A Communication-centric Look at Automated Driving

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November 5, 2016
IEEE 5G Summit Seattle

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

This talk is partially based on joint work with Dr. Haris Kremo
Vehicular Connection Types

Wireless (Cellular) Infrastructure

via existing technology

specifically designed

ITS Infrastructure

specifically designed

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

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.

Source: http://www.toyota-global.com
Automated Driving: are we there yet?

- Conditional automated (2020)
- Highly automated (2025)
- Fully automated (2030)

Role of comms

Introduction (2020)
Expansion (2030)
Becomes ubiquitous in society (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

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

Source: SIP-adus
## Rough comparison of “sensors”

<table>
<thead>
<tr>
<th></th>
<th>Sonar</th>
<th>Small Lidar</th>
<th>Sweeping Lidar</th>
<th>Camera</th>
<th>Mmwave radar</th>
<th>V2V/V2R Comms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain/Snow</td>
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<tr>
<td>Night</td>
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<td>☺</td>
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<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>Detection distance</td>
<td>Several meters</td>
<td>Several 10s of meters</td>
<td>Ped. 60m Veh. 150m</td>
<td>Ped. 30m Veh. 100m</td>
<td>Up to 200m</td>
<td>Few 100s of meters</td>
</tr>
<tr>
<td>Cost</td>
<td>Very low</td>
<td>Mid</td>
<td>Very High</td>
<td>Low</td>
<td>Mid</td>
<td>Low</td>
</tr>
</tbody>
</table>
Communications as another sensor

SENSORS

- GPS
- Lidar
- Radar 1
- Radar 2
- Camera
- Wet road, etc.

SET POINT

- Destination

CONTROL SYSTEM

- Preloaded data (maps, etc.)
- Via wireless to/from V2V and V2I

ACTUATORS

- Steering column
- Throttle
- Brakes, ABS
- Gear box
- Lights, blinkers, etc.
- Suspension, etc.
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

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

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

Lidars create around $7 \text{ Mbps} \times n$

Lidar creates around 33 Mbps
Cooperative Perception vs Cooperative Decision Making

Communication requirements

Cooperative perception

Cooperative decision making

Joining car convoy

Lane change

Zipper merge

Multiple lane change to exit

Maintaining position with respect to automated and legacy cars

Weaving

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

- Very strict requirements
- Strict requirements
- Somewhat relaxed requirements
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**

**Hierarchical map on every car**

- **Highly-D (<1sec)**
- **Dynamic (<1min)**
- **Quasi-stat (<1hour)**
- **Static (<1month)**

**Ad-hoc** (V2V)

**Infrastructure** (V2I)

“crowdsourcing”

**Layer 4:** Highly Dynamic

**Layer 3:** Dynamic

**Layer 2:** quasi-static

**Layer 1:** static map
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

<table>
<thead>
<tr>
<th>Relevance and range</th>
<th>Application</th>
<th>Contents</th>
<th>Requirements</th>
</tr>
</thead>
</table>
| **Immediate neighbors** | 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 |
| **Maximum range: Up to 50 m** | Sharing of highly processed and compressed sensor information. | - List of detected “targets” and their properties  
- Vehicle context information | |
| **Cars sharing the same road section (for example, at the same intersection)** | Coordination of maneuvers | - Sharing of planned trajectories | - Moderate throughput per car  
- Very short latency  
- Very high reliability |
| **Maximum range: 50 to 300 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 |
| **Cars inside the radio coverage** | Coordination of maneuvers | - Sharing of high-level trajectory decisions like turns at intersections | |
Thank you.