QUALCOMM®

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®

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]

[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

Highly intelligent

Always connected

Increasingly autonomous

Highly secure

Increasingly electric (or hybrid)

Safer–towards zero road accidents

Greener–reduce air pollution & emissions

More predictable and productive travel

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[1]

Fewer driving fatalities/injuries

>1.2M

people die each year on the roads worldwide[2]

More predictable, productive travel

3.1B

gallons of fuels wasted due traffic congestion in the US[3]

Less greenhouse gas emissions

14%

of all global warming emissions from transportation[4]

[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-infrastructure (V2I)

e.g. traffic signal timing / priority

Vehicle-to-network (V2N)

e.g. real-time traffic / routing, cloud services

Vehicle-to-vehicle (V2V)

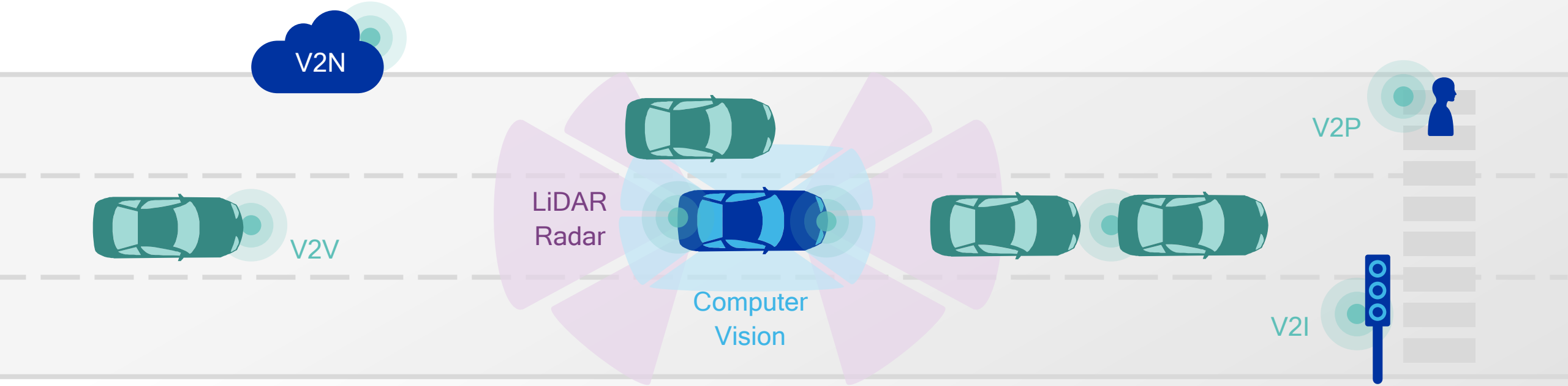
e.g. collision avoidance safety systems

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

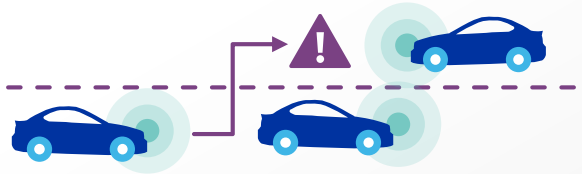
Increased situational awareness

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

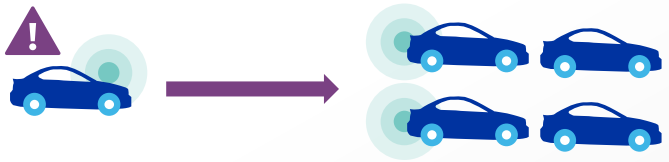
Much more than collision avoidance

Forward collision warning



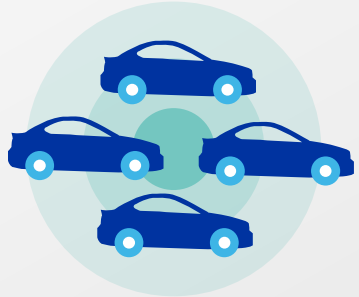
Do Not Pass Warning (DNPW)

Blind intersection

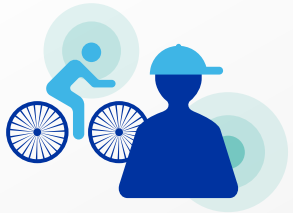


Queue warning

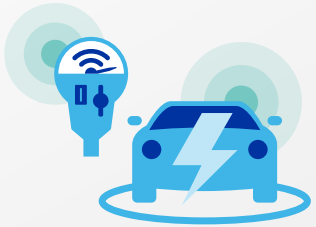
Curve speed warning



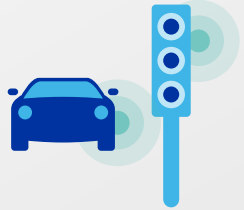
Cooperative adaptive cruise control & platooning



Vulnerable Road User (VRU) alerts



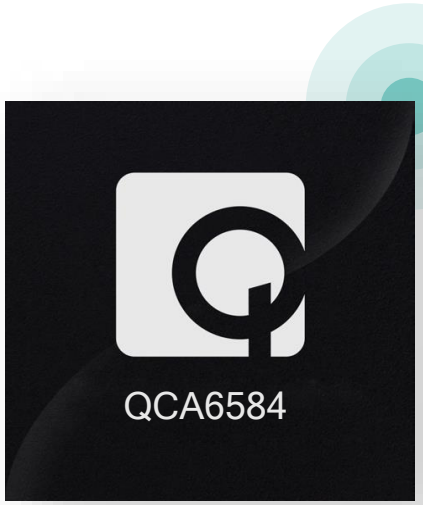
Discover parking and charging



Traffic signal priority and optimal speed advisory

Emergency vehicle alert

802.11p has established the foundation for V2X



2nd generation Qualcomm Technologies 802.11p offering with integrated Wi-Fi LAN and Bluetooth

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[1]

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[2]

Leverages existing LTE networks for V2X network communications

Using LTE Broadcast optimized for V2X to offer additional applications/services

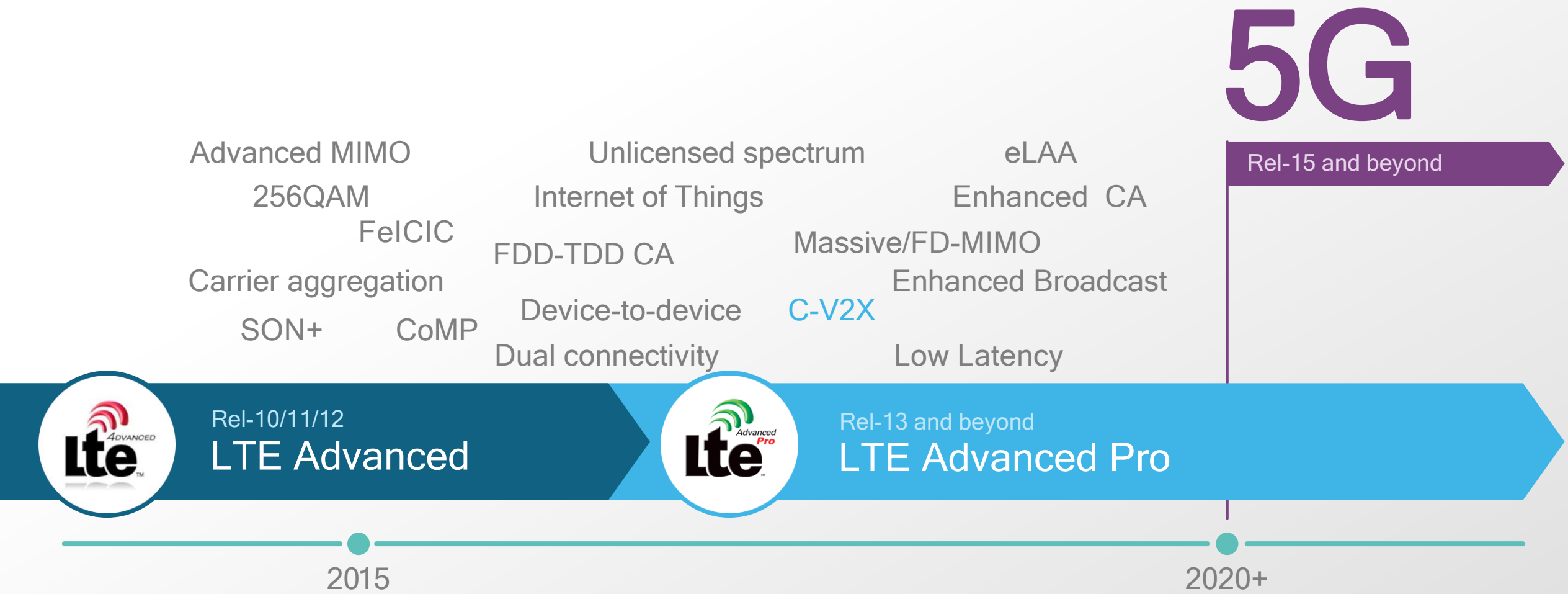
Rich roadmap towards 5G with strong ecosystem support

Technology evolution to address expanding capabilities/use cases

[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

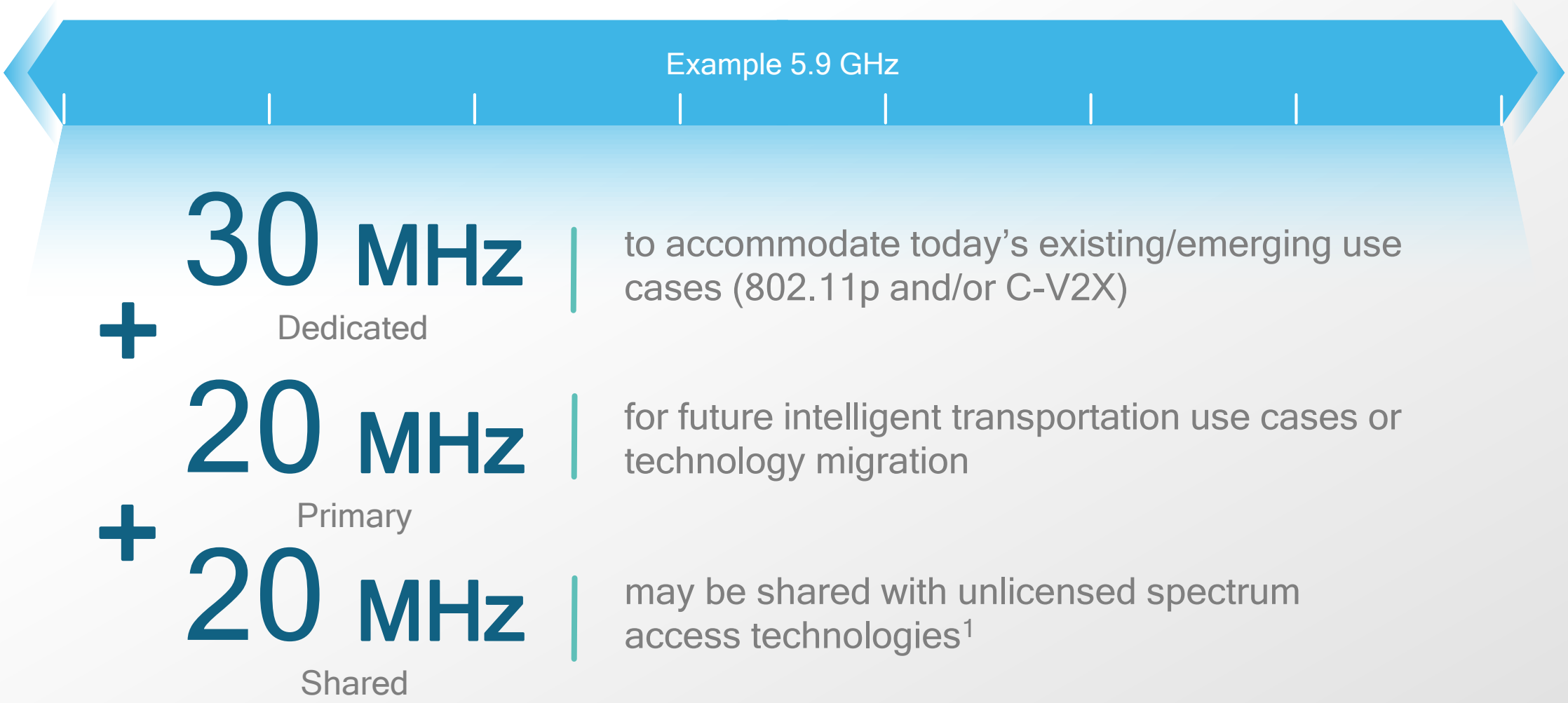
Paving the path to 5G



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



[1] Must prove it can co-exist with V2X technologies

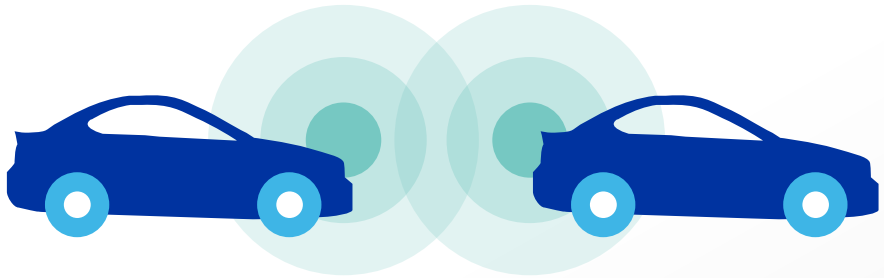
Expanding and evolving the cellular system for V2X communications

Introduced in 3GPP Release 14—part of LTE Advanced Pro

C-V2X defines two complementary transmission modes

PC5 interface

e.g. location, speed



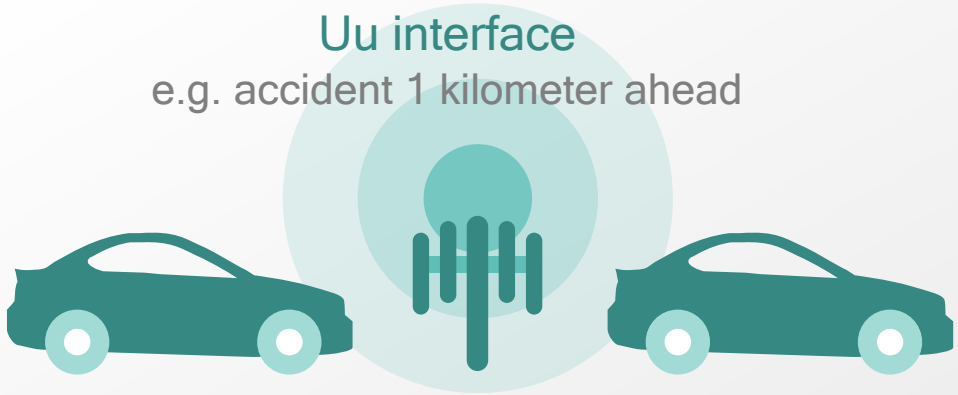
Direct communications

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

Uu interface

e.g. accident 1 kilometer ahead



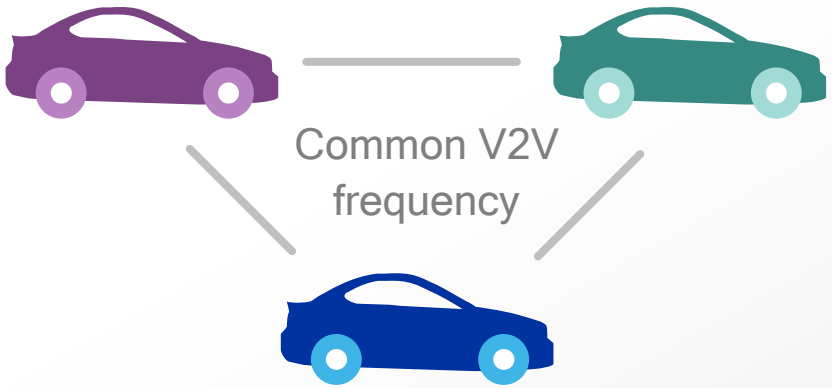
Network communications

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

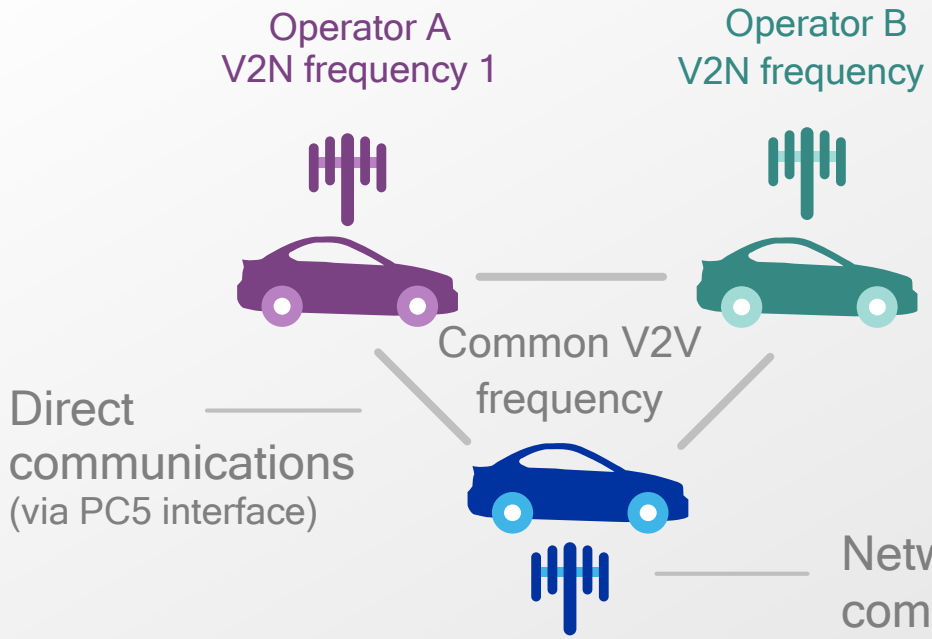
C-V2X designed for both in-coverage and out-of-coverage

Out-of-coverage



Direct communications
(via PC5 interface)

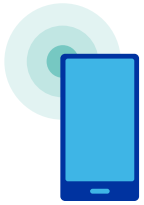
In-coverage



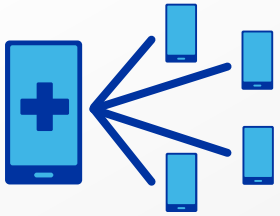
[1] C-V2X also supports a single MNO managed network for in-coverage

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/private[1] and inter-frequency

Device-to-network relays[2]

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)

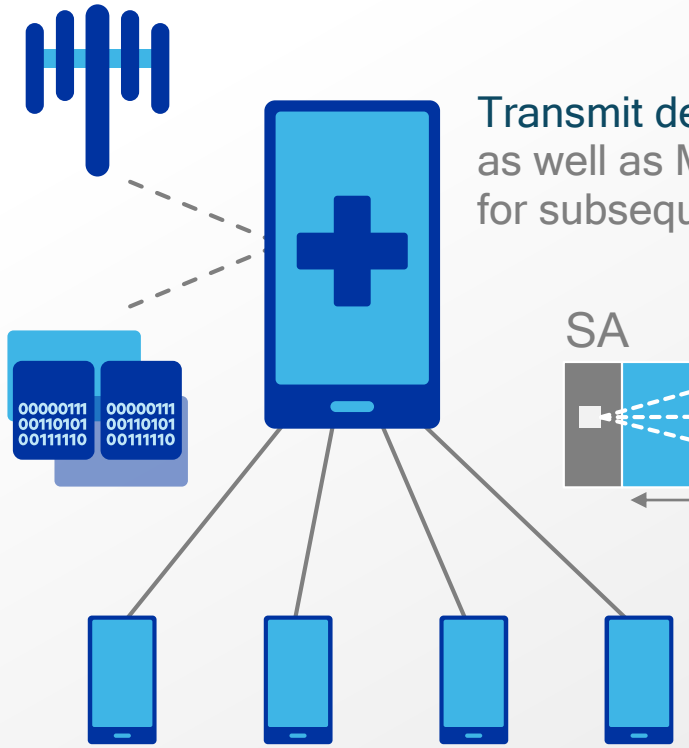
[1] Important for e.g. Social Networking discovery use cases; [2] Designed for Public Safety use cases

LTE Direct device-to-device communications

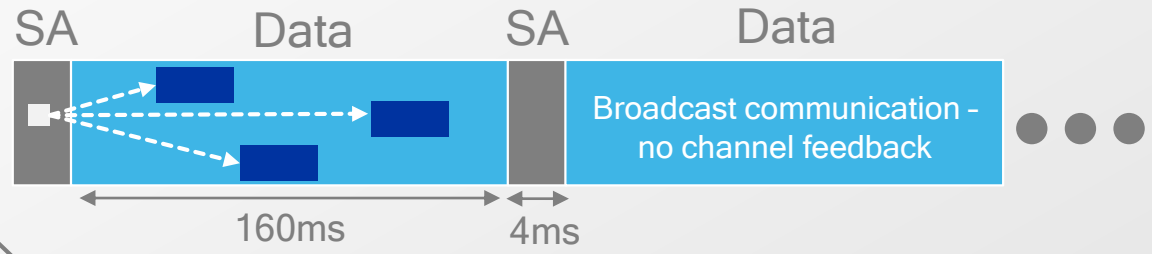
Introduced in Release 12 for public safety use cases, e.g. push-to-talk

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

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



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

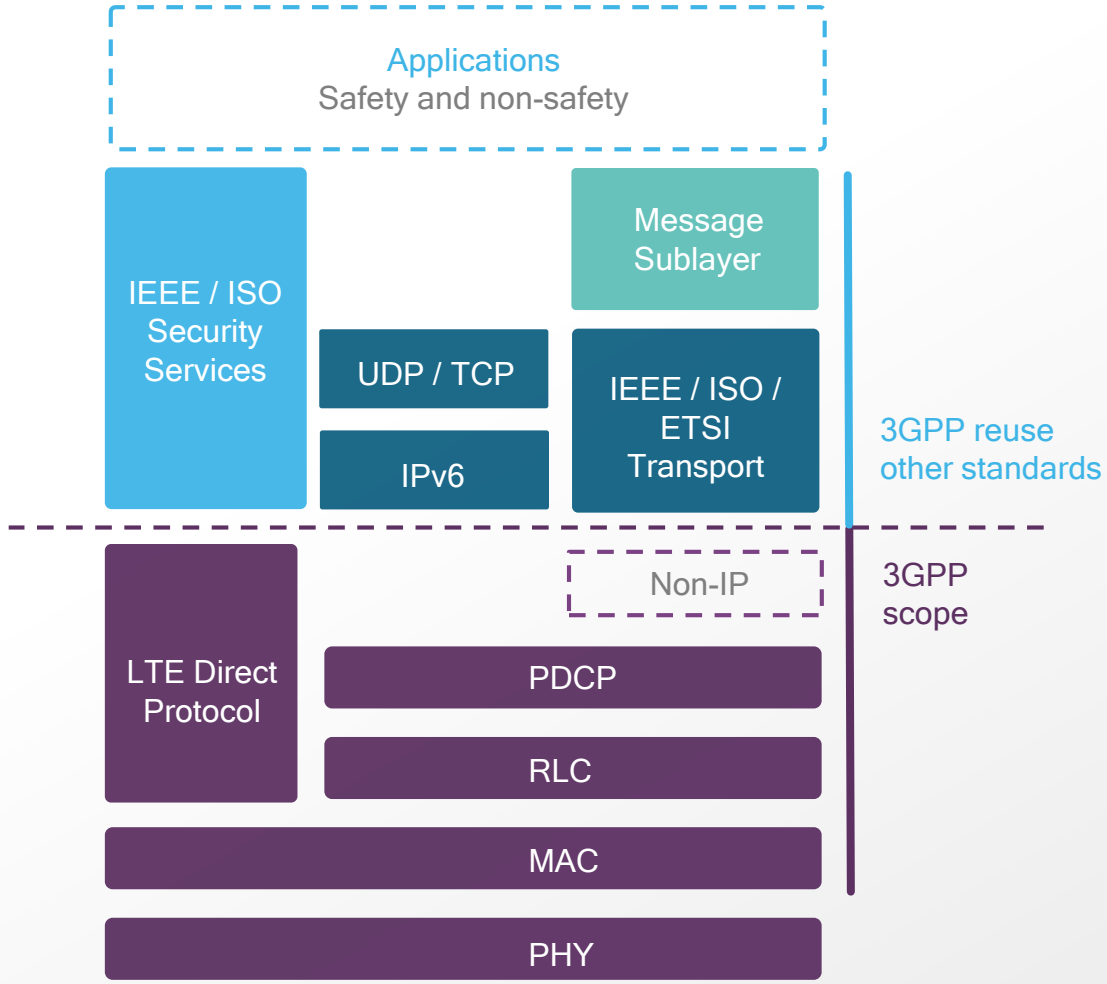


Receive devices monitor SA resource to determine when to listen for data transmission

* 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

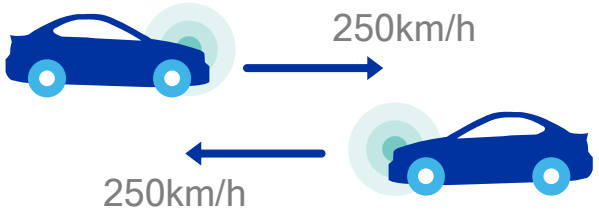
Defined by ISO, ETSI, and IEEE 1609 family

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

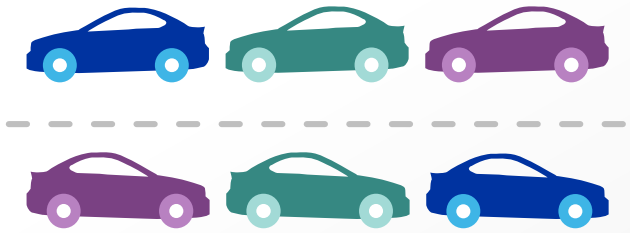


V2X Challenges

High relative speeds
Leads to significant Doppler shift / frequency offset

C-V2X Solutions

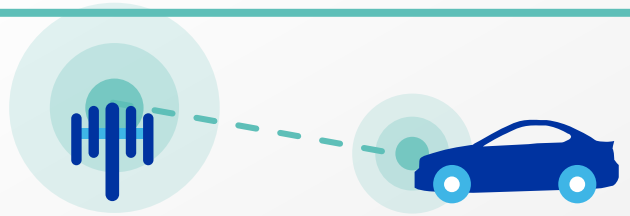
Enhanced signal design
E.g. increasing # of ref signal symbols to improve synchronization and channel estimation



High node densities
Random resource allocation results in excessive resource collisions

Enhanced transmission structure
Transmit control and data on the same sub-frame to reduce in-band emissions

More efficient resource allocation
New methods using sensing and semi-persistent resource selection

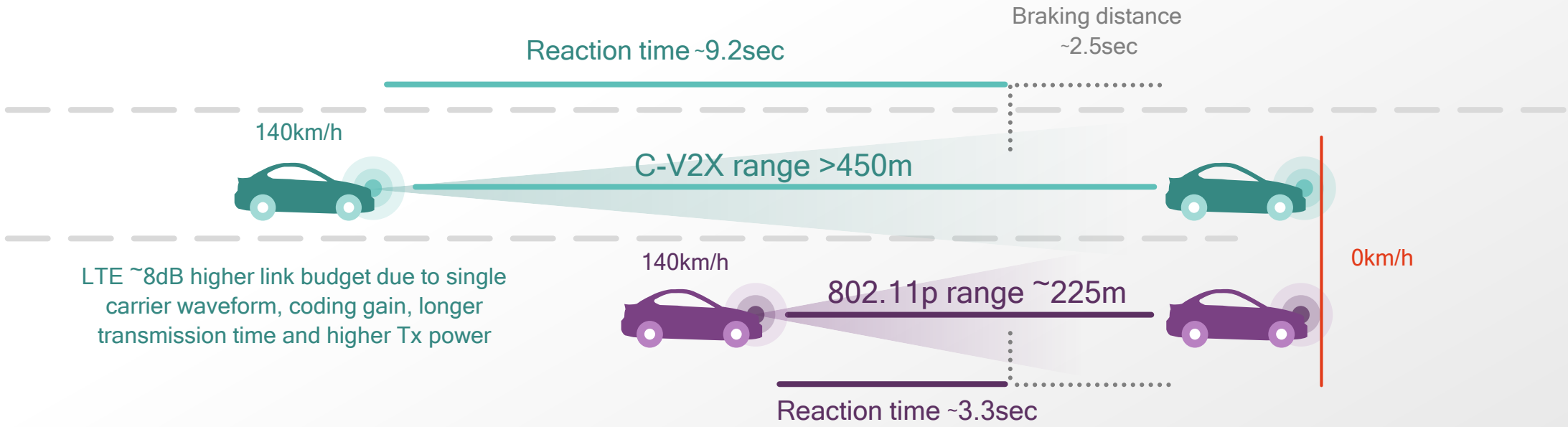


Time synchronization
Lack of synchronization source when out-of-coverage

Allow utilization of GPS timing
Enhancements to use satellite (e.g. GNSS) when out-of-coverage

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

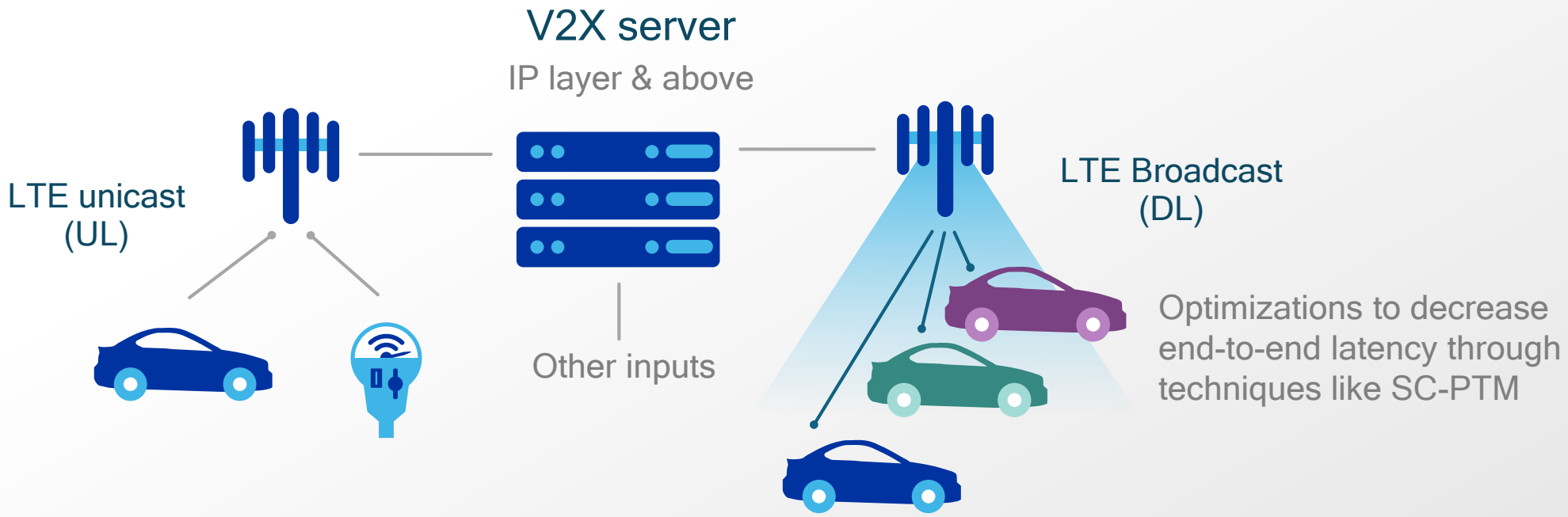
Increased situational awareness

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



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

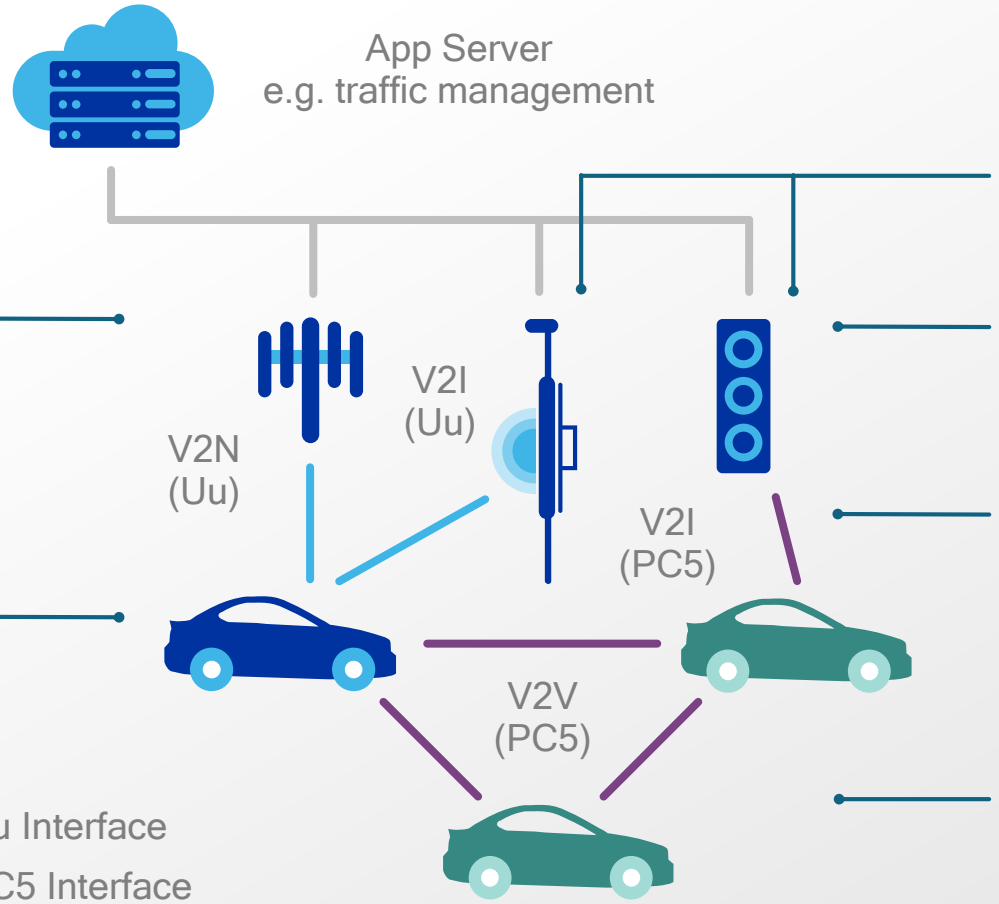
Unified service platform

New opportunities for MNOs[2] combined with today's services

[1] SC-PTM: Singe-Cell - Point-To-Multipoint; [2] MNOs: Mobile Network Operators

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

1ms end-to-end latency

Through a faster, more flexible frame structure; also new uplink RSMA non-orthogonal access

Edgeless connectivity

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

High availability

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

High reliability

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

[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

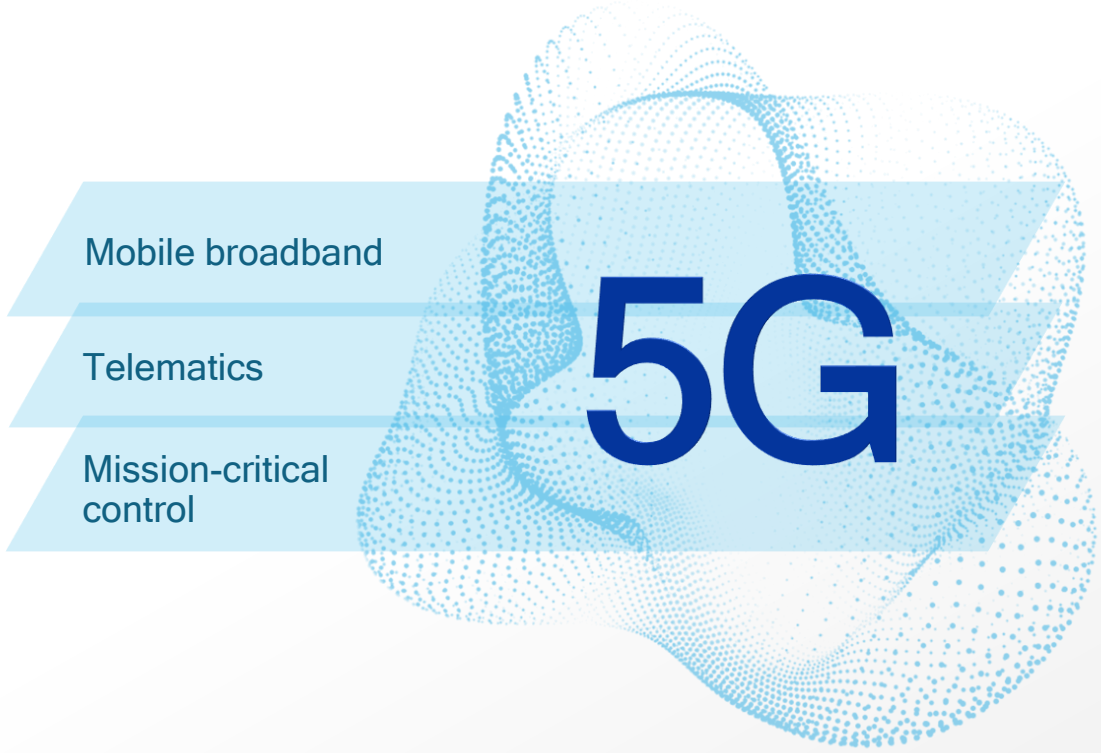
C-V2X direct and network communications

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

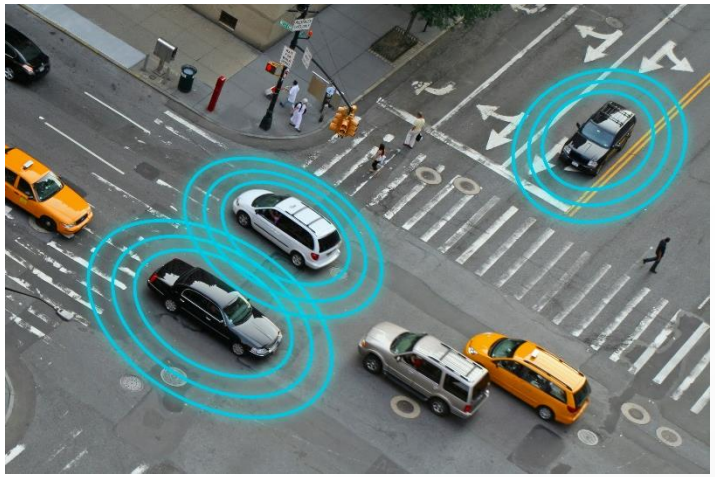


- Configurable end-to-end connectivity per vertical
- Modular, specialized network functions per services
- Flexible subscription models
- Dynamic control and user planes with more functionality at the edge

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

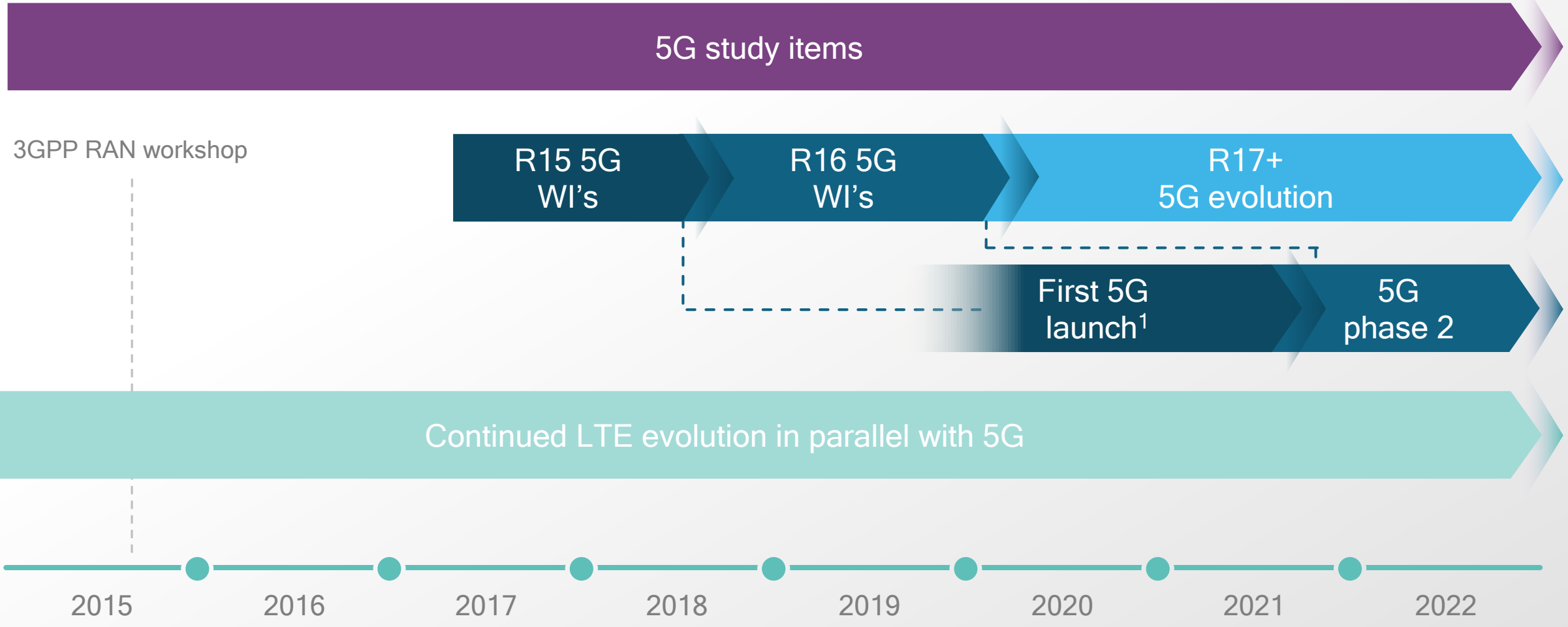
V2X augmented reality

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



Learn more at: www.qualcomm.com/5G

Note: Estimated commercial dates; 1 Forward compatibility with R16 and beyond

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

Multimedia

Power Management

GPU

RF

Software/ HLOS

Position/ Location

Powerline

Ethernet

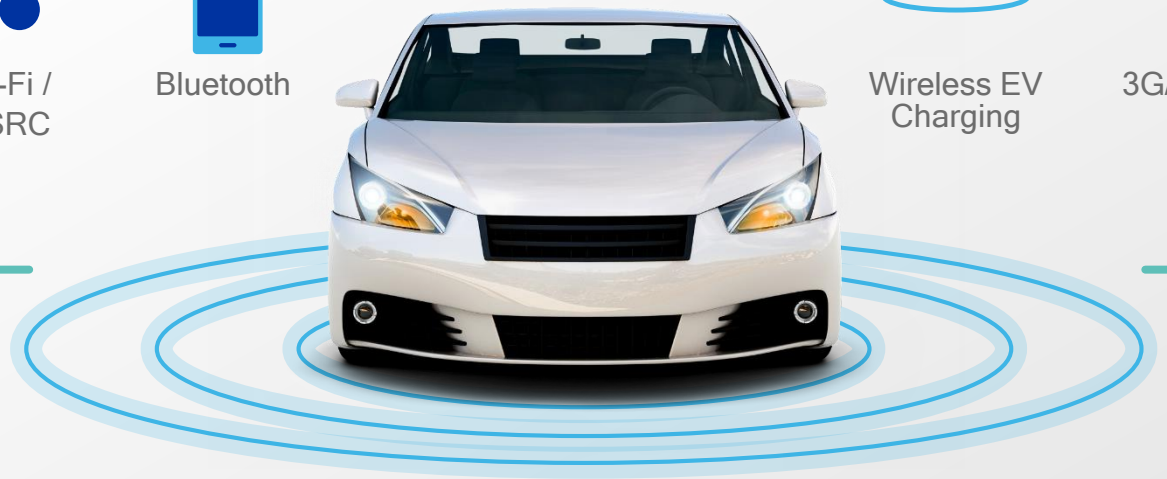
Security

Multi-OS support

DSP

Wi-Fi / DSRC

Bluetooth



Wireless EV Charging

3G/4G LTE

CPU

Computer Vision

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

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. This use case is a hypothetical depiction of potential applications for Snapdragon product offerings–not actual connected car and infotainment product. All screen images are simulated.

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

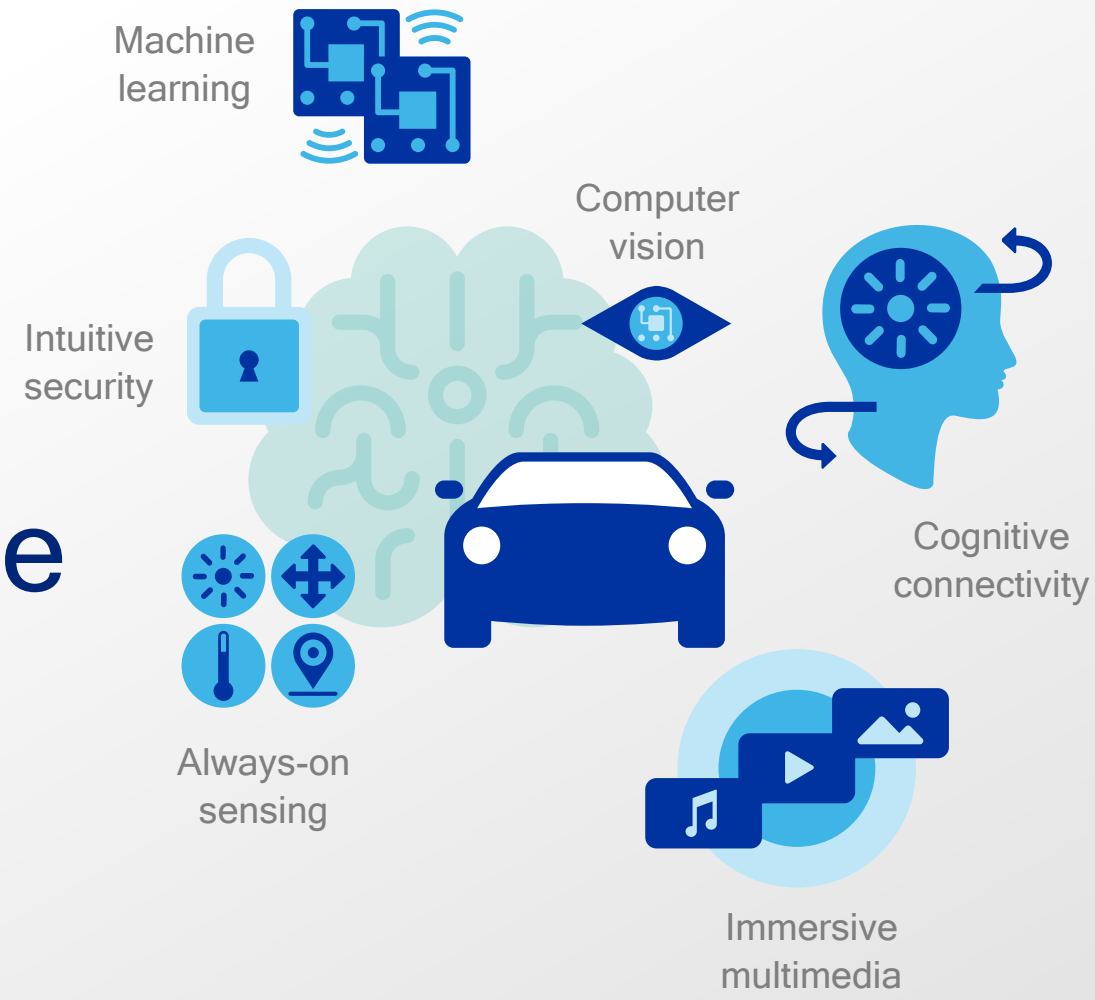
Driving LTE Advanced Pro and 5G from standardization to commercialization

Leading global network experience and scale

Providing the experience and scale that the future of mobile networks demands

Delivering new levels of on-device intelligence and integration

Bringing cognitive technologies to life



In summary

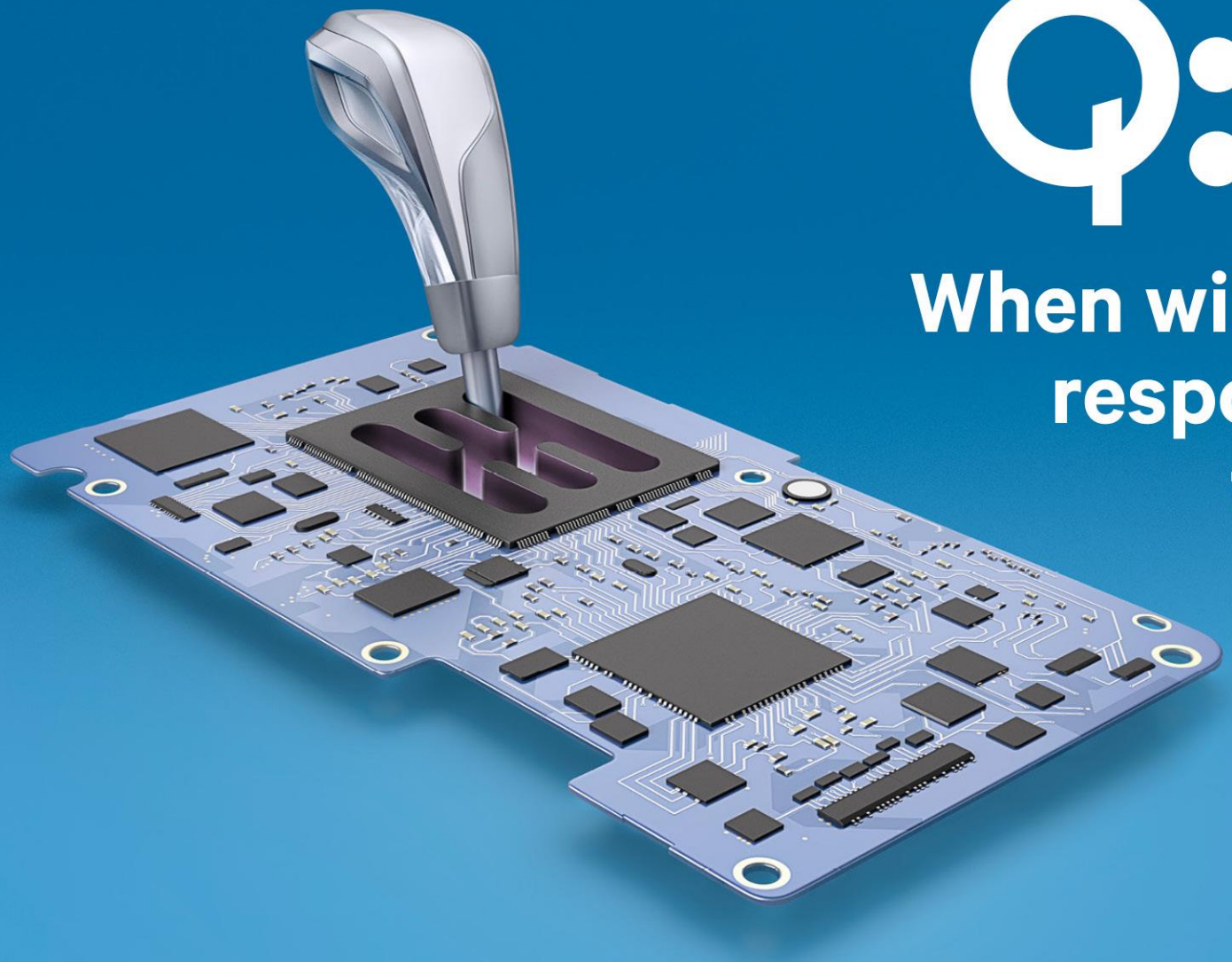
V2X is a critical component of our vision for the always-connected, more autonomous vehicle of the future

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 brining new levels of on-device intelligence

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



Q:

When will our cars respond to more than just the road?

Why Wait™

QUALCOMM®

Questions? - Connect with Us

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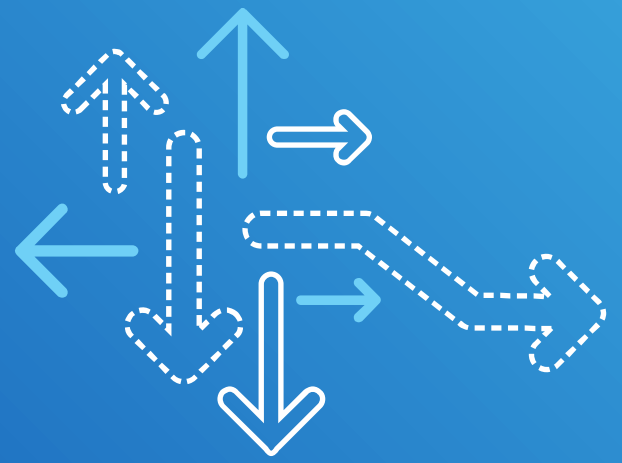
http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution



Thank you

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