Installing DSRC Systems for Vehicle to Infrastructure Applications

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Overview

• Connected Vehicles - Background
• Utah Deployment Overview
• Software
• Hardware
• Installation
• Project Costs
• System Demonstration
• Challenges
• Recommendations
Transportation Challenges

- Safety (35,000+ deaths per year)
- Congestion
- Travel and Transit Reliability
- Traveler Information
- Truck Parking (I-15 / I-80 / I-70)
- Managing Freight Movements / Ports of Entry
- Specific Road Weather Info / Hazards / Closures
- Incident Management
- Winter Inversion / Poor Air Quality
- Reliable / Real-time Construction Info

CONNECTED VEHICLE TECHNOLOGY CAN HELP US
The Connected Vehicle system will combine technologies:

- advanced roadside infrastructure,
- wireless communications,
- advanced vehicle sensors,
- onboard computer processing,

- to provide vehicles the capability to detect threats and hazards on the roadway and to communicate this to the driver through alerts and warnings.
Automated Vehicles

- Automated Vehicles use various technologies:
  - LiDar
  - Digital Imagery
  - Radar Sensors
  - GPS

- . . . to sense their surroundings and take some (or all) driving functions from the human driver

- Six levels of automation
Connected Automation for Greatest Benefits

**Autonomous Vehicle**
Operates in isolation from other vehicles using internal sensors

**Connected Vehicle**
Communicates with nearby vehicles and infrastructure

**Connected Automated Vehicle**
Leverages autonomous and connected vehicle capabilities
## 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)

### 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

### 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

### 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

### Smart Roadside
- Wireless Inspection
- Smart Truck Parking

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DSRC Deployments

Source: Kevin Gay, USDOT and Suzanne Murthy, OmniAir Consortium
Question 3: CV Applications Included in Agencies Plans or Proposals for Deployment
(Top 11 Applications Selected; # of Responders = 21)

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<th># of Responders</th>
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<td>Incident Scene</td>
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<td>Work Zone Alerts</td>
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<td>Vehicle Data for Traffic Operations</td>
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<tr>
<td>Emergency Vehicle Preemption</td>
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<tr>
<td>Intelligent Traffic Phase and Timing</td>
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<tr>
<td>Curve Speed Warning</td>
<td>11</td>
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<tr>
<td>Warnings about Hazards in a...</td>
<td>9</td>
</tr>
<tr>
<td>Warnings about Upcoming Work...</td>
<td>10</td>
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</table>

- Applications potentially deployable in rural areas
Moving Forward with Connected Vehicles

• What investments could be made to leverage a nationwide fleet of equipped vehicles in support of state and local policy and operational objectives including safety?

• Important issues for state and local agencies:
  • What the deployment decision could mean to you
  • How do you get started?
  • What you need to know to prepare for the emerging connected vehicle environment
Vehicle to Vehicle Communications

- NHTSA Issued a Notice of Proposed Rule Making (NPRM)
  - January 2017
  - 90-day Comment Period – 400+ comments
  - Will require DSRC for V2V in all new light vehicles
- Final Rule Anticipated – Late 2019
  - Phase-in Starting Late 2020 (2021 Model Year)
The SPaT Challenge

Challenge state and local public sector transportation Infrastructure Owners & Operators (IO&Os) to **deploy DSRC infrastructure with SPaT (and MAP) broadcasts** in at least one coordinated corridor or network (approximately 20 signalized intersections) in each state by January 2020.

Additional V2I Applications that build on SPaT are also encouraged!

**20 Intersections in 50 states by 2020!**
SPaT Challenge Resources

www.transportationops.org/spatchallenge
Utah DSRC Deployment

Redwood Road (1700 West)
(400 S to 8020 S)
Redwood Road DSRC Corridor

11-mile urban arterial corridor
- 35 signalized intersections
- Varies from 5 to 7 lanes
- ADT: 18,000 to 40,000
  - 60,000 peak at I-215
  - Truck Traffic: 24%
- Two light-rail crossings
- UDOT-owned corridor
- Demographic variety
  - Commercial / Retail
  - Residential
  - High School
  - Community College
Redwood Road DSRC Corridor

35 signalized intersections
- Full fiber optic connectivity
- All signals connected to central system
  - Intelight MaxView
- Running ATSPMs (signal performance metrics)
- Two brands of signal controller:
  - Econolite (Cobalt)
  - Intelight
Goals of the Utah Deployment

- Transit Signal Priority for Improved Schedule Reliability
  - UTA Bus Route 217
  - Goal: increase from 86% to 94%
  - Minimal impact to other traffic

- Meet the SPaT Challenge

- Full DSRC Corridor
  - Future testing / deployment
  - Prepare for equipped vehicles
Transit Signal Priority with MMITSS (MMITSS-AZ)  
(Multi-modal Intelligent Traffic Signal System) 
• Written by Dr. Larry Head, University of Arizona  
• Funding: CV Pooled Fund Study / FHWA  
• Also deployed in Palo Alto by Caltrans / PATH (MMITSS-CA)  
• Balances priority requests from various modes  
• UDOT focus was on transit priority  
• MMITSS software modified to:  
  • query bus schedule and occupancy  
  • operate with multiple DSRC platforms  
  • operate within coordinated corridor  
  • enable peer-to-peer / extend DSRC range  
Traffic analysis will measure system effectiveness & impact
Basic Connected Vehicle Schematic

Signal Phase and Timing Data
NTCIP 1202

Application Processor

Processor could be:
• In controller
• In DSRC
• Standalone

On-Board DSRC (OBU)

WME Forwarder sends J2735 messages to DSRC API, which encapsulates into IEEE 1609 format and sends

Basic Safety Message (BSM)
SAE J2735

Road-side DSRC (RSU)

Signal Phase and Timing (SPaT) Intersection Geometry (MAP)
SAE J2735

Traffic Management Center

On-Board DSRC (OBU)
**Utah MMITSS Schematic**

Roadside Processor (RSP) ➔ SPaT / MAP / PSM* ➔ BSM⁺/ SRM* ➔ (RSU) ➔ SPaT / MAP / PSM* ➔ (OBU) ➔ SPaT / MAP / PSM* ➔ BSM⁺/ SRM* ➔ On Board Processor (OBP)

- **SPaT / MAP / PSM***: Signal Request Message
- **BSM⁺/ SRM***: Priority Status Message
- **PSM**: ART: Active Request Table
- **BSM⁺**: Not the full J2735 BSM, contains GPS data, speed, direction
- **SPaT / MAP**: GPS, Schedule

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**NOTES**

*SRM: Signal Request Message
PSM: Priority Status Message
PSM = ART: Active Request Table

BSM⁺: Not the full J2735 BSM, contains GPS data, speed, direction

**NCTCIP**

**Command**

**GPS, Schedule**

**MMITSS**
DSRC Channels

DSRC Band Plan
- 5.850 – 5.925 GHz spectrum, granted by FCC
- Seven 10-MHz channels / One 5-MHz channel
- Channel 172 & 184 designated for safety of life and property
- Channel 178 designated as a control channel
- Two sets of 10-MHz channels may be combined

Source: FCC Request to Update U-NII Record, FCC 16-68, ET Docket No. 13-49, June 1, 2016
MMITSS Use of DSRC Channels

- **High Availability**
- **Low Latency**
- **BSM @ 10Hz**
- **MAP @ 1Hz**
- **SPaT @ 10Hz**
- **WSA** (WAVE Service Announcement)
- **Selected MMITSS Priority Channel**
- **SRM**
- **PSM / ART**
- **High Power Long Range (Public Service)**

**MMITSS Messages**

**SCMS**
MMITSS Operation (Simplified)

- Bus comes into range of DSRC at intersection
  - Connects to system
  - Receives SPaT and MAP data
- GPS reports bus location
  - MMITSS determines bus location in lane
- MMITSS queries bus schedule system
  - If bus is late, MMITSS generates request for priority
  - Priority request is sent to roadside
- AZ MMITSS: Algorithm manages signal operation to accommodate bus priority request
- Utah MMITSS: Sends priority request to controller
  - Sends NTCIP command to controller – sets input PIN
Getting SPaT Data from the Controller

- Retrieving SPaT data is controller-specific
  - Varied solutions – software and hardware (contact vendor)
- V2I Hub is a potential generic solution
- FHWA Open Source Application Development Portal (OSADP)

https://www.itsforge.net
OSADP Application Categories

- A variety of FHWA-sponsored open source software available

MMITSS-AZ is found in here

V2I Hub is found in here
V2I Hub

• Message handler that acts as a translator and data aggregator/dissemninator for infrastructure components of a connected vehicle deployment.

• Software platform that enables connected vehicles to talk to existing traffic management hardware and systems, such as traffic signal controllers, Transportation Management Centers, pedestrian and vehicle detection systems, road weather sensors, and dynamic message signs.

• Translates communication between different standards and protocols
V2I Hub

- SPAT Plugin - Communicates with a traffic signal controller (TSC) using **NTCIP 1202 v3**, and creates a J2735 SPAT Message.
- MAP Plugin - Produces intersection geometry in J2735 MAP format.
- Works with the following controllers:
  - Econolite ASC/3 (v2.58 or newer) and Cobalt
  - McCain ATC eX
  - Siemens M50
MAP Data File (MMITSS “NMAP” File)

• An ASCII text file which contains intersection map data required by MMITSS
• Components of the NMAP File
  • Intersection Information
    • Identification Number
    • Intersection Attributes (bit field definitions)
    • Reference Point (latitude, longitude)
  • Approach Information
    • Number of Approaches in the intersection
    • Approach Type (approach or an egress)
    • Number of traffic lanes in the approach
MAP Data File (MMITSS “NMAP” File)

- Establish points for each lane / element
  - One pair for each lane
  - < 0.5 meter accuracy
- Assign attributes for each lane
MAP Data File (MMITSS “NMAP” File)

MAP_Name 4610SouthRedwoodRoadReduced.nmap
RSU_ID 4610SouthRedwoodRoad
IntersectionID 7605
Intersection_attributes 00110011   /* elevation: Yes, lane width: Yes, Node data 16 bits, node offset solution: cm, geometry: Yes, navigation: Yes */
Reference_point 40.6698353 -111.9388660 13110   /* lat, long, elevation (in decimeters) */
No_Approach 8
Approach 1
Approach_type 1   /* 1: approach, 2: egress */
No_lane 2
Lane 1.1
Lane_ID 1
Lane_type 1   /* 1 to 5, for this intersection all 1: motorized vehicle lane */
Lane_attributes 0000000000101010   /* Approach path, straight permitted, right turn permitted, no u-turn, turn on red, */
Lane_width 365   /* in centimeter = 12 feet */
No_nodes 2
1.1.1 40.6698529 -111.9386633
1.1.2 40.6698459 -111.9369704
No_Conn_lane 26.1 4   /* Lane 1.1, Straight ahead */
end_lane
Lane 1.2
Lane_ID 2
Lane_type 1   /* 1 to 5, for this intersection all 1: motorized vehicle lane */
Lane_attributes 0000000001010100   /* Approach path, left turn permitted, yield, u-turn allowed, no turn on red */
Lane_width 305   /* in centimeter = 10 feet */
No_nodes 2
1.2.1 40.6698201 -111.9386637
1.2.2 40.6698190 -111.9384932
No_Conn_lane 4.3 2   /* Lane 1.2, Left Turn */
end_lane
end_approach
.. end_map

A Typical NMAP File
Other (Future) Messages

- Security Credential Management System (SCMS)
  - A unique security credential
  - Authenticate the message
  - SCMS being built for the CV Pilot Projects
    - Estimated availability to the rest of us: Summer 2018
- GPS Correction Factor (RTCM)
  - Might be needed for some applications
  - Provides higher accuracy on GPS coordinates
  - Some “public” sources of this data exist
DSRC Hardware

• Vendors
  • Arada / Lear
  • Cohda
  • Savari
  • Kapsch (on-board only, for the vehicle market)
  • Other new entrants into the market (Wave Mobile, etc.)

• Partnerships being formed to offer turnkey systems:
  • Savari – Econolite
  • Wave Mobile – Intelight

• Software Development Kit (SDK) needed for any development
DSRC Hardware Procurement

• Standards and Verification
  • RSU Spec 4.0 – manufacturers meeting this spec
  • RSU Spec 4.1 – been published
    • Adds a “hardware security module” for SCMS
      • Some vendors will provide firmware upgrade to 4.1
    • Support single channel & dual channel alternating DSRC
    • Contain internal computer processing & permanent storage
    • Power-over Ethernet (PoE) that supports IPv4 & IPv6
  • Device certification system being developed
DSRC Hardware Procurement

• No Standard Specification for OBU
  • Some have single DSRC, others have dual DSRC
  • Dual DSRC needed for some applications (MMITSS)
• Procurement Methods & Challenges
  • Government procurement often requires low cost
    • Two-step process allows technical evaluation then cost
    • Research or testing often allows direct purchase
DSRC Hardware

- Savari RSU
- Cohda OBU
- Antenna
- Cohda RSU
- Arada RSU
- Lear RSU
- Savari OBU
- Lear OBU
- Arada OBU
- Beaglebone Application Processors
- Signal Controllers
Linux Board

- Some DSRC units don’t have sufficient computational power to run applications
- Beaglebone Linux Board
  - Roadside Processor (RSP)
  - On-Board Processor (OBP)
  - 1GHz CPU with 4GB flash memory
- Mounted in protective case
- Power Supply
Redwood Road Installation

DSRC Hardware

- Equip 30 of 35 Intersections with RSU
  - Skip two freeway interchanges
  - Skip reversible-lane cross-street
- Equip buses with OBU (currently Cohda)
- Deployed three (four?) brands of DSRC
  - Did this to verify and test interoperability
  - Arada (purchased by Lear)
  - Lear
  - Savari
  - Cohda
Redwood Road Installation

- RSU mounted on signal pole, mast arm, luminaire pole
  - Omni-directional antenna, but obstructions can impair signal
  - 300 meter range (nominal)
- Ethernet cable to cabinet
Signal Cabinet Installation

- Ethernet (Fiber) Switch
- Ethernet Power Supply
- Processor Power Supply
- Fiber Jumper
- Roadside Application Processor (RSP)
- Signal Controller
DSRC Licensing

- Entity must have a “geographic DSRC license” from FCC
- NTIA has transmitters operating in this band in isolated locations
- Individual DSRC RSU sites must be “registered” with FCC
  - Device brand and model
  - Location of deployment (coordinates)
  - Antenna specifications
  - No license fee
- Many DOTs have person who oversees wireless systems
- On-Board DSRC does not need to be registered
On-Board Installation

- Installed in electronics cabinet behind driver
- Equipment:
  - DSRC OBU (currently Cohda)
  - “Beaglebone” On-board Processor (OBP)  
    (Mounted on pin-rail)
  - Power Supply
  - Antenna (roof of bus)  
    (DSRC and GPS)
Project Costs

- **Hardware**
  - RSU: $1200 - $3300 each $73,000
  - OBU: $900 - $1500 each $22,000
  - Beaglebone: $105 each (w/enclosure) $3,700
  - Misc Hardware (brackets, cables, SDK, shipping): $15,000

  Total Hardware Costs: $113,700

- **Installation / Integration / Coordination**: $153,600
  (including testing, verification, etc.)

- **Project Evaluation / Assessment**: $104,000
Project Costs

- Software
  - Modifications to MMITSS $178,000
  - Peer to Peer Feature $104,000
  - Hardware Interoperability $118,000
  - User Interface $  59,000

  Total Software Costs: $459,000

- Grand Total: $830,300

- Note: Internal costs not shown

And, we aren’t done yet!
### User Interfaces

#### MAP Data Log Per Intersection

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Data Feed Based on Checked Boxes</th>
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<tbody>
<tr>
<td>1500 S</td>
<td>Bus Location: Intersection</td>
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<td>1700 S</td>
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#### BSM Data

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<tr>
<td>Heading: unknown</td>
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<tr>
<td>Location: 40.7334211/-111.939341</td>
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<td>Speed: 0 mph</td>
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#### Signal Request Message (SRM)

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<td>Status: 4</td>
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<td>In Appr: 5</td>
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<tr>
<td>Out Appr: 0</td>
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<tr>
<td>Veh Appr: 2</td>
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<tr>
<td>Heading: South</td>
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<tr>
<td>Location: 40.7512315/-111.9391091</td>
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<td>Speed: 29 mph</td>
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#### ART Data (PSM)

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#### MAP Data

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#### OBU Interface

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Utah MMITSS System Demonstration
Challenges: General

• This is an emerging market
  • The hardware is still immature
    • Hardware specifications are changing
    • Interoperability is difficult (particularly with applications)
    • Integration with controllers and systems (incl. SPaT data)
    • Hardware idiosyncrasies
  • There are very few “off the shelf” applications
    • Research to operations is a big leap
    • Agencies (and consultants) have limited technical “bandwidth”
• Many applications need significant market penetration
  • NHTSA NPRM on V2V is crucial
Challenges

• Modifying code written by others is difficult
  • Prototype code not well documented
  • MMITSS messages weren’t standard messages
  • Segmentation faults in code
  • Data logging had to be altered to fit within available storage

• Variations between Vendors
  • Wmefwd needed to be modified / written for each platform
    • Crucial to sending standardized data packets – or NOT?
  • GPS data is handled differently – results in altered locations
  • Speed units were different

• Antenna types vary
Recommendations

• Start Small and Scale Up
  • The best way to learn is to “just do it”
    • SPaT Challenge
  • The time to deploy is now: it isn’t perfect, but it won’t be until we deploy and test

• Work Together / Share Experience
  • There is strength in numbers
  • Systems need to cross borders (Interoperability)

• Don’t expect it to be easy
Resources

- SPaT Challenge web site (Nat’l Ops Center of Excellence)
  - [www.transportationops.org/spatchallenge](http://www.transportationops.org/spatchallenge)
  - Lots of good resource documents
- V2I Deployment Coalition
  - Joint effort of AASHTO, ITS-America, ITE
- AASHTO Connected & Automated Vehicle Working Grp
- ITS-America Connected Vehicle Task Force
- ITE Connected Vehicle Task Force
- Caltrans: Greg Larson
  - Headquarters Div of Traffic Ops