Vehicle Safety Communications Project
Final Overview
Vehicle Safety Communications (VSC) Project

- 2.5 year program started in May 2002
- VSC Consortium Members: BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW
- Facilitate the advancement of vehicle safety through communication technologies
  - Identify and evaluate the safety benefits of vehicle safety applications enabled or enhanced by communications
  - Assess communication requirements, including vehicle-vehicle and vehicle-infrastructure modes
  - Contribute to DSRC standards and ensure they effectively support safety
  - Develop next generation DSRC testing system
  - Test and evaluate DSRC communications functionalities for potential vehicle safety implementations
Communications-Based Vehicle Safety Applications

- Brainstormed application scenarios enabled or enhanced by wireless communications
- Defined 45 application scenarios and their associated preliminary communication requirements
- Ranked applications based on their estimated safety benefits
- Selected a subset of highest ranking applications for further research
- Results published in Task 3 Public Report and Addendum, and released
Communications-Based Safety Applications

Communications Between Vehicle and Infrastructure

- Blind Merge Warning
- **Curve Speed Warning**
- Emergency Vehicle Signal Preemption
- Highway/Rail Collision Warning
- Intersection Collision Warning
- In Vehicle Amber Alert
- In-Vehicle Signage
- Just-In-Time Repair Notification
- **Left Turn Assistant**
- Low Bridge Warning
- Low Parking Structure Warning
- Pedestrian Crossing Information at Intersection
- Road Condition Warning
- Safety Recall Notice
- SOS Services
- **Stop Sign Movement Assistance**
- Stop Sign Violation Warning
- **Traffic Signal Violation Warning**
- Work Zone Warning

Communications Between Vehicles

- Approaching Emergency Vehicle Warning
- Blind Spot Warning
- Cooperative Adaptive Cruise Control
- Cooperative Collision Warning
- **Cooperative Forward Collision Warning**
- Cooperative Vehicle-Highway Automation System
- **Emergency Electronic Brake Lights**
- Highway Merge Assistant
- **Lane Change Warning**
- Post-Crash Warning
- **Pre-Crash Sensing**
- Vehicle-Based Road Condition Warning
- Vehicle-to-Vehicle Road Feature Notification
- Visibility Enhancer
- **Wrong Way Driver Warning**

*Note:* Highest ranking applications based on safety benefit estimates are highlighted in yellow.
Preliminary Communications Requirements

- Defined communications parameters that include:
  - Types of Communications (one-way, two-way, point-to-point, point-to-multipoint)
  - Transmission Mode (event-driven, periodic)
  - Minimum Frequency (Update Rate)
  - Allowable Latency (communication delay)
  - Message Set (Data to be Transmitted and/or Received)
  - Maximum Required Range of Communication

- Specified communications parameter values for application scenarios based on engineering judgment and industry experience
## Preliminary Communications Requirements for High-Priority Application Scenarios (Task 3)

<table>
<thead>
<tr>
<th>Types of Communication</th>
<th>Traffic Signal Violation Warning</th>
<th>Curve Speed Warning</th>
<th>Emergency Electronic Brake Lights</th>
<th>Pre-Crash Warning</th>
<th>Cooperative Forward Collision Warning</th>
<th>Left Turn Assistant</th>
<th>Lane Change Warning</th>
<th>Stop Sign Movement Assistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmision Mode</td>
<td>one-way, point-multipoint</td>
<td>one-way, point-multipoint</td>
<td>one-way, point-multipoint</td>
<td>two-way, point-point</td>
<td>one-way, point-multipoint</td>
<td>one-way, point-multipoint</td>
<td>one-way, point-multipoint</td>
<td>one-way, point-multipoint</td>
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<tr>
<td>Minimum Frequency (Hz)</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>50</td>
<td>10</td>
<td>10</td>
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<td>Allowable Latency (milliseconds)</td>
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<td>20</td>
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<td>Estimated Message Size (bytes)</td>
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<tr>
<td>Maximum Required Range of Communication (meters)</td>
<td>250</td>
<td>200</td>
<td>300</td>
<td>50</td>
<td>150</td>
<td>300</td>
<td>150</td>
<td>300</td>
</tr>
</tbody>
</table>

- **Red**: Requires communication between Infrastructure & vehicles
- **Blue**: Requires communication between vehicles
DSRC Communications Testing

- Designed and assembled 20 1st generation communications test kits (including DGPS units)
- Developed data collection software and analysis tools to conduct tests
- Developed test plan with representative test scenarios
- Conducted field testing on test track and public roadways including multi-sender capability
- Analyzed data from field testing
- Results published in Task 4 report
Initial Field Testing Results

- 78% of packets received up to 300 meters with heavy traffic
- Multi-sender (3-4) testing showed no noticeable interference
- 100% packet reception within 200m for vehicles approaching at freeway speeds
- 100% packet reception up to 350 meters - stationary vehicle as RSU and vehicle traveling at 60 mph
- 78% of packets received up to 300 meters with heavy traffic

- Multi-sender (3-4) testing showed no noticeable interference
Communication Performance in Real-World Intersection

- Assess viability of DSRC communications in real-world conditions
- 9 intersections in Michigan
- 7 intersections in California
- One RSU (sender)
- One OBU (receiver)
- 500 byte messages
- Every 100 msec, typically
- 6 Mbps data rate
- Sub-optimal RSU antenna and location:
  - RSU antenna is an “inverted” OBU antenna
  - RSU is positioned at intersection corner and height is approximately 10 ft
Vehicle Safety Communications Consortium

- One RSU (sender)
- One OBU (receiver)
- 500 byte messages
- Every 100 ms

Collected Data includes Received Signal Strength Indicator (RSSI - colorized track on aerial photograph of intersection)

- Sub-optimal RSU set-up

Intermittent packet reception before traffic light is seen by driver

I-696 & Woodward Ave Intersection

Intermittent packet reception before traffic light is seen by driver

Test terminated

Parking structure

GPS outage only
No DSRC outages

RSSI
63
47
31
16
0

R=100 m
- One RSU (sender)
- One OBU (receiver)
- 500 byte messages
- Every 100 ms
- DSRC packet reception at actual intersection locations

**RSSI**
- 69
- 52
- 35
- 18
- 1
Sand Hill Road & Whiskey Hill Road Intersection

- One RSU (sender)
- One OBU (receiver)
- 500 byte messages
- Every 100 ms
- Future optimization of RSU transmitter and antenna locations, and use of repeaters, likely able to mitigate packet loss due to terrain obstructions (hills, curves, foliage, etc.)
Current VSC DSRC/WAVE Radio Module
Functional Specification

- Support both 10MHz and 20MHz bandwidth
- Support any 802.11a and DSRC channel selection
- Support any 802.11a and DSRC data rate
- Support selectable transmit power up to 20 dBm (1 dBm increments)
- Implement APIs for real-time software control of variable parameters including access to RSSI value of each received frame
- Support random MAC address generation for OBU
- Largely compliant with ASTM E2213-03
- Ethernet interface to communicate with a Host Device
- Interfaces to Vehicle Data Bus and Traffic Signal Controllers (via Host Device)
- Continuous send and receive capability
Orchard Lake & Ten Mile Road Intersection

- One RSU in send & receive mode
  - Synchronized traffic signal controller with actual one
  - 500 byte messages including signal state & timing
  - Every 100 msec
- One OBU in send & receive mode
  - Sending 200 byte message including actual v2v common message set using actual data
  - every 100 msec
  - Driving through each lane of intersection, including turn lanes

View of Southbound Orchard Lake Rd

DSRC outages due to road sign obstruction of antenna

RSSI (dBm)
-35.0
-49.5
-64.0
-78.5
-93.0
RSU message packet reception (actual signal state & timing) was better than 88% within 250 m with sub-optimal RSU set-up:

1. RSU antenna is an “inverted” roof-mount OBU antenna
2. RSU is positioned at intersection corner and height is approximately 10 ft
Orchard Lake & Ten Mile Road Intersection: Signal State & Timing Reception

• Demonstrated end-to-end connectivity between traffic signal controller and vehicle (via a synchronized unit)
• Current serial information from controller has inadequate time resolution and update rate (only 1 second resolution for time remaining in current phase updated only every 200 msec)
DSRC Outage Characterization
An example: Orchard Lake & Ten Mile Rd Intersection

Only 1 packet missed at a time: can be mitigated with data coasting techniques

Long outage (~ 1 second) due mainly to road sign obstruction of antenna: can be remedied with a more optimal RSU set-up
V-V Communication Performance in Real World

- Industry First Safety Communications - CAN information from different vehicle makes were exchanged wirelessly (Sept '04)
- Seven OBU (send & receive)
- 200 byte messages (GPS position, speed, yaw-rate, acceleration, brake status, etc)
- Every 100 ms
- Urban roads & freeway setting
V-V Communication with 7 OBU-caravan on freeway ramp

- Packet reception results were better than expected
- Demonstrated communications between vehicles in traffic separated by multiple vehicles
Test Track V-V Maximum Communication Range at different relative speeds

- No degradation in performance at high speed

Relative Speed = 20 mph

Relative Speed = 140 mph

Distance between GM28 and Ford28 calculated from data received by Ford28

- RSSI > -50dBm
- -70dBm < RSSI < -50dBm
- -90dBm < RSSI < -70dBm
- RSSI < -90dBm

Gap indicates lost packets

Color (from red to purple) indicates received packets with increasing RSSI
DSRC Security

- Constructed a proposed security architecture and protocol that appears to meet the technical requirements within the constraints identified in the project
- Presented and promoted VSC requirements and solution suggestions into standards development process
- Other stakeholders’ requirements presently being integrated with VSC requirements for proposed DSRC security standard
- Drafting group currently preparing updated documents for consideration by DSRC security standard committee
DSRC Security Architecture

- Proposed OBU and RSU authentication:
  - All units are issued certificates (OBUs get several)
    - Certificates are in a special compact format; those for RSUs contain special authorization information (e.g. type of unit, authorized geographic area)
    - OBU certificates do not contain the vehicle identity
  - Safety-relevant messages are digitally signed
    - Proposed security per-packet overhead totals 150 bytes
  - Compromised units are revoked
    - Units suspected of being compromised are put on a Certificate Revocation List (CRL); that list is flooded to all units
    - OBU certificates are linked to permit revocation as a group
DSRC Standards

- The preliminary SAE common vehicle-to-vehicle DSRC safety message set was implemented in VSC field testing
  - Longitude
  - Latitude
  - Height
  - Time
  - Heading Angle
  - Speed
  - Lateral Acceleration
  - Longitudinal Acceleration
  - Yaw Rate
  - Throttle Position
  - Brake Applied Status
  - Brake Applied Pressure
  - Steering Wheel Angle
  - Headlight Status
  - Turn Signal Status
  - Traction Control State
  - Anti-Lock Brake State
  - Vehicle Length / Width

- Preliminary vehicle safety communications requirements:
  - Supported by FCC Report & Order, current lower layer standards
  - Being considered in development of upper layer and security standards
**DSRC Standards (Continued)**

- High-availability, low-latency DSRC channel appears to be required for some vehicle safety applications, but was not designated in FCC Report & Order.
- Future technical work required to fully justify need for high-availability, low-latency channel, but important to reserve a DSRC channel now for this potential usage.
- Upper layer DSRC standards enforcement will be necessary to ensure interoperability of vehicle safety applications.
- Testing and validation of the emerging DSRC standards should be initiated as soon as the standards become available.
VSC Project Summary

- Prepared a comprehensive list of thirty-four potential vehicle safety applications enabled or enhanced by wireless communications
- Estimated potential safety benefits for potential vehicle safety applications and identified eight high-priority applications
- Defined preliminary communications requirements for the high-priority vehicle safety applications
- Evaluated proposed DSRC standards, identified specific technical issues, presented vehicle safety requirements, and secured necessary revisions in eight major areas
- Developed test system based on lower layer DSRC standard and conducted extensive communication field testing
VSC Project Summary (Continued)

- Confirmed viability of DSRC communications for vehicle safety applications at real intersections
- Implemented and demonstrated successful exchange of preliminary SAE common safety message set needed for vehicle-to-vehicle safety applications
- Identified channel capacity in stressing traffic environments as large scale deployment issue
- Determined that 5.9 GHz DSRC wireless technology is potentially best able to support the communications requirements of the majority of vehicle safety applications
Next Steps

- Prototype Cooperative Intersection Collision Avoidance safety applications
- Prototype communication-based vehicle-to-vehicle safety applications
- Develop intelligent DSRC protocol (to improve communication reliability in stressful traffic environment)
- Continue to influence and contribute to DSRC standards development from vehicle safety communication requirements standpoint
- Implement and test upper layer & security standards when available