C-V2X - A Communication Technology for Cooperative, Connected and Automated Mobility

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Outline

• Motivation
• Introduction of C-V2X
• LTE-V2X basic and enhanced safety use case examples
• Evolution towards 5G NR use cases
• Conclusions
Motivation
Prospects of future of driving

How it is envisaged ...

![Illustration of a futuristic cityscape with people driving cars.](www.mondaynote.com) - Courtesy: Popular Mechanics

How it should not end ...

![Cartoon of skeletons driving a car.](www.spectator.co.uk)
Envisioned Evolution of Automated Driving

Today - L2+ autonomy emerging in premium tier segment
L3 mass market adoption beginning 2022?

- Front Collision Warning
- Lane Departure Warning
  - Radar, Camera

- Auto Emergency Braking
- Lane Keep Assist
- Adaptive Cruise Control
  - Basic Self Park
  - Radar + Camera

- Highway Autopilot
- Traffic Jam Assist
- Autonomous Parking Assist
  - Radar + Camera

Driverless
- Ridesharing
- Anytime
- Anywhere

- Controlled Fleets
- Last-mile freight
- Multi LiDAR + Multi Radar + Multi camera
  + HD Maps + V2X

- Multi Radar + Multi camera + GNSS

Conditional Autonomy (convenience)

Active Safety

Passive Safety

Driver Assistance (ADAS)

Vehicle SOP 2017


Level 1

Level 2

Level 3

Level 4

Level 5

Automated Level
Motivation (cont’d)
Connectivity can augment vehicle sensors to reduce accidents
Cellular Vehicle-to-Everything Communication (C-V2X)

Provides connectivity for coordinated, connected and autonomous mobility

Vehicle-to-infrastructure (V2I)
e.g. traffic signal timing/priority

Vehicle-to-vehicle (V2V)
e.g. collision avoidance safety systems

Vehicle-to-pedestrian (V2P)
e.g. safety alerts to pedestrians, bicyclists

Vehicle-to-network (V2N)
e.g. real-time traffic/routing, cloud services
5G standardization and projected ecosystem expansion

Rel-14
LTE-V2X

Rel-15

Rel-15
Commercialization

Rel-16

Rel-16
Commercialization

Rel-17+

Non-Standalone (NSA)

Standalone (SA)

IoDTs

Field trials

We are here

5G NR C-V2X Study Item
5G NR C-V2X Work Item

2017
2018
2019
2020
2021
2022
2023+

eMBB deployments in both mmWave and sub-6 GHz

New 5G NR technologies to evolve and expand the 5G ecosystem

Expanded ecosystem

Smartphone form factor, connected laptops, CPE fixed access

Private network, industrial IoT indoor mmWave for enterprises, Boundless XR...

Industrial IoT with eURLLC, 5G NR C-V2X...

Integrated access and backhaul, unlicensed/shared spectrum, continued eMBB evolution

5G NR C-V2X
Study Item
5G NR C-V2X
Work Item

2018
2019
2020
2021
2022
2023+

Rel-16

Rel-17+

Commercialization

Rel-15

Rel-16

Rel-17+ evolution

Rel-15

We are here

we are here

2018
LTE-V2X providing support for enhanced safety use cases
By extending electronic horizon, providing more reliability, and better NLOS performance

- Do not pass warning (DNPW)
- Blind curve / local hazard / emergency break warning (EEBL)
- Road works warning
- Intersection movement assist (IMA) at a blind intersection
- Vulnerable road user (VRU) alerts at a blind intersection
- Left turn assist (LTA)
LTE-V2X Example: Intersection Movement Assist (IMA)
Conducted as part of the ConVeX Project Demo Event July 6, 2018
LTE-V2X Examples: EEBL, LTA, IMA

Conducted as part of the ConVeX Project Demo Event July 6, 2018
LTE-V2X High Vehicular Speed Testing

Conducted as part of the ConVeX Project

- Two cars driving in opposite direction on Autobahn A9 with highest possible speeds
- Close to error free communication between the cars when in LOS
- Range for this run was limited to ~ 1.2km due to morphology
- No impact of the high relative speed of more than 400 km/h (max. 430 km/h for this run)
LTE-V2X vs DSRC/ITS-G5 Comparison Examples

LTE-V2X provides superior performance compared to DSRC/ITS-G5

- Measured radio performance with added channel impairment (AWGN)

![Graph showing PER vs Noise PSD (dBm/Hz)](image)

- Measured Line-of-Sight Field Test Results

![Graph showing Transmit Power (EIRP) vs Range in (m)](image)

<table>
<thead>
<tr>
<th>Transmit Power (EIRP)</th>
<th>DSRC</th>
<th>C-V2X</th>
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</thead>
<tbody>
<tr>
<td>5dBm</td>
<td>625</td>
<td>1050</td>
</tr>
<tr>
<td>11dBm</td>
<td>925</td>
<td>&gt;1350</td>
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Evolving C-V2X Direct Communications towards 5G NR

While maintaining backward compatibility

Evolution to 5G NR, while being backward compatible
C-V2X Rel-14 is necessary and operates with Rel-16

Basic and enhanced safety
C-V2X Rel-14/Rel-15 with enhanced range and reliability

Basic safety
IEEE 802.11p

Autonomous driving use cases
5G NR C-V2X Rel-16

Backward compatible with Rel-14/Rel-15 enabled vehicles

- Higher throughput
- Higher reliability
- Wideband carrier support
- Lower latency

Sensor Sharing
Intention Sharing
Coordinated Driving

Sudden braking and lane change on a freeway
Enabling a new paradigm of communication design

• Efficient sidelink link level design for optimized performance at all speeds
• Connectionless ‘on-the-fly’ distance-based groups
• Multicast with distance-based reliability and application relevancy

Adapting R15 5G NR flexible framework to vehicles

Scalable OFDM-based air interface

Flexible slot-based framework

Advanced channel coding

Enabling a new paradigm of communication design

Building on R14/15 C-V2X framework with backward compatibility

Such as frequency division multiplexing, guaranteed latency performance and prioritization support

5G NR C-V2X builds on existing frameworks and enables a new paradigm of communication design
Coordinated driving

Intention sharing allows more efficient maneuvers for coordinated driving

Highway
Coordinated highway entrance and lane changes

Urban
Vehicles can navigate intersections without stopping
Sensor sharing

Sensor object sharing enables benefit of V2X with limited penetration rate.

C-V2X vehicle
Detects non-C-V2X vehicle via its on-board sensors (e.g. camera)

1. Non-C-V2X vehicle

C-V2X vehicles
Inform other vehicles with the presence of non-C-V2X vehicles

1. Non-C-V2X vehicle

2. Non-C-V2X vehicle
Rel-14 C-V2X
Broadcast without feedback, which can’t ensure reliability

Rel-16 5G NR C-V2X
Multicast with feedback for higher reliability; if signal can’t be decoded, NACKs are sent on the same radio resources (SFN-like approach)

Multicast support for higher reliability
HARQ feedback to achieve higher reliability | Introducing efficiency by sending only NACKs using SFN
Intent/trajectory sharing for faster yet safe maneuvers

A vehicle trying to do a left turn is demonstrated for two scenarios.
Evolving C-V2X Direct Communications towards 5G NR by ensuring backward compatibility through anchoring of use cases to deployment releases.

5G NR C-V2X will be backwards compatible with C-V2X R14/R15.
Future 5G NR Rel. 16 and beyond will be backward compatible with earlier C-V2X releases by anchoring use cases to deployment releases.

C-V2X establishes the foundation for Cooperative, Connected and Automated Mobility (CCAM) in Rel. 14/15 with continued evolution towards 5G NR C-V2X Rel. 16 for advanced use cases.

C-V2X Rel. 14/15 employs newer and more advanced technologies than WiFi-based systems, providing better performance, while reusing upper layers defined by the automotive industry.

5G NR Rel. 16 brings further improvements via a flexible sidelink design using distance-based multicast communication with HARQ feedback allowing even higher throughput, better reliability, and lower latency.

Future 5G NR Rel. 16 and beyond will be backward compatible with earlier C-V2X releases by anchoring use cases to deployment releases.

5G NR provides advanced safety and better travel efficiency through increased situational awareness, sensor sharing, and coordinated driving.

Learn more at: www.qualcomm.com/C-V2X