Future of V2X
X – Vehicles, Smartphones, Infrastructure

Silicon Valley Automotive Open Source
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CEO, Savari
About Savari

✓ Established in 2008. Global HQ: Santa Clara CA with ~Forty employees
Three R&D centers in CA, MI and India

✓ Savari develops V2X technologies for road infrastructure & co-operative
advanced driver assistance systems

✓ First to market with commercial deployment in Q1 2015

✓ Deployed V2X infrastructure in Arizona, California, Michigan, Virginia

✓ Partnered closely with:
  ➢ US DOT: RITA, FHWA, NHTSA
  ➢ OEMs: CAMP (GM, Ford, Hyundai, Nissan, VW, Mercedes, Toyota)
  ➢ Transportation Research: UMTRI – MI, VTTI – VI, UofA - AZ
V2X via Vehicles, Phones & Infrastructure

MobiWAVE™

www.savarinetworks.com
Path to Automated Vehicles

Today

- Autonomous Vehicles
  + Actuators
  - Connected Vehicles
    + V2X

Semi Autonomous Vehicles
Self-braking
Proximity warning

Camera
RADAR
LIDAR
## V2X Big Picture

<table>
<thead>
<tr>
<th>Key Information</th>
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<tbody>
<tr>
<td><strong>V2X Overview</strong></td>
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<tr>
<td>▶ V2V is inexpensive system with many safety-related applications</td>
</tr>
<tr>
<td>▶ V2I has similar apps, but requires complex network infrastructures</td>
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<td>▶ Growing driver distraction requires technology solutions like V2X</td>
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<tr>
<td><strong>V2V vs V2I</strong></td>
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<tr>
<td>▶ V2V can address 75% plus of all accident (non-impaired drivers)</td>
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<tr>
<td>▶ V2I can address remaining accidents categories</td>
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<tr>
<td>▶ V2I has many ITS and eco-related applications</td>
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<tr>
<td><strong>V2P vs P2I</strong></td>
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<td>▶ Smartphones are supported with key enabling technologies</td>
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<td>▶ Communication via DSRC, Cellular to the infrastructure</td>
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<tr>
<td><strong>Standards</strong></td>
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<tr>
<td>▶ US Standards – WAVE - 802.11p, IEEE 1609.2, 1609.3, 1609.4</td>
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<td>▶ EU standards – 802.11p, ITS G5, Geo Networking, IPV6</td>
</tr>
<tr>
<td><strong>Summary</strong></td>
</tr>
<tr>
<td>▶ V2V is least costlier way to lower accident costs</td>
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<tr>
<td>▶ V2V is only useful if nearby vehicles/phones have V2V (network effect)</td>
</tr>
<tr>
<td>▶ Deployment – NHTSA driven mandate in USA 2017+, EU 2015+</td>
</tr>
</tbody>
</table>
V2V Overview
Vehicle-to-Vehicle Communications
Starts with Data Broadcast

Latitude, Longitude, time, heading angle, speed, lateral acceleration, longitude acceleration, yaw rate, throttle position, brake status, steering angle, headlight status, turn signal status, vehicle length, vehicle width, vehicle mass, bumper height

source: USDOT
V2V Safety Applications

- Emergency brake light warning
- Forward collision warning
- Intersection movement assist
- Blind spot and lane change warning
- Do not pass warning
- Control loss warning
- Weather-related vehicle stabilization activation
Forward Warning

FCW

FCW1

FCW2

FCW3

EEBL

FCW4

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Lane Changing

<table>
<thead>
<tr>
<th>BSW</th>
<th>LCW</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="BSW Diagram" /></td>
<td><img src="image2" alt="LCW Diagram" /></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>DNPW</th>
</tr>
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<tbody>
<tr>
<td><img src="image3" alt="DNPW Diagram" /></td>
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</tbody>
</table>
Intersections

IMA

IMA1

IMA2

LTA
V2I, I2V Overview
What are V2I & I2V & I2I?

- V2I is defined by wireless data exchange between any type of (multimodal) transportation vehicle, and immobile roadside unit.
  - Data can be exchanged between vehicles and “the infrastructure” by many different “over-the-air” interfaces.

- USDOT’s Connected Vehicles Research Program has so far focused on 5.9 GHz band DSRC; however, and perhaps just as appropriate for mobility and environmental applications, other technologies are viable as either one or two way data exchanges:
  - Pre & post 4G cellular, WiFi, Sirius XM, DTB Radio (eg. HD FM, TMC)
  - DSRC V2I may be operated by local or state road operators who are best situated to utilize the transportation data currently being considered, and/or provide it to other users as necessary for particular use cases.
Smart Infrastructure

- Enhanced intersection safety and efficiency through use of vehicle trajectory data
- Further advantages include performance measures based on multi-modal ITS systems, capacity to provide real-time traffic information
- Provides opportunity to create open network that connects transportation corridors, people and data to transform the way the world moves
Traffic Signal Priority/Preemption

- Signal Preemption for emergency, freight vehicles
- Expanded availability, more efficient handling of multiple requests, reduction in transit delay and variability
- Today’s solutions are commonly based on infrared, GPS, wireless systems, and lack common service scalable integrated framework
Eco Driving

- Smarter operations through vehicle awareness of intersection state
- Substantial improvements in fuel savings
- This could also be extended as a service by the infrastructure provider
- Use of environmental sensors attached to target vehicles (delivery vehicles for sub/urban; utility vehicles at airports, ports) creates micro-emissions and micro-weather capabilities
Transportation Pricing

- V2I technology can add opportunity for smart tags to do congestion pricing, VMT based pricing, variable parking fees
- Provides more opportunities to deploy V2I technologies in controlled environments
  - Airport
  - Seaports
  - Corridors
  - Hot lanes
  - Environmentally sensitive geographies
National footprint

Source: USDOT
P2V, P2I Overview
Context Awareness in Smartphones
Turn on DSRC at the right moment based on where you are & what you are doing. Always ON and power efficient

DSRC capable WiFi chipsets
Enable DSRC without adding HW cost Ride on high penetration of WiFi chipsets in smartphones

Augmented Positioning
Improve GPS positioning accuracy Enhance positioning with WiFi or Cellular and sensors

Source: Qualcomm
Pedestrian-to-Vehicle (P2V)

Pedestrian-to-Vehicle
- Deploy smart phones, equipped with DSRC support to act as beacons for pedestrians
  - phone can alert driver to pedestrian presence in path
  - ‘pedestrian BSM’ can aid awareness for vehicles
  - Well suited for bicyclists also

Pedestrian-to-Infrastructure
- Smart phone, through DSRC/cellular, transmits pedestrian presence to crosswalks/ signals
   - enables advanced crosswalk lighting/warning scheme
   - enables “bundling” of pedestrian presence to vehicles
Pedestrian-to-Infrastructure (P2I)

- System to deliver SPaT, MAP and other SAE J2735 messages to the smartphone.
- Allows pedestrians to request WALK at the crosswalk.
- Designed to be communication medium agnostic.
Standards
### US DSRC Spectrum: Seven 10 MHz channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency</th>
<th>Service Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH 172</td>
<td>5.850 GHz</td>
<td>5 MHz Reserved</td>
</tr>
<tr>
<td>CH 174</td>
<td>5.850 GHz</td>
<td>10 MHz Service</td>
</tr>
<tr>
<td>CH 176</td>
<td>5.850 GHz</td>
<td>10 MHz Service</td>
</tr>
<tr>
<td>CH 178</td>
<td>5.850 GHz</td>
<td>10 MHz Control</td>
</tr>
<tr>
<td>CH 180</td>
<td>5.925 GHz</td>
<td>10 MHz Service</td>
</tr>
<tr>
<td>CH 182</td>
<td>5.925 GHz</td>
<td>10 MHz Service</td>
</tr>
<tr>
<td>CH 184</td>
<td>5.925 GHz</td>
<td>10 MHz Service</td>
</tr>
</tbody>
</table>

- **Ch. 172:** Collision Avoidance Safety
- **Ch. 178:** Control Channel
- **Ch. 184:** Public Safety

- WAVE Service Advertisements are broadcast here, indicating how to access services on other “Service Channels”
Potential new Wi-Fi channels in 5 GHz band

- 802.11n introduced 40 MHz channels
- 802.11ac introducing 80 MHz and 160 MHz channels
- UNII-2 (A, B, C): radar is primary, Dynamic Frequency Selection (DFS) is required by Wi-Fi

Source: John Kenney Slides
“Detect-and-vacate” concept

- Key is to avoid colliding with or delaying DSRC packets
- Wi-Fi devices already avoid overlapping transmissions via a “listen-then-talk” protocol
  - Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)
- Wi-Fi can detect DSRC device in area via similar function that looks for 10 MHz DSRC packet “signature”
- Before sending anywhere in 5.9 GHz band, listen for DSRC in all 7 channels
  - If no DSRC detected, ok to operate WLAN
  - If DSRC detected, keep out of the band for [TBD] time

V2X Global Standards

- IPV6
- Geo Routing, BTP
- SAE J2735, CAM, DENM
- IEEE 1609.1-4
- IEEE 802.11p
- ITS G5

US/Europe
US Standards Overview

- **DSRC Security (IEEE 1609.2)**: 2013
  - Messages (SAE J2735)
  - Min. Perf. Req. (SAE J2945) Draft

- **DSRC PHY+MAC (IEEE 802.11p)**: 2010

- **DSRC Upper-MAC (IEEE 1609.4)**: 2010

- **IPv6**: 2010

- **TCP/UDP**: 2013

- **Non-safety applications**: 2010

- **Service Advertisement (IEEE 1609.3)**: 2010

Savari networks

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US - WAVE Scope

External Systems

ROAD SIDE UNIT

Applications

WAVE Stack

Covered by WAVE Standards

ON-BOARD UNITS

Applications

WAVE Stack

Optional External Interface

Air Interface

Optional External Interface

External Systems
US - 1609.2 Security Services

Two primary functions:
1. Authentication – Shows sender is authorized, and that data not altered
2. Encryption – keeps data secret (need for this limited)

Both use “elliptic curve” cryptographic algorithms

Note: Privacy is key element of V2X security

1609.2 supports pseudonymous certificates – not linked to car Identifiers (certificates, MAC, etc.) changes every few minutes
US - 1609.2 Security Overview

DSRC 5.9 GHz

V2V Communication Security

Certificate

BSM/CAM

Signature

Request and Renew Certificates

Certificate Authority / Security Credential Management Server

Certificate

DSRC, 3G, Wi-Fi, ...

Report misbehavior and receive certificate revocation lists

Misbehavior Report / CRL

Signature

Security Credential Management System
US - 1609.3 Networking Services

Management plane (WME: WAVE Management Entity)

Generates contents of service advertisements based on higher layer info
  Including IP configuration info and security credentials
Monitors received service advertisements for services of interest to higher layers
  Estimates channel quality
Determines channel allocation/switching schedule to satisfy service requests

Data plane

Incorporates standard LLC and IPv6
Introduces thin WAVE Short Message Protocol (WSMP)
  Allows direct control of RF parameters (e.g., power, data rate) by the higher layer
US - 1609.3 Standards

WAVE device

IEEE 1609.2
- WAVE Service Security
- Networking Services
- Lower Layers

Medium

IEEE 1609.1, et al.

IEEE 1609.3

IEEE 1609.4, IEEE 802.11p

1609.2

Future higher layer standards

1609.3

1609.4

802.11

Security

Management

UDP / TCP

IPv6

WSMP

LLC

WAVE MAC (including channel coordination)

PHY
US - 1609.4 Transmit Operation

MAC (with Muti-Channel Operation)

Management frames

CCH (WSM data only)
AC=1 AC=2 AC=3 AC=4

SCH (WSM and/or IP data)
AC=1 AC=2 AC=3 AC=4

Management frames

Channel Routing

Internal Contention

Channel Selector and Medium Contention

Transmission Attempt
US - WAVE Short Message Protocol WSMP

Messages transmitted on request by higher layer

Dest. MAC address, User Priority, Channel, Data rate, Transmit Power, PSID

Messages delivered (unicast or broadcast) over the air by MAC address

Messages delivered up the stack by protocol and PSID

EtherType distinguishes WSMP from IP
**US - SAE Standards**

**J2735 Message Set Dictionary**
- Defines 15 messages and constituent data elements
- Key messages:
  - Basic Safety Message (V2V safety)
  - Signal Phase and Timing
  - MAP

Typically sent by roadside unit at intersection

**J2945 Minimum Performance Requirements (MPR)**
- Not yet published – expected 2015
- Example content for Basic Safety Message:
  - Message frequency and transmit power
  - Accuracy of sensor data in message (e.g. position, velocity)
### US - SAE J2735 Basic Safety Message (BSM)

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>3D Position</td>
</tr>
<tr>
<td>Position Accuracy</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Heading</td>
</tr>
<tr>
<td>Steering Wheel Angle</td>
</tr>
<tr>
<td>Acceleration</td>
</tr>
<tr>
<td>Brake Status</td>
</tr>
<tr>
<td>Vehicle Size</td>
</tr>
<tr>
<td>Event Flags</td>
</tr>
<tr>
<td>Path History</td>
</tr>
<tr>
<td>Path Prediction</td>
</tr>
<tr>
<td>Other optional fields</td>
</tr>
</tbody>
</table>

BSM is broadcast by each vehicle several times per second over a few hundred meters.
Current State
Headlines

- July 2014 – President Obama got a look at V2X, Federal Highway Administration Research Center, McLean VI
- Aug 2014 - NHTSA announces the start of the rule-making process (A-NPRM) for V2V mandate
- Oct 2014 – GM CEO “Mary Barra” announces 2017 Cadillac CTS would be the first GM vehicle to carry V2X technology. Partnered with MDOT, UMTRI – 300M investment to explore V2I.
- FHWA calls for V2I deployment proposals from various states
Summary

- V2X is a game-changer for safety, because when enough cars share information about such factors as speed, direction and braking, we’ll be able to reduce crashes dramatically.
- Infrastructure deployment can improve road congestion & fuel efficiency.
- Smartphone support will improve the market penetration.
- Suppliers like Savari who work on V2X are ready to ignite the market.
Thank You