track
Intersection Test Results

Stationary vehicle receiving
Moving vehicle transmitting and approaching

Stationary vehicle transmitting
Moving vehicle approaching and receiving

Significant performance advantage in obstructed view intersection.
5GAA Shadowing Test

**Purpose:**
Assess capability for V2V message exchange in non-line of sight (NLOS) scenario with significant obstruction.

**Note:** The blocker is positioned in front of the stationary vehicle in order to create a significant (and constant) line of sight obstruction. The Stationary Vehicle and Blocker remain motionless during the entire test.
CAMP Shadowing Test

**Purpose:**
Assess V2V message exchange capability through obstruction in a highway queue-forming scenario.

**Note:** In this test *the effect of the blocker is negligible at maximum vehicle separation* (obstruction appears very small to the SV). As a result, the test will produce better range than the more demanding 5GAA shadowing test regardless of technology.
5GAA shadowing test is more demanding than the CAMP test. CV2X outperforms DSRC in shadowing scenarios by large margin.
Purpose:
Assess capability to resist out-of-band interference.

Both OBUs were operating in CH184 and the interferer was shifted from center frequency 5,775MHz to 5,835MHz.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Power</td>
<td>23 dBm</td>
</tr>
<tr>
<td>Utilization</td>
<td>76%</td>
</tr>
</tbody>
</table>
Line-of-sight UNII-3 Out-of-band Interference Test: Results

Moving vehicle transmitting and approaching, Stationary vehicle receiving

CV2X is more resilient to UNII-3 interference than DSRC.
Latency Lab Results

**Purpose:**
Measure end-to-end latency at PRR > 90% in various lab tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Technology</th>
<th>95%-ile IPG (ms)</th>
<th>95%-ile latency (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabled Tx/Rx</td>
<td>CV2X</td>
<td>106</td>
<td>22*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(with 20ms latency budget)</td>
</tr>
<tr>
<td></td>
<td>DSRC</td>
<td>104</td>
<td>20</td>
</tr>
<tr>
<td>Congestion</td>
<td>CV2X</td>
<td>105</td>
<td>99*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(with 100ms latency budget)</td>
</tr>
</tbody>
</table>

*In C-V2X, latency budget can be configured based on the application/situational need. The latencies remain bounded by the configured budget independent of the level of congestion.

Both CV2X and DSRC satisfy SAE J2945/1 requirements.
## Technology benchmark summary

<table>
<thead>
<tr>
<th>Category</th>
<th>Lab Cabled Test</th>
<th>Field Non-Line-of-Sight (NLOS) Range Tests</th>
<th>Field Co-existence of V2X with Adjacent DSRC Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion</td>
<td>Cabled Congestion Control</td>
<td></td>
<td>Pass</td>
</tr>
<tr>
<td>Reliability</td>
<td>Cabled Tx and Rx Tests</td>
<td>Line-of-Sight (LOS) Range Tests</td>
<td>CV2X better</td>
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<td>Interference</td>
<td>Cabled Test with Simulated Co-channel Interference</td>
<td>Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3</td>
<td>CV2X better</td>
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<tr>
<td></td>
<td>Cabled Near-Far Test</td>
<td></td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co-existing of V2X with Adjacent DSRC Carrier</td>
<td>Pass</td>
</tr>
</tbody>
</table>

CV2X radio technology consistently outperforms DSRC.
## Field results summary

<table>
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<tr>
<th>Test Procedure</th>
<th>Range at 90% Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DSRC</td>
</tr>
<tr>
<td>Line-of-Sight (LOS) Range</td>
<td>675m</td>
</tr>
<tr>
<td>Non-Line-of-Sight (NLOS) Blocker (5GAA)</td>
<td>125m</td>
</tr>
<tr>
<td>Non-Line-of-Sight (NLOS) Blocker (CAMP)</td>
<td>400m (200m)²</td>
</tr>
<tr>
<td>Non-Line-of-Sight (NLOS) Intersection</td>
<td>375m</td>
</tr>
<tr>
<td>Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3</td>
<td>300m (75m)</td>
</tr>
<tr>
<td>Co-existing of V2X with Adjacent DSRC Carrier</td>
<td>400m (100m)</td>
</tr>
</tbody>
</table>

**CV2X radio technology consistently outperforms DSRC.**

¹ Number in parenthesis indicate first drop below 90% reliability
BMW, Ford, PSA, Qualcomm CV2X demonstration in Paris, France, July 2018. Click Here For More
Appendix
Cabled Near-Far Test

*Purpose:* Assess half-duplex C-V2X capability.

C-V2X copes well with transmissions in same time slot, different frequency.
Line-of-sight Adjacent Channel Interference Test

Purpose:
Assess capability to resist adjacent channel interference.

Interfering vehicle

Parameter | Value
--- | ---
Tx Power | 19 dBm
Utilization | 96%
Line-of-sight Adjacent Channel Interference Test Results

Interference vehicle: OFF

Interference vehicle: Transmitting

Moving vehicle transmitting and approaching, Stationary vehicle receiving

CV2X is more resilient to adjacent channel V2X interference than DSRC.
CAMP Shadowing Test Results (21 dBm)

- Range for both technologies exceeds 1.4km at higher power
- Drop in PRR consistent for both technologies

Increase in path loss observed close to the middle of the track.