DSRC: Deployment and Beyond

WINLAB Research Review
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Outline

• Introduction to Toyota ITC
• DSRC Background
• DSRC Deployment
• DSRC Challenges
  – Congestion Control
  – Spectrum Sharing
• DSRC Future
• Connecting Vehicles
Toyota ITC Overview

Japan HQ
- Investors: Toyota, Denso, KDDI, Toyota Tsusho, Aisin, Kyocera, Toyoda Gosei, Toyota Industries
- Headquarters: Tokyo, Japan
- Location: 6-6-20, Akasaka, Minato-ku
- Personnel: about 70
- Established: January, 2001

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

US HQ and R&D: Mountain View Research Park
- Location: Mountain View, CA
- Personnel: about 35
- Established: April, 2001

Location: New York City, NY
Business Research
DSRC Basics

• **Dedicated Short Range Communication**
• Dedicated: 5.850-5.925 GHz licensed spectrum
• Short Range: Hundreds of meters
• Vehicle-to/from-X, where X =
  – Another vehicle (V2V)
  – Roadside infrastructure (V2I)
  – Pedestrian, bicycle, train, …

• Caveat: in Japan and Europe “DSRC” often refers to electronic tolling systems operating in the 5.8 GHz band
What’s it good for?

32,719  Traffic Fatalities in  2013
DSRC V2V Safety Concept

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

- **National Highway Traffic Safety Administration**
  - Regulator for cars, part of US Dept. of Transportation

- **Feb. 2014** – NHTSA announces intention to require DSRC BSM transmitters in light vehicles

- **Aug. 2014** – NHTSA issues Advance Notice of Proposed Rulemaking (ANPRM)

- **May 13, 2015**: US DOT Sec. Foxx announces aggressive regulatory plan

- **Early 2016**: NPRM expected

- **2017-2018**: Finalize regulations

- **2019-2020**: Expect initial mandated deployment

- However, GM plans early voluntary Cadillac deployment in model year 2017
**What else is it good for?**

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**Connected Vehicle Applications**

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<th>V2I Safety</th>
<th>Environment</th>
<th>Mobility</th>
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<td>Red Light Violation Warning</td>
<td>Eco-Approach and Departure at Signalized Intersections</td>
<td>Advanced Traveler Information System</td>
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<td>Curve Speed Warning</td>
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<td>Stop Sign Gap Assist</td>
<td>Eco-Traffic Signal Priority</td>
<td>Signal Priority (transit, freight)</td>
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<td>Connected Eco-Driving</td>
<td>Mobile Accessible Pedestrian Signal System (PED-SIG)</td>
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<td>Pedestrian in Signalized Crosswalk Warning</td>
<td>Eco-Lanes Management</td>
<td>Dynamic Speed Harmonization (SPD-HARM)</td>
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<tr>
<td>(Transit)</td>
<td>Eco-Speed Harmonization</td>
<td>Queue Warning (Q-WARN)</td>
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<td>Eco-Cooperative Adaptive Cruise Control</td>
<td>Cooperative Adaptive Cruise Control (CACC)</td>
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<td>Eco-Traveler Information</td>
<td>Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)</td>
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<td>Eco-Ramp Metering</td>
<td>Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)</td>
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<td>Low Emissions Zone Management</td>
<td>Emergency Communications and Evacuation (EVAC)</td>
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<td>AFV Charging / Fueling Information</td>
<td>Connection Protection (T-CONNECT)</td>
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<td>Eco-Smart Parking</td>
<td>Dynamic Transit Operations (T-DISP)</td>
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<tr>
<td></td>
<td>Dynamic Eco-Routing (light vehicle, transit, freight)</td>
<td>Dynamic Ridesharing (D-RIDE)</td>
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<td>Freight-Specific Dynamic Travel Planning and Performance</td>
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<td><strong>Agency Data</strong></td>
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<td>Drayage Optimization</td>
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<td>Probe-based Pavement Maintenance</td>
<td><strong>Road Weather</strong></td>
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<td>Probe-enabled Traffic Monitoring</td>
<td>Motorist Advisories and Warnings (MAW)</td>
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<td>Vehicle Classification-based Traffic Studies</td>
<td>Enhanced MDSS</td>
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<tr>
<td>CV-enabled Turning Movement &amp; Intersection Analysis</td>
<td>Vehicle Data Translator (VDT)</td>
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<tr>
<td>CV-enabled Origin-Destination Studies</td>
<td>Weather Response Traffic Information (WxTINFO)</td>
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<td>Work Zone Traveler Information</td>
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<td></td>
<td><strong>Smart Roadside</strong></td>
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<td>Wireless Inspection</td>
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<td></td>
<td>Smart Truck Parking</td>
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</tbody>
</table>

Source: US Department of Transportation

Most of these use V2I DSRC
DSRC Standards

- DSRC PHY+MAC (IEEE 802.11p)
- DSRC Upper-MAC (IEEE 1609.4)
- DSRC WAVE Short Message Protocol and WSA (IEEE 1609.3)
- Safety Message (SAE J2735)
- Min. Perf. Req. (SAE J2945)
- Non-safety applications
- TCP/UDP
- IPv6

New in 2015

NHTSA Requirement: “Stable” standards by Sept. 2015

Europe:
• Cooperative ITS, a.k.a. ITS-G5
• Similar technology (802.11p-based, 5.9 GHz)
• Voluntary deployment model
  – Expect more gradual penetration, perhaps starting earlier
  – More emphasis on “day 1” benefits

Japan:
• Advanced Safety Vehicle (ASV) – 760 MHz
  – V2V and V2I
  – Toyota voluntary deployment starting 2015
• Driving Safety Support System (DSSS) – 5.8 GHz
  – V2I, many roadside units deployed, many vehicles equipped
We’ve come a long way

- Field Tests
- interoperability
- safety feasibility
- privacy
- positioning
- mobility
- standards
- spectrum

1999

2015
Still to go … near term

- Spectrum Sharing
- Deployment
- Scalability
- Security
Security

• Twin goals:
  – Authenticate sender while preserving privacy
• PKI approach: asymmetric cryptography
• Two components
  – Per-message digital signature (pseudonymous)
  – Security infrastructure
    • SCMS: Security Credential Management System
    • Replenish short term credentials
    • Report & Revoke misbehaving actors
• Most technical work is done
• Important policy questions remain
  – Example: who owns/runs SCMS?
Scalability

Basic question: will all this still work here?
Biggest concern: BSM safety channel congestion

- Subject of a much published research
- Automaker consortium has researched two main approaches, in cooperation with US DOT
- Main distinction: Reactive vs. Adaptive Control
- Secondary distinction: Emphasis on message rate vs. transmit power control
Each vehicle determines its message rate $r_i(t)$ from current channel load (e.g. look up rate in a table).

$CBR(t) = \text{Channel Busy Ratio}$

$CBR$ is a channel loading metric.

Can equivalently control power, or both power & rate.
Distributed Adaptive Control

Each vehicle computes its message rate $r_i(t)$ adaptively based on the difference between channel load and a target load.

Algorithm Goals: controlled load, convergence, fairness

$CBR = Channel Busy Ratio$
$A channel loading metric$

$CBR Target is associated with high channel throughput$
Why drive CBR to target?

Test Parameters
- 30 radios
- 6 Mbps
- 544 μsec
- AIFS N = 6
- CWmin = 7

Throughput maximized when CBR in 60-70% range

An Adaptive DSRC Message Transmission Rate Control Algorithm, Weinfield, Kenney, Bansal, ITS World Congress, October 2011
LIMERIC

- Linear MESSAGE Rate Integrated Control
- Provable stability, convergence and fairness

\[ r_j(t) = (1 - \alpha)r_j(t - 1) + \beta(r_g - r(t - 1)) \]

- \( 0 < \alpha < 1 \): contraction parameter, impacts fairness, convergence speed
- \( \beta > 0 \): linear gain adaptive parameter, impacts stability, convergence speed

CBR Target \quad \text{Current CBR}

Rate for node j

\[ e(t - 1) \]

LIMERIC: A Linear Adaptive Message Rate Algorithm for DSRC Congestion Control, Bansal, Kenney, Rohrs, IEEE TVT Nov. 2013
Convergence:
• Provable conditions
• Fair
• Exact

Example fair convergence
Congestion Control Decision

• Critical for NHTSA Rulemaking, so needs to be standardized in 2015
  – SAE will standardize in J2945/1

• EU (ETSI/Car2Car) facing similar choice
  – Decided on a “reactive” approach for Day 1
  – Considering allowing adaptive approach
  – Mixed network behavior is critical
5 GHz Spectrum Sharing

- 2013: 5 GHz rules allow some unlicensed use:

- New IEEE 802.11ac (Gigabit Wi-Fi) standard allows 80 MHz and 160 MHz channels. Need large new blocks.
- Potential to add 4 new 80 MHz and 3 new 160 MHz channels in 5 GHz band.
  - One 80 and one 160 MHz channel in DSRC 5.9 GHz band
### Zoom in to 5.9 GHz band

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.850</td>
<td>CH 172: Collision Avoidance Safety</td>
</tr>
<tr>
<td></td>
<td>CH 184: High Power Public Safety</td>
</tr>
<tr>
<td>5.925</td>
<td>CH 178: Control Channel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CH 172</th>
<th>CH 174</th>
<th>CH 176</th>
<th>CH 178</th>
<th>CH 180</th>
<th>CH 182</th>
<th>CH 184</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service</td>
<td>Service</td>
<td>Service</td>
<td>Control</td>
<td>Service</td>
<td>Service</td>
<td>Service</td>
</tr>
<tr>
<td>10 MHz</td>
<td>10 MHz</td>
<td>10 MHz</td>
<td>10 MHz</td>
<td>10 MHz</td>
<td>10 MHz</td>
<td>10 MHz</td>
</tr>
</tbody>
</table>

**FCC DSRC Channel Designations**

- **Reserved 5 MHz**
- **20 MHz**
- **20 MHz**
- **20 MHz**
- **20 MHz**
- **40 MHz**
- **40 MHz**
- **80 MHz**
- **160 MHz**

**Overlapping Wi-Fi**
Major Stakeholders

US Congress

US President

FCC

IEEE WiFi

NTIA

Department of Transportation

UNited States of America

Global Automakers

Auto Alliance

Driving Innovation
Qualcomm Proposal

- Move DSRC safety from Ch. 172 to upper band (non-overlap portion)
- Cancel highest 20 MHz Wi-Fi (Ch. 181)
- DSRC use 20 MHz channels in overlap portion instead of 10 MHz
Cisco Proposal

- Wi-Fi devices listen for DSRC
- If no DSRC ➔ Wi-Fi ok to operate in 5.9 GHz
- Continues to listen while WLAN operates

- When car appears, Wi-Fi detects DSRC
- If DSRC detected ➔ Wi-Fi NOT ok to operate in 5.9 GHz (minimum TBD second delay after each DSRC packet)
- Detection leverages DSRC’s heritage as 802.11p
- Note: in-car Wi-Fi will never use 5.9 GHz
Spectrum Sharing Milestones

- **Feb. 2013**: FCC issues NPRM for 5 GHz
  - Asks if 5.9 GHz sharing is feasible
- **Aug. 2013**: IEEE forms “Tiger Team”
  - DSRC stakeholders participate fully
- **Fall 2013**: Qualcomm and Cisco offer sharing proposals
- **Nov. 2013**: Congressional hearing
- **Winter 2014**: Sen. Rubio bill puts pressure on FCC
- **Sept. 2014**: DSRC critiques Qualcomm proposal
  - Also indicates Cisco proposal has potential
- **March 2015**: Tiger Team ends
  - Poll of participants shows strong support for additional work on Cisco proposal, weak support for Qualcomm
- **May 5 2015**: Auto Trade Associations and Cisco tell FCC about plans for joint testing
Spectrum Sharing Milestones

• May 13, 2015: US DOT Sec. Foxx promises to test within 12 months of receiving prototype sharing equipment
Post-deployment challenge: Protocol evolution

- Contrast master-slave network with ad hoc
- Master (Base station, Access Point) can manage multiple generations of clients
- Ad hoc:
  - Unicast or small group: Negotiation to common protocol generation
  - Broadcast: ???
- Evolution of lower layers more difficult than higher layers
What else is it good for?
Remote sensing for automated driving

Non-line-of-sight (NLOS) obstacles are a major challenge for automated vehicles, especially at intersections.

Sharing sensor information can improve an automated vehicle’s awareness of potential hazards, including pedestrians, bicyclists, other vehicles, road works …
Augmenting & Sharing Real-Time Map

- Scalability is a concern
- Need adaptive content management
- “Connected, automated vehicles that can sense the environment around them and communicate with other vehicles and with infrastructure have the potential to revolutionize road safety and save thousands of lives.” – US DOT Sec. Foxx 5/13/15
Connected Car

- DSRC
- LTE
- AM/FM/XM
- GPS
- Wi-Fi
- BT

- Connecting with many things, in and out of the car
- New modalities being added all the time
What about 5G for V2X?

3GPP/ITU-R Timeline for 5G (3/17/15)
Note: As was the case with the previous generation - 3GPP does not intend to explicitly use the term “5G” when the work starts. “5G” will remain a marketing & industry term that companies will use as they see fit.

- Dino Flore, Chairman of 3GPP RAN and Balazs Bertenyi, Chairman of 3GPP SA

“When I use a word,” Humpty Dumpty said in rather a scornful tone, “it means just what I choose it to mean -- neither more nor less.”

- Humpty Dumpty in Lewis Carrol’s *Through The Looking Glass*
3GPP Work on V2X

- Recent study begun in SA1 (Services WG)
- Many use cases brought to April 2015 meeting:
  - Forward Collision Warning
  - Control Loss Warning
  - Emergency Vehicle Warning
  - Emergency Stop
  - C-ACC
  - Queue Warning
  - Road Safety Services
  - Automated Parking
  - Wrong way driving
  - Message Transfer
  - Pre-crash Sensing
  - Traffic Flow Optimization
  - Curve Speed Warning
  - Pedestrian Collision
  - Vulnerable Road User Safety

- Company contributions: LG, Ericsson, Huawei, Qualcomm, ETRI, Samsung, CATT, IPCom, Intel, Interdigital, Nokia, KT Corp., Sony
• Observation #1: Most use cases have safety implications
• Observation #2: Automakers are not proposing these use cases
• Toyota believes 5.9 GHz DSRC is the only technology that has been demonstrated to deliver safety-relevant information with sufficiently low latency and high reliability
• LTE/5G may offer excellent vehicle connectivity options
• We are interested to see this work progress
• Suggest use cases emphasizing non-safety applications be given more attention
What else is DSRC good for?

Invitation for Innovation
Larry Roberts’ ARPANET topology diagram, ca. 1969
Source: Where Wizards Stay Up Late

Some great things began as small ideas