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A Perspective on V2X in the United States

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SIP-adus Workshop on Connected and Automated Driving Systems

Outline

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- V2X Background
- V2X Applications
- V2X Deployment
- V2X Technical Challenges
- V2X Regulatory Challenges

Toyota InfoTechnology Center

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CENTER, U.S.A., INC.

Japan HQ Owned by Toyota Motor Corporation

Headquarters: Akasaka, Tokyo, Japan

Established: January, 2001

US Center Wholly-owned subsidiary of Toyota InfoTechnology Center Co., Ltd.

Base: Mountain View Research Park (US Headquarters)

Location: Mountain View, CA

Established: April, 2001

Additional Location: New York City, NY

Vehicular Network Hierarchy

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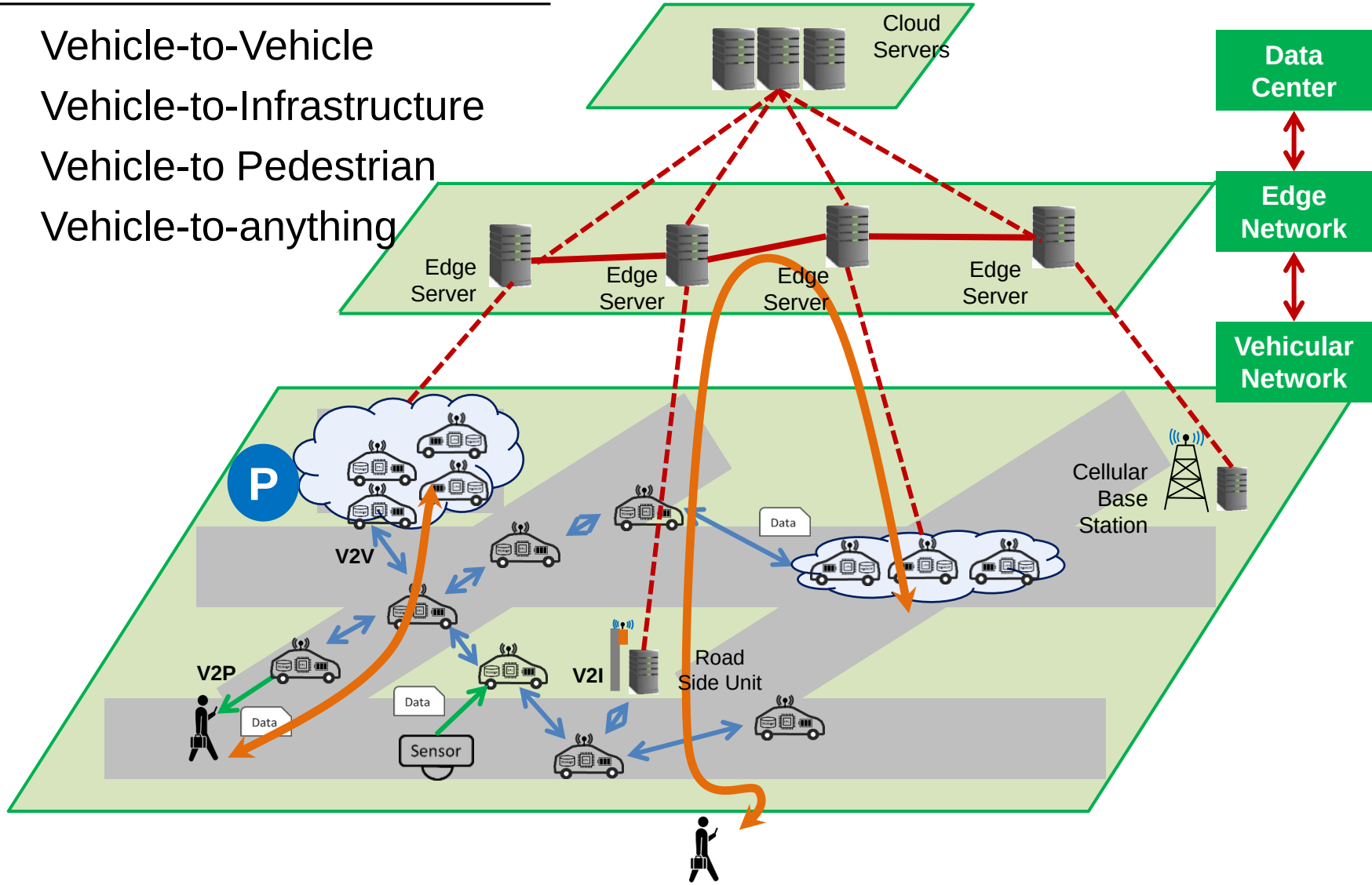
This talk focuses on V2X:

- Vehicle-to-Vehicle
- Vehicle-to-Infrastructure
- Vehicle-to Pedestrian
- Vehicle-to-anything



V2V Safety Concept

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- Concept: each vehicle sends Basic Safety Messages frequently in all directions.
- Receiving vehicles assess collision threats
- Threat: Warn driver or take control of car

SAE J2735 Basic Safety Message

Part I

Basic Vehicle State

(Temp ID, Seq. #, Time, Position
Motion, Control, Vehicle Size)

Mandatory in Basic Safety Message

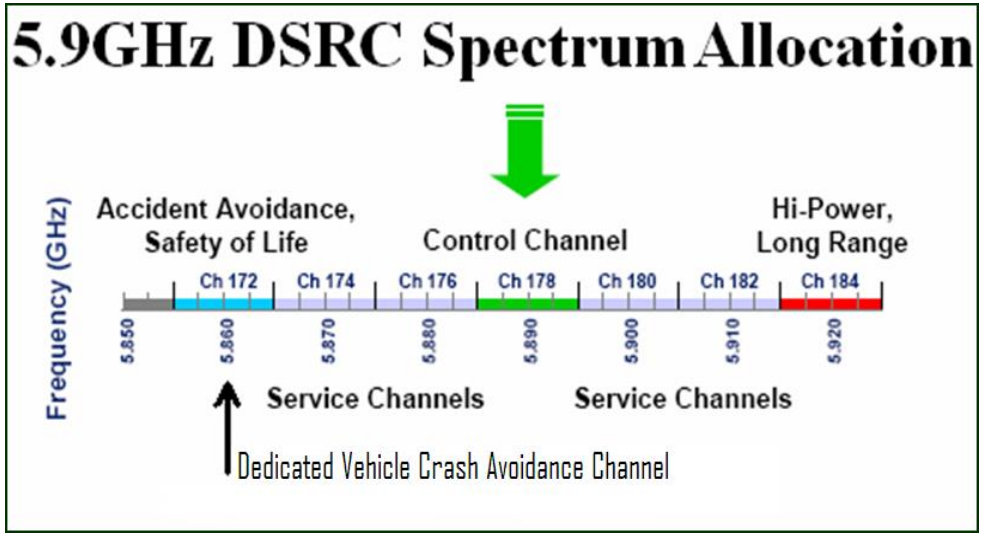
Part II

Vehicle Safety Extension

Event Flags
Path History
Path Prediction

Required for V2V Safety Applications

Other optional safety-related data



Connected Vehicle Applications

V2I Safety

- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Spot Weather Impact Warning
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized Crosswalk Warning (Transit)

V2V Safety

- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Left Turn Assist (LTA)
- Blind Spot/Lane Change Warning (BSW/LCW)
- Do Not Pass Warning (DNPW)
- Vehicle Turning Right in Front of Bus Warning (Transit)

Agency Data

- Probe-based Pavement Maintenance
- Probe-enabled Traffic Monitoring
- Vehicle Classification-based Traffic Studies
- CV-enabled Turning Movement & Intersection Analysis
- CV-enabled Origin-Destination Studies
- Work Zone Traveler Information

Environment

- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
- Connected Eco-Driving
- Wireless Inductive/Resonance Charging
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Traveler Information
- Eco-Ramp Metering
- Low Emissions Zone Management
- AFV Charging / Fueling Information
- Eco-Smart Parking
- Dynamic Eco-Routing (light vehicle, transit, freight)
- Eco-ICM Decision Support System

Road Weather

- Motorist Advisories and Warnings (MAW)
- Enhanced MDSS
- Vehicle Data Translator (VDT)
- Weather Response Traffic Information (WxTINFO)

Mobility

- Advanced Traveler Information System
- Intelligent Traffic Signal System (I-SIG)
- Signal Priority (transit, freight)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)
- Queue Warning (Q-WARN)
- Cooperative Adaptive Cruise Control (CACC)
- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)
- Freight-Specific Dynamic Travel Planning and Performance
- Drayage Optimization

Smart Roadside

- Wireless Inspection
- Smart Truck Parking

Source US DOT

Most of these are V2I

Applying V2X to Automated Driving

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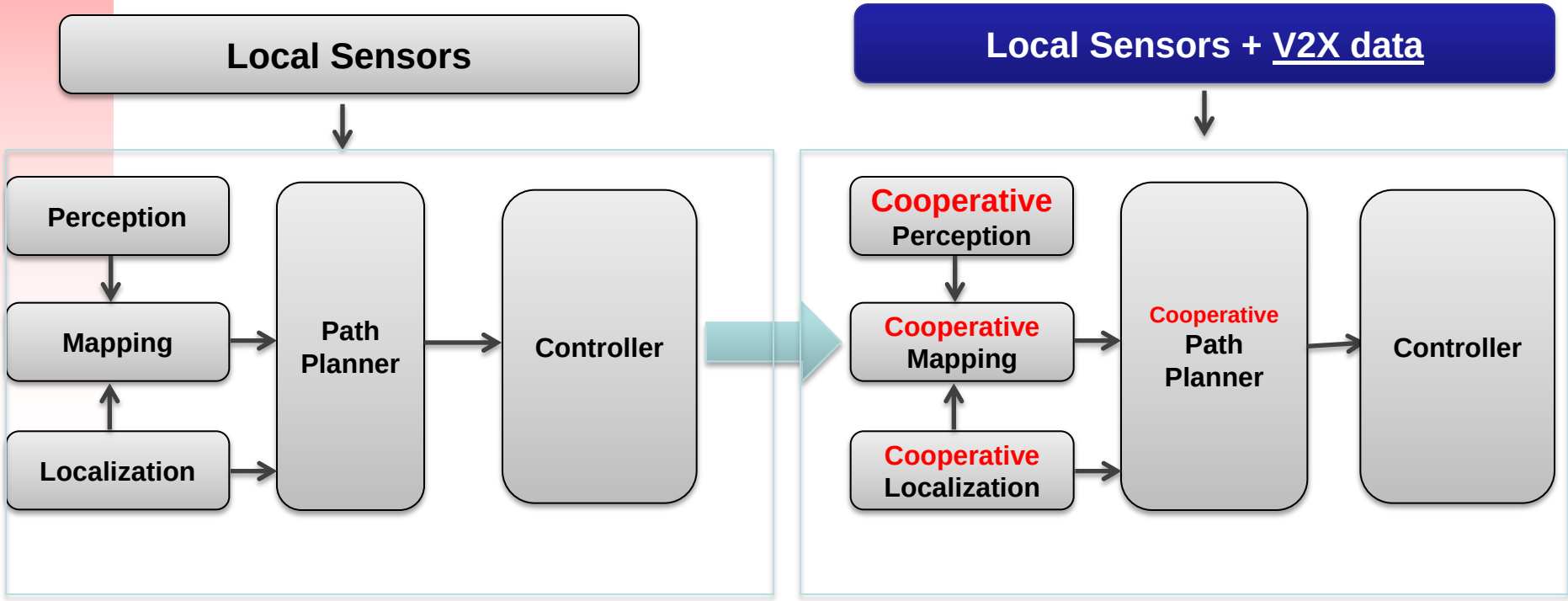
Cooperative Automated Driving (CAD) with improved localization & mapping, perception, and path planning



CAD is an active research topic for Toyota ITC and others

Protocol Stack

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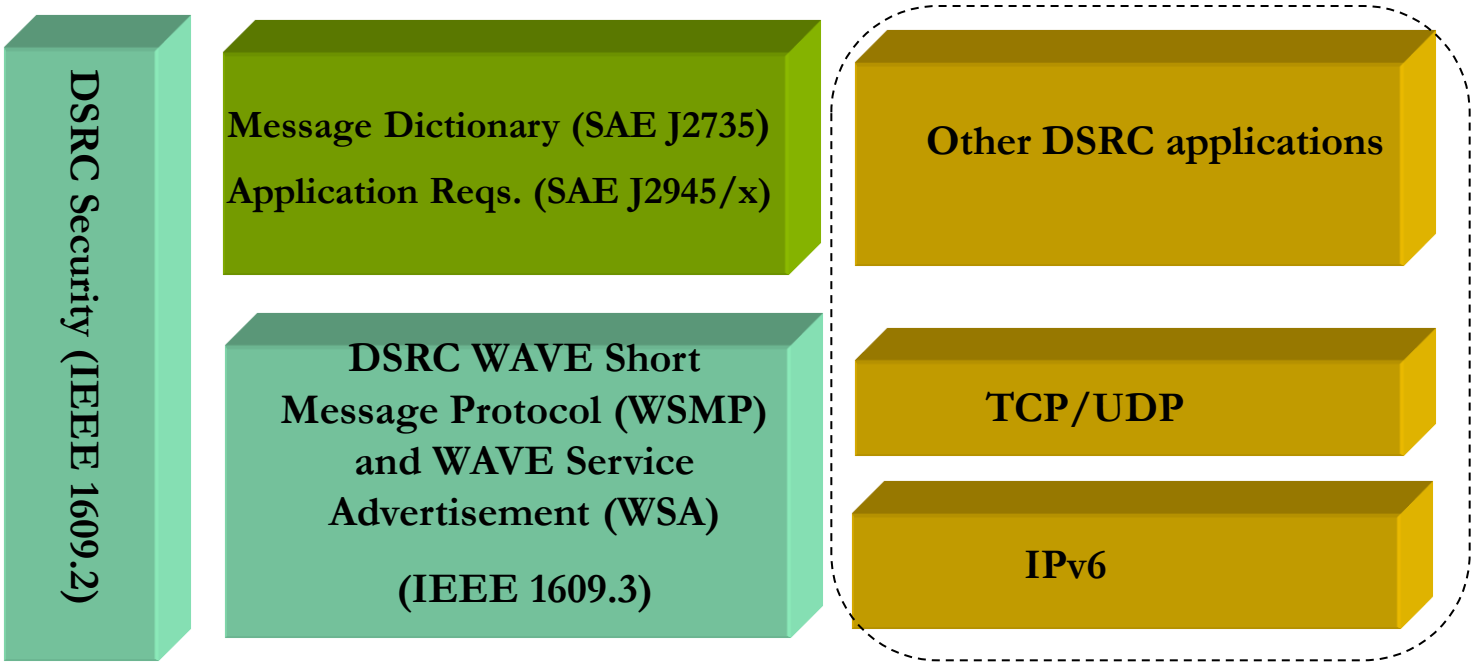
- Standards are necessary for interoperability
- Standards are mature



Other regions:

JP = ARIB

EU = ETSI

All based on 802.11p

See: J. Kenney, "DSRC Standards in the United States", Proc. IEEE, July 2011, Vol. 99, No. 7, pp. 1162-1182

US Deployment Situation

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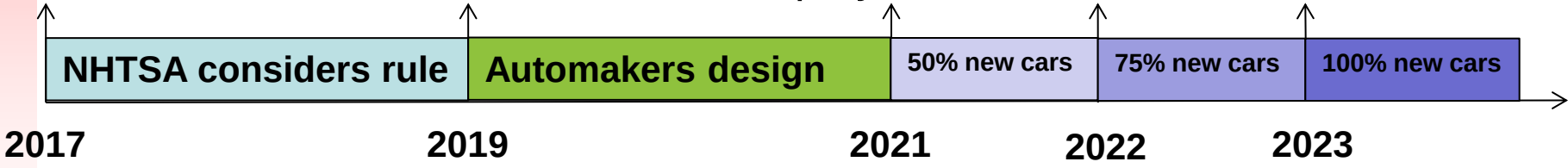
- NHTSA proposal to require DSRC in cars for V2V safety
  - Issued in January 2017
  - Must send and receive Basic Safety Messages (BSMs)
  - Most automakers support this BSM requirement
  - Opposition from some Wi-Fi and Cellular stakeholders
  - Possible timeline for mass deployment:



- Voluntary deployments have begun
  - Commercial: GM Cadillac (March 2017)
  - National: US DOT Pilot Deployments and Smart City
  - States: "SPaT Challenge" for 1000 intersection devices
  - Even if no NHTSA mandate, DSRC mass deployment will come

NHTSA = National Highway Transportation Safety Administration (part of US DOT), SPaT = Signal Phase and Timing message

US Deployment continued

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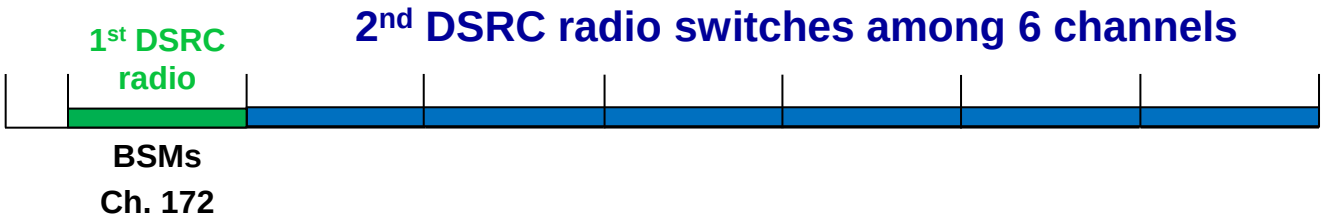

- US DSRC has 7 channels
- V2V Mandate (BSM) uses only 1 channel
- Many other DSRC applications will use other channels:
  - V2I safety
  - V2P safety
  - Traffic efficiency
  - Automated Driving
- Automakers may install 2-radio systems.
  - 2nd radio voluntary

Worldwide deployment

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- Japan: ITS Connect technology
  - Toyota and other automakers, 760 MHz
- Europe: Cooperative ITS or ITS-G5
  - Volkswagen announced 2019 deployment
  - Car2Car Communications Consortium also aiming at 2019 deployment
  - Many trials
- Other countries actively exploring deployment
  - Korea, Australia, China, …
- Strong Government-Industry partnership is key to successful deployment
- Voluntary deployment takes leadership and courage

Technical Challenges: Ad Hoc

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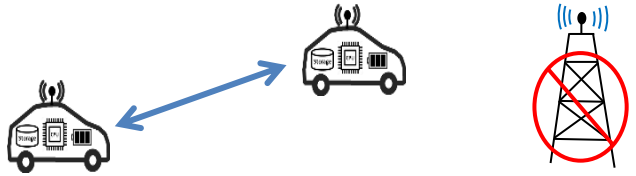
- High vehicle mobility + Short range communication = Ad hoc communication
- There is no central base station or access point
  - The main innovation of 802.11p is removing the AP



- Implications:
  - Standards and voluntary agreements are critical for interoperability, especially lower layer protocols
  - Long vehicle lifetimes mean technology must remain stable for a long time.
    - Evolution is very different from Cellular or Wi-Fi models
  - Trust/security/privacy model is complicated

Technical Challenges: Scalability

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Basic question: will all this still work here?

Aspects of Scalability

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- Processing resources
  - Collision threat assessment
  - Per-message Security
- Security Infrastructure
- Wireless Channel resources
  - Toyota has created a channel congestion control algorithm called LIMERIC to adaptively control congestion
  - *LIMERIC: A linear adaptive message rate algorithm for DSRC congestion control, G. Bansal, J. Kenney, C. Rohrs, IEEEE Trans. Veh. Tech., 2013*

Hard to address this just with $ or ¥

Regulatory Challenge: Sharing spectrum with Wi-Fi

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- DSRC/C-ITS operates in licensed 5.9 GHz spectrum in the US
- Unlicensed devices (Wi-Fi, LTE-U) want access to more spectrum
  - Government regulators see economic growth advantages
- Sharing between licensed & unlicensed devices is new emphasis
  - Unlicensed must not cause "Harmful Interference" to licensed
  - Sharing with radar systems works, based on "detect & vacate"
  - But, sharing with short range V2V and V2I is quite different
- US Federal Communications Commission (FCC) is investigating and testing if sharing 5.9 GHz spectrum can protect DSRC
- European Regulators/Industry recently completed a study of sharing
  - See ETSI TR 103 319
  - CEPT Preliminary View is for no sharing of ITS 5.9 GHz spectrum

Regulatory Challenge: Cellular V2X

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- Auto industry in US/EU/JP decided 10+ years ago to use a variant of Wi-Fi protocol as basis for V2X: IEEE 802.11p
  - Simple, proven, effective for ad hoc, leverages billions of chips in deployment
- Since that decision, focus is on other, bigger challenges, like scalability, security, applications
- Cellular stakeholders are now pushing a new protocol: LTE V2X
  - First generation standard published by 3GPP this year
  - Many issues not yet resolved
  - No silicon available yet, no significant testing
  - It will be years before it can be deployed as a safety system
  - 5GAA is pushing for changes to regulations, could disrupt deployment plans
- In JP/EU/US deployment of 802.11p either ongoing or very soon
- Those regions should not delay deployment for an incomplete, immature, untested, unavailable technology.
  - Other regions that have not invested in 802.11p may choose LTE V2X (China)

Summary

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- V2X is mature, deployment has started in US
- V2V safety is initial focus, but many new applications are coming
- Cooperative Automated Driving is an important emerging application
- Technical challenges include ad hoc communication and scalability
  - Good solutions exist for these
- Regulatory challenges include:
  - Spectrum sharing (big issue in US)
  - Protocol competition from cellular (big in EU)
  - These should not disrupt deployment