V2X
Vehicle to Everything
Ever heard a Traffic light & Car talking?

5G unified connectivity

Intelligently connecting the car to cloud and surroundings

Vehicle-to-vehicle

Vehicle-to-infrastructure
3D HD live map updates

Vehicle-to-network

Vehicle-to-pedestrian

AR/VR
Teleoperation
HD video
Agenda

• Introduction to V2X?
• Overview of DSRC and C-V2X
• 3GPP Evolution of C-V2X
• Test challenges
• LitePoint Solution portfolio
What is V2X?

**Vehicle to Everything Communication**

Enables road safety & autonomous driving allowing vehicles to directly communicate with each other and with the infrastructure around.
Wireless Technologies in V2X

- Two Competing Wireless Standards:
  - **DSRC** (Dedicated Short Range Communications)
  - **C-V2X** (Cellular V2X)

- **DSRC**:
  - Defined by IEEE
  - Dedicated radio in the 5.9 GHz band
  - PHY layer uses 802.11p

- **C-V2X**:
  - Defined by 3GPP
  - Dedicated radio in the 5.9 GHz band
  - Additional radio in the licensed cellular band (LTE/5GNR)
Overview of DSRC

- DSRC was introduced over 10 years ago to add intelligence to transportation systems

- Uses 802.11p wireless technology in the 5.9 GHz band

- Key features enabled by DSRC:
  - Speed detection, collision avoidance, real-time road condition, toll payments, autonomous driving vehicle collaboration

- Mature technology with proven road-tested experience

- Limited market adoption:
  - Not governmentally mandated to be installed in new cars
  - Other technologies have solved some of the use-cases: RADAR, LiDAR, ultrasonic sensors, electronic toll systems
  - Latency of DSRC limits maximum speed for effectiveness
Overview of C-V2X

- C-V2X has recently been defined as part of the 3GPP initiative
  C refers to cellular technologies (4G LTE/5G NR)

- Builds on the capabilities of DSRC, and also adds a wide-area connection to the cellular network (key for autonomous driving)

- Requires (at least) two radios to operate:
  - Cellular radio (sub 6Ghz or mmwave): LTE/NR
  - Dedicated radio (5.9 GHz): improves on 802.11p

- Lower latency = operates at higher vehicular speeds

- Adoption timing unclear:
  - New technology: automotive market adoption is SLOW!!
  - Not governmentally mandated to be installed in new cars
C-V2X Communication Modes

**Direct Communication/ (PC5/Sidelink)**

**Network Communication (Uu Interface)**

Source: AutoTalks
C-V2X (Release 14) Operation Band

### Table 4.3.3.1-1 V2X operating band over PC5

<table>
<thead>
<tr>
<th>V2X Operating Band</th>
<th>E-UTRA Operating Band</th>
<th>V2X UE transmit</th>
<th>V2X UE receive</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>47</td>
<td>5855 MHz - 5925 MHz</td>
<td>5855 MHz - 5925 MHz</td>
</tr>
</tbody>
</table>

### Table 4.3.3.1-2 V2X operating band over Uu

<table>
<thead>
<tr>
<th>V2X Operating Band</th>
<th>Uplink (UL) operating band ↓ BS receive ↓ UE transmit</th>
<th>Downlink (DL) operating band ↓ BS transmit ↓ UE receive</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1710 MHz - 1785 MHz</td>
<td>1805 MHz - 1880 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>7</td>
<td>2500 MHz - 2570 MHz</td>
<td>2620 MHz - 2690 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>8</td>
<td>880 MHz - 915 MHz</td>
<td>925 MHz - 960 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>39</td>
<td>1880 MHz - 1920 MHz</td>
<td>1880 MHz - 1920 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>41</td>
<td>2496 MHz - 2690 MHz</td>
<td>2496 MHz - 2690 MHz</td>
<td>TDD</td>
</tr>
</tbody>
</table>
## V2X Technology Similarities and Comparisons

<table>
<thead>
<tr>
<th>Radio Design</th>
<th>DSRC/ ITS-G5</th>
<th>Cellular + Sidelink / C-V2X</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>IEEE</td>
<td>3GPP</td>
</tr>
<tr>
<td><strong>Radio Technology</strong></td>
<td>802.11p</td>
<td>Optimized Cellular technology (Rel-14/15/16)</td>
</tr>
<tr>
<td><strong>Frequency Band</strong></td>
<td>Dedicated radio in 5.9GHz</td>
<td>Dedicated radio 5.9GHz. With optional support for cellular radio</td>
</tr>
<tr>
<td><strong>Channel Size</strong></td>
<td>10/20Mhz</td>
<td>Rel 14/15 - 10/20Mhz Rel 16 - 10/20/40/60/80/100/...Mhz</td>
</tr>
<tr>
<td><strong>Transmission Mode</strong></td>
<td>TDM (TDD)</td>
<td>Both TDD &amp; FDD (Longer transmission time provides better quality of service)</td>
</tr>
<tr>
<td><strong>Resource Selection</strong></td>
<td>Carrier Sense Multiple Access – Collision Avoidance</td>
<td>Semi-persistent scheduling based on relative energy; eNB based scheduling</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>&lt;10 msec</td>
<td>&lt;10 msec</td>
</tr>
<tr>
<td><strong>Modulation Support</strong></td>
<td>Up to 64QAM</td>
<td>Up to 64QAM direct comm Up to 256QAM with cellular support</td>
</tr>
<tr>
<td><strong>Transmission Range</strong></td>
<td>Up to ~250m</td>
<td>~250m using direct communication Large via cellular network infrastructure</td>
</tr>
</tbody>
</table>
## Technology Similarities and Comparisons

<table>
<thead>
<tr>
<th>General</th>
<th>DSRC/ ITS-G5</th>
<th>C-V2X/ Sidelink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>Supports only direct communication (V2V, V2P, V2I)</td>
<td>Includes both direct and network communication (V2V, V2P, V2I and V2N)</td>
</tr>
<tr>
<td>Target Use Case</td>
<td>Mainly for safety</td>
<td>Safety, positioning, autonomous driving</td>
</tr>
<tr>
<td>Performance</td>
<td>Packet loss at high density</td>
<td>Promise for almost no packet loss at higher densities</td>
</tr>
<tr>
<td>High Mobility Support</td>
<td>Up to relative speeds of 500km/hr</td>
<td>For relative speeds much &gt; 500km/hr</td>
</tr>
<tr>
<td>Advantages</td>
<td>Mature technology, Reliable, road-tested</td>
<td>Leverages LTE infrastructure, 3GPP viewed as high reliability</td>
</tr>
<tr>
<td>Limitations</td>
<td>Short range comm., Limited scalability, Vehicular speed limitations, No cloud/local area update</td>
<td>Long range communication, Scalable (better spectral efficiency), For speeds &gt;500Km/hr, Capable of Real time updates</td>
</tr>
<tr>
<td>Market Adoption</td>
<td>N America, Europe, Japan</td>
<td>China</td>
</tr>
</tbody>
</table>
C-V2X Advantages

- Autonomous / Coordinated Driving
- Cellular Infrastructure Independence
- Path Planning & Perception
- 3D mapping and precise positioning
- Situational Awareness
- Enhanced reliability
- Higher throughput/Traffic efficiency
- Lower latency
DSRC evolution to C-V2X?
Adoption dependent on regulation or mandate?
Automaker Adoption

Despite the regulatory uncertainty and debate between 802.11p/DSRC versus C-V2X, certain automakers have chosen to adopt one and planned roll outs

• DSRC roll out expected in 2019:
  Cadillac, Toyota / Lexus, Volkswagen, General Motors

• CV2X roll out expected by 2021, 2022:
  Ford, BMW, Daimler, Groupe PSA, SAIC, Geely, Audi, and Jaguar Land Rover.

Global spending on V2X is expected to grow at a CAGR of more than 170% between 2019 and 2022.

Research predicts that by the end of 2022, V2X market will account for a market worth $1.2 Billion, with nearly 6 Million V2X-equipped vehicles worldwide.

Source: prnewswire.com
3GPP Evolution of C-V2X
C-V2X Evolution with 3GPP Release

- **3GPP Rel. 8-13** (March 2016)
  - LTE V2N Uu

- **3GPP Rel. 14** (March 2017)
  - Direct Communication LTE V2V/V2I (PC5)

- **3GPP Rel. 15** (June 2018)
  - 5G NR V2N Uu
  - High bandwidth/low latency

- **3GPP Rel. 16** (December 2019)
  - 5G NR Uu URLLC
  - Direct Communication 5G NR V2V/V2I

Hazard warning

V2V safety use case

Enhanced Navigation & Infotainment

Cooperative automated driving

Source: http://5gaa.org
### Newer Capabilities for Sidelink

<table>
<thead>
<tr>
<th>NR Design</th>
<th>5G NR C-V2X capabilities for autonomous driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalable OFDM-based air interface</td>
<td>5G C-V2X is expected to efficiently address diverse spectrum bands for different use cases, leveraging wideband carrier support and OFDMA to deliver higher data rates.</td>
</tr>
<tr>
<td>Self-contained slot structure</td>
<td>Smaller slot structure with immediate feedback to enable ultra reliable low latency communications.</td>
</tr>
<tr>
<td>Advanced channel coding</td>
<td>State of the art LDPC/polar coding to deliver higher reliability with low complexity.</td>
</tr>
<tr>
<td>Wideband carrier support</td>
<td>Wideband carrier based higher data rates and system capacity.</td>
</tr>
<tr>
<td>Larger number of antenna</td>
<td>Efficiently utilize larger number of antennas than Rel-14 to deliver higher data rate and long range.</td>
</tr>
</tbody>
</table>
## LTE C-V2X and NR C-V2X

### Basic safety application by LTE-V2X (PC5) @ 5.9 GHz

New vehicles deploy both LTE-V2X and NR-V2X to enable the inter-operability with old vehicles:

1. LTE-V2X (PC5): Basic safety
2. NR-V2X (sidelink): Autonomous Driving

### Flexible selection between LTE-V2X and NR-V2X

Provide policies/criteria to UE to assist radio technology selection, according to V2X application type, QoS requirements, etc.

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<table>
<thead>
<tr>
<th>V2X Application</th>
<th>CAM</th>
<th>DENM</th>
<th>Platooning</th>
<th>Auto Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

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Diagram showing the V2X adaptation layer with LTE-V2X and NR-V2X.
Cellular - V2X

Manned Vehicle without C-V2X
No blind Spot detection
Chances of collision

Smart vehicle without C-V2X
Still less reliable
higher latency & response time

Smart vehicle with 5GNR + C-V2X
Highly reliable, safe & fast

Sensor data sharing
Path Planning
Real time Updates
Coordinated Driving

Wideband Carrier Support
High Throughput
Low Latency
Ultra High Reliability

Source: highwaysafety.utah.gov
Source: govpololu.com
Innovation does not come easy
Test challenges for PC5 / Sidelink

• Scalability

• Rx Sensitivity/Low PER

• Calibration

• Wide Area Network (WAN)

• Small Error Tolerance
Physical Layer Testing

- Calibration
- Tx: Power, EVM, Mask Testing
- Rx: BLER/PER, RSSI, Sensitivity
LitePoint at your rescue

With a comprehensive solution
C-V2X waveform analysis

Power vs Time

Power Spectral Density

EVM

Modulation quality
Transforming Complexity to Simplicity
Comprehensive V2X solution

Chipset
Module
Product
OEM / CM

Calibration Algorithms
Measurement Algorithms

Characterization
Data Visualization

Automation
Solutions

R&D
IC / Module
development Test

DVT
Design Verification
Testing

Final Product
Manufacturing Test

Source: luginnotek

Source: commsignia

Source: driverless.global
Testing made much simpler and faster

- Chipset or Module
  we test it all

- Higher Throughput
  with multi DUT testing

- Shorter time to market

- Reduced Testing cost

- Customer Support

Source: barcodedatalink
Source: cloudlibrarydownunder.wordpress.com
Source: entrepreneur.com
Thank You!