The Connected Car: Will Autonomous Vehicles Finally Get Them on the Road?

Jim Lansford, Ph.D.
Director, Technical Standards
Qualcomm Technologies, Inc
CCNC Keynote
January 10, 2020

Qualcomm

CCNC

IEEE ComSoc IEEE Communications Society

IEEE

IEEE Consumer Communications & Networking Conference
9-12 January 2021 // Virtual Conference

Announcing: the 2021 connected car!

Engineers push state of the art…secure, high bandwidth, no interference!

Source: https://jalopnik.com/auto-engineers-in-the-70s-used-this-crazy-ass-contrapti-5798454

First some terms…

Every technology has its acronyms!

- AV: Automated Vehicles
- CAV: Connected and Automated Vehicles
- ADAS: Advanced Driver Assistance Systems – Sensors and control systems that sense, warn, and possibly control (brake, steer) a vehicle
- V2X: Vehicle to anything communication (vehicles, infrastructure, pedestrians, networks, etc.)
- DSRC: Dedicated Short Range Communication – A communications protocol/stack based on 802.11p radio access technology, with the ability to do V2X communication in the 5.9GHz band
- Cellular-V2X: A communications protocol/stack based on 3GPP Release-14 PC5 Sidelink radio access technology, with the ability to do V2X communication in the 5.9GHz band (aka LTE-V2X)
- 5G NR: 3GPP “New Radio” Release-16 (and beyond) – enhanced capabilities for AV
- SAE: Society of Automotive Engineers – develops specifications for automated driving levels (J3016), V2X message types (J2735), upper layer protocols/standards/test procedures for DSRC and C-V2X (J2945 & J3161 families)

The big picture….

V2X – whether for ADAS or AV – is addressing big issues in transportation

- Safety
  - Traffic deaths – 34,247 in the US in 2017 (NHTSA)
    - https://cdan.nhtsa.gov/tsftables/National%20Statistics.pdf
    - Large percentage is due to human error
  - Injuries – 1,889000 in the US in 2017 (NHTSA)
  - Property damage – 4,530,000 crashes
- In addition:
  - 3.1B gallons of fuel wasted due to traffic congestion
  - 14% of all global warming emissions from transportation
  - Countless hours of time wasted
- Modern safety assistance and Automated Vehicles are expected to reduce fatalities and injury
  - Sensors will be in (almost) all vehicles
  - Increasing numbers of vehicles will be connected, either direct V2V or through WAN (V2N or V2N2V)

Connected Vehicles: The Road Ahead

Precise positioning
Lane-level accuracy anywhere, anytime

Bluetooth
For high quality voice and audio

Wi-Fi6
For in-car experiences and car OEM services

4G/5G
For car OEM services

4G/5G
For driver and passengers

C-V2X
For car to infrastructure communication

C-V2X
For car to car communication

Car connectivity in the 5G era

Heterogeneous connectivity

Secure, virtualized wireless links

Advanced positioning

Multi-environment implementation

V2X History

FCC allocated 70MHz for DSRC in 1999 (5850-5925MHz)

Originally Based on 802.11a (and 802.11j)

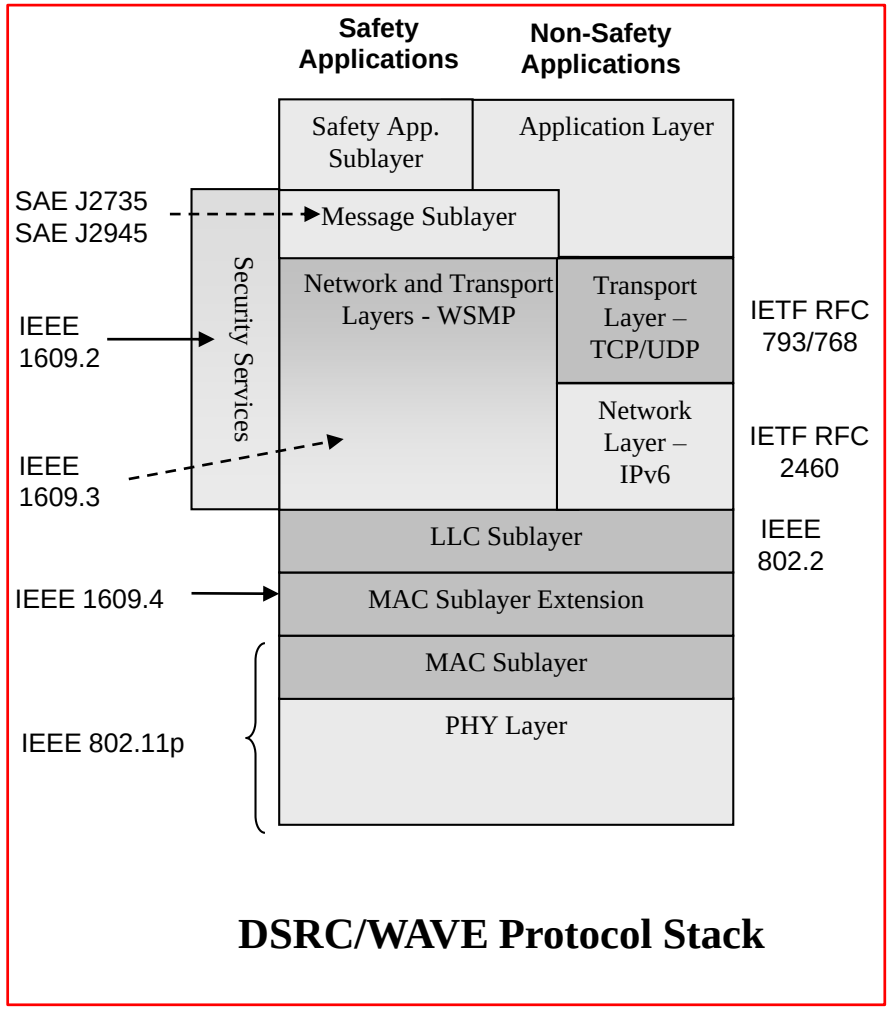
- Uses 10 MHz channel option defined similar to 802.11j (½ clocked from 20 MHz)
- Tighter spectral mask
- Slightly different MAC (OCB plus 1609.x enhancements)
- Differences in layers above PHY and MAC as well

Special FCC channel designations:

- Ch. 172 is for vehicle collision avoidance communication
  - Basic Safety Message (BSM) sent using 3Mbps preamble (R=1/2, BPSK), 6Mbps payload (R=1/2, QPSK)
- Ch.178 is the control channel
- Ch. 184 is for long distance public safety communication

Europe: Similar band/channelization

Japan: Uses 11p PHY in 760 MHz, but higher layers quite different.



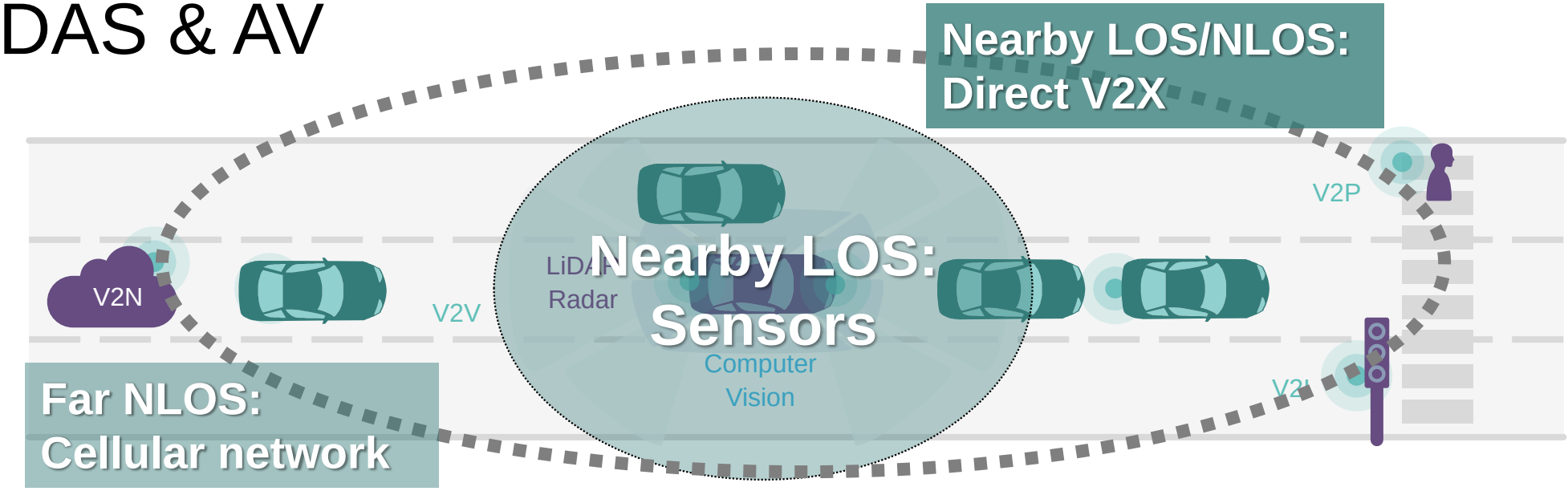
Changes in Automotive and Communication Technology

Rapid evolution in sensor and cellular technology have changed the connected vehicle landscape

- In the 20 years since the ITS spectrum was allocated, vehicles have significantly increased ADAS capabilities
  - Sensors – radar, cameras, ultrasound/sonar, lidar
  - Processing – artificial intelligence
- 802.11p (based on 802.11a) is a relatively old communication technology
  - Cellular technology has advanced dramatically over the last 20 years
  - Robustness and reliability have significantly improved – especially NLOS
  - 3GPP added the capability for device to device…allows vehicles to communicate without infrastructure: Cellular-V2X
- The FCC changed the spectrum allocation in December 2020 to reflect these changes – and made C-V2X the de facto standard

Sensors + AI + advanced wireless technology = improved safety

V2X is a key technology enabler for enhanced ADAS & AV

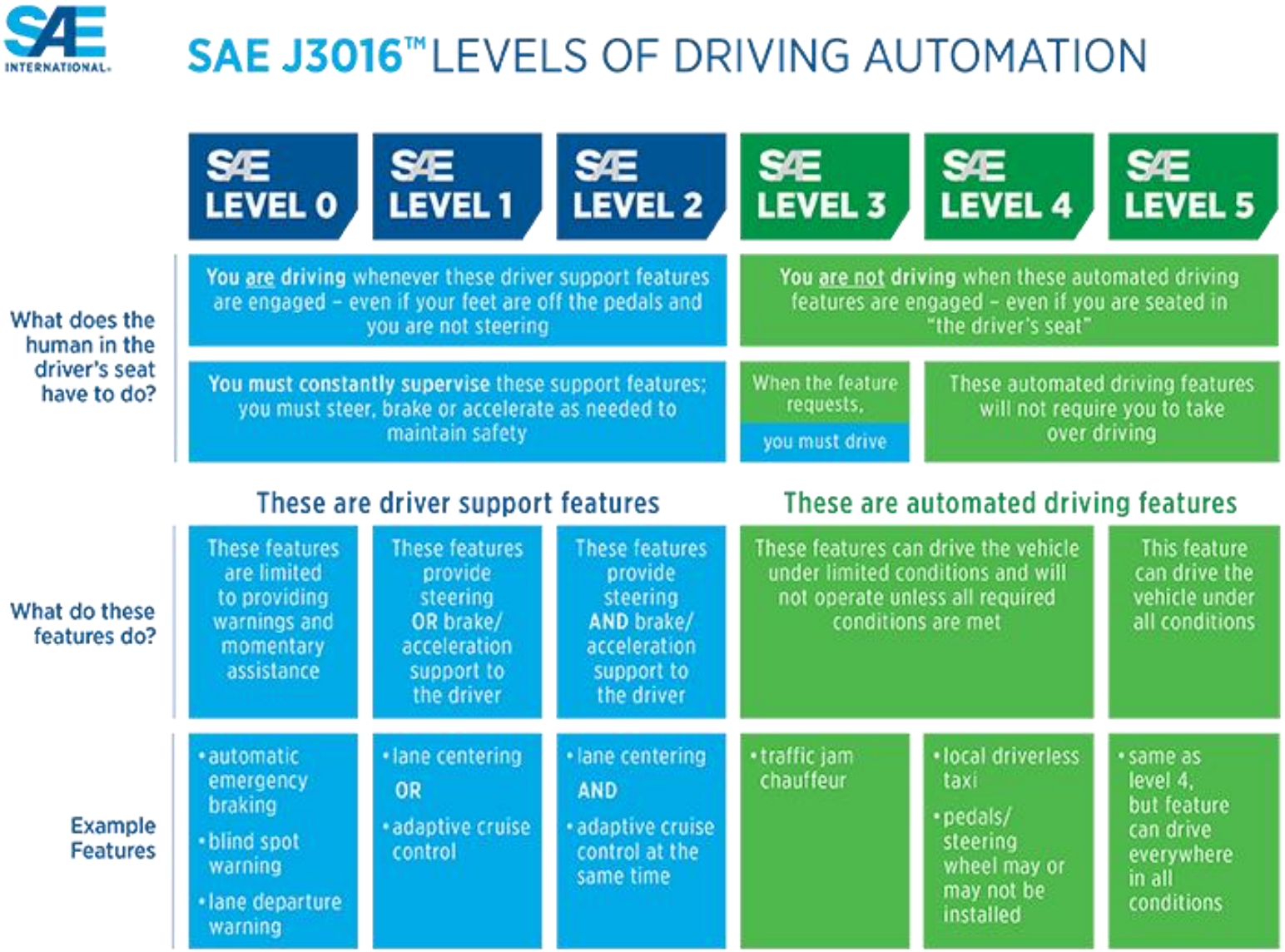


- Sensors: Camera, Radar. Lidar, ultrasonic, etc. – typically Line of Sight (LOS)
- Direct V2X: DSRC/C-V2X – augments sensors with additional information, especially Non-Line of Sight (NLOS)
  - BSM – time critical situational awareness of vehicles around you
  - I2V/V2I – SPaT, MAP, TIM, etc
- WAN (V2N and V2N2V)
  - Now – Non-time critical, wider area information about traffic, weather, etc.
  - 5G - URLLC…relay information between vehicles in a few milliseconds
- Processing
  - AI/compute power fuses information together for ADAS and/or AV

SAE Automated Driving Levels

Connected and Automated Vehicles:

Automated vehicles are usually assumed to be connected, but a connected vehicle may not be automated



V2X Use Cases

Qualcomm

Connected urban transport

PC5-based C-V2X

E.g. for collision avoidance and coordinated driving

Precise positioning

E.g. for lane management and lane-level navigation

Edge/on-device AI

E.g. for detecting hazards and speed harmonization

Connected highways

4G/5G networks

E.g. for TMC-based traffic monitoring & advisory

PC5-based C-V2X

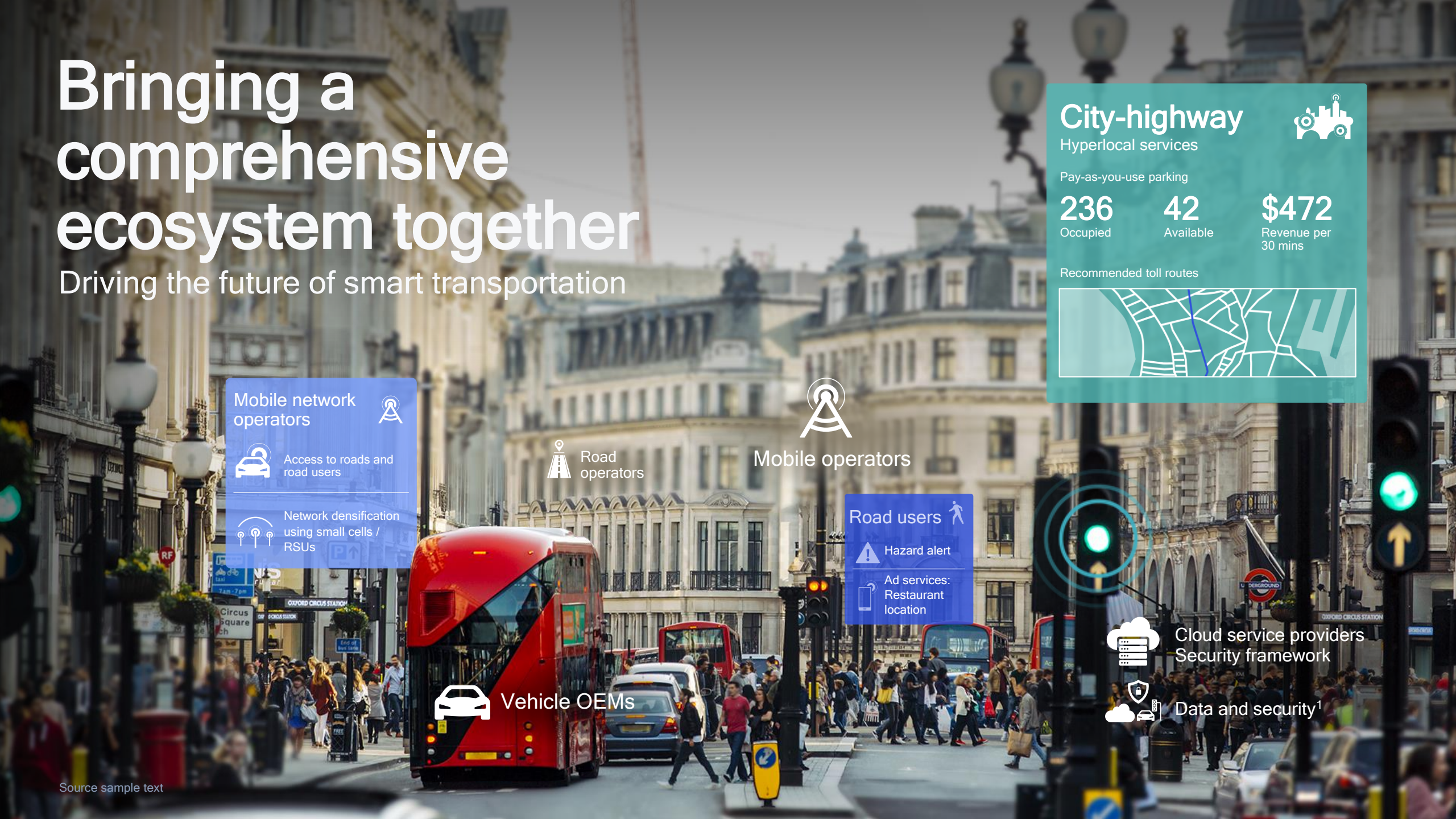
E.g. for collision avoidance and coordinated driving

Precise positioning

E.g. for lane management and lane-level navigation

Bringing a comprehensive ecosystem together

Driving the future of smart transportation



City-highway

Hyperlocal services

Pay-as-you-use parking

236	42	$472
Occupied	Available	Revenue per 30 mins

Recommended toll routes

Mobile network operators

Access to roads and road users

Network densification using small cells / RSUs

Road operators

Mobile operators

Road users

Hazard alert

Ad services: Restaurant location

Vehicle OEMs

Cloud service providers
Security framework

Data and security[1]

Source sample text

Facilitating multi-tiered services

Pedestrian detection

AR-based navigation

Virtual assistant

Traffic information

Freemium

Feature management

Vehicle features

- Your music stations added
- Day running lights on
- City speed limit set

Premium

On demand unlocking and locking

Context-based personalized information

Premium

Road safety comes free

Pedestrian 10ft ahead

Cellular-V2X:
What it is and how it works

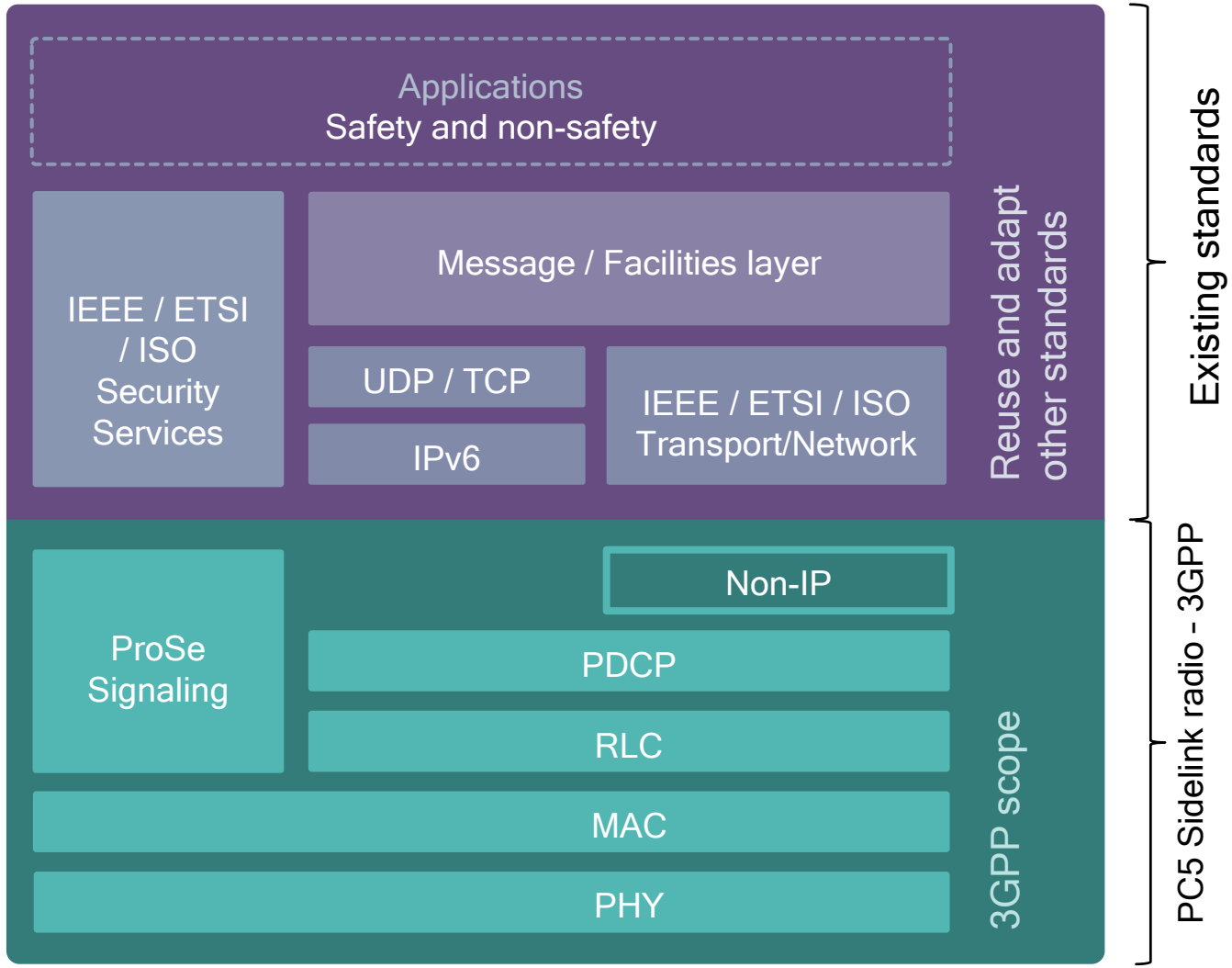
Qualcomm

What is Cellular-V2X?

Summary: It's a more modern radio doing direct V2X using the existing DSRC stacks

- C-V2X is based on 3GPP release 14 PC5 "Sidelink" (direct device to device)
  - It doesn't need a SIM, carrier access, or licensed spectrum
  - Doesn't require infrastructure – but can communicate V2V or V2I
  - PC5 Modem can be integrated into telematics for cost savings
  - Radio access based on scheduled, deterministic reservations – no CSMA/CA
  - PHY picks best (lowest energy) resources available for the reservation
  - Superior performance compared to 11p, especially in NLOS
    - Longer range/more robust at the same range
    - Fewer RSU's needed for coverage
- Layers above the PHY/MAC are almost identical to DSRC
  - Uses IEEE 1609.2 security
  - Uses SAE J2735 message set
  - Uses modified version of SAE J2945/1 (J3161) – only changes in radio layer and congestion control

C-V2X reuses upper layers defined by ITS industry



Reuse 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)

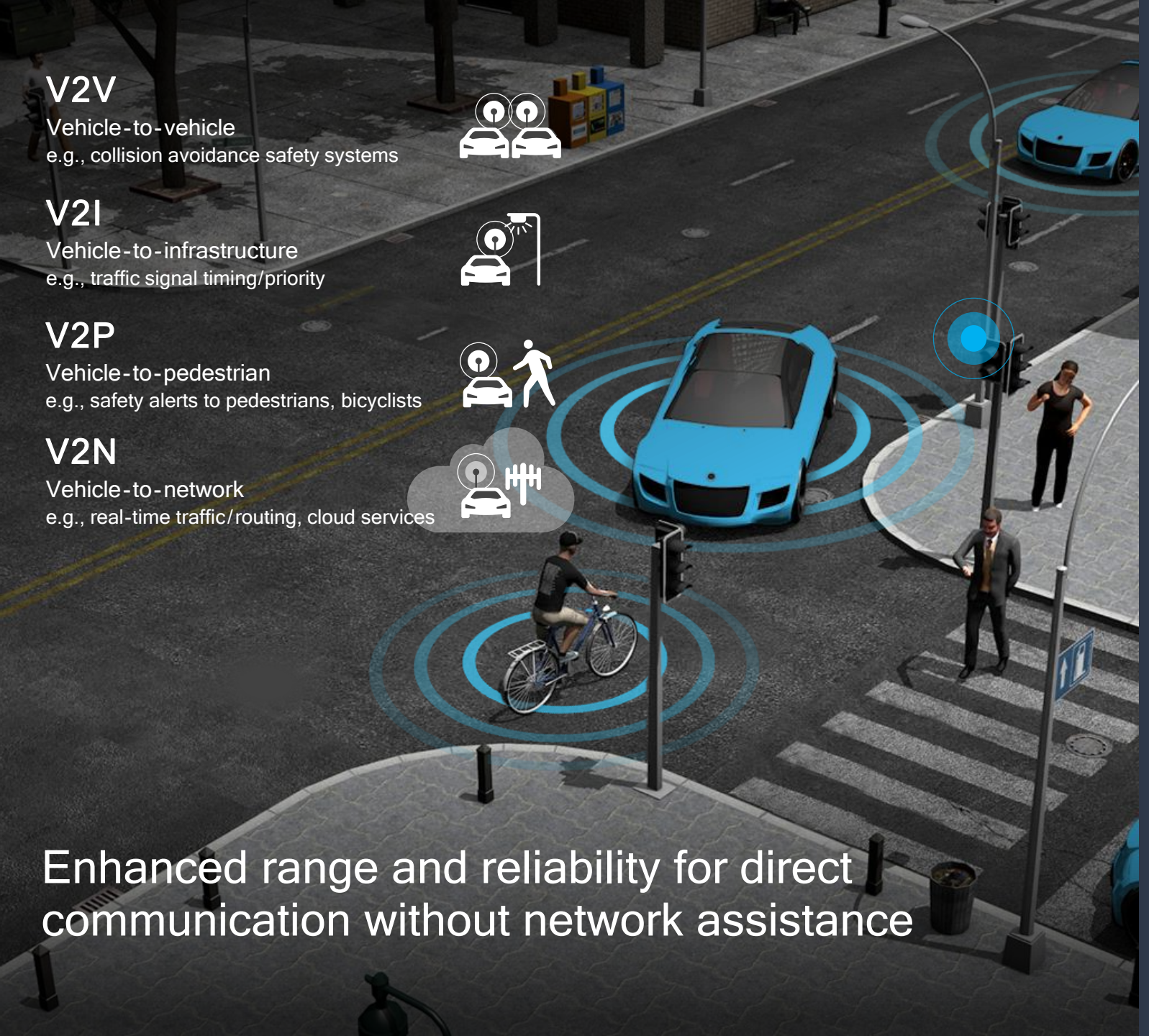
Reuse existing security and transport layers

- 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

Establishes the foundation for safety use cases and a continued 5G NR C-V2X evolution for future autonomous vehicles

- Release 14 C-V2X completed in 2017
- Broad industry support – 5GAA
- Global trials started in 2017
- Our 1st announced C-V2X product in September, 2017

C-V2X defines two complementary transmission modes

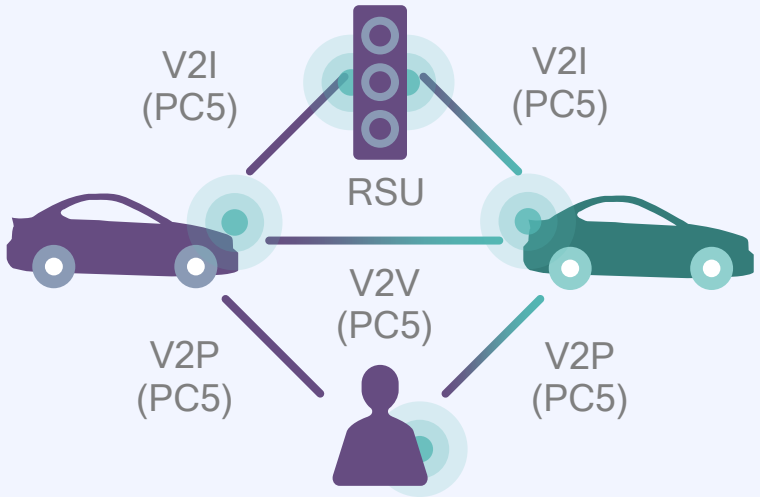
Direct communications

V2V, V2I, and V2P on “PC5” Interface, operating in ITS bands (e.g. ITS 5.9 GHz) **independent of cellular network**

Similar to DSRC

PC5 interface

e.g. location, speed

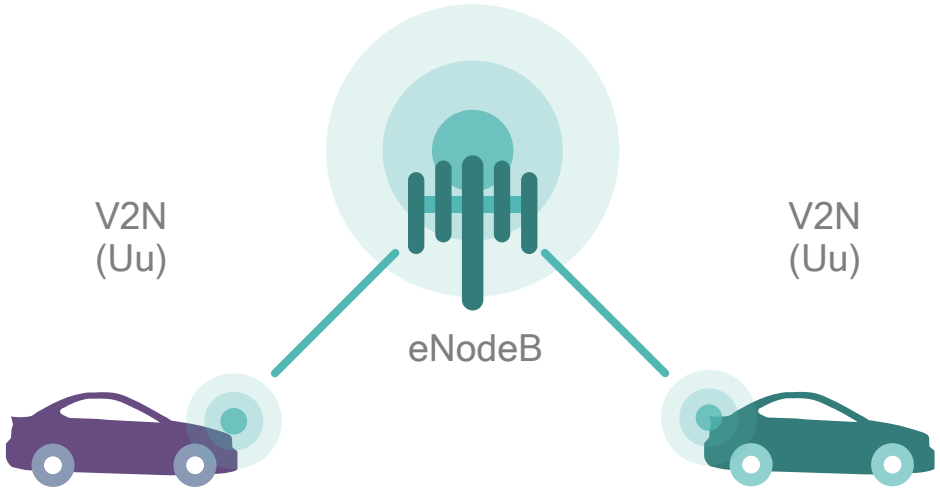


Network communications

V2N on “Uu” interface operates in traditional mobile broadband licensed spectrum

Uu interface

e.g. accident 2 kilometer ahead



C-V2X is designed to work without network assistance[1]

V2V/V2I/V2P direct communications enables low latency applications

USIM-less operation

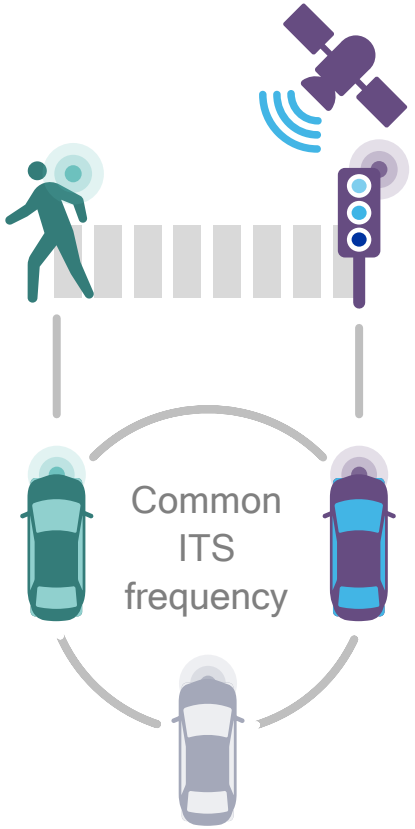
C-V2X direct communications doesn't require USIM

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

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

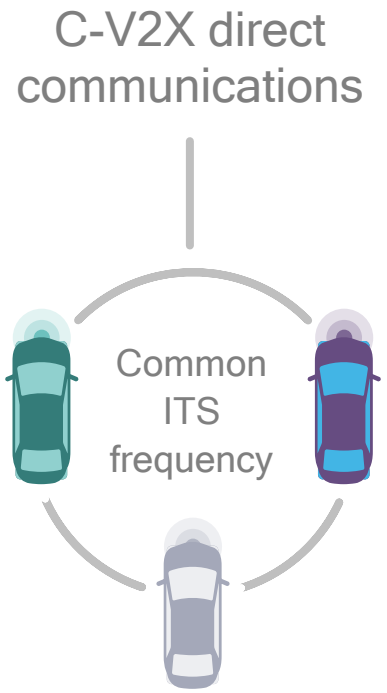
C-V2X support in ITS band was added in 3GPP Release 14[1]

Harmonized spectrum for safety

C-V2X uses harmonized/common, dedicated spectrum for vehicles to talk to each other

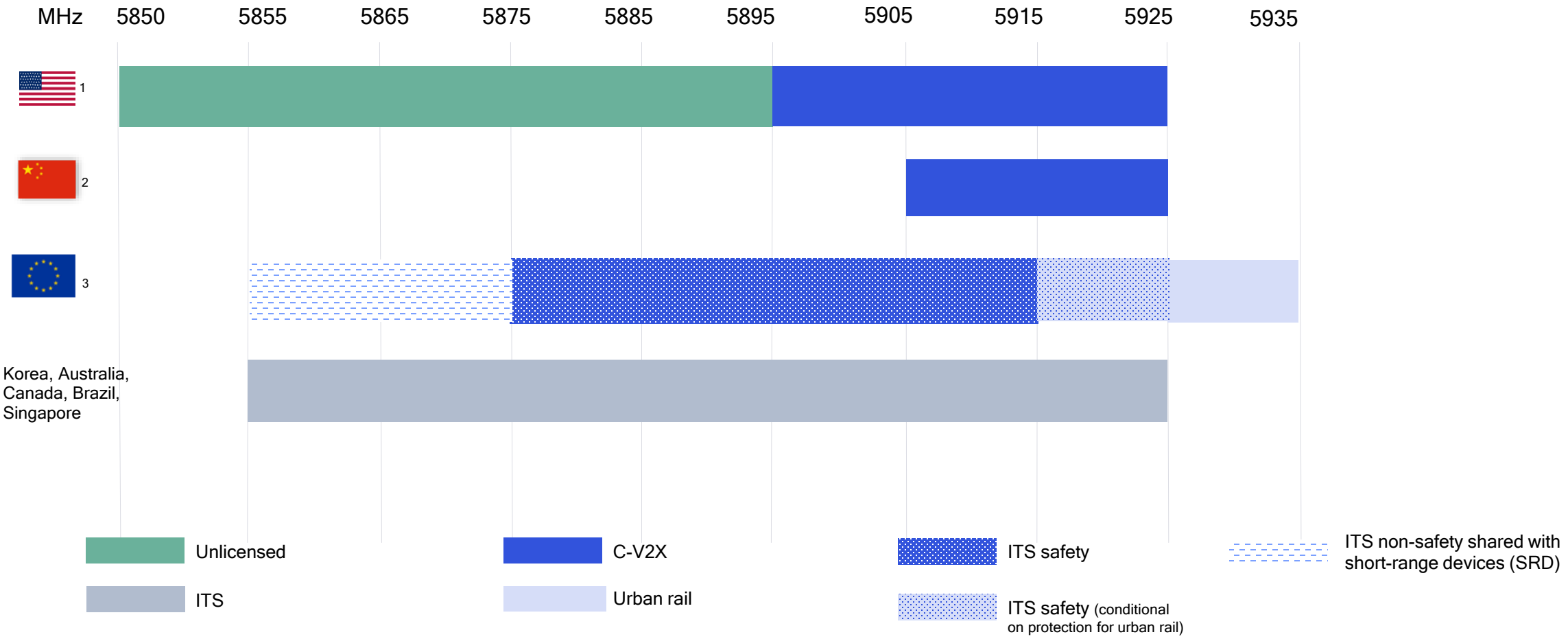
Coexistence with 802.11p (EU)

C-V2X and 802.11p can co-exist by being placed on different channels in the ITS band (in Europe)



1 5GHz support began in release 13 with LAA, and expanded with release 14 for ITS

Global snapshot of allocated/targeted ITS spectrum



1 FCC assigned upper 30 MHz of ITS band (5.895-5.925 GHz, B47). 2 MIIT officially regulated the upper 20 MHz (5.905-5.925 GHz). 3 ITS spectrum allocation in Europe is still pending. The EU has adopted technology neutrality in spectrum allocation.

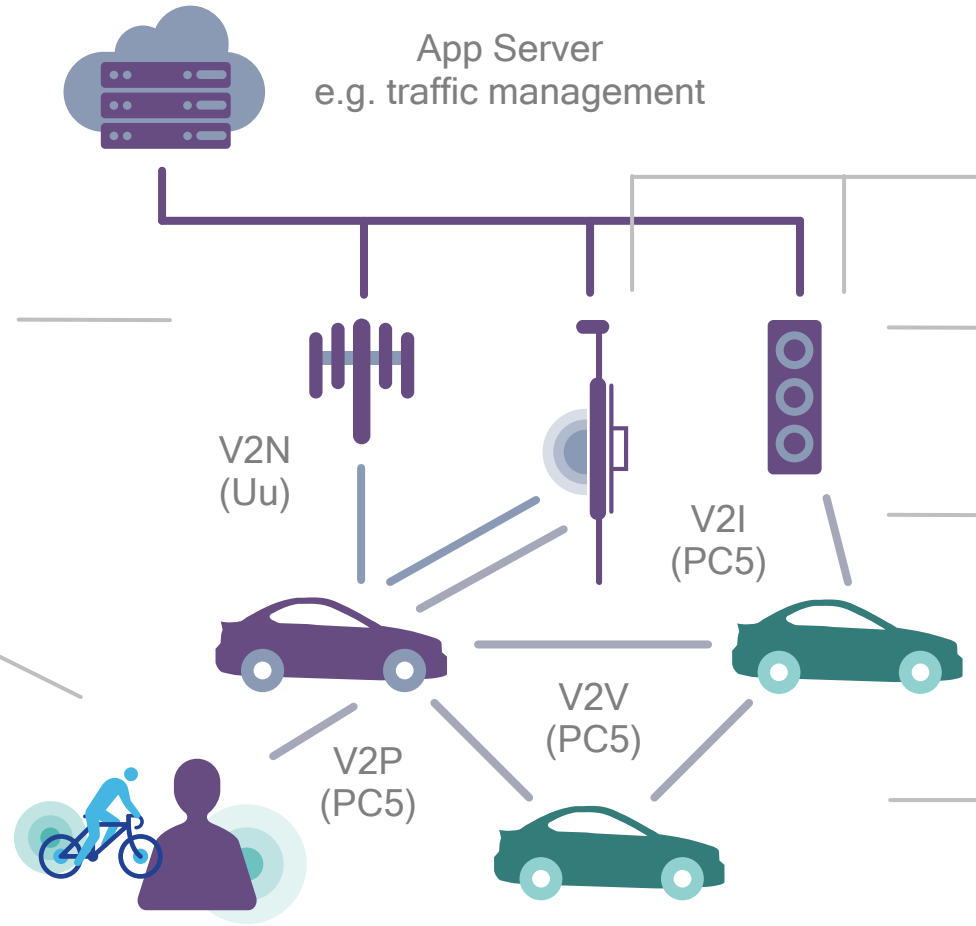
Advanced services further enabled by V2V+V2I+V2P+V2N

Offering new business models and enhancing most use cases

Most use cases use a combination of interfaces

V2N provides over-the-top cloud services

V2P enhances safety for vulnerable road-users



RSUs combined with eNodeBs or standalone roadside devices

RSUs can connect to network for cloud services

V2I allows RSU[1]s to monitor traffic, e.g. traffic signals, tolls

V2V mostly for safety and ADAS services

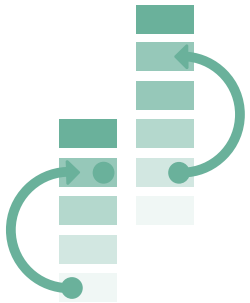
Uu Interface

PC5 Interface

1 Road Side Units

System is designed for high density vehicle deployments

Guaranteeing low latency access for safety critical messages even at high density

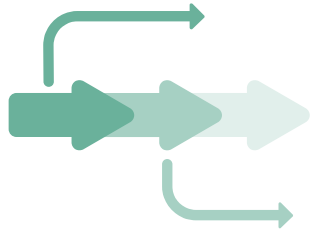


Deterministic resource scheduling

Choose resources with the lowest received energy leading to optimal resource selection

Guaranteed latency performance

New methods using sensing and semi-persistent resource selection that choose resource blocks with lowest energy levels to meet latency requirements



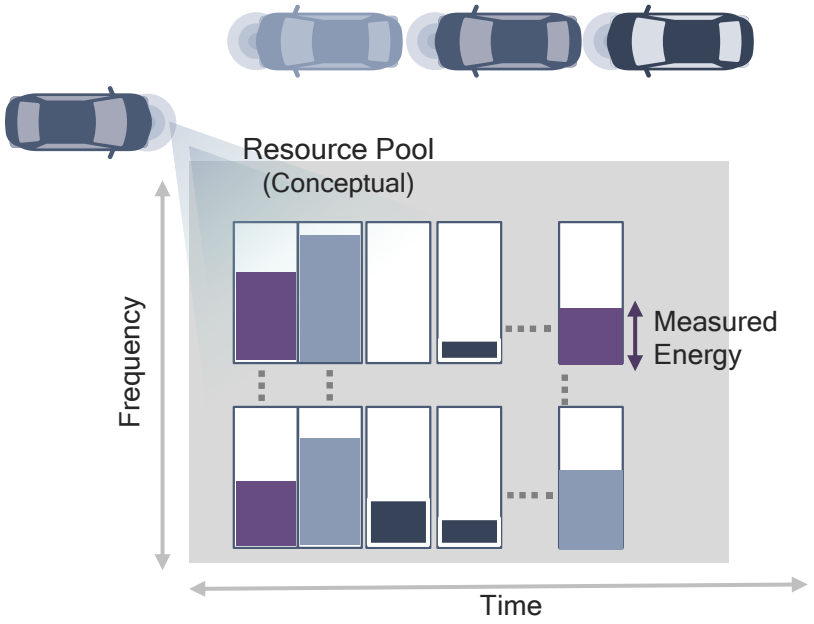
Enhanced congestion control

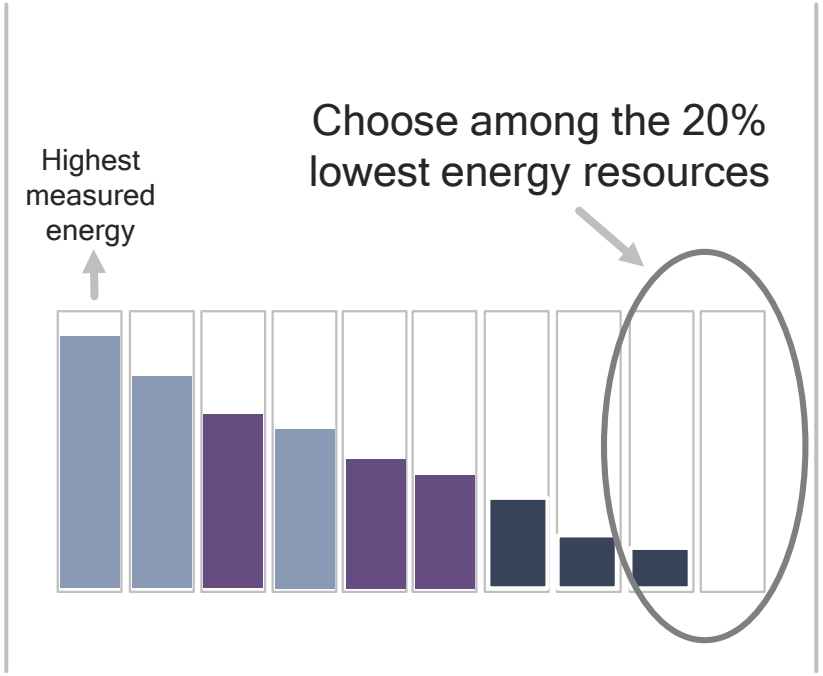
Enhanced performance with MAC/PHY congestion control with more flexible tools along with leveraging higher layers to tune congestion control parameters

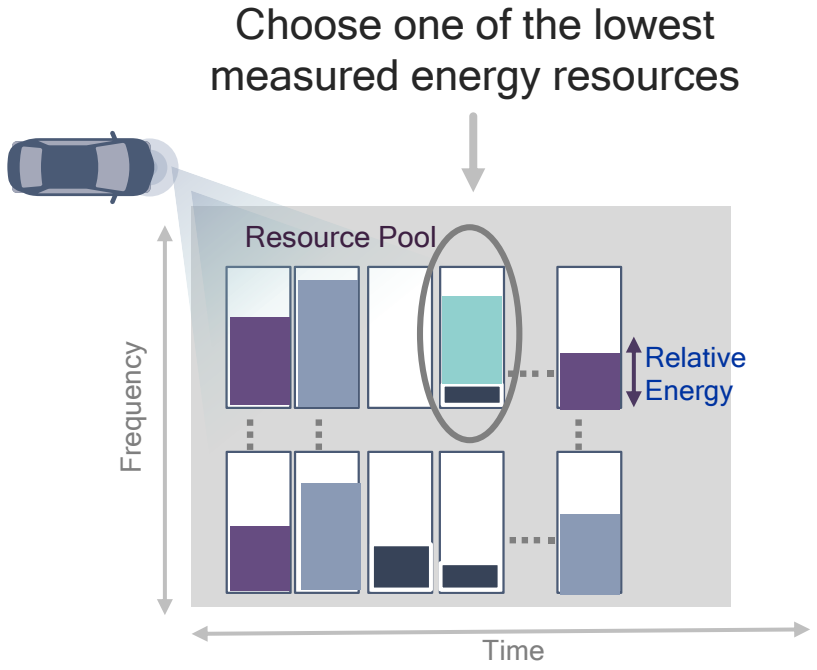
Deterministic access control and resource scheduling

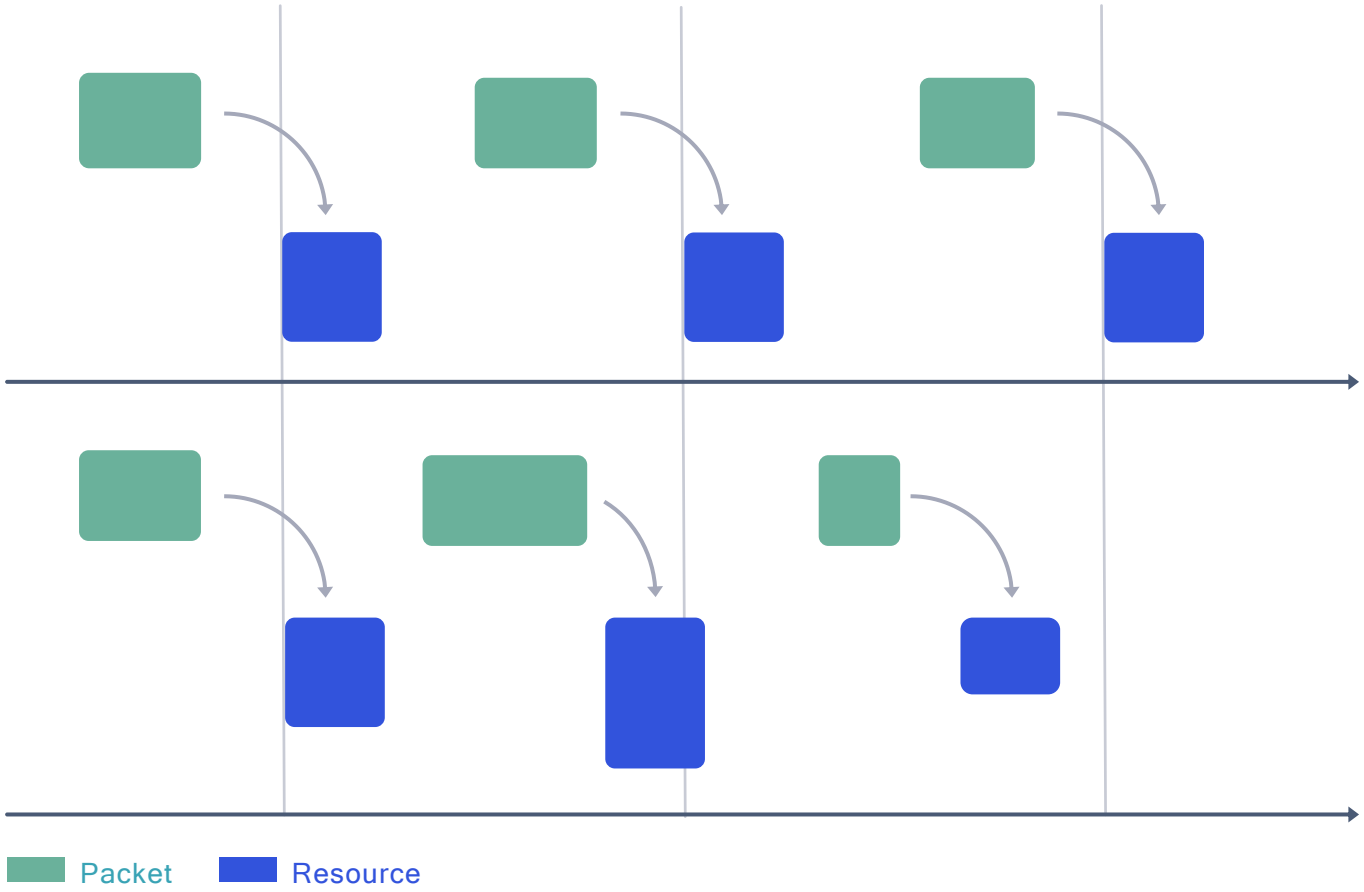
Chooses blocks with lowest energy levels, while meeting latency requirements

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









Semi-persistent scheduling

Suitable for basic safety messages with similar packet sizes

Periodic transmission (typically ~100 msec)

Per packet scheduling

Variable traffic model based on the varying packet sizes

Lower latency (< 100 msec)

Efficient and flexible resource allocation for advanced applications with variable traffic

Working with regional standards to define applications globally

SAE for North America, ETSI ITS for Europe, and C-SAE/C-ITS for China

Supporting emerging use cases

Standardizing messages for new use cases (e.g., sensor data sharing among vehicles)

Providing interoperability

Allowing vehicles from different automakers to benefit from new use cases

Specifying minimum requirements

Defining application layer-specific minimum requirements for new messages

Evolution

Qualcomm


A world where virtually everyone and everything is intelligently connected
5G
Multi-gigabit speed
Scalable to extreme simplicity
Ultra-low latency
Virtually unlimited capacity
Extreme reliability
On-device intelligence

5G V2X builds on C-V2X

with advanced use cases

Safety use cases

Advanced use cases

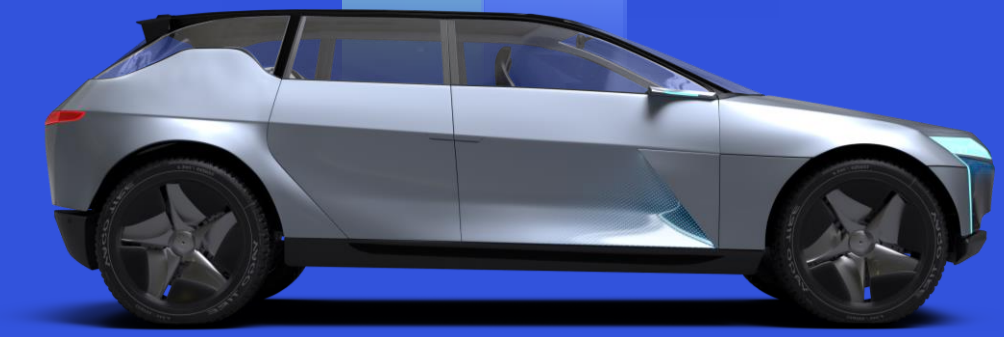
Upper layers

Mapping use cases to transport profile

C-V2X

Rel 14/15 sidelink

Broadcast messages



5G V2X

Rel 16+ sidelink

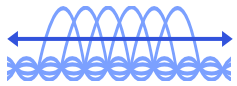
Multicast messages

5G V2X sidelink

Building on existing frameworks

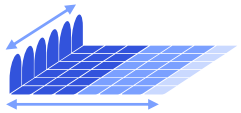
Utilizes NR flexible framework

Scalable OFDM-based air interface



Such as wideband carrier support (>20 MHz) and different sub-carrier spacing

Flexible slot-based framework



Such as adding sidelink and dynamic reference signal for various speed

Advanced channel coding

State of the art LDPC / polar coding to deliver performance

Leverages LTE C-V2X concepts

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

5G C-V2X

Introduces advanced capabilities

- 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

And increased performance

- Lower latency
- Higher spectral efficiency
- Higher capacity

NR C-V2X delivers a design that addresses advanced use cases

Significant physical layer gains

NR C-V2X enhancements

Spectral efficiency: up to 2x for broadcast

Scalable OFDM and flexible DMRS provide higher spectral efficiency, which reduces bandwidth usage and allow for more capacity

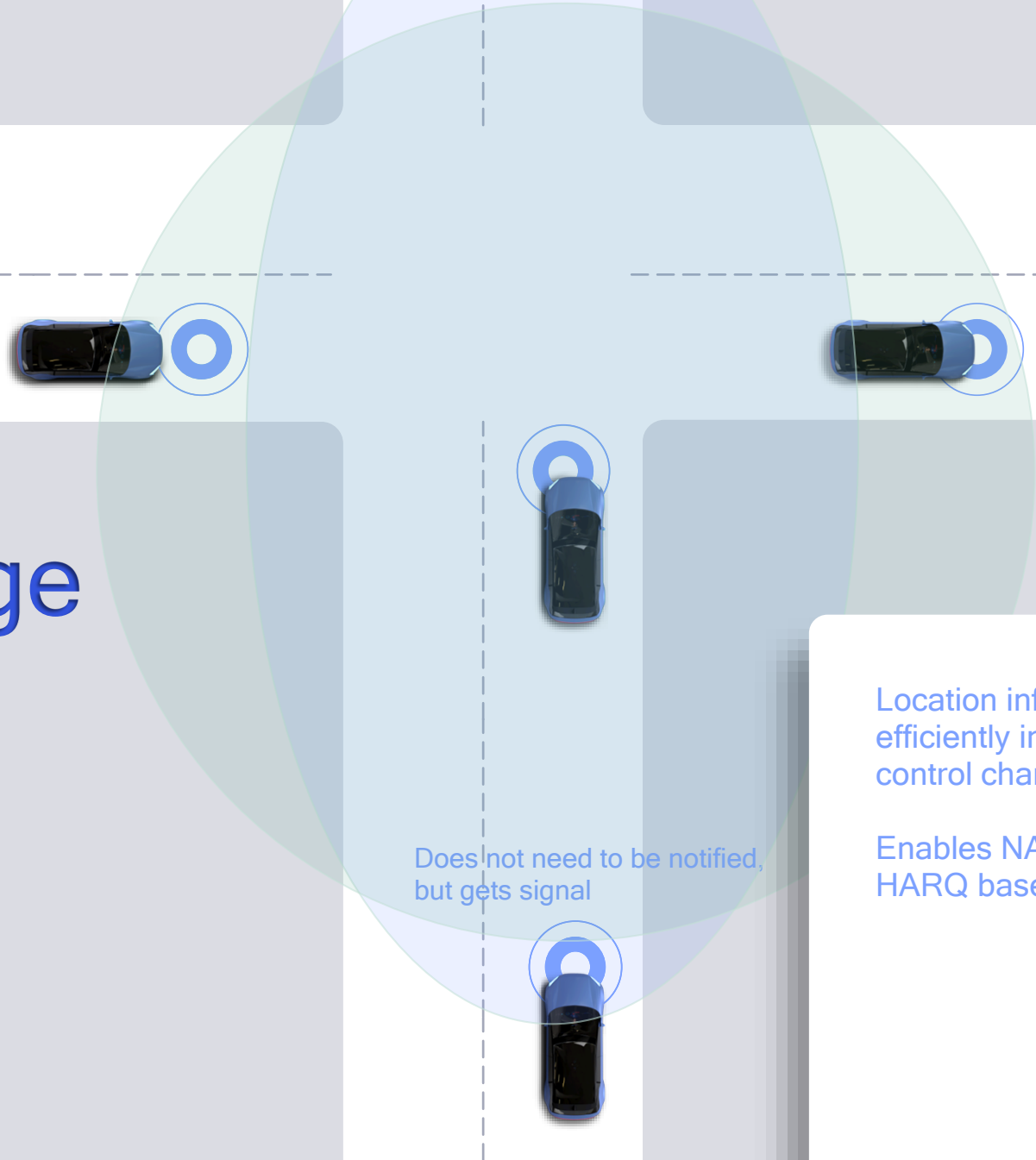
Lower latency: Tx latency as low as 1.5 ms

Due to shorter slots and resources allocation enhancements

Higher capacity: 2x for per packet scheduling

Achieved through link-level gain, HARQ feedback, and resource allocation enhancements

Uniform coverage by adding distance as a dimension



Location information shared efficiently in the physical layer control channel

Enables NAK feedback with HARQ based on distance

Groups can reliably connect based on distance

Vehicles within a certain distance and interested in same services form an ‘on-the-fly’ group

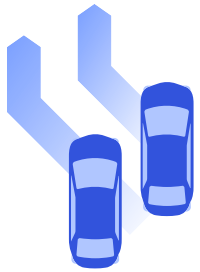
5G V2X enables advanced use cases

Increased situational awareness

Sharing of vehicle-specific info with other vehicles and road infra-structure (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

Conclusion

V2X is an emerging technology area (sort of)

- 5.9GHz spectrum has been available for 20 years
  - Very little deployment of 802.11p based DSRC – so FCC has reallocated the lower 40MHz for unlicensed use and allocated the upper 30MHz (5895-5925MHz) exclusively for C-V2X
- 3GPP-based C-V2X is gaining traction
  - Uses “Sidelink” from Release 14 – direct device to device communication
  - 5GAA – over 120 member companies (www.5gaa.org)
  - Ford has announced intention to deploy in model year 2022
- C-V2X will be complemented by 5G NR (Release 16+)
  - Advanced use cases (sensor sharing, HD maps, coordinated driving, platooning, see-through)
  - Enhancement specifically designed for Autonomous Vehicles
- 5G Uu (cellular) also complements C-V2X
  - Cooperative automated driving
  - Teleoperation

Qualcomm

Thank you!

Follow us on:

For more information, visit us at:

www.qualcomm.com & www.qualcomm.com/blog

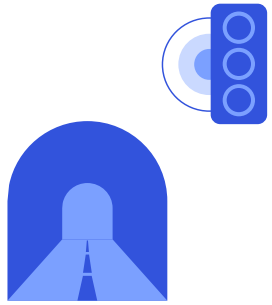
Backup

Qualcomm

Designed to get synchronization from different sources

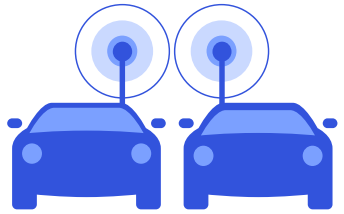
GNSS Satellite synchronization

GNSS can be the primary synchronization source



Infrastructure synchronization

3GPP has defined a detailed protocol for vehicles to use eNodeB/RSU as time synchronization source



UE synchronization

3GPP allows vehicles to use other vehicles on the road as a time synchronization source