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

5G

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 - pedestrian
Vehicle-to-infrastructure
3D HD live map updates
AR / VR
Teleoperation
HD video
Vehicle-to-network
Vehicle-to-vehicle

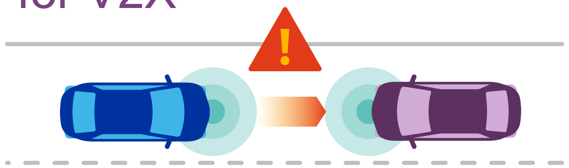
Continuous V2X technology evolution required

And careful spectrum planning to support this evolution

Evolution to 5G,
while maintaining backward compatibility

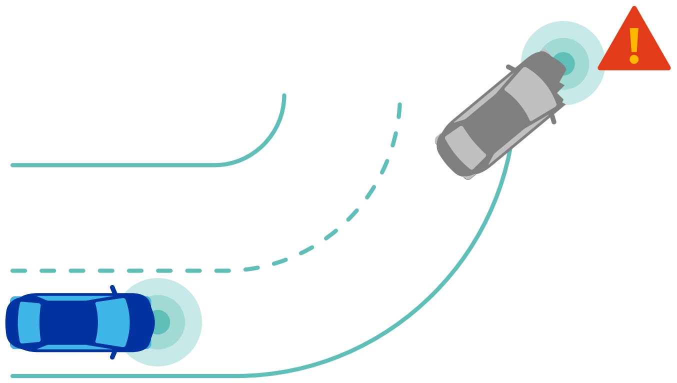
Basic safety
802.11p or C-V2X R14

Established foundation for V2X



Enhanced safety
C-V2X R14/15

Enhanced range and reliability



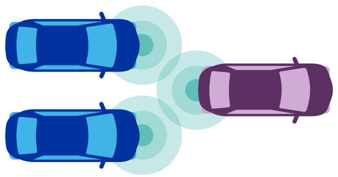
Advanced safety
C-V2X R16 (building upon R14)

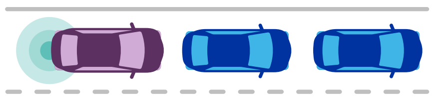
Higher throughput

Higher reliability

Wideband ranging and positioning

Lower latency





Evolving C-V2X towards 5G for autonomous driving

D2D communications
R12/13

Established foundation for basic D2D comm.

Enhanced safety
C-V2X R14 (Ph. I) C-V2X R15 (Ph. II)

Enhanced communication's range and reliability for V2X safety

Autonomous driving
C-V2X R16 5G NR support (Ph. III)
(Advanced safety applications)

Ultra-reliable, low latency, high throughput communication for autonomous driving

	D2D communications	Enhanced safety	Autonomous driving
Network independent	No	Yes	Yes
Communications[1]	Broadcast only	Broadcast only	Broadcast + Unicast/Multicast
High speed support	No	Yes	Yes
High density support	No	Yes	Yes
Throughput		High throughput for enhanced safety	Ultra-high throughput
Latency		Low latency for enhanced safety applications	Ultra-low latency
Reliability		Reliability for enhanced safety application	Ultra-high reliability
Positioning	No	Share positioning information	Wideband ranging and positioning

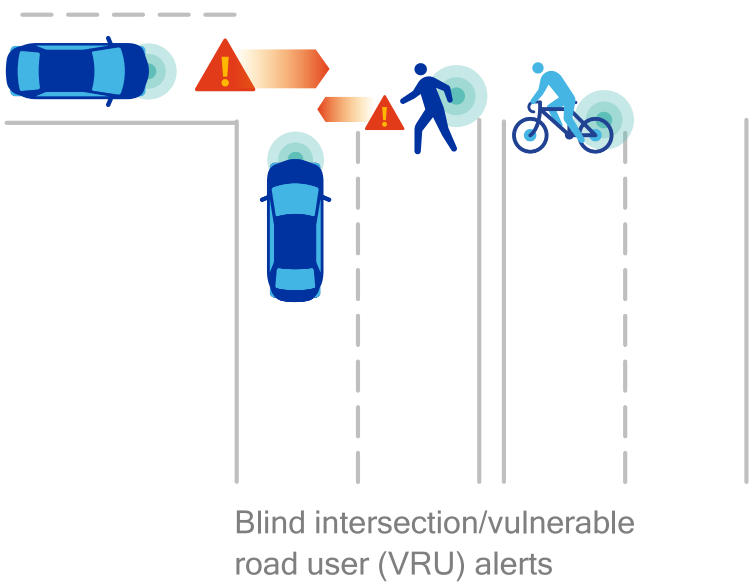
1. PHY/MAC communications; R16 is still under development

C-V2X is a critical component for safer autonomous driving

Communicating intent and sensor data even in challenging real world conditions

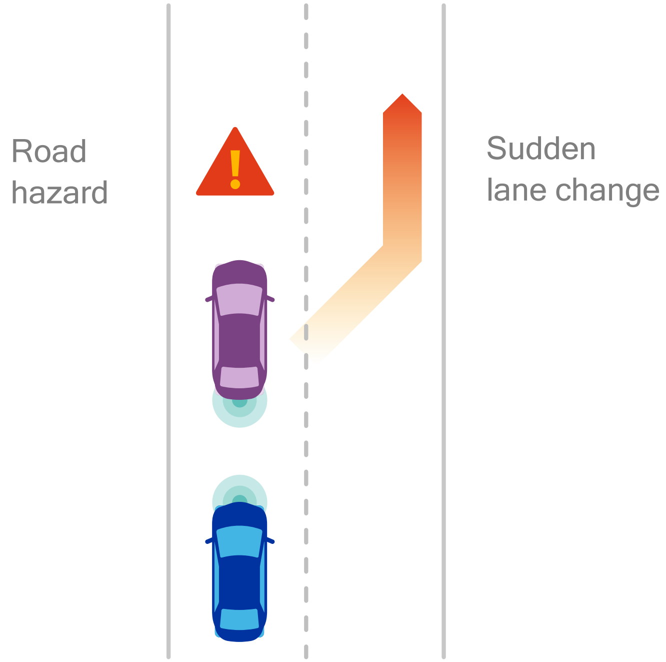
Non line-of-sight sensing

Provides 360˚ NLOS awareness, works at night and in bad weather conditions



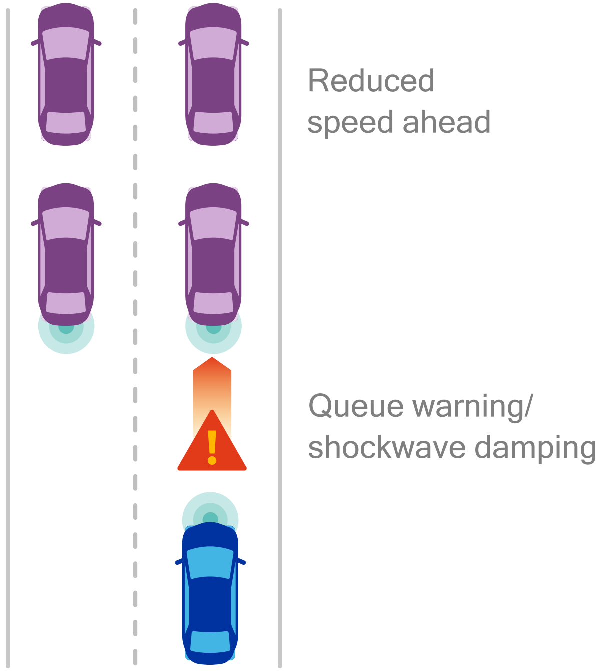
Conveying intent

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



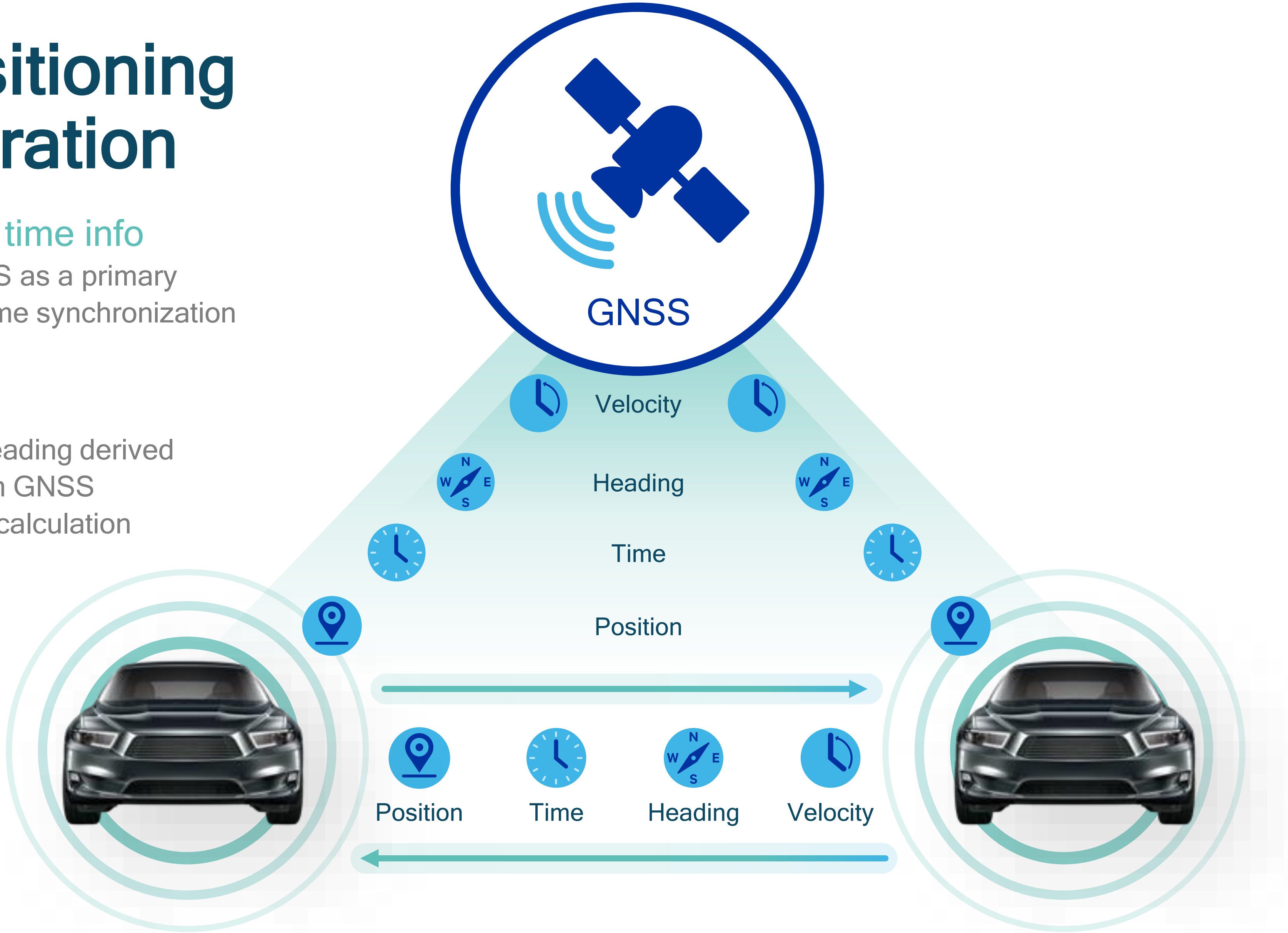
High precision positioning is key for V2X operation

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

Accurate time info
Using GNSS as a primary source of time synchronization

Velocity
Accurate speed derived directly from GNSS positioning calculation

Heading
Accurate heading derived directly from GNSS positioning calculation



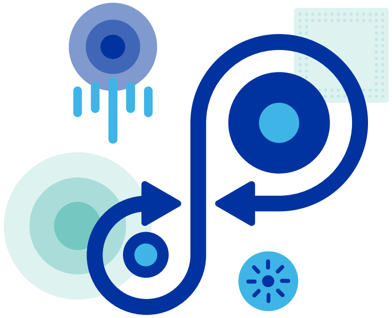
Enhancing positioning on multiple fronts

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 satellites for improved accuracy and availability

Extend accuracy and availability in more places w/ better sensors

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

- 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

- 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

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

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
VIO

C-V2X Release 14 enhances range and reliability

Paving the path to autonomous driving

C-V2X offers key advantages in multiple dimensions

C-V2X
R-14

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

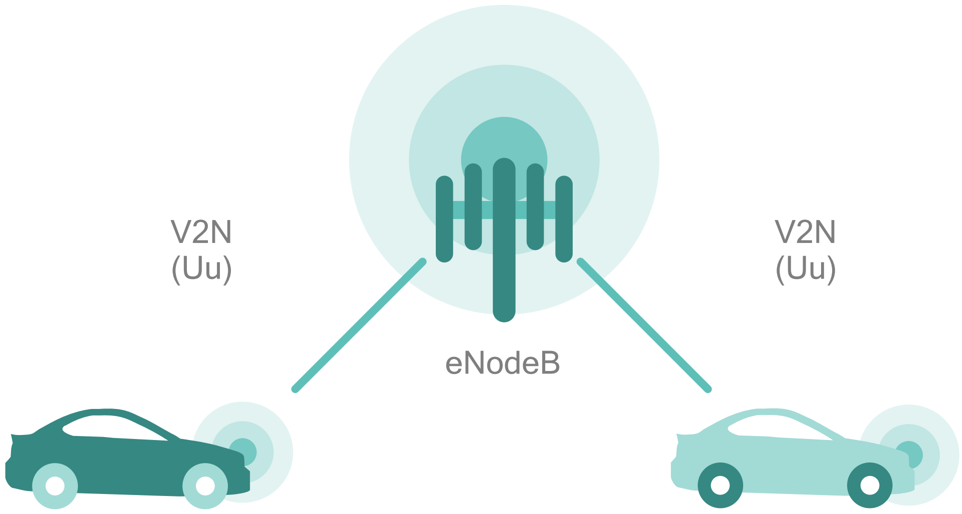
C-V2X defines two complementary transmission modes

Network communications

V2N on "Uu" interface operates in traditional mobile broadband licensed spectrum

Uu interface

e.g. accident 2 kilometer ahead

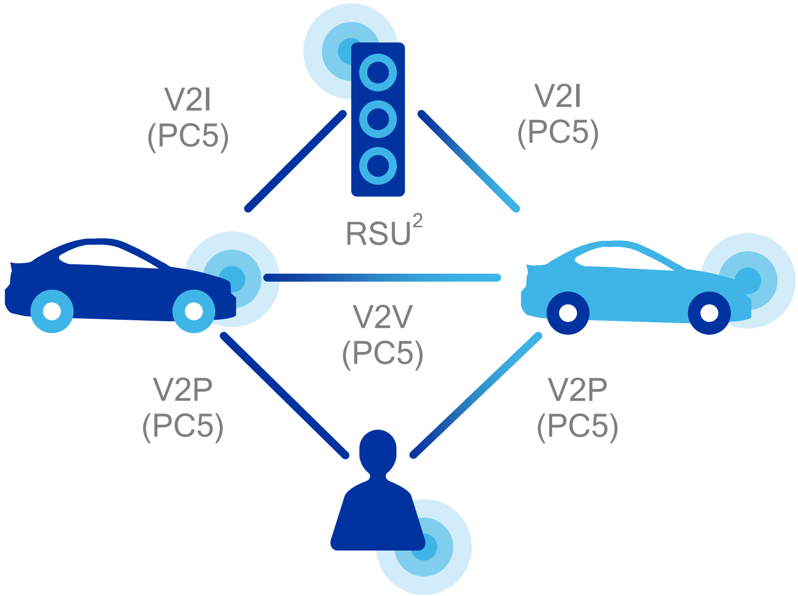


Direct communications

V2V, V2I, and V2P on "PC5" interface[1], operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network

PC5 interface

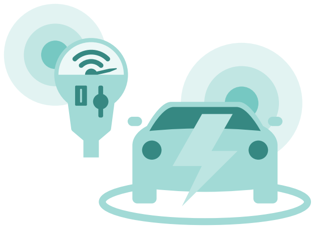
e.g. location, speed



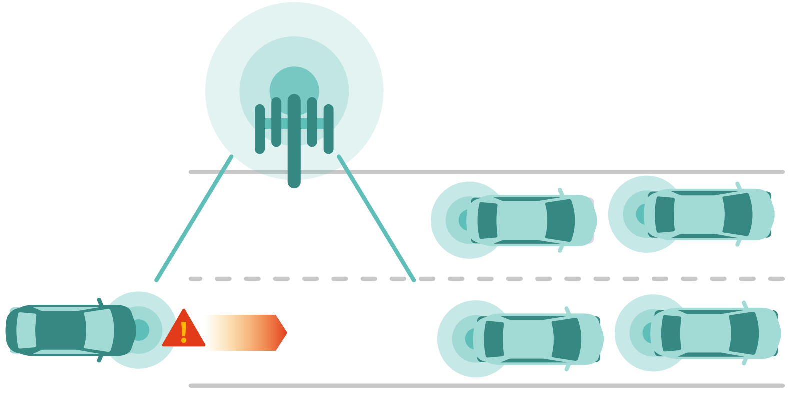
1. PC5 operates on 5.9GHz; whereas, Uu operates on commercial cellular licensed spectrum 2. RSU stands for roadside unit.

Network communications for latency tolerant use cases

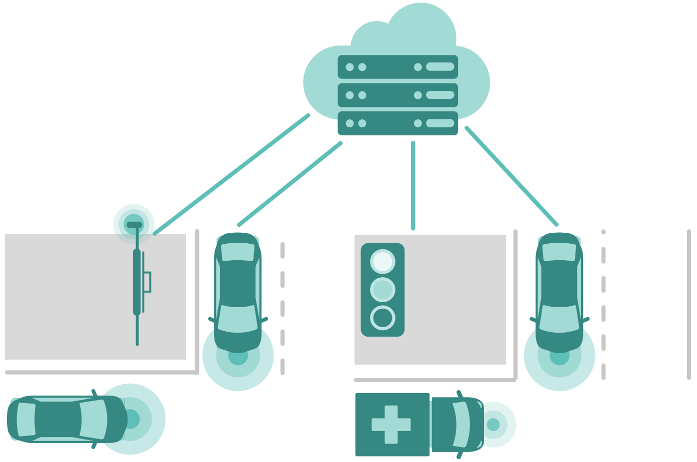
Suitable for telematics, infotainment and informational safety use case



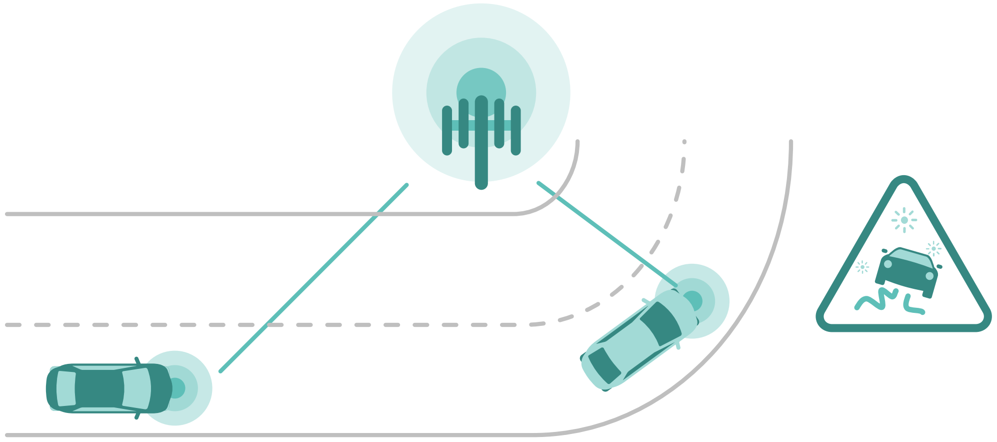
Discover parking and charging



Traffic flow control/ Queue warning



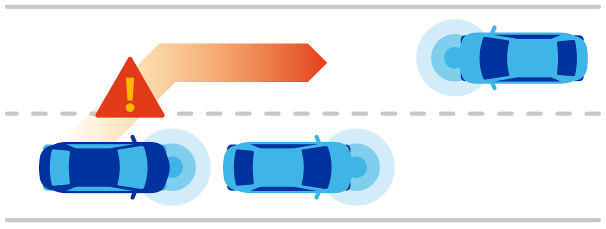
Cloud-based sensor sharing



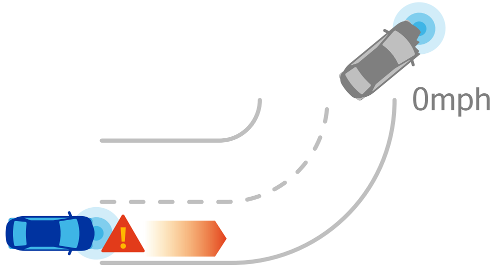
Road hazard warning 1 km ahead

Direct communications for active safety use cases

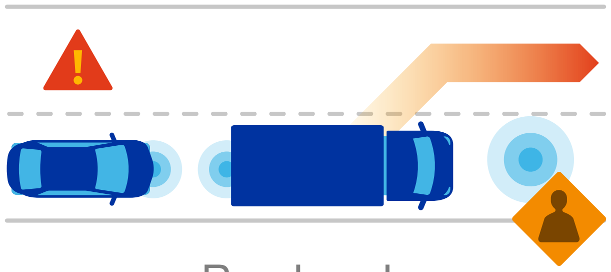
Low latency communication with enhanced range, reliability, and NLOS performance



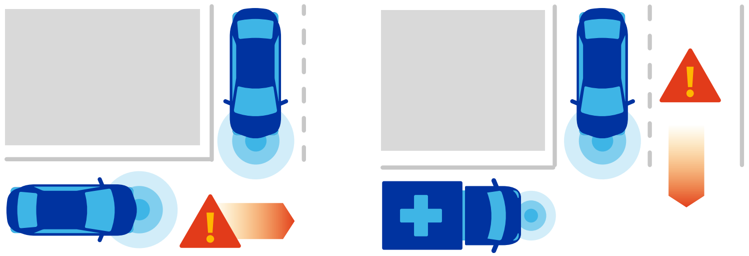
Do not pass
warning (DNPW)



Blind curve/
Local hazard warning

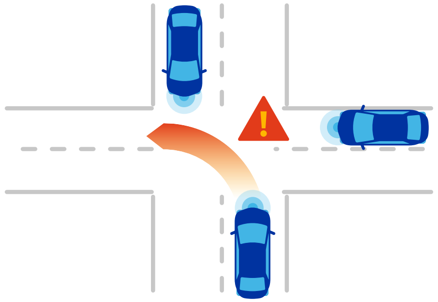


Road works
warning



Intersection movement assist
(IMA) at a blind intersection

Vulnerable road user (VRU)
alerts at a blind intersection

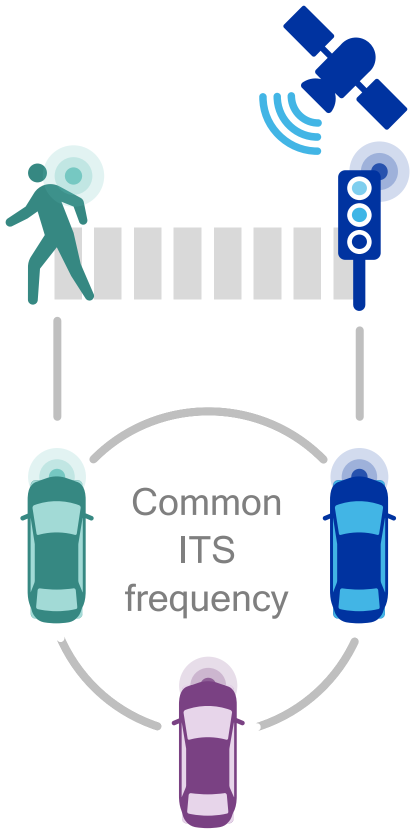


Left turn
assist (LTA)

C-V2X can work without network assistance[1]

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[2], C-V2X also uses GNSS for time synchronization without relying on cellular networks



Direct communications
(via PC5 interface on 5.9GHz)

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

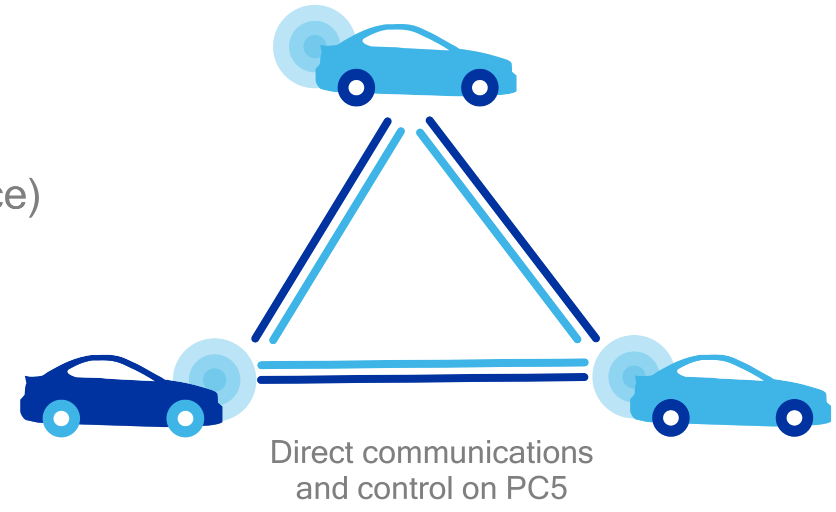
Increased reliability

Doesn't rely on network coverage, doesn't suffer from service interruption during handover

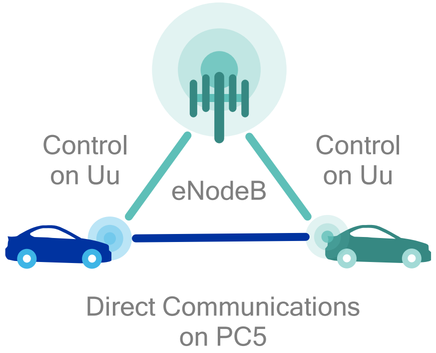
Reduced complexity

Doesn't rely on coordination between operators for resource assignment, doesn't require subscription

Self-managed
(no network assistance)



Network-assisted



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

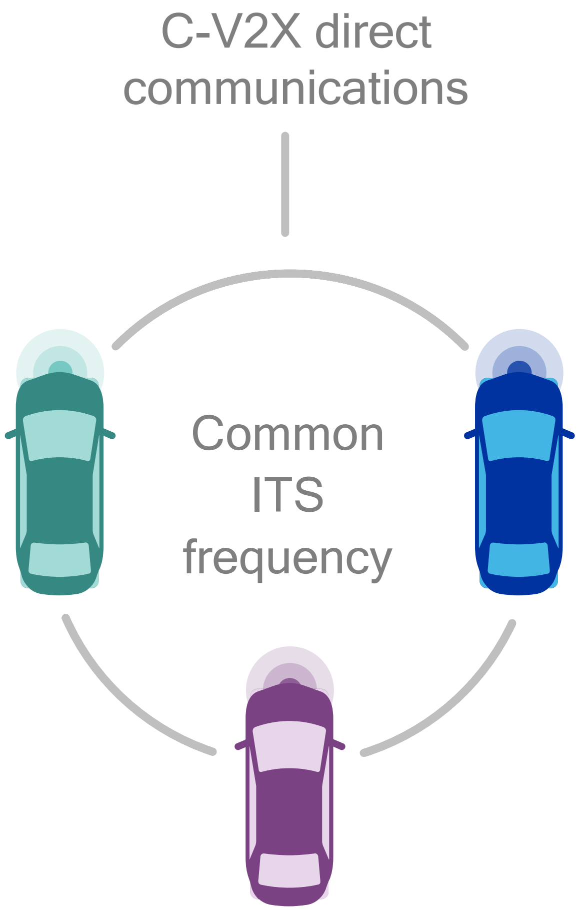
C-V2X support in ITS band was added in 3GPP Release 14

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

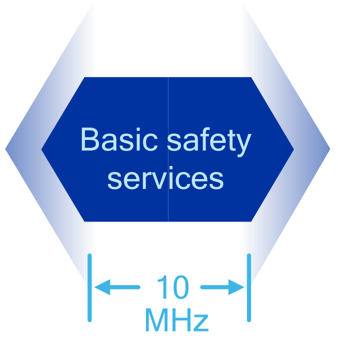


5GHz support began in release 13 with LAA, and expanded with release 14 for ITS

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



10MHz

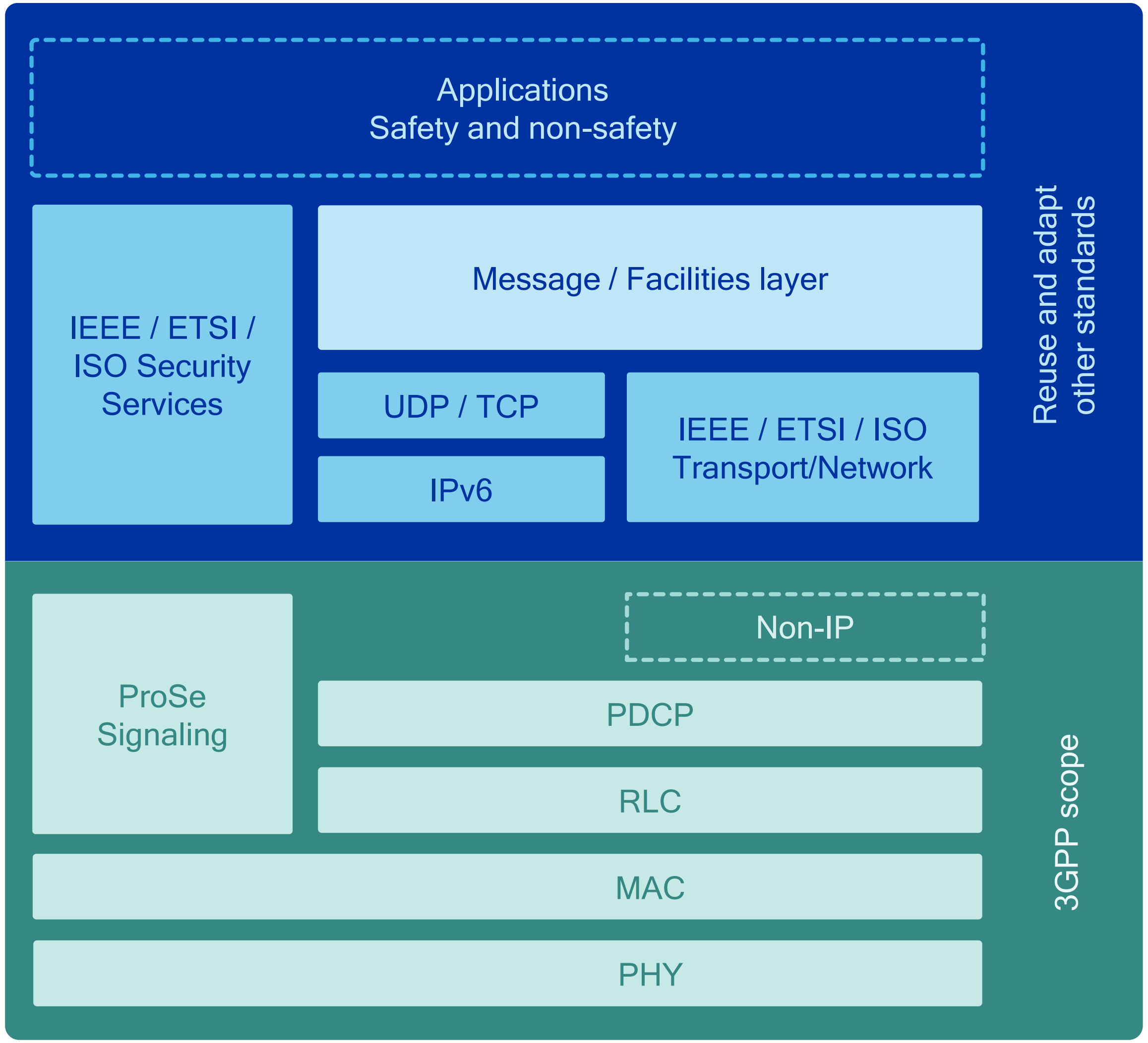
Support today's safety use cases on small subset of the band (using 802.11p or C-V2X)

C-V2X Rel-15+ can operate in the same Rel-14 spectrum

70MHz

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

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

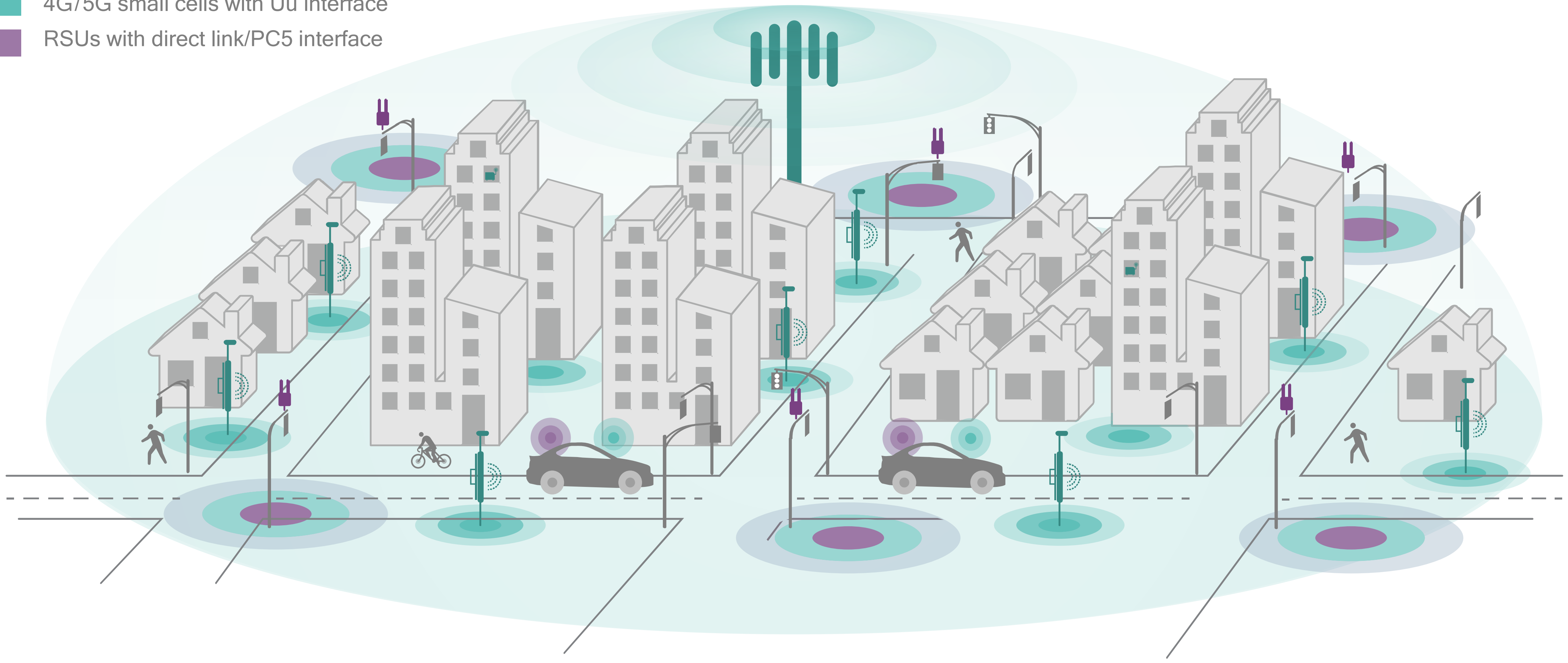
Keeps technology relevant to new use cases by avoiding one-off technology lifecycle obsolescence

C-V2X reduces cost of infrastructure deployment

Combined RSUs and 4G/5G small cell, benefiting from cellular network densification

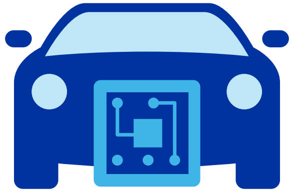
4G/5G small cells with Uu interface

RSUs with direct link/PC5 interface



C-V2X offers new business models and economic benefits

Leveraging existing, ubiquitous cellular networks and mobile ecosystem support

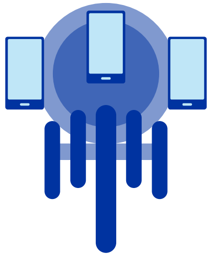


More integrated solution

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 802.11p[1]

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

~2X
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[1]

4.8dB (3X)

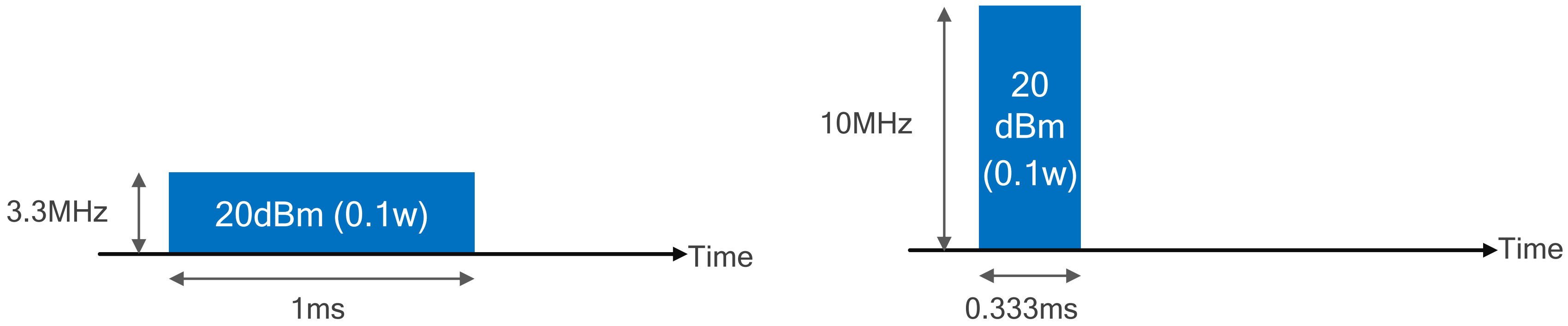
Gain per packet for C-V2X

C-V2X

Energy per packet = 0.1 mWs

802.11p

Energy per packet = 0.033 mWs



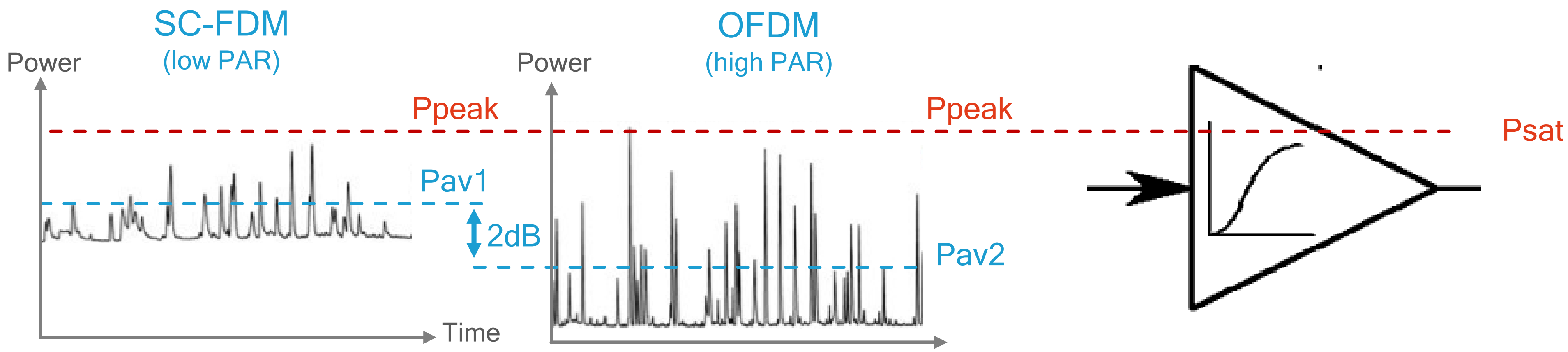
- C-V2X has longer transmission time for the same number of transmitted bits, leading to better energy per bit (as energy is accumulated over a longer period of time)
- FDM transmission has been adopted as an efficient mode of packet transmission in 4G cellular systems

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]



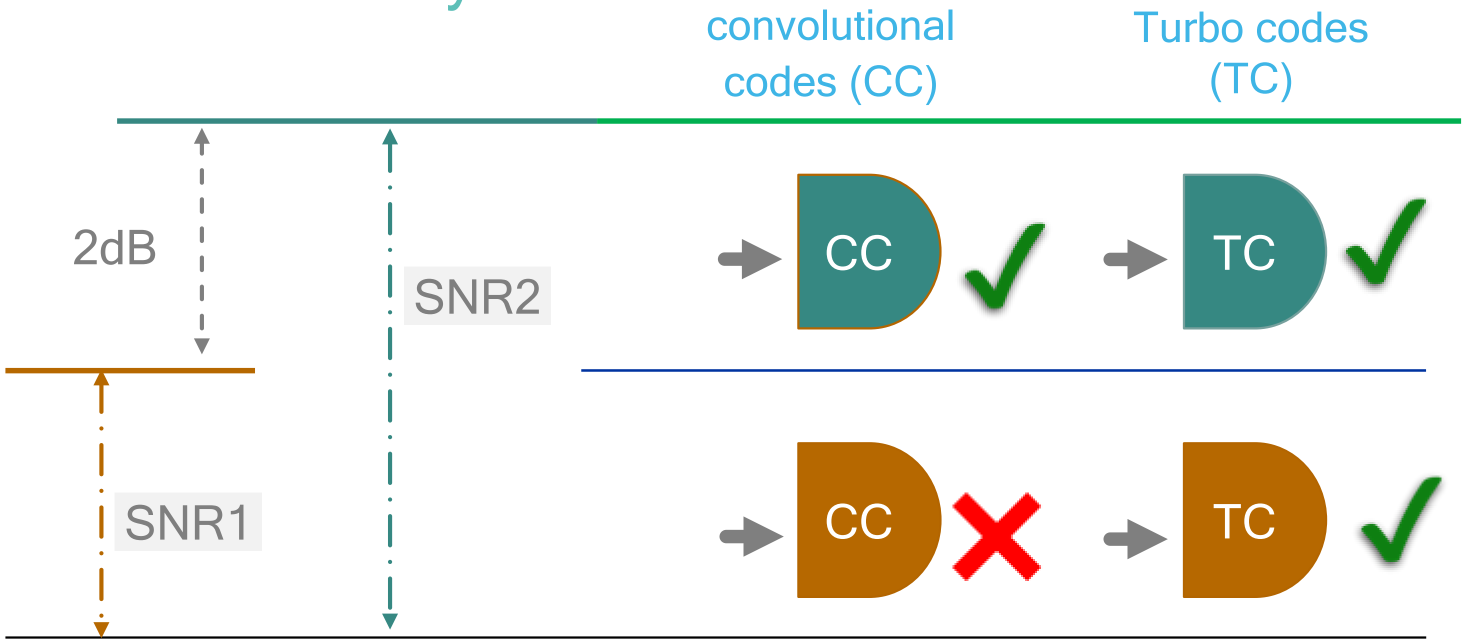
- SC-FDM groups resource blocks together in a way that reduces peak-to-average power ratio (PAPR), hence support driving power amplifier closer to saturation, leading to better transmit power efficiency
- Used for LTE uplink and 5G macro deployments, where transmit power efficiency is particularly important

[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

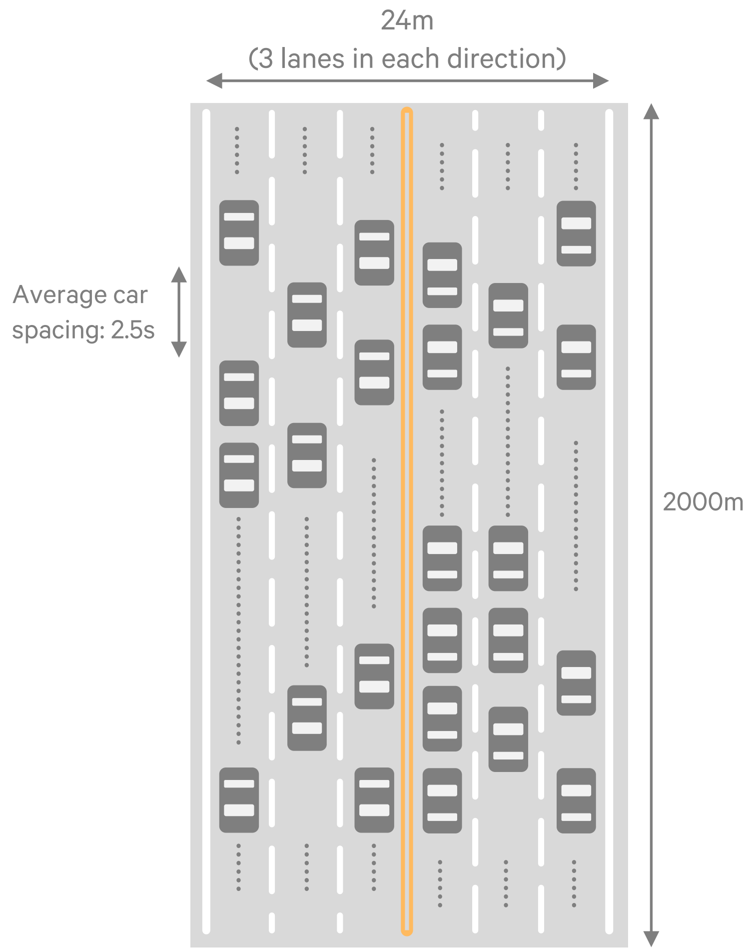
The required SNR for receiving a specific packet size with 1% block error rate is 2dB lower with TC than CC



- 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

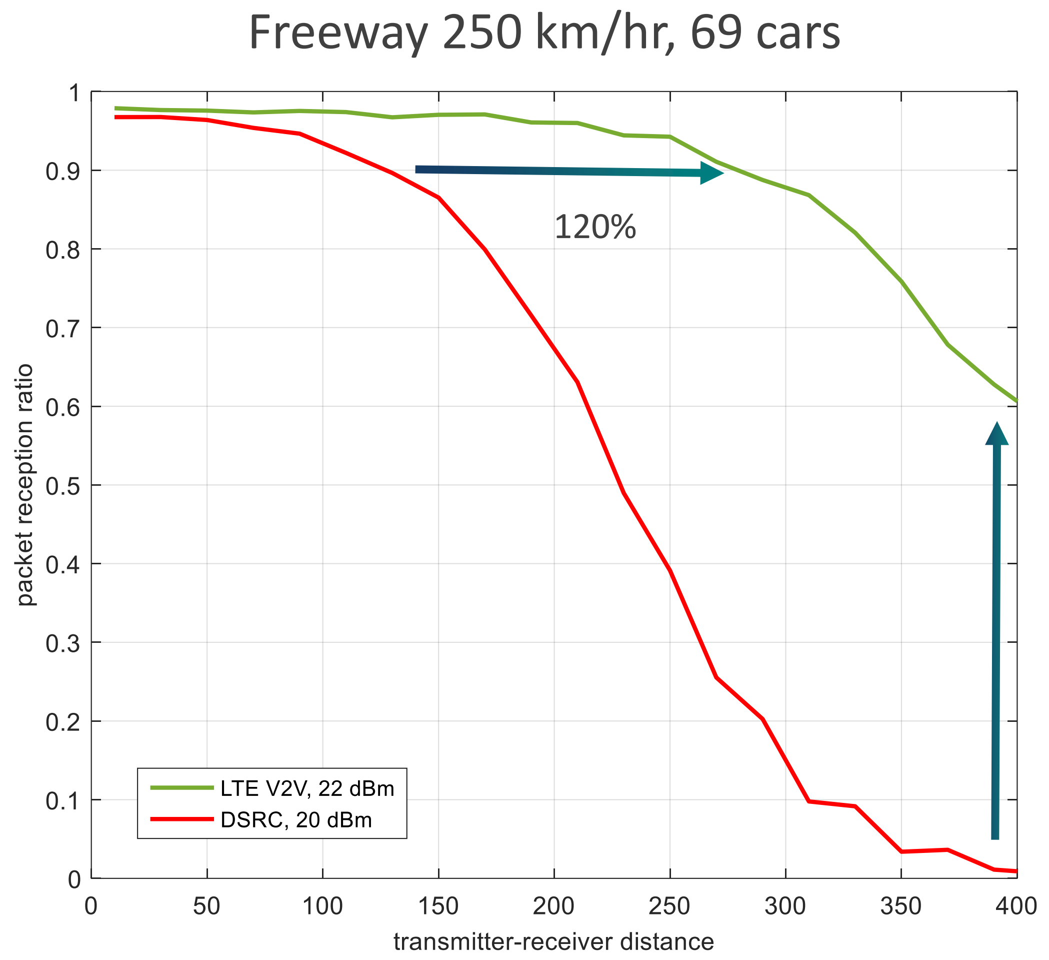


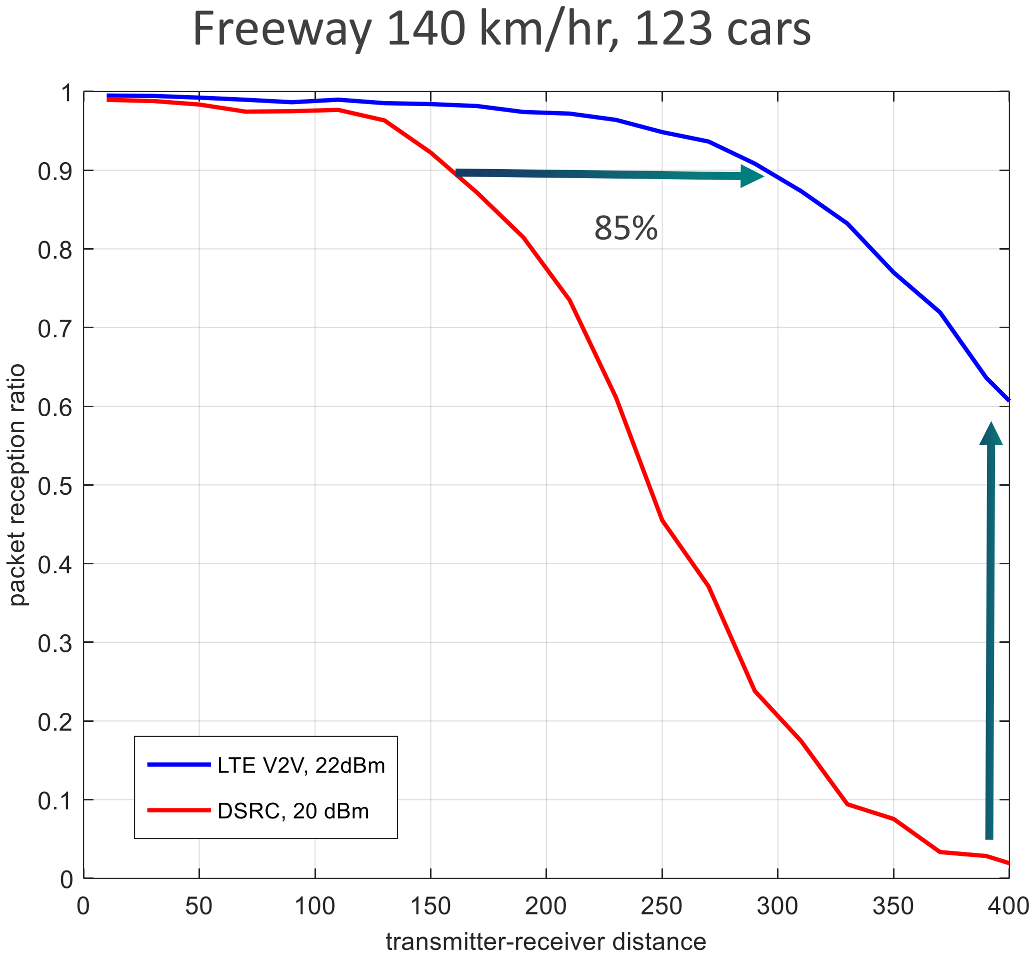
Simulation assumptions:

- 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

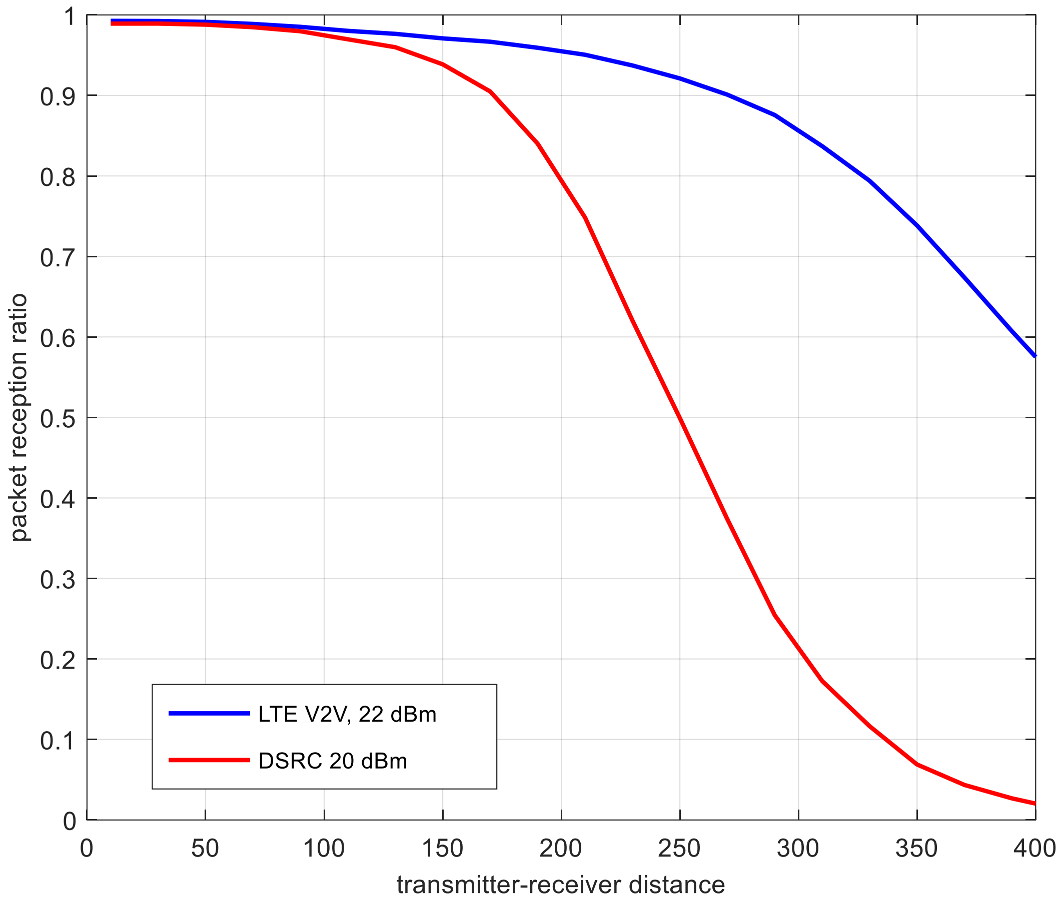
~100% gain in distance at 0.9 PRR; @400m PRR changed from 0.02 to 0.6





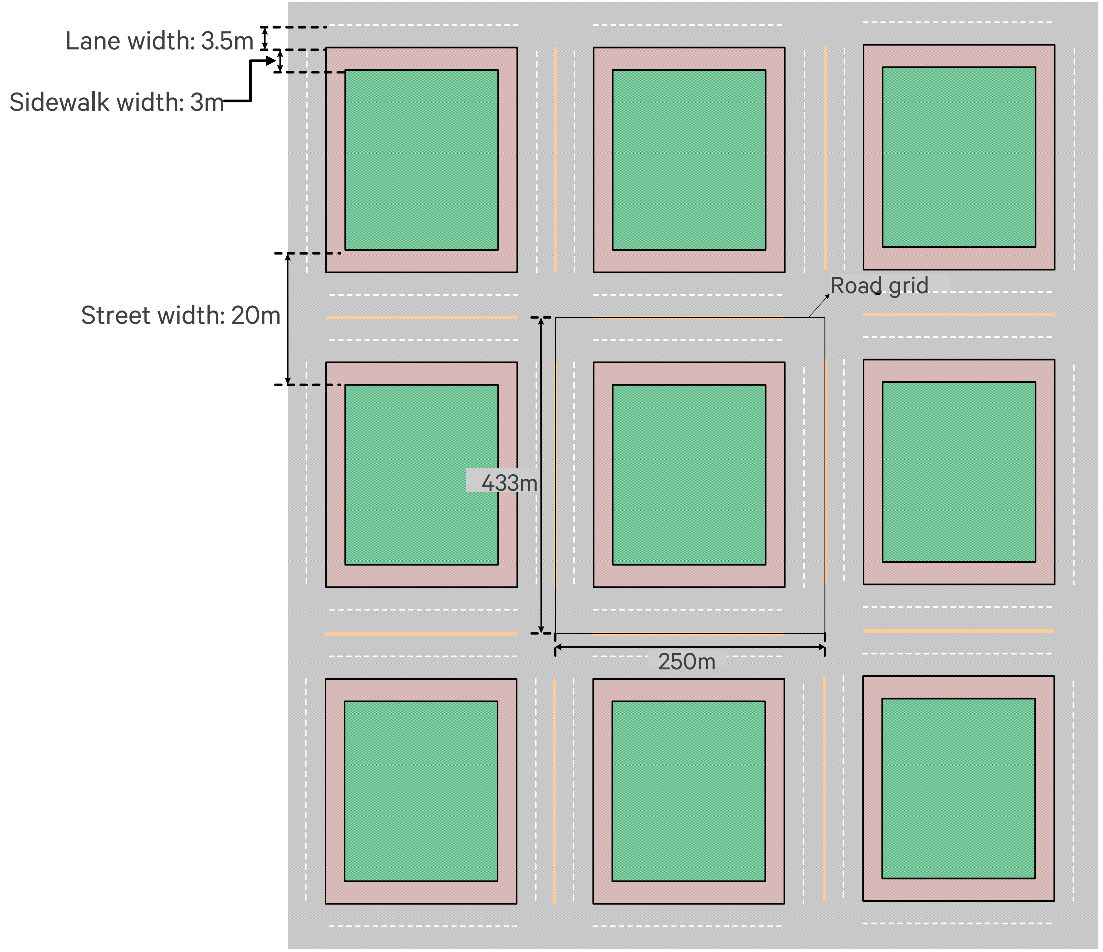
Enhanced range and reliability: Free way 70 km/hr speed

~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: 15km/hr, 60 km/hr
- Cars dropped according to Poisson process, avg. car spacing is 2.5s

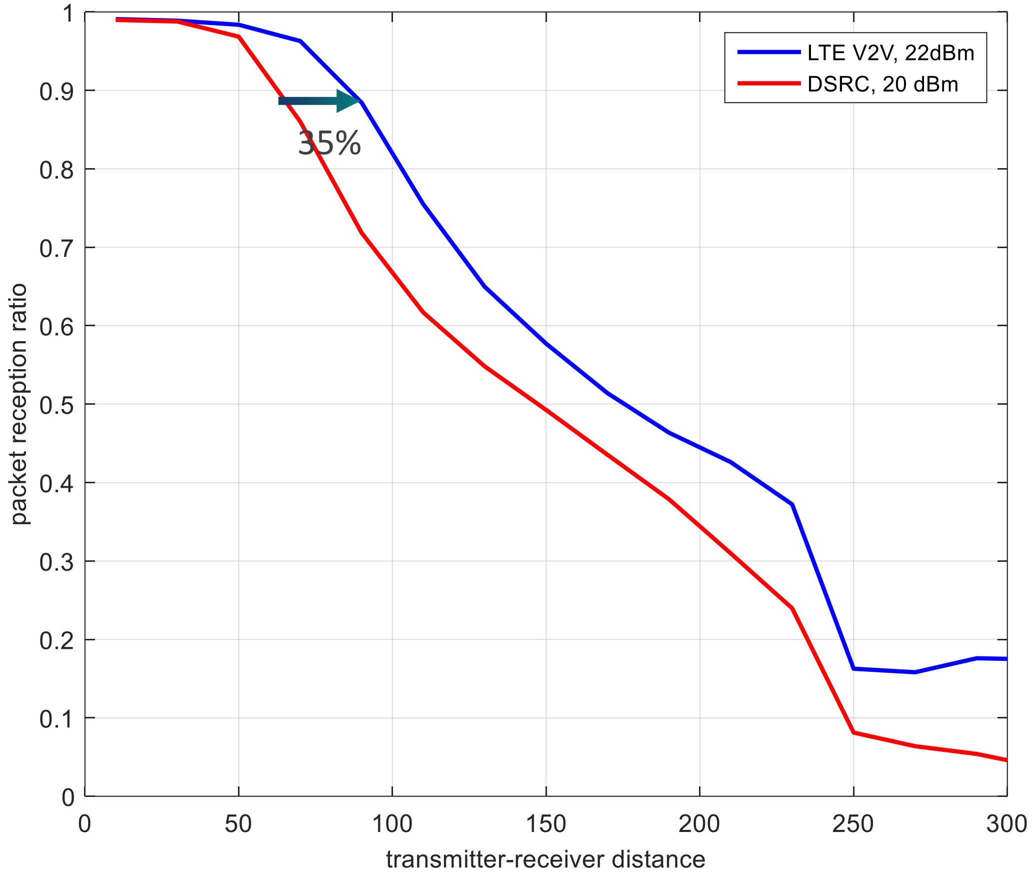
  590, 2360 cars
- Packet transmission periodicity:

  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

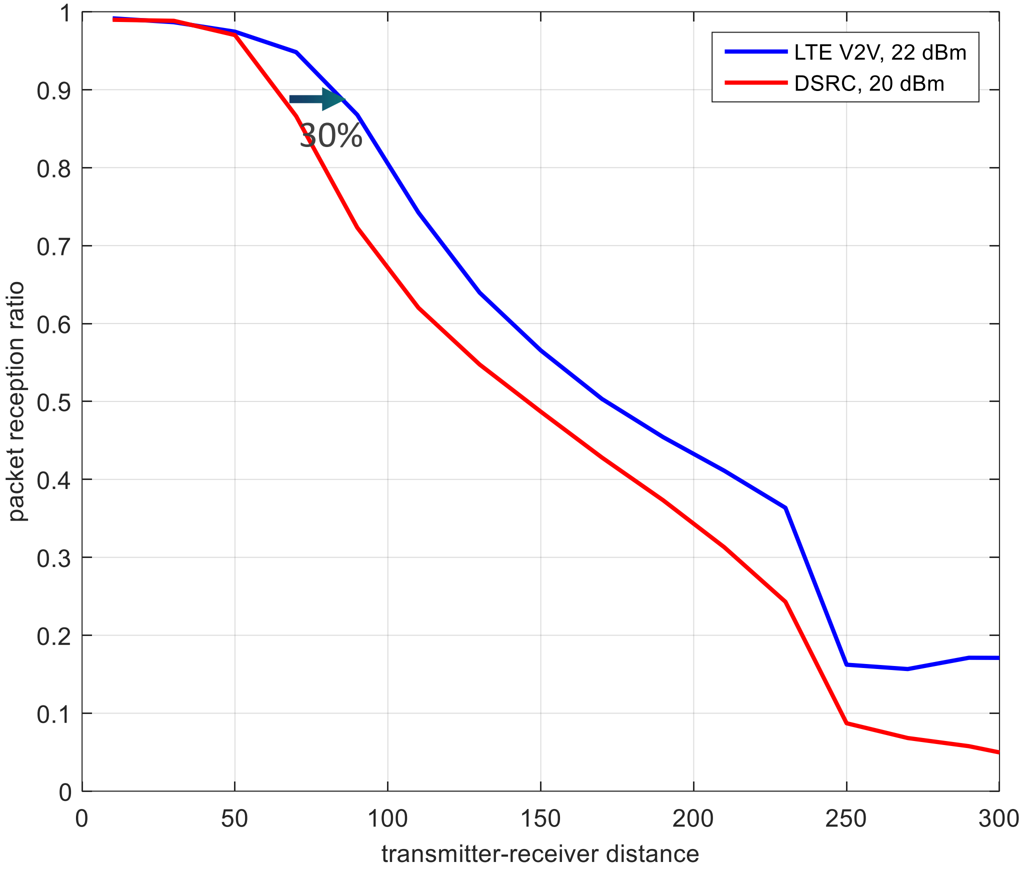
Enhanced range and reliability: Urban 60 km/hr, 15 km/hr

~ 30% gains at 0.9 PRR; Gains muted due to challenging pathloss model

Urban 60 km/hr, 590 cars

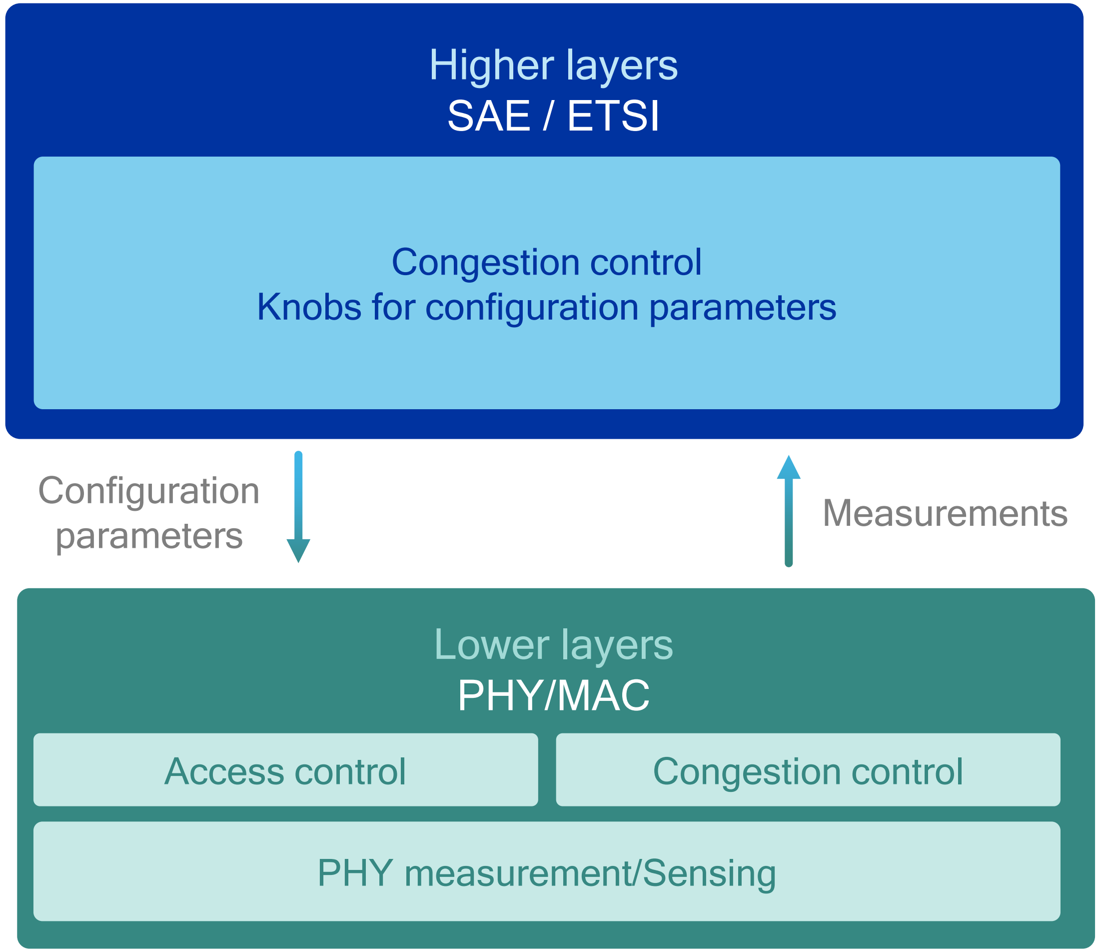


Urban 15 km/hr, 2360 cars



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

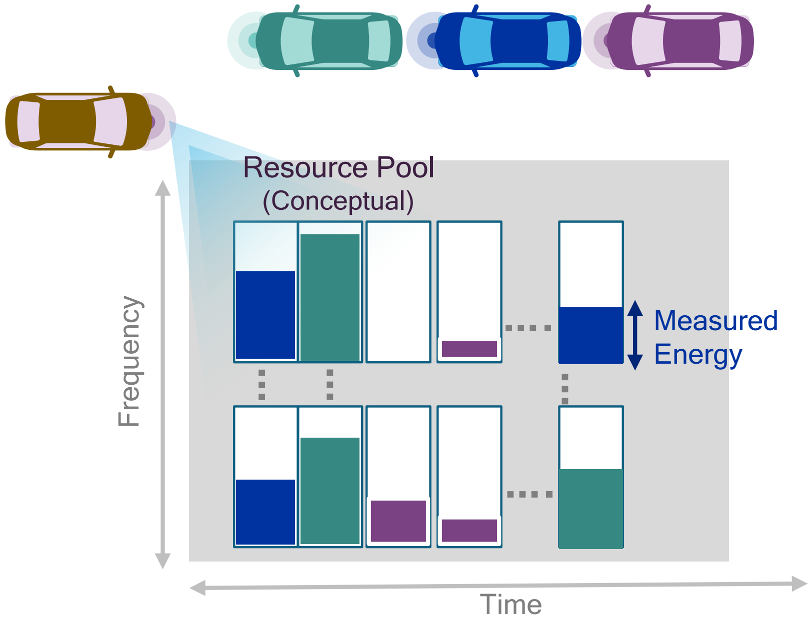
Enhanced performance with MAC/PHY congestion control

Deterministic access control and resource scheduling in PHY/MAC

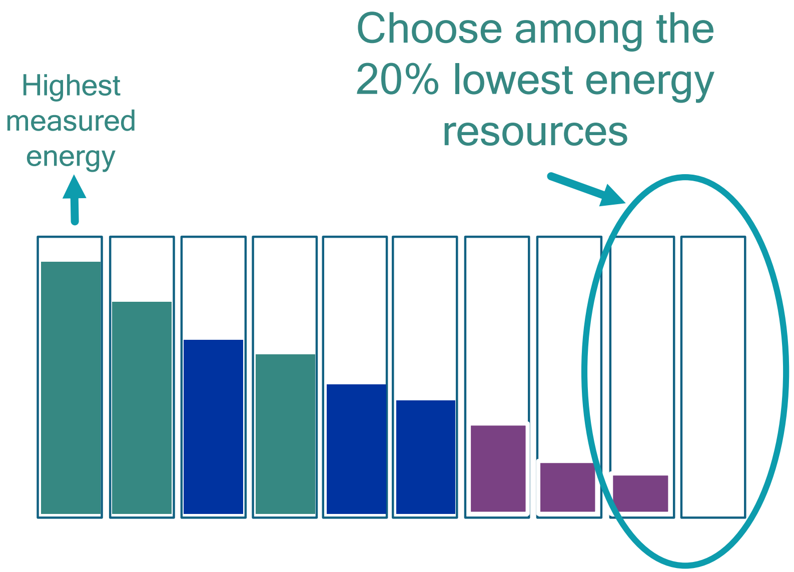
Deterministic access control and resource scheduling

Chooses blocks with lowest energy levels to meet latency requirements

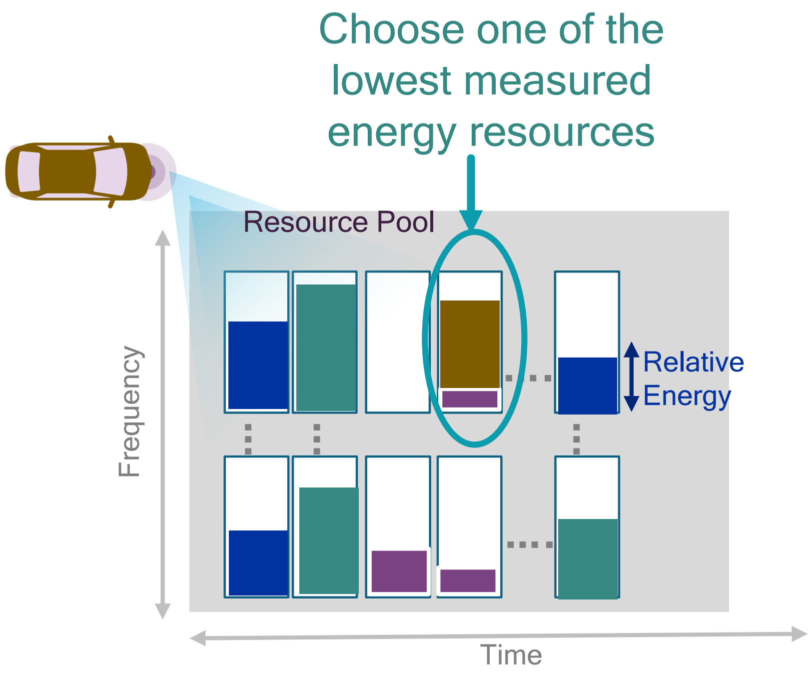
1 Measure relative energy of next “n” resources



2 Rank the resources according to the measured energy



3 Choose one of the lowest energy blocks for transmission



C-V2X access control advantages over 802.11p

System keeps on scaling

Optimized resource scheduling

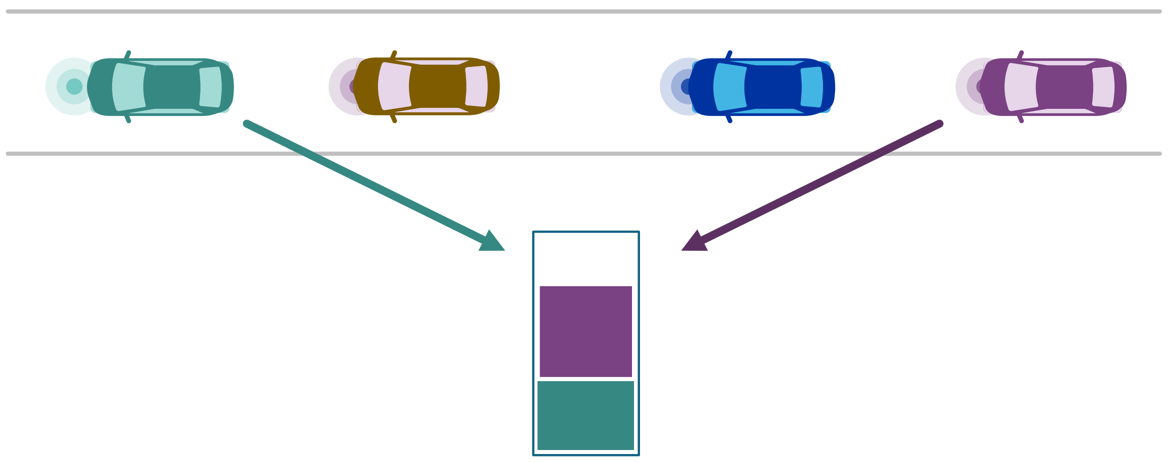
By choosing the lowest relative energy blocks

Does no get denied access

Two cars far apart from each other can use same resources

Designed to meet latency requirements

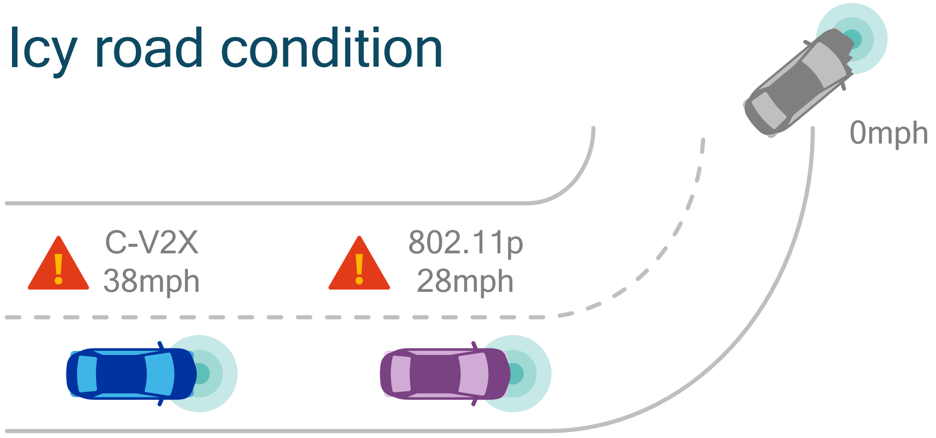
By scheduling and obtaining access to resources in timely manner



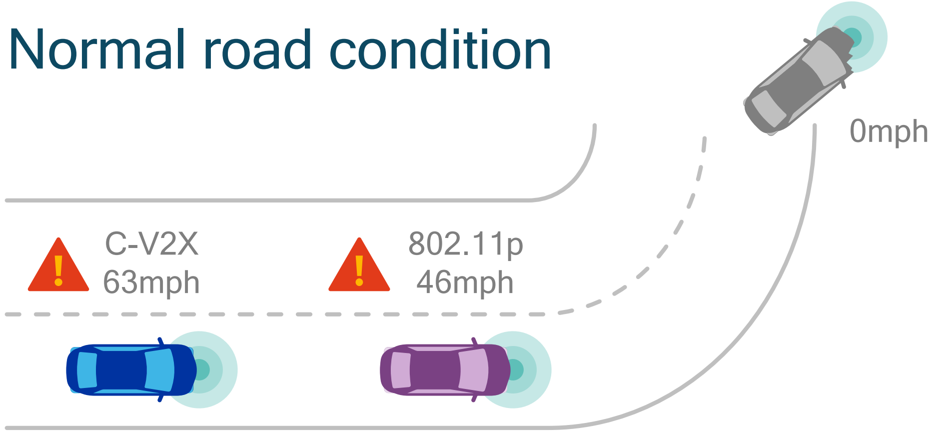
Improved reliability at higher vehicle speeds

Disabled vehicle after blind curve use case example

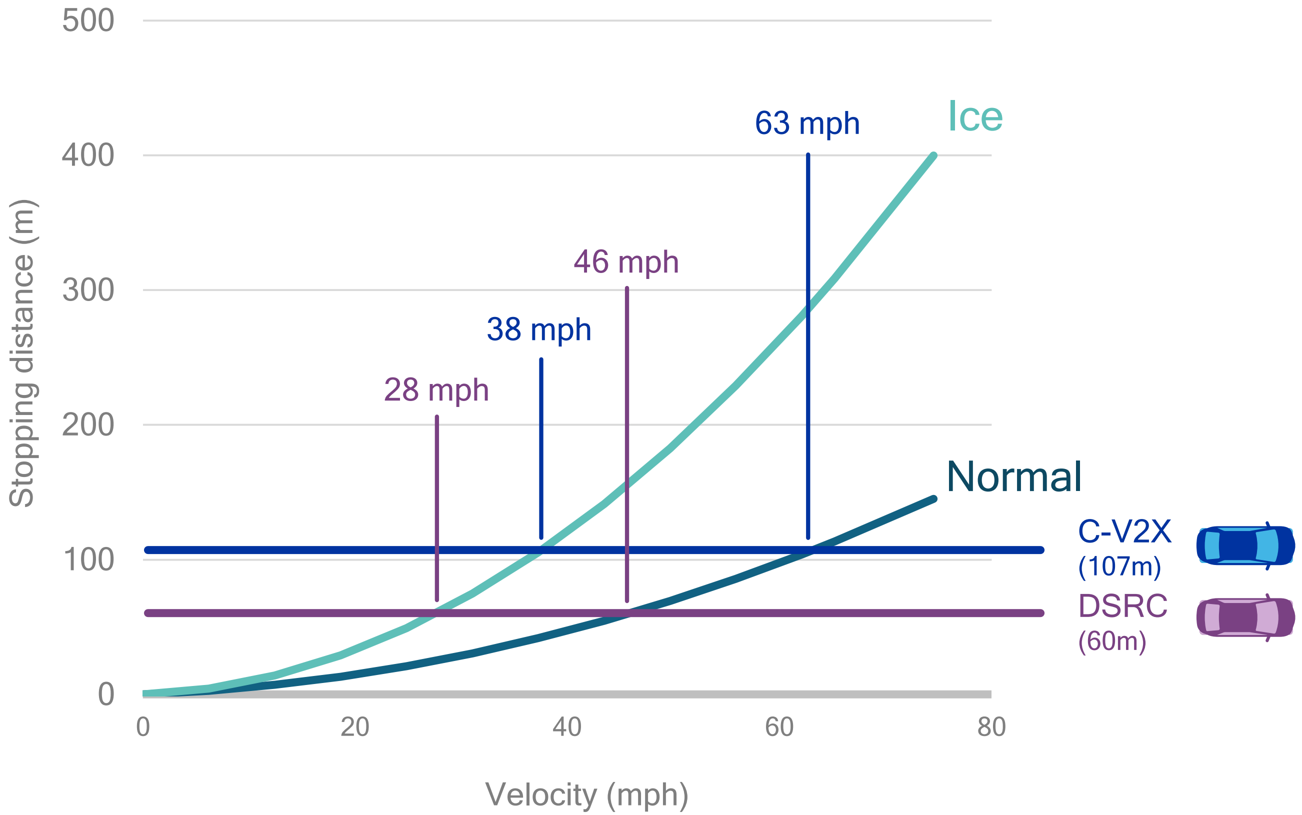
Icy road condition



Normal road condition



Stopping distance estimation[1] (Driver reaction time + braking distance)

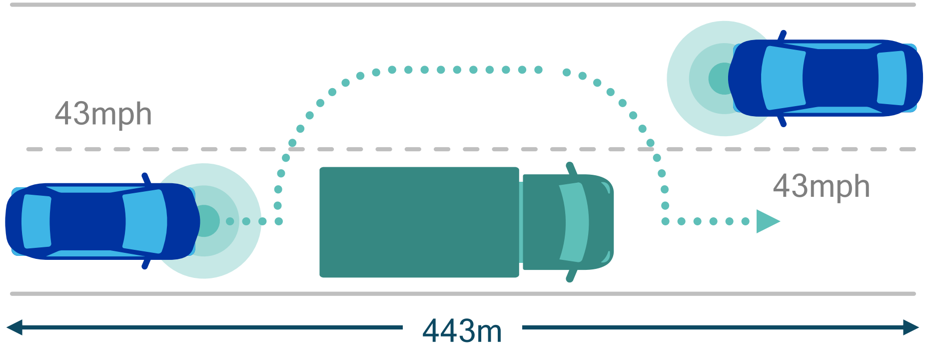


1. "Consistent with CAMP Deceleration Model and AASHTO "green book;

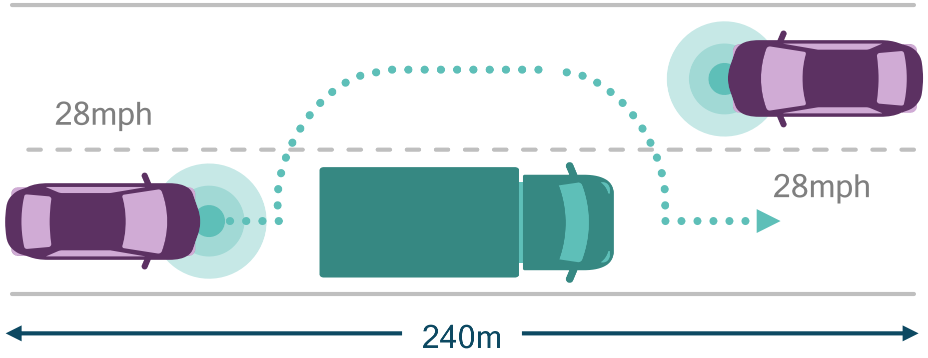
Improved reliability at higher speeds and longer ranges

Do not pass warning (DNPW) use case example

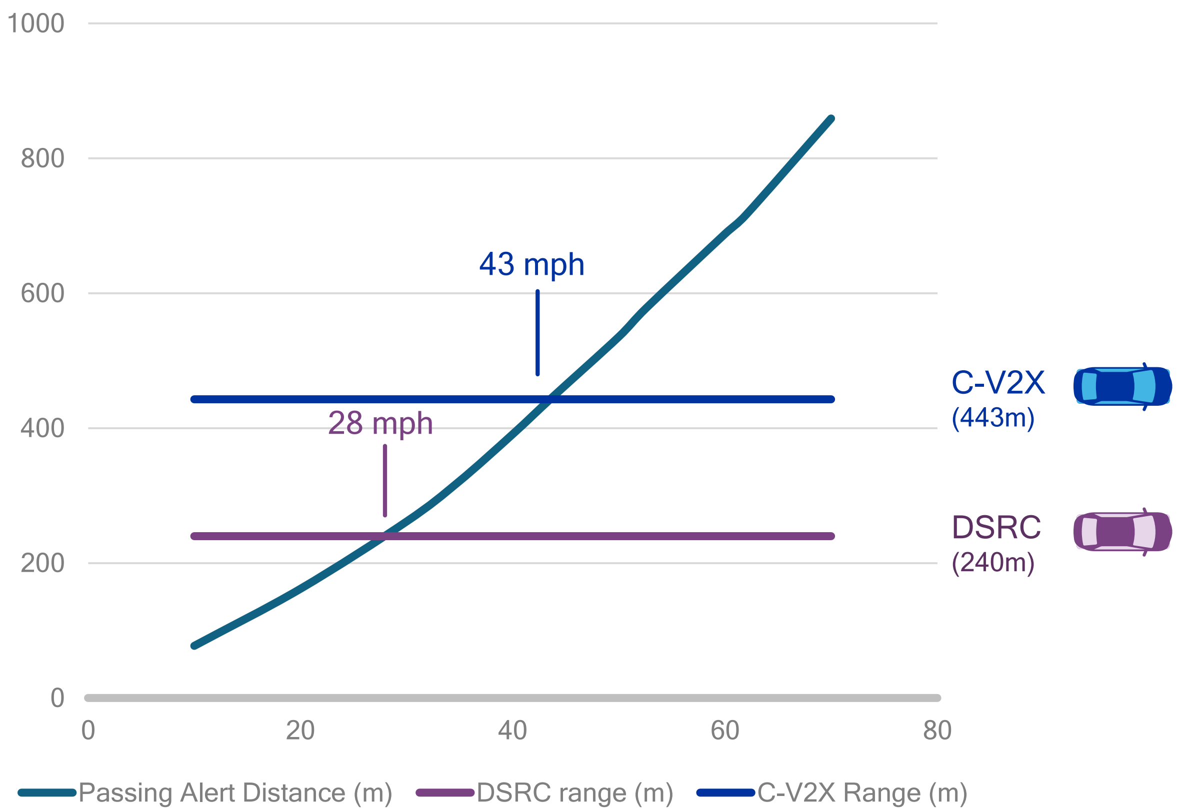
C-V2X



802.11p



Required passing alert distance (m) vs. speed (mph)[1]



1. Calculations based on AASHTO "green book"

Comparison: Technology operation

Technology operation	802.11p	C-V2X Rel-14/15	C-V2X Rel-16 (expected design)
Specification completed	Completed	Rel-14 completed in 2016. Rel-15 to be completed in 2018	2019
Support for low latency direct communications	✓	✓ (Rel-14 – 4ms)	✓ (≤ 1ms)
Support for network communications	Limited (via APs only)	✓	✓
Can operate without network assistance	✓	✓	✓
Can operate in ITS 5.9 GHz spectrum	✓	✓	✓
SIM-less operation	✓	✓	✓
Security and privacy on V2V/V2I/V2P	✓ (as per IEEE WAVE and ETSI-ITS security services)	✓ (as per IEEE WAVE and ETSI-ITS security services)	✓ (as per IEEE WAVE and ETSI-ITS security services)
Security/Privacy on V2N	N/A	✓	✓
Coexistence in 5.9GHz	✓ (Adjacent channel with 3GPP tech)	✓ (Adjacent channel with 11p; co-channel coexistence from R14 onwards)	✓ (Adjacent channel with 11p; co-channel coexistence from R14 onwards & WiFi)
Evolution path	✗	✓	✓ Compatible with Rel-14/15

Comparison: Radio design

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

Comparison: Use cases and performance

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

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

5GAA
Automotive Association

Automotive industry

Vehicle platform, hardware, and software solutions

Telecommunications

Connectivity and networking systems, devices, and technologies

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

Analog Devices AT&T Audi BAIC BMW Bosch CAICT CETECOM China Mobile Continental Daimler

Danlaw Denso Ericsson FEV Ficosa Ford Gemalto Hirschmann Car Communication Huawei Infineon

Intel Interdigital Jaguar KDDI Keysight Technologies KT Laird Land Rover LG MINI muRata Nokia

NTT DoCoMo P3 Panasonic Qualcomm Rohde & Schwarz ROHM Rolls-Royce SAIC Motor Samsung Savari

SK Telecom SoftBank T-Mobile Telefonica Telstra TÜV Rheinland Valeo Verizon VLAVI Vodafone ZF ZTE

Source: http://5gaa.org/; accurate as of August 31st, 2017

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

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

Standards

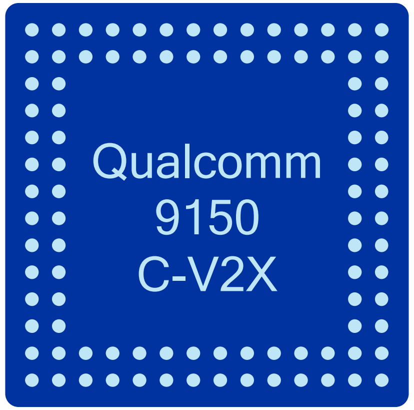
- Standards development organizations
- Telecom and auto industry organizations
- ITS organizations
- Road operator organizations

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

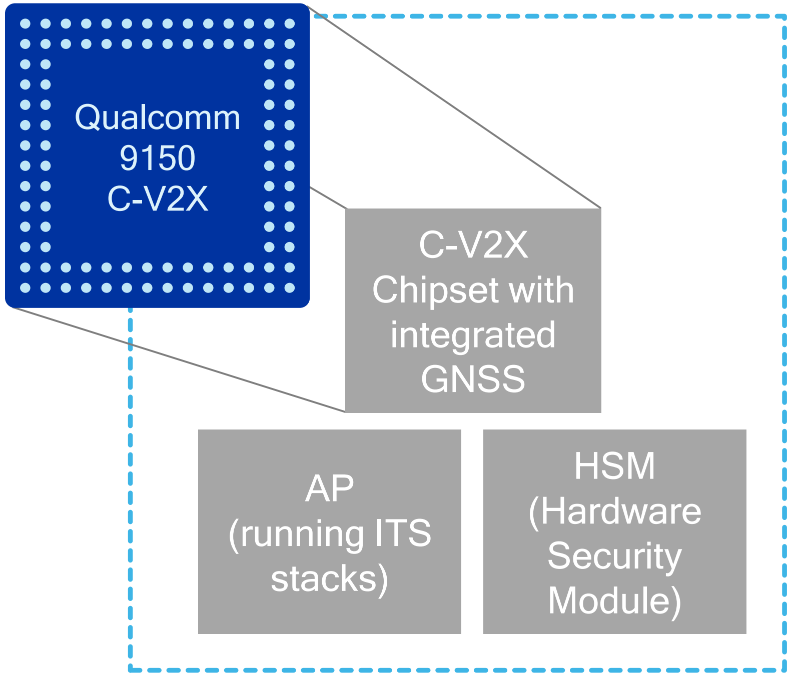
Qualcomm 9150 C-V2X Chipset is a product of Qualcomm Technologies, Inc.

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).

Qualcomm® C-V2X Reference Design



The Qualcomm 9150 C-V2X chipset will be featured as a part of the Qualcomm® C-V2X Reference Design

Qualcomm C-V2X Reference Design is a product of Qualcomm Technologies, Inc.

Supported by global car OEMs – Europe examples

““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

Supported by global car OEMs - US and China examples

“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.”

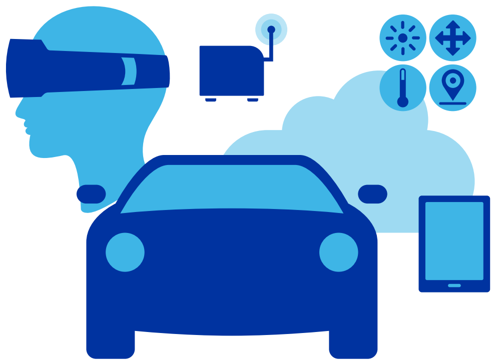
– SAIC

5G will bring new capabilities for autonomous vehicles

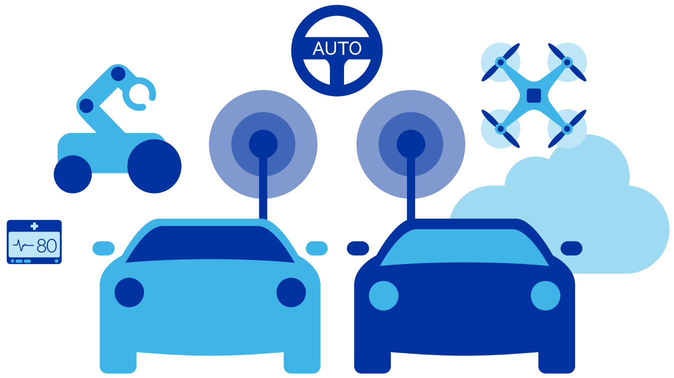
While maintaining backward compatibility

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

- Scalable OFDM numerology
- Wideband transmissions for positioning
- Advanced LDPC/polar channel coding
- Self-contained sub-frame
- Low-latency slot structure design
- Massive MIMO

5G NR

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

5G V2X brings new capabilities for the connected vehicle

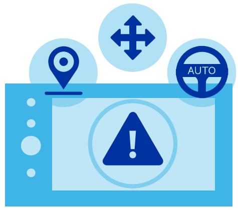
While maintaining backward compatibility

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

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

Autonomous vehicle

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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