Leading the world to 5G: Cellular Vehicle-to-Everything (C-V2X) technologies

June 2016
The connected vehicle is already a mainstream reality

60%

Cellular penetration in new light vehicles sales by 2021\(^1\)

Qualcomm Technologies, Inc. is a proven, trusted solution provider for automotive

#1 in telematics\(^2\)

Decades of industry experience

Broad portfolio of technologies

340M+ ASICs shipped, serving 20+ OEMs globally\(^3\)

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\(^1\) Combination of Strategy Analytics, Jan. '16 and LMC Automotive; \(^2\) Qualcomm Technologies, Inc. company data; \(^3\) Includes SoC, Cellular, Bluetooth, Wi-Fi, GNSS and PLC
Our vision for the always-connected vehicle of the future

A safer, more efficient, more enjoyable driving experience

- **Safer**—towards zero road accidents
- **Greener**—reduce air pollution & emissions
- **More predictable and productive travel**

**Highly secure**
**Highly intelligent**
**Always connected**
**Increasingly autonomous**
**Increasingly electric (or hybrid)**
Requires new levels of connectivity and intelligence

Heterogeneous connectivity

- Vehicle-to-Everything communications
- Connected infotainment
- Wireless EV charging
- Real-time navigation

- Bluetooth
- Wi-Fi / Hotspot
- Cellular 3G/4G/5G
- Always-on telematics
- CAN / Ethernet / Powerline

On-device intelligence

- Intuitive instrumentation
- Immersive multimedia
- Augmented reality
- Always-on sensing
- Computer vision
- Intuitive security
- Machine learning
Delivering significant economic and societal impact

Total potential economic impact of over $1 Trillion USD per year

- Fewer driving fatalities/injuries
  - >1.2M people die each year on the roads worldwide

- More predictable, productive travel
  - 3.1B gallons of fuels wasted due to traffic congestion in the US

- Less greenhouse gas emissions
  - 14% of all global warming emissions from transportation

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1 Rocky Mountain Institute 2016; 2 Global Status Report on Road Safety, World Health Organization 2015; 3 Texas Transportation Institute Urban Mobility Report, 2015; 4 U.S. Environmental Protection Agency (EPA) 2014
V2X is a critical component to our vision
Giving vehicles the ability to communicate with each other and beyond

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

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

Vehicle-to-network (V2N)  e.g. real-time traffic / routing, cloud services

Vehicle-to-pedestrian (V2P)  e.g. safety alerts to pedestrians, bicyclists
V2X is a key technology enabler to enhanced ADAS

Bringing significant value to Advanced Driver Assistance Systems (ADAS)

- Improved active safety
  Provides 360° non-line-of-sight awareness, e.g. intersections/on-ramps, environmental conditions

- Better traffic efficiency
  Allows vehicles to safely drive closer to each other and enables optimization of overall traffic flow

- Increased situational awareness
  Provides ability to gather data from further ahead to deliver a more predictable driving experience
V2X enables a broad and growing set of use cases

Much more than collision avoidance

- Forward collision warning
- Queue warning
- Do Not Pass Warning (DNPW)
- Curve speed warning
- Blind intersection
- Cooperative adaptive cruise control & platooning
- Vulnerable Road User (VRU) alerts
- Discover parking and charging
- Traffic signal priority and optimal speed advisory
- Emergency vehicle alert
Wi-Fi based technology - 802.11p standard
Adapted for latency-critical V2X communications in the 5.9 GHz band

Established security and upper layer specifications
With service layer / performance requirements defined by SDOs, e.g. SAE, ETSI-ITS\(^1\)

Path to DSRC\(^2\) rulemaking in USA by NHSTA\(^3\) expected to start in 2016\(^4\)
Based on 802.11p standard

Large scale field trials completed over the last decade
Commercially available technology here today

1. Standard Development Organizations, e.g. Society for Automotive Engineers, European Telecommunications Standards Institute - Intelligent Transport Systems; 2. Dedicated Short Range Communications (DSRC); 3. National Highway Traffic Safety Administration; 4. To improve road safety for future ‘light vehicles’ - Qualcomm has conducted extensive research into various use cases for DSRC, including V2P applications that could extend the safety benefits to vulnerable road users such as pedestrians and cyclists.
Paving the path to more autonomous driving

Requires continued V2X technology evolution

Increasing safety requirements
Active safety use cases need to account for faster moving vehicles and denser traffic conditions

Expanding use cases
New situational awareness, traffic management, and connected cloud services

More vehicle data
From sharing simple status data today to a fully coordinated driving experience
Introducing Cellular V2X (C-V2X)

A unified connectivity platform for the connected vehicle of the future

Part of Release 14 of the global 3GPP standard
Target C-V2X specification completion end of 2016

Builds upon existing LTE connectivity platform for automotive
LTE already delivering key services today, e.g. telematics, eCall, connected infotainment

Enhances LTE Direct for V2X direct communications
Improvements over 802.11p - up to a few additional seconds of alert latency and 2x range

Leverages existing LTE networks for V2X network communications
Using LTE Broadcast optimized for V2X to offer additional applications/services

Rich roadmap towards 5G with strong ecosystem support
Technology evolution to address expanding capabilities/use cases

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1 For Direct communications component (enhancements to LTE Direct) - overall spec completion expected mid-2017; 2 Based on Qualcomm Research simulations (see future slides for further information)
Part of rich roadmap of technologies

Paving the path to 5G

Advanced MIMO
256QAM
FeICIC
Carrier aggregation
SON+
CoMP
Unlicensed spectrum
Internet of Things
FDD-TDD CA
Device-to-device
Dual connectivity
Massive/FD-MIMO
Enhanced Broadcast
C-V2X
Low Latency
eLAA
Enhanced CA

Rel-10/11/12
LTE Advanced

Rel-13 and beyond
LTE Advanced Pro

Note: Estimated commercial dates. Not all features commercialized at the same time
V2X requires regionally harmonized ITS spectrum

Recommend at least 70 MHz of spectrum to support technology / use case evolution

- **30 MHz** Dedicated to accommodate today’s existing/emerging use cases (802.11p and/or C-V2X)
- **20 MHz** Primary for future intelligent transportation use cases or technology migration
- **20 MHz** Shared may be shared with unlicensed spectrum access technologies

\(^1\) Must prove it can co-exist with V2X technologies
Expanding and evolving the cellular system for V2X communications

Introduced in 3GPP Release 14—part of LTE Advanced Pro
C-V2X defines two complementary transmission modes

**Direct communications**
Building upon LTE Direct device-to-device design with enhancements for high speeds / high Doppler, high density, improved synchronization and low latency
- Proximal direct communications (100s of meters)
- Operates both in- and out-of-coverage
- Latency-sensitive use cases, e.g. V2V safety

**Network communications**
Using LTE Broadcast to broadcast messages from a V2X server to vehicles and beyond. Vehicles can send messages to server via unicast.
- Wide area networks communications
- Leverages existing LTE networks
- More latency tolerant use cases, e.g. V2N situational awareness
C-V2X designed for both in-coverage and out-of-coverage

Out-of-coverage

- Common V2V frequency
- Direct communications (via PC5 interface)

In-coverage

- Operator A
  - V2N frequency 1
- Operator B
  - V2N frequency 2
- Operator C
  - V2N frequency 3
- Direct communications (via PC5 interface)
- Common V2V frequency
- Network communications (Via Uu interface)

1 C-V2X also supports a single MNO managed network for in-coverage
Evolving the LTE Direct device-to-device platform

Release 12
D2D platform for consumer and public safety use cases
- Discovery of 1000s of devices/services in ~500m
- Reliable one-to-many communications (in- and out-of-coverage)²

Release 13
Expanded D2D discovery and D2D communications
- More flexible discovery such as restricted/private¹ and inter-frequency
- Device-to-network relays²

Release 14 and beyond
Multi-hop communication and more use cases
- Additional D2D communication capabilities, e.g. multi-hop for IoT
- Enhancements for vehicle-to-everything (V2X)

¹ Important for e.g. Social Networking discovery use cases; ² Designed for Public Safety use cases
LTE Direct device-to-device communications

Introduced in Release 12 for public safety use cases, e.g. push-to-talk

Centralized (Mode 1)
eNodeB allocates control (SA*) and data resources to transmit devices

Transmit devices send SA to identify resources, as well as Modulation and Coding Scheme (MCS) for subsequent data transmission

Receive devices monitor SA resource to determine when to listen for data transmission

Distributed (Mode 2)
Transmit device selects SA and data resources from resource pools; can operate out-of-coverage

Broadcast communication - no channel feedback

* SA = Scheduling Assignments
C-V2X builds upon LTE Direct D2D communications
With enhancements to address V2X requirements

- Reuse established service & app layers
  Already defined by automotive community, e.g. SAE
- Reuse existing security and transport layers
  Defined by ISO, ETSI, and IEEE 1609 family
- Enhancements to LTE Direct PHY/MAC
  To address latency-critical, reliable V2X communications

Note: Also enhancements to the LTE Direct network architecture / system design to support V2X
### Overcoming the challenges of V2X communications

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<tr>
<th>V2X Challenges</th>
<th>C-V2X Solutions</th>
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<tr>
<td><strong>High relative speeds</strong>&lt;br&gt;Leads to significant Doppler shift / frequency offset</td>
<td><strong>Enhanced signal design</strong>&lt;br&gt;E.g. increasing # of ref signal symbols to improve synchronization and channel estimation</td>
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<td><strong>High node densities</strong>&lt;br&gt;Random resource allocation results in excessive resource collisions</td>
<td><strong>Enhanced transmission structure</strong>&lt;br&gt;Transmit control and data on the same sub-frame to reduce in-band emissions</td>
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<td><strong>Time synchronization</strong>&lt;br&gt;Lack of synchronization source when out-of-coverage</td>
<td><strong>More efficient resource allocation</strong>&lt;br&gt;New methods using sensing and semi-persistent resource selection</td>
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<td><strong>Allow utilization of GPS timing</strong>&lt;br&gt;Enhancements to use satellite (e.g. GNSS) when out-of-coverage</td>
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C-V2X increases reaction time over 802.11p/DSRC

For improved safety use cases - especially at high-speeds, e.g. highway

Safer driving experience
Increased driver reaction time

Support for high speeds
Relative speeds up to 500km/h

Increased situational awareness
Gather data from further ahead

Based on link level curves and the 3GPP LOS path loss model @ 10% Packet Error - Actual performance varies significantly with vehicle density and environment
C-V2X leverages existing, ubiquitous LTE networks

With V2X communications via the network

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With V2X communications via the network

V2X server
IP layer & above

LTE unicast (UL)

LTE Broadcast (DL)

Other inputs

Optimizations to decrease end-to-end latency through techniques like SC-PTM

Increase range / utility
Increase situational awareness using messaging via the network

Further enhance V2V safety
By rebroadcasting V2V info via network in high-density use cases

Unified service platform
New opportunities for MNOs\(^2\) combined with today’s services

\(^1\) SC-PTM: Singe-Cell - Point-To-Multipoint; \(^2\) MNOs: Mobile Network Operators

1. SC-PTM: Singe-Cell - Point-To-Multipoint; 2. MNOs: Mobile Network Operators
Delivering advanced services to vehicles
Opening up new opportunities and diverse business models for MNOs

V2N provides over-the-top cloud services
Most use cases use a combination of interfaces

RSUs can be eNodeBs or standalone roadside devices
RSUs\(^1\) can connect to network for cloud services
V2I allows RSUs to monitor traffic, e.g. traffic signals, tolls
V2V mostly for safety and ADAS services

1 Road Side Units
Roadmap to 5G will bring even more opportunities for the connected vehicle

3GPP Release 15 and beyond
5G will bring new capabilities for the connected vehicle

New OFDM-based 5G air interface scalable to an extreme variation of requirements

Extreme throughput
Up to multi-Gpbs with more uniformity—wider bandwidths, advanced antenna techniques

Edgeless connectivity
New ways of connect, e.g. multi-hop to extend coverage, plus natively incorporate D2D

High reliability
Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

1ms end-to-end latency
Through a faster, more flexible frame structure; also new uplink RSMA non-orthogonal access

High availability
Multi-connectivity to provide multiple links for failure tolerance and mobility

1 Also exploring alternative roots of trust beyond the SIM card
5G will build upon and enhance C-V2X

New 5G platform will augment/complement C-V2X—no ‘rip and replace’

- Multi-mode vehicle with simultaneous connectivity across 4G LTE, C-V2X and 5G
- 4G LTE: Continue to evolve and provide ubiquitous coverage as 5G is rolled out
- C-V2X: C-V2X direct and network communications
- 5G: Bring new capabilities for C-V2X network communications and augment C-V2X direct communications over time
Flexible 5G network architecture also brings benefits

Leveraging virtualized network functions to create optimized network slices

- Configurable end-to-end connectivity per vertical
- Modular, specialized network functions per services
- Flexible subscription models
- Dynamic control and user planes with more functionality at the edge

Better cost/energy efficiency | Optimized performance | Flexible business models | Dynamic creation of services
Enabling the next gen of connected vehicle experiences

Sample use cases

Fully autonomous driving
- e.g. cooperative collision avoidance and high-density platooning which requires new levels of latency and reliability, plus larger message sizes

V2X augmented reality
- e.g. see-through capability when driving behind truck or leveraging real-time video feeds for navigation systems

Extreme mobile broadband
- Passengers can enjoy the next generation of connected immersive experiences, e.g. Virtual Reality, 3D/UHD video telepresence
5G standardization progressing for 2020 launch

5G study items

- R15 5G WI's
- R16 5G WI's
- R17+ 5G evolution
- First 5G launch
- 5G phase 2

Continued LTE evolution in parallel with 5G

3GPP RAN workshop

Learn more at: www.qualcomm.com/5G
Qualcomm is leading the way towards the connected vehicle of the future

An established leader today—pioneering tomorrow’s technologies
Our technology is enabling the connected car experience today
Qualcomm® Snapdragon™ automotive solutions
Transforming in-car experiences of the future

- Application processor
- Location and navigation
- Wi-Fi/BT
- Telematics via 4G LTE/3G
- Informational ADAS
- V2X–DSRC
- AM/FM/DAB/HD tuner

Multimedia streaming
- Bluetooth
- Wi-Fi hotspot
- 4G LTE telematics

Mobile device integration
- CarPlay, Android Auto, Miracast

Content sharing

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Pioneering C-V2X technologies

LTE Direct and LTE Broadcast are the foundation to C-V2X

**LTE Direct**
Device-to-device communications platform
- Main contributor to 3GPP
- World’s 1st LTE Direct discovery demo
- World’s 1st LTE Direct communications demo

**LTE Broadcast**
Multicast communications platform
- Main contributor to 3GPP
- World’s 1st LTE Broadcast solution
- Powered the 1st commercial launch

**C-V2X**
Actively driving ongoing C-V2X
Release 14 Work Item
Qualcomm, leading the world to 5G
Building on our leadership foundation

Wireless/OFDM technology and chipset leadership
- Pioneering new LTE and 5G technologies to meet extreme requirements

End-to-end system approach with advanced prototypes
- Driving LTE Advanced Pro and 5G from standardization to commercialization

Leading global network experience and scale
- Providing the experience and scale that the future of mobile networks demands

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Delivering new levels of on-device intelligence and integration

Bringing cognitive technologies to life
In summary

V2X is a critical component of our vision for the always-connected, more autonomous vehicle of the future

Cellular V2X brings improvements over 802.11p/DSRC for active safety use cases and beyond - part of 3GPP Release 14

Roadmap to 5G will bring even more potential for the connected vehicle—built upon C-V2X, so no ‘rip or replace’

Qualcomm is leading the way to the connected vehicle of the future - pushing wireless boundaries and bringing new levels of on-device intelligence

Learn more at: www.qualcomm.com/C-V2X
When will our cars respond to more than just the road?

Why Wait

QUALCOMM
Thank you

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