Accelerating C-V2X commercialization
Shaping the future of automotive

- Connecting vehicles to everything
- Transforming the in-vehicle experience
- Paving the road to autonomous driving
Paving the road to tomorrow’s autonomous vehicles

Offering essential technologies for the connected car platform

Autonomous car

- Power optimized processing for the vehicle
- Fusion of information from multiple sensors/sources
- Unified connectivity with C-V2X
- 3D mapping and precise positioning
- On-board intelligence
5G unified connectivity

Intelligently connecting the car to cloud and surroundings

Vehicle-to-infrastructure
3D HD live map updates

Vehicle-to-pedestrian

Vehicle-to-network
Teleoperation
HD video

Vehicle-to-vehicle
Continuous V2X technology evolution required

And careful spectrum planning to support this evolution

Evolution to 5G, while maintaining backward compatibility

Basic safety
802.11p or C-V2X R14

Established foundation for V2X

Enhanced safety
C-V2X R14/15

Enhanced range and reliability

Advanced safety
C-V2X R16 (building upon R14)

Higher throughput
Higher reliability

Wideband ranging and positioning
Lower latency
### Evolving C-V2X towards 5G for autonomous driving

<table>
<thead>
<tr>
<th></th>
<th>D2D communications</th>
<th>Enhanced safety</th>
<th>Autonomous driving</th>
</tr>
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<tr>
<td></td>
<td>R12/13</td>
<td>C-V2X R14 (Ph. I)</td>
<td>C-V2X R16 5G NR support (Ph. III)</td>
</tr>
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<td></td>
<td></td>
<td>C-V2X R15 (Ph. II)</td>
<td>(Advanced safety applications)</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td><strong>Established foundation for basic D2D comm.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enhanced communication’s range and reliability for V2X safety</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ultra-reliable, low latency, high throughput communication for autonomous driving</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network independent</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Communications¹</td>
<td>Broadcast only</td>
<td>Broadcast only</td>
<td>Broadcast + Unicast/Multicast</td>
</tr>
<tr>
<td>High speed support</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>High density support</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Throughput</td>
<td></td>
<td>High throughput for enhanced safety</td>
<td>Ultra-high throughput</td>
</tr>
<tr>
<td>Latency</td>
<td></td>
<td>Low latency for enhanced safety applications</td>
<td>Ultra-low latency</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td>Reliability for enhanced safety application</td>
<td>Ultra-high reliability</td>
</tr>
<tr>
<td>Positioning</td>
<td>No</td>
<td>Share positioning information</td>
<td>Wideband ranging and positioning</td>
</tr>
</tbody>
</table>

1. PHY/MAC communications; R16 is still under development
C-V2X is a critical component for safer autonomous driving

Communicating intent and sensor data even in challenging real world conditions

**Non line-of-sight sensing**
Provides 360° NLOS awareness, works at night and in bad weather conditions

**Conveying intent**
Shares intent, sensor data, and path planning info for higher level of predictability

**Situational awareness**
Offers increased electronic horizon to support soft safety alerts and graduated warning

- **Road hazard**
- **Sudden lane change**
- **Reduced speed ahead**
- **Queue warning/shockwave damping**

Blind intersection/vulnerable road user (VRU) alerts
High precision positioning is key for V2X operation

Precise positioning
Use GNSS along with precise positioning services to get <1 meter accuracy

Velocity
Accurate speed derived directly from GNSS positioning calculation

Heading
Accurate heading derived directly from GNSS positioning calculation

Accurate time info
Using GNSS as a primary source of time synchronization
Enhancing positioning on multiple fronts

**More accurate**
Sub-meter level accuracy (e.g. lane-level accuracy) with high integrity for V2X and autonomous driving applications

**Anywhere, anytime**
Combined precise GNSS positioning with sensor inputs to provide accurate positioning everywhere, including dense urban environments, parking garages and multi-level interchanges

**More frequently updated**
Updated very frequently to provide fresh, accurate positioning information (e.g. vehicles send their most recent location at least every 100ms for V2X applications)
Evolving positioning technologies for V2X and autonomy

To offer more precise positioning, anywhere, anytime

Positioning

Navigation / emergency service / regulatory

Satellite-based navigation

More precise positioning at higher update rates

Precise positioning <2m

V2X enhanced safety

More precise positioning at higher update rates

Ultra-precise positioning <<1m

Autonomous driving

Ultra-precise positioning anywhere, anytime for autonomy

**Satellite-based navigation**
- More satellites for improved accuracy and availability
- Extend accuracy and availability in more places w/ better sensors

**Precise positioning <2m**
- GPS
- 2D Dead Reckoning (DR) using single axis sensors
- Glonass
- BDS
- Galileo
- QZSS
- Satellite-based augmentation system (SBAS)
- 6DOF MEMS sensors
- 3D Dead Reckoning (3D DR)
- Higher frequency => 10Hz
- L1 Correction services
- Camera VIO

**Ultra-precise positioning <<1m**
- Higher frequency => 10Hz
- L1 Correction services
- Camera VIO
- Multi-frequency GNSS
- RF and Baseband
- Software
- Correction Services
- 5G NR V2X
On-board intelligence: C-V2X complements other sensors
Providing higher level of predictability and autonomy

- **Radar**
  - Bad weather conditions
  - Long range
  - Low light situations

- **Camera**
  - Interprets objects/signs
  - Practical cost and FOV

- **Lidar**
  - Depth perception
  - Medium range

- **Ultrasonic**
  - Low cost
  - Short range

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**ADAS**
Advanced Driver Assistance Systems

Brain of the car to help automate the driving process by using:

- Immense compute resources
- Sensor fusion
- Machine learning
- Path planning

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**V2X wireless sensor**
See-through, 360° non-line of sight sensing, extended range sensing

**3D HD maps**
HD live map update
Sub-meter level accuracy of landmarks

**Precise positioning**
GNSS positioning
Dead reckoning
VI0
C-V2X Release 14 enhances range and reliability

Paving the path to autonomous driving
C-V2X offers key advantages in multiple dimensions

- Enhanced range and reliability
- High density support
- Self managed for reduced cost and complexity
- Synergistic with telematics platform
- Reuse of DSRC/C-ITS higher layers
- High speed support
- Leverage of cellular ecosystem
- Strong evolution path towards 5G
C-V2X defines two complementary transmission modes

**Network communications**
V2N on “Uu” interface operates in traditional mobile broadband licensed spectrum

**Direct communications**
V2V, V2I, and V2P on “PC5” interface, operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network

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1. PC5 operates on 5.9GHz; whereas, Uu operates on commercial cellular licensed spectrum. 2. RSU stands for roadside unit.
Network communications for latency tolerant use cases

Suitable for telematics, infotainment and informational safety use case

Discover parking and charging

Cloud-based sensor sharing

Traffic flow control/Queue warning

Road hazard warning 1 km ahead
Direct communications for active safety use cases

Low latency communication with enhanced range, reliability, and NLOS performance

- Do not pass warning (DNPW)
- Blind curve/Local hazard warning
- Road works warning
- Intersection movement assist (IMA) at a blind intersection
- Vulnerable road user (VRU) alerts at a blind intersection
- Left turn assist (LTA)
C-V2X can work without network assistance

V2V/V2I/V2P direct communications can be self managed

- **USIM-less operation**: C-V2X direct communications doesn’t require USIM
- **Autonomous resource selection**: Distributed scheduling, where the car selects resources from resource pools without network assistance
- **GNSS time synchronization**: Besides positioning, C-V2X also uses GNSS for time synchronization without relying on cellular networks

1. 3GPP also defines a mode, where eNodeB helps coordinate C-V2X Direct Communication; 2. GNSS is required for V2X technologies, including 802.11p, for positioning. Timing is calculated as part of the position calculations and it requires smaller number of satellites than those needed for positioning.
Advantages of self-managed over network-assisted

**Reduced cost**
Doesn’t use prime licensed spectrum for control, no additional network investment

**Increased reliability**
Doesn’t rely on network coverage, doesn’t suffer from service interruption during handover

**Reduced complexity**
Doesn’t rely on coordination between operators for resource assignment, doesn’t require subscription

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**Self-managed**
(no network assistance)

- Direct communications and control on PC5

**Network-assisted**

- Control on Uu
- eNodeB
- Direct Communications on PC5
- Control on Uu
C-V2X is designed to work in ITS 5.9 GHz spectrum

For vehicles to talk to each other on harmonized, dedicated spectrum

3GPP support of ITS 5.9 GHz band

C-V2X support in ITS band was added in 3GPP Release 14

Harmonized spectrum for safety

C-V2X uses harmonized/common, dedicated spectrum for vehicles to talk to each other

Coexistence with 802.11p

C-V2X and 802.11p can co-exist by being placed on different channels in the ITS band

5GHz support began in release 13 with LAA, and expanded with release 14 for ITS
Fully leveraging ITS 5.9 GHz band for 5G V2X services
Supporting today’s basic safety, and tomorrow’s advanced use cases

Example 5.9 GHz

10 MHz
Support today’s safety use cases on small subset of the band (using 802.11p or C-V2X)

70 MHz
In addition to basic safety, support advanced safety services (e.g. higher bandwidth sensor sharing and wideband ranging/positioning)

C-V2X Rel-15+ can operate in the same Rel-14 spectrum
C-V2X reuses upper layers defined by automotive industry

Reuse of DSRC/C-ITS established service and app layers
- Already defined by automotive and standards communities, e.g. ETSI, SAE
- Developing abstraction layer to interface with 3GPP lower layers (in conjunction with 5GAA)

Reuse of existing security and transport layers
- Defined by ISO, ETSI, and IEEE 1609 family

Continuous enhancements to the radio/lower layers
- Supports the ever-evolving V2X use cases

Note: Also enhancements to the LTE Direct network architecture / system design to support V2X
C-V2X reduces vehicle communications complexity and cost

Most optimal platform
- Takes advantage of already planned embedded modem installation in vast majority of new vehicles

Cost efficient solution
- Leverages mobile ecosystem and existing engineering know-how, resources and solutions

Strong evolution path
- Keeps technology relevant to new use cases by avoiding one-off technology lifecycle obsolescence
C-V2X reduces cost of infrastructure deployment

Combined RSUs and 4G/5G small cell, benefiting from cellular network densification
C-V2X offers new business models and economic benefits

Leveraging existing, ubiquitous cellular networks and mobile ecosystem support

- More integrated solution
  - C-V2X functionality can be integrated in vehicle’s modem to enable most optimal platform

- Reduced deployment cost
  - Combined RSU and eNodeB infrastructure synergies provide economic benefits

- Mobile ecosystem expertise
  - Benefits from cellular player's extensive experience in deploying, managing, and maintaining complex communication systems

- New services and business opportunities
  - Leverages unified C-V2X / telematics offerings and addresses new services for shared mobility and autonomous driving
C-V2X Performance Advantage
C-V2X Rel-14 has significantly better link budget than 802.11p¹

Leading to longer range (~2X range)—or more reliable performance at the same range

- **Transmission time**
  - Longer transmit time leads to better energy per bit
  - Energy per bit is accumulated over a longer period of time for C-V2X

- **Waveform**
  - SC-FDM has better transmission efficiency
  - SC-FDM allows for more transmit power than OFDM for the same power amplifier

- **Channel coding**
  - Gains from turbo coding and retransmission
  - Coding gain from turbo codes and HARQ retransmission lead to longer range

¹ Link budget of C-V2X is around 8 dB better than 802.11p
Longer transmission time: leads to link budget gain
Usage of FDM in C-V2X provides an advantage compared to TDM in 802.11p

Example

4.8dB (3X)
Gain per packet for C-V2X

C-V2X
Energy per packet = 0.1 mWs

802.11p
Energy per packet = 0.033 mWs

1. Assumptions: 190 bytes packet size, ½ rate coding for 802.11p, 0.444 rate coding for C-V2X, QPSK modulation used for both 802.11p and C-V2X,
SC-FDM Waveform: better transmission efficiency

Providing 2dB better transmission efficiency than OFDM, with the same PA\(^1\)

SC-FDM’s higher average power due to its lower PAPR\(^2\)

- SC-FDM groups resource blocks together in a way that reduces peak-to-average power ratio (PAPR), hence support driving power amplifier closer to saturation, leading to better transmit power efficiency
- Used for LTE uplink and 5G macro deployments, where transmit power efficiency is particularly important

\(^1\) At 0.1% peak-to-average-ratio Complementary Cumulative Distribution Function (CCDF) operating point; \(^2\) Power graphs used to illustrate the point and are not based on real data nor drawn to scale
Channel Coding: TC provides ~2dB coding gain over CC

Providing 2dB better transmission efficiency at the same PA

The required SNR for receiving a specific packet size with 1% block error rate is 2dB lower with TC than CC

- C-V2X uses the more modern turbo codes (TC), while 802.11p uses K=7 convolutional codes (CC)
- TC used for Wi-Fi evolution (11.ac) and in 3G/4G to reduce bit error rate
Freeway scenarios: Simulation assumptions

Freeway drop is used to simulate high speed performance

Simulation assumptions:

- 6 lanes for 4m each, 3 lanes in each direction
- Three speeds => 250 km/hr, 140 km/hr, 70 km/hr
- Cars dropped according to Poisson process, avg. car spacing is 2.5s
  - 69, 123, 246 cars
- All cars are LOS
- Actual mobility simulated: correlated shadowing, independent fading
- Packet transmission periodicity:
  - 140, 250 km/hr => 100ms; 70 km/hr => 200ms
Enhanced range and reliability in free way scenarios

~100% gain in distance at 0.9 PRR; @400m PRR changed from 0.02 to 0.6

Freeway 250 km/hr, 69 cars

Freeway 140 km/hr, 123 cars
Enhanced range and reliability: Free way 70 km/hr speed

~60% gain in distance at 0.9 PRR; @400m PRR changed from 0.02 to 0.58
Urban Scenarios: Simulation assumptions

Urban drop is used to simulate high density drops

Simulation assumptions:

- 4 lanes for 3.5m each, 2 lanes in each direction
- Speeds: 15 km/hr, 60 km/hr
- Cars dropped according to Poisson process, avg. car spacing is 2.5s
  - 590, 2360 cars
- Packet transmission periodicity:
  - 60 km/hr => 250ms; 15 km/hr => 1000ms
- LOS on same road, NLOS on cross roads
- Actual mobility simulated:
  - Correlated shadowing, independent fading
  - Turn left/right with probability 0.25
- Other parameters same as freeway drop
Enhanced range and reliability: Urban 60 km/hr, 15 km/hr
~ 30% gains at 0.9 PRR; Gains muted due to challenging pathloss model
C-V2X is designed for high density vehicle deployments

Guaranteeing low latency access for safety critical messages even at high density

- Leveraging higher layers to tune congestion control parameters
- Enhanced performance with MAC/PHY congestion control
- Deterministic access control and resource scheduling in PHY/MAC
Deterministic access control and resource scheduling

Chooses blocks with lowest energy levels to meet latency requirements

1. Measure relative energy of next “n” resources

2. Rank the resources according to the measured energy

3. Choose one of the lowest energy blocks for transmission

Choose among the 20% lowest energy resources

Choose one of the lowest measured energy resources
C-V2X access control advantages over 802.11p

System keeps on scaling

- **Optimized resource scheduling**: By choosing the lowest relative energy blocks.
- **Does no get denied access**: Two cars far apart from each other can use same resources.
- **Designed to meet latency requirements**: By scheduling and obtaining access to resources in timely manner.
Improved reliability at higher vehicle speeds

Disabled vehicle after blind curve use case example

**Icy road condition**

- C-V2X: 38mph
- 802.11p: 28mph

**Normal road condition**

- C-V2X: 63mph
- 802.11p: 46mph

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Stopping distance estimation

1. Driver reaction time + braking distance

<table>
<thead>
<tr>
<th>Normal</th>
<th>Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 mph</td>
<td>63 mph</td>
</tr>
<tr>
<td>38 mph</td>
<td></td>
</tr>
<tr>
<td>46 mph</td>
<td></td>
</tr>
</tbody>
</table>

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1. “Consistent with CAMP Deceleration Model and AASHTO *green book*”
Improved reliability at higher speeds and longer ranges

Do not pass warning (DNPW) use case example

**C-V2X**

- 43mph
- 443m

**802.11p**

- 28mph
- 240m

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**Required passing alert distance (m) vs. speed (mph)**

- 43mph
- 443m
- 28mph
- 240m

1. Calculations based on AASHTO “green book”
<table>
<thead>
<tr>
<th>Technology operation</th>
<th>802.11p</th>
<th>C-V2X Rel-14/15</th>
<th>C-V2X Rel-16 (expected design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification completed</td>
<td>Completed</td>
<td>Rel-14 completed in 2016. Rel-15 to be completed in 2018</td>
<td>2019</td>
</tr>
<tr>
<td>Support for low latency direct communications</td>
<td>✓</td>
<td>✓ (Rel-14 – 4ms)</td>
<td>✓</td>
</tr>
<tr>
<td>Support for network communications</td>
<td>Limited (via APs only)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Can operate without network assistance</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Can operate in ITS 5.9 GHz spectrum</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SIM-less operation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Security and privacy on V2V/V2I/V2P</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Security/Privacy on V2N</td>
<td>N/A</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Coexistence in 5.9GHz</td>
<td>✓</td>
<td>✓ (Adjacent channel with 11p; co-channel coexistence from R14 onwards)</td>
<td>✓ (Adjacent channel with 11p; co-channel coexistence from R14 onwards &amp; WiFi)</td>
</tr>
<tr>
<td>Evolution path</td>
<td>✗</td>
<td>✓</td>
<td>✓ (Compatible with Rel-14/15)</td>
</tr>
</tbody>
</table>
## Comparison: Radio design

<table>
<thead>
<tr>
<th>Radio design</th>
<th>802.11p</th>
<th>C-V2X Rel-14/15</th>
<th>C-V2X Rel-16 (expected design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronization</td>
<td>Asynchronous</td>
<td>Synchronous</td>
<td>Synchronous</td>
</tr>
<tr>
<td>Channel size</td>
<td>10/20Mhz</td>
<td>Rel-14 – 10/20Mhz</td>
<td>10/20 MHz and wideband (e.g. 40/60/80/100/…MHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rel-15 – 10/20/Nx20 MHz(^1)</td>
<td></td>
</tr>
<tr>
<td>Resource multiplexing across vehicles</td>
<td>TDM only</td>
<td>TDM and FDM</td>
<td>TDM and FDM possible</td>
</tr>
<tr>
<td>Data channel coding</td>
<td>Convolutional</td>
<td>Turbo</td>
<td>LDPC</td>
</tr>
<tr>
<td>HARQ Retransmission</td>
<td>No</td>
<td>Rel-14/15 – yes</td>
<td>Yes, along with ultra-reliable communication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rel-15 – ultra-reliable communication possible(^2)</td>
<td></td>
</tr>
<tr>
<td>Waveform</td>
<td>OFDM</td>
<td>SC-FDM</td>
<td>Likely OFDMA but many options available</td>
</tr>
<tr>
<td>Resource Selection</td>
<td>CSMA-CA</td>
<td>Semi-persistent transmission with frequency domain listen-before-talk</td>
<td>Many options available</td>
</tr>
<tr>
<td>MIMO support</td>
<td>No support standardized</td>
<td>Rx diversity for 2 antennas mandatory</td>
<td>Support up to 8 tx/rx antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tx diversity for 2 antennas supported</td>
<td>Mandatory support for 2tx/rx antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Both diversity and spatial multiplexing supported</td>
</tr>
<tr>
<td>Modulation support</td>
<td>Up to 64QAM</td>
<td>Up to 64 QAM</td>
<td>Up to 256QAM</td>
</tr>
</tbody>
</table>
## Comparison: Use cases and performance

<table>
<thead>
<tr>
<th>Use Cases</th>
<th>802.11p</th>
<th>C-V2X Rel-14/15</th>
<th>C-V2X Rel-16(expected design)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Use Cases</strong></td>
<td>Day 1 safety only</td>
<td>Day 1 safety &amp; enhanced safety use cases</td>
<td>Advanced use cases to assist in autonomous driving including, ranging assisted positioning,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>high throughput sensor sharing &amp; local 3D HD map updates</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High density support</strong></td>
<td>Packet loss at high</td>
<td>Can guarantee no packet loss at high densities</td>
<td>Can guarantee no packet loss at high densities</td>
</tr>
<tr>
<td></td>
<td>densities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**High mobility</td>
<td>Up to relative speeds of</td>
<td>Up to relative speed of 500</td>
<td>Up to relative speed of 500</td>
</tr>
<tr>
<td>support</td>
<td>500 km/hr with advanced</td>
<td>km/hr as a minimum requirement.</td>
<td>km/hr as a minimum requirement.</td>
</tr>
<tr>
<td></td>
<td>receiver implementation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transmission range</strong></td>
<td>Up to ~225m</td>
<td>-Over 450m using direct mode</td>
<td>-Over 450m using direct mode</td>
</tr>
<tr>
<td>@ 90% error, 280 km/hr</td>
<td></td>
<td>-Very large via cellular infrastructure</td>
<td>-Very large via cellular infrastructure</td>
</tr>
<tr>
<td>relative speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>**Typical transmission</td>
<td>Once every 100msec (50ms</td>
<td>Once every 100ms (20ms is also possible)</td>
<td>Supports packet periodicities of a few ms.</td>
</tr>
<tr>
<td>frequency for periodic</td>
<td>is also possible)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>traffic</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
C-V2X ecosystem and momentum
C-V2X gaining support from automotive and telecom leaders

5GAA is a cross-industry consortia helps define 5G V2X communications

End-to-end solutions for intelligent transportation mobility systems and smart cities

Automotive industry
Vehicle platform, hardware, and software solutions

Telecommunications
Connectivity and networking systems, devices, and technologies

Building a comprehensive ecosystem with diverse expertise

Necessary for C-V2X’s successful commercialization and deployment

Testing and certifications
- Certification and compliance organizations
- Test equipment vendors

Certification and compliance organizations
- ITS stack providers
- Chipset manufacturers
- Traffic industry suppliers
- Telecom suppliers
- Auto suppliers
- Road operators
- MNOs
- Vehicle OEMs

Standards
- Standards development organizations
- Telecom and auto industry organizations
- ITS organizations
- Road operator organizations
Qualcomm is driving C-V2X towards commercialization

Chipset anticipated to be available for commercial sampling in the second half of 2018

- Supports C-V2X Direct Communications (V2V, V2I and V2P) for automakers and roadside infra providers
- Integrated GNSS support
- Pre-integrated with telematics unit for V2N operation
- Supports SIM-less operation
- Designed to work in ITS 5.9 GHz spectrum
- Designed for extended communication range and enhanced reliability
- Optimized for high vehicle density deployments
- Designed to empower vehicles, VRUs and RSUs

Qualcomm® 9150 C-V2X Chipset

Qualcomm Technologies’ first-announced C-V2X commercial solution based on 3GPP R-14 for PC5-based direct communications
Delivering complete C-V2X solution for automotive road safety

Leveraging Qualcomm’s unique capabilities in precise positioning, efficient processing and security

- C-V2X chipset with integrated GNSS
- An application processor running the Intelligent Transportation Systems (ITS) V2X stack
- A Hardware Security Module (HSM).

The Qualcomm 9150 C-V2X chipset will be featured as a part of the Qualcomm® C-V2X Reference Design
“Qualcomm Technologies’ anticipated 9150 C-V2X chipset serves as a major milestone in paving the road for 5G and safer autonomous driving,” said Dr. Thomas Müller, Head Electrics/Electronics, Audi. “As C-V2X continues to serve as an essential ingredient for enhanced safety for next-generation vehicles, Qualcomm Technologies’ 9150 C-V2X chipset will certainly help accelerate the adoption and deployment of C-V2X technologies.”

—Audi

“We are pleased to see C-V2X gaining momentum and broad ecosystem support, and how Qualcomm Technologies has helped the automotive industry make great strides in bringing this to fruition, including the announcement of the 9150 C-V2X chipset,” said Carla Gohin, Senior Vice President, Head of Innovation at Groupe PSA. “Groupe PSA is strongly involved in the 5G standardization and trials and has great expectations on 5G as an enabler for the connected and autonomous vehicles. C-V2X and its strong evolution path to 5G will serve as a key enabler for new mobility services. Groupe PSA will evaluate this technology, with Qualcomm Technologies’ support, to adopt for our cars.”

—Groupe PSA
“Ford is committed to V2X communications and sees it as a critical technology to improve vehicle safety and efficiency,” said Don Butler, executive director, Connected Vehicle and Services at Ford Motor Company. “We welcome Qualcomm Technologies’ cellular-V2X product announcement, as the automotive industry and ecosystem work towards C-V2X implementation, and pave the path to 5G broadband and future operating services.”

— Ford Motor Co.

“SAIC has always attached great importance to the development and application of new technologies. It is actively promoting the commercialization of new energy vehicles and internet-connected vehicles, and the development of autonomous vehicles. As vehicles become increasingly intelligent, it’s critical that our vehicles are equipped with premium-tier technologies to provide seamless communication between the vehicle and the roadway and beyond,” said Dr. Liu Fen, Director of Intelligent Driving, Research & Advanced Technology Department of SAIC. “We deem C-V2X technologies as the best choice, and look forward to utilizing these technologies in V2X. We admire the efforts Qualcomm Technologies has made and believe that the planned commercialization of their 9150 C-V2X chipset will accelerate the development of next-generation intelligent and connected vehicles.”

— SAIC
5G will bring new capabilities for autonomous vehicles

While maintaining backward compatibility
5G is important for our automotive vision

Providing a unifying connectivity fabric for the autonomous vehicle of the future

Enhanced mobile broadband

Mission-critical services

Massive Internet of Things

Unifying connectivity platform for future innovation

Starting today with Gigabit LTE, C-V2X Rel-14, and massive IoT deeper coverage
5G NR brings new capabilities to V2X communications

Bringing complementary capabilities

Direct communications

V2V, V2I, and V2P on “PC5” Interface, operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network

- Higher throughput
- URLLC capabilities
- Designed to work without network assistance in ITS spectrum

Network communications

V2N on “Uu” interface operates in traditional mobile broadband licensed spectrum

- Higher throughput
- URLLC capabilities

Scalable OFDM numerology

Wideband transmissions for positioning

Advanced LDPC/polar channel coding

Self-contained sub-frame

Low-latency slot structure design

Massive MIMO
5G V2X brings new capabilities for the connected vehicle
While maintaining backward compatibility

- **High throughput sensor sharing**
  - High throughput and low-latency to enable the exchange of raw or processed data gathered

- **Intention/Trajectory sharing**
  - High throughput and low-latency to enable planned trajectory sharing

- **Wideband ranging and positioning**
  - Wideband carrier support to obtain accurate positioning and ranging for cooperated and automated use cases

- **Local high definition maps / “Bird’s eye view”**
  - High throughput to build local, dynamic maps based on camera and sensor data; and distribute them at street intersections

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Wideband carrier support | High throughput | Ultra-low latency | Ultra-high reliability | Strong security
We are accelerating the future of autonomous vehicles

V2X wireless sensor
802.11p (DSRC/ITS-G5) C-V2X

3D HD maps
Semantic lane information
Landmark and lane coordinates for positioning

Precise positioning
GNSS positioning
Dead reckoning VIO

Heterogeneous connectivity
Cellular 3G / 4G / 5G
Wi-Fi / BT
CAN / Ethernet / Powerline

On-board intelligence
Heterogeneous computing
On-board machine learning
Computer vision
Sensor fusion
Intuitive security

Power optimized processing for the vehicle
Fusion of information from multiple sensors/sources
Path prediction, route planning, control feedback
Thank you

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