Qualcomm

Introduction to Cellular V2X

80-PE732-62 Rev A

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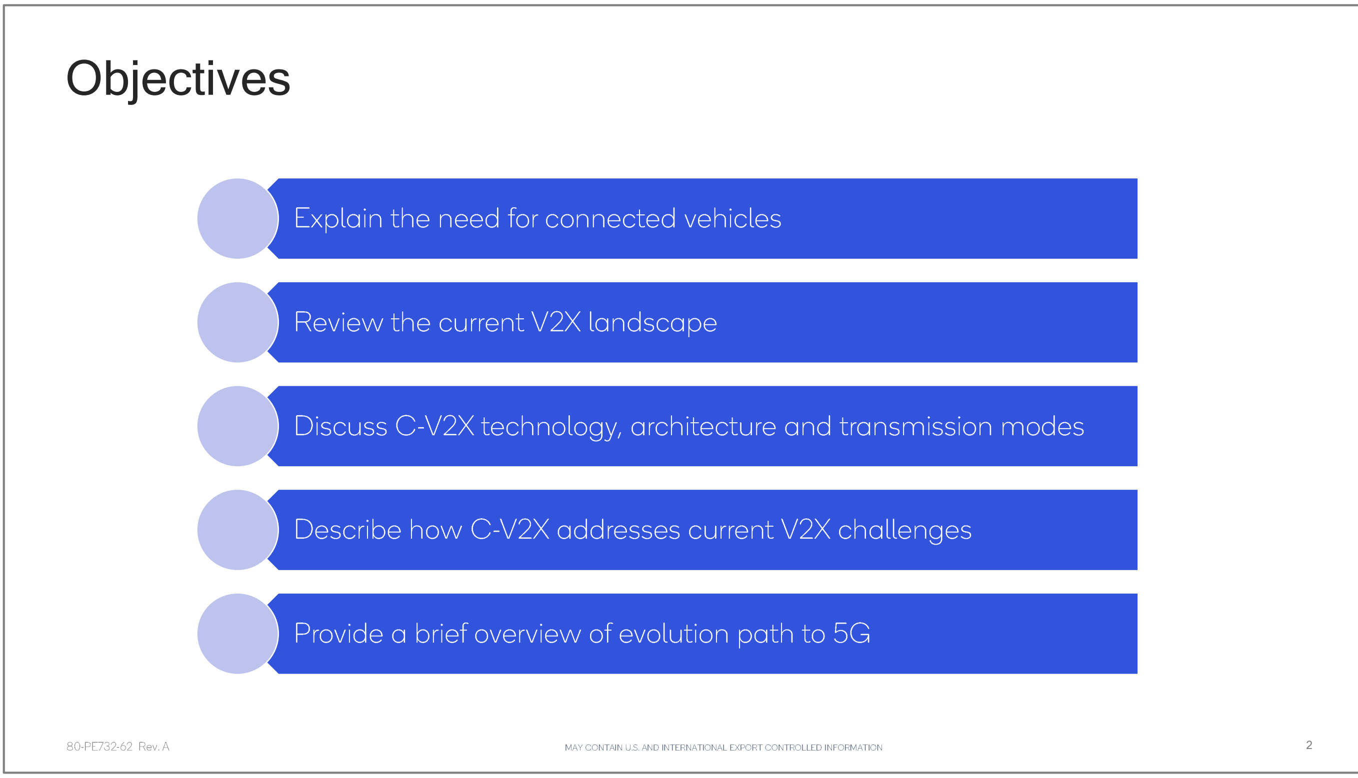
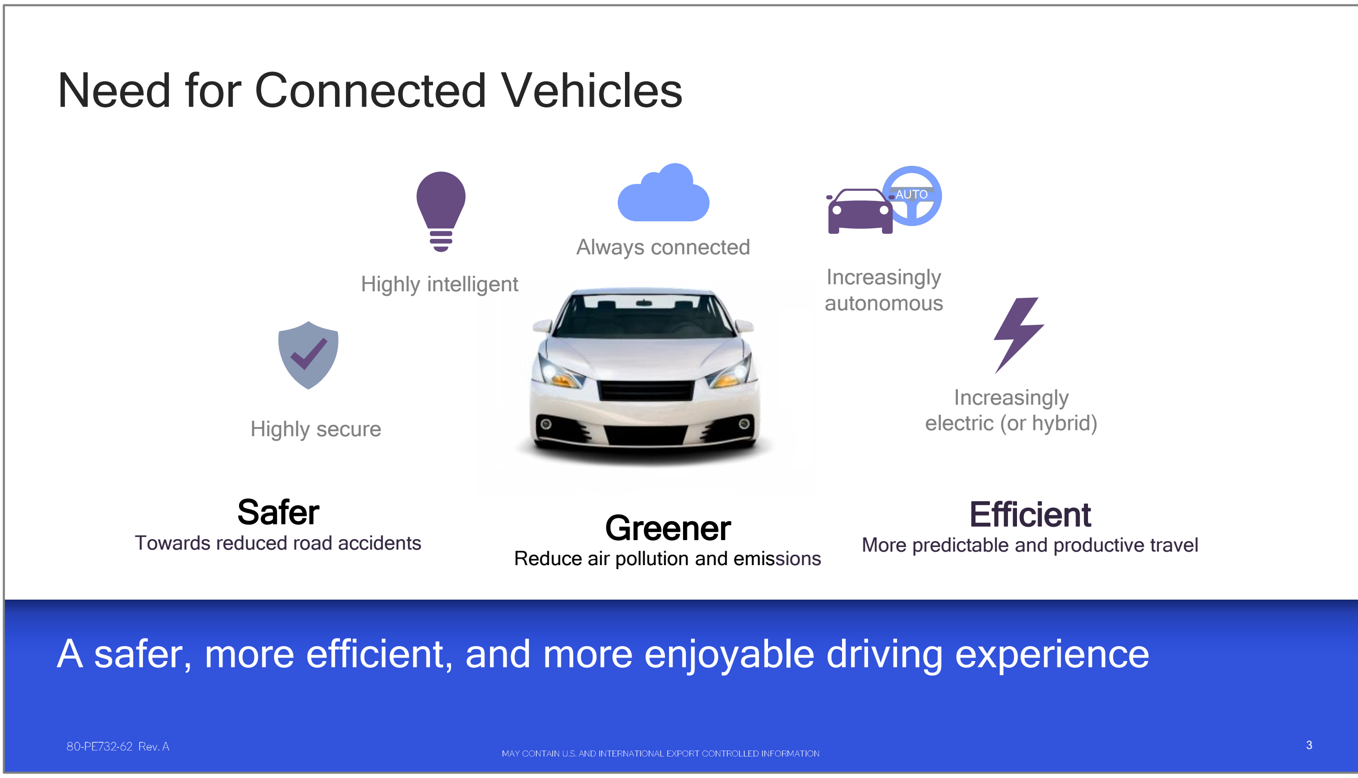


An introduction to Cellular-V2X will cover some key topics, spanning the need for connected vehicles, defining what is V2X, and the existing technologies for providing V2X, and focusing more on the challenges that Cellular-V2X addresses with an evolution path to 5G.



According to the US Department of Transportation, there were circa 6 million police reported crashes in 2017.

In some accidents, the driver could be distracted for a few seconds (checking the phone, texting) or it could be over speeding vehicles skipping the traffic light, accidents due to driving under the influence of alcohol or drugs, and sometimes due to non-conducive road conditions, e.g., icy slippery roads or obstacles on the road.

There is a lot of interest in the automotive industry to upgrade cars and heavy vehicles with more advanced safety features.

Until now, discreet physical features in the car, such as multiple airbags and strong body/chassis, were touted as features providing the most safety to passengers.

The latest trend is to use ubiquitous connectivity around us to provide much advanced warnings to the driver or the car of an impending accident.

Topic Map

- Current Vehicle-to-Everything (V2X) landscape
- Cellular V2X

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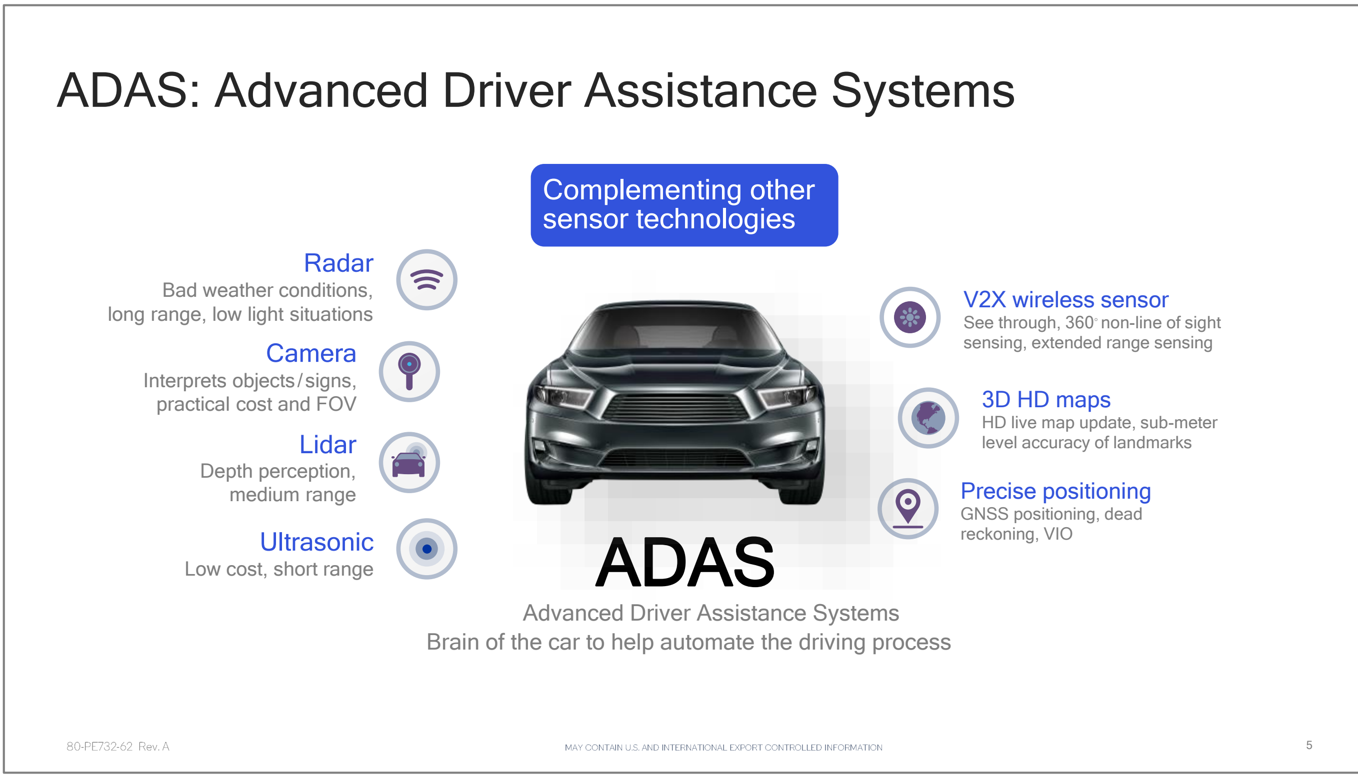


The current generation cars have the BSW (Blind Spot Warning) camera as a common feature.

Some cars are even offering front and side facing cameras.

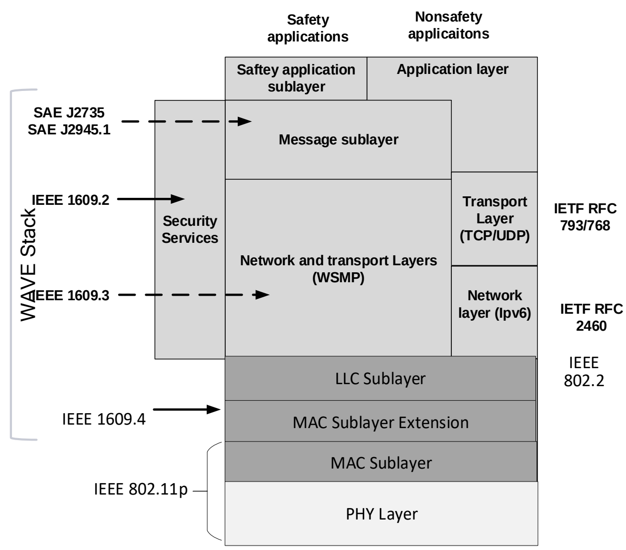
Radars and more expensive, but high performing lidar are also being incorporated to assess the surroundings of the car.

These sensors are unable to provide 360 degree vision of the surrounding of the car when there could be impediments, e.g., blind bend corner or buildings or large vehicles blocking the field of view.

In such situations, V2X sensor complements these other sensors and provides the see through, 360 degree non line-of-sight vision (well beyond the drivers' horizon).

Dedicated Short Range Communications (DSRC) Overview

- Developed for vehicle-vehicle communication
  - Also supports vehicle-infrastructure communications
- Capable of two-way communications up to 1000 m
- Operates in the 75 MHz band of 5.9 GHz spectrum
- Upper layers and security specified by IEEE 1609 family
- Wi-Fi based technology - 802.11p standard (Phy and MAC)
- Adapted for latency-critical V2X communications in 5.9 GHz band



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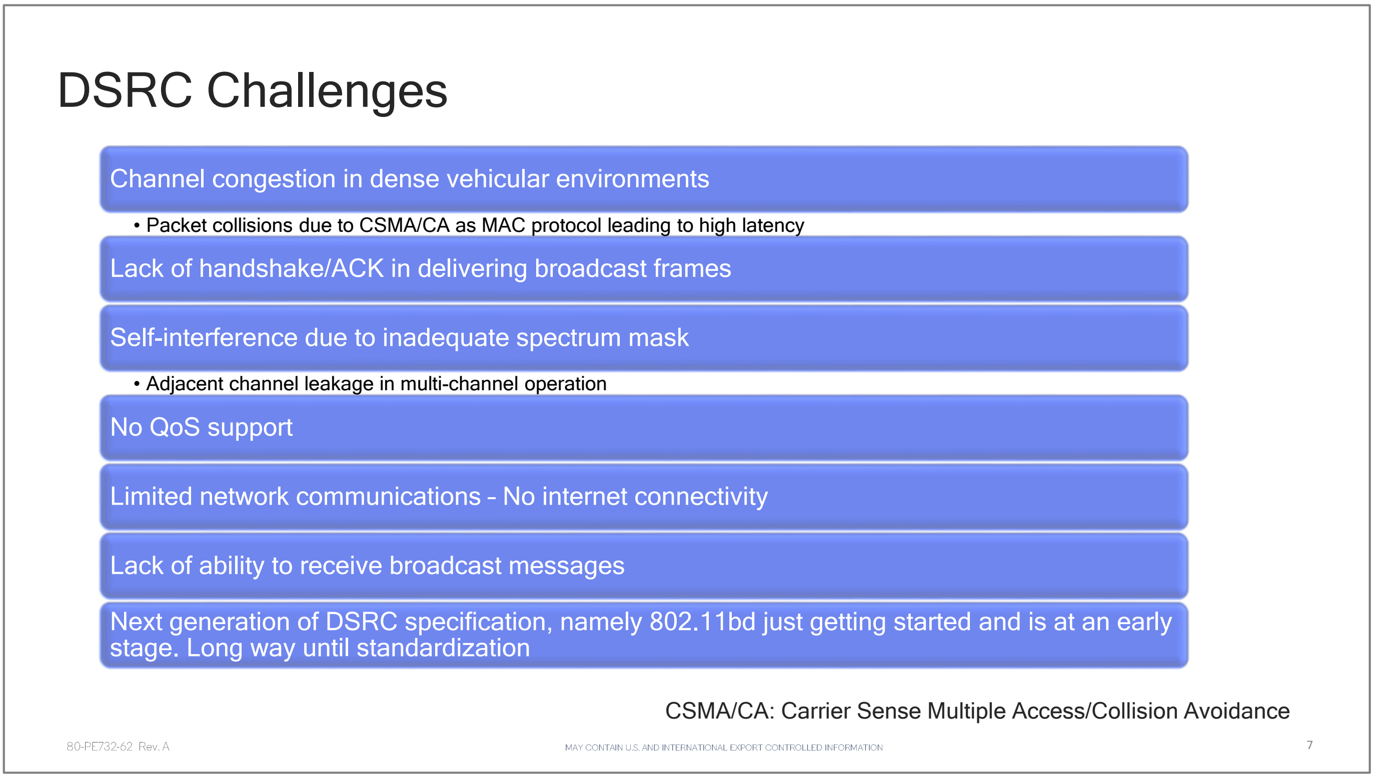
DSRC or Dedicated short range communication is a type of V2X technology which provides the ability for vehicles to communicate with other vehicles and infrastructure around them, exchanging BSMs (Basic Safety Messages) for collision avoidance.

DSRC is based on the IEEE 802.11p standard and operates in the 5.9GHz spectrum. It is composed of multiple stack layers as depicted in the figure above.

WAVE stands for Wireless Access in Vehicular Environment. It is composed of all upper layers messages sublayer from the SAE International (Society of Automotive Engineers) J2735 dictionary and J2945/1 performance requirements. Networking and transport layers are implemented based on IEEE 1609.3 standards, and security services are implemented based on IEEE 1609.2 standards. It is also composed of the MAC sublayer based on IEEE 1609.4 standard.

The PHY and MAC layer are based on the IEEE 802.11p standard.



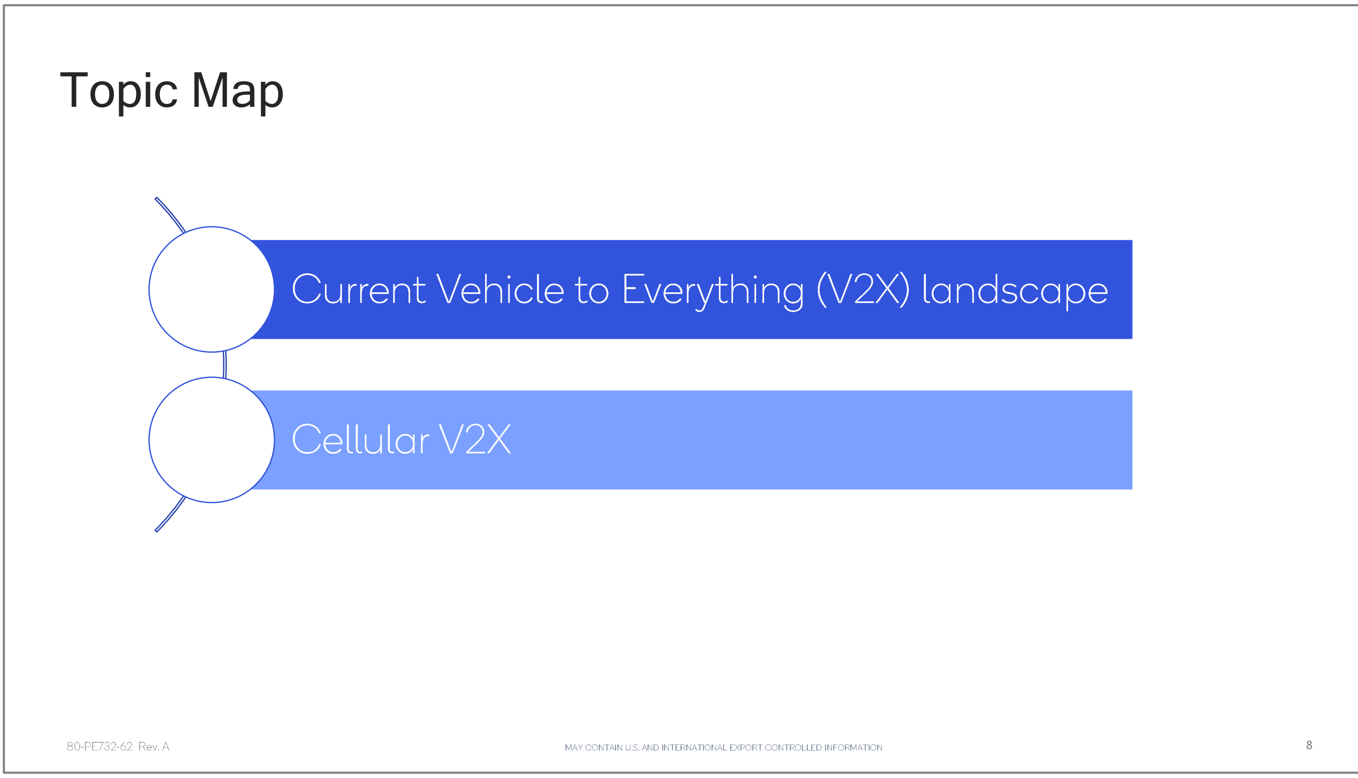
DSRC or 802.11p is based on CSMA/CA: Carrier Sense Multiple Access/Collision Avoidance.

DSRC Challenges

An IEEE 802.11p packet starts with a few wideband Pilot symbols and then the data symbol and SIGNAL symbol, which carries the PLCP header. Only four out of the 52 subcarriers are used for Pilots. In other words, for the 10 MHz operation in IEEE 802.11p, two adjacent subcarriers are 2.4 MHz away.

Typical IEEE 802.11p devices first obtain a wideband channel estimate from Pilot symbols, and then monitor the residual channel variation using the Pilot subcarriers. The latter is usually referred to as Pilot tracking. In benign channel models, such algorithms are sufficient. However, in vehicular channels, after the coherence time, the channel estimates obtained from the Pilot symbol becomes obsolete. However, the sparse Pilot subcarriers are not sufficient to track the channel. Thus, the packet reception can fail even when the received power of the packet is well above the thermal noise.

Vehicle safety communication applications rely heavily on periodic broadcast of basic safety messages (BSM) which contain the positions, velocities, and other information about the vehicles. These messages with the PHY layer overheads typically measure around 300 bytes with the full security certificate header [10] and are expected to be transmitted up to once every 100 ms. The periodicity is chosen to meet latency and accuracy requirements of vehicle safety applications.


Topic Map
Current Vehicle to Everything (V2X) landscape
Cellular V2X
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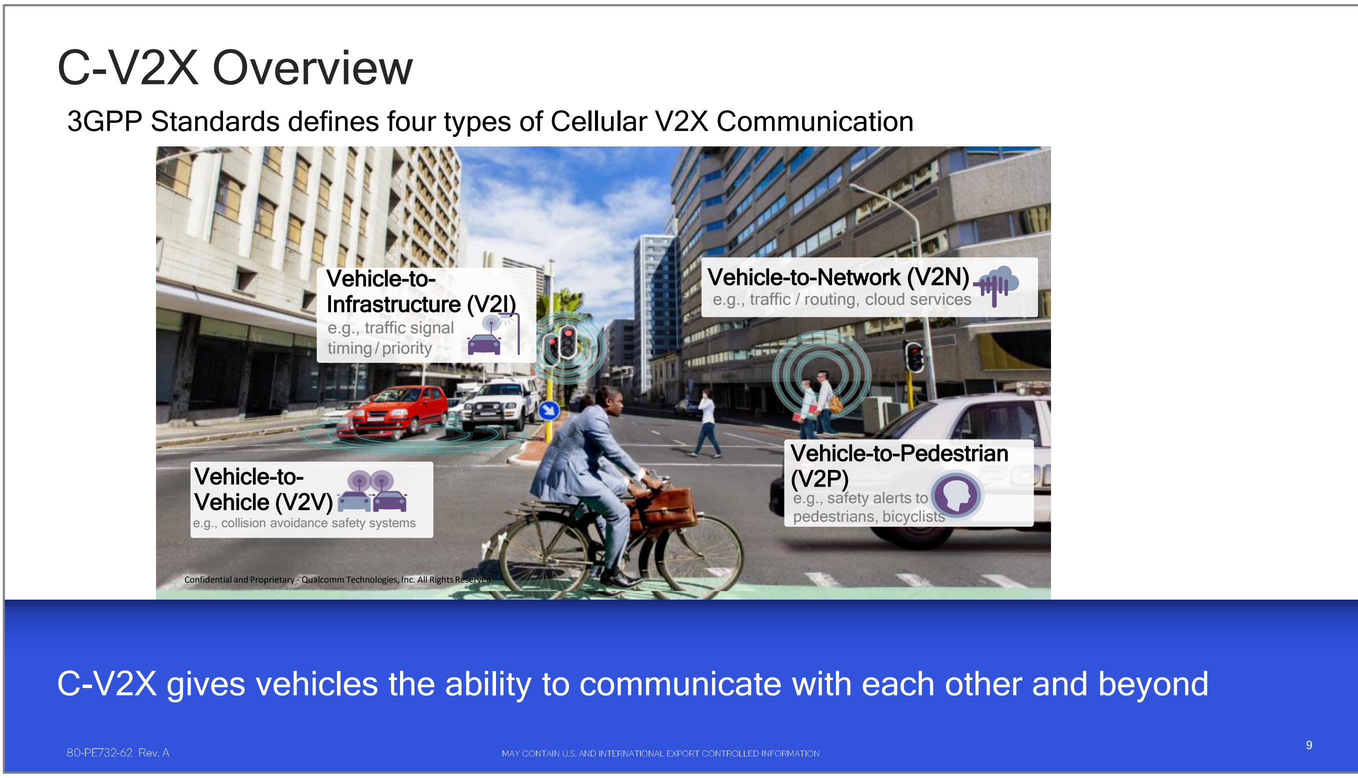


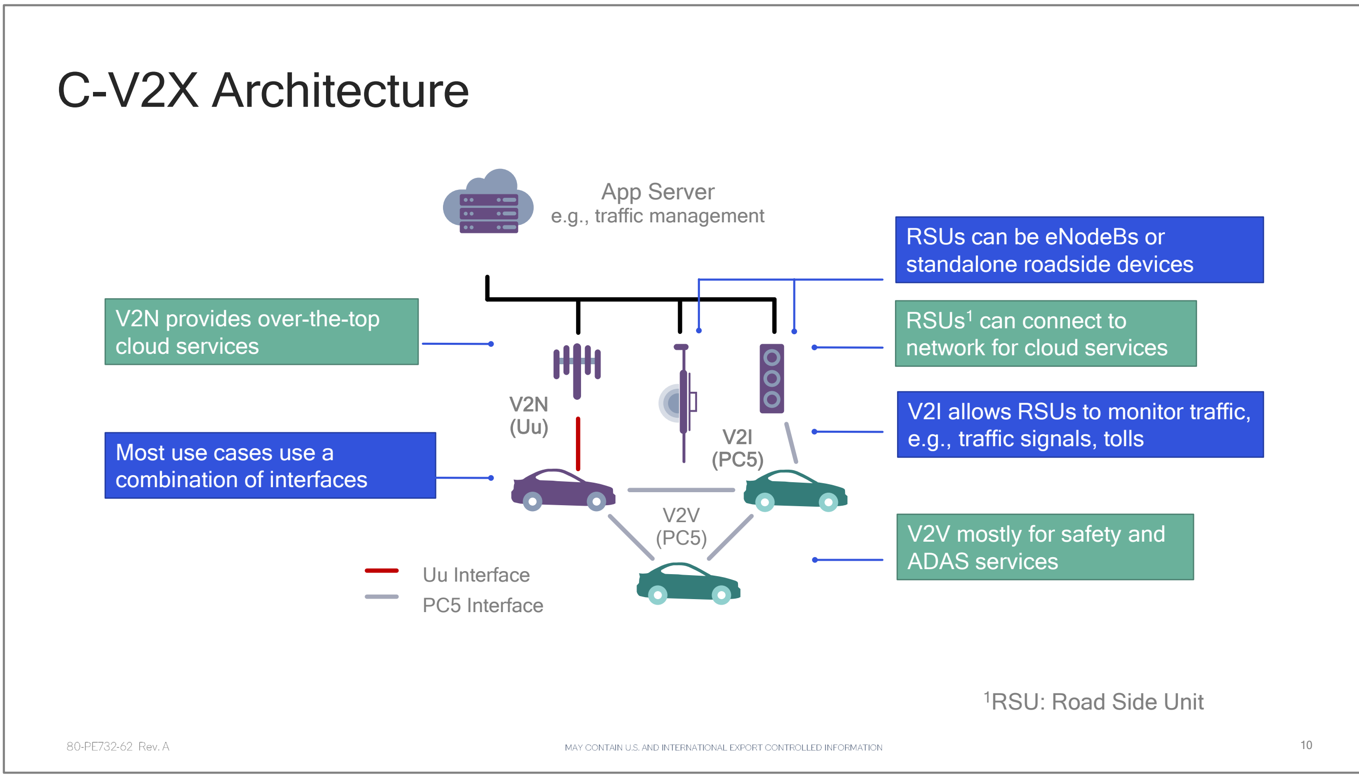
Vehicle-to-everything (V2X) communication is essential to redefining transportation by providing real- time, highly reliable, and actionable information flows to enable safety, mobility and environmental applications

V2X communications and its solutions enable the exchange of information between vehicles and between vehicle network infrastructure.

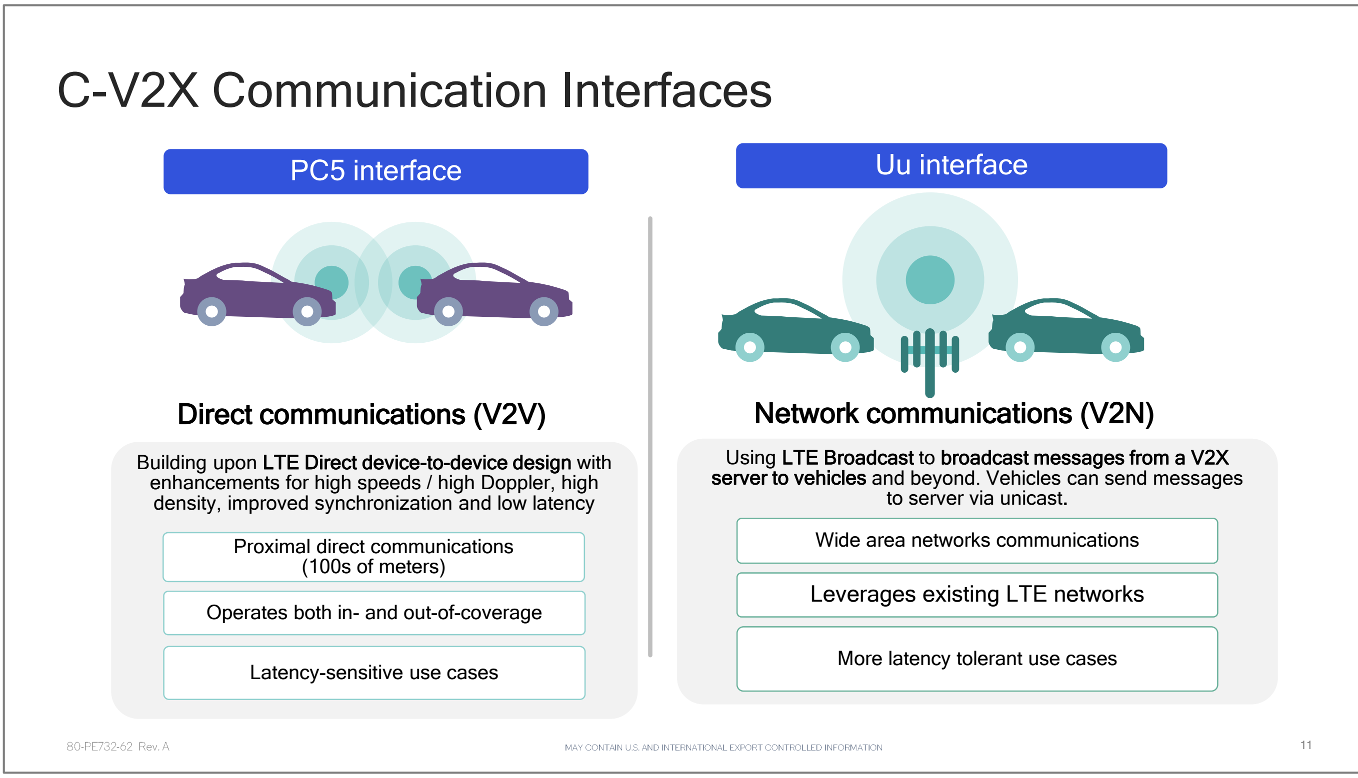
The goal of V2X is to improve road safety, increase the efficient flow of traffic, reduce environmental impacts and provide additional communications, traveler information services.

V2X communications consists of four types of communications:

- Vehicle-to-vehicle (V2V)
- Vehicle -to-infrastructure (V2I)
- Vehicle-to-network, (V2N)
- Vehicle-to-pedestrian (V2P)



Cellular-V2X defines a new air interface called PC5 for V2V, V2I communication. V2N is still over the legacy LTE Uu air interface and provides over the top cloud services.



C-V2X defines two Complimentary Transmission Modes:

1) **Direct safety communication independent of cellular network**
   - Low latency Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Person (V2P) operating in ITS bands (e.g., 5.9 GHz)

2) **Network communications for complementary services**
   - Vehicle-to-Network (V2N) operates in the mobile operator's licensed spectrum

Direct communications (V2V) via PC5 interface

Building upon LTE Direct device-to-device design with enhancements for high speeds / high Doppler, high density, improved synchronization, and low latency

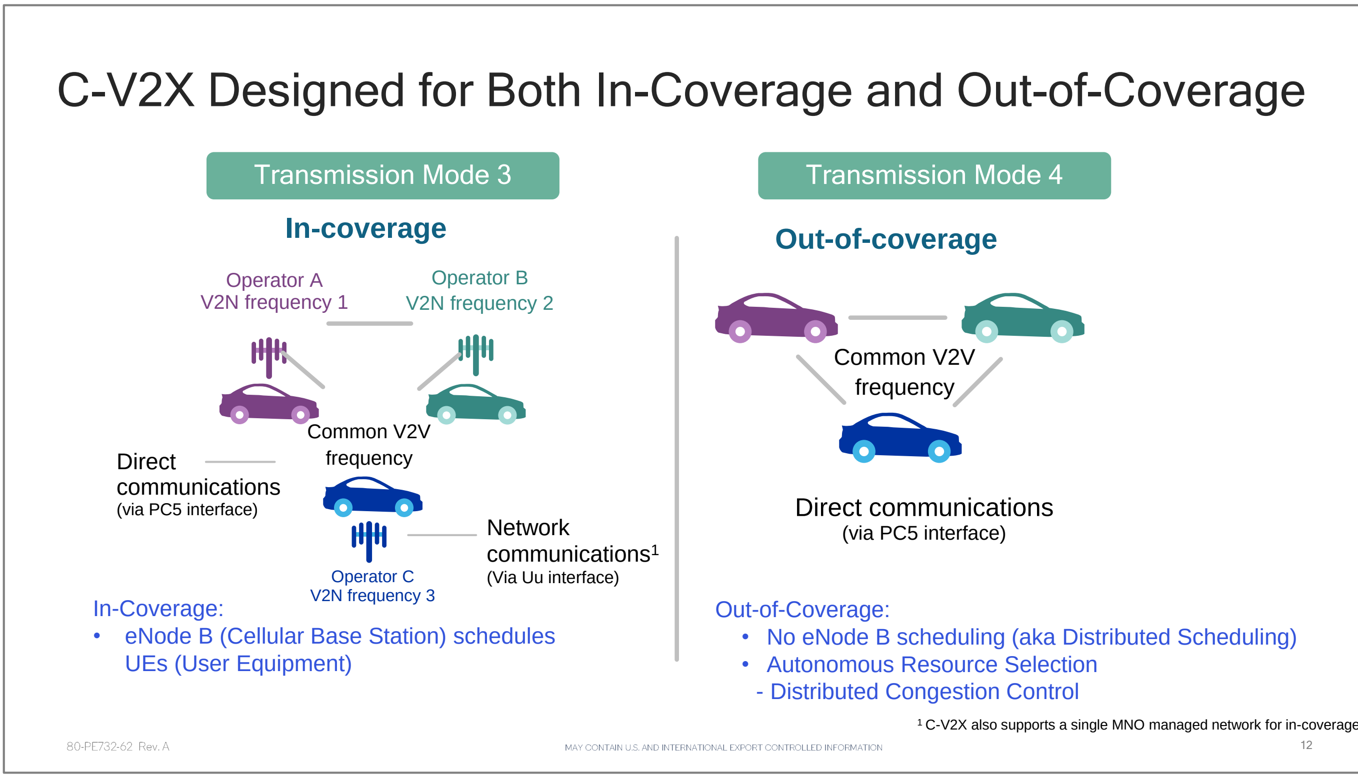
- Proximal direct communications (100s of meters)
- Operates both in- and out-of-coverage
- Latency-sensitive use cases, e.g., V2V safety

Network communications (V2N) via Uu interface

Using LTE 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

Examples:
Latency-sensitive use cases, e.g., V2V safety
More latency tolerant use cases, e.g., V2N situational awareness

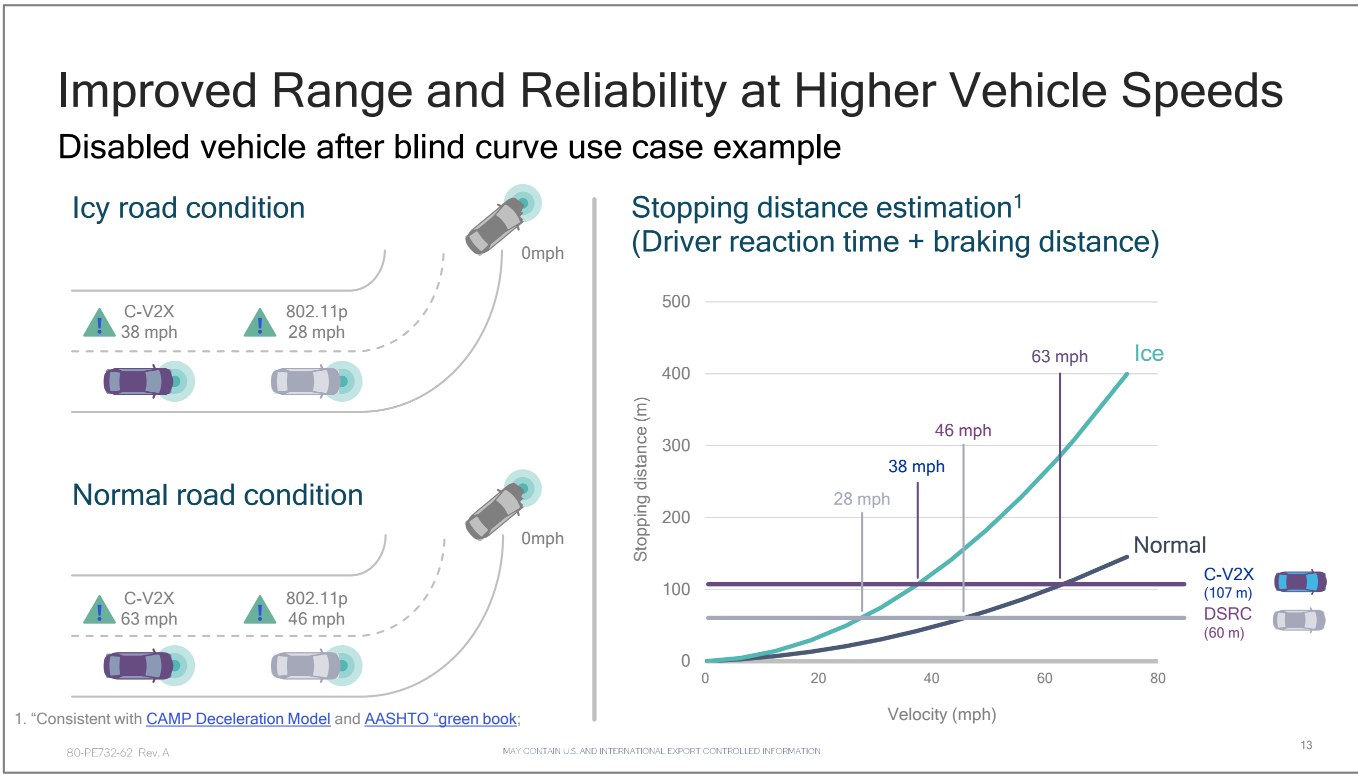


C-V2X designed for both In-coverage and Out-of-coverage.

Transmission mode 3 is defined as when network does the scheduling of resources for vehicles to communicate on.

Transmission mode 4 is defined as when vehicles autonomously does resource selection based on sensing the environment. There is no involvement of the network on TM4.

Note: Qualcomm strongly supports and promotes TM4 as there is no operator interest in implementing TM3.



The intent of these simulation plots is to signify the advantage of vehicles operating with C-V2X compared with DSRC in real life conditions.

The plots show that C-V2X can operate at higher speeds in icy road conditions as well as normal road conditions, to reliably bring moving vehicle to a complete stop and to avoid collision with a stalled vehicle in their path.

Cellular V2X Advantages Over Other Technologies

Rich roadmap/evolution with:

- Strong global technology forum to support expanding functionality and use cases
- Roadmap to 5G brings more potential for connected vehicles

- C-V2X introduced in 3GPP release 14 specification
- Supports high relative speeds and high node densities

Improved situational awareness with V2N network communications

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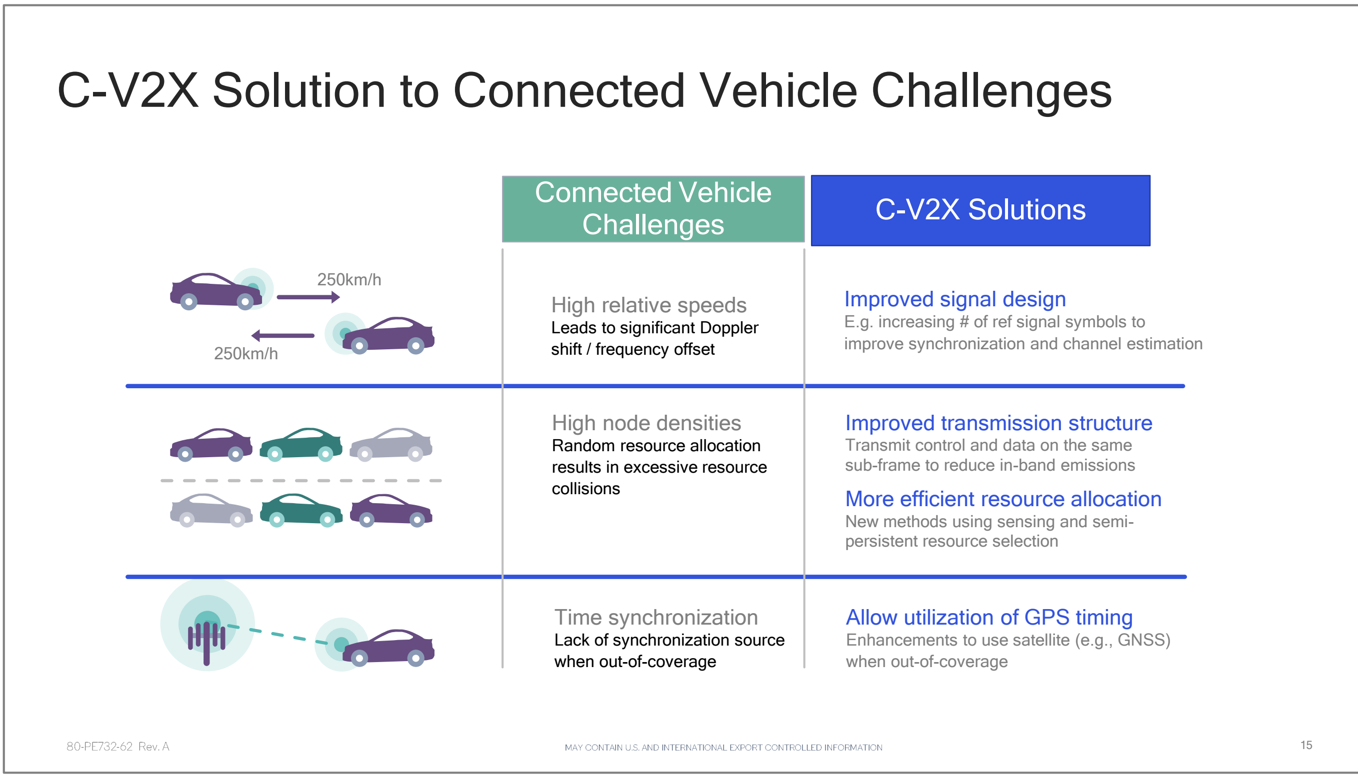
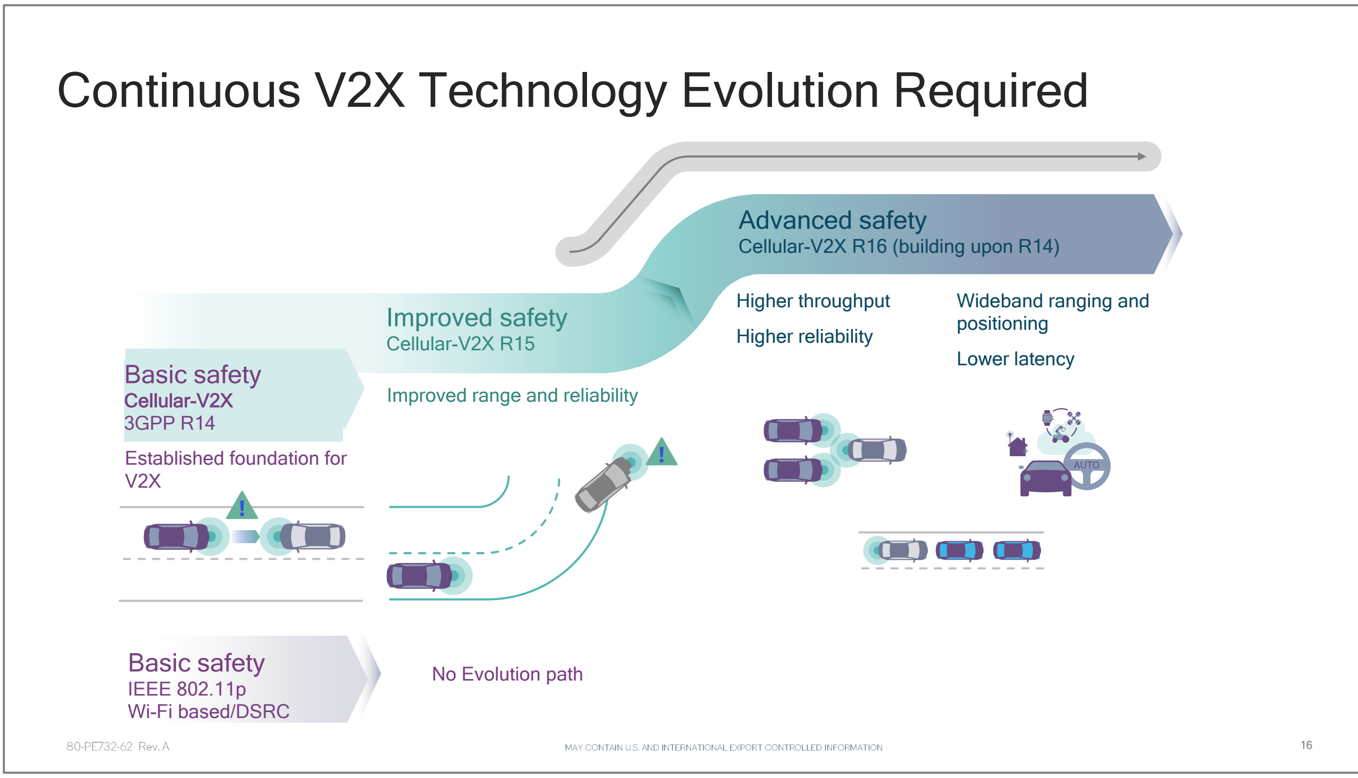


Vehicles at high speeds face a challenging RF environment for message transmission and reception.

With relative speeds of 500 Km/hr, there is a large Doppler shift and frequency offset observed. C-V2X addresses this with an improved signal design by introducing extra reference signal symbols for improved channel estimation.

In situations of dense vehicular traffic, there could be congestion in radio resource allocations. C-V2X address this by elaborate algorithms comprising sensing the available resources, sorting them and picking the least congested resources for transmission over a semi persistent resource allocation methodology.

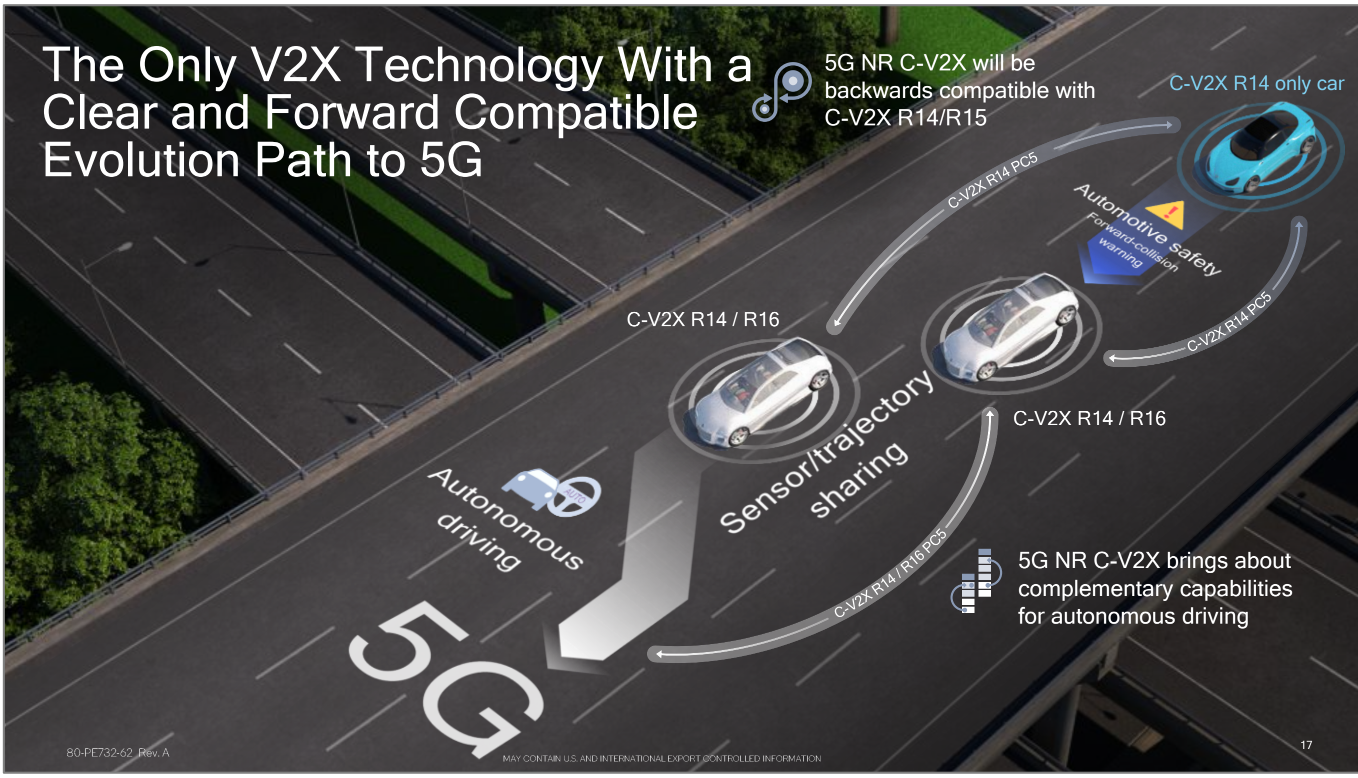
C-V2X is inherently a synchronous system and utilizes GNSS for time synchronization. In out of coverage scenarios, it utilizes GNSS time from other sources for time maintenance.



3GPP Release 14 based C-V2X establishes the foundation for V2X communication for basic safety messages exchange.

Release 15, 3GPP release, incorporates additional features like Transmit Diversity and 10 ms PDB (Packet Delay budget) which bring improved range and reliability.

The 5G NR C-V2X, based on the next 3GPP Release 16 standard, will usher in a new era of much higher throughput, much higher reliability, lower latencies, and opening up possibilities of newer use cases.



There is backward and forward compatibility built in the various 3GPP Releases.

A Release 16 capable vehicle can communicate with another Release 14 car using Release 14 air interface for BSM exchanges.

A Release 16 capable vehicle can communicate with other release 16 cars using the new 5G NR C-V2X air interface for advanced use cases like sensor/trajectory sharing.

Key Takeaways

- Connected vehicles make for a safer, more efficient and more enjoyable driving experience.
- V2X provides 360 degree, non-line of sight sensing.
- DSRC faces several challenges, mainly channel congestion, no internet connectivity and no evolution path.
- C-V2X is able to address more efficient resource allocation and forward compatible evolution path to 5G.

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Notes


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C-V2X Use Cases: Categories

Safety, automated driving and advanced driver assistance systems (ADAS)	• Requires high reliability and low latency • Ex: Forward collision warning, blind spot and lane change warning, etc.
Situational Awareness	• High reliability, Longer latency • Ex: Queue warning, etc.
Mobility	• Inter-model travel and Congestion reduction • Ex: Traffic advisories
Auxiliary Services	• Infotainment, fleet management, and other services

Impact of Connected Vehicles

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

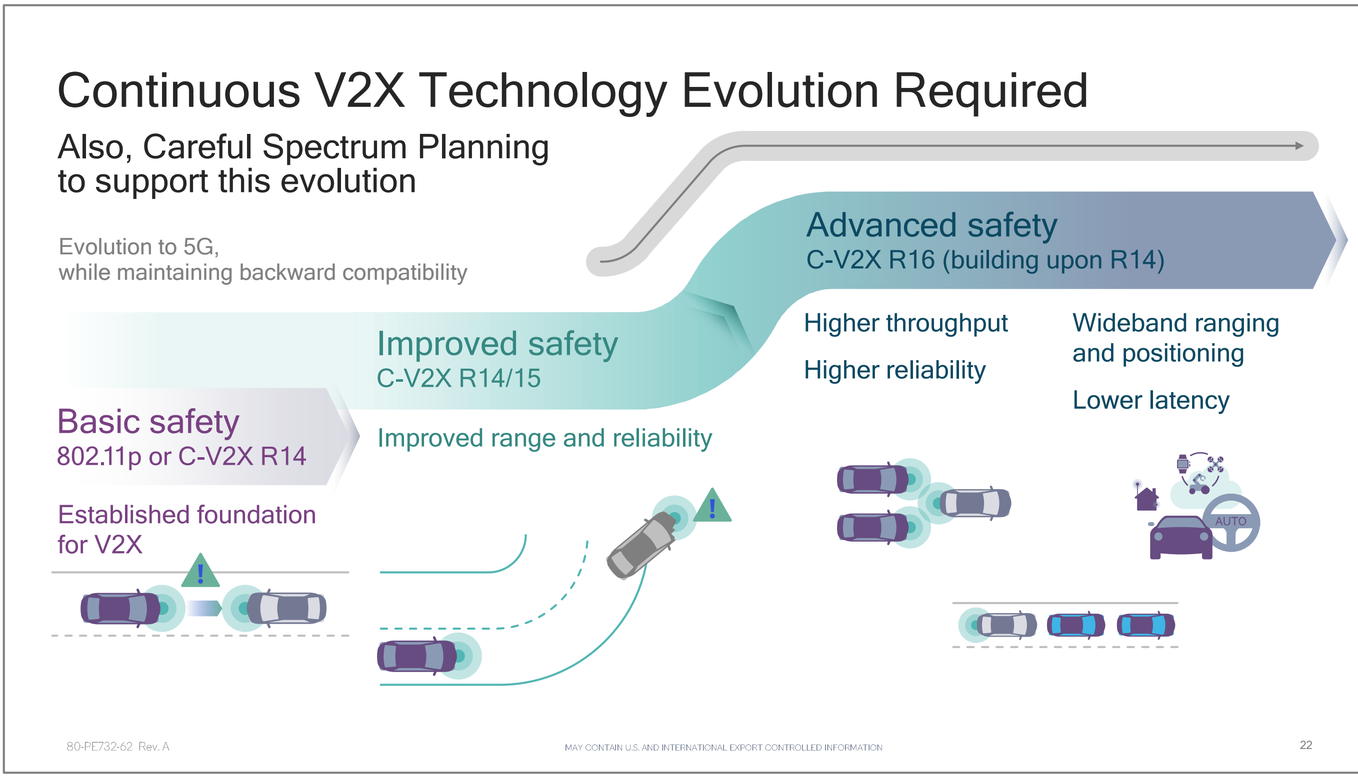
gallons of fuels wasted due traffic congestion in the US[3]

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


Continuous V2X Technology Evolution Required
Also, 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
Improved safety
C-V2X R14/15
Improved range and reliability
Advanced safety
C-V2X R16 (building upon R14)
Higher throughput
Higher reliability
Wideband ranging
and positioning
Lower latency
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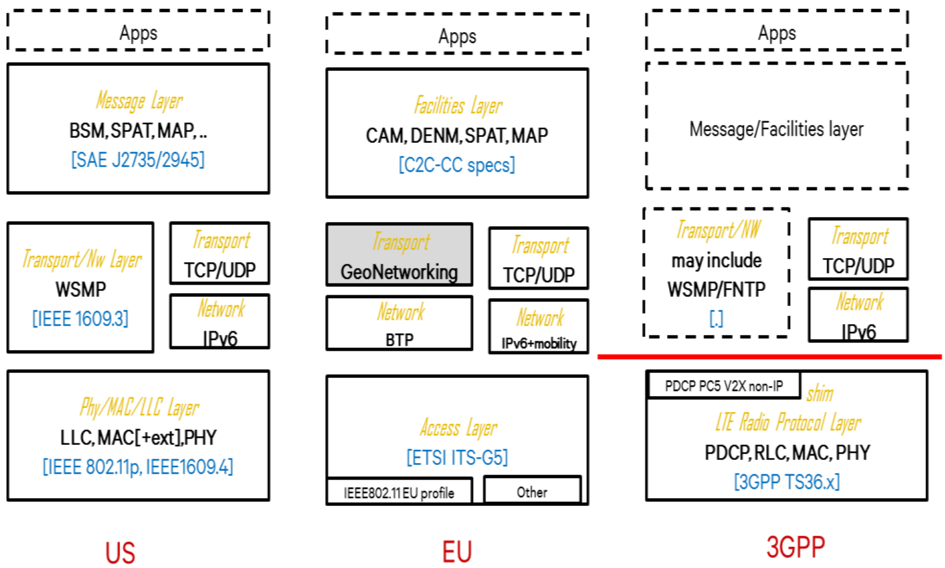
Different Stacks Comparison



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