2017 Summer Professional Development Course

Advanced Automotive Technology

Topic 2:
Cooperative Connected Vehicles

Instructor: Dr. Radoven Muicic
Wayne State University

July 10 ~ 11, 2017

Overview

- Connected Vehicles
- DSRC Intro
- Cooperative Safety Applications: V2V, V2P, and V2I
- Vehicle Positioning
- Connected and Autonomous Vehicle
- DSRC Scalability
- DSRC Security, Privacy, Threats and Requirements

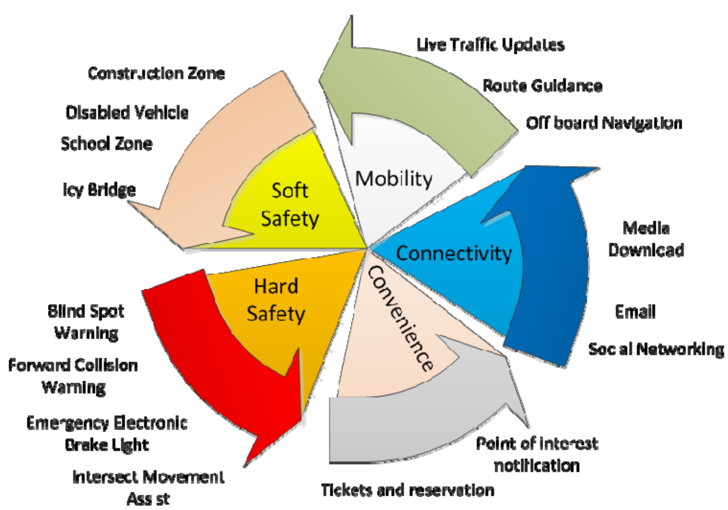
Connected Vehicles

Prepared by Radovan Miucic

Connected Vehicle Applications

- Hard Safety Applications e.g.
  - Emergency Electronic Brake Light (EEBL)
  - Intersection Movement Assist (IMA)
- Soft Safety Applications
  - Weather, road, traffic condition advisory
  - E.g. Icy Road ahead, construction, reduced visibility, pot holes, traffic jams
- Mobility and Convenience
  - Mobility: navigation, road guidance, traffic information, assistance and information services
  - Convenience: point of interest notification, e-mail, social networking, media download, app. Updates
  - E.g Ford's Sync (uses combination of user's smartphone with embedded display, sound and voice commands)

Connected Vehicle Applications



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Uniqueness in Consumer Vehicle Networks

- Vehicles talk to each other and to the roadside infrastructure
- Vehicles may be only few seconds in communication range of each other or infrastructure
- Vehicles need to instantly communicate with each other to support hard safety application latency needs (100ms)
- Vehicle somehow need to trust other vehicles and infrastructure
- Designing networking and security system for ~250 million vehicles will be challenging

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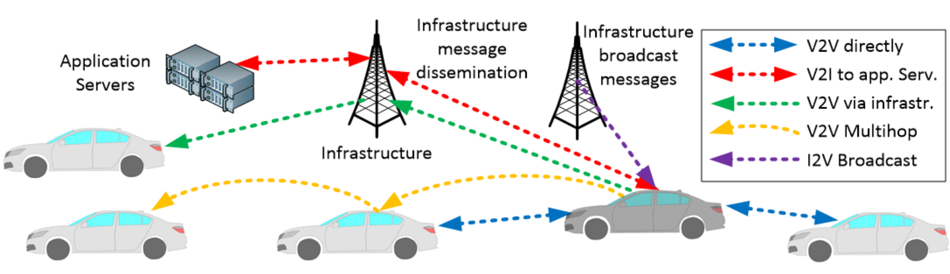
Vehicle Communication Modes

- Vehicle talk directly to other vehicles
- Vehicle talk to other vehicles via multi hop
- Vehicle talk to other vehicles through infrastructure
- Vehicle talk to application servers through infrastructure
- Infrastructure Broadcasts messages



Comparison of wireless comm. technologies

	DSRC	Wi-Fi	Bluetooth	3G	4G LTE	SDARS
Range	Hundreds of meters	Hundreds of meters	Up to 100 m	Tens of kilometers	10s of meters up to 100 km	Countrywide
End-to-end message delay	10 ms	10 ms	10 ms	50 to 100's of ms	10's of ms	10-20 seconds
Connection/call setup time	Not needed	3-5 seconds	3-4 seconds	100's of ms to seconds	~50ms	Not applicable
V2V local broadcast	Yes	Yes	Impractical	With server	With server	No
V2V multihop messaging	Yes	Yes	Impractical	With server	With server	No
I2V local broadcasting	Yes	Yes	Impractical	Not offered by all network operators	Not offered by all network operators	Yes
V2I bidirectional	Yes	Yes	Impractical	Yes	Yes	No

SDARS = Satellite Digital Audio Radio Service

Backward Compatibility

- Wireless technology for a vehicle may get outdated before the end of the life
- New vehicles should benefit from new wireless technologies but they should be backward compatible and interoperable with existing vehicles
- Applications, design and standards have to take these requirements into consideration

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Example: Test Equipment Setup

Car setup

Motorcycle setup

SAE INTERNATIONAL

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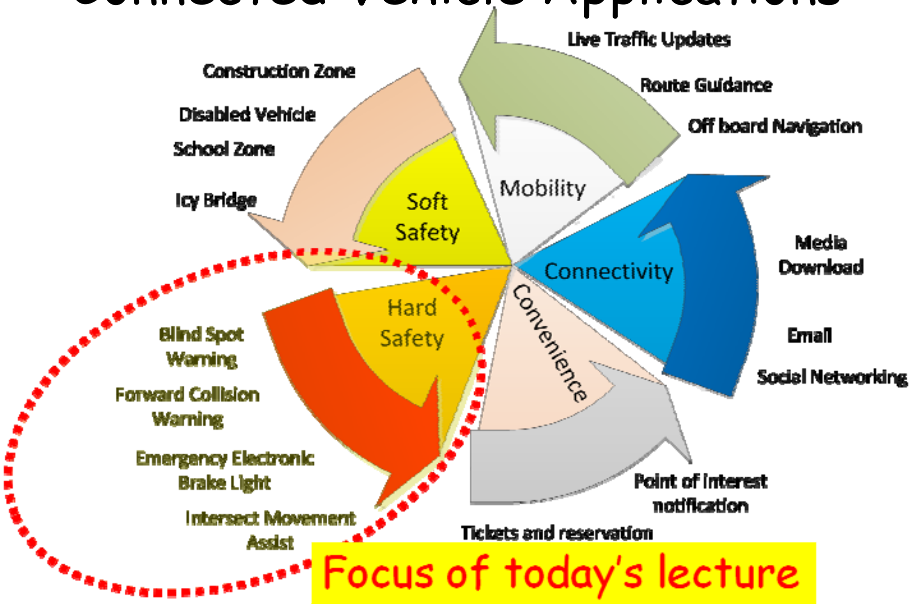
Example: Test Equipment Setup and DVI

SAE INTERNATIONAL 10

Connected Vehicle Applications



Dedicated Short Range Communication (DSRC)

Prepared by Radovan Miucic

Timeline

- 1997 ITSA petitioned FCC for 75MHz
- 1999 FCC allocated 75MHz band (5.850 - 5.925 GHz) to DSRC as a licensed radio band
- Functions:
  - Improve travelers safety
  - Decrease traffic congestion
  - Reduce air pollution
  - Reduce fuel consumption
  - …

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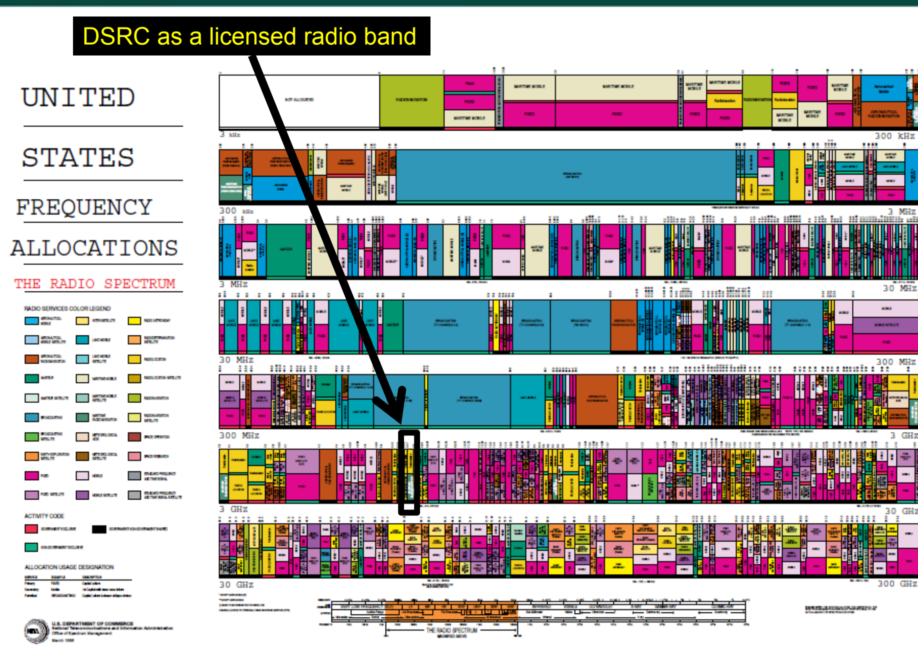

Licensed vs Unlicensed Spectrum

- **Licensed** radio bands
  - FCC allocates a frequency range
  - FCC usage (function) of the frequency band
  - FCC specify how the frequency range can be used or shared
  - a license must be obtained from a government agency
  - Examples: FM broadcast (87.5 to 108.0 MHz), Cellular phones (840 MHz), **DSRC(5.850-5.925 GHz)**

Licensed vs Unlicensed Spectrum

- **Unlicensed** radio bands
  - Regulations exist around these bands
  - Still need to use compliant devices
  - Do not need a license to use the spectrum (anyone can use)
  - Examples:
    - Industrial, Scientific, Medical (ISM): medical monitors and other devices (900-MHZ, 2.4-GHz, and 5-GHz bands)
    - Unlicensed National Information Infrastructure (U-NII): WLAN access points and routers (5-GHz band)
    - Unlicensed Personal Communications Services (UPCS): cordless phones (1.9-GHz band)

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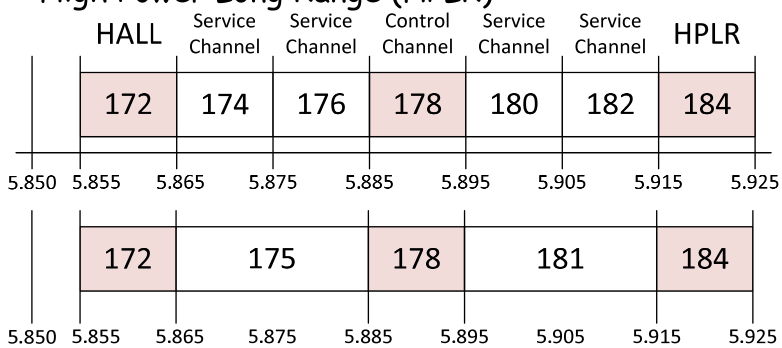
DSRC Usage and Channels

- Public safety apps through
  - Vehicle to Vehicle V2V
  - Vehicle to Infrastructure V2I

  High Availability Low Latency (HALL)

  High Power Long Range (HPLR)



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DSRC Usage and Channels cont.

- CH172 is dedicated for V2V
  - Accident avoidance and safety of life and property apps
- CH178 is control channel
- CH184 is for public safety
  - Also for safety of life and property apps
- CH174, CH176, CH180, and CH182
  - Safety and non safety apps
- Center frequency (in MHz) from Channel Number:

$$f(CN) = 5000 + 5CN$$

DSRC Operations

- DSRC is restricted in usage and communication technology
- Usage of devices (even at low power) that do not strictly comply with DSRC standards is not allowed
- Operating in 5.9 GHz spectrum
  - Avoids crowded cellular networks
  - Dedicated spectrum avoids competition from other wireless stations
  - Low weather dependency
  - Able to meet range requirements imposed by most safety apps
  - However, operating in high frequencies imposes some limitations: waves are not able to penetrate as far as low frequency signals, solid objects such as walls tend to absorb waves at 5.9 easily, limiting range in urban environments.

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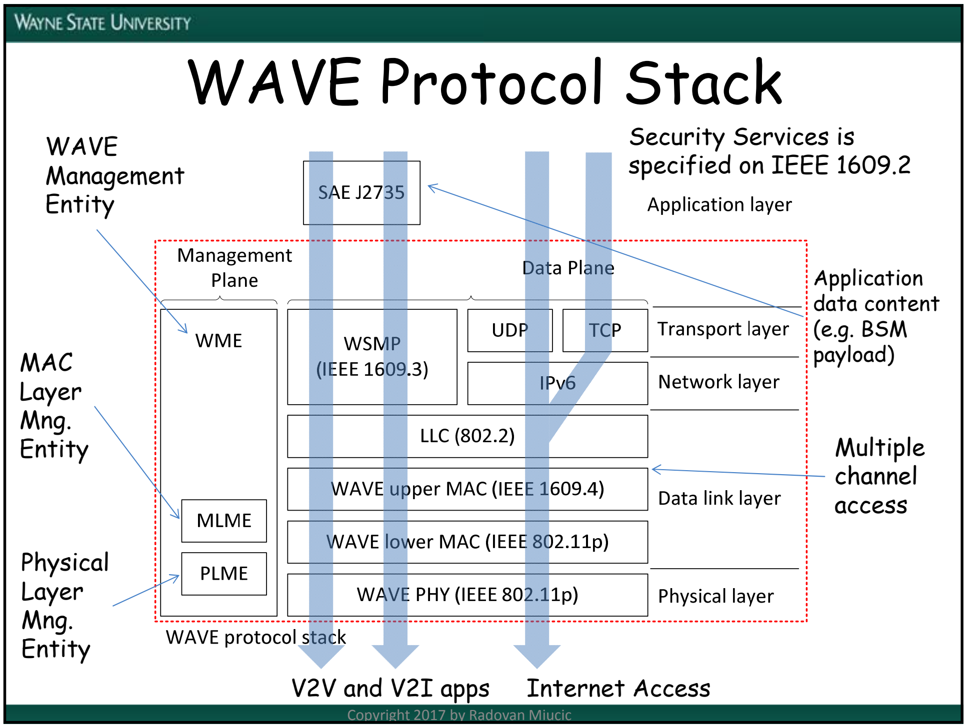
DSRC Intro

- Connected Vehicle The Future of Transportation Video

https://youtu.be/Q8Cn47L8FRQ
- Dedicated Short Range Communication (DSRC)
- Each Car will be broadcasting periodically (or frequently) awareness messages to the neighboring vehicles
- There is no need for infrastructure for broadcast
- Awareness message is called Basic Safety Message (BSM)
- Payload content (application layer) of the BSM is defined in SAE J2735 standard.
- Rest of the slides are derived from 2009 SAE J2735 standard with some explanation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WAVE Protocol Stack
WAVE Management Entity
SAE J2735
Security Services is specified on IEEE 1609.2
Application layer
Management Plane
Data Plane
Application data content (e.g. BSM payload)
WME
WSMP (IEEE 1609.3)
UDP
TCP
Transport layer
IPv6
Network layer
MAC Layer Mng. Entity
LLC (802.2)
WAVE upper MAC (IEEE 1609.4)
Data link layer
Multiple channel access
MLME
WAVE lower MAC (IEEE 802.11p)
PLME
WAVE PHY (IEEE 802.11p)
Physical layer
Physical Layer Mng. Entity
WAVE protocol stack
V2V and V2I apps
Internet Access
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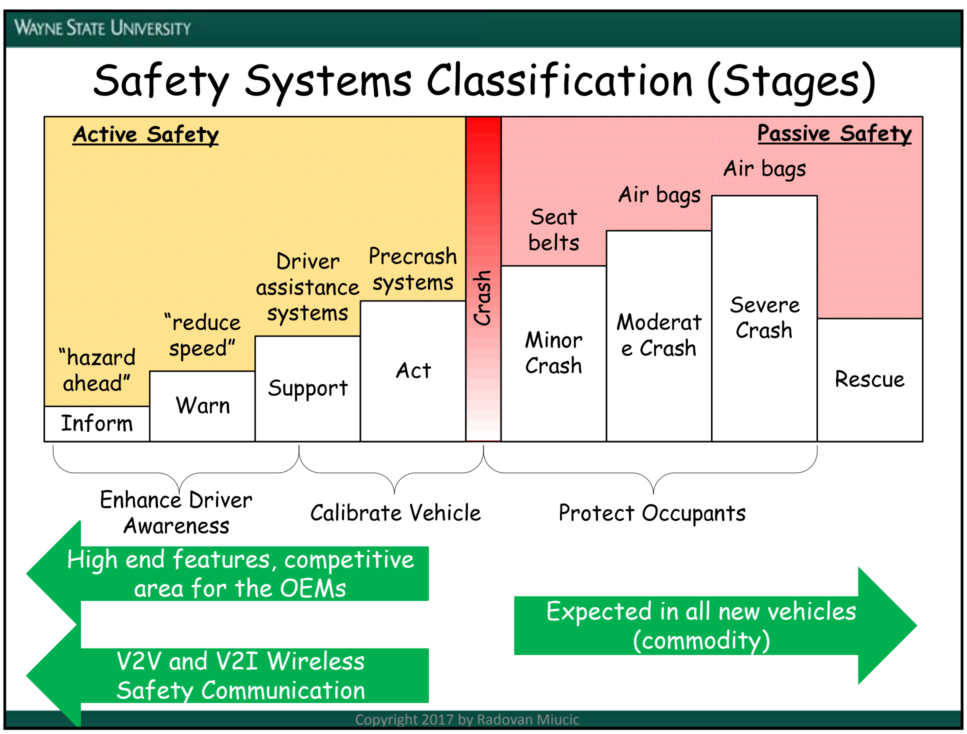
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Safety Systems Classification (Stages)
Active Safety
Passive Safety
Crash
"hazard ahead"
Inform
"reduce speed"
Warn
Driver assistance systems
Support
Precrash systems
Act
Seat belts
Minor Crash
Air bags
Moderate Crash
Air bags
Severe Crash
Rescue
Enhance Driver Awareness
Calibrate Vehicle
Protect Occupants
High end features, competitive area for the OEMs
V2V and V2I Wireless Safety Communication
Expected in all new vehicles (commodity)
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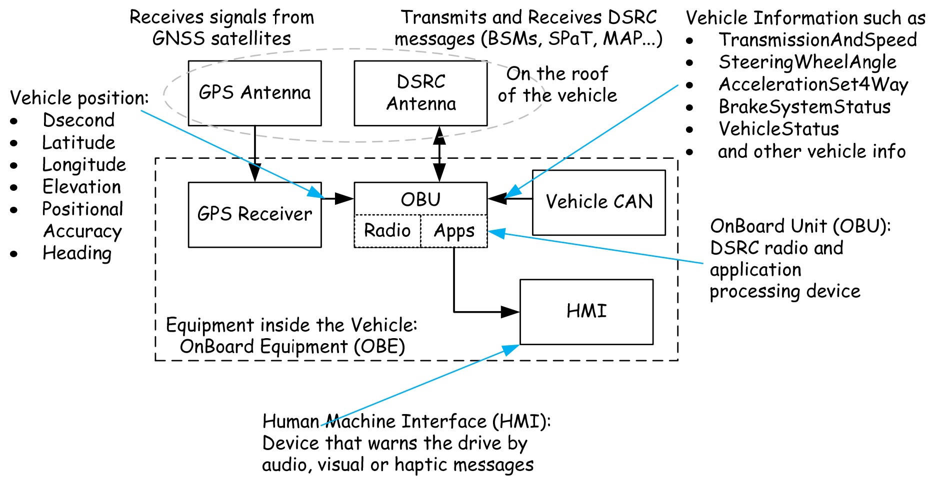
Vehicle Equipment



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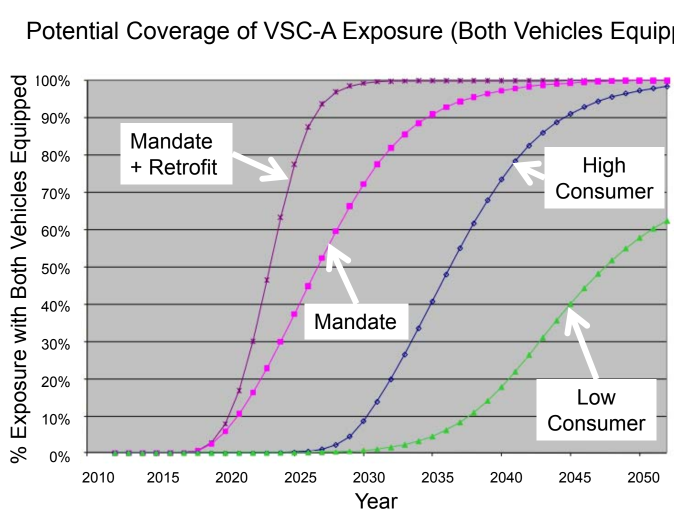

•It will take many years(estimates vary from 10 to 40 or more years) to achieve 100 % market penetration

James Chang, Noblis, "Discussion Document - Market Penetration Analysis for VSC-A Safety Benefit Opportunities Estimation", June 8, 2010. Contract #: DTFH61-05-D-00002

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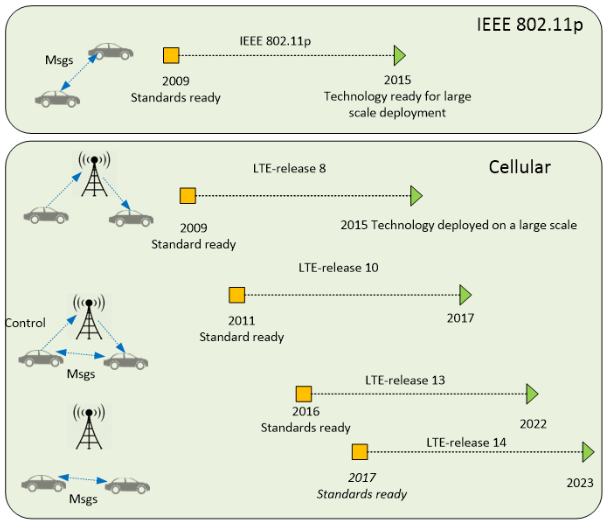
VANET Current and Future

- What about Cellular for V2X?
- Cellular community will find a technical solution for V2X. The question is not if, but when.



http://www.automotive-eetimes.com/design-center/why-80211p-beats-lte-and-5g-v2x/

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BSM Definition

Basic Safety Message (BSM)

The basic safety message (BSM) is used in a variety of applications to exchange safety data regarding vehicle state. This message is broadcast frequently (rate 10 times per second is typical) to surrounding vehicles with a variety of data content as required by safety and other applications. Part I data shall be included in every BSM. Part II data are optional for a given BSM and are included as needed according to policies. A BSM without Part II content is also a valid message.

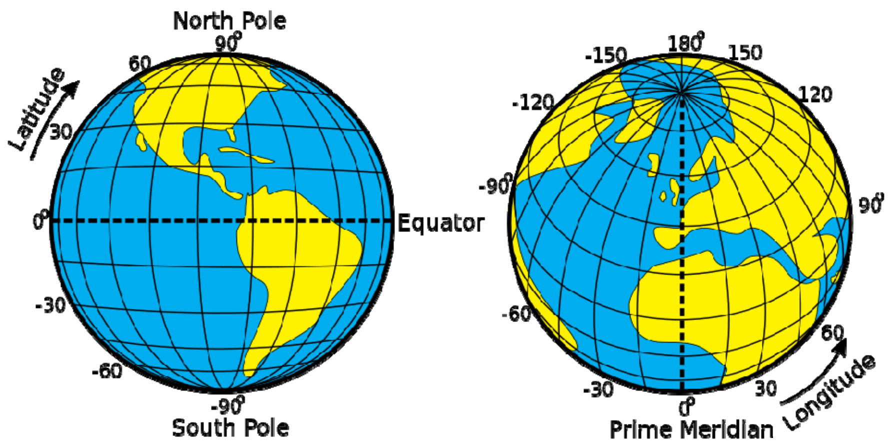
BSM Part I and II

	Sub group	Element	Bytes	Required
PART I	Header	**MsgCount**	1	Y
		TemporaryID	4	Y
		DSecond	2	Y
	PositionLocal3D	**Latitude**	4	Y
		Longitude	4	Y
		Elevation	2	Y
		PositionalAccuracy	4	Y
	Motion	**TransmissionAndSpeed**	2	Y
		Heading	2	Y
		SteeringWheelAngle	1	Y
		AccelerationSet4Way	7	Y
	Control	**BrakeSystemStatus**	2	Y
	VehicleBasic	**VehicleSize**	3	Y
PART II	VehicleSafetyExtension	**PathHistory** **PathPrediction** **EventFlags**	variable	Y
	VehicleStatus		variable	Optional

Always sent…

BSM PART I

Latitude and Longitude



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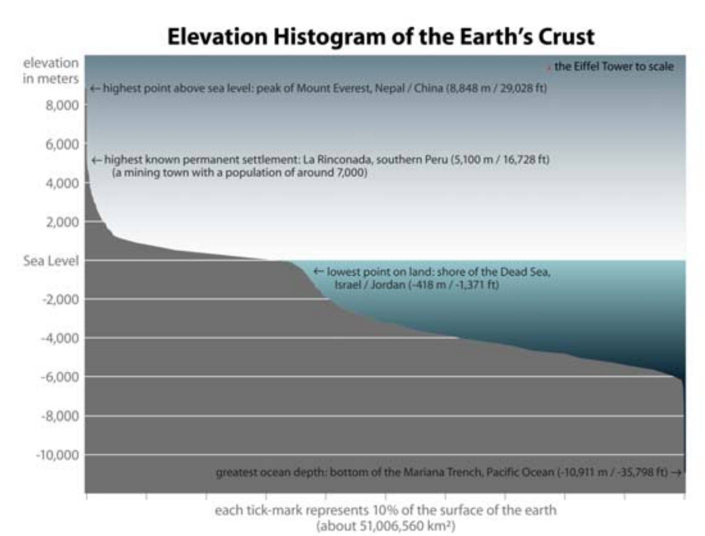
Elevation



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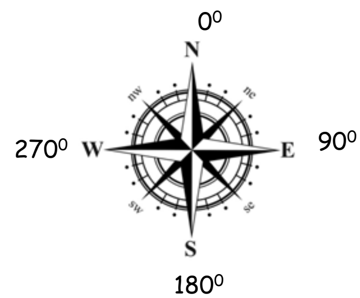
BSM Part I (Heading)

Heading

The current heading of the sending device, expressed in unsigned units of degrees from North. North shall be defined as the axis. Headings "to the east" are defined as the positive direction.



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BSM Part I (Transmission State and Speed)

Transmission State data element is used to provide the current state of the vehicle transmission:

- neutral
- park
- forward Gears
- reverseGears
- unavailable

Speed of the vehicle expressed in meters per second.

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BSM Part I (SteeringWheelAngle)

Steering Wheel Angle

The angle of the steering wheel, expressed in degrees

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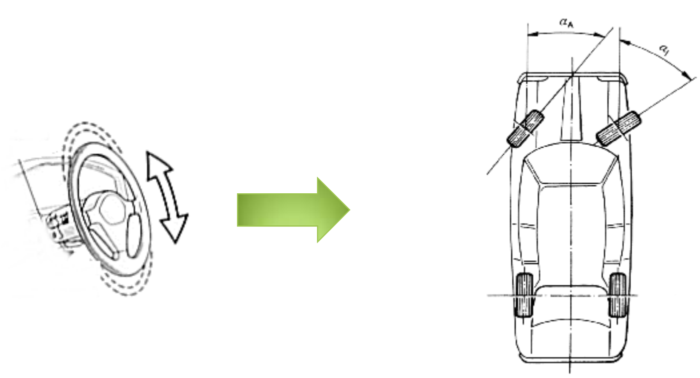
Steering Wheel to Wheel Angle



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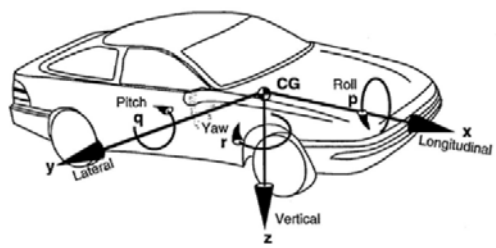
SAE J670 Vehicle Axis System

- Yaw, Roll and Pitch rate
- All are in [deg/sec]



Vehicle Axis System

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BSM Part I (Brake Status)

__Brake Information__

- **Brake Applied Status** data element indicates independently for each of four wheels whether braking is currently active.
- **Traction Control State** data element reflects the status of the vehicle traction system
- **Anti Lock Brake Status** data element conveys the state of the sender's anti-lock braking system.
- **Stability Control Status** reflects the current state of the stability control system status.
- **Stability Control Status**
- **Brake Boost Applied** indicates emergency braking.

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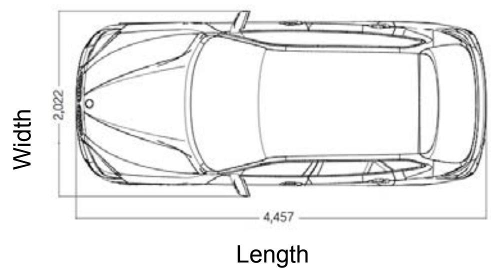
BSM Part I (Vehicle Size)

Vehicle Width,
Vehicle Length



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Some parts sent optionally, others triggered by events …

BSM PART II

BSM Part II (VehicleSafetyExtension)

- **Event Flags**, element conveys the sender's state with regard to a set of events
- **Path History**, PathHistory data frame defines an adaptable set of PathHistoryPointSets reflecting recent vehicle movement over some period of time and/or distance.
- **Path Prediction**, frame allows vehicles to share their predicted path trajectory by estimating future vehicle path of travel.

BSM Part II(EventFlags)

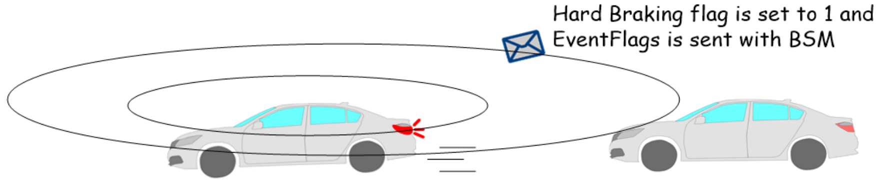
The **Event Flags** data element conveys the sender's state with regard to a set of events. For each event, the sender has the option to set the flag to 1 if the stated criteria are met, but it is not required to do so. The set of event flags and their respective minimum criteria are listed in the next slide. The Event Flag data element should not be included in a Basic Safety Message unless at least one event flag is set to 1. When one or more criteria associated with an event are no longer satisfied the sender shall set the flag to zero in any Event Flag data element it sends. The presence of the Event Flag element in a message indicates that an unusual event has occurred. A vehicle receiving such a message might decide to process it differently than a message that does not include the Event Flag element. When a given event flag is set to 1 the message might include related optional data as well.

BSM Part II(EventFlags) cont.

Further normative definitions of when to assert each event are given below.

- Hazard Lights: The hazard lights are active.
- Stop Line Violation: The vehicle anticipates it will pass the line without coming to a full stop before reaching it.
- ABS: system activated exceeding 100 mSec in length and active
- Traction Control: system activated exceeding 100 mSec in length and active
- Stability Control: system activated exceeding 100 mSec in length and active
- Hazardous Materials: The vehicle known to be carrying hazardous material and is placarded as such.
- Emergency Response: The vehicle is a properly authorized public safety vehicle, is engaged in a service call, and is currently moving (lights and sirens may not be evident).
- Hard Braking: The vehicle has (or is) decelerated at a rate of greater than 0.4g
- Lights Changed: The status of the external lighting of the vehicle has changed recently (the new state of the lights is presented in another element).
- Wipers Changed: The status of wipers (font or rear) of the vehicle has changed recently (the new state of the wipers is presented in another element).
- Flat tire: The vehicle has determined that at least one tire has run flat.
- Disabled Vehicle: Any vehicle that considers itself disabled.
- Air Bag Deployment: At least one airbag has been deployed.

eventHardBraking Example



BSM Part II (EventFlags)

If no events are active eventFlags value will be zero and it will not be sent with BSM.

eventAirBagDeployment	eventDisabledVehicle	eventFlatTire	eventWipersChanged	eventLightsChanged	eventHardBraking	eventEmergencyResponse	eventHazardousMaterials	eventStabilityControlactivated	eventTractionControlLoss	eventABSactivated	eventStopLineViolation	eventHazardLights	Value	Action
0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000	Do Not Send with BSM
0	0	0	0	0	0	0	0	0	0	1	0	0	0x0004	Send with BSM
0	0	0	0	0	1	0	0	0	0	1	0	0	0x0084	Send with BSM

BSM Part II (Path History)

The **<u>Path History</u>** data frame defines an adaptable set of Path History Points reflecting recent vehicle movement over some period of time and/or distance. The points present in the history represent a concise representation of the actual path history of the vehicle based on allowable position error tolerance between the actual vehicle path and its concise representation. This data frame allows creating a sequence of positions (typically a vehicle motion track) over a limited period of time or distance.

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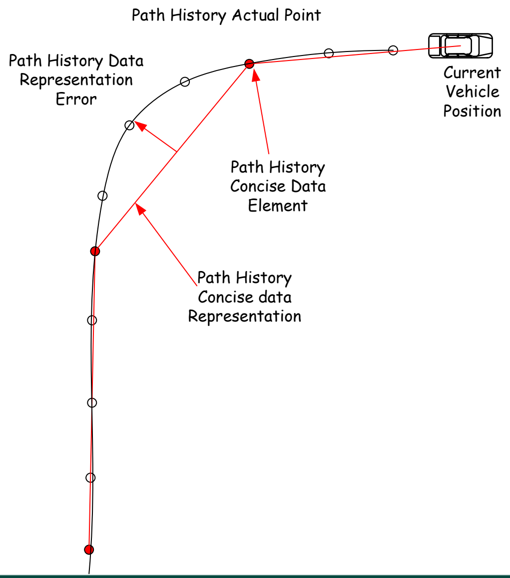
Concise Representation of Path History



- Up to 23 PH points
- Up to 300m in length

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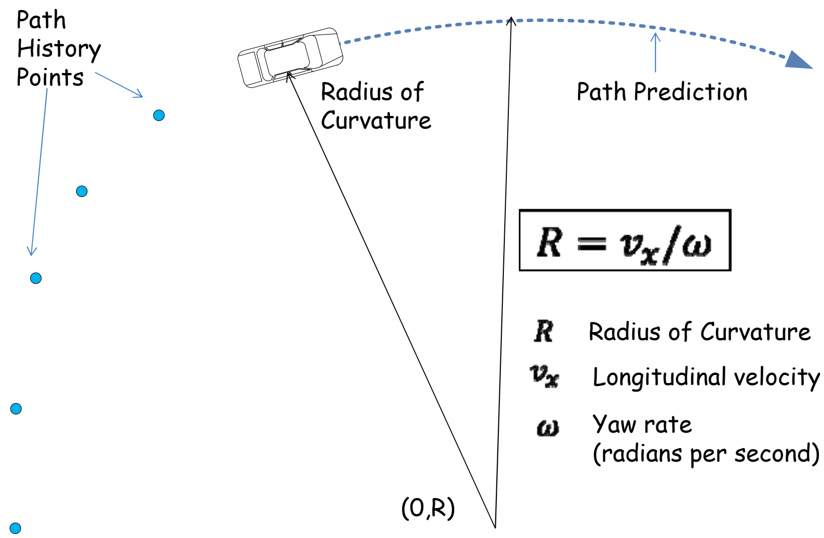
BSM Part II (PathPrediction)

Path Prediction data frame allows vehicles to share their predicted path trajectory by estimating future vehicle path of travel. This future trajectory estimation provides an indication of future positions of the transmitting vehicle and can significantly enhance in-lane and out-of-lane threat classification. Trajectories in the Path Prediction data element are represented, at a first order of curvature approximation, as a circle with a radius R and an origin located at (0,R), where the x-axis is bore sight from the transmitting vehicle's perspective and normal to the vehicle's vertical axis.

The radius can be derived from a number of sources including, but not limited to, map databases, rate sensors, vision systems, and global positioning, the precise algorithm to be used is outside the scope of this document.

Path Prediction and Path History



$$R = v_x / \omega$$

R	Radius of Curvature
v_x	Longitudinal velocity
ω	Yaw rate (radians per second)

Cooperative Vehicular Safety Applications

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VSC-A Video

Vehicle-to-Vehicle Safety Applications

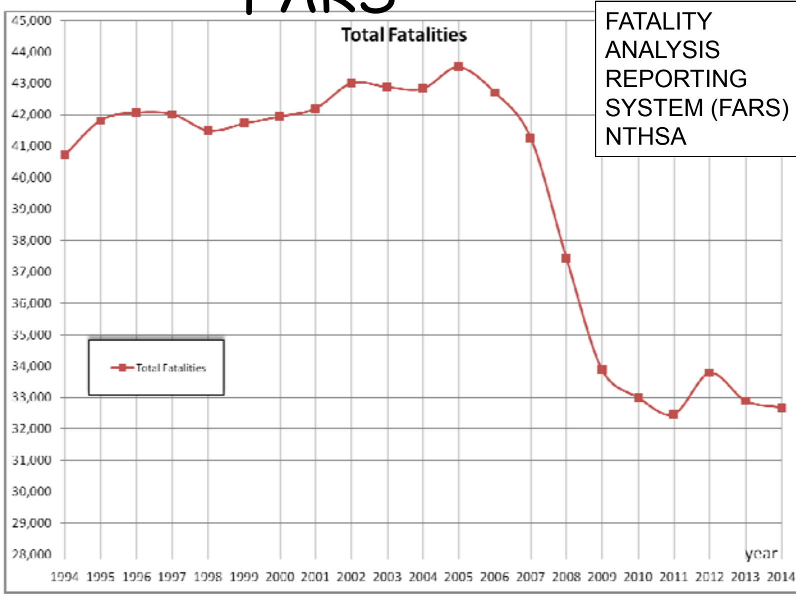
https://youtu.be/PEHrXmfQyQA

Motivation

- Fatality Analysis Reporting System (FARS) for National Safety Highway Administration (NTHSA)
  - http://www-fars.nhtsa.dot.gov/Main/index.aspx
- National Safety Council (NSC) Motor Vehicle Fatality Estimate
  - http://www.nsc.org/NewsDocuments/2017/12-month-estimates.pdf

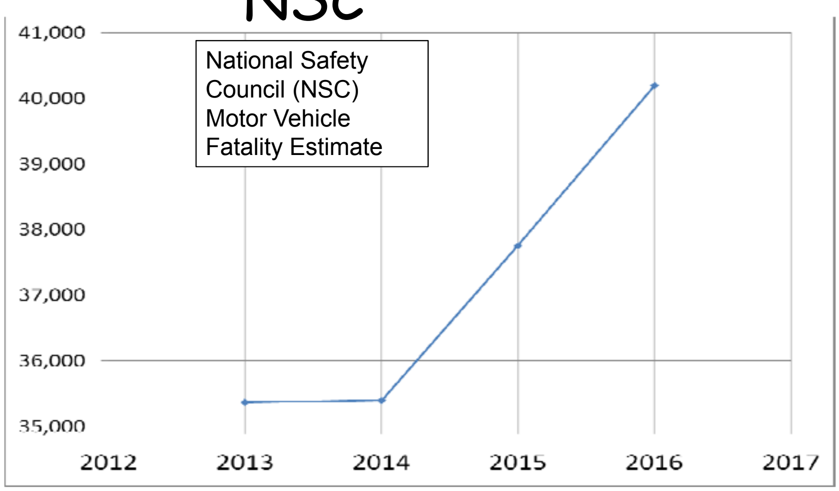
FARS

FATALITY ANALYSIS REPORTING SYSTEM (FARS) NTHSA



NSC

National Safety Council (NSC) Motor Vehicle Fatality Estimate



NOTE: National Safety Council figures are not comparable to National Highway Traffic Safety Administration figures. NSC counts both traffic and nontraffic deaths that occur within a year of the accident, while NHTSA counts only traffic deaths that occur within 30 days.

Communication Requirements

- Share current position, speed, accelerations, brake, throttle, path history and path prediction
- High availability
- Low latency (100 ms) for V2V and V2I
- Security:
  - exchange of msgs has to be authentic, privacy has to be present, and the mesgs must be trustworthy
- Extensible
  - Design need to accommodate improvements and changes

Vehicular Positioning

- Global Navigation Satellite Systems

  Operational
  - GPS (USA)
  - GLONASS (Russia)

  In Development
  - Beidou (China)
  - Galileo (EU)
  - IRNSS (India)
- Positioning Requirements for VSC-A needs to be lane level (with in 1.5 m)

Vehicle Safety Communications-Applications

Based on US Government statistics on crash frequency, cost, and functional years lost VSC-A identified seven safety applications:

- Emergency Electronic Brake Lights (EEBL):
  - Warns of sudden braking of vehicles in the forward path.
- Forward Collision Warning (FCW):
  - Warns of impending rear-end collision with forward vehicle.
- Blind Spot Warning (BSW)/Lane Change Warning (LCW):
  - Warns during a lane-change attempt if there is another vehicle moving in the same direction (or soon will be in) the blind spot. Secondary advisory whenever there is a vehicle in the blind spot.
- Intersection Movement Assist (IMA):
  - Warns when it is not safe to enter intersection.
- Do Not Pass Warning (DNP):
  - Warns when oncoming vehicle poses collision threat if a lane change is attempted.
- Control Loss Warning (CLW):
  - Self-generated warning when vehicle loses control. Other vehicles will be warned depending on the threat.

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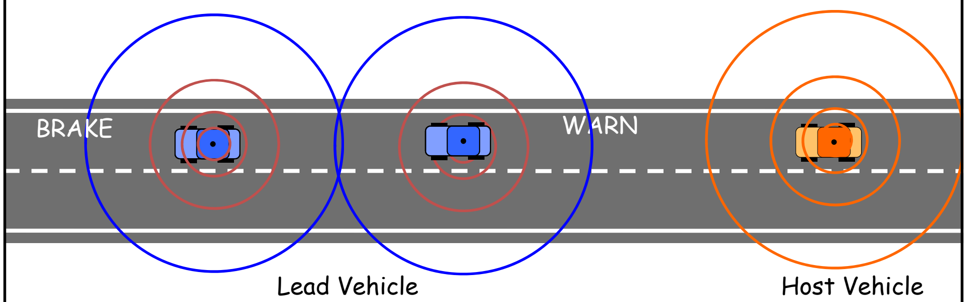
Emergency Electronic Brake Lights (EEBL)

- Host vehicle monitors BSMs from other vehicles ahead and in the same lane
- Host vehicle provides warning to driver when he is in danger of rear-end collision with vehicle ahead in lane in advance



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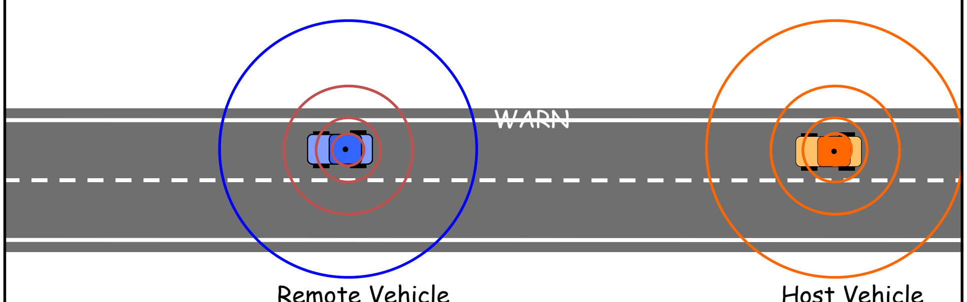
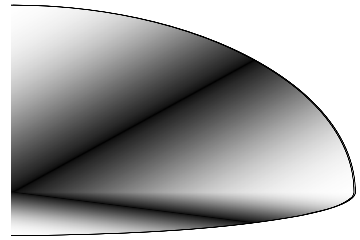
Forward Collision Warning (FCW)

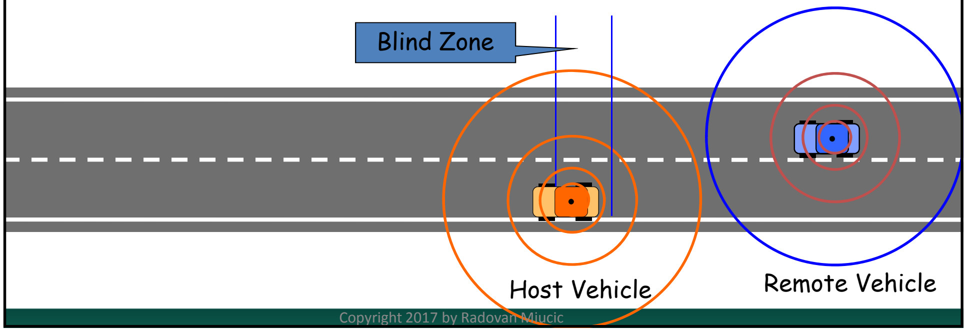
- Host vehicle monitors BSMs from other vehicles ahead and in the same lane
- Host vehicle provides warning to driver when he is in danger of rear-end collision with vehicle ahead in lane



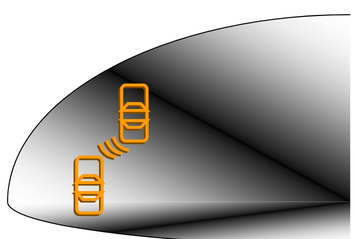
Blind Spot Warning (BSW)

- Host vehicle provides advisory (steady amber) to the driver when there is a vehicle in blind zone
- Host vehicle provides warning (flashing amber + haptic seat) to the driver when there is a vehicle in blind zone and turn lamp is activated

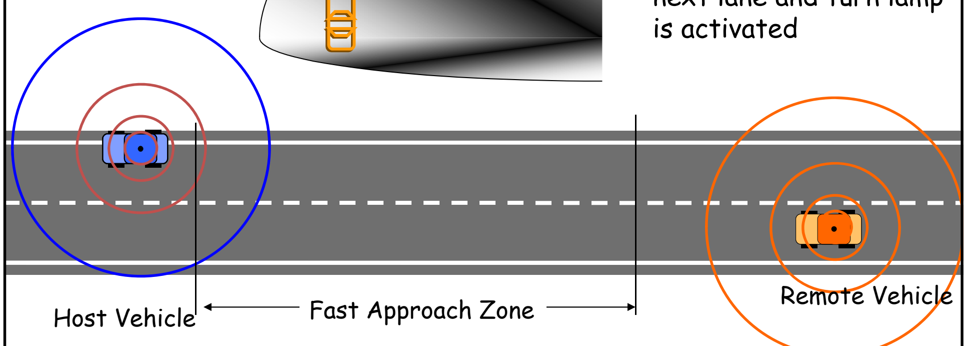




Lane Change Warning - Closing Vehicle



- Host vehicle warns (flashing amber) when there is another overtaking vehicle in next lane and turn lamp is activated



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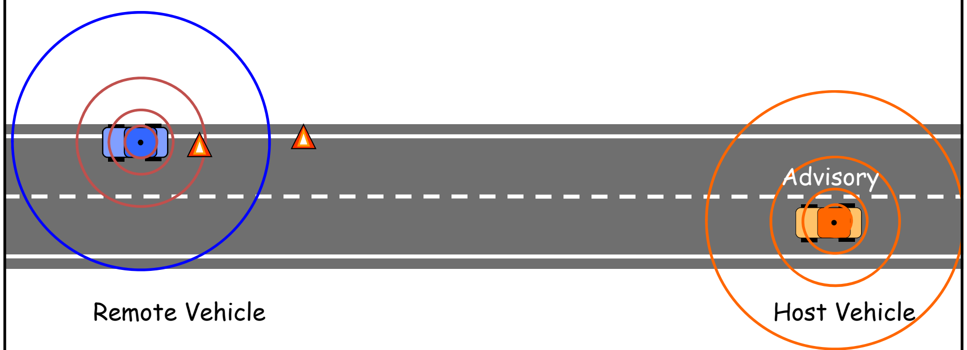
Slow / Stopped Vehicle Advisor

- Host vehicle monitors messages from other vehicles up to 250m ahead
- Host vehicle advises driver when any vehicle ahead (in lane, right / left lane) is stopped or traveling 20 mph slower than the host



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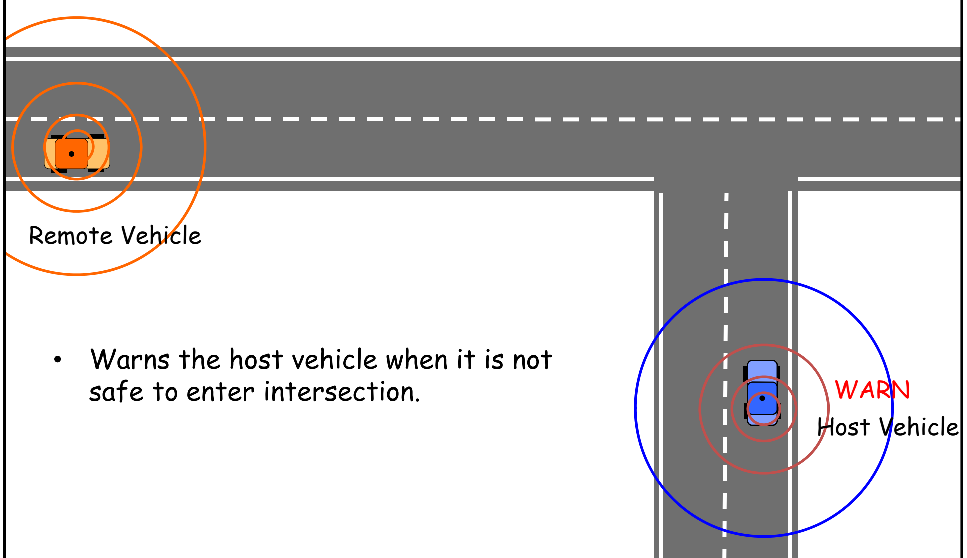
Intersection Movement Assist (IMA)



- Warns the host vehicle when it is not safe to enter intersection.

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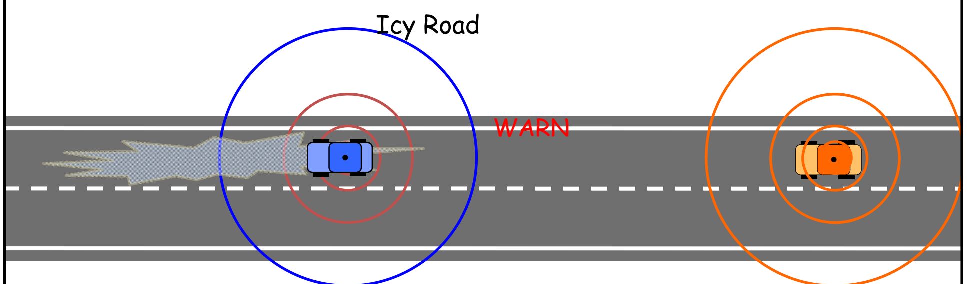
Control Loss Warning (CLW)

- Host vehicle monitors BSMs from other vehicles ahead and in the same or adjacent lanes
- Host vehicle provides warning to driver when he is in danger of rear-end collision with vehicle ahead in the same or adjacent lanes


+ Haptic Seat

Detected, Caution, Warning



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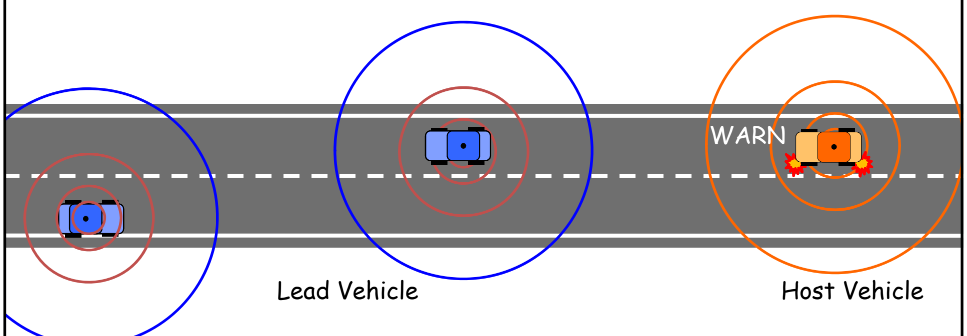
Do Not Pass Warning (DNP)

- Host vehicle monitors BSMs from other vehicles ahead and in the opposite direction adjacent lane
- Host vehicle provides warning to driver when he is in danger of head on collision with vehicle in the opposite lane



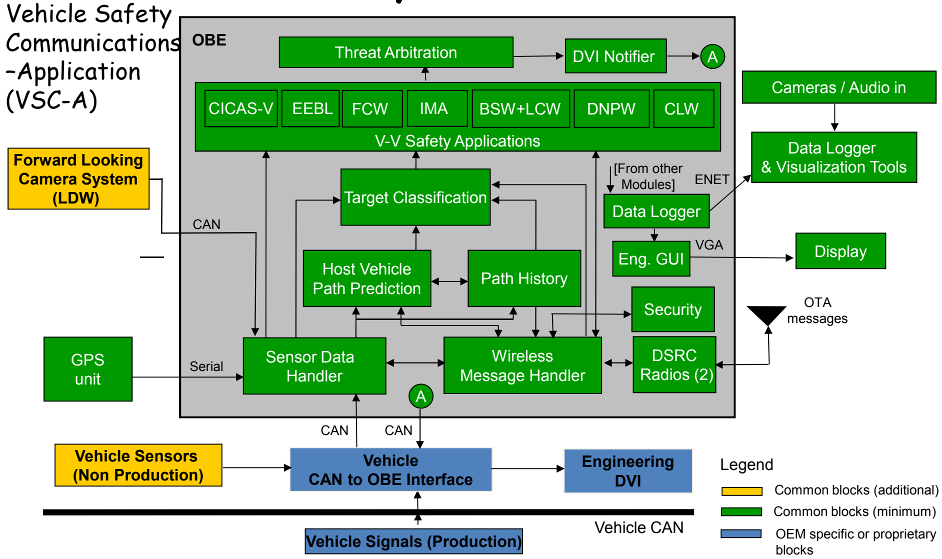
Performance Metrics

- Packet Delivery Ratio (PDR)
  -PDR is the probability of successful packet delivery.
  -PDR is calculated at the receiver and it a ratio of the number of packets transmitted at transmitter (TX) and number of packets received at receiver (RX)
- Inter Packet Gap (IPG) is defined as the time between successive successful receptions of messages sent by a specific transmitter.
- Received Signal Strength Indicator (RSSI) is an indication of the power level being received by the antenna.
  - The higher the RSSI number, the stronger the signal.
  - In dBm.

PDR, IPG, RSSI can be expressed as function of TX-RX, distance, number of TX nodes, environment (such as line of site, non line of site, urban or rural) etc.

VSC-A System Test Bed

Vehicle Safety Communications -Application (VSC-A)



VSC-A presentation - ISO TC204 Standards Workshop Sept 08 JBK.ppt

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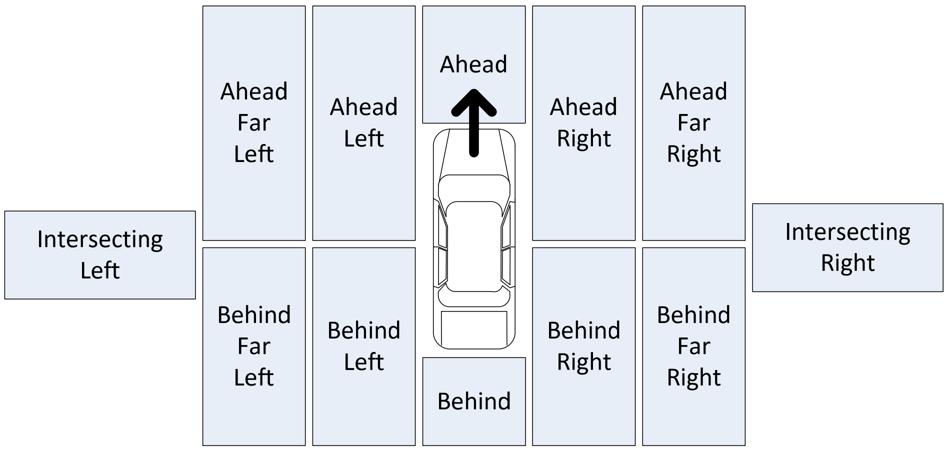
Target Classification



http://www.its.dot.gov/presentations/CV_Safety_sept2012/pdf/Day%201%20-%20DSRC%20Performance%20Testing%20-%20CAMP.pdf

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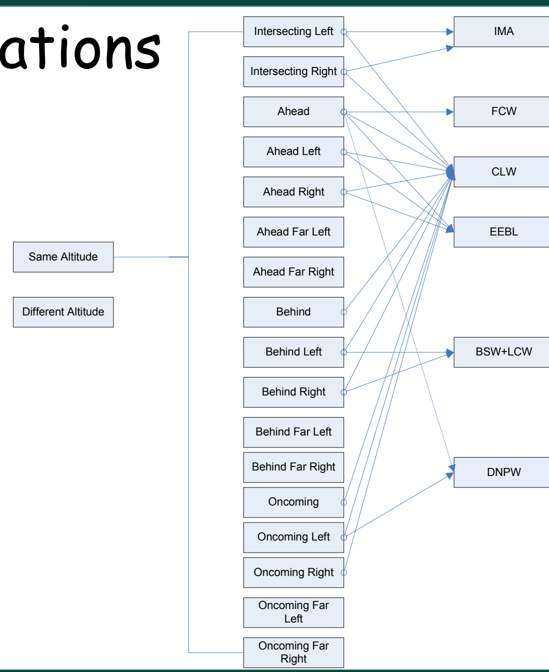
TC and Applications

- The TC module provides "360 degree" relative classification of the locations of communicating remote vehicles relative to the host vehicle
- Possible classifications of remote vehicles that would meet the classification requirements for the safety applications are shown
- TC also provides the lateral offset, longitudinal offset, Relative Speed, Range, Range Rate, Azimuth, etc. of communicating remote vehicles relative to the local host vehicle



VSCA_J2735_1609_final_6_15_2009_201.ppt

Vehicle to Pedestrian

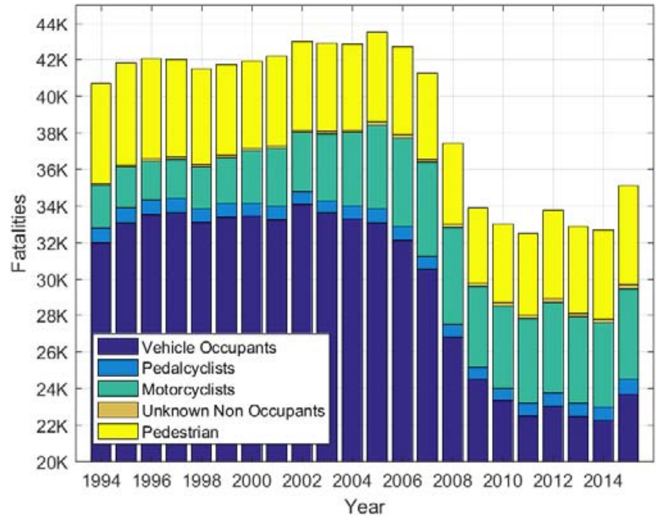
Prepared by Radovan Miucic

Vehicle 2 Pedestrian

Cooperative Safety Application between vehicle and pedestrian (smartphone).

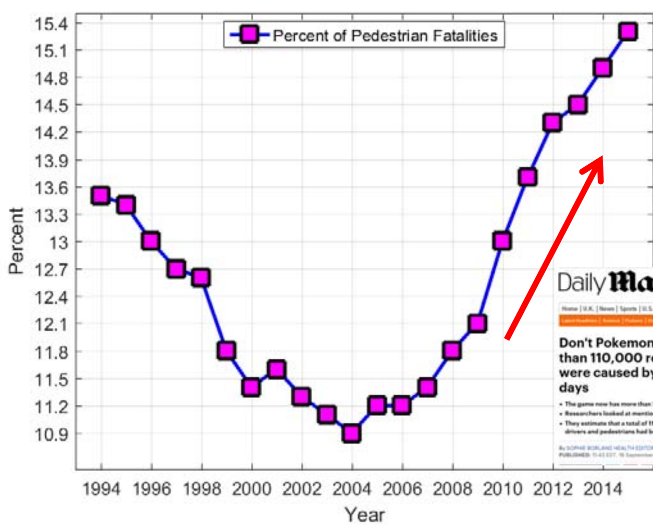
- Vehicle and smartphone exchange Over the air msgs
- https://youtu.be/fc1X4M96ins

Traffic Fatalities in the US



Graph composed from data taken from Fatality Analysis Reporting System (FARS) website available at http://www-fars.nhtsa.dot.gov/Main/index.aspx

Pedestrian Fatalities on the rise



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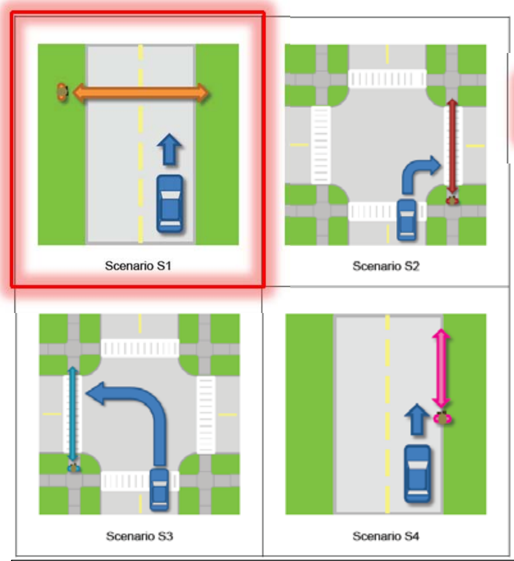
Critical Scenarios



Scenario	Cases	% All FYL	Fatalities
S1	115,000	84%	7,000
S2	2,000	1%	16
S3	9,000	1%	0
S4	13,000	10%	1,000

Taken from "Objective Tests for Forward Looking Pedestrian Crash Avoidance/Mitigation Systems - Final Report" available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2014/812040_CAMP_FLV_MitigationReport%20.pdf

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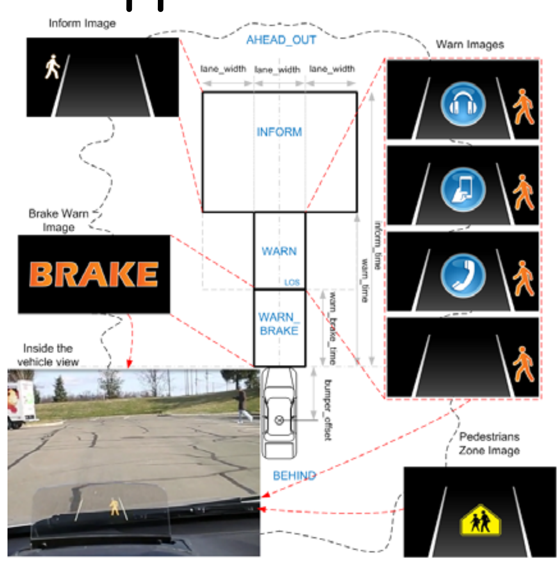
V2P Application Strategy



Heads Up Display

Miucic, R. "Vehicle-to-Pedestrian Cooperative Safety Application," Intelligent Transportation System World Congress, *2014*.

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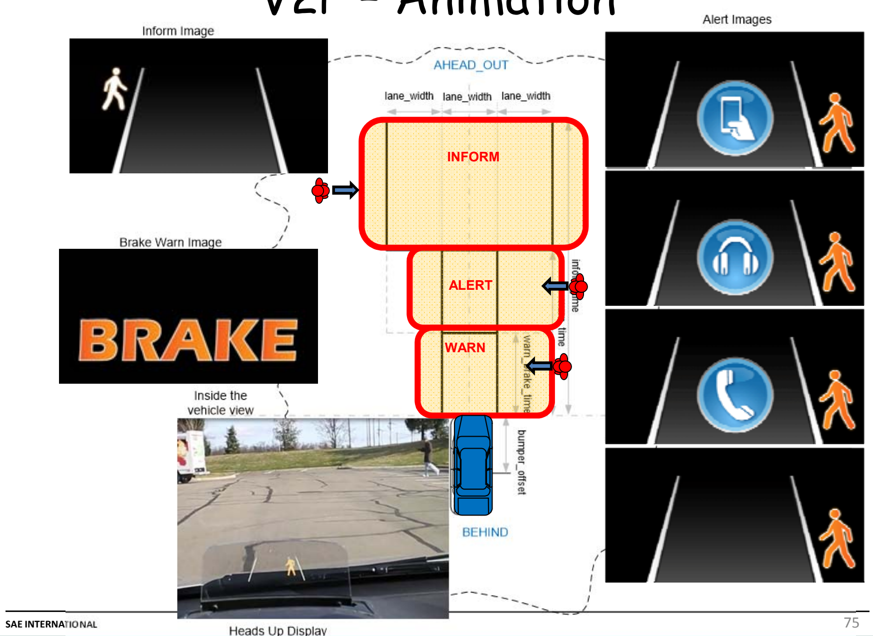
V2P - Animation



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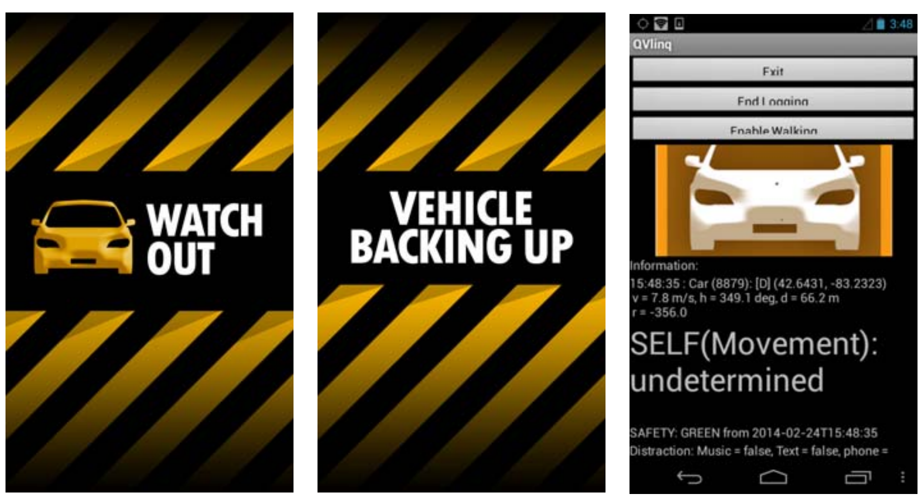
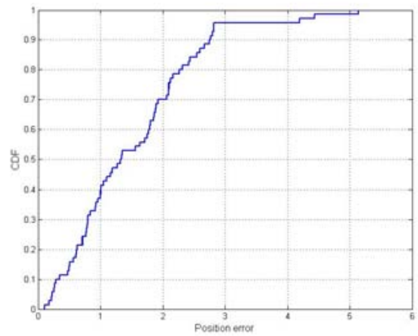
Phone Side Warning



Xinzhou Wu; Miucic, R.; Sichao Yang; Al-Stouhi, S.; Misener, J.; Sue Bai; Wai-hoi Chan, "Cars Talk to Phones: A DSRC Based Vehicle-Pedestrian Safety System," *Vehicular Technology Conference (VTC Fall), 2014 IEEE 80th* , vol., no., pp.1,7, 14-17 Sept. 2014

Phone GPS Error

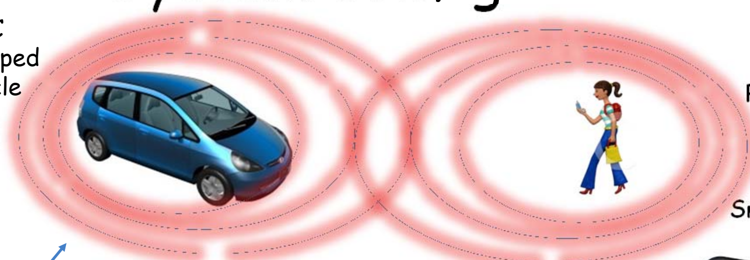
Pedestrian with phone in hand walking on known (surveyed) path.



Cumulative Distribution Function, e.g. 90% of the time position error was less than 3[m], or 80% of the time was less than 2.5[m]

System Configuration

DSRC Equipped Vehicle



Pedestrian Carrying DSRC Equipped Smartphone

Vehicle and pedestrian exchange messages periodically **both send at <u>10Hz</u>**.

Basic Safety Message

Part I	GPS Information: Latitude, Longitude, Elevation, Heading, ...
	Vehicle Information: Speed, yaw_rate, steering_angle, brakes, ...
Part II	Events, Path History, Path Prediction...

Pedestrian Awareness Message

GPS Information: Latitude, Longitude, Heading, Speed ...
Pedestrian Distraction Information: Texting, Listening to music, On the Phone

DSRC Chip in the phone

<u>Unique solution</u> in the pedestrian message

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Performance Metrics

- Packet Delivery Ratio (PDR)
  -PDR is the probability of successful packet delivery.
  -PDR is calculated at the receiver and it a ratio of the number of packets transmitted at transmitter (TX) and number of packets received at receiver (RX)
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  - The higher the RSSI number, the stronger the signal.
  - In dBm.

PDR, IPG, RSSI can be expressed as function of TX-RX, distance, number of TX nodes, environment (such as line of site, non line of site, urban or rural) etc.

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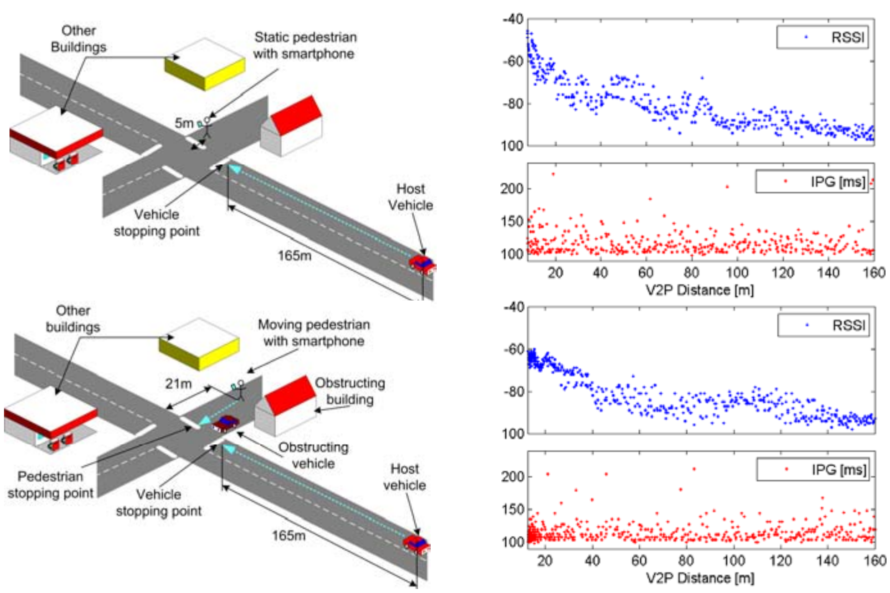
RSSI and IPG



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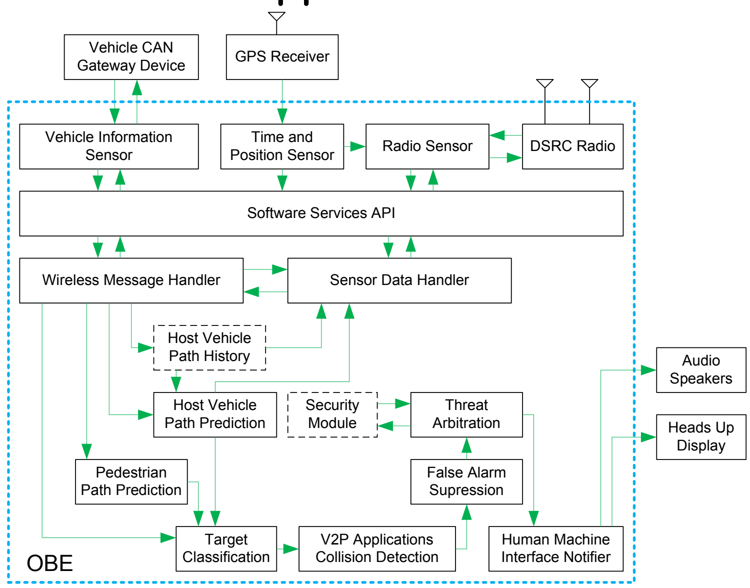
Vehicle V2P Application Architecture



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V2P Challenges: Mobile Positioning Accuracy

- Effective V2P application depends on good relative positioning between vehicles and pedestrians.
- Smartphones acquire position every seconds (at the current prototype messages are exchanged every 100ms)
- Accuracy need improvement
  - e.g. 90% of the time position error was less than 3[m], or 80% of the time was less than 2.5[m]

V2P Challenges: Security Design

- Vehicle security is based on the public-key infrastructure and applied at four stages: bootstrapping, certificate provisioning, misbehavior reporting and revocation.
- Smartphones are always connected to the infrastructure, allowing for an easier security management.
  - smartphone security must be compatible with the vehicle

Vehicle to Infrastructure Safety Application

Prepared by Radovan Miucic

Vehicle to Infrastructure Videos

- Consumers Report Video https://youtu.be/QB8XoHMZc8U
- GAO: Vehicle-to-Infrastructure Safety Applications https://youtu.be/Ke7LdyOnjLw

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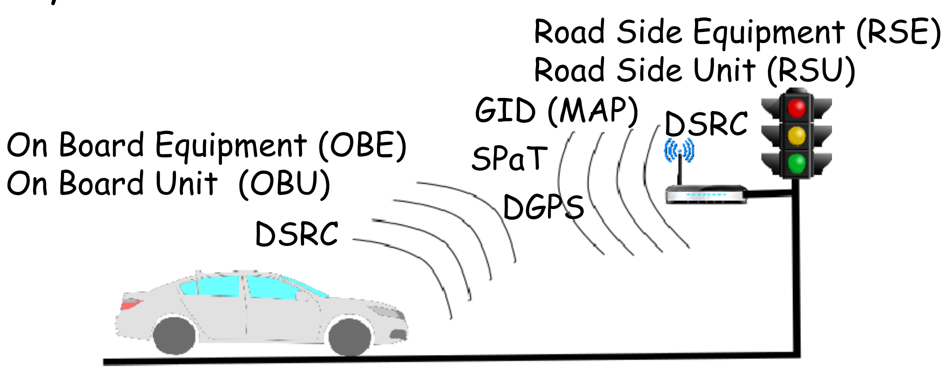
Intersection Crashes

- In the US annually
  - 1.72 million intersection crashes
  - 9000 fatalities
- Stop sign and traffic signal violations
  - 302,000 crashes (250,000 running red light)
  - $7.9 billion economic loss

CICAS-V

- Cooperative Intersection Collision Avoidance System for Violation (CICAS-V) project
  - (2006-2009)
  - US DOT and 5 major OEMs collaboration
- CICAS-STLA – Signalized left turn assistance
- CICAS-SSA – Stop Sign Assistance

Cooperative Intersection Collision Avoidance System for Violation CICAS-V



- Geometric Intersection Description(GID)/MAP message
- Differential corrections for Global Positioning Sys. (DGPS)
- Signal Phase and Timing (SPaT)

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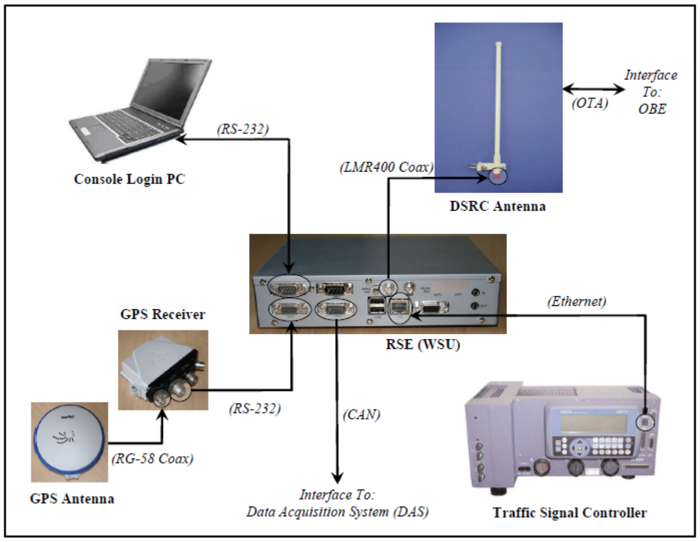
CICAS-V RSE HW Interfaces and Components



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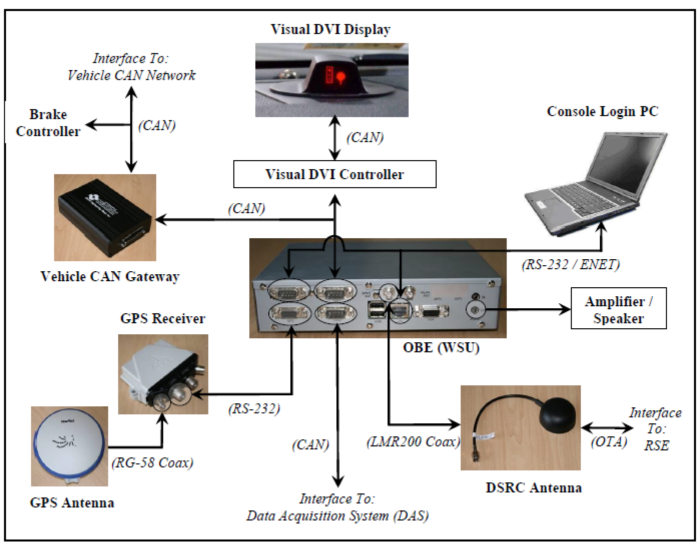
CICAS-V OBE HW Interfaces and Components



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Vehicular Positioning

Prepared by Radovan Miucic

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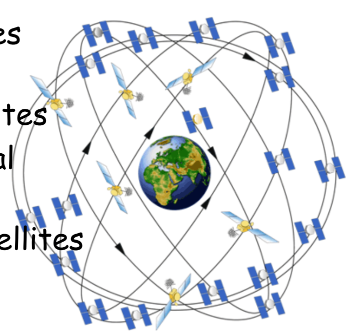
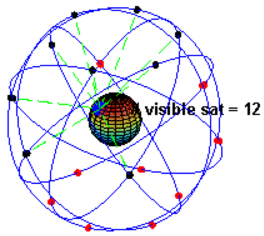
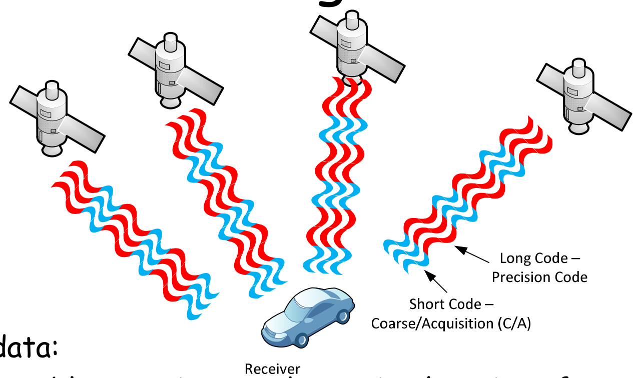
Vehicle Positioning

- Global Positioning System (GPS):
  - For military and civilian use
  - ~30 (at least 24 95% time) satellites orbiting the earth
  - Low power radio signals from satellites
  - Receives determines Time of Arrival (TOA) and performs ranging
  - Almanac coarse position of the satellites
  - Ephemeris used to compute precise position of each satellite.
  - Broadcast CDMA on two freq. L1(1575.42MHz) and L2(1227.6MHz)
  - Can achieve sub meter accuracy for commercial receivers



Vehicle Positioning … cont



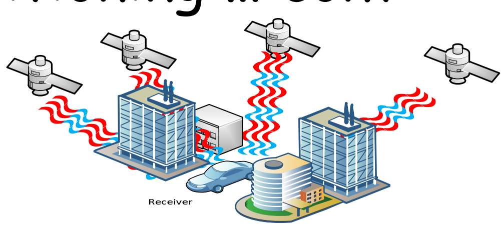


Sat. Transmitted data:

- Navigation data enables receiver to determine location of satellite at the time of transmission
- Ranging codes enables receiver to determine propagation time
- 4 satellites are needed for a GPS solution:
  - 3 for ranging + 1 to resolve time due imperfect clocks in the GPS receivers

Vehicle Positioning … cont

- GPS requires Line of Sight between receiver and the satellites
- Signals from some or all satellites may be lost if the vehicle is in the urban canyon, due to heavy foliage, tunnel, etc.
- Modern vehicles temporary relay on dead reckoning when GPS is lost.



- Dead reckoning uses data from vehicle sensors such as wheel speed, yaw rate, steering wheel angle, inertial sensor and map matching.
- Dead reckoning may be sufficient for few minutes for navigation purposes but may not be sufficient for VSC-apps.

Positioning Accuracy

- Road level - "Which Road" the vehicle is traveling on (5m or better)
- Lane level - "Which Lane" the vehicle is traveling on (1.5m-half lane width or better)
- Navigation Applications require road level accuracy
- Safety Applications require lane level accuracy
- GPS Improvements (sub meter acc.):
  - Differential GPS (DGPS)
  - WAAS
  - RTK GPS (relative GPS)

Vehicular Positioning

- Global Navigation Satellite Systems

  Operational
  - GPS (USA)
  - GLONASS (Russia)

  In Development
  - Beidou (China)
  - Galileo (EU)
  - IRNSS (India)
- Positioning Requirements for VSC-A needs to be lane level (with in 1.5 m)

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What is the Global Positioning System

- U.S. military system
  - Conceived in 1960
  - First satellites launched in 1978
  - Fully operational in April 1995
- GPS consists of 24 satellites
  - Each one circle the globe once every 12 hours
- GPS makes it possible to precisely identify locations on the earth by measuring distance from the satellites.

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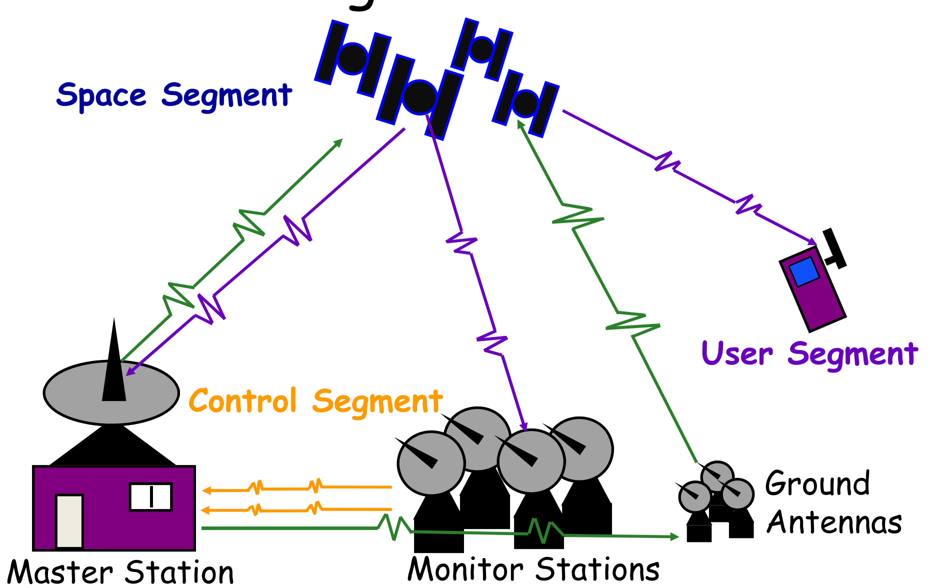
Three Segments of the GPS



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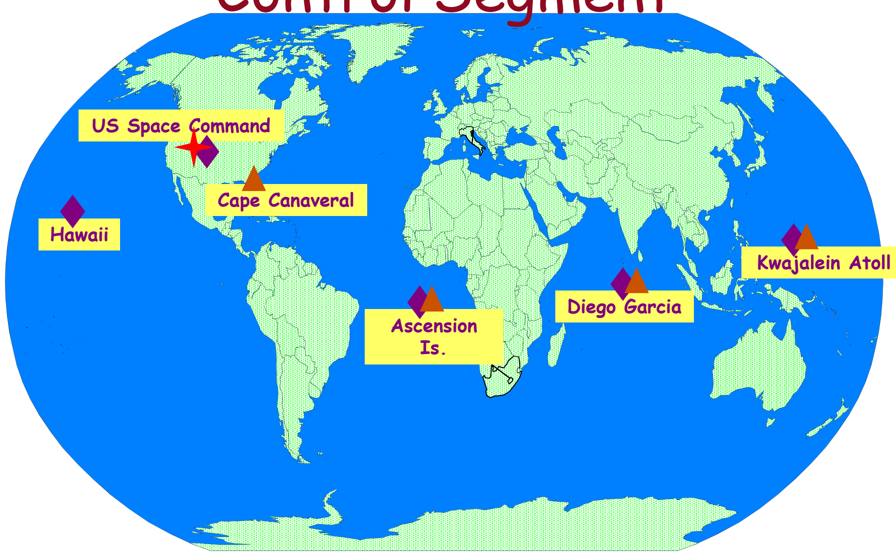
The 3 segments of GPS

- (1) Space segment
  - 24 satellites circling the earth at 12,000 miles in altitude
  - orbits arranged such that GPS receiver on earth can always receive a signal from at least 4 satellites at any given time
  - satellite transmits low radio signals
  - with a unique code on different frequencies, allowing the GPS receiver to identify the signals.
  - coded signals is to allow for calculating travel time from the satellite to the GPS receiver.
  - The travel time multiplied by the speed of light equals the distance from the satellite to the GPS receiver.
  - important to have a clear view of the sky

The 3 segments of GPS (cont.)

- (2) The Control segment
  - tracks the satellites and then provides them with corrected orbital and time information.
- (3) The User segment:
  - The user segment consists of the users and their GPS receivers.
  - The number of simultaneous users is limitless.

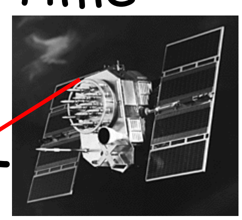
Control Segment



Master Control Station   Monitor Station   Ground Antenna

Position is Based on Time

Radio waves travel at the speed of light. If GPS signal leaves satellite at time "T"...



T

T + 3

...and is picked up by the receiver at time "T + 3."

Then distance between satellite and receiver = "3 times the speed of light"

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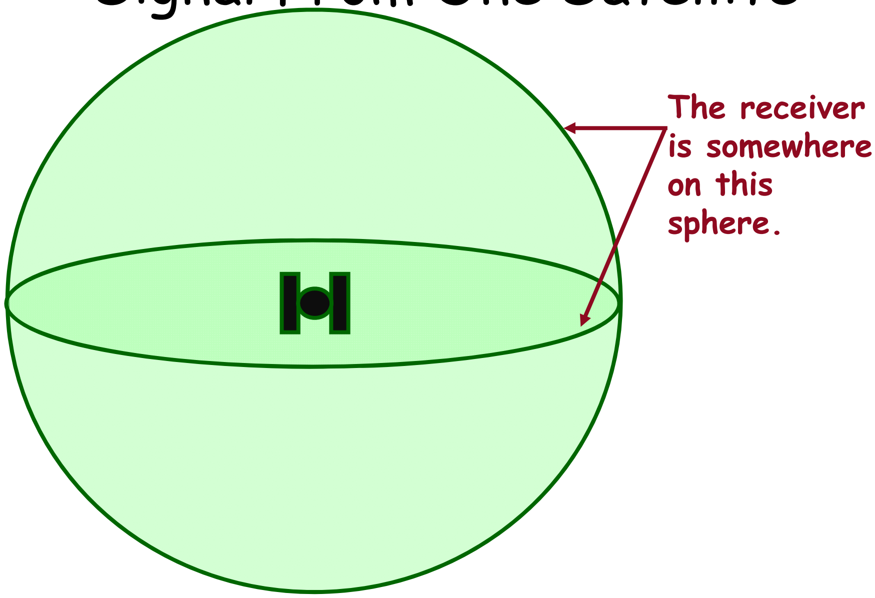
Signal From One Satellite



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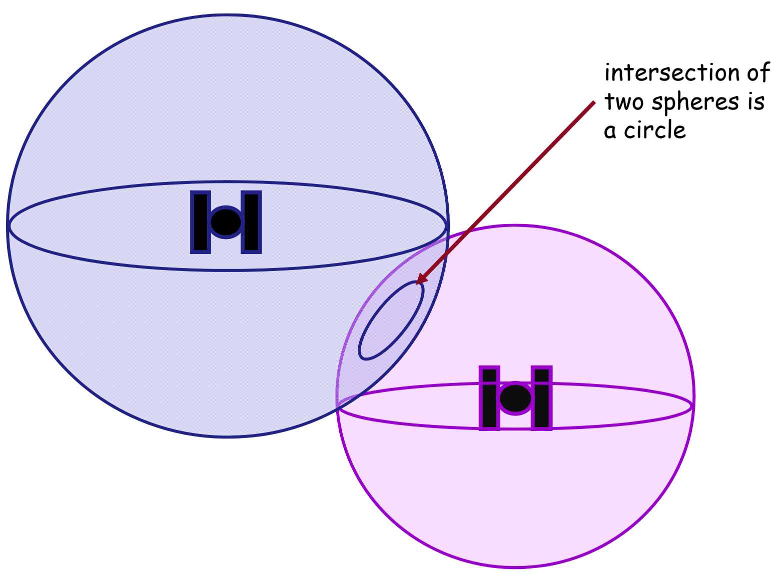
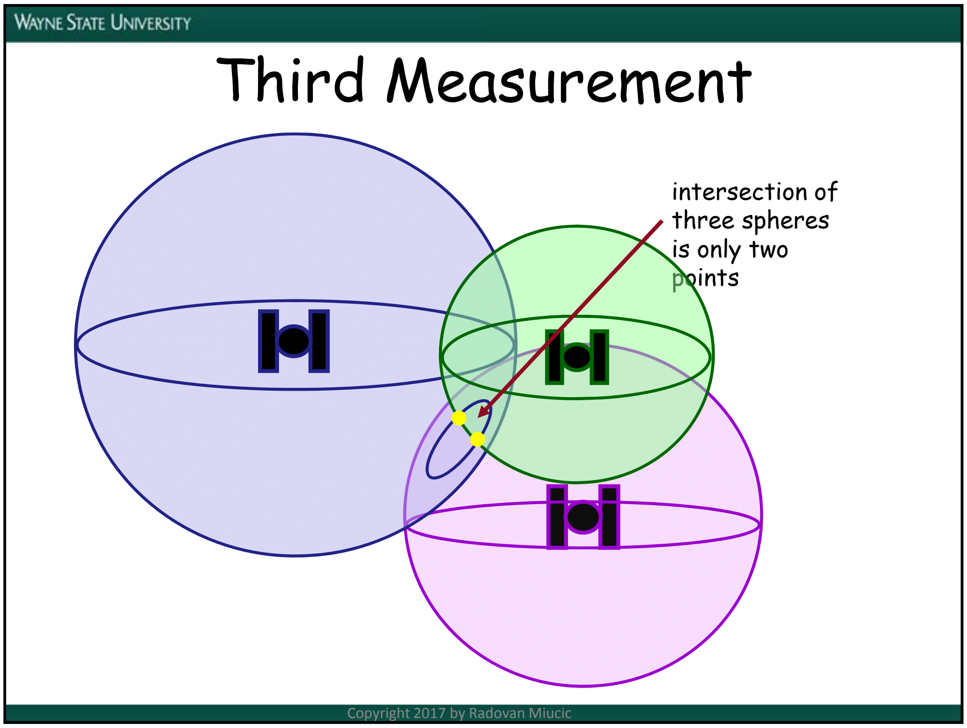
Second Measurement

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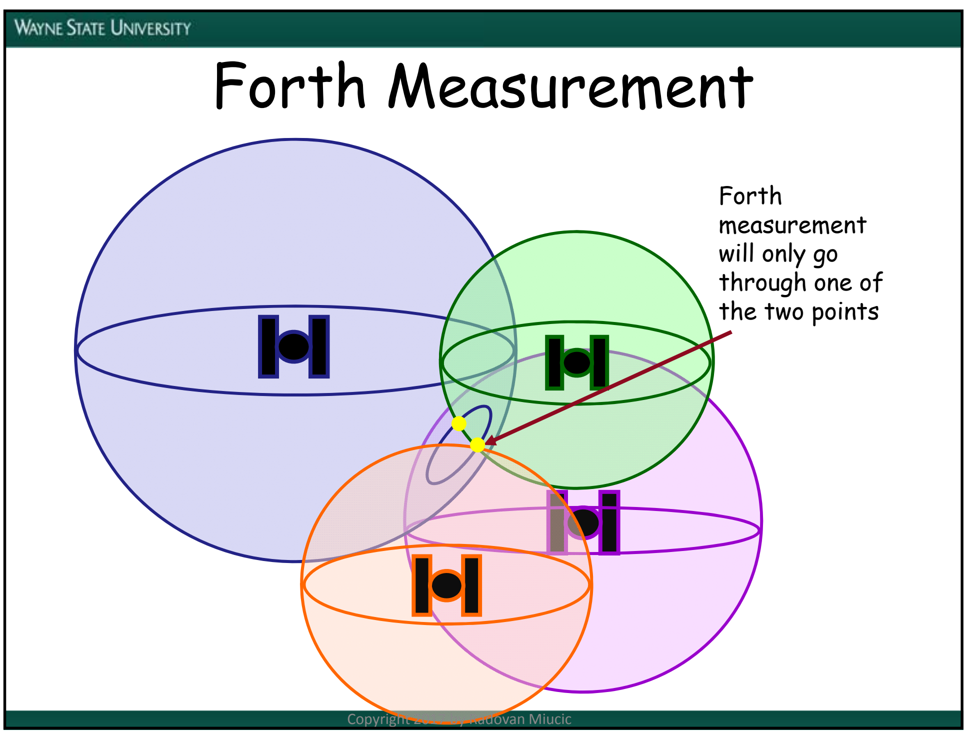
Third Measurement
intersection of
three spheres
is only two
points
Copyright 2017 by Radovan Miucic


Wayne State University
Forth Measurement
Forth
measurement
will only go
through one of
the two points

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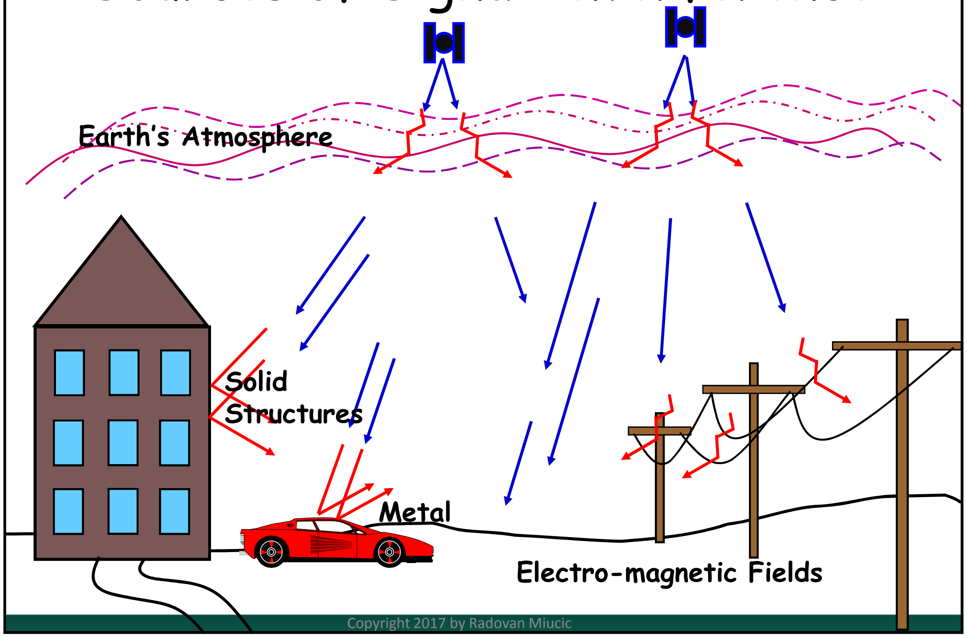
Sources of Signal Interference



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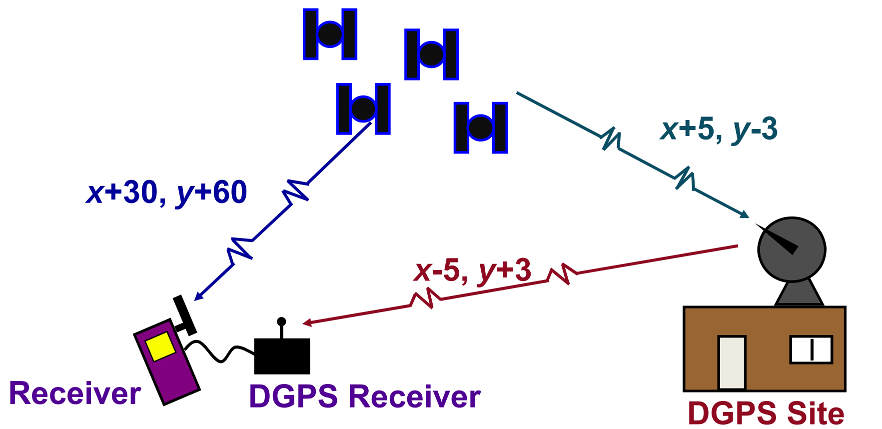
Positioning Improvements

Positioning improvements

- Differential GPS (DGPS)
  - Ground reference station of a know location calculates pseudo-range corrections for each satellite and wirelessly transmits the corrections to the vehicles.
  - E.g. NDGPS (National DGPS) run by Coast Guard and the U.S. Department of Transp.
- Wide Area Augmentation System (WAAS)
  - Developed by the Federal Aviation Administration
  - uses a network of ground-based reference stations (20 in US). They monitor and calculate GPS corrections in the different area (continental US). The corrections are then sent to satellites and satellites rebroadcast that information.
- Visual Odometery
  - Using camera to enhance position

Real Time Differential GPS



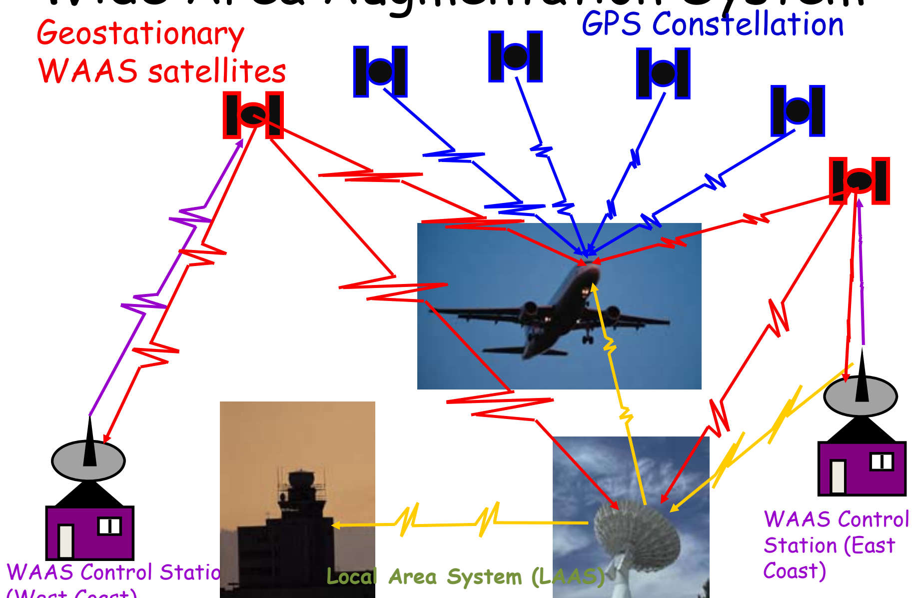
True coordinates = *x*+0, *y*+0

Correction = *x*-5, *y*+3

DGPS correction = *x*+(30-5) and *y*+(60+3)

True coordinates = *x*+25, *y*+63

Wide Area Augmentation System



Positioning Improvements

- Inertial Measurement Unit (IMU)
  - is an electronic device that measures and reports changes in a vehicles velocity, orientation, and gravitational forces, it can use a combination of accelerometers and gyroscopes, sometimes also magnetometers.
  - If used as a standalone suffers from position drifts.
  - GPS/IMU/other vehicle sensors integration improves position solution and bridges the gap between GPS signal outages (enhancing dead reckoning)
  - Fiber optics based IMUs are high accuracy but currently cost prohibitive for vehicles
  - MEMS based IMUs are cheaper but lower accuracy

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Positioning Improvements

- Real Time Kinematic (RTK)
  - Uses phase lock loops on the carrier waves
  - Suffers from lock slippage when the line of between vehicle and a satellite sight is lost
- Wireless Ranging
  - Using wireless signal (WiFi, LTE) to trilaterate positon from known locations of base stations

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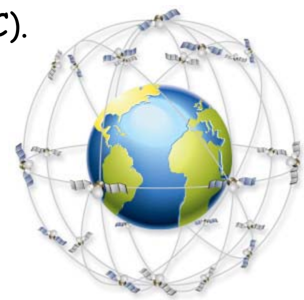
GPS Almanac

- The almanac consists of
  - ephemeris data: orbit (current and predicted) and status information for each satellite in the constellation,
  - an ionospheric model, and
  - information to relate GPS derived time to Coordinated Universal Time (UTC).
- Complete almanac is transmitted by each satellite



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Connected and Autonomous Vehicle

Prepared by Radovan Miucic

Stages of Autonomy (NHTSA Logic)

Transition to and from autonomous diving will be HMI intensive

Level 0
No Automation

Driver in charge

Level 1
Function-specific automation

Single control such as braking, lane keep, or speed control are automated

Level 2
Combined function automation

More than one control is automated, driver is still expected to be available at all times and on short notice

Level 3
Limited self-driving automation

Vehicle takes control most of the time Driver is expected for occasional control with comfortable transition times

Level 4
Full self-driving automation

Vehicle takes control all of the time Driver not expected be available for control at any time

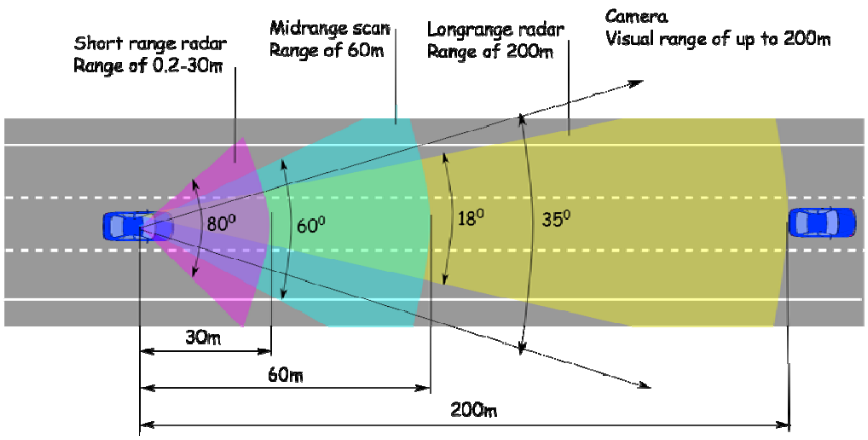
National Highway Traffic Safety Administration (NHTSA)

Vehicle Sensors

Radars:
- Uses radio waves
- Detects object
- Determines position and velocity
- Long range (250m rng)
  - 15 deg-20 deg field of view
- Mid range (150m rng)
- Short range (50-60m rng)
- Radars are good for distance measurements

Cameras
- Cameras (having good angle of resolution) an be integrated with radars (distance and velocity detection)
- Mono or Stereo
- low cost
- Used for
  - Pedestrian detection
  - Lane recognition
  - Lane keeping assist
  - Sign Detection (e.g. Speed limit detection)

Vehicle Sensors … cont



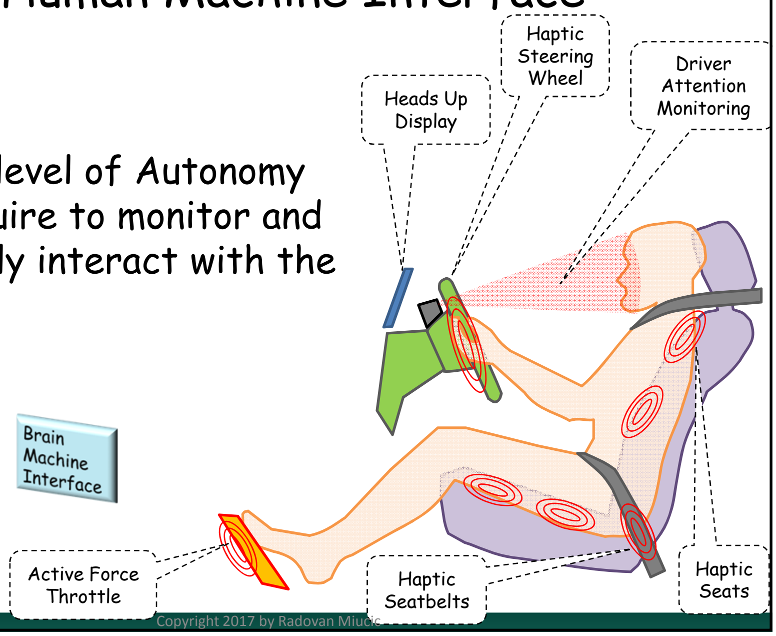
Human Machine Interface

- Higher level of Autonomy will require to monitor and correctly interact with the driver

Augmented Reality

Brain Machine Interface

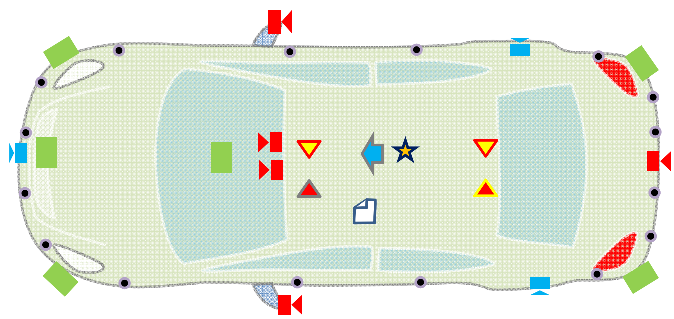
Driver Health Monitoring



Connected Autonomous Vehicle

External Sensors:

- 6 LIDARs (Solid State)
- 3-5 Radars
- 4-6 Cameras
- 10-16 Ultrasonic Sens.
- ADAS Map
- 2xGPS Receivers
- DSRC
- LTE Cellular
- IMU



Unified Controller

Radars
Cameras
Ultrasonic
Map
GPS
DSRC
CAN

→ Unified Controller →

Sensor Fusion
Pedestrian, vehicle, lane, and road furniture detection and classification
Target Tracking
Awareness Grid
Path Prediction
Human Machine Interface
Vehicle Control

Communication and computation demanding

DSRC Scalability

Prepared by Radovan Miucic

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DSRC Scalability

Video

DSRC Scalability

Problem Statement

Assumptions:

- All vehicle in the future are equipped with DSRC radios
- For V2V applications vehicles send out BSMs frequently (periodically)

Problem:

- How many vehicles can communicate in the same communication range?

DSRC Scalability

- From the example in lecture 8 for one BSM of 300 bytes channel is occupied for 448us ~ 0.5ms.
- Transmission frequency is 10 BSM/second
- Therefore each vehicle occupies 5ms in a 1 seconds or 0.5% of the channel
- Assuming that vehicles send BSMs one after another (not a realistic assumption in CSMA/CA) there can be at most 200 vehicles in a given communication range before BSMs start colliding over the air. In practice much less than 200 vehicles causes BSMs to collide over the air.

Transmission Parameters

- Focus on V2V msgs (most frequent)
- Transmission Parameters
  - Message rate [packets/second] or message frequency [Hz] (how many msgs a vehicle sends per second?)
  - Data rate [MBPS] – (how many bits are transmitted per second?)
  - TX power [dBm] – (how far can msg travel?)
  - Message size [bytes]

Data Rate and Msg Frequency

- In a 10 MHz channel data rate (6 MBPS) is fixed and it is optimized for multipath and high mobility vehicular environments.
- Message frequency and communication range is determined by the application needs.
  - Msg. frequency of 10 Hz suffice all V2V applications (e.g. EEBL, FCW, BSW/LCW)
  - adjusting frequency to be 2-10 Hz is considered

Message Frequency

- Lower message frequency less timely support for the V2V application.
- Higher message frequency more chances for OTA collisions and increased communication congestion.
- A vehicle traveling 80mph (36 m/s) and transmitting at 10Hz will update its position every 3.6m

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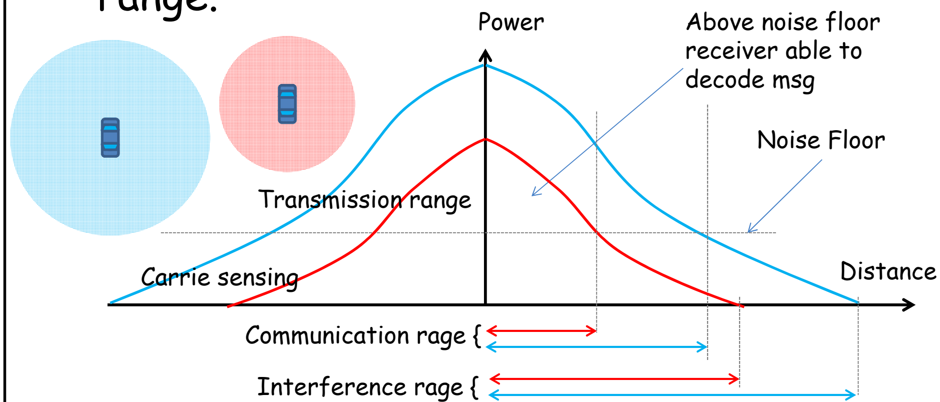
Transmission Power

- Transmission power translates into the communication rage and interference range.



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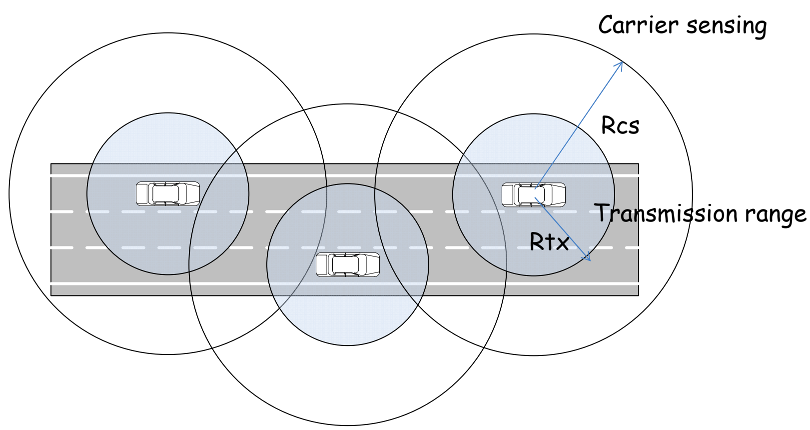
Transmission Power



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Channel Load Assessment

- Channel load is determined with Clear Channel Assessment (CCA) function available on all IEEE 802.11 devices
- PHY layer declares channel busy when the cumulative power received within certain interval exceeds the carrier sensing threshold (CST).
- WAVE radios periodically invoke CCA to calculate fraction of the time channel is busy -> Channel Busy Ratio (CBR)

Communication Congestion Mitigation Strategies

- Adjust TX Power
  – Based on the feed back from the vehicles within its carrier sensing range
- Adjust message rate
  – Based on the dynamics of the host vehicle

DSRC Security, Privacy, Threats and Requirements

Prepared by Radovan Miucic

- 60 Minutes Video
  https://youtu.be/7E1WsdODxu0

- Car Hacking DARPA
  https://youtu.be/zurrQiETDHA

Adversaries

- Individuals or organizations that mount security and privacy attacks
- Based on the resources and capabilities, adversaries can be classified as:
  - **Individuals** operating on their own with limited $ (computer hackers, car enthusiasts, electronics hobbyists and researchers)
  - **Loosely coordinated groups**, little more $, e.g. and individual obtain private key from a vehicle shares it with others via internet
  - **Insiders** owning sensitive information about the security system e.g. have access to the security servers
  - **Adversary organization** abundant $ and sophisticated technologies
  - **Forein government:** highly organized, abundant $ and sophisticated technologies
  - **Domestic government:** highly organized, abundant $ and sophisticated technologies, permitted to breach driver privacy.

Security Threats

- Send false safety messages using valid security credentials
- Falsely accuse innocent vehicles
- Impersonate vehicles or network entities
- Denial of service attacks

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TX False Msgs with Valid Credentials

- Send false safety messages using valid security credentials
  - Altering inputs to the OBU
  - Installing malicious SW
  - Adding devices onto the vehicle CAN that are then used to feed OBU
  - Compromising OBU SW and HW
- E.g. adversary can send counterfeited BSMs (wrong position, speed, brakes status…) to other vehicles causing them to issue false warnings.

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Falsely Accuse Innocent Vehicles

- To identify misbehaving vehicles, vehicles may be required to report observed misbehavior.
- Global misbehavior detection system may use these reports from multiple vehicles to identify misbehaving vehicle.
- However, misbehaving vehicle can abuse the reporting system and falsely accuse an innocent vehicle undermining the misbehavior detection system.

Impersonate Vehicles or Network Entities

- Vehicle pose as a different vehicle using compromised credentials.
- Sybil attack: a malicious vehicle broadcasts safety messages in attempt to convince that there are more vehicles present than there actually are.

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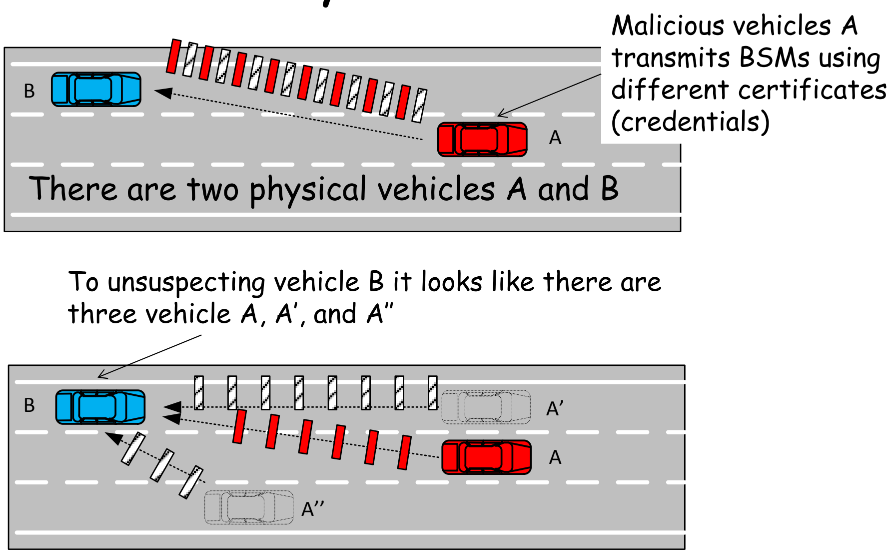
Sybil Attack



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Denial of Service

- DoS attack intended to disrupt, degrade and disable communications capability and cooperative vehicle safety application.
- DoS forms:
  - Jam the radio waves to disable reception of the authentic messages
  - Flood the network with wasteful messages to overload radio communication
  - Compromise road side units (RSUs) to disable their services

Compromise OBU SW or HW

- It has been shown that software and hardware of a modern automobile can be hacked remotely.
- Researches from University of Washington and University of California San Diego have used cellular connection to the vehicle and the function intended fro remote software upload to hack into a vehicle.
- Malicious code inserted into the OBU can be used to mount previously described attacks.

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Privacy Threats

Privacy in a vehicle network:

- Vehicle anonymity
- Message linkability
  - Short term message linkability
    - Is needed for needed for proper functionality of cooperative vehicle safety applications
  - Long term message unlinkability
    - It is desired that messages cannot be linked to the sender over time span

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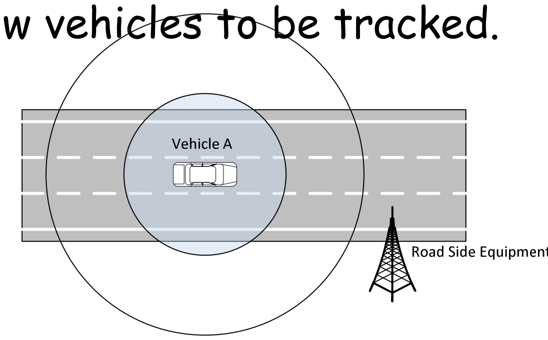
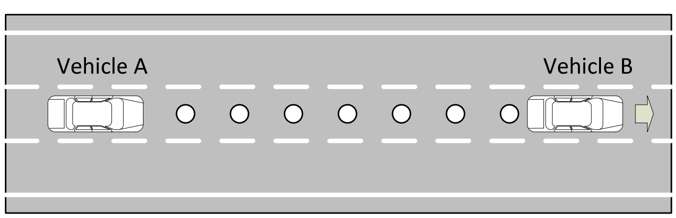
Long Term Message Unlinkability

- If a vehicle A travels next to the RSE every day, RSE should not be able to identify vehicle A just by examining vehicle A's BSMs. The system should not allow vehicles to be tracked.



Short Term Message Linkability

- E.g. vehicle A should be able to connect the messages and attribute them to vehicle B for proper VSC application (such as FCW or EEBL)



Basic Security Capabilities

- Authentication
- Misbehavior Detection and Revocation
- Data Integrity

Authentication

- Broadcast msg authentication: the ability for vehicles to determine whether a broadcast msg is from a another vehicle or RSU authorized to send such a msg
- Vehicles and RSU must trust one another
- Trust is needed for safety applications
- It does not require uniquely identifying the message originator, it is sufficient to determine that originator is part of a group (vehicle or RSU) entitled to send given message.
- This can be achieved with use of Public Key Infrastructure (PKI)

Misbehavior Detection and Revocation

- Misbehavior Detection: ability to detect malicious entities (vehicles)
- Revocation: removing the privilege of sending messages that others will trust, effectively removing misbehaving entities from the system.
- Requirement for the real world deployment of the vehicle safety communications system

Data Integrity

- Data have not been altered in an unauthorized manner
- Data can be altered by:
  - faulty equipment(noisy signal)
  - Deliberately (maliciously)
- Vehicle should be able to have diagnostic functions during data collection to locally discover faulty (noisy) signals before composing BSMs

Privacy Protection Capabilities

- Privacy-preserving system should support:
  - Vehicle anonymity
  - Message long term unlinkability
- Linking msgs over short time period is not a security concern and usually it is required for cooperative apps.
- Long term unlinkability should be cost prohibitive for the potential advesaries.

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Design and Performance

- Scalability:
  - Must be scalable to support 250 million vehicles (currently in use in the US)
  - If each vehicle uses a different certificate every 5 minutes, and it is reloaded every month, it means that system needs to support over 2 trillion certificates in operation.
- Currently the largest digital certificate provider (VeriSign) supports only tens of millions of certificates in operation today (mostly for Internet)

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Balancing Competing Requirements

- Supporting Security
  - Should not impact Enabling Vehicle Safety Apps
  - Important to support message long term unlinkability, many apps require short term linkability.
  - Should not jeopardize driver privacy

- Protecting Privacy
  - Not jeopardize ability to detect misbehaving vehicles (when vehicles are anonimus and msgs are unlinkable it is difficult to do misbehavior detection)
- Enabling Cooperative Vehicle Safety Applications

Minimal Side Effects

- Security and Privacy Protection should not:
  - Cause excessive disruption to the driving public (cause drivers to bring vehicles to dealers)
  - Create excessive computational burden and wireless overhead
  - Open new risks that can result from abusing privacy protecting system by adversaries

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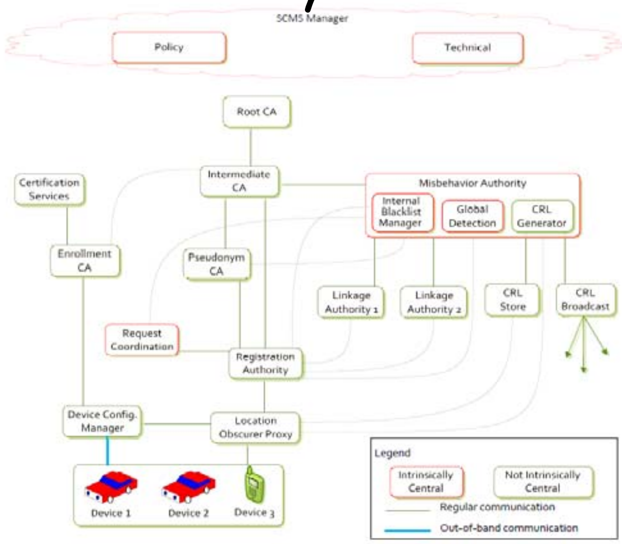
SCMS System Architecture



CA – Certificate Authority

CRL – Certificate Revocation List

PKI - Public-Key Infrastructure

SCMS – Security Credential Management System

Whyte, W.; Weimerskirch, A.; Kumar, V.; Hehn, T., "A security credential management system for V2V communications," *Vehicular Networking Conference (VNC), 2013 IEEE* , vol., no., pp.1,8, 16-18 Dec. 2013

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Contact:

Radovan Miucic

radovan@wayne.edu