CAMP

Vehicle Safety Communications Consortium

DaimlerChrysler Research and Technology North America, Inc.

GM

TOYOTA TOYOTA TECHNICAL CENTER, USA, INC.

NISSAN

Ford

BMW

IVI Light Vehicle Enabling Research Program

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)

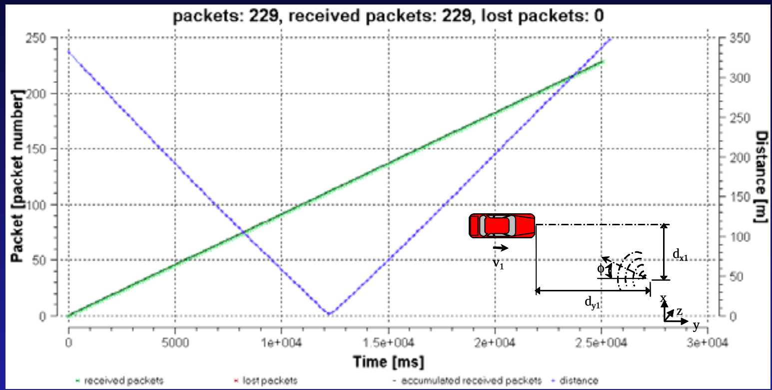
	Traffic Signal Violation Warning	Curve Speed Warning	Emergency Electronic Brake Lights	Pre-Crash Warning	Cooperative Forward Collision Warning	Left Turn Assistant	Lane Change Warning	Stop Sign Movement Assistance
Types of Communication	one-way, point-multipoint	one-way, point-multipoint	one-way, point-multipoint	two-way, point-point	one-way, point-multipoint	one-way, point-multipoint	one-way, point-multipoint	one-way, point-multipoint
Transmission Mode	periodic	periodic	event-driven or periodic	event-driven	periodic	periodic	periodic	periodic
Minimum Frequency (Hz)	10	1	10	50	10	10	10	10
Allowable Latency (milliseconds)	100	1000	100	20	100	100	100	100
Estimated Message Size (bytes)	500	200	200	200	200	500	200	500
Maximum Required Range of Communication (meters)	250	200	300	50	150	300	150	300

Requires communication between Infrastructure & vehicles — Requires communication between vehicles

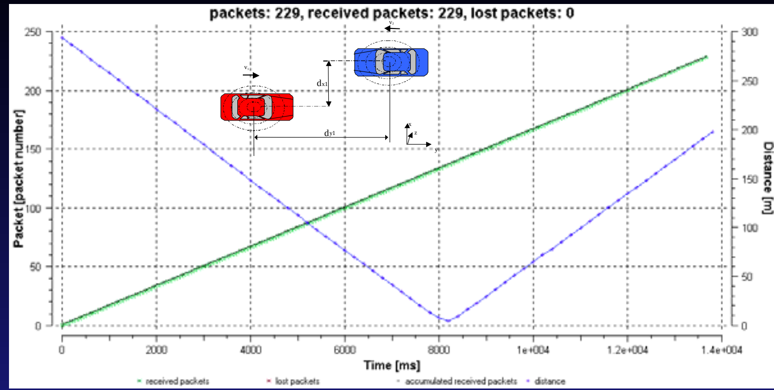
DSRC Communications Testing

- 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

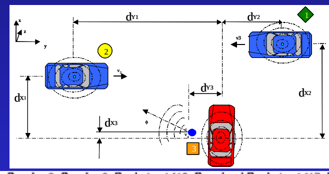
Initial Field Testing Results

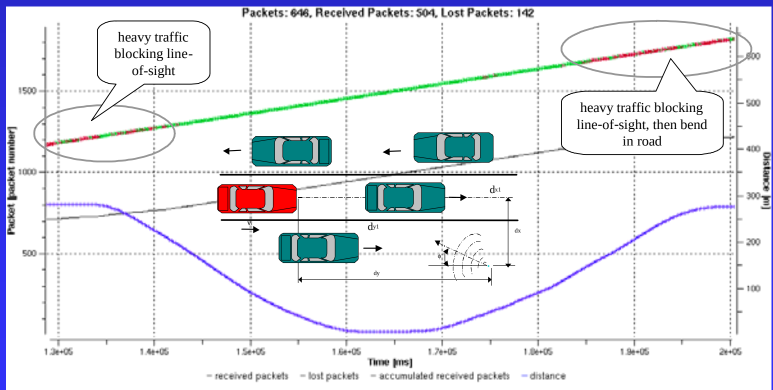


•100% packet reception up to 350 meters - stationary vehicle as RSU and vehicle traveling at 60 mph

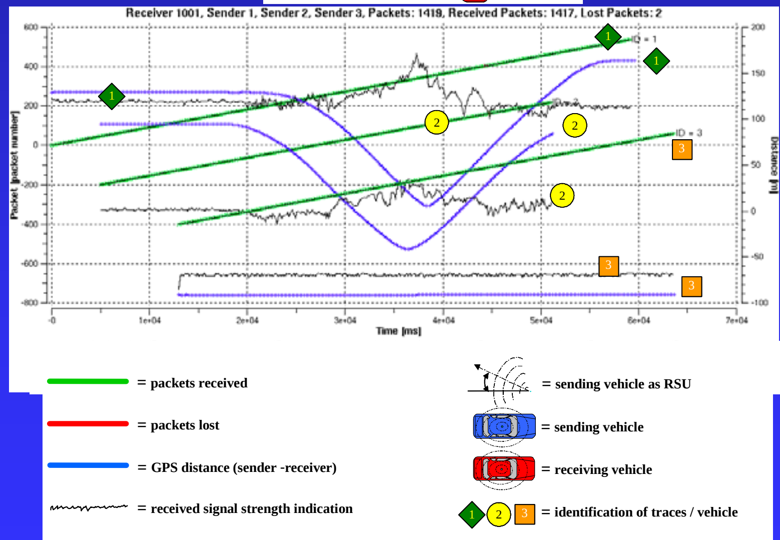


•100% packet reception within 200m for vehicles approaching at freeway speeds





•78% of packets received up to 300 meters with heavy traffic



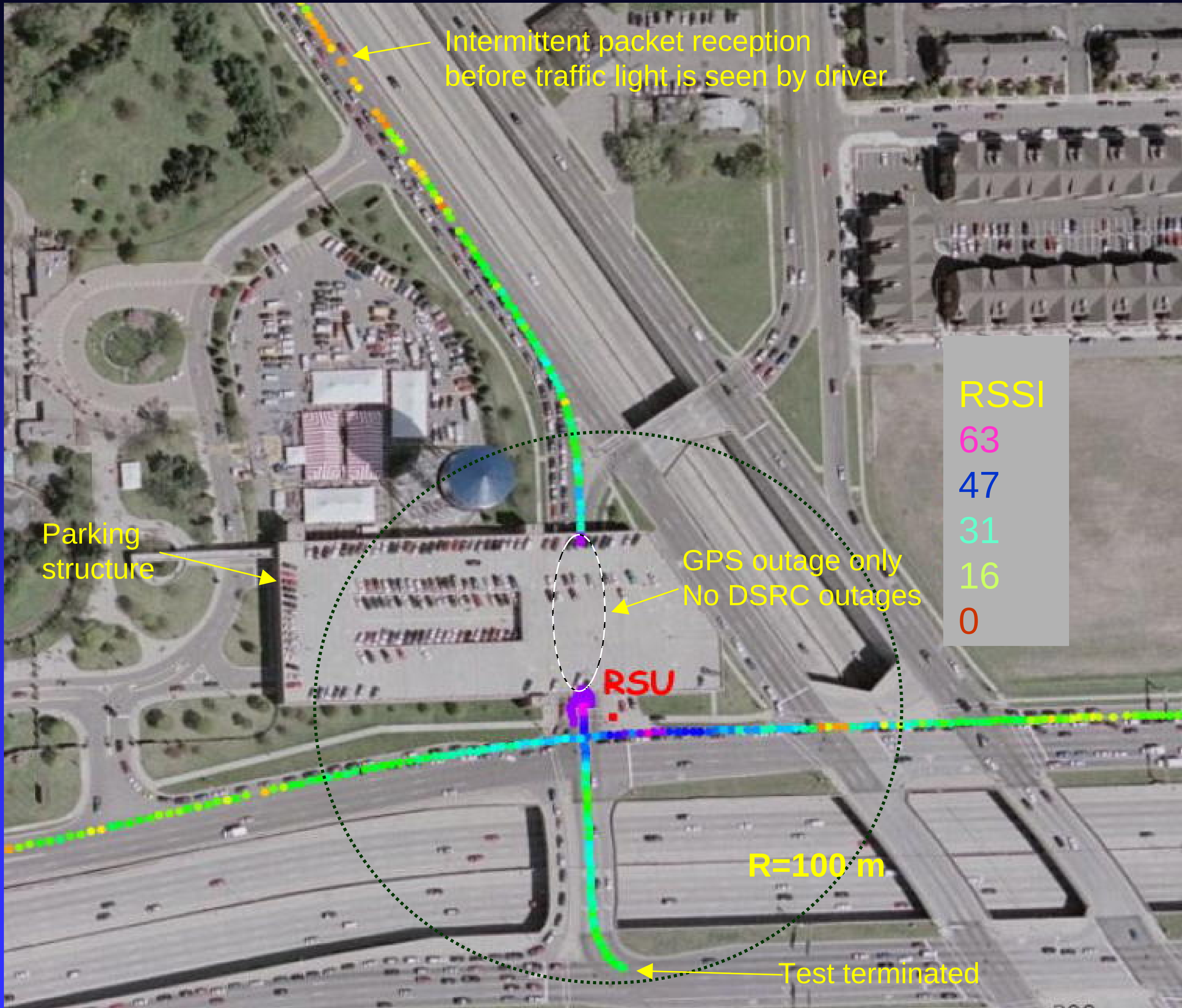
• multi-sender (3-4) testing showed no noticeable interference

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

I-696 & Woodward Ave Intersection

- 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

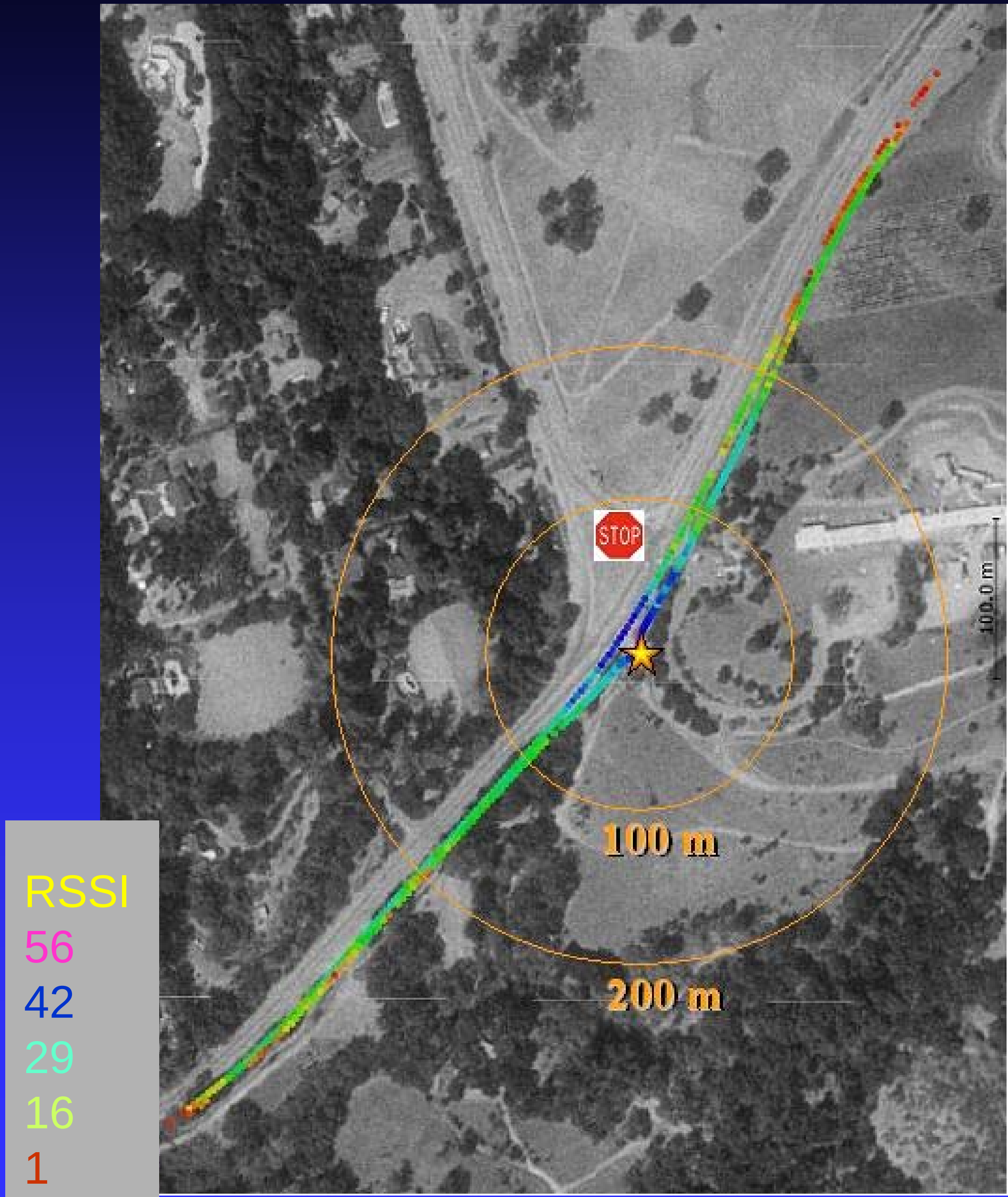


Oakwood Blvd & Michigan Ave Intersection

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

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 Testing System

WAVE Radio Module

SMA RF connection

DSRC prototype antenna magnetically mounted on OBU vehicle

ethernet

RSU configuration

serial

EPAC300 M30
Traffic Signal Controller

serial

DGPS receiver & antenna

usb

OBU configuration

USB to CAN adapter

OBU vehicle

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

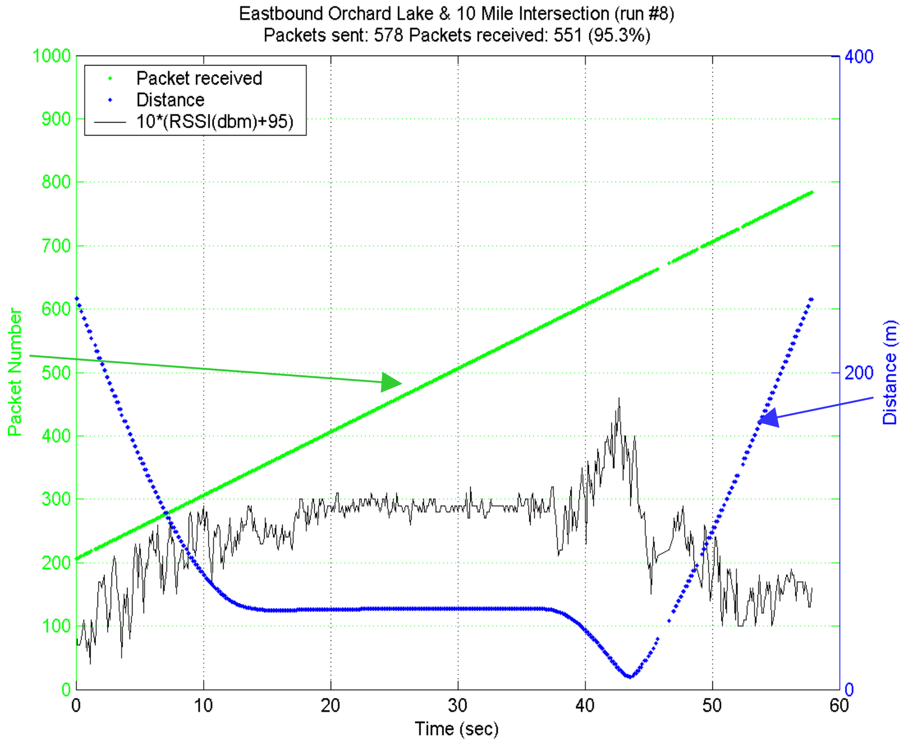
Orchard Lake & Ten Mile Road Intersection

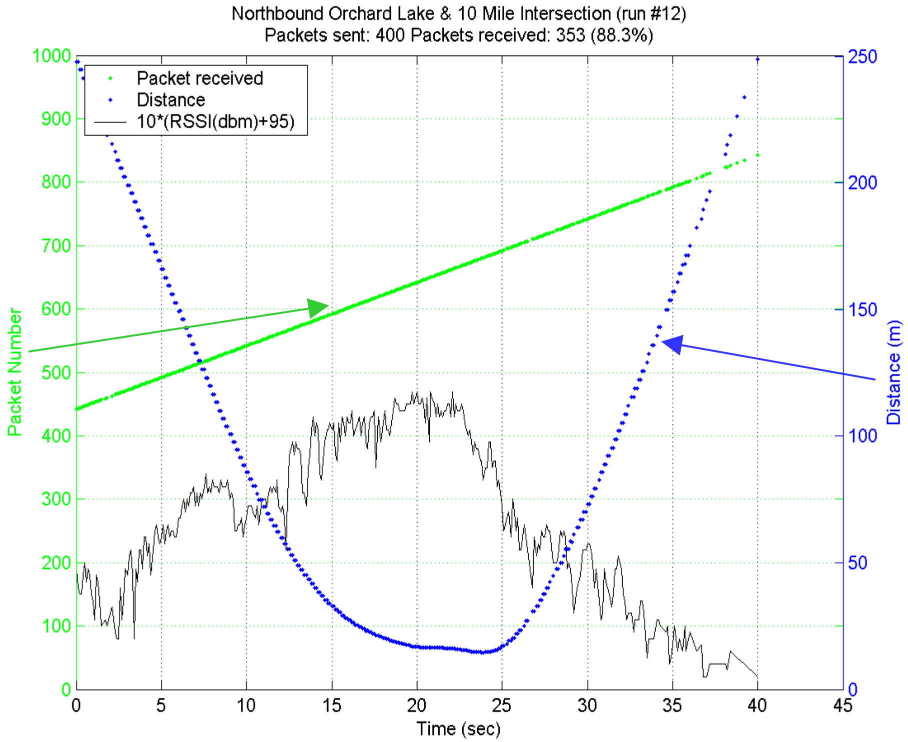
- One RSU in send & receive mode
  - Synchronized traffic signal controller with actual one
  - 500 byte messages including signal state & timing
  - Every 100 msec
- One OBU in send & receive mode
  - Sending 200 byte message including actual v2v common message set using actual data
  - every 100 msec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

Orchard Lake & Ten Mile Road Intersection: Received Packets versus Distance

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

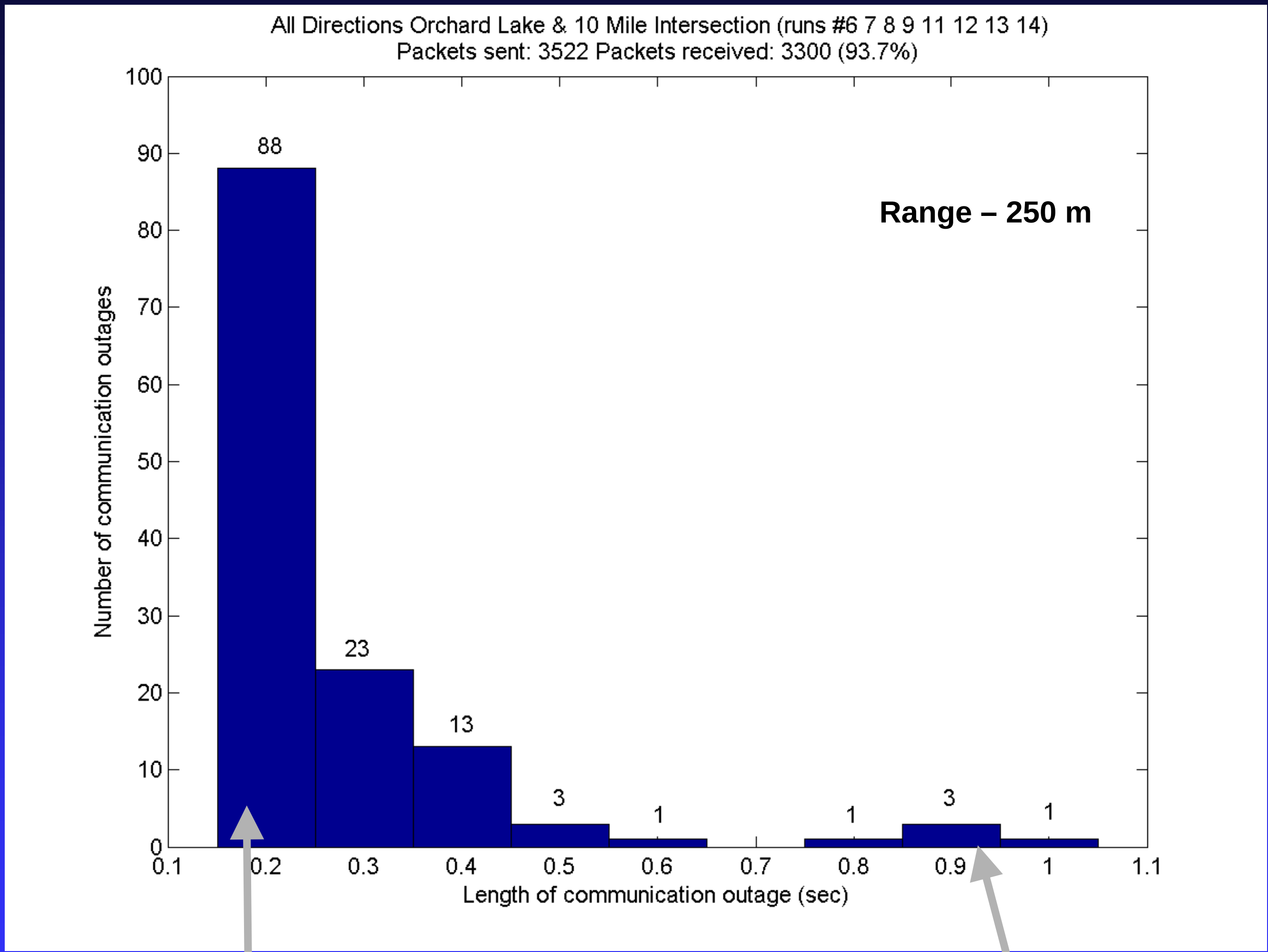




Orchard Lake & Ten Mile Road Intersection: Signal State & Timing Reception

- 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



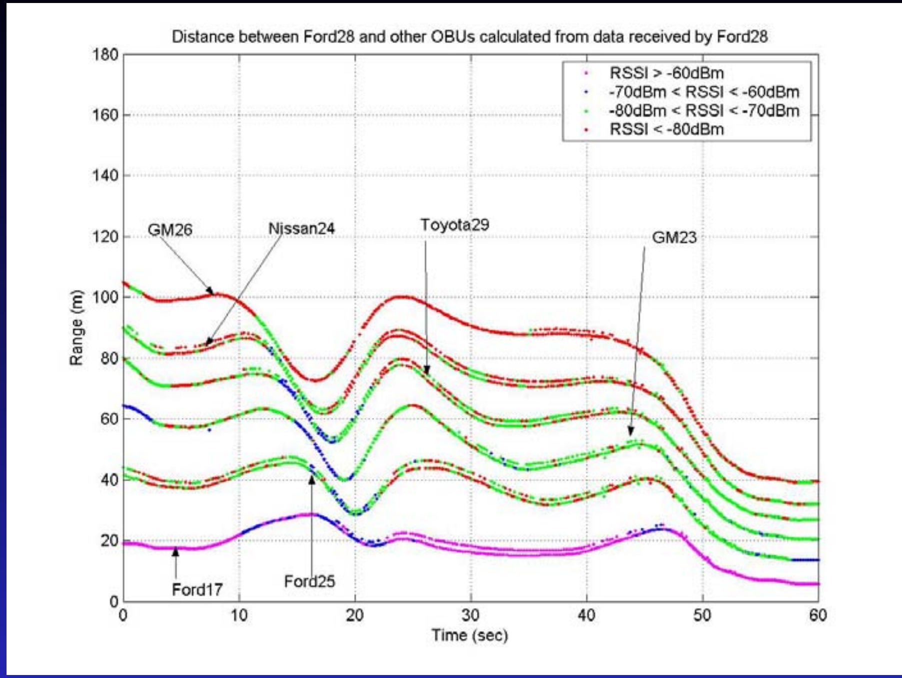
Only 1 packet missed at a time: can be mitigated with data coasting techniques

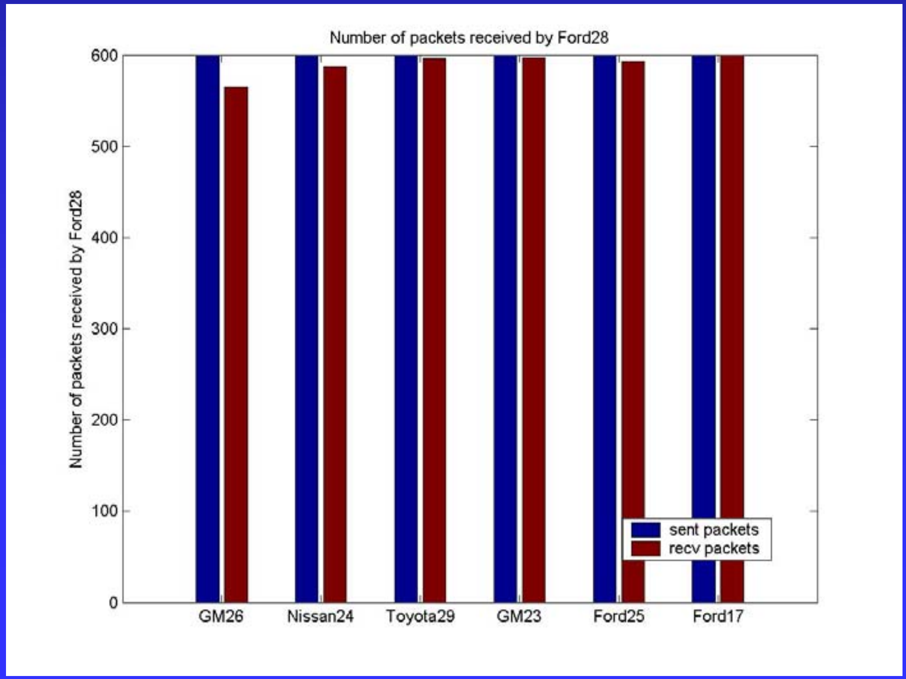
Long outage (~ 1second) due mainly to road sign obstruction of antenna: can be remedied with a more optimal RSU set-up

V-V Communication Performance in Real World

- Industry First Safety Communications - CAN information from different vehicle makes were exchanged wirelessly (Sept ’04)
- Seven OBUs (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

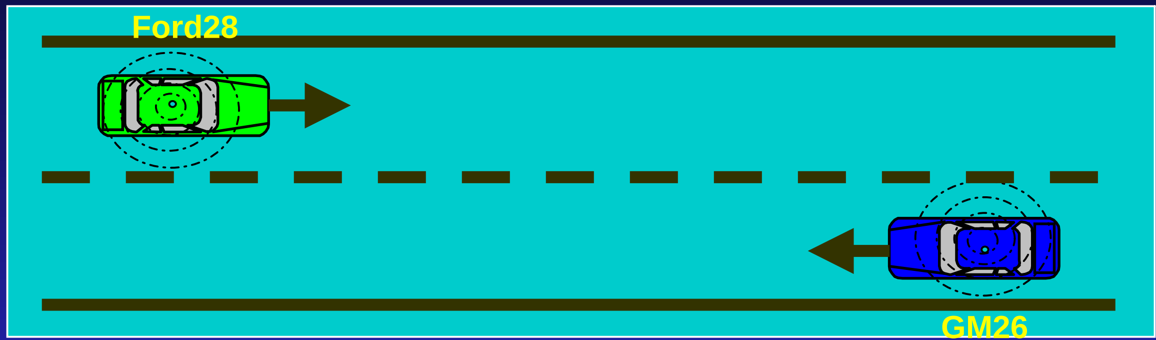


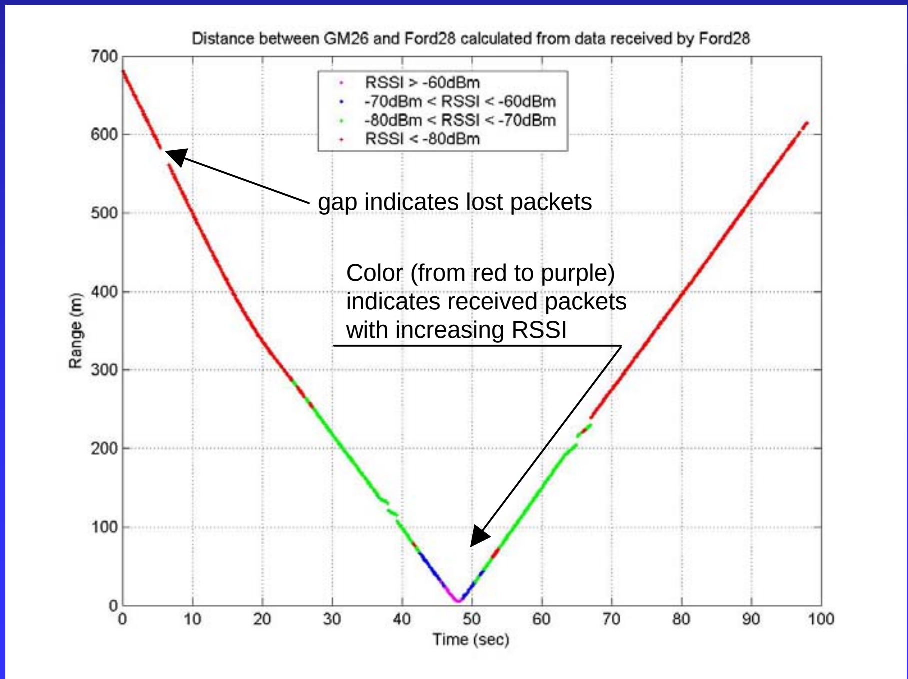


- Packet reception results were better than expected
- Demonstrated communications between vehicles in traffic separated by multiple vehicles

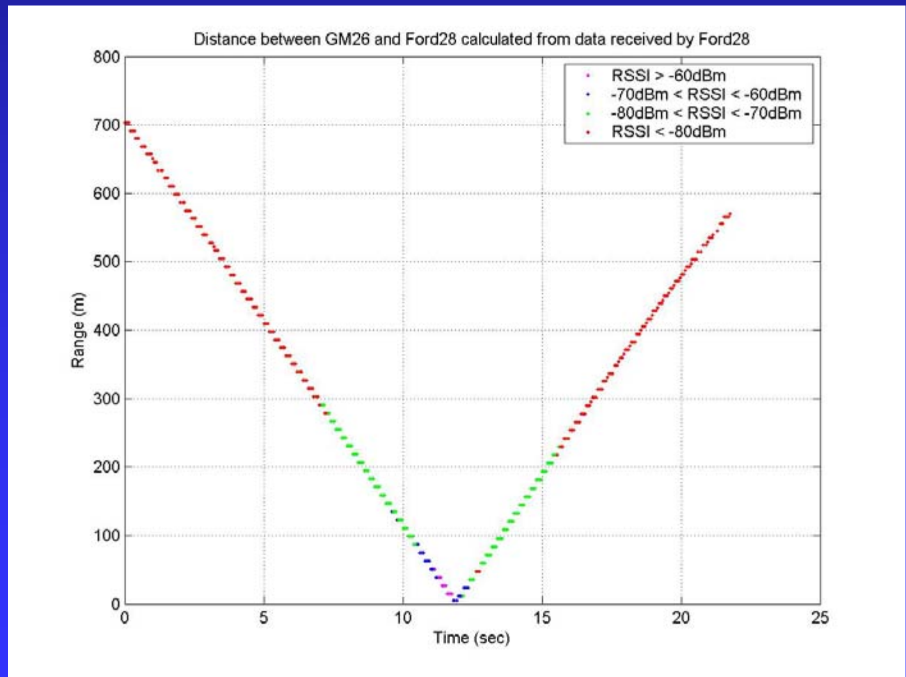
Test Track V-V Maximum Communication Range at different relative speeds

- No degradation in performance at high speed





Relative Speed = 20 mph



Relative Speed = 140 mph

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