Evolution of C-V2X for advanced automotive use cases

Shailesh Patil, Principal Engineer/Manager
Maged Zaki, Director, Technical Marketing
Qualcomm Technologies, Inc.

To listen to our webinar recording, PLEASE CLICK ON THIS LINK
Rel-14 C-V2X momentum and commercial readiness
C-V2X

Established the foundation of C-V2X for safety in Rel-14/15 with continued evolution in Rel-16 5G NR for advanced use cases

- **V2V** Vehicle-to-vehicle e.g., collision avoidance safety systems
- **V2P** Vehicle-to-pedestrian e.g., safety alerts to pedestrians, bicyclists
- **V2I** Vehicle-to-infrastructure e.g., traffic signal timing/priority
- **V2N** Vehicle-to-network e.g., real-time traffic/routing, cloud services

- Release 14/15 C-V2X standards completed
- 5G
- Broad industry support with 5GAA
- Global trials started in 2017
- Qualcomm® 9150 C-V2X chipset announced in September, 2017
- Integration of C-V2X into the Qualcomm® Snapdragon™ Automotive 4G and 5G Platforms announced in February, 2019

Qualcomm 9150 C-V2X and Qualcomm Snapdragon Automotive 4G/5G Platforms are products of Qualcomm Technologies, Inc. and/or its subsidiaries
Driving C-V2X global presence with trials and demos

Gaining traction across numerous regions and industry sectors
From standards completion to independent field testing to early commercialization

Key participants
Driving global C-V2X activities with Qualcomm Technologies

Ford
PSA
BMW
Daimler
SAIC
Continental
Bosch
LG
ZTE

Kapsch
Swarco
CommSignia
Genvict
Neubulink
R&S
Datang
Ficosa
Savari

On Board Security
Neusoft Reach
Simcom
Sasken,
Thundersoft
Telt
Lacroix
And more...

5GAA Automotive Association

Airbus • Aircell • Alpine Electronics • American Tower Corporation • Analog • Aonstar
Applied Information • AT&T • Audi • BAIC • Baolai • Baosheng • Beijing University
of Technology • Bell • BlackBerry • BMW Group • Bosch • CATT • Celenet • China Mobile
China Transinfo • China Unicom • Cohda Wireless • CMCC • Commissignia • Continental
Daimler • Danlaw • Denka • Denso • Dr&Co • Deutsche Telekom • Equinix • Ericsson
Faraday Future • FarEasTone • FEV • Ficosa • Ford • Fraunhofer-Institut FKUS
Geely • Gemalto • General Motors • Gett • Hirschmann • Hitachi • Honda • Huawei
Hyundai America Technical Center • Hyundai Mobis • Infineon • Intel • Interdigital • JLR
Juniper Networks • KDDI • Keysight • KPI • KT • Latvia/Mobilis Telefons • Lear Corp
LG • Laird Tech • Magneti Marelli • Mitsubishi Electric • Molex • Murata • Naviforsk
Neusoft NID • Nissan Motor • Nokia • Nera Networks • NTT DoCoMo • Oki • Orange • P3
Panasonic • Proximus • PSA Group • Qorvo • Qualcomm • Quectel Wireless Solutions
Renault • Rohde & Schwarz • SAIC • Samsung • Savari • SGS • SIAC • SK Telecom
Skyworks • Smart Mobile Labs • Softbank • Sumitomo • Swift Navigation • Telefonica
Telekom • Telekom Austria • Telstra • Teku • TerraNet AB • TUV • Valeo • Veniam
Verizon • Vivaldi • Vodafone • Volkswagen • Volvo Cars • VTIDirect • WNC • ZF • ZTE
5G and AI aim to transform automotive and the whole transportation industry

Evolution to 5G NR is designed to serve as the unified connectivity fabric
Smarter transportation infrastructure
Requiring next level of connectivity and intelligence

Road world model
Software stack
Perception, sensor fusion

Compute
Heterogenous computing for perception and sensor fusion

Communications
- I2V via C-V2X
- C2V via 4G/5G

AI-based RSU

Localization

Radar

Multiple cameras

Lidar

Multiple radars

Multiple cameras

I2V
Road world model

Smart, connected vehicle
A unified connectivity fabric for distributed intelligence

Smart cloud

**Smart infrastructure** (RSU/small cell)

- Artificial intelligence
- Mobile edge computing
- Computer vision
- Precise positioning and 3D HD map updated
- Sensor fusion

**Smart car**

**AI-based cockpit**

- Artificial intelligence
- Heterogeneous computing
- Computer vision
- Precise positioning
- Audio

**Autonomous driving**

- Artificial intelligence
- Heterogeneous computing
- Computer vision
- Precise positioning
- Sensor fusion

**5G connected car**

- Multimode 4G/5G
- C-V2X
- Precise positioning
- Wi-Fi/BT

---

Road world model over I2V to augment car perception

**Road world model over I2N for teleoperation**

Teleoperations

Data analytics
Enhanced network communication
Faster access to cloud for in-vehicle experiences, car OEM services and telematics

New direct communication
V2V, V2I, and V2P communications for latency-sensitive use-cases, e.g. collision avoidance

Massive Internet of Things
Deeper coverage to connect road infrastructure (e.g. sensors and traffic cameras)

Evolution to 5G is designed to serve as the unified connectivity fabric
Road Safety
V2V/V2I: Intersection management assist

Shaping the future of automotive and smart transportation

Edge AI
E.g. for detecting pedestrians or hazards

C-V2X (I2V)
E.g. send 3D HD map updates or hazard warning

Localization
E.g. for lane-level warning, and navigation

RSU with AI-based camera
Traffic hazard warning
AI-based camera detects a hazard on the right lane and alert other cars on the road; via precise positioning other cars avoid the lane with the hazard

Pedestrian alert
Traffic light detects a pedestrian crossing the street and alert oncoming cars via I2V; Also, possible via direct V2P communication

Send updated 3D HD map with the hazard via 5G NR C-V2X
Backward compatible evolution to Rel-16 5G NR C-V2X

New use cases require a more flexible and efficient direct communication design
5G standardization and projected ecosystem expansion

- **Rel-15**: Non-Standalone (NSA)
  - IoT DTs
  - Field trials
- **Rel-16**: Standalone (SA)
  - eMBB deployments in both mmWave and sub-6 GHz
  - Smartphone formfactor, connected laptops, CPE fixed access
- **Rel-17+**: Rel-15 Commercialization
  - New 5G NR technologies to evolve and expand the 5G ecosystem
  - Expanded ecosystem
  - Industrial IoT with eURLLC, 5G NR C-V2X
  - Integrated access and backhaul, unlicensed/shared spectrum...
  - Continued eMBB evolution

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>5G NR Commercialization (Standalone)</td>
</tr>
<tr>
<td>2018</td>
<td>5G NR Commercialization (Non-Standalone)</td>
</tr>
<tr>
<td>2019</td>
<td>5G NR Commercialization (Standalone)</td>
</tr>
<tr>
<td>2020</td>
<td>5G NR Commercialization (Non-Standalone)</td>
</tr>
<tr>
<td>2021</td>
<td>5G NR Commercialization (Standalone)</td>
</tr>
<tr>
<td>2022</td>
<td>5G NR Commercialization (Non-Standalone)</td>
</tr>
<tr>
<td>2023</td>
<td>5G NR Commercialization (Standalone)</td>
</tr>
<tr>
<td>2023+</td>
<td>5G NR Commercialization (Non-Standalone)</td>
</tr>
</tbody>
</table>
Evolving C-V2X direct communications towards 5G NR

Rel-16 5G NR C-V2X vehicles is designed to support Rel-14/Rel-15 for safety

5G NR C-V2X brings about complementary capabilities while being backwards compatible
5G NR C-V2X is backward compatible at upper layers

By facilitating coexistence of Rel16 with previous releases

Rel-16 C-V2X vehicles are expected to be designed to support Rel-14/Rel-15 for safety
5G NR C-V2X facilitates advanced use cases

- **Increased situational awareness**
  - Sharing of vehicle-specific info with other vehicles and road infrastructure (e.g. door open warning)

- **Sensor sharing**
  - Sharing of sensor data, e.g., vehicle’s perception, including road world model

- **Coordinated driving/intention sharing**
  - Exchanging intention and sensor data for more predictable, coordinated autonomous driving

- **Real-time infrastructure updates**
  - Real-time sharing of 3D HD map and other information between vehicles and infrastructure

**Higher throughput**

**Lower latency**

**Higher reliability**

**Application aware**
5G NR C-V2X
Brings new benefits

- **Advanced safety**
  Real-time situation awareness and sharing of new kinds of sensor data take safety to the next level

- **Faster travel/energy efficiency**
  More coordinated driving for faster travel and lower energy usage

- **Accelerated network effect**
  Sensor sharing and infrastructure deployment bring benefits, even during initial deployment rollouts

- Increased situational awareness
- Sensor sharing
- Coordinated driving / intention sharing
- Real-time infrastructure updates
Intention sharing allows more efficient maneuvers for coordinated driving.

**Highway**
- Coordinated highway entrance and lane changes

**Urban**
- Vehicles can navigate intersections without stopping
Autonomous driving

Benefits from real-time update from infrastructure

RSU sends a 3D HD map update to oncoming vehicles with the lane reconfiguration due to construction
Sensor sharing

Sensor object sharing supports benefit of V2X with limited penetration rate

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

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

Non-C-V2X vehicle

Non-C-V2X vehicle
Introducing a new communication design paradigm
Adapting R15 5G NR flexible framework to vehicles

Scalable OFDM-based air interface

Flexible slot-based framework

Advanced channel coding

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

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

Facilitating 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

5G NR C-V2X builds on existing frameworks and facilitates a new paradigm of communication design
Higher throughput
High spectral efficiency to achieve higher throughput

Lower latency
Connectionless “on-the-fly” groups and distance-based design

Higher reliability
Multicast support using efficient feedback

High-speed performance
Up to 3.5 higher spectral efficiency at 500kmph relative speeds

Application aware
Performance tailored to application requirements, such as minimum distance

Backward compatibility
Vehicles with Rel-16 will also support Rel-14 for safety

Resulting in a 5G NR C-V2X design that addresses tomorrow’s vehicle use case requirements
High-speed performance with adaptive reference signal

Rel-16 C-V2X can support ~3.5x higher spectral efficiency as compared to Rel-14 at high speeds

- Higher carrier spacing allows better handling of Doppler and frequency offset
- Variable reference signal design density
- Strategic placement of reference symbols
- Up to ~3.5x higher spectral efficiency at 500kmph relative speed

1. Demodulation Reference Signal
Vehicles approaching intersection

Group formed among vehicles for coordinated intersection management

Group disbanded after intersection is navigated

Connectionless ‘on-the-fly’ distance-based groups

Vehicles within a certain distance and interested in same services form a group
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
Application-aware, distance-based multicast communication

- Application-specific distance is determined based on relevancy
- Transmitting vehicles adapt transmission to relevant vehicles within range
- Receiving vehicles only acknowledge relevant messages
Specifying minimum requirements
Defining application layer-specific minimum requirements for new messages

Providing interoperability
Allowing vehicles from different manufacturers to benefit from new evolving use cases

Supporting emerging use cases
Introducing new messages for emerging use cases, (e.g. sensor object sharing between vehicles needs to be standardized)

Participating in higher layer protocol stacks’ regional standards including SAE, ETSI ITS and C-SAE/C-ITS
R16 5G NR C-V2X builds on R14 C-V2X, which is gaining momentum and getting ready for launch for automotive safety

5G NR brings complementary advanced use cases via a new direct communication link design with higher throughput, better reliability, lower latency and application aware performance

5G NR allows vehicles to share more information such as richer sensor data and intended actions with each other and their surroundings, realizing benefits even with initial limited deployments

5G NR provides increased situational awareness for safer driving; and coordinated driving for shorter travel time and energy efficiency
Thank you

Follow us on:  

For more information, visit us at:  
www.qualcomm.com & www.qualcomm.com/blog

Nothing in these materials is an offer to sell any of the components or devices referenced herein.

©2019 Qualcomm Technologies, Inc. and/or its affiliated companies. All Rights Reserved.

Qualcomm and Snapdragon are trademarks of Qualcomm Incorporated, registered in the United States and other countries. Other products and brand names may be trademarks or registered trademarks of their respective owners.

References in this presentation to “Qualcomm” may mean Qualcomm Incorporated, Qualcomm Technologies, Inc., and/or other subsidiaries or business units within the Qualcomm corporate structure, as applicable. Qualcomm Incorporated includes Qualcomm’s licensing business, QTL, and the vast majority of its patent portfolio. Qualcomm Technologies, Inc., a wholly-owned subsidiary of Qualcomm Incorporated, operates, along with its subsidiaries, substantially all of Qualcomm’s engineering, research and development functions, and substantially all of its product and services businesses, including its semiconductor business, QCT.