Cellular V2X for Safety and Cooperative Driving of Intelligent Transport Systems

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Outline

- Motivation
- Introduction of C-V2X
- Use Case Examples
- Simulation and Field Test Results
- Conclusions

Motivation

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

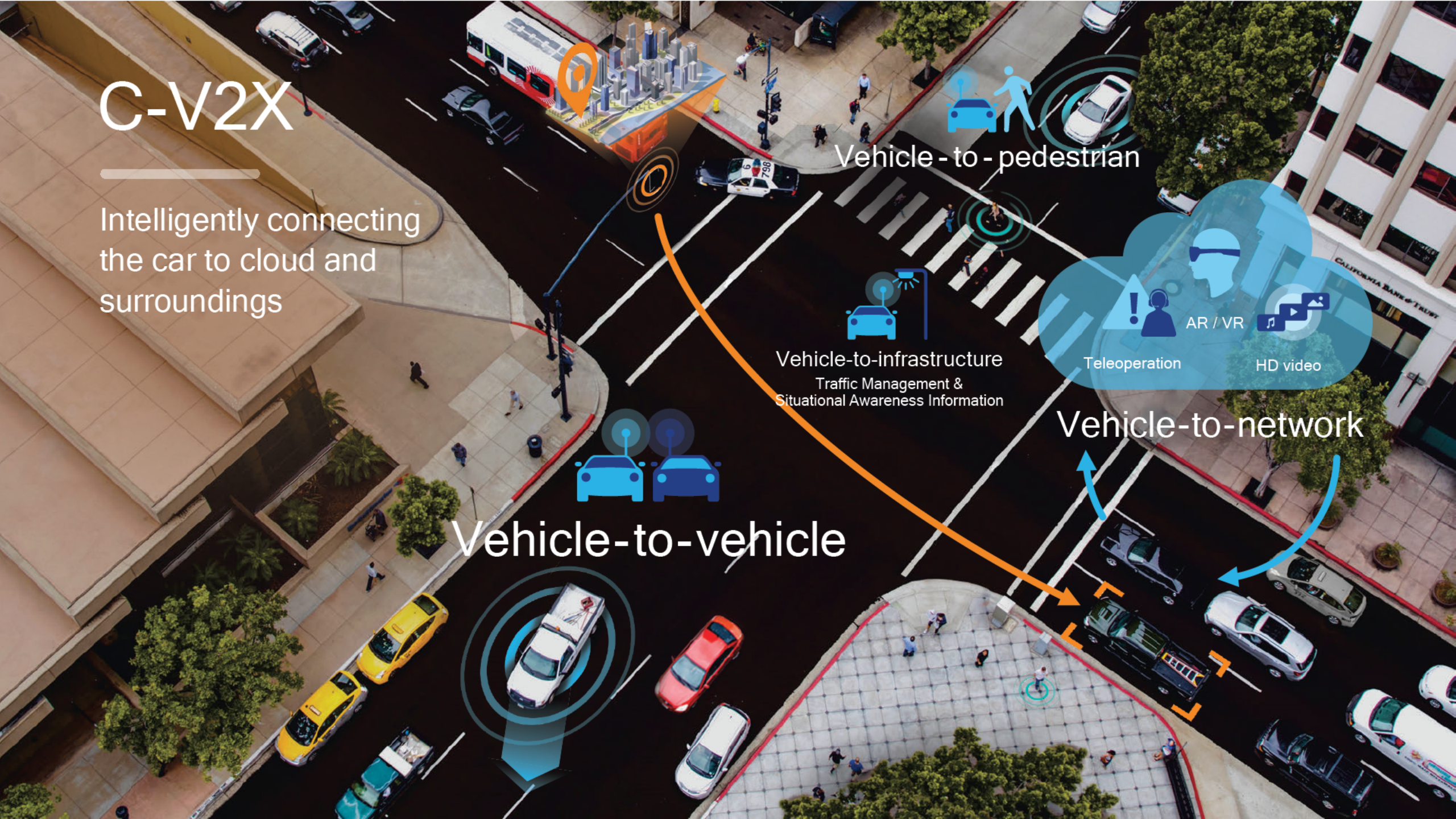
gallons of fuels wasted due traffic congestion in the US[3]

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

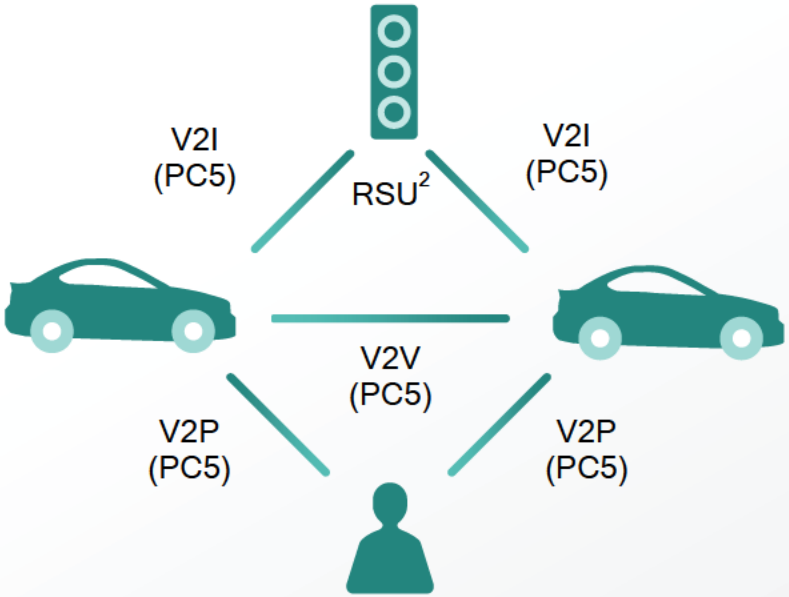

C-V2X
Intelligently connecting the car to cloud and surroundings
Vehicle-to-vehicle
Vehicle-to-infrastructure
Traffic Management & Situational Awareness Information
Vehicle-to-network
Vehicle-to-pedestrian
AR / VR
Teleoperation
HD video

C-V2X has two complementary communication modes

Providing flexible communication scenarios

Direct

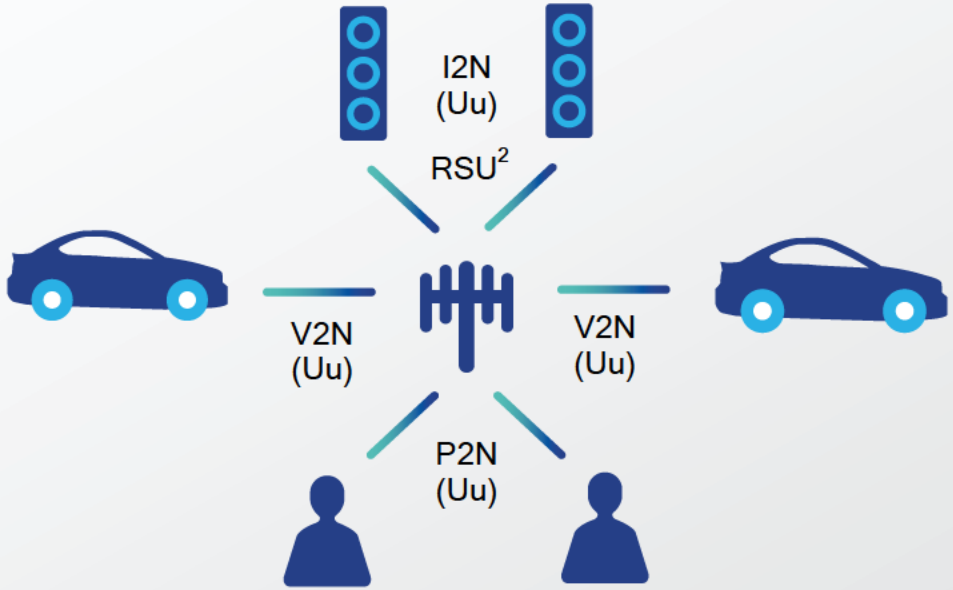
V2V, **V2I**, and **V2P** operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network



Short range (<1 kilometer), location, speed …
Implemented over “PC5 interface”[1]

Network

V2N operates in traditional mobile broadband licensed spectrum

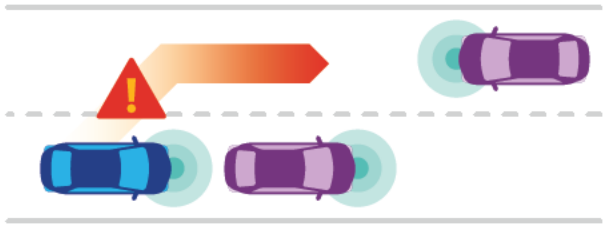


Long range (>1 kilometers). e.g. accident ahead
Implemented over “Uu interface”

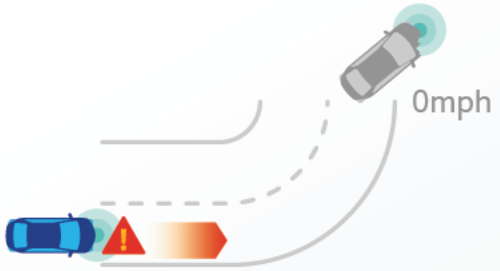
1. PC5 operates on 5.9GHz; whereas, Uu operates on commercial cellular licensed spectrum. 3GPP also defines a mode, where eNodeB helps coordinate C-V2X Direct Communication;
2. RSU stands for roadside unit.

Providing support for enhanced safety use cases

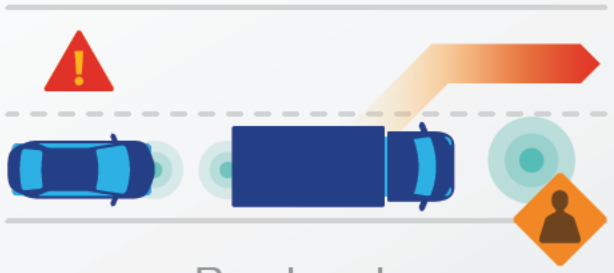
By extending electronic horizon, providing more reliability, and better NLOS performance



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)

Evolving C-V2X Direct Communications towards 5G NR

While maintaining backward compatibility

Evolution to 5G NR, while being backward compatible
C-V2X Rel-14 is necessary and operates with Rel-16

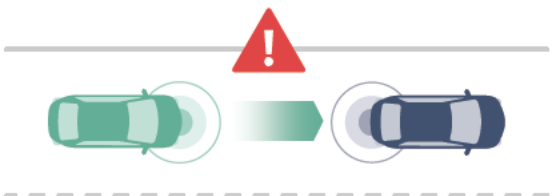
Autonomous driving use cases
5G NR C-V2X Rel-16

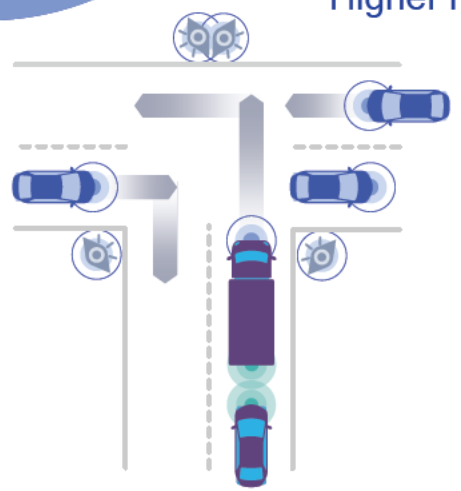
Backward compatible with Rel-14/Rel-15 enabled vehicles

Higher throughput
Higher reliability
Wideband carrier support
Lower latency

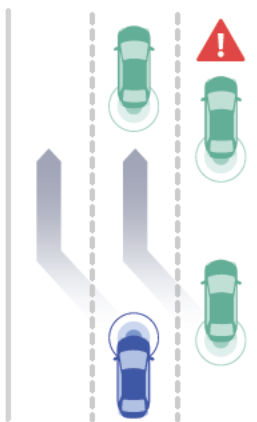
Basic and enhanced safety
C-V2X Rel-14/Rel-15 with enhanced range and reliability

Basic safety
IEEE 802.11p



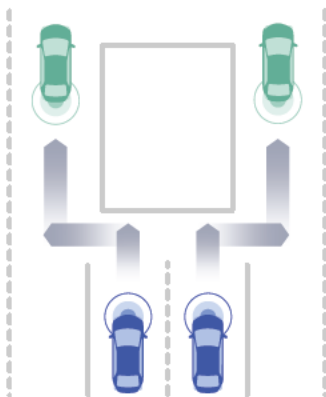


Sensor Sharing



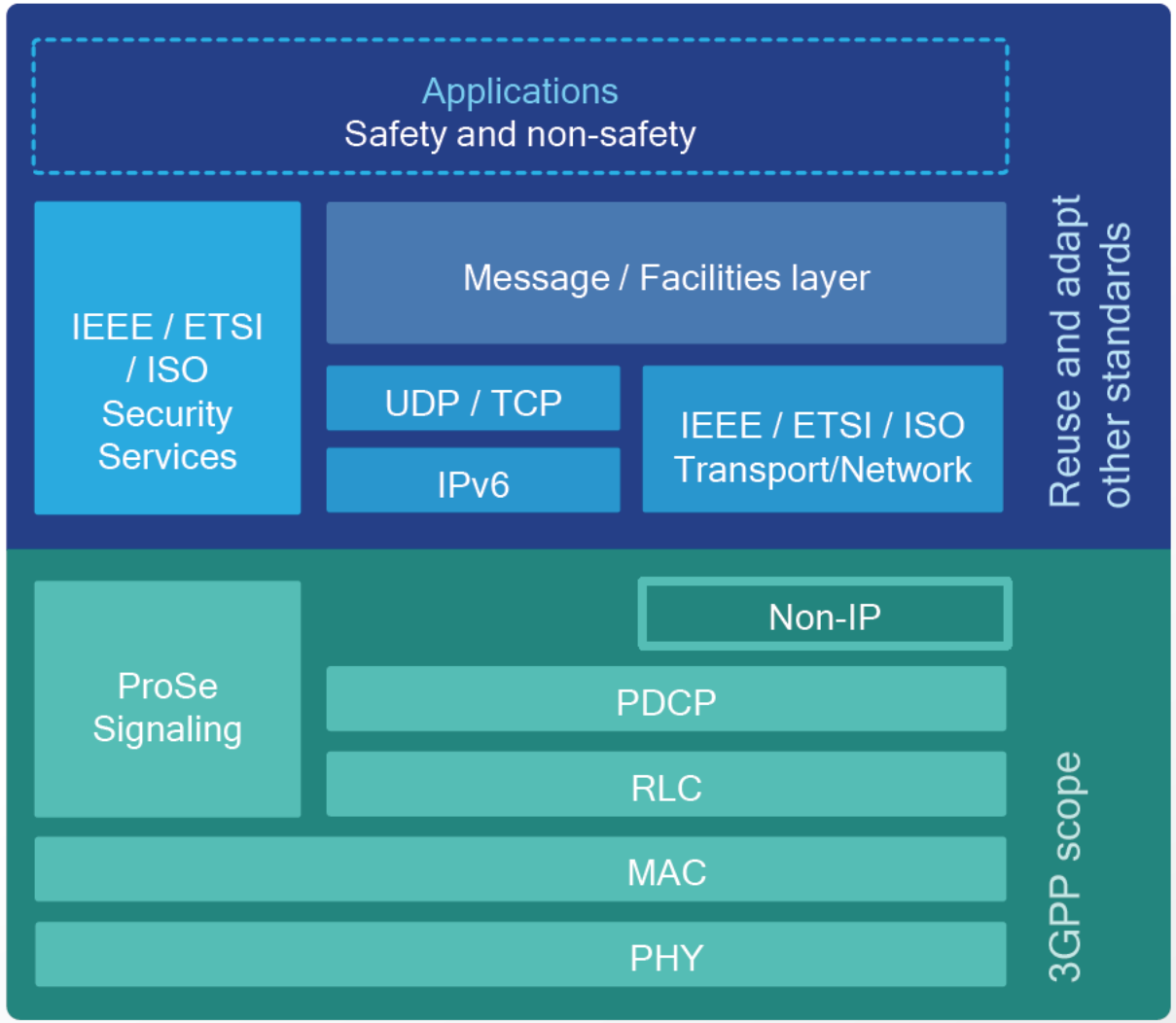
Sudden braking and lane change on a freeway

Intention Sharing



Coordinated Driving

C-V2X reusing upper layers defined by automotive 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 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

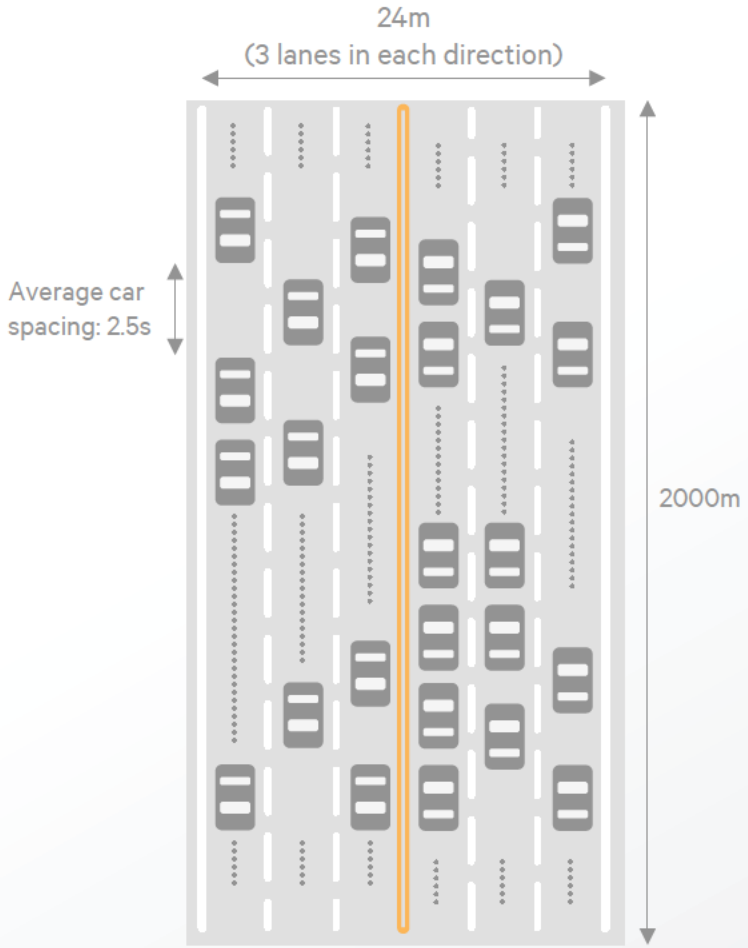
Coding gain from turbo codes and HARQ retransmission lead to longer range

~2X
Longer range

1 Link budget of C-V2X is around 8 dB better than 802.11p

Freeway scenarios to simulate high speed performance

Simulation Parameters and Assumptions



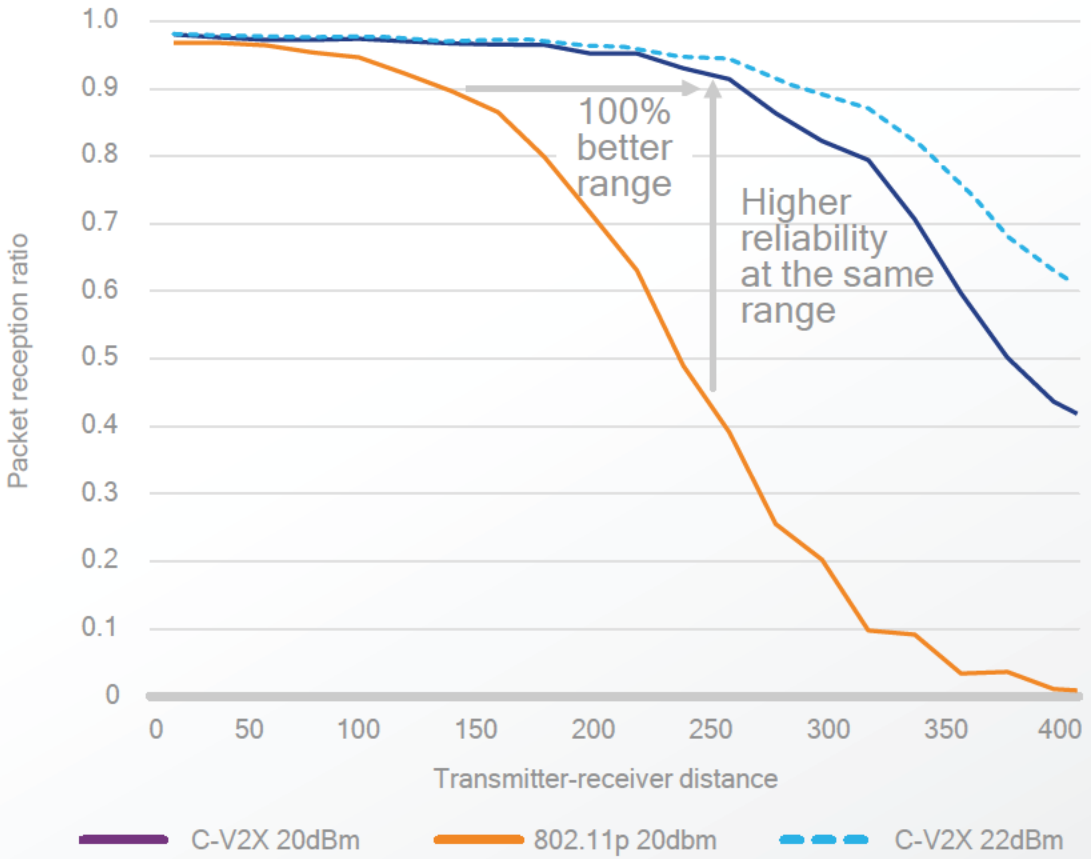
- 6 lanes for 4m each, 3 lanes in each direction
- Cars dropped according to Poisson process
- Avg. car spacing is 2.5s
- All cars are LOS (line of sight)
- Actual mobility simulated: correlated shadowing, independent fading
- Packet transmission periodicity: 100ms

- Shown results for Speed & Density:
  1. 250 km/h & 69 cars
  2. 140km/h &123 cars

Enhanced range and reliability in freeway scenarios

Simulation Results

Freeway 250 km/h & 69 cars



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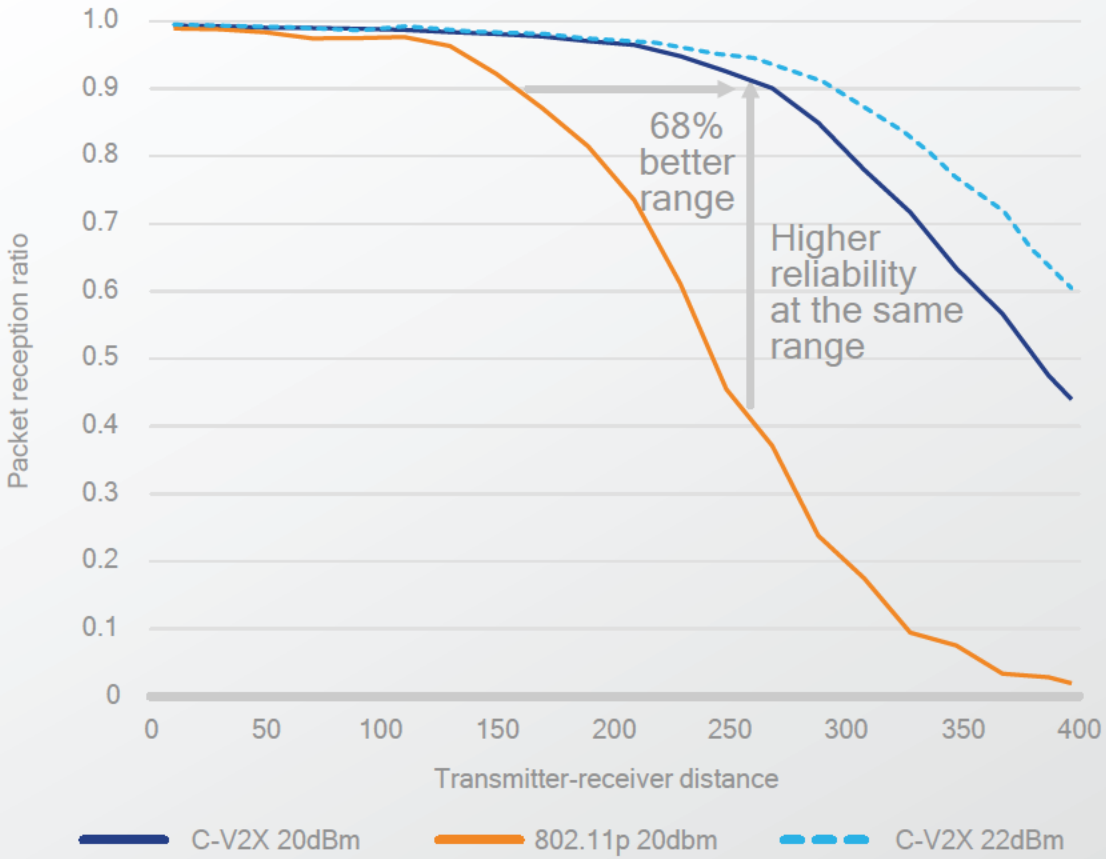
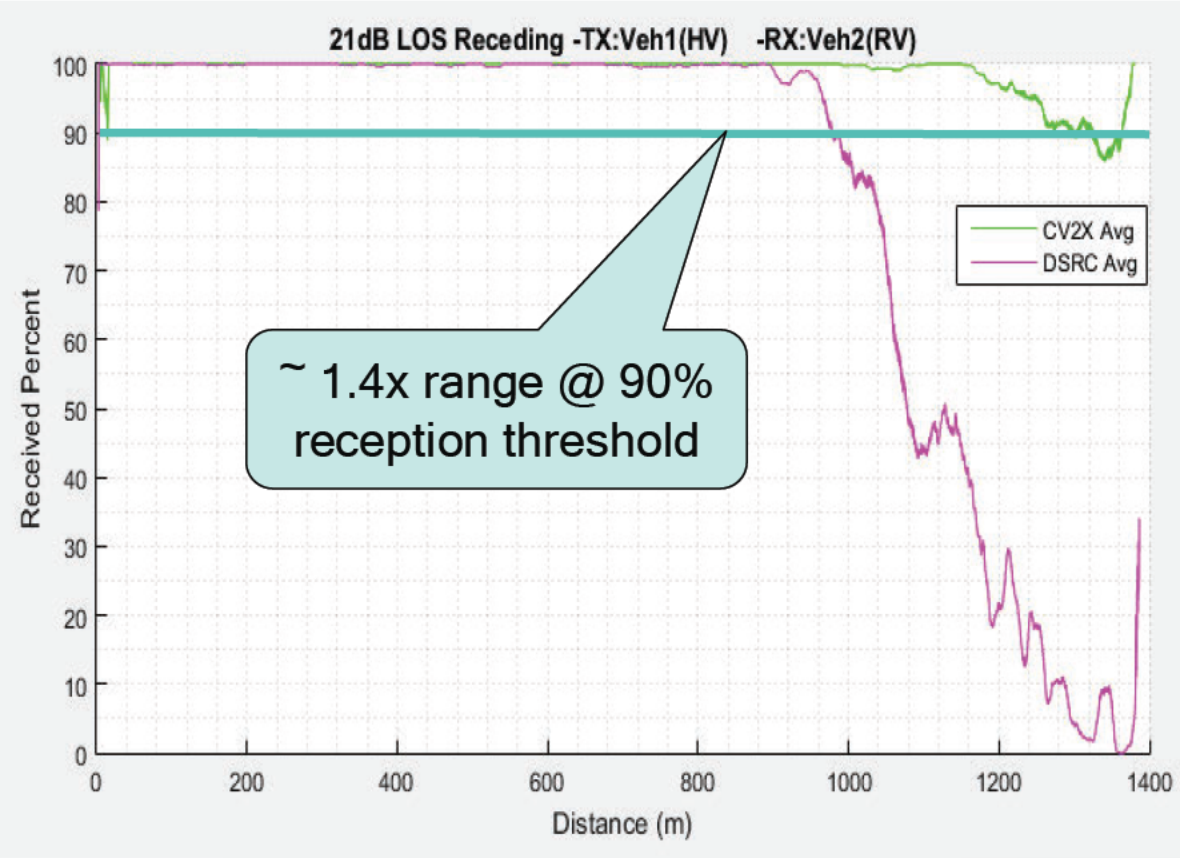
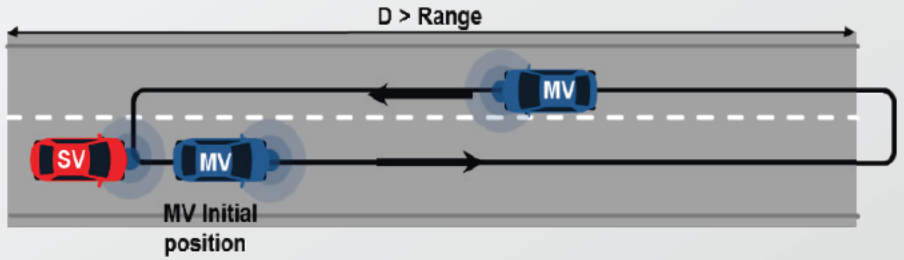


Initial Field Test Results: Line-of-Sight (LOS) Range

Ford/Qualcomm Measurements conducted in Fowlerville, Michigan

Source: Ford, 5GAA Workshop, April 26, 2018



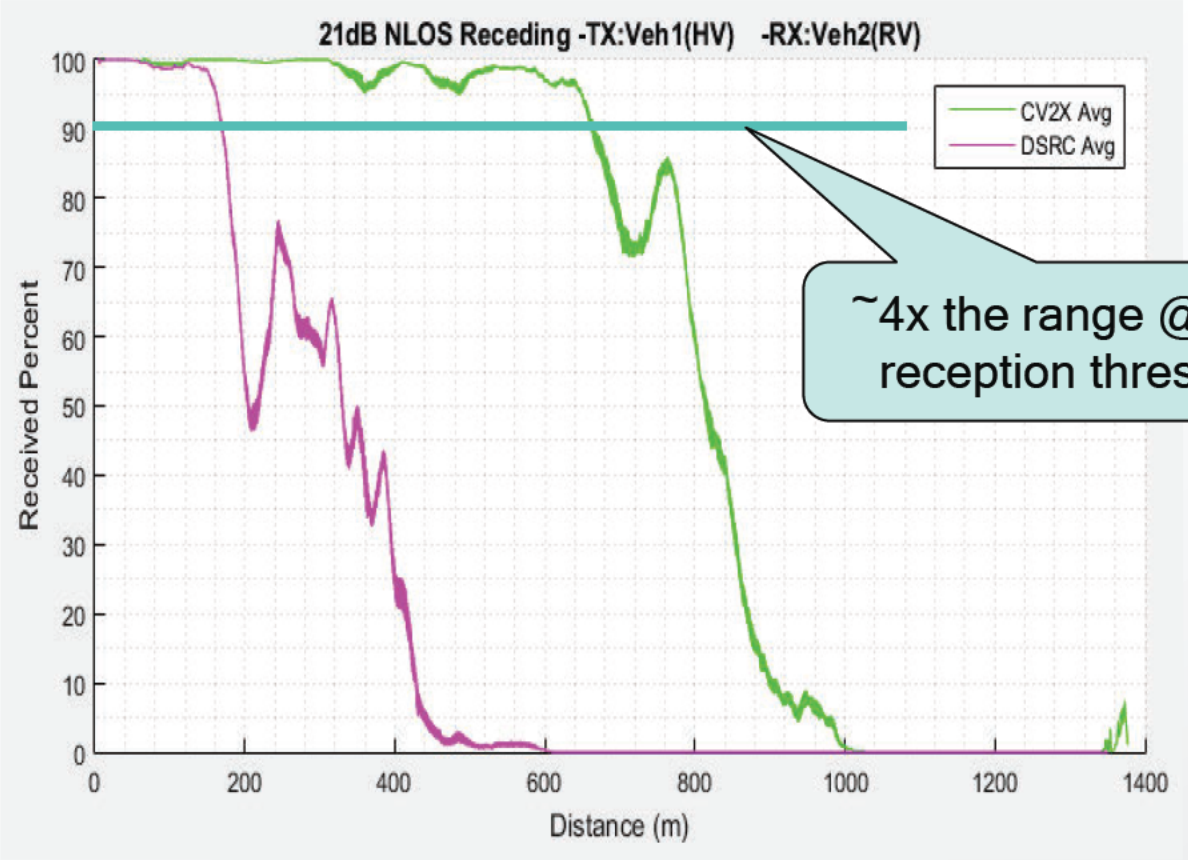


Ford in partnership with Qualcomm have been testing C-V2X devices since 2H17. Work to be completed in 2H18.

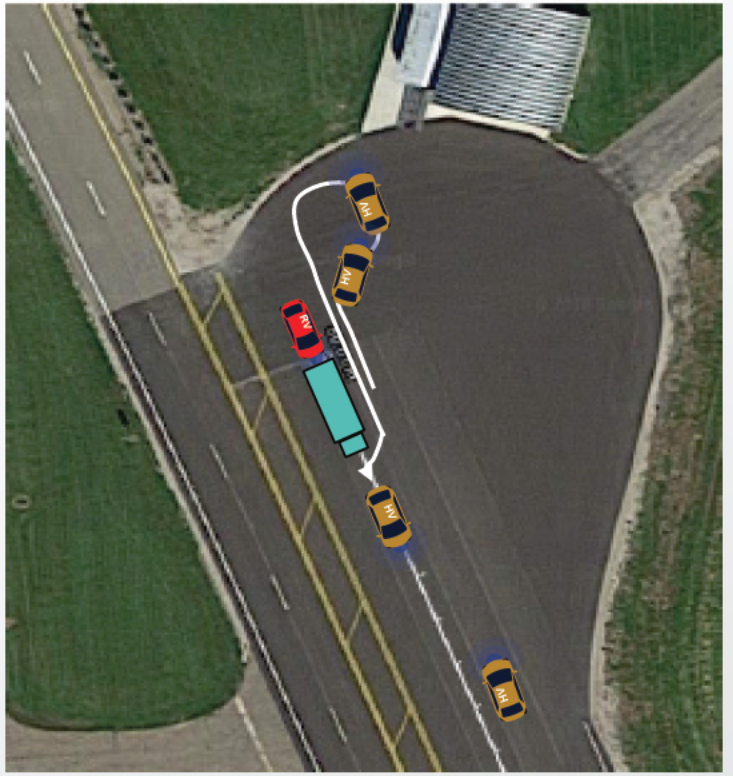
Initial Field Test Results: Non-Line-of-Sight (NLOS) Range

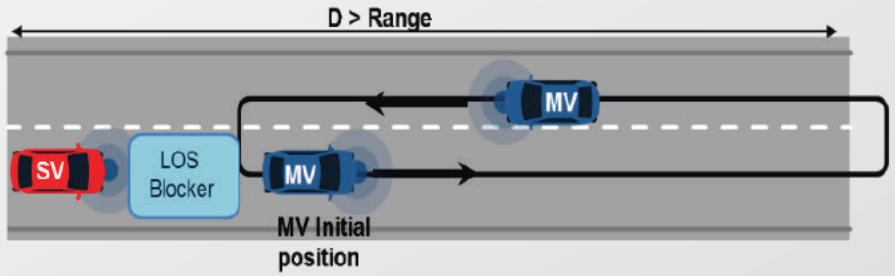
Ford/Qualcomm Measurements conducted in Fowlerville, Michigan

Source: Ford, 5GAA Workshop, April 26, 2018



~4x the range @ 90% reception threshold





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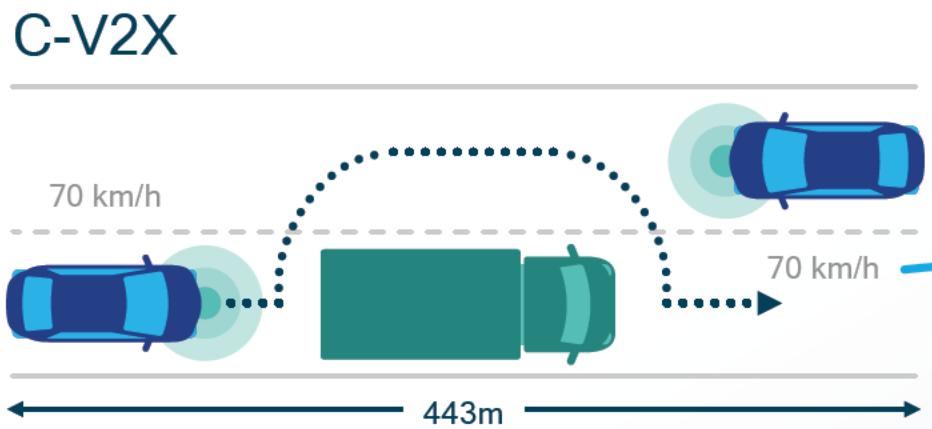
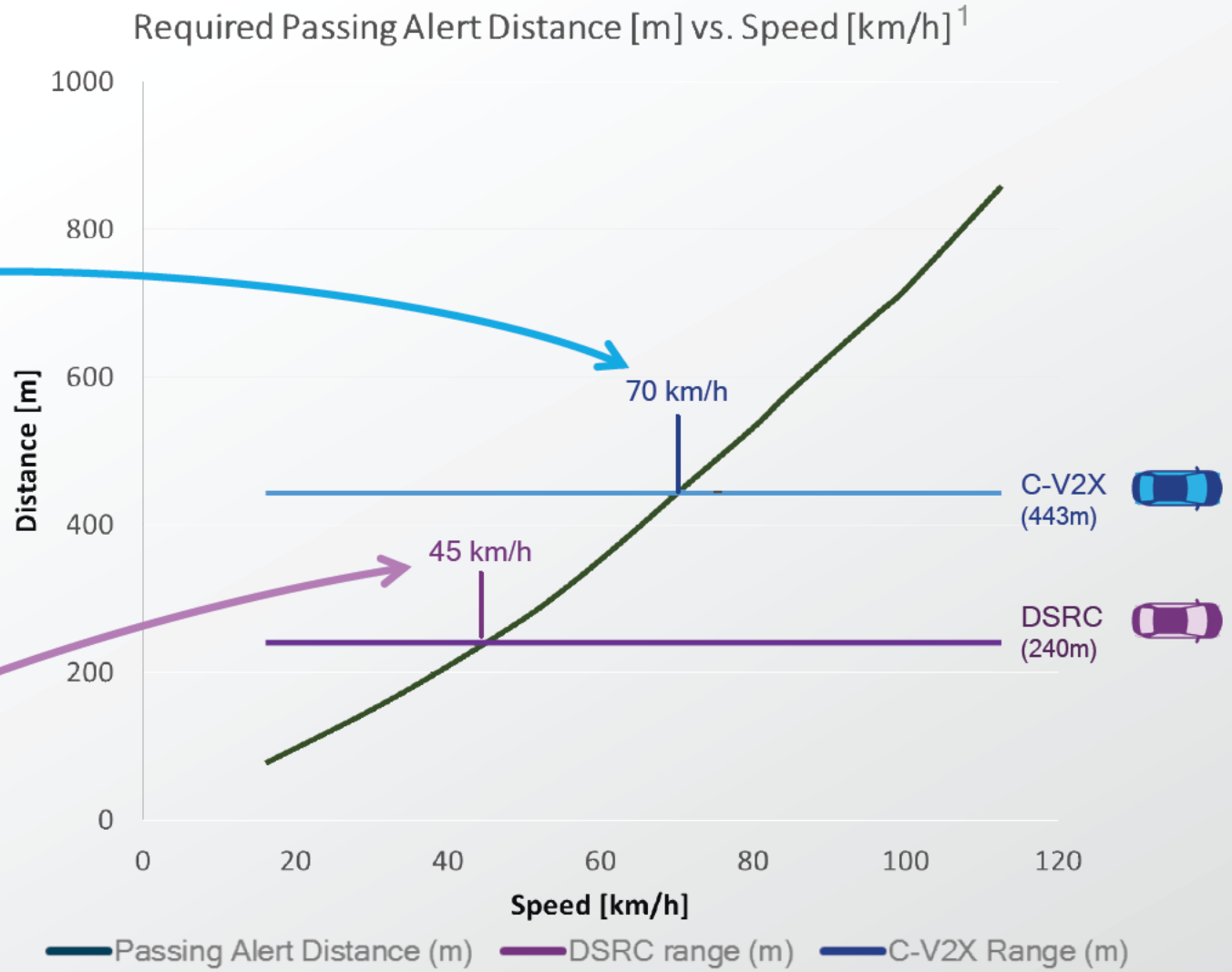
More reliability at higher speeds and longer ranges

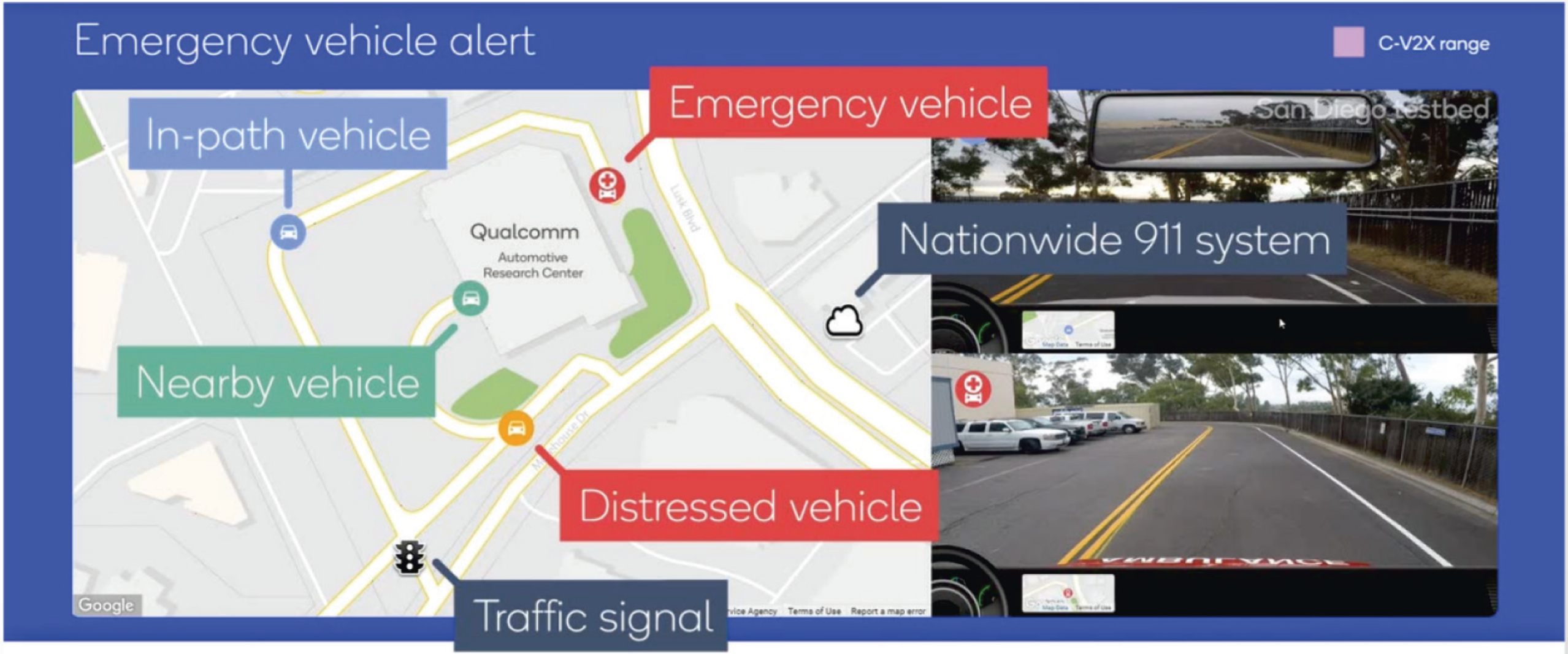
Do not pass warning (DNPW) use case example





1. Calculations based on AASHTO "green book"

C-V2X trial platform showcased at MWC 2018



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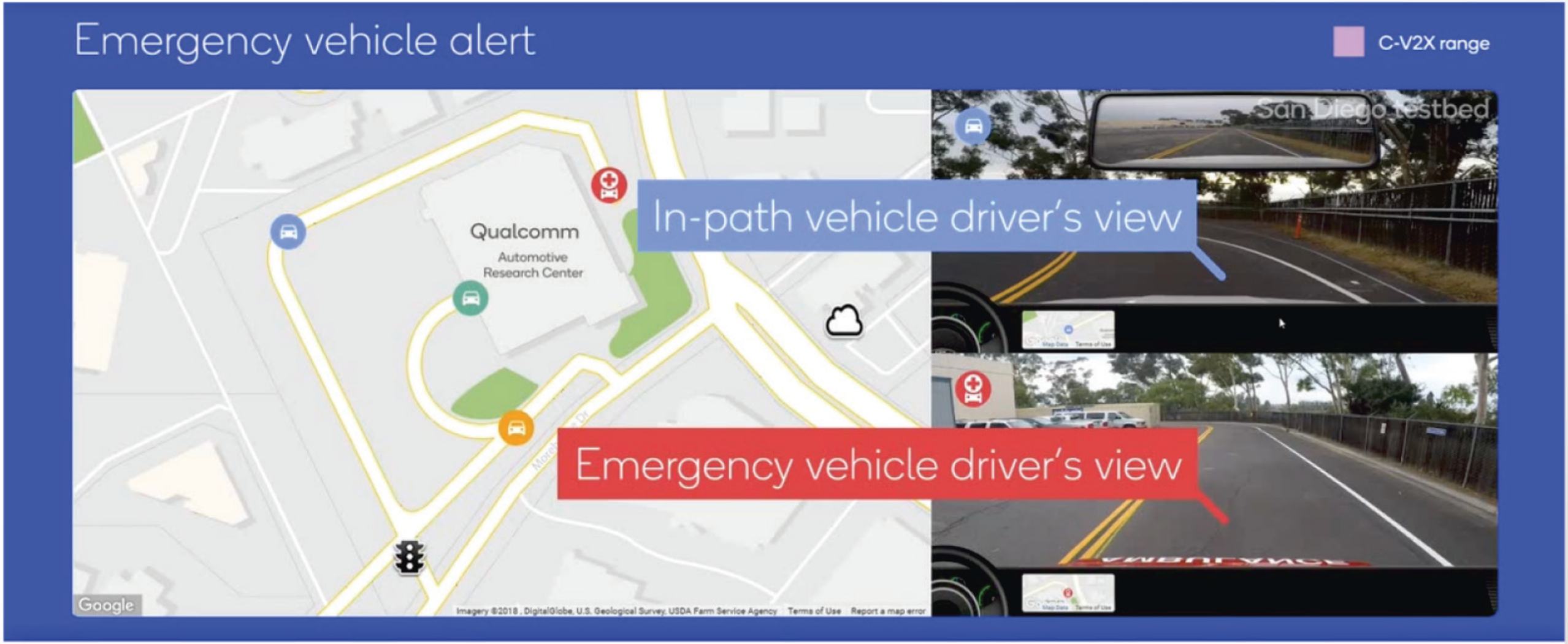
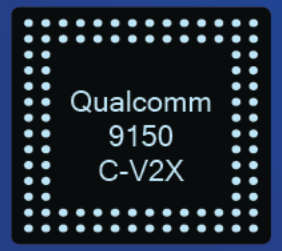


Conclusion



C-V2X offers 2 complementary modes: Direct and Network Mode

C-V2X provides a higher performance radio than 802.11p, employing newer and more advanced technologies developed over the last 2 decades, while reusing upper layers defined by the automotive industry

Initial test results are consistent with simulations and encourage the deployment of C-V2X technology

Test procedures and conformity assessments are currently reviewed and harmonized within the 5G Automotive Association (5GAA)

Large-Scale product commercialization has started and will be fostered by cellular modems being embedded for telematics and eCall

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

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