A Communication-centric Look at Automated Driving

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Views expressed in this talk do not necessarily represent those of Toyota Motor Corporation.

Acknowledgements

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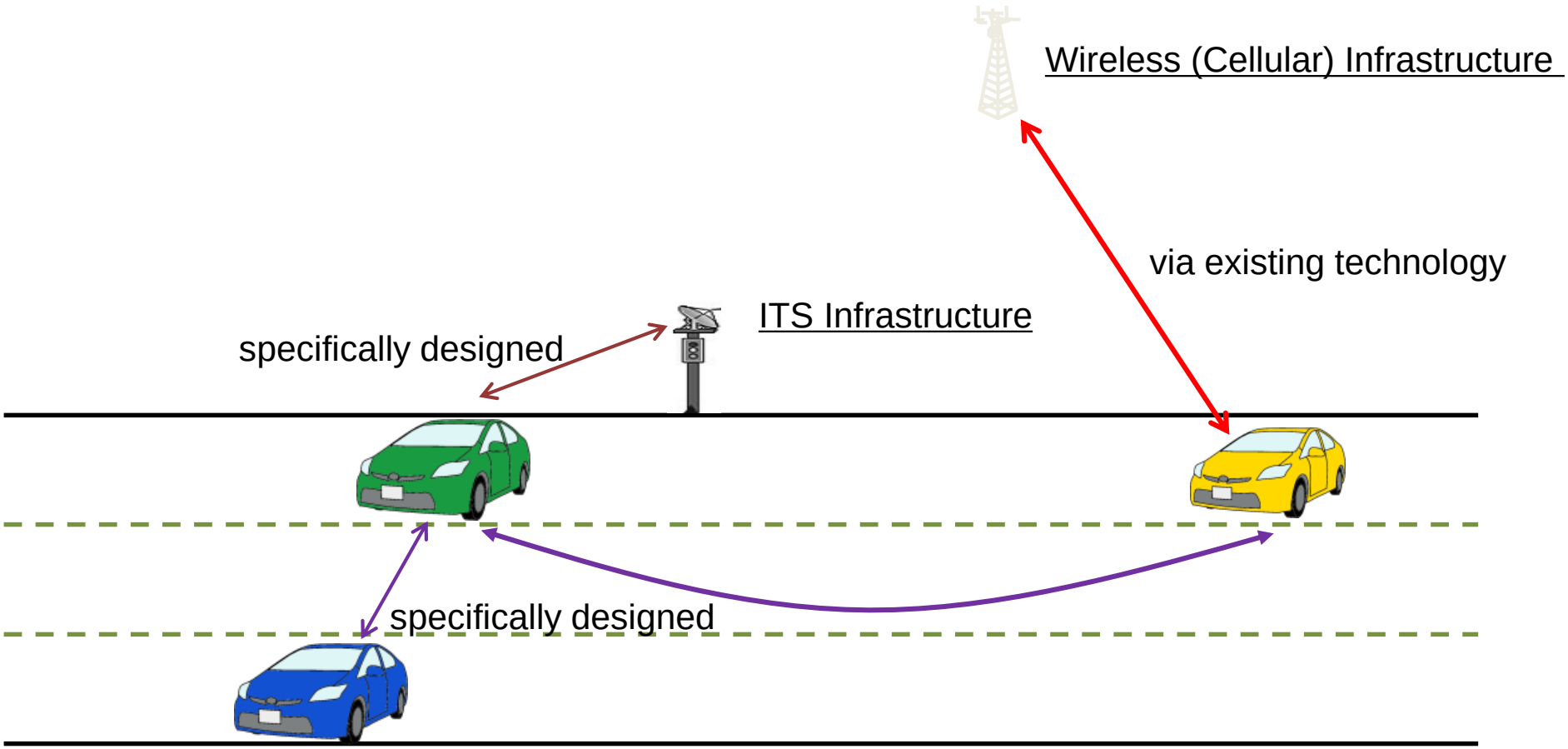
Vehicular Connection Types



Specifically designed protocols between Roadside Units (RSU) and vehicles;
and vehicles to vehicles: IEEE WAVE, ETSI ITS-G5, ARIB T109, IEEE 802.11p

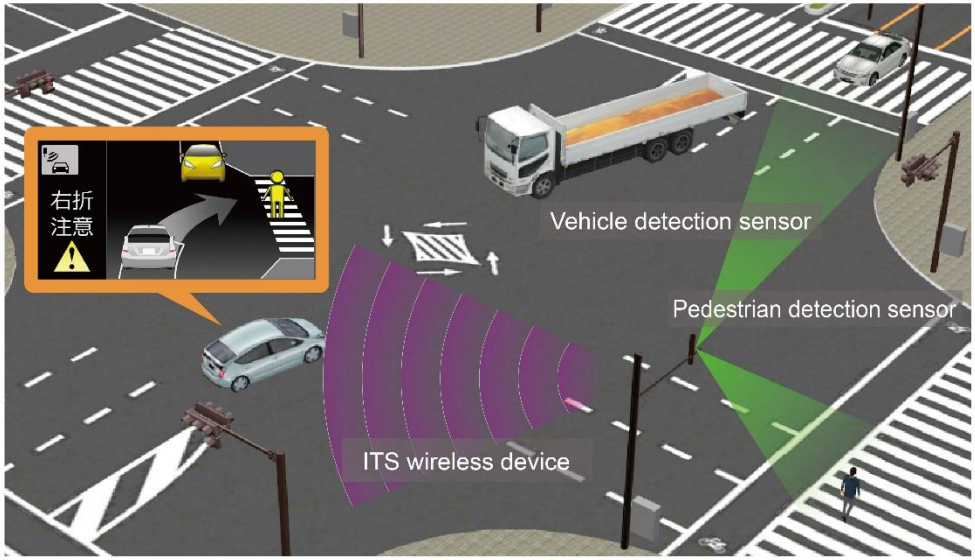
Vehicular Communications Status Update

- Japan: carmaker(s) rolling out systems with optional (voluntary) packages
  - 10 MHz of spectrum in 760 MHz
  - Additionally 5775 - 5845 MHz for ETC/DSRC
- U.S. federal government's V2V mandate is proceeding
  - Announcement is expected
  - Mandated deployment to start 2019-2021 (estimated)
  - Spectrum: 75 MHz in 5850 - 5925 MHz
- Europe: Auto industries expect market introduction in 2017
  - Spectrum: 70 MHz in 5855-5925 MHz
  - 63 GHz to 64 GHz (V2V and V2R communications)
    - Likely to be used by truck platooning applications

http://www.jari.or.jp

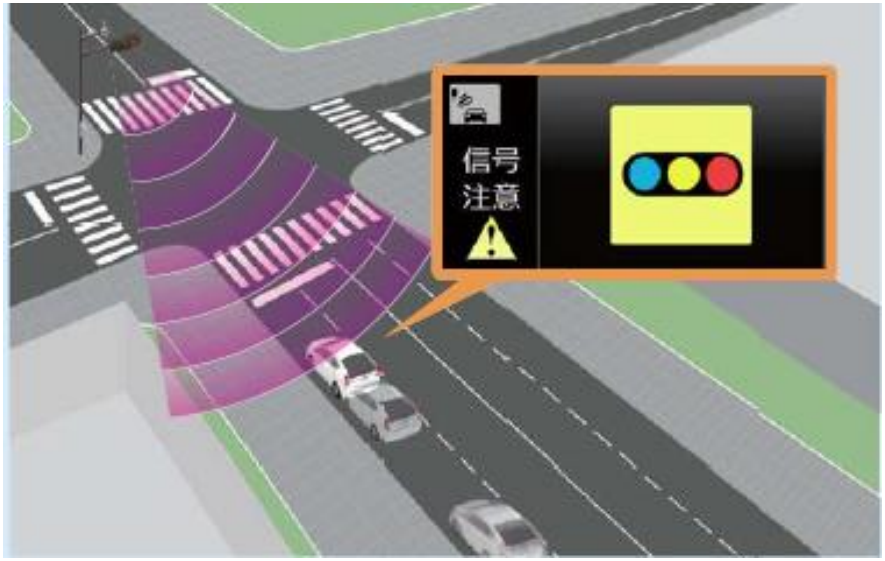
ITS Services in Japan

Right Turn Collision Warning



Alerts the driver of oncoming vehicles that can be difficult to see and pedestrians crossing the road

Red Light Warning



Alerts the driver when the light ahead has changed or is about to change

Source: http://www.toyota-global.com

ITS Services in Japan

Emergency Vehicle Notification

Driver is notified when an emergency vehicle approaches

Source: http://www.toyota-global.com

Cooperative-adaptive Cruise Control

Cars share information on speed changes in real-time.

Allows for a more efficient adaptive cruise control system. Multiple cars will drive as if they were a single unit, making highway driving more comfortable, safer, and simpler.

Reduced braking and accelerating, will help to ease traffic, cut carbon dioxide emissions, and decrease fuel costs.

Automated Driving: are we there yet?

Conditional automated

Highly automated

Fully automated

2020 2025 2030

Role of comms

Introduction

Expansion

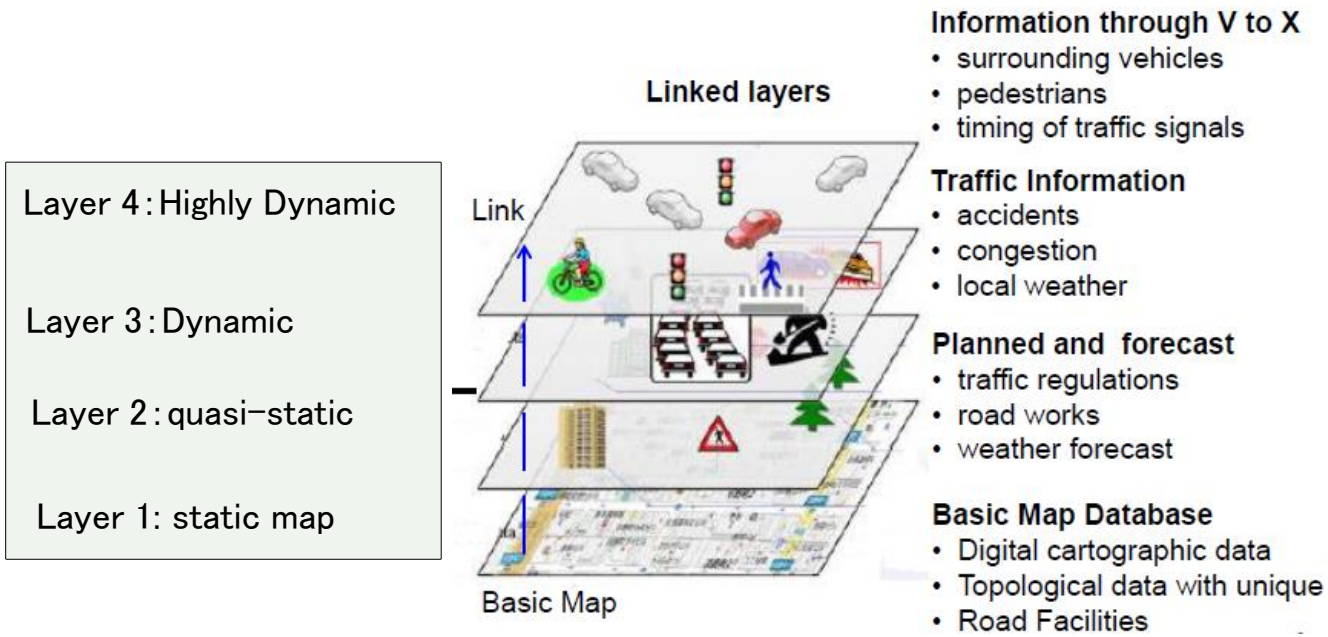
Becomes ubiquitous in society

2020 2030 2050

Based on projections of Japan Automobile Manufacturers Assoc., Inc.

Autonomous Car

- Localization: where am I?
- Sensing the surroundings: what is happening around me?
- Perception (fusion of sensor data)
- Reasoning and decision making
- Motion control

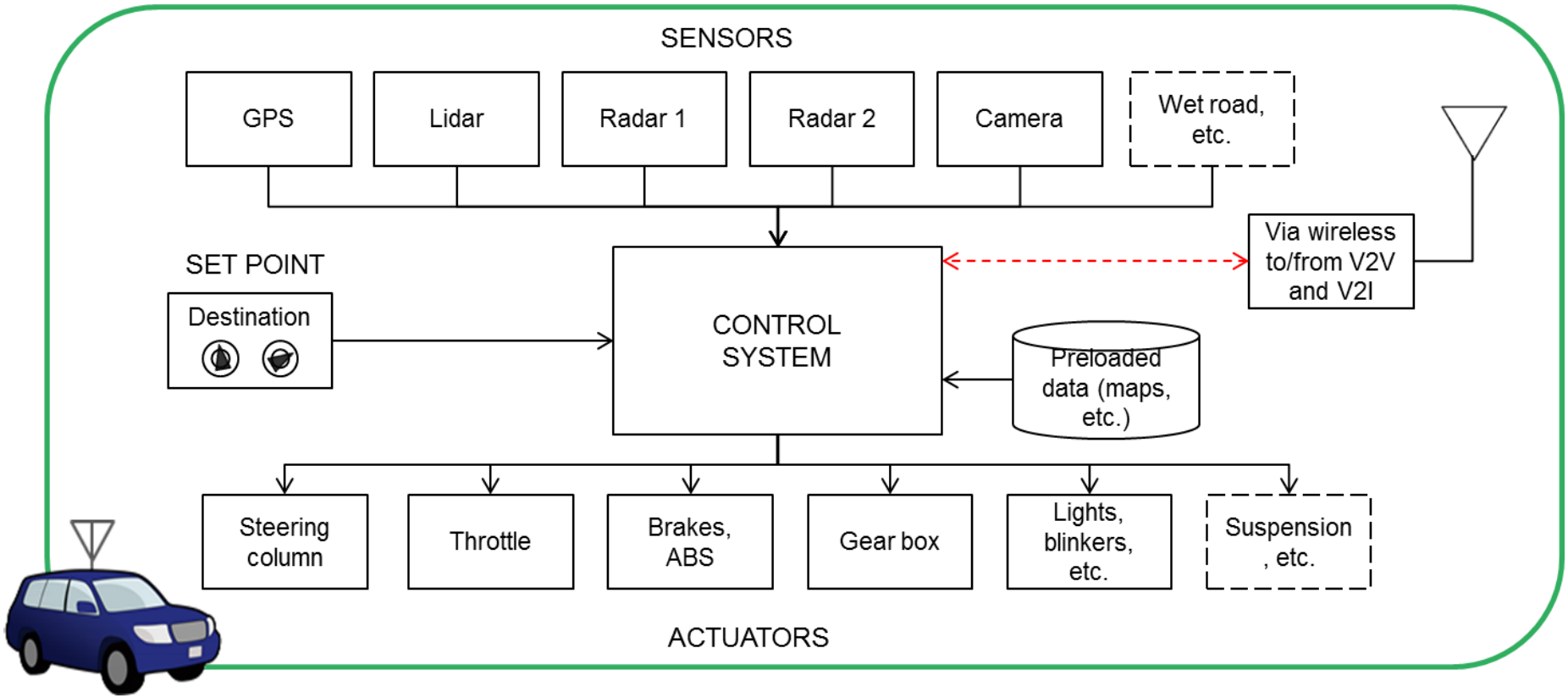


Source: SIP-adus

Rough comparison of “sensors”

	Sonar	Small Lidar	Sweeping Lidar	Camera	Mmwave radar	V2V/V2R Comms
Rain/Snow	☺	☹	☹	☹	☺	☺
Fog	☺	☹	☹	☹	☺	☺
Night	☺	☺	☺	☹	☺	☺
Detection distance	Several meters	Several 10s of meters	Ped. 60m Veh. 150m	Ped. 30m Veh. 100m	Up to 200m	Few 100s of meters
Cost	Very low	Mid	Very High	Low	Mid	Low

Communications as another sensor

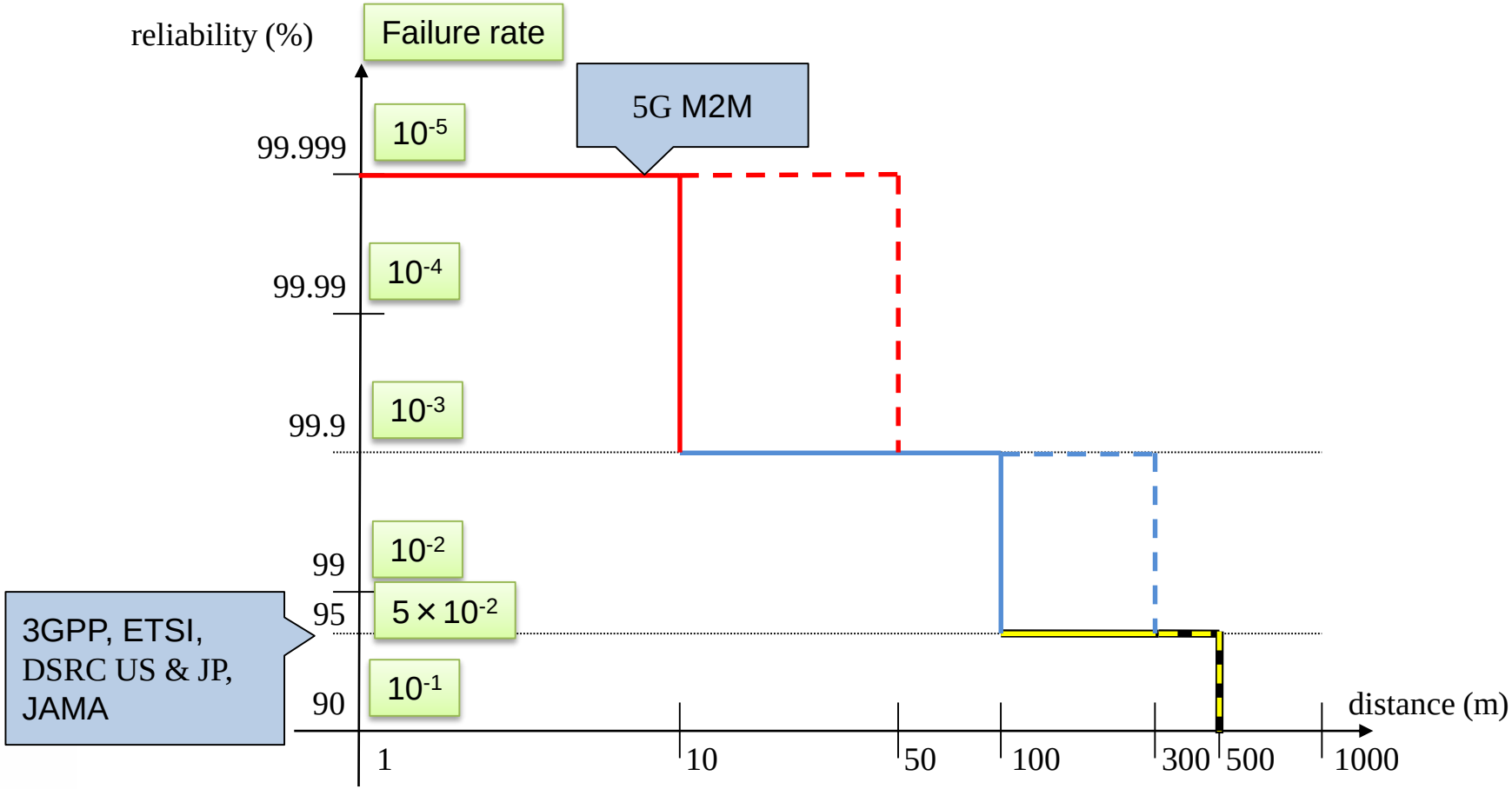


How can communication help?

- Communication between cars helps to
  - improve situational awareness,
  - provide redundancy if sensors fail,
  - resolve traffic bottlenecks,
  - reduce road congestion
- What to send?
  - only broadcast basic info
  - list of detected objects
  - coordination messages
  - full sensor data

Autonomous Vehicle Communication Needs

- Reliability in “informed driving”
  - 80% PDR, in two attempts 95%
  - Human driver has the control



Automated Driving and Communication Needs

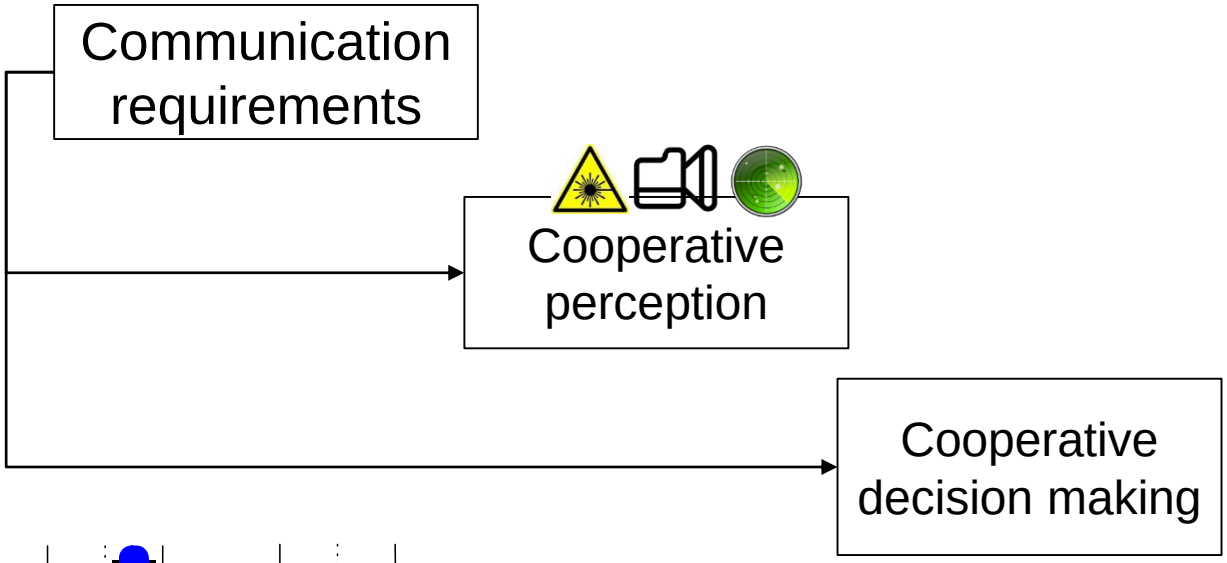
Lidars create around
7 Mbps x *n*

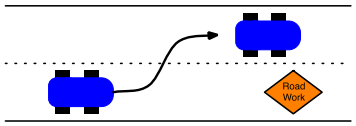
Lidar creates around 33 Mbps

Sensors (including cameras) gather
and process data in the order of Gbit/s

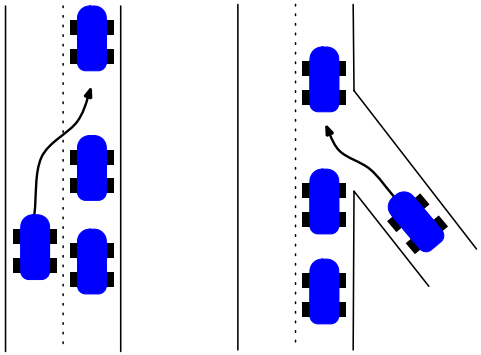
How much of that data needs to be shared with peers?

Cooperative Perception vs Cooperative Decision Making

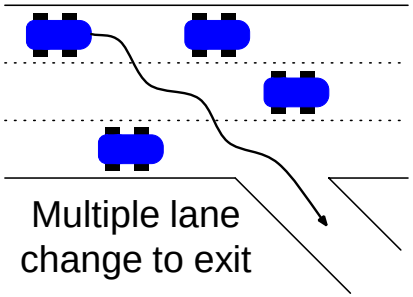




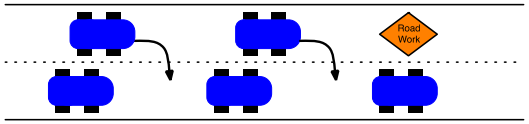
Lane change



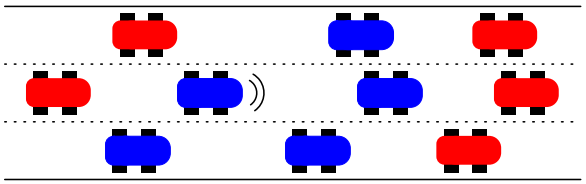
Joining car convoy



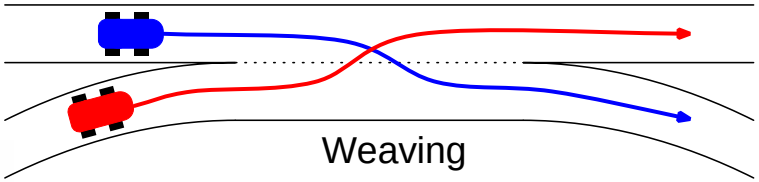
Multiple lane change to exit



Zipper merge



Maintaining position with respect to automated and legacy cars

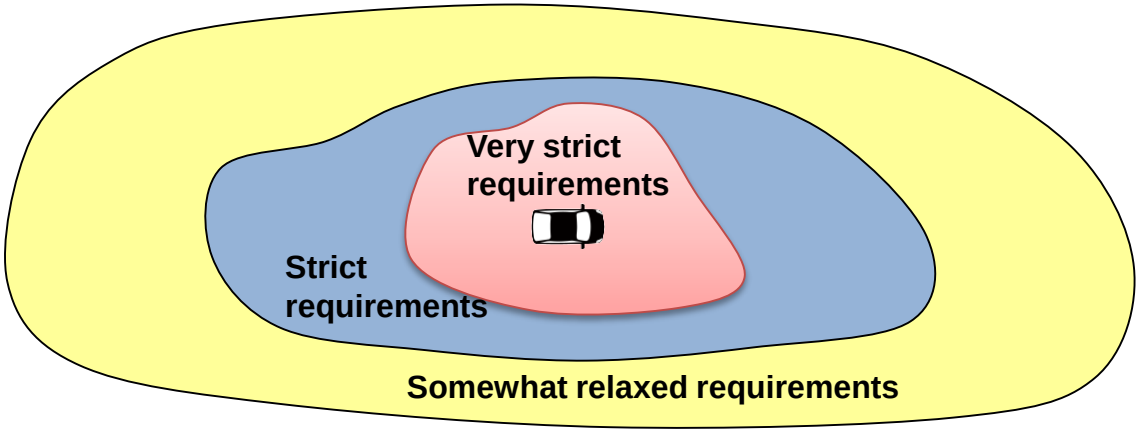


Weaving

G. Ozbilgin, U. Ozguner, O. Altintas, H. Kremo, J. Maroli, "Evaluating Requirements for Wireless Communication in Collaborative Automated Driving," IEEE Intelligent Vehicles 2016

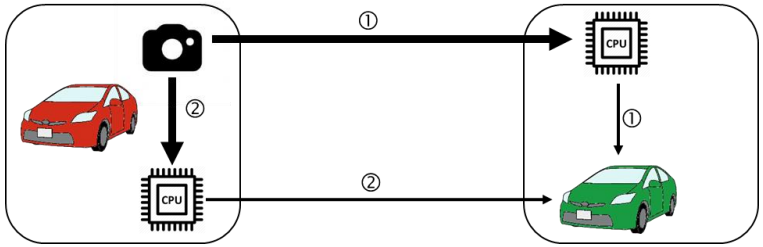
Relationship between the requirements and the vehicle dynamics

- Because of the car dynamics, the communication requirements are related to the communication distance and car speed v



Throughput per vehicle versus applications

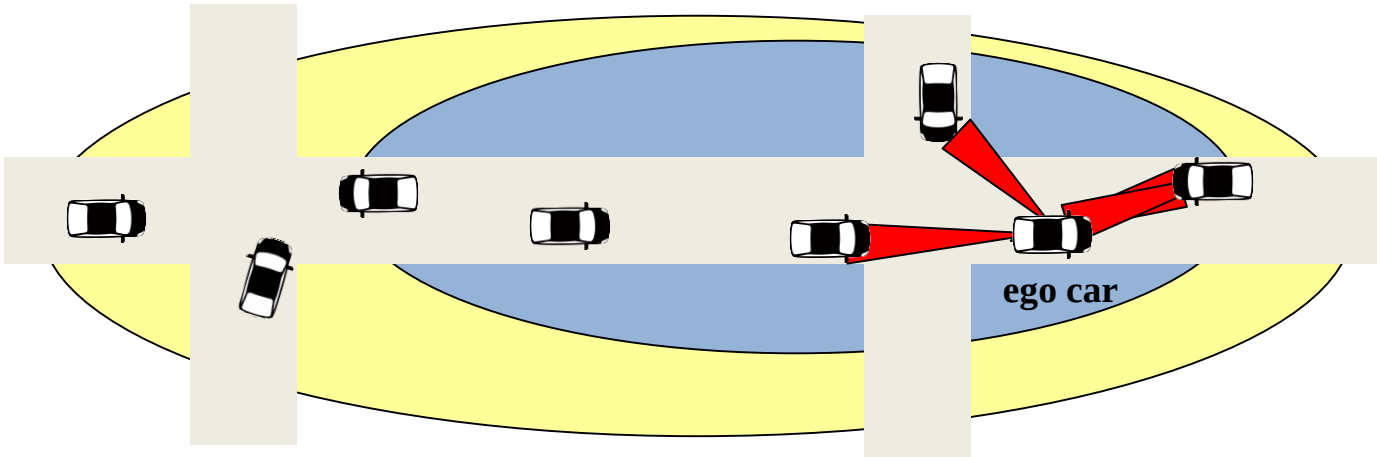
- Required throughput per vehicle depends on specific application



  - High throughput applications
    - Occupancy grid
    - Full sensor (lidar, camera, radar) images
  - Moderate throughput applications
    - Sharing of planned trajectories
    - Sharing of “high level” coarse traveling decisions
  - Low throughput applications
    - Short emergency messages
    - Short messages to coordinate maneuvers
    - Periodic DSRC-like broadcast of short messages

Feasibility of high throughput together with bounded latency and high reliability

- Sharing of full compressed sensory information beyond nearest neighbors is not feasible, but also most likely not needed
  - Includes too much data to be sent very far.
  - Contains highly dynamic information which quickly becomes irrelevant with distance.
- Therefore, use mm waves, visual light, or communication in the radar bands for exchange of full sensory information
  - Sharing of full images requires large bandwidth.
  - It also benefits from spatial reuse achieved through high directionality.



Requirements with respect to the Dynamic Map

High volume
- Images from sensors
- Occupancy grid
- Cooperative decision making

Medium volume
- "List of targets"
- Vehicle context
- Cooperative decision making

Low volume
- Basic broadcast
- Emergency info

Communication volume

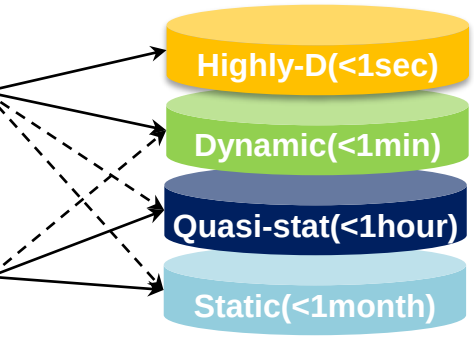
real time and near real time operation

Ad-hoc (V2V)

Infrastructure (V2I)

"crowdsourcing"

Hierarchical map on every car

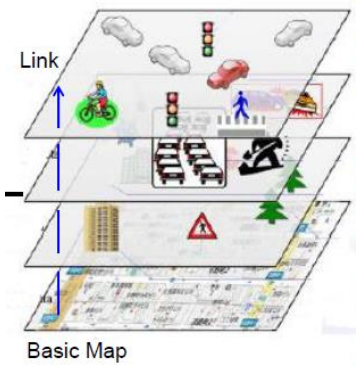


Layer 4 : Highly Dynamic

Layer 3 : Dynamic

Layer 2 : quasi-static

Layer 1: static map



Information through V to X
- surrounding vehicles
- pedestrians
- timing of traffic signals

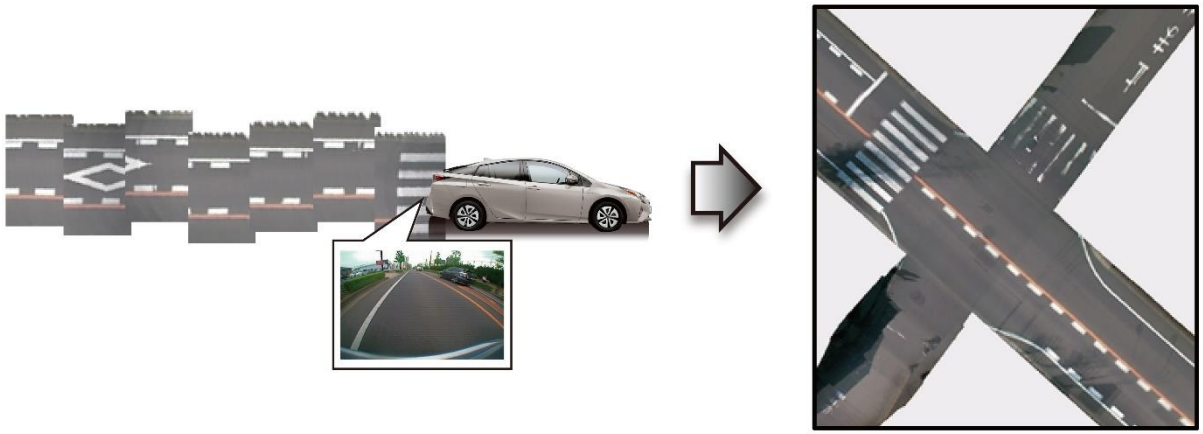
Traffic Information
- accidents
- congestion
- local weather

Planned and forecast
- traffic regulations
- road works
- weather forecast

Basic Map Database
- Digital cartographic data
- Topological data with unique
- Road Facilities

It’s not only downloading

- “Toyota will expand installation of DCMs (Data Communication Module) to more models”
  - *“Toyota Big Data Center”* to support data-intensive connected services
  - “a high-precision map generation system that will use data from on-board cameras and GPS devices installed in production vehicles”



http://corporatenews.pressroom.toyota.com/releases/toyota+connected+car+technology+accelerates.htm

Qualitative requirements

Relevance and range	Application	Contents	Requirements
Immediate neighbors Maximum range: Up to 50 m	Sharing of large amount of sensory information	- Camera, lidar, or radar images - Occupancy grid	- Very high throughput per car - Extremely short latency - Extremely high reliability
Cars sharing the same road section (for example, at the same intersection) Maximum range: 50 to 300 m	Sharing of highly processed and compressed sensor information.	- List of detected “targets” and their properties - Vehicle context information	- Moderate throughput per car - Very short latency - Very high reliability
	Coordination of maneuvers	- Sharing of planned trajectories	
Cars inside the radio coverage Maximum range: 300 to 500 m	Sharing of very basic “DSRC-like” information	- Car location, speed, and heading - Emergency breaking, road work, etc.	- Low throughput per car - Short latency - High reliability
	Coordination of maneuvers	- Sharing of high-level trajectory decisions like turns at intersections	

Thank you.