Networking for Connected Vehicles : Prospects & Challenges

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Outline

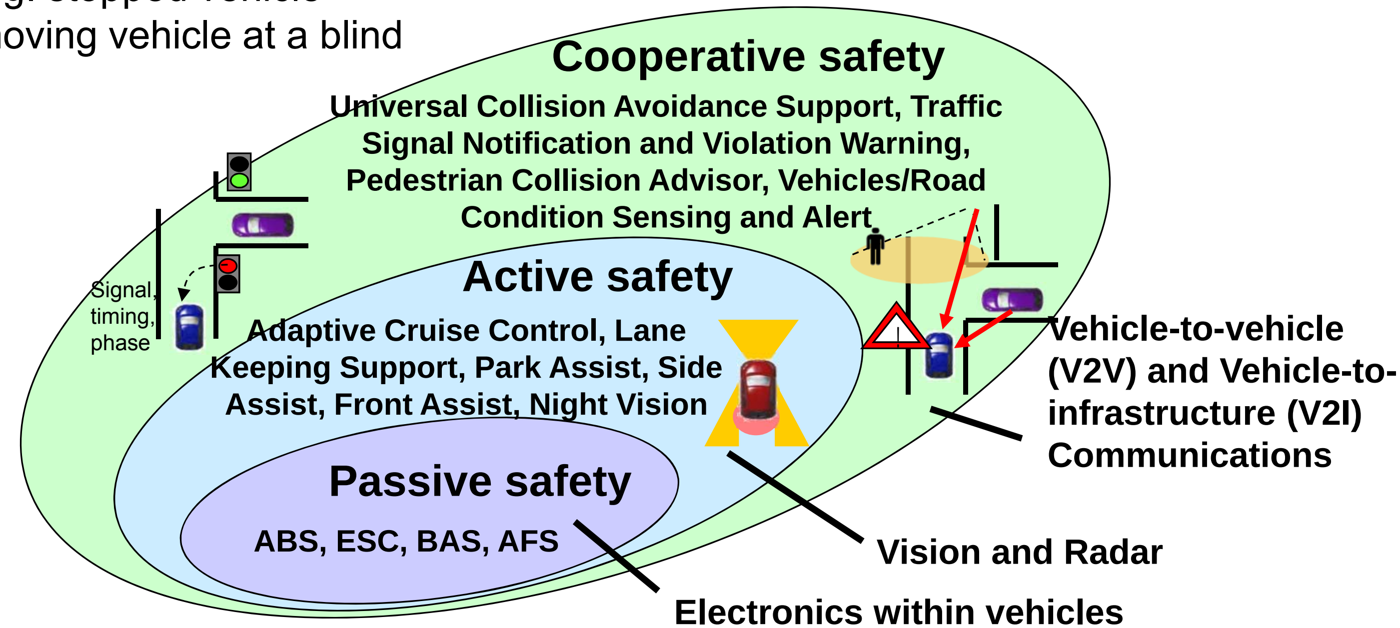
Part I: **Connected Vehicles: Use Cases from a Networking Perspective**

Part II: **Technology Options & Current Challenges**

- A Happy Mess !

Connected Vehicles: v-2-v

- **Vehicle-to-Vehicle (V2V) Communications**
  - Allows nearby vehicles to exchange position data to warn drivers of potential collisions
  - Capable of warning drivers of potential hazards not visible to sensors (e.g. stopped vehicle blocked from view, or moving vehicle at a blind intersection)

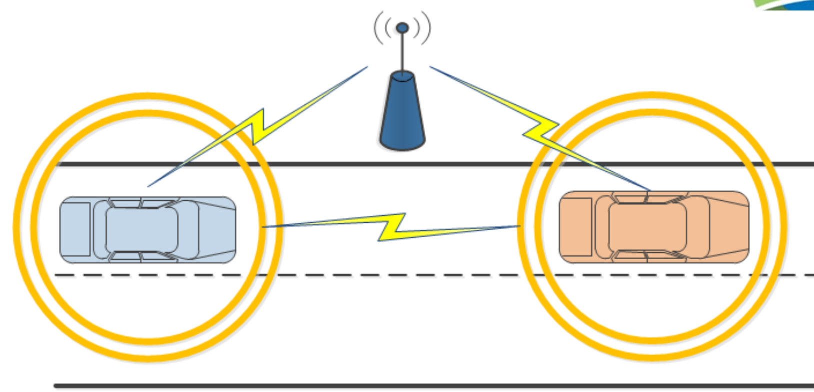


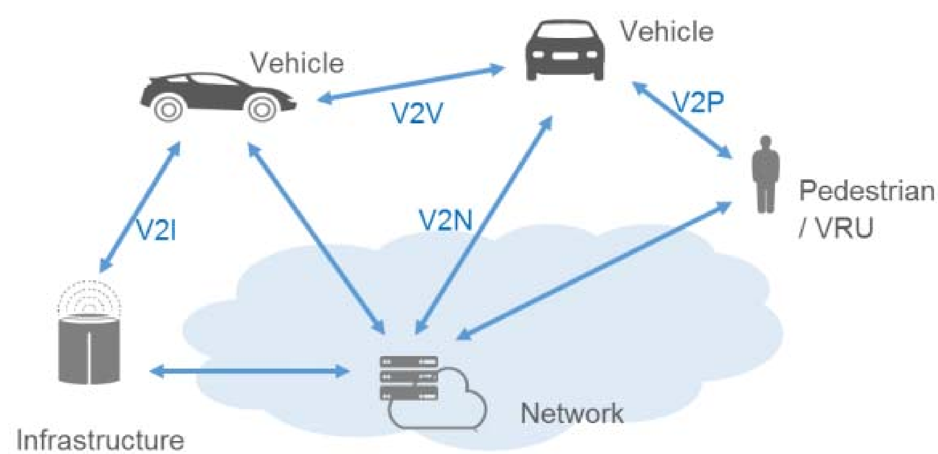
Radar	(< 200 m)
Camera	(< 80 m)
Ultrasonic	(< 4m)

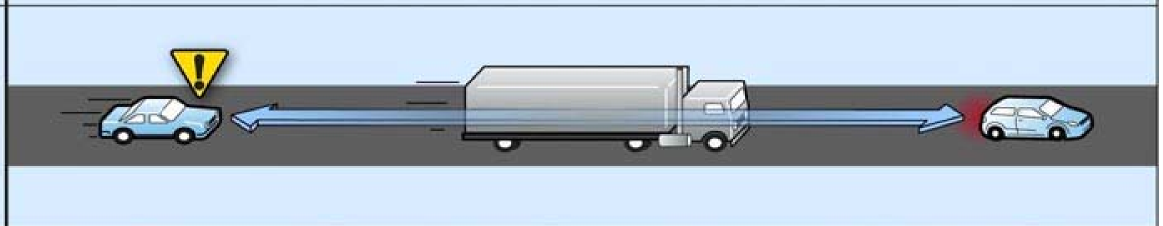
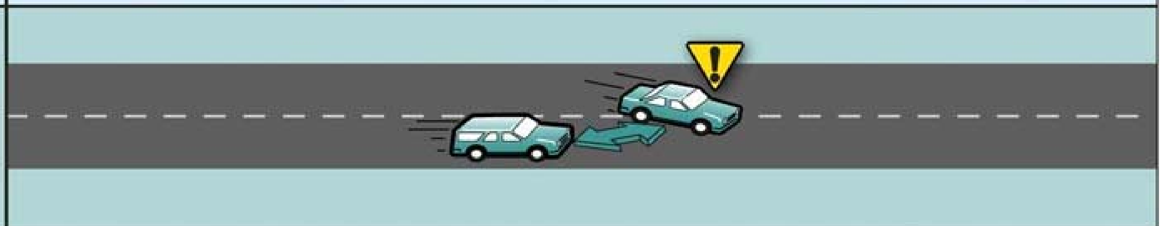
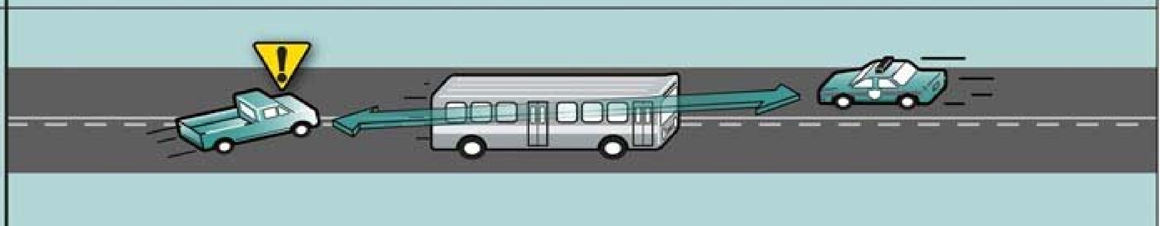
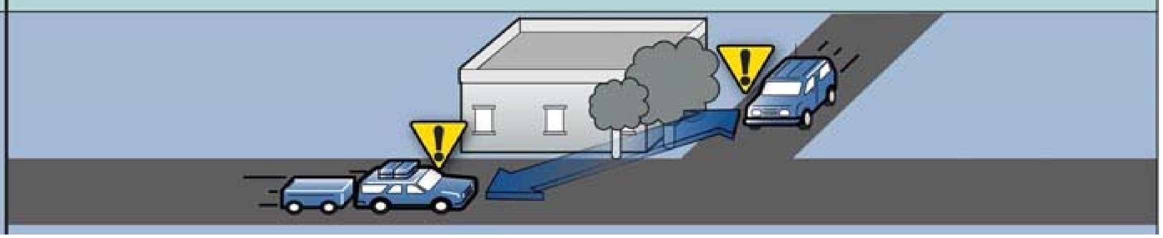
V2V-Based Cooperative Applications

– Address crashes/hazards that cannot be prevented by current in-vehicle camera and sensor-based technologies (“vehicle-resident” technologies)
- Not restricted by line-of-sight limitations

– V2V communications (BSMs) contain additional information, such as path predictions and driver actions (braking, steering) not available from traditional sensors.



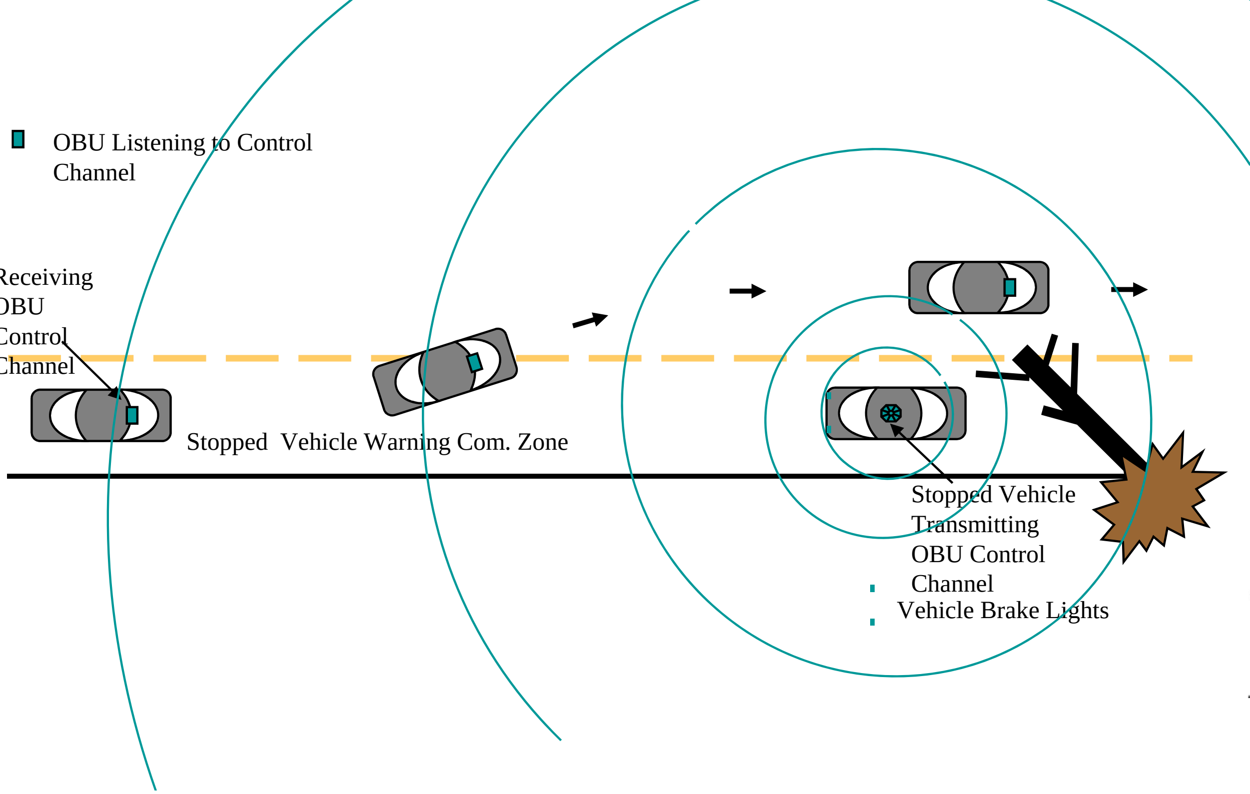


Scenario and warning type		Scenario example
Rear end collision scenarios	**Forward collision warning** Approaching a vehicle that is decelerating or stopped.	
	Emergency electronic brake light warning Approaching a vehicle braking hard or stopped in roadway but not visible due to obstructions.	
Lane change scenarios	**Blind spot warning** Beginning lane change that could encroach on the travel lane of another vehicle traveling in the same direction; can detect vehicles already in or soon to be in blind spot.	
	Do not pass warning Encroaching onto the travel lane of another vehicle traveling in opposite direction.	
Intersection scenario	**Intersection warning** Encroaching onto the travel lane of another vehicle with whom driver is crossing paths at a blind intersection or an intersection without a traffic signal.	

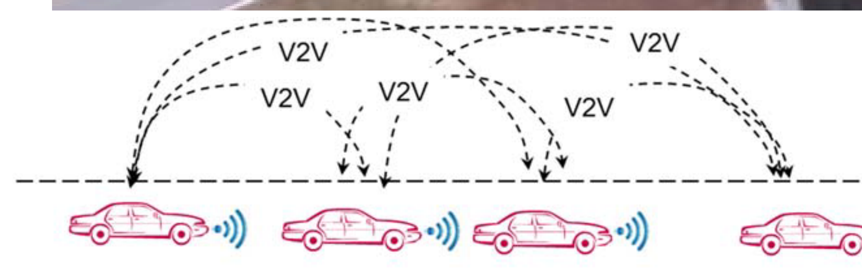
5.9 GHz DSRC V-2-V APPLICATIONS

Stopped Vehicle Warning (SVW) message is sent in the direction of arriving traffic when the stopping vehicle's brakes are applied and its speed drops **20 mph** below the speed limit of the road or its speed drops below **5 mph**. Sent every 100ms with range of 1000 ft

STOPPED VEHICLE WARNING

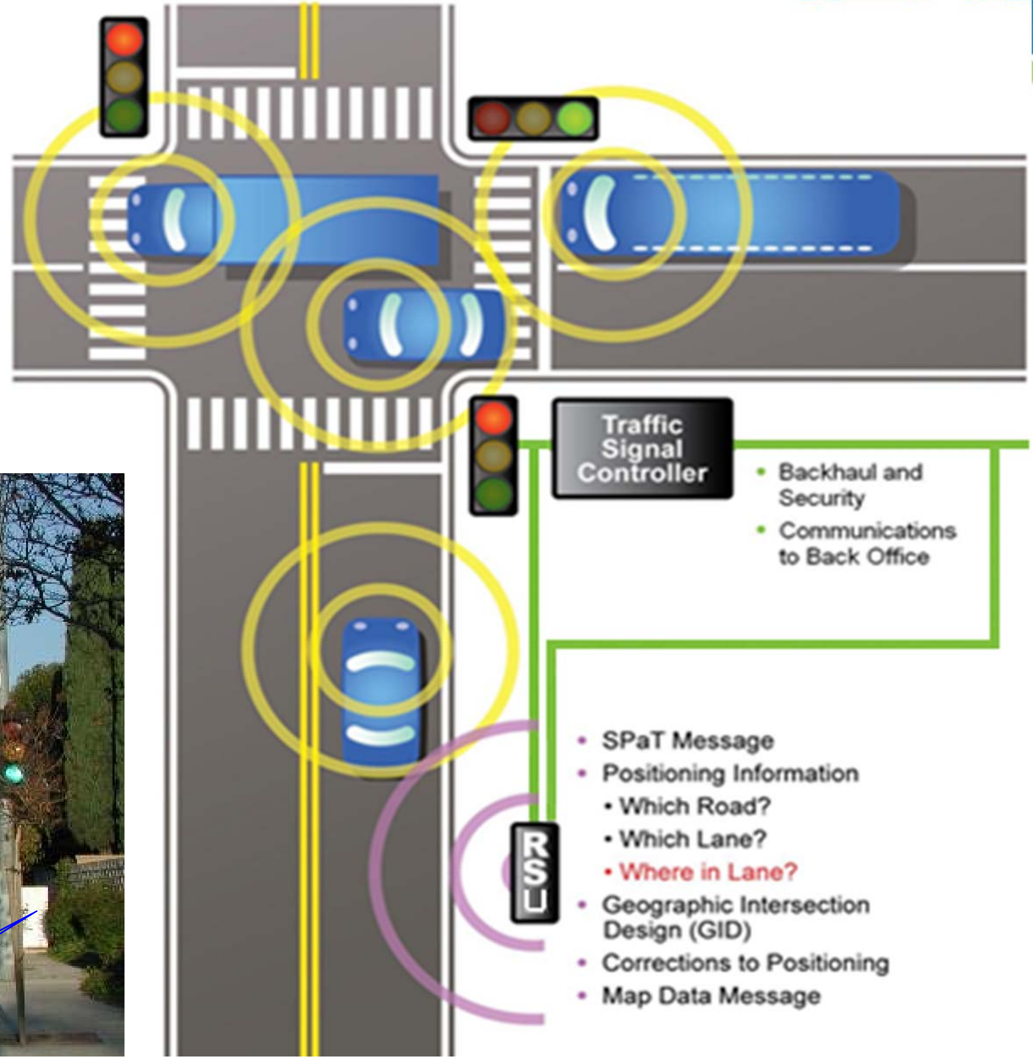


Cooperative Assistive Cruise Control (CACC) - Platooning



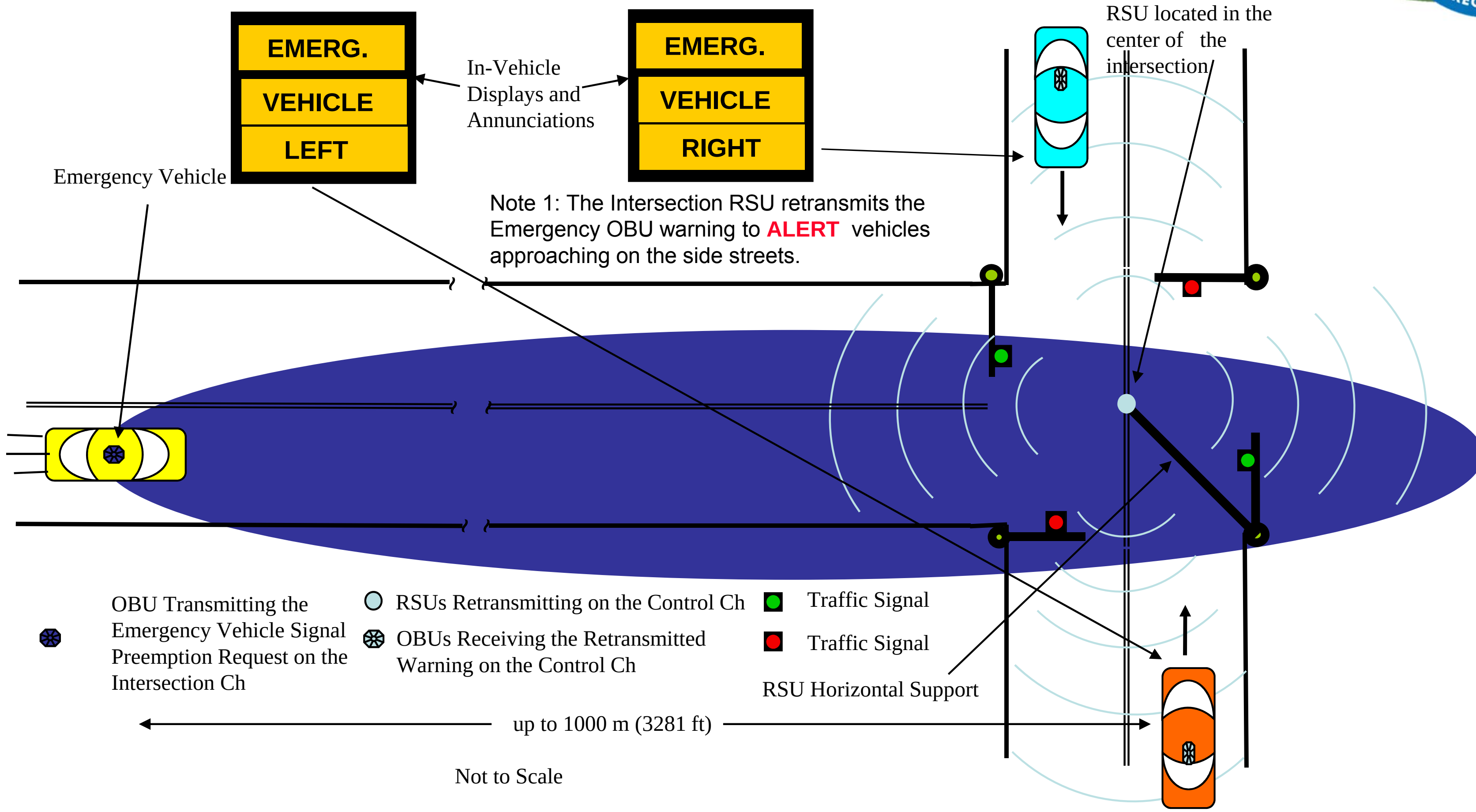
Connected Vehicles: v-2-I

- **Vehicle-to-Infrastructure (V2I) Communications**
  - Inform drivers about weather, traffic, work zones etc.
  - Allows for coordinated signal timing and enhanced parking information systems to improve urban traffic flow



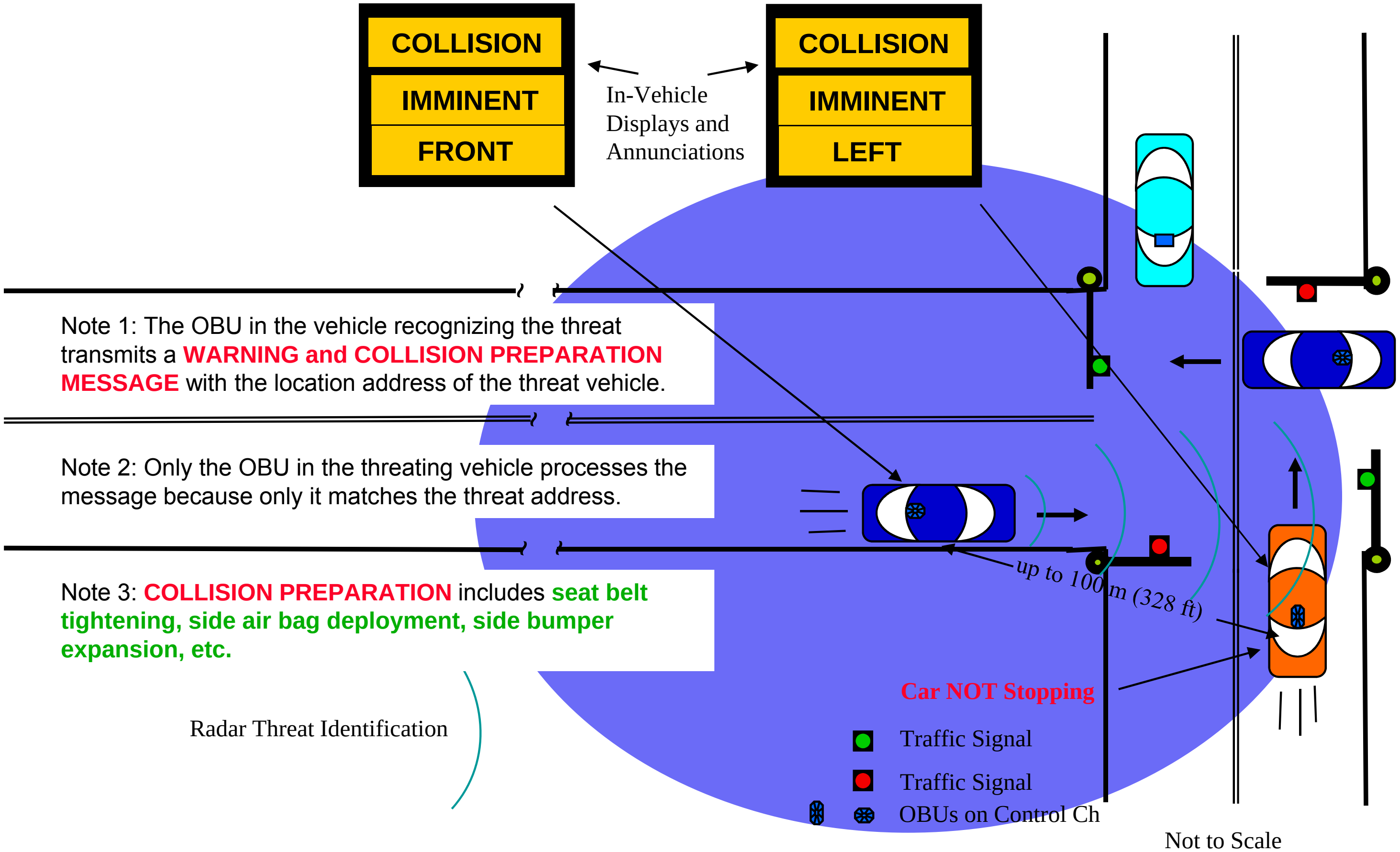
5.9 GHz DSRC ROADSIDE TO VEHICLE APPLICATION

EMERGENCY VEHICLE APPROACH WARNING - INTERSECTION RELAY



5.9 GHz DSRC VEHICLE TO VEHICLE APPLICATION

IMMINENT COLLISION WARNING



Note 1: The OBU in the vehicle recognizing the threat transmits a **WARNING and COLLISION PREPARATION MESSAGE** with the location address of the threat vehicle.

Note 2: Only the OBU in the threating vehicle processes the message because only it matches the threat address.

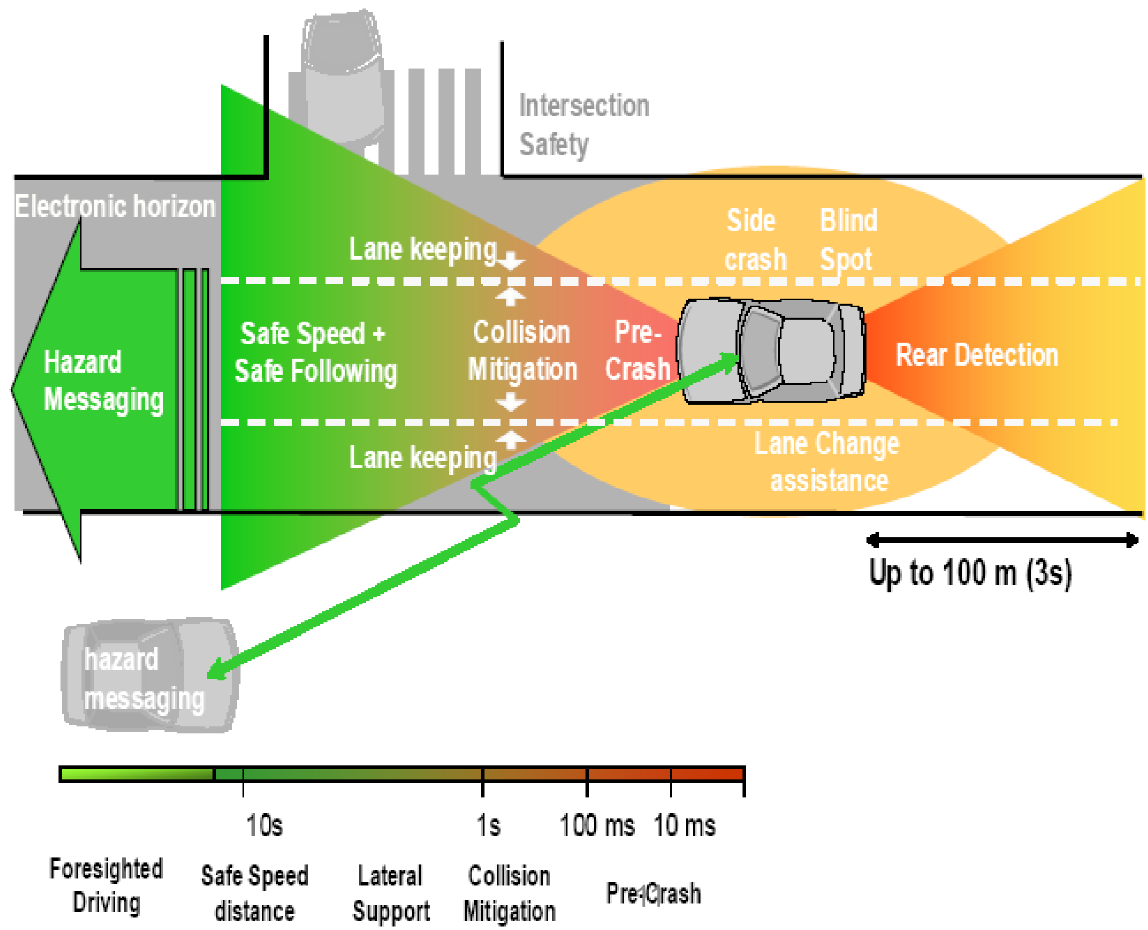
Note 3: **COLLISION PREPARATION** includes **seat belt tightening, side air bag deployment, side bumper expansion, etc.**

V2X: Vehicle-to-everything

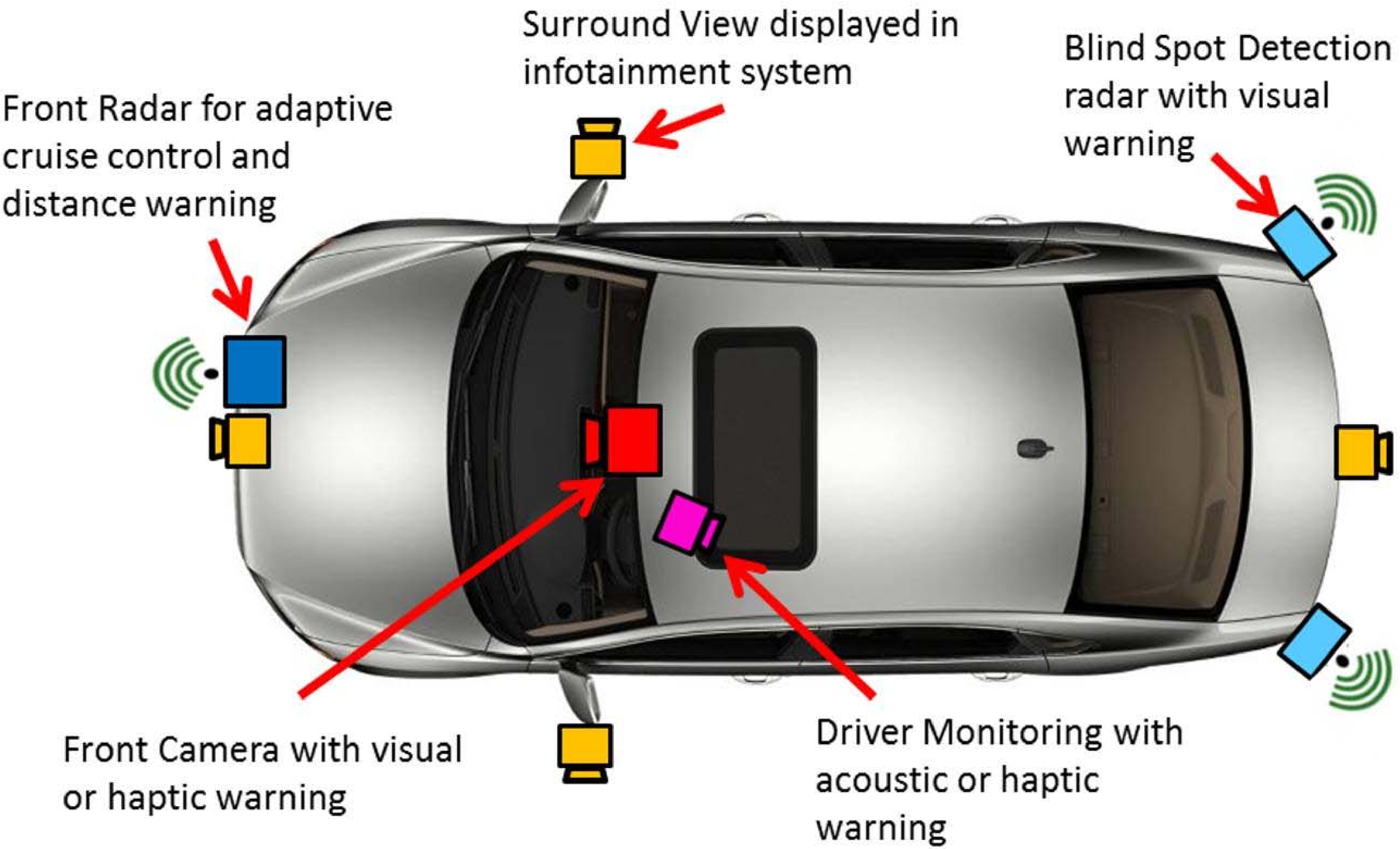
(beyond v-2-v & v-2-I)

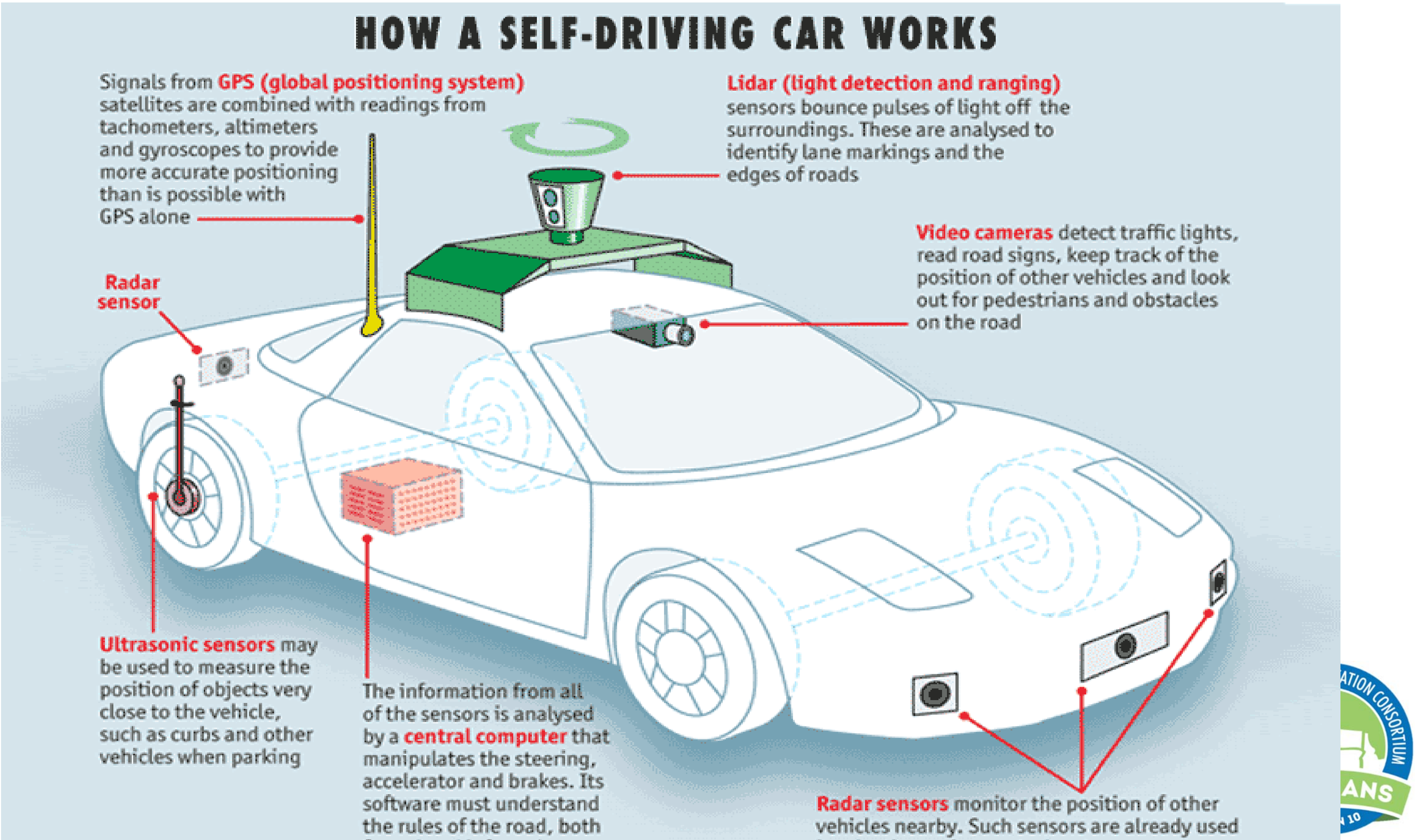
Advanced Driver Assistance Systems

- Collision warning and automatic braking
- Adaptive front headlights
- Lane departure warning
- Lane keeping assistance
- Blind spot
- Driver monitoring
- Speed alert
- Assisted parking
- Overtaking assistance
- Signal violation warning
- …. Cooperative systems
- V2V, V2I, V2X



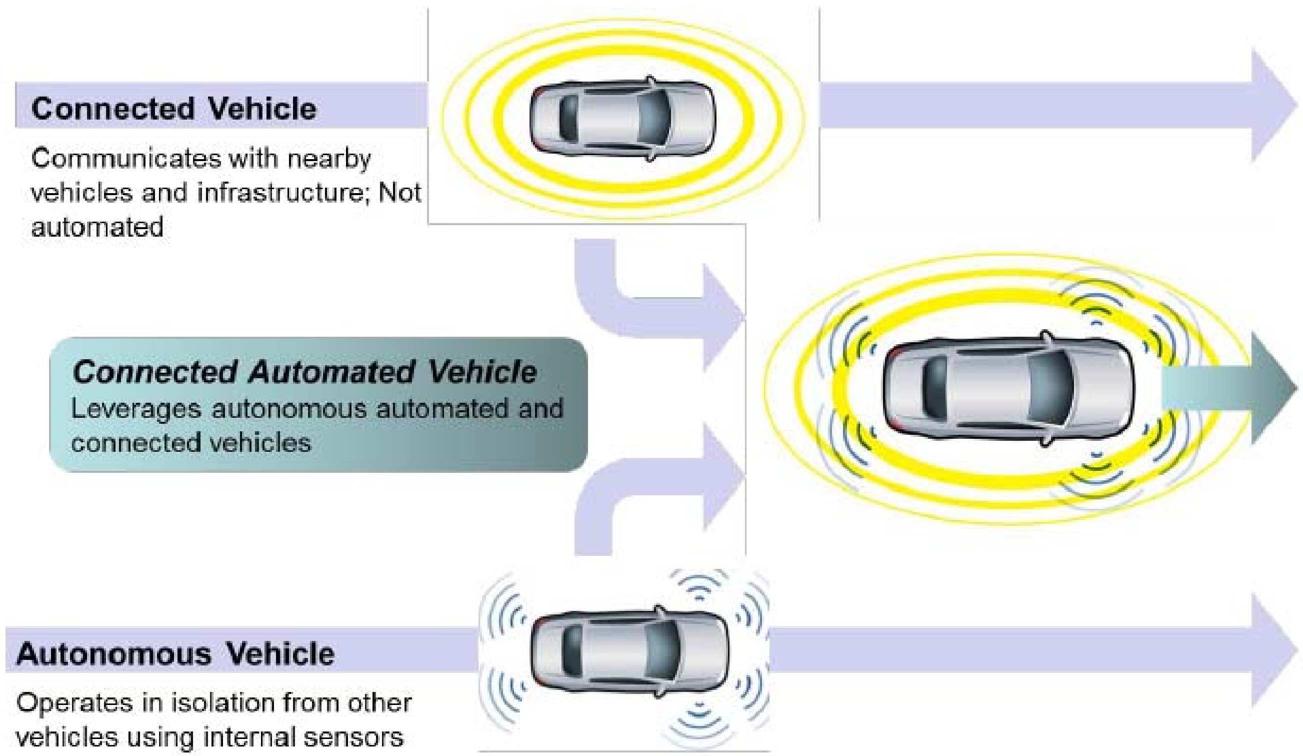

UBER
ADVANCED
TECHNOLOGIES
CENTER
UBERATC.COM/CAR


Surround View displayed in infotainment system
Blind Spot Detection radar with visual warning
Front Radar for adaptive cruise control and distance warning
Front Camera with visual or haptic warning
Driver Monitoring with acoustic or haptic warning


HOW A SELF-DRIVING CAR WORKS
Signals from GPS (global positioning system) satellites are combined with readings from tachometers, altimeters and gyroscopes to provide more accurate positioning than is possible with GPS alone
Lidar (light detection and ranging) sensors bounce pulses of light off the surroundings. These are analysed to identify lane markings and the edges of roads
Video cameras detect traffic lights, read road signs, keep track of the position of other vehicles and look out for pedestrians and obstacles on the road
Radar sensor
Ultrasonic sensors may be used to measure the position of objects very close to the vehicle, such as curbs and other vehicles when parking
The information from all of the sensors is analysed by a central computer that manipulates the steering, accelerator and brakes. Its software must understand the rules of the road, both
Radar sensors monitor the position of other vehicles nearby. Such sensors are already used

Planning for CAV Convergence

- Connectivity enables V2X but also improved autonomy
- ITS planning should consider connected and autonomous markets
- Continue developing and testing V2X applications
- Be aware of technology evolution – momentum gaining for using both DSCR and 5G



<u>Part II</u>: Technology Options & Current Challenges

- A Happy Mess !

DSRC

Dedicated Short Range Communications: short to medium range communications service that supports both Public Safety and Private operations in roadside-2- vehicle and vehicle -2-vehicle environments. Attempts to providing reliable, low latency communication over relatively small communication zones (< 1 Km)

- **FCC sets aside 75 MHz (5.850-5.925 GHz) in 1999 [licensed use, free]**
- **ASTM E17.51 DSRC Standards Writing Group selected & standardized IEEE 802.11a/RA Physical Layer + 802.1 Medium Access Control (MAC) Layer. (RA – Road Access), Oct. 2001.**
- **Since then: automakers + vendors have invested in V2X technology, but no real uptake by auto makers till recently (GM earliest to integrate DSRC in-vehicle, now Honda & VW, 2017)**
  - ❑ **Expectation: Public Safety should be a Federal Mandate !**

- **NHTSA's Notice of Proposed Rulemaking 2016 49 CFR Part 571 / Docket No. NHTSA-2016-0126**

aimed at mandating DSRC V2V technology on all light vehicles and standardizing the format of V2V transmission

- ❑ **No possibility of a Federal mandate currently → technology choices left to private sector & state/local agencies.**

802.11 for Next Generation V2X Communication

- **802.11p - matured and robust for Dedicated Short Range Communications (DSRC) applications**
  - **short packets (BSMs), delivered over small ranges rapidly (100 ms) reliably**
- **Needs have escalated significantly beyond the original goals:**
  - **V2X applications: vehicle to anything on/side of the road, beyond just v2v and v2I**
  - **Significant desire for increased rates for v2I, support for streaming type (continuous connectivity) applications**
- **802.11 WLAN standards (on which .11p is based) have continue to evolved – to support much higher data rates, and now, lower latencies**

→ **Leverage the evolution of the 802.11 technologies to future proof 11p/DSRC for new application scenarios (v2X)**

Direction for a long term roadmap (DSRC)

- 802.11 PHY has evolved after 802.11p amendments (.11n → 11ac → 11ax) with proven technologies, e.g. advanced coding, varying symbol/GI durations, higher data rates, longer range and better high Doppler performance.
- Natural to adopt some recent 802.11 technologies for new V2X applications, e.g. for higher throughput applications, and/or better reliability/efficiency.
- Backward compatible with 802.11p.
- New design requirements **from** existing field trials may also be addressed.

FCC Pushing Spectrum Sharing for 5.9 GHz

- June 1, 2016: FCC notice in Rev. Part 15 of Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band ET Docket No. 13-49

→ reconcile use of 5.9 GHz band between DSRC and Wi-Fi

– "Detect and Vacate" - DSRC and Wi-Fi would share the spectrum, unlicensed devices would detect DSRC operations and vacate the spectrum.

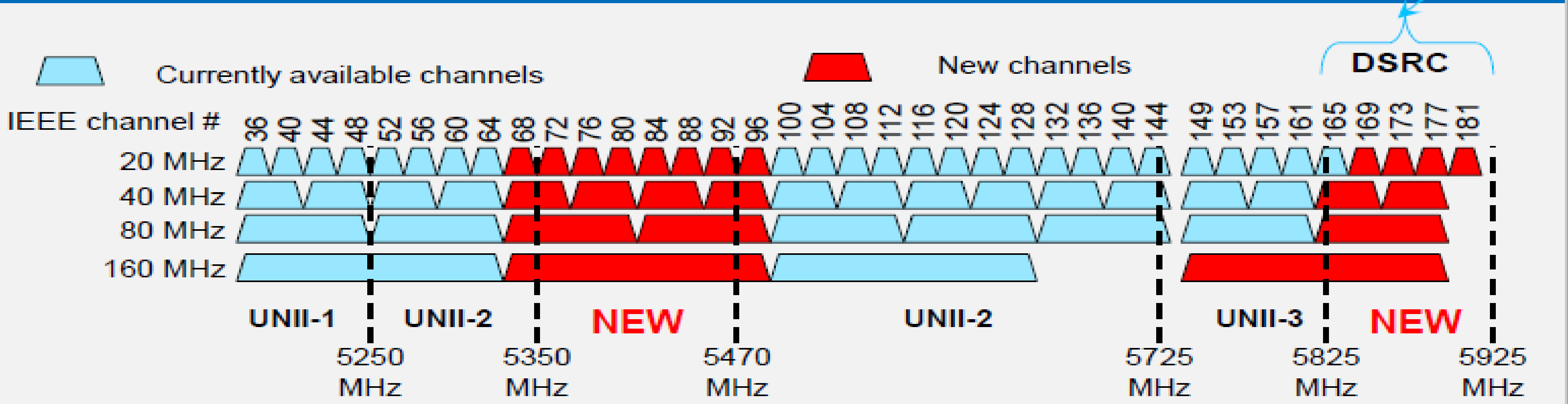
– "Rechannelization" – Split the DSRC band into 2 contiguous blocks
  - Upper 30 MHz exclusively for safety-related communications; Lower 45 MHz for non-safety DSRC communications

➢ **Concerns about ability to protect DSRC from interference!**

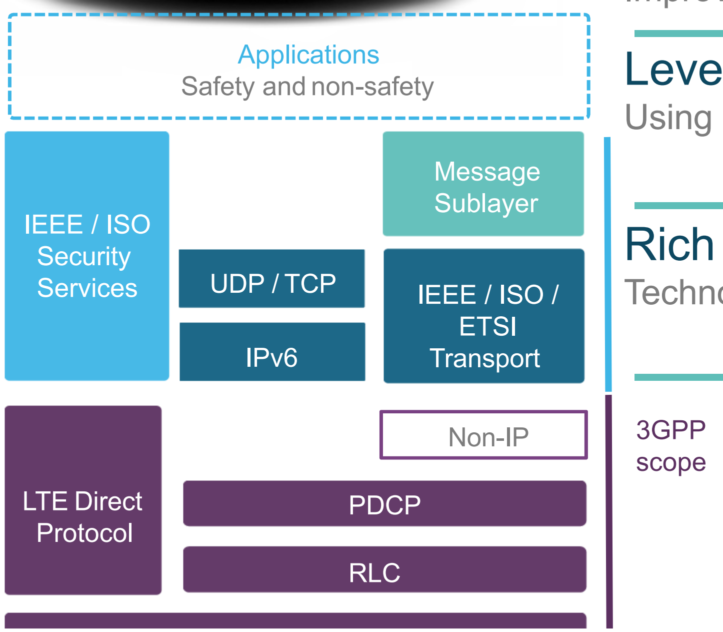
Spectrum Sharing- 802.11 in 5.9 Ghz

- Wide bandwidth channels desired to support high throughput requirements
- At the same time, large number non-overlapping channels desired to support high QoS requirements
  - To avoid co-channel interference
- Current U-NII spectrum allows only
  - Six 80 MHz channels
  - Two 160 MHz channels
- Additional unlicensed use of 5.35-5.47 GHz and 5.85-5.925 GHz would potentially allow a total of
  - Nine 80 MHz channels (Three new)
  - Four 160 MHz channels (Two new)

Possibly shared between DSRC and WLAN



Cellular V2X (C-V2X): Building on LTE D-2-D



Part of Release 14 of the global 3GPP standard

C-V2X specification completed Jun. 2017[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

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

Evolving LTE Direct device-to-device

Release 12
D2D platform for consumer and public safety use cases

Release 13
Expanded D2D discovery and D2D communications

Release 14 and beyond
Multi-hop communication and more use cases

Discovery of 1000s of devices/services in ~500m

More flexible discovery such as restricted/private[1] and inter-frequency

Additional D2D communication capabilities, e.g. multi-hop for IoT

Reliable one-to-many communications (in- and out-of-coverage)[2]

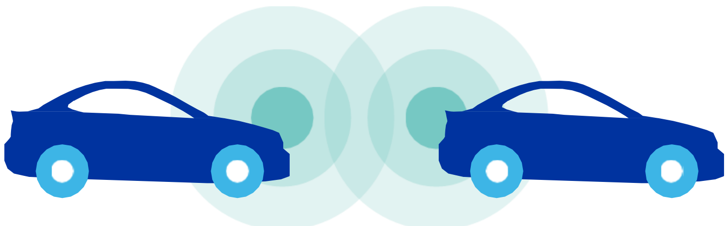
Device-to-network relays[2]

Enhancements for vehicle-to-everything (V2X)

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

C-V2X: 2 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

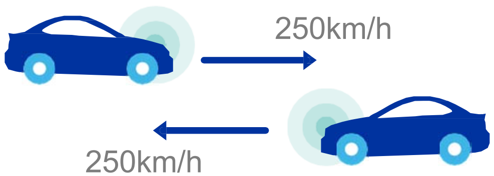
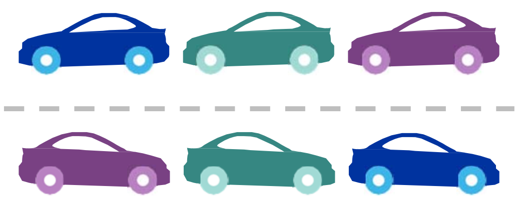
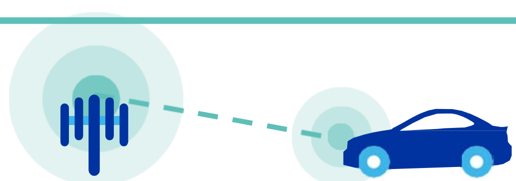
Uu interface
e.g. accident 1 kilometer ahead

Network communications

Using LTE Broadcast to broadcast messages from a V2X server to vehicles and beyond. Vehicles can send messages to server via unicast.

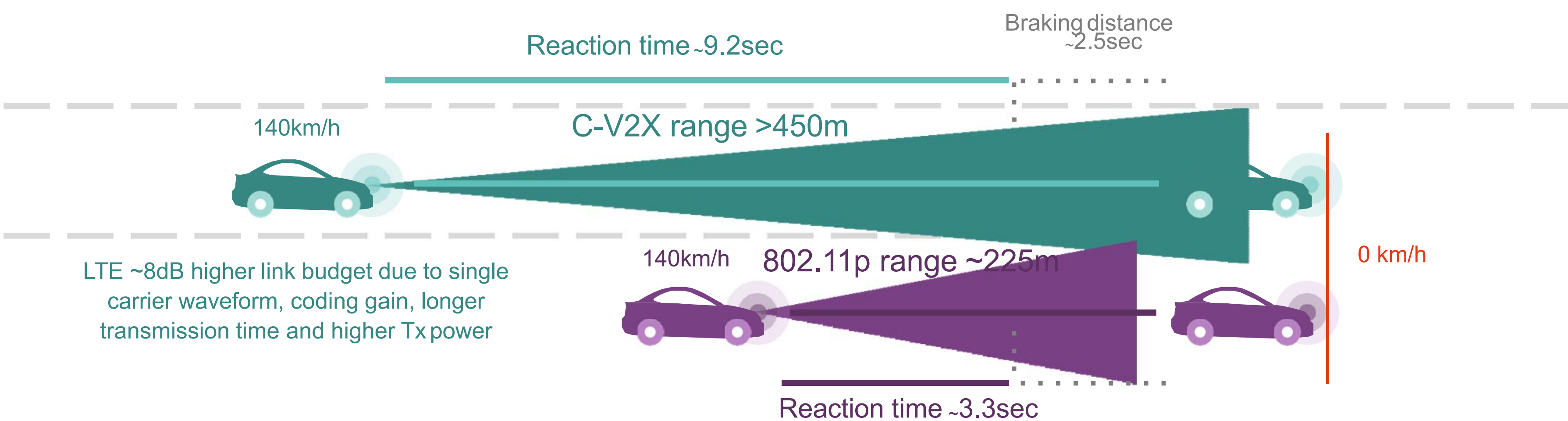
- Wide area networks communications
- Leverages existing LTE networks
- More latency tolerant use cases, e.g. V2N situational awareness

Overcoming the challenges of V2X

	V2X Challenges	C-V2X Solutions
	**High relative speeds** Leads to significant Doppler shift / frequency offset	**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

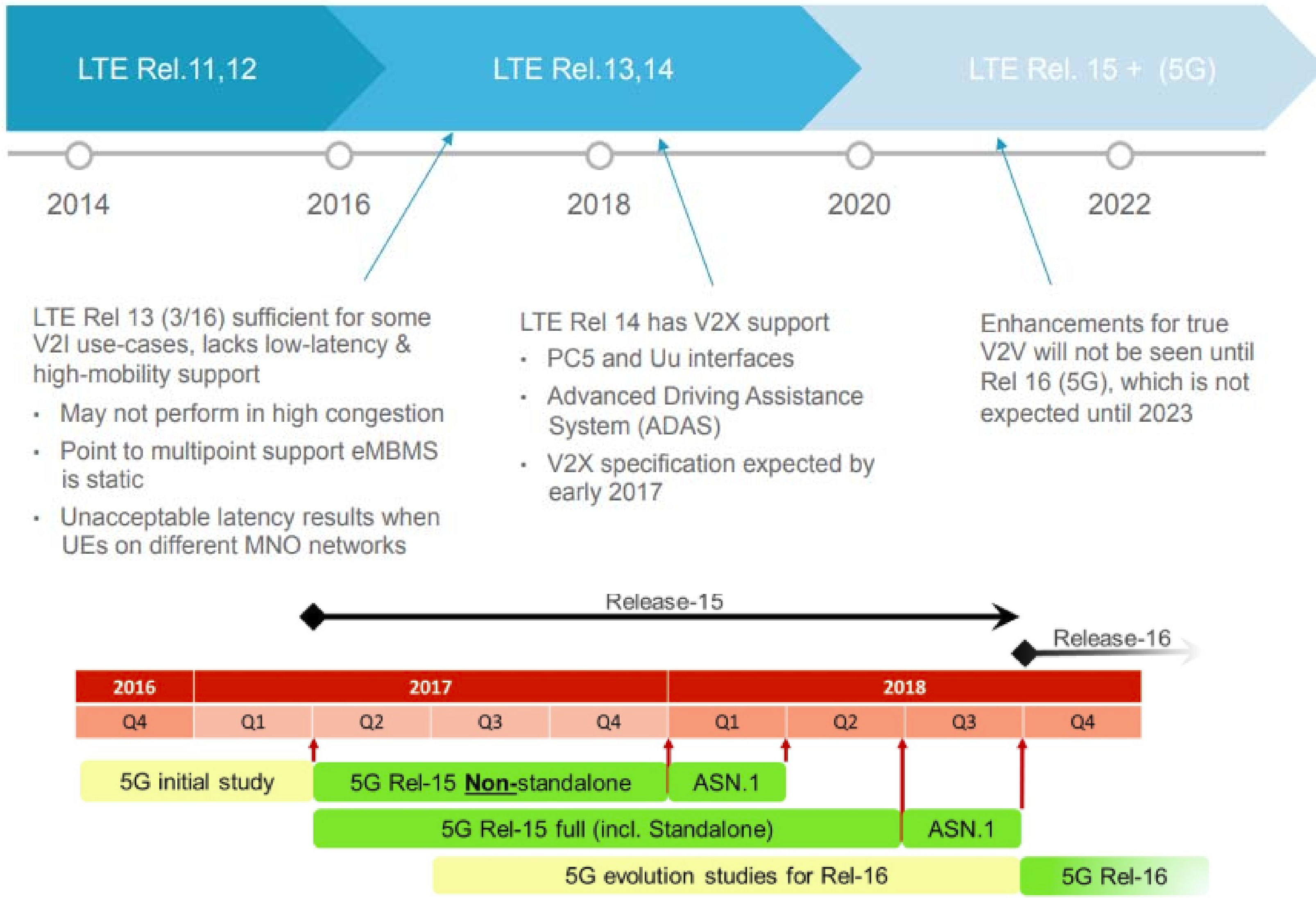
Increased situational awareness

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

5G C-V2X vs DSRC ?

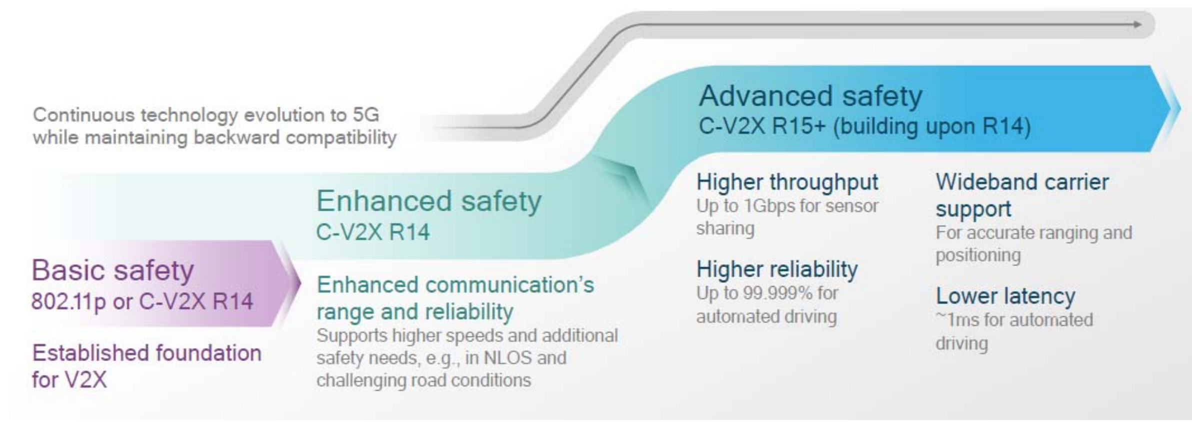
KEY ELEMENTS	DSRC/ IEEE 802.11	Rel 14 C-V2X	5G C-V2X (Rel 15,16) (expected)
Out-of-network operation	✓	✓	✓
Support for V2V	✓	✓	✓
Support for safety-critical uses	✓	✓	✗*
Support for V2P	✓	✓	✓
Support for V2I	*limited*	✓	✓
Support for multimedia services	✗	✓	✓
Network coverage support	*limited*	✓	✓
Global economies of scale	✗	✓	✓
Regulatory/testing efforts	✓	*limited*	✗
Very high throughput	✗	✗	✓
Very high reliability	✗	✗	✓


LTE Rel.11,12
LTE Rel.13,14
LTE Rel. 15 + (5G)
2014
2016
2018
2020
2022
LTE Rel 13 (3/16) sufficient for some V2I use-cases, lacks low-latency & high-mobility support
May not perform in high congestion
Point to multipoint support eMBMS is static
Unacceptable latency results when UEs on different MNO networks
LTE Rel 14 has V2X support
PC5 and Uu interfaces
Advanced Driving Assistance System (ADAS)
V2X specification expected by early 2017
Enhancements for true V2V will not be seen until Rel 16 (5G), which is not expected until 2023
Release-15
Release-16
2016
2017
2018
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
5G initial study
5G Rel-15 Non-standalone
ASN.1
5G Rel-15 full (incl. Standalone)
ASN.1
5G evolution studies for Rel-16
5G Rel-16

CONCLUDING REMARKS

Technology Options & Current Challenges - A Happy Mess !

- 802.11p (DSRC)
  - Products ready - private manufacturers now beginning to integrate into vehicles.
  - Testing at State/Local levels: e.g. Utah's Salt Lake City Corridor
  - GOOD FOR LIMITED ORIGINAL GOALS (reliable delivery of control info)
- Cellular-V2X (C-V2X):
  - Not expected for several years
  - More advanced PHY layer (coding etc.) under network control
  - supports diff. set of use cases - high throughput, lower latency (1 ms in 5G)



BACKUP

DSRC/WAVE Overview

- **WAVE: Wireless Access in Vehicular Environments**
  - IEEE 1609 (North America)
  - ETSI EN 302 (Europe)
  - Intended to provide automatic wireless communication services in transportation environments
  - Supports services to
    - Improve traveler safety
    - Reduce traffic congestion
    - Reduce fossil fuel consumption

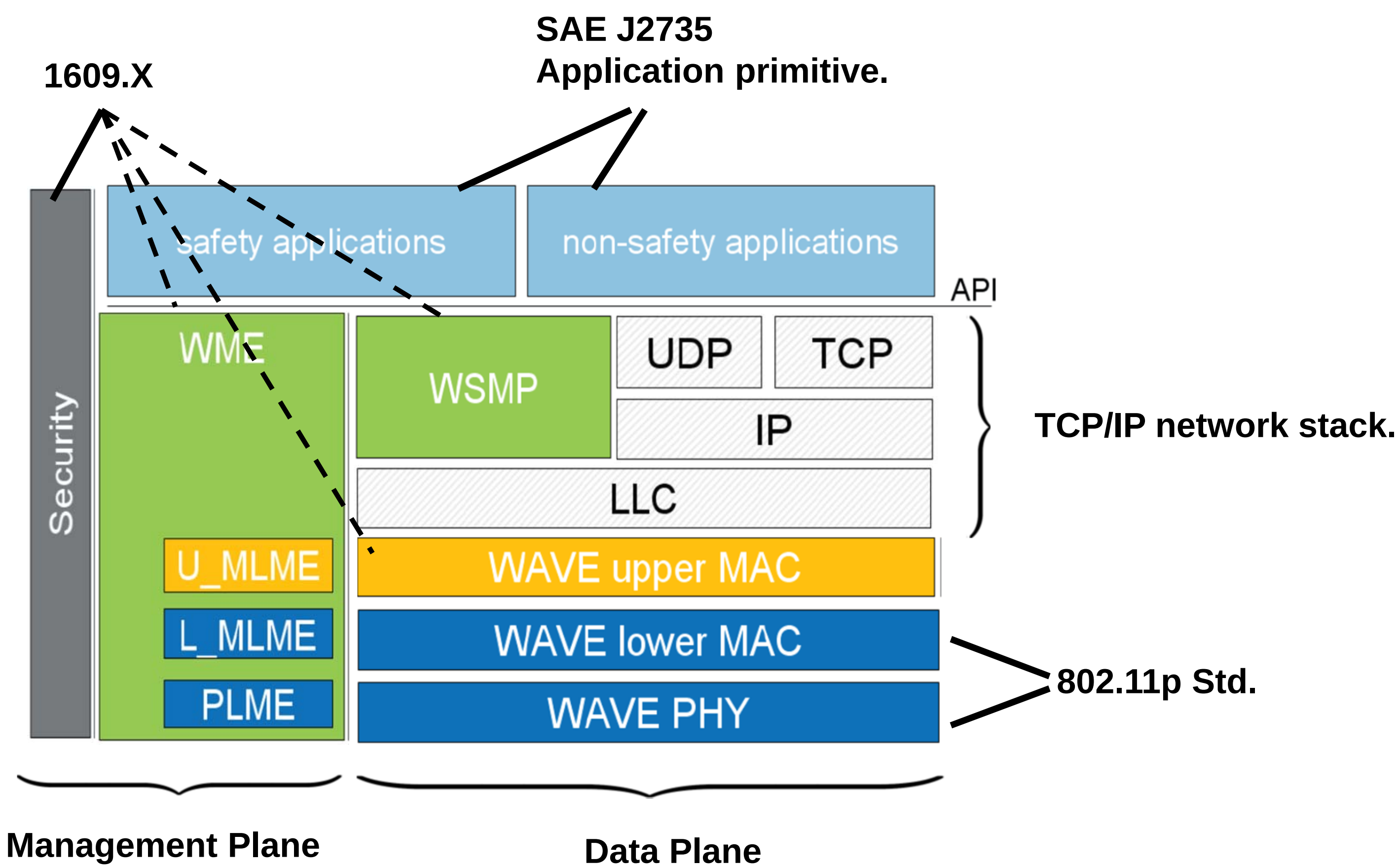
4

5

DSRC/WAVE Overview

- IEEE1609 runs on top of 802.11p MAC and PHY layers
- Designed to operate outside of a BSS (Connectionless)
- Range of 1km with transmission rate of 3-27Mps and vehicle speeds of 260km/h
- Offers time division for coordinating CCH and SCH monitoring
- Offers control over priority, channel, transmit power, data rate
- Restricted channels for control and safety communications

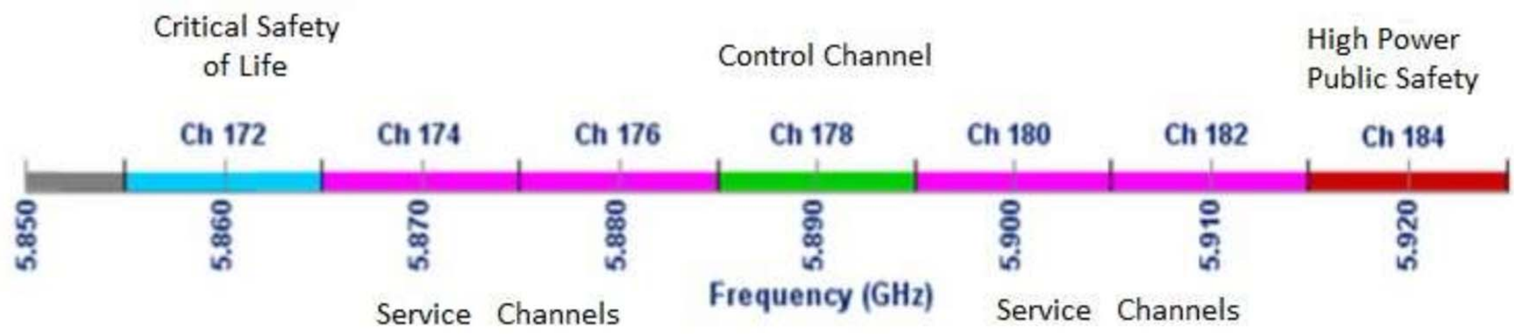
WAVE/DSRC Protocol Stack



WAVE = Wireless Access in Vehicular Environments

DSRC/WAVE Overview

- DSRC: Dedicated Short Range Communications
  - 5.850 - 5.925 GHz band allocated in NA for vehicular communications
  - 7 Channels = 6 Service (SCH) + 1 Control (CCH), each 10 MHz



172 – Public Safety V2V (collision avoidance) uses

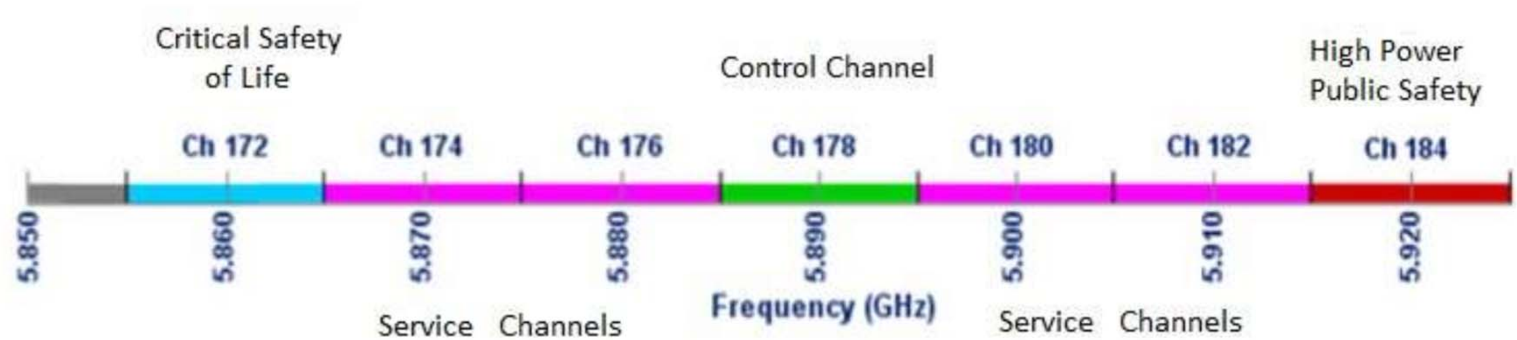
174,176, 180, 182: for private use

184 – High Power Public Safety and Non-public safety (v2I)

178 - control channel for link between the Roadside Unit (RSU) and OnBoard Unit (OBU)

DSRC/WAVE Overview

- CH 174-176 and 180-182 can be combined to make 20MHz channels (SCH)

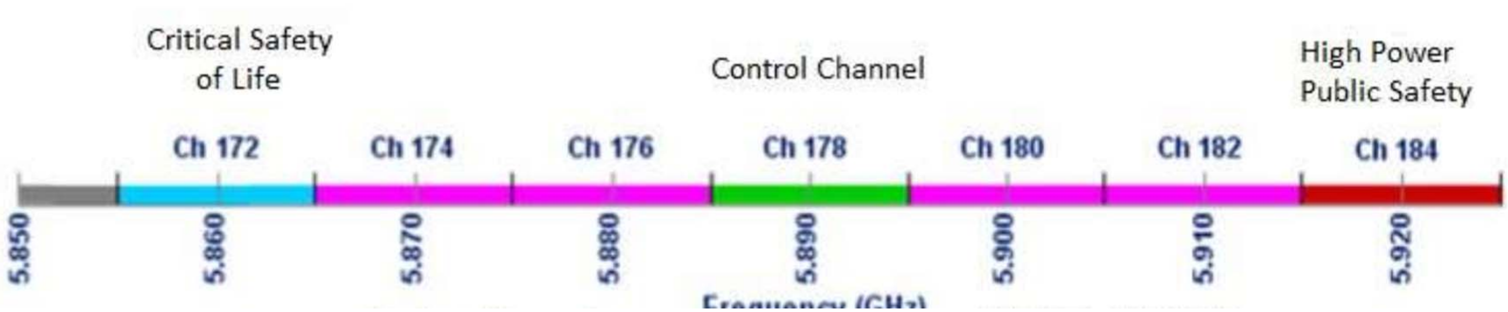


- CCH (control channel): short control messages/service announcements [broadcast] 10x /sec – info about vehicle state

- SCH (service channel) : data channel (can be aggregated to 20 MHz) bidirectional, TCP/IP traffic

DSRC/WAVE Overview

- Each unit has 2 radios: one permanently listening to CCH, and the other on SCH as needed
- All devices synchronized with a network clock
- Services available on SCH advertised with service advertisement on CCH.
  - WSA (Wave Service Announcements)
  - WSMP (Short Message Protocol) for high-priority traffic



WAVE Protocol Stack

Each link:

- WAVE mode (default)
  - Use broadcast for instant message exchange.

Zero latency
Poor reliability

V2I: WAVE BSS

- A car can join a WAVE BSS passively by only receiving an AP advertisement.
- Neither association nor authentication.

Low latency

V2V Networking

- WSMP: WAVE Short Message Protocol Layer
  - No layer 3 control over broadcast packets
  - No routing provided

No reliable layer 3 connection

Compared to WLAN, WAVE system has low overhead operation that is specially adapted for vehicular environments.

BSS = Basic Service Set

Basic Safety Message

Each class of device must be capable of transmitting a valid, signed **Basic Safety Message (BSM)** and receiving BSMs.

- The “Here I Am” message is the BSM (subset) of SAE J2735 conveyed in the 5.9GHz DSRC medium according to IEEE 802.11p and 1609.2 - 1609.4.
- The primary information conveyed in the message is the location of a vehicle at a particular time.
- Other data items are included as well.
- The message is properly signed so that receivers can check authenticity.

Vehicular Mesh Routing

- Prior Work: uses airplug middleware to transmit WAVE packets over **802.11a** (instead of 802.11p)

1. Packets are routed opportunistically as per the WAVE standard from one vehicle to another till it reaches an RSU (connected to the internet).
2. Delays are characterized vs. increasing number of vehicles in the network [see graph]

Challenges/Issues :

1. 802.11p accounts for mobility, thus results could have been refined if 802.11p PHY/MAC were used.
2. Vehicular (and not infrastructure) multi-hopping
3. Opportunistic communication leaves room for exploring routing algorithms in WAVE scenarios.

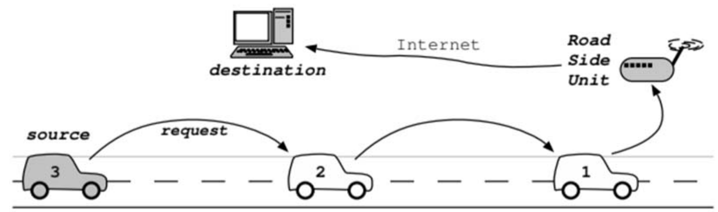


Figure 1: First stage: sending a request to the infrastructure.

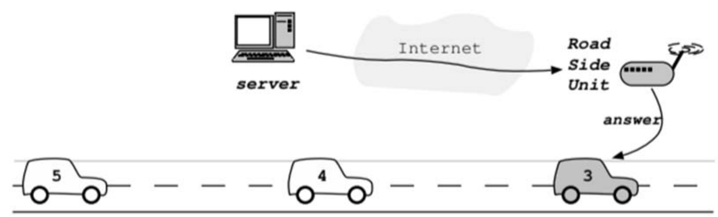
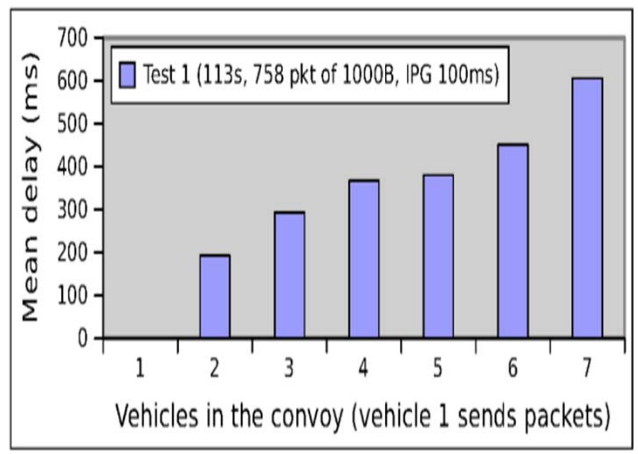
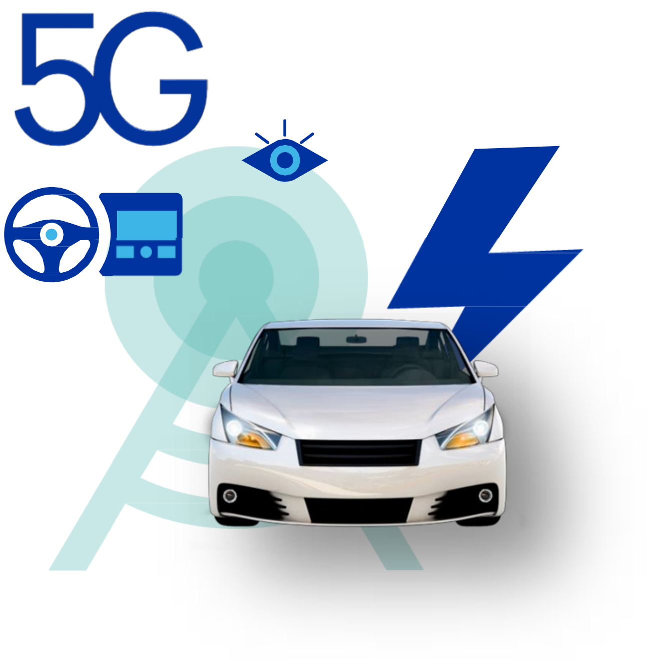


Figure 2: Second stage: fetching the answer.



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

Edgeless connectivity

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

High reliability

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

1ms end-to-end latency

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

High availability

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

[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'

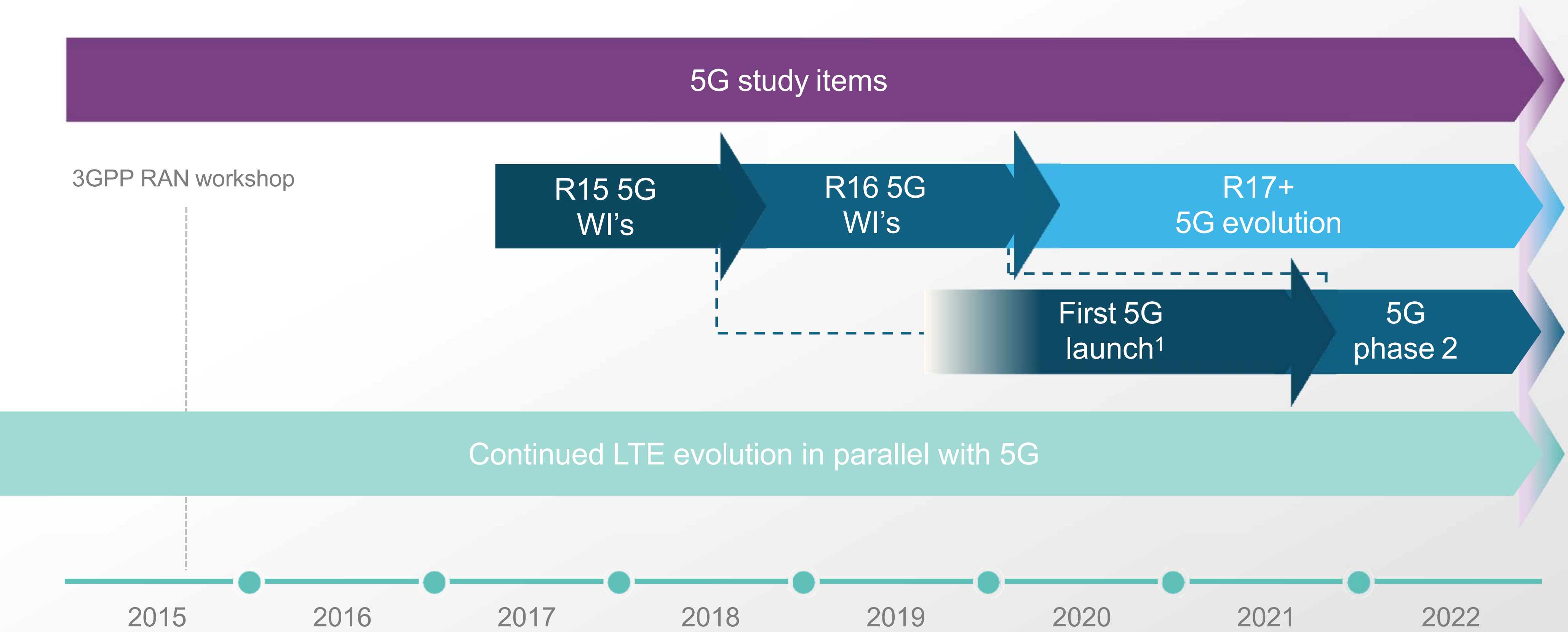
Multi-mode vehicle with simultaneous connectivity across 4G LTE, C-V2X and 5G

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

5G standardization progressing for 2020 launch



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

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