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Telematics Research
Research and Technology Center Palo Alto

Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communication Recent Developments, Opportunities and Challenges

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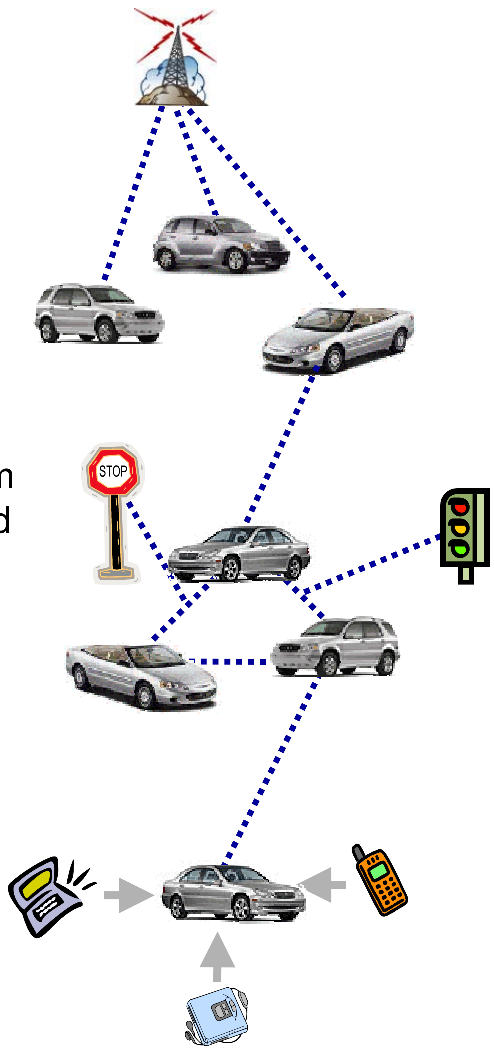
Contribution to the Workshop:
Future Generation Software Architectures in the Automotive Domain
Connected Services in Mobile Networks

January 10-12, 2004
La Jolla, CA

Communication on the Road so far…

Wireless Communication: Automotive Scenarios



- Connecting **vehicle to a back-end infrastructure** to be able to retrieve information (e.g. diagnostics data) from the vehicle or to allow vehicle to access network resources (e.g. MB-Portal, A-Class-Online, smart webmove, …)
- Connecting **vehicles to each other** and with the infrastructure allows them to share and exchange information and sensor data among each other and among them and the infrastructure (e.g. for entertainment, diagnostics, safety, probe data collection, wireless payments, toll collection in the U.S.)
- Connecting **portable devices to the vehicle** allows us:
  - to enhance the vehicle's functionality (e.g. digital address book as input to the navigation system, MP3 player to play digital music)
  - to make use of vehicle resources on the portable device (e.g. better connectivity, audio system, vehicle controls, diagnostic applications, …)

Wireless Communication: Principle Challenge

Implication:

- Wireless communication for vehicular applications has no “one size fist all” or “one technology fits all” solution

Challenge:

- Regardless of the selected technology, there are always three competing factors:
  - **Cost** (e.g. equipment cost, usage cost: airtime, flat fee, data volume, …)
  - **Quality of Service** (e.g. bandwidth, latency, scalability, …)
  - **Availability** (e.g. coverage area, indoors, outdoors, …)

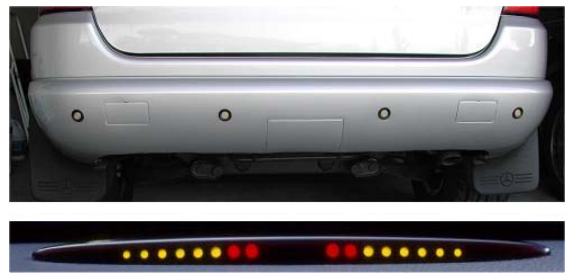
- Generally only up to two of these three factors can be optimized on the cost of the remaining one(s).

Wireless Communication: Technology Options

Coverage	Technology	Pros	Cons	Trend
Wide Area	Satellite Data/Voice Communication	Global Coverage	Very expensive, Low data rate	↓
	AM/FM Radio	Regional Coverage Ubiquitous Deployment	Only Broadcast, Low data rate, No uplink	→
	Digital Satellite Radio	Continent Coverage Exclusive Data Channel	Only Broadcast, No Uplink	→
	Digital Audio Broadcast	Regional Coverage High Data Rate	Only Broadcast, Not widely deployed yet, No uplink	→
	Cellular	Sufficient Population Coverage, Reasonable data rate (2.5G+)	Relative expensive for data, Low data rate (1 and 2 G)	→
Local Area (Short to Medium Range)	Wireless LAN (WLAN)	No license cost, Inexpensive, High bandwidth, Strong industry support	Hotspot coverage	↑
	Infrared	No license, inexpensive, already established	Limited range, limited bandwidth, only line of sight	→
Personal Area (Immediate Proximity)	Infrared	No license, inexpensive	Limited range, limited bandwidth, only line of sight	↘
	Bluetooth	No license, inexpensive	Limited range, limited bandwidth	→
	UWB	No license, Very high bandwidth	No standards yet	→

Wireless Communication for Safety: Traditional Sensors Reach Their Limits

- Radar or Ultrasonic systems support current safety and comfort applications such as DISTRONIC and PARKTRONIC



- Vision and LIDAR system can provide additional functionality for e.g. vision-based lane-keeping applications, object detection, etc.

- However, all those traditional sensors have their natural limits:
  - They only sense the immediate vehicle environment (short-haul)
  - They are mostly passive (radar has limited data capabilities)
  - They are relatively expensive and typically not versatile

Wireless Communication as a new "Sensor"

- Wireless communication is a new "sensor" that allows us to look **further away** in space and **further ahead** in time

- Wireless communication electronically extending the driver's horizon and thereby enabling an entirely new class of safety applications

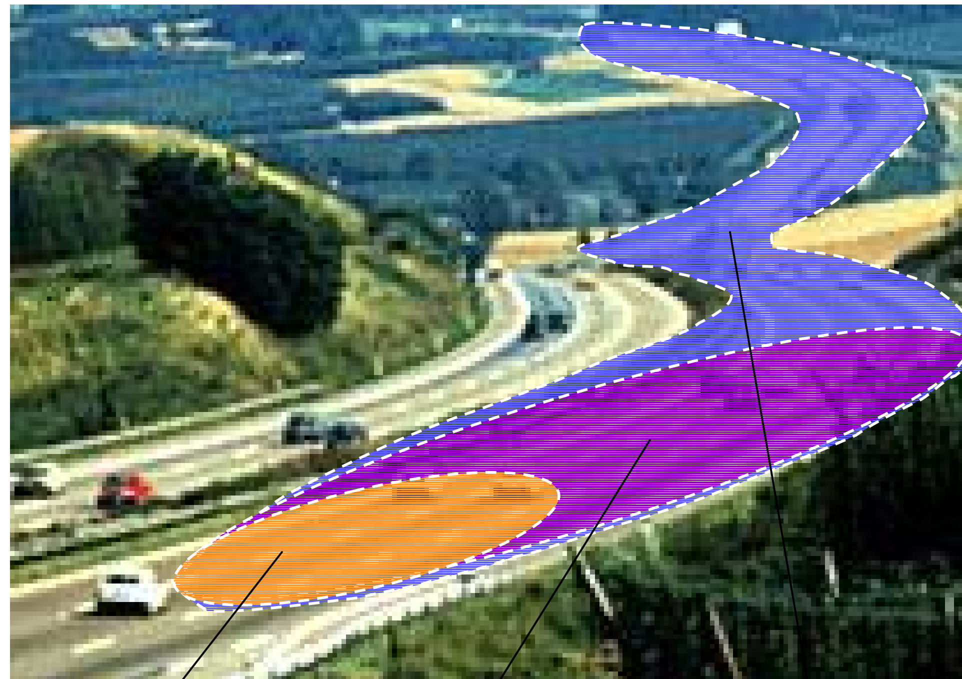
- Vehicles can act as information sources, information relays and recipients of information

- Relevant information is mostly found in the extended local environment of a vehicle which:
  - reaches beyond the limits of the traditional sensors (e.g. multiple cars ahead, vision or radar systems typically only see one car ahead)
  - but does not necessarily require wide area communication (e.g. there is typically no need to communicate with cars in another part of the city)

The General Principle: Looking Ahead

Reaching an area
- No other sensor can reach
- Even the driver can usually not reach

Creating a "Telematics Horizon"
- Looking further away
- Looking further ahead
- Looking beyond the surface
  - Non-physical attributes
  - Rules



How it works:

Pre-Inform → Event

Without telematics sensors

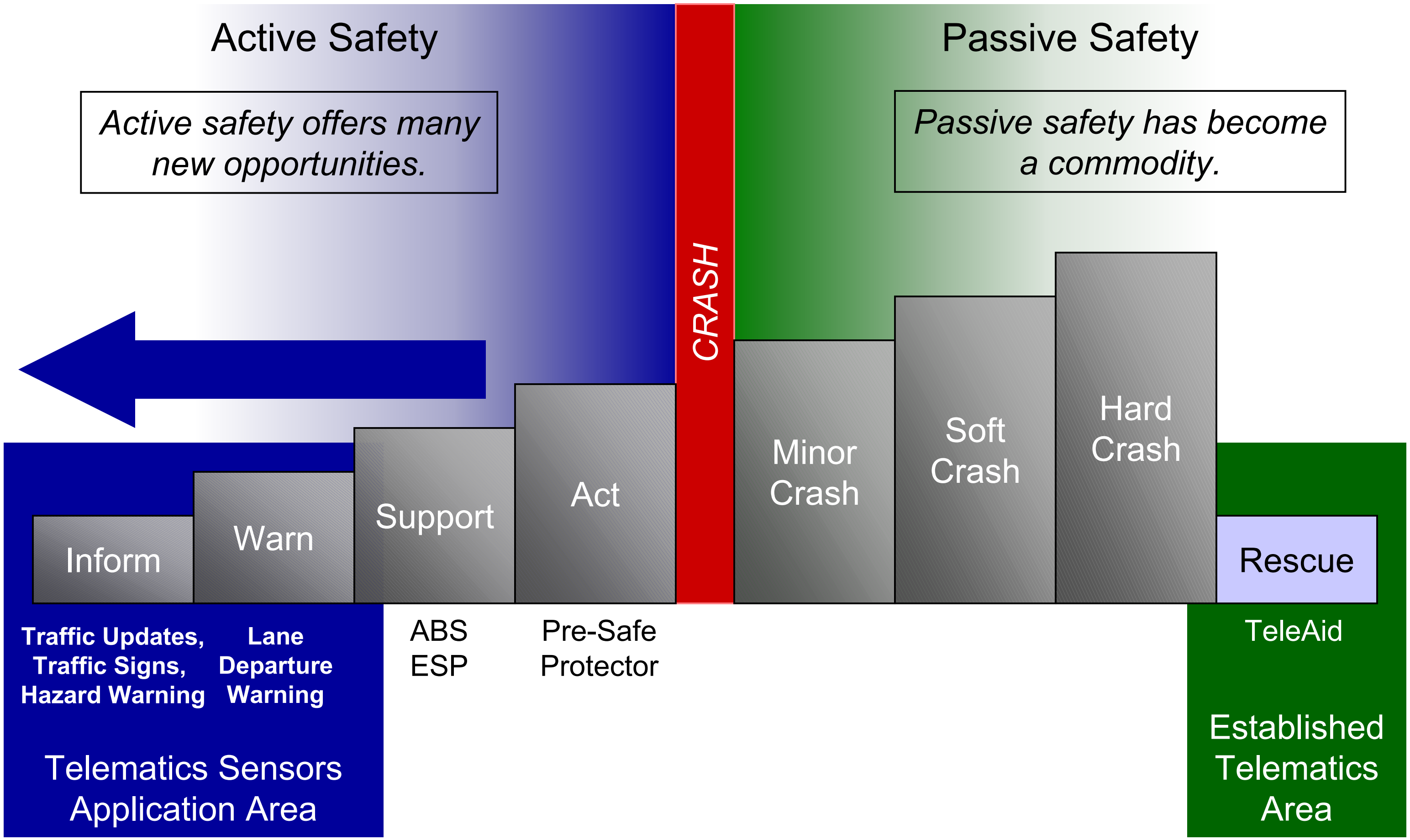
Event → Stimulus → Perception → Recognition → Decision → Action

Pre-Inform → Stimulus → Perception → Recognition → Decision → Action → Gain!

With telematics sensors

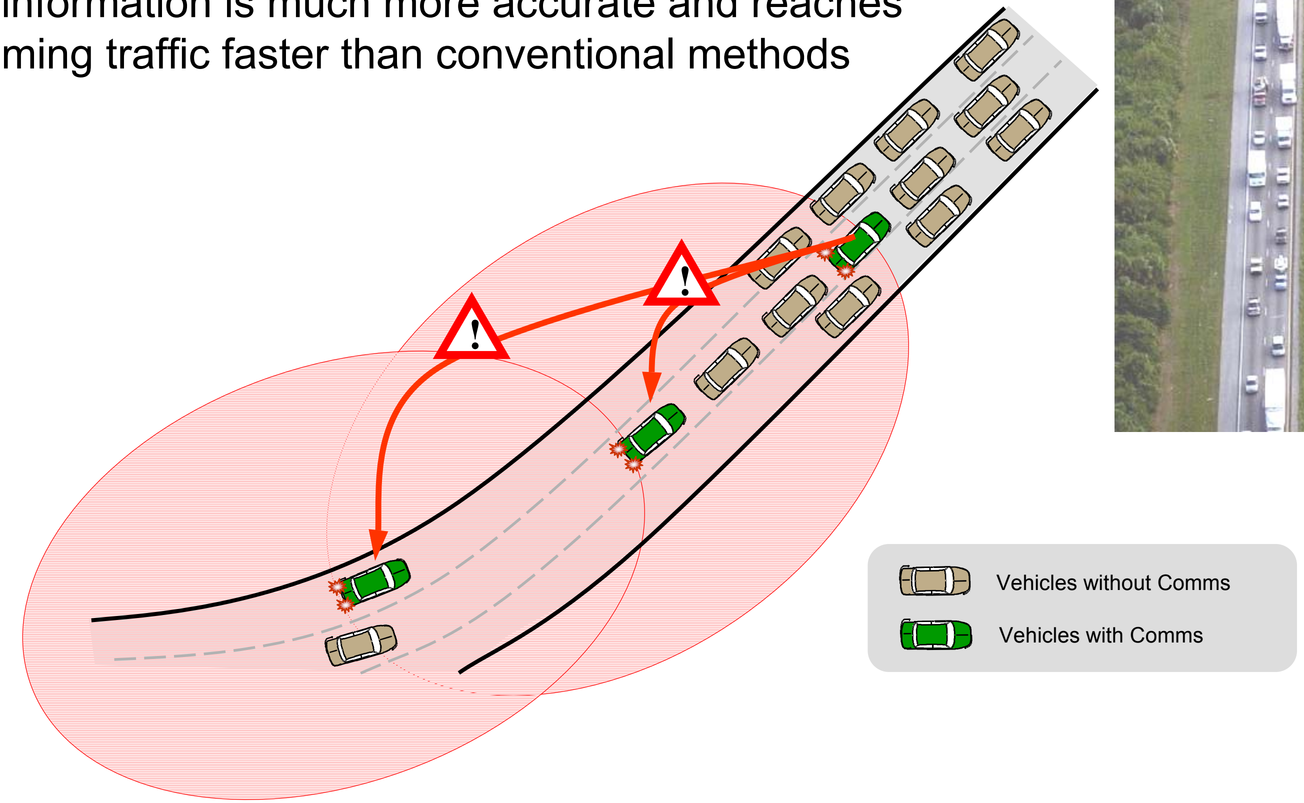
Key Motivation: Active Safety

Focus in safety shifts towards accident avoidance and collision mitigation.



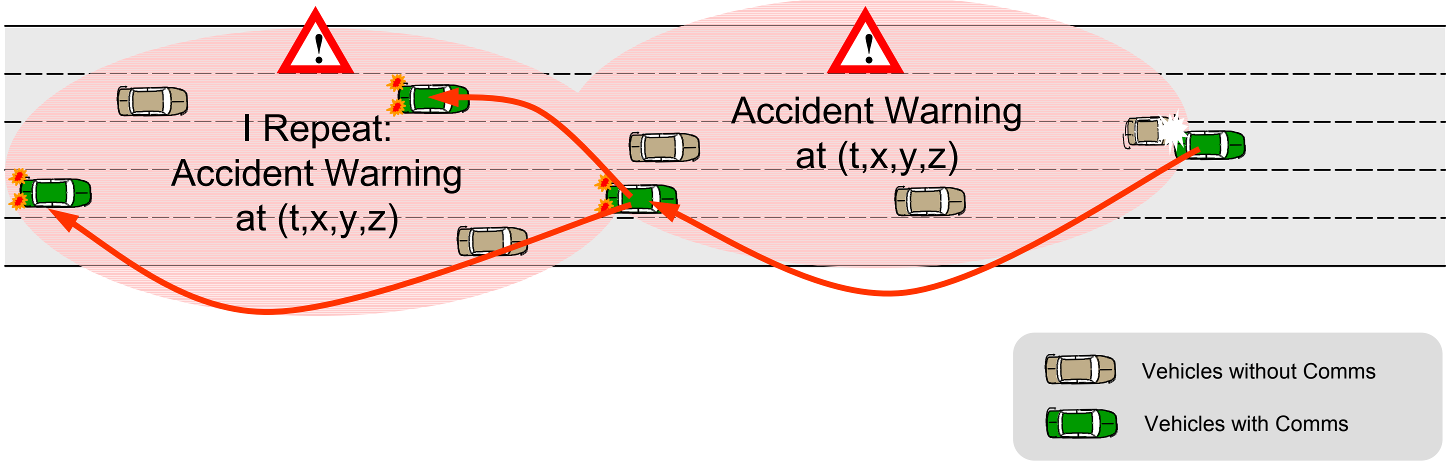
Example of Safety Applications: Hazard Warning

- Vehicles that are in a traffic jam and turned on their hazard warning lights, communicate this information back to other vehicles
- This information is much more accurate and reaches upcoming traffic faster than conventional methods



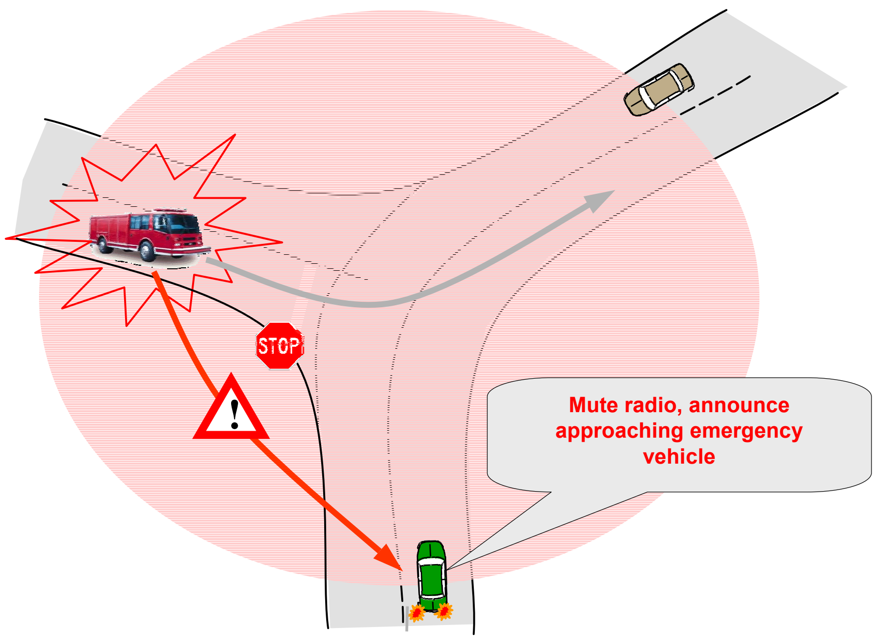
Example of Safety Applications: Accident Warning

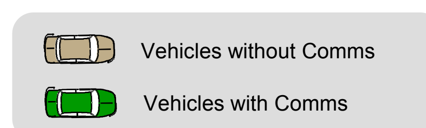
- Vehicles that are involved in an accident are the most reliable source of information about the very fact that there is an accident
- If vehicles involved in an accident are equipped with short-range communication, they can send out a warning message to the following traffic e.g. to avoid mass collisions.
- In order to extend the reach of the message, a repeat mechanism can carry the message further in the direction that is concerned



Example of Safety Applications: Approaching Emergency Vehicle Warning

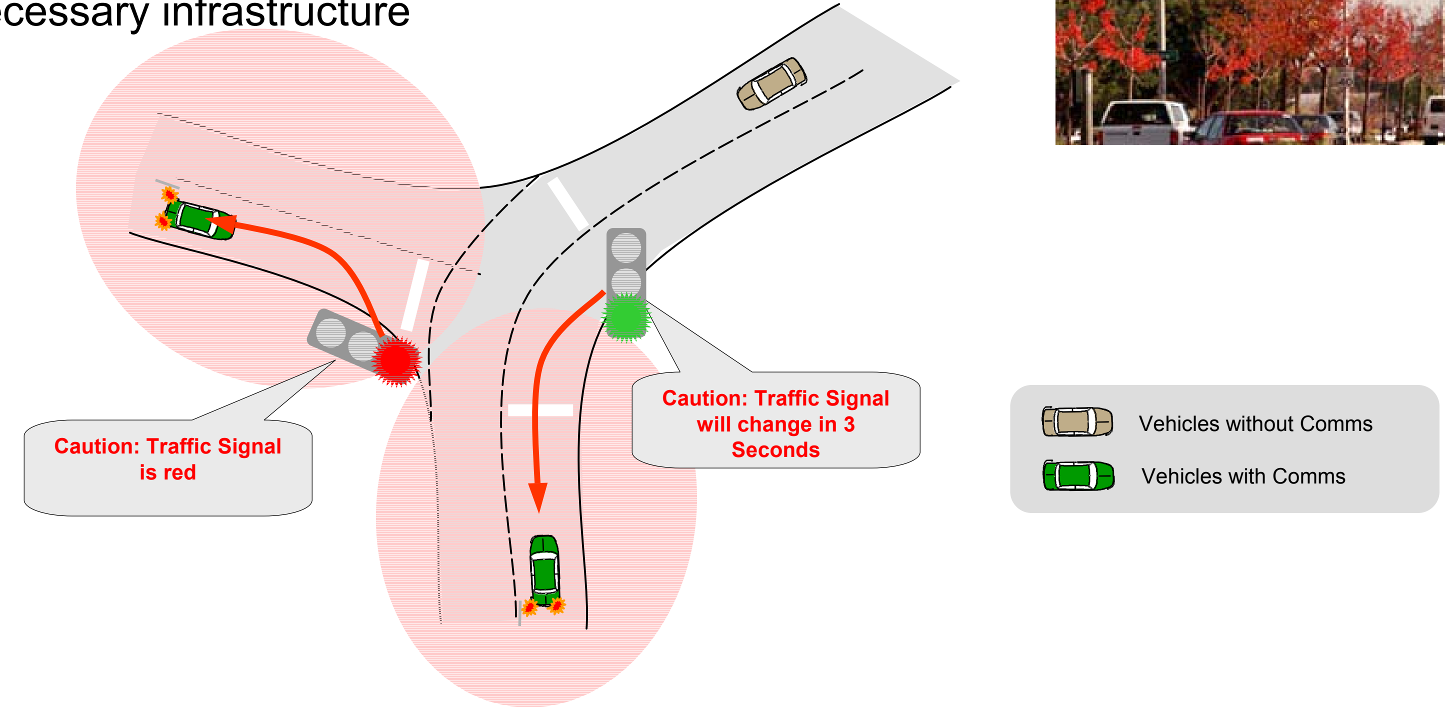
- Approaching emergency vehicles send out a warning message to warn vehicles that are in its vicinity
- Receiving vehicles can automatically mute the radio or the handsfree-phone and give an audible or visual warning message to the driver





Example of Safety Applications: Traffic Signal Violation Warning

- Vehicles can be warned about an imminent change of a traffic light and if they are in danger of running a red light
- Traffic lights can send out their timing and phase to prevent red light violations and potential accidents
- U.S. DoT plans for significant investment to deploy necessary infrastructure

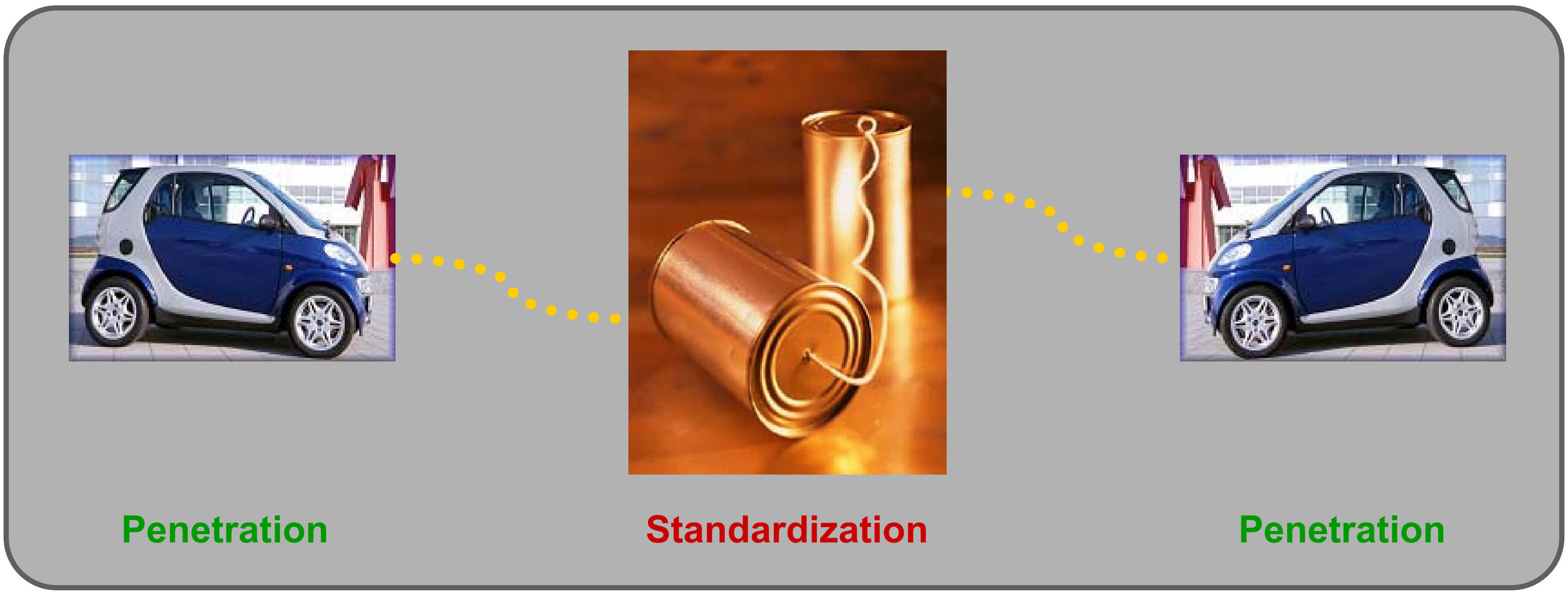


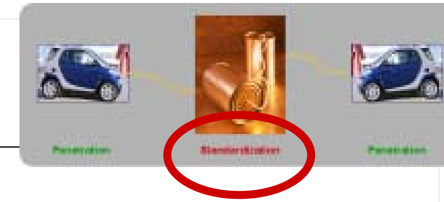
Open Issues

This all might sound very convincing, however …

… for communication you need a common language ⇨ **Standardization**

… and you need at least two parties to communicate! ⇨ **Penetration**





Standardization: Joint Industry and Government Initiatives

Consortium	Participants	Mission
Vehicle Safety Communication Consortium (VSC) (Founded 05/2002)	BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, VW, Department of Transportation United States of America	• 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 associated communication requirements including vehicle-vehicle and vehicle-infrastructure communications. • Contribute to 5.9GHz DSRC standards and ensure they effectively support safety.
Car2Car Communication Consortium (C2CC) (Founded 08/2002)	Audi, BMW, DaimlerChrysler, VW	• Specification of an industrial standard for an open inter-vehicle communication platform and for basic safety applications. • To achieve allocation of an European frequency band dedicated for active safety applications. • To include other OEMs and suppliers into the consortium.

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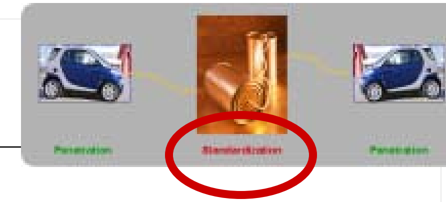


Standardization: U.S. Dedicated Short Range Communication (DSRC)

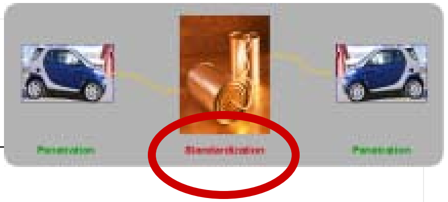
- In 1999 the U.S. Federal Communication Commission (FCC) allocated **75MHz** of spectrum at **5.9GHz** to be used exclusively for **vehicle-to-vehicle** and **infrastructure-to-vehicle** communication in the U.S. called Dedicated Short Range Communication (DSRC)

- The primary purpose is to **save lives** and **improve traffic flow**
  - *"… operations related to the improvement of traffic flow, traffic safety and other intelligent transportation service applications, in a variety of public and commercial environments."*

- On December 17, 2003 the FCC adopted licensing and service rules for DSRC and lower layer standards developed by the ASTM 5.9Ghz standards working group

- DSRC is based on IEEE 802.11a technology and is in the process of becoming part of the IEEE 802.11 WLAN standards family

- DSRC distinguishes between **public safety applications** and **private applications**
  - Supports vehicle-to-vehicle mode that opens new opportunities for safety applications
  - Allows for the implementation of wireless electronic payment systems at toll-booths, gas stations, drive-through restaurants, parking structures, …
  - Provides data channels complementary to cellular systems for volume data transfers
  - Allows for additional services e.g. entertainment through WLAN compatibility



Standardization: Automotive Involvement

Why the automotive industry needs to be involved:

- To make sure upcoming standards are in line with automotive requirements

Selected examples of what the automotive industry has influenced and accomplished in the standardization process so far:

- Agreement on the radio hardware according to automotive needs (one radio instead of three)
- Introduction of a Vehicle Link Layer to address specific automotive needs (geographic addressing, multihop-forwarding, security, channel switching, ….)
- Prevented the use of a probing mechanism
- Introduced the use of randomized MAC address for anonymity and privacy
- Identified ad-hoc trust or ad-hoc security problem for vehicular safety communication

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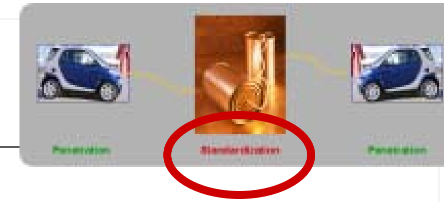
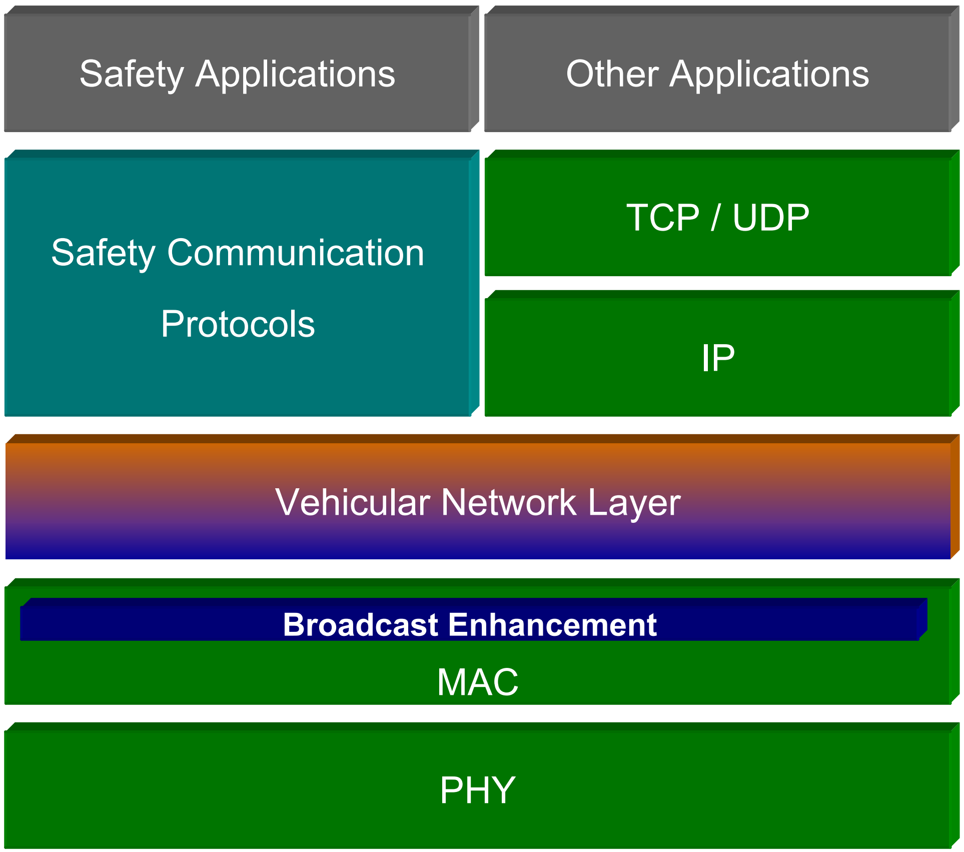


Standardization Example: Vehicle Link Layer



Note: The vehicular link layer is transparent if IP is used to talk with a standard AP

Safety Communication Protocols

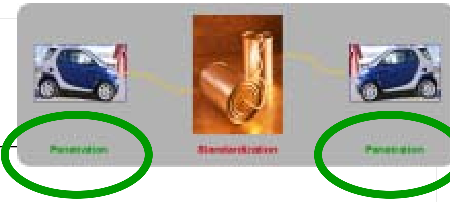
- Regulate multi-channel operations

Vehicular Network Layer

- Filters packets via Geo addresses
- Provides limited multi-hop forwarding and routing
- Maintains neighborhood table
- Monitors channel condition
- Decides transmission power and strategy (i.e. single or multi-hops)

MAC Enhancement

- Improves broadcast reliability efficiently using standard or slightly modified IEEE 802.11 MAC features
- Algorithms to handle priorities in one channel



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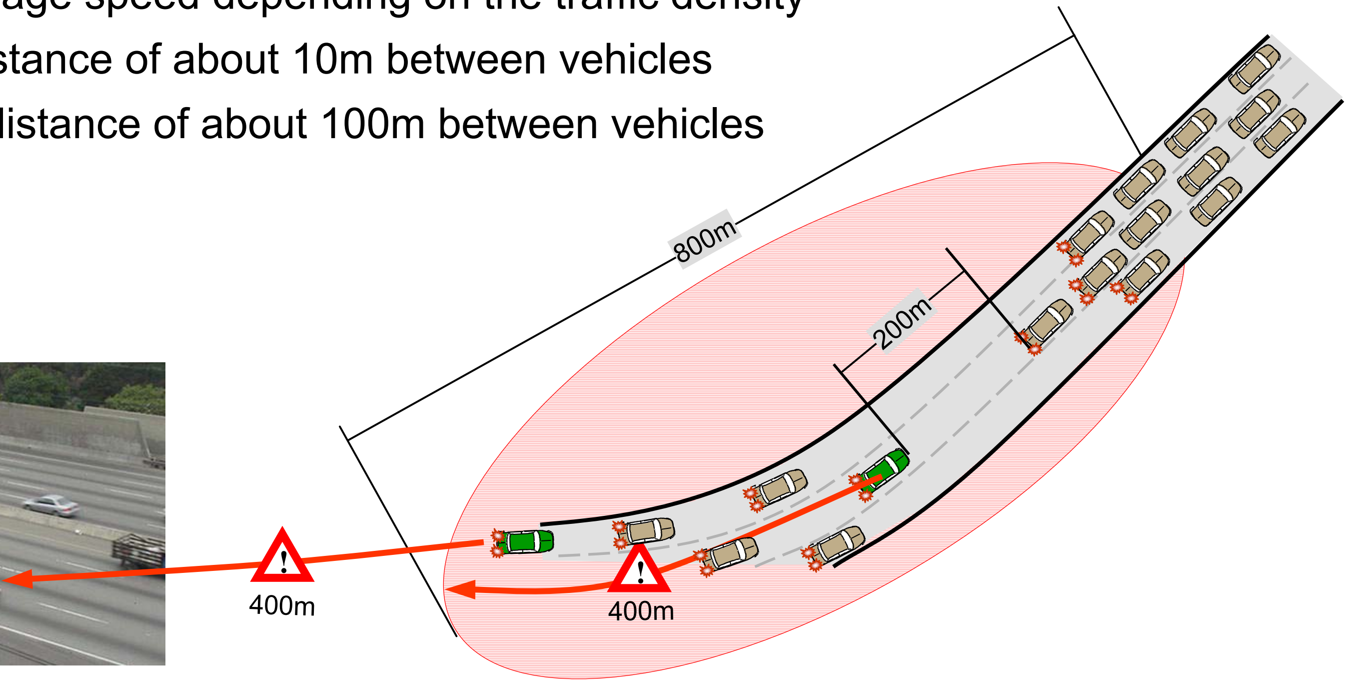
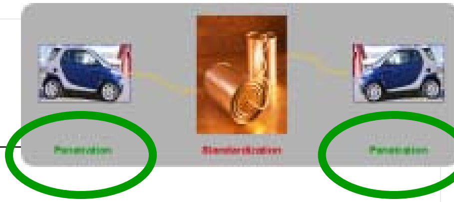
Penetration: Calculation based on the Example of Hazard Warning

To have a benefit (initial effectiveness) at least one car needs to receive a message within the downstream communication range, before this car itself can detect the incident.

Assumptions:

- Communication range: 400m
- Repetition: Every 200 ms for 10 times
- We assume an average speed depending on the traffic density
  - Jammed traffic: distance of about 10m between vehicles
  - Very Light traffic: distance of about 100m between vehicles





Penetration: Initial Effectiveness

Required penetration rate for initial effectiveness is equal to the probability of having at least one sender and one receiver within the communication range. That means if a vehicle is equipped with a communication unit, the following table shows the required penetration rate so that for the given scenario another vehicle will receive the warning message.

Traffic load		Two lanes	Three lanes	Four lanes
Very Light	Minimum average distance between vehicles: 100m	5.0%	3.3%	2.5%
Light	Minimum average distance between vehicles: 50m	2.4%	1.6%	1.2%
At capacity	Minimum average distance between vehicles: 30m	1.4%	0.9%	0.7%
Jammed	Minimum average distance between vehicles: 10m	0.5%	0.3%	0.2%

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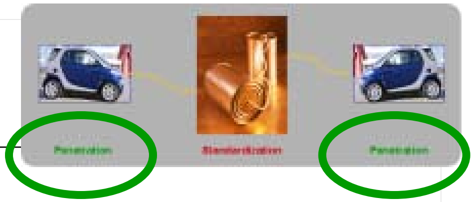
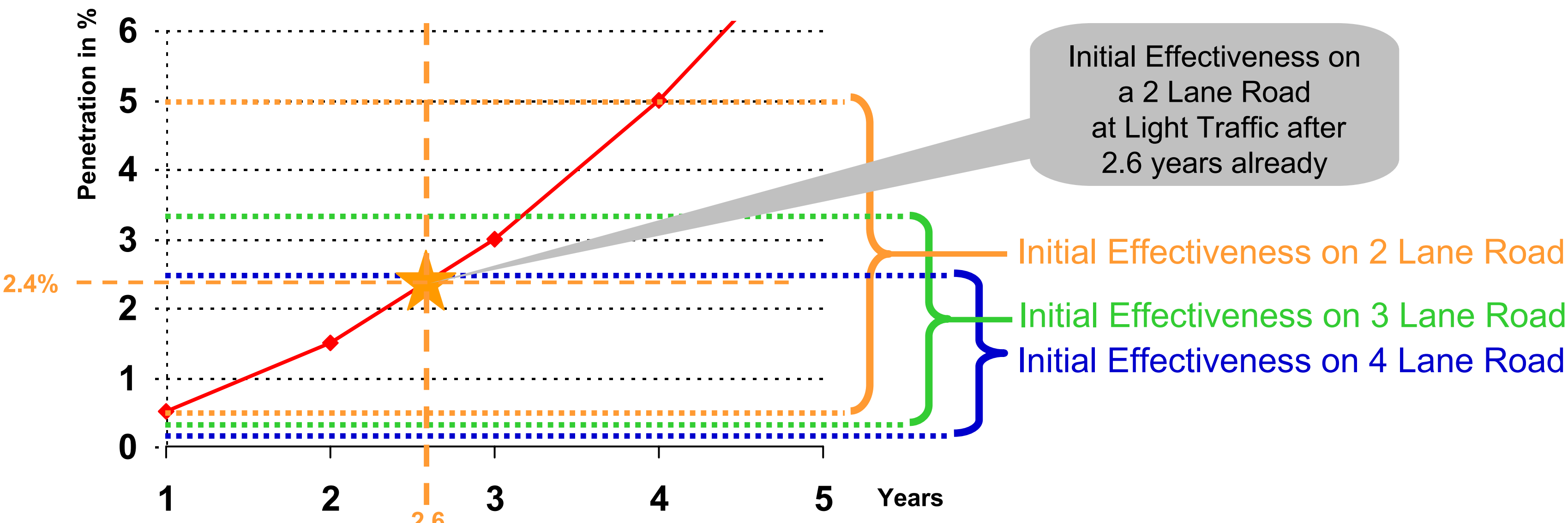


Penetration: Calculation Example

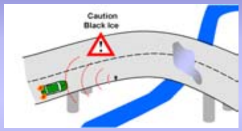
New vehicles per year (typical, U.S. and Germany)	8% of total cars				
	Year 1	Year 2	Year 3	Year 4	Year 5
Estimated Navigation Units install rate on new vehicles	6%	12%	18%	24%	30%
Navigation units installed in year X (Cumulative)	0.5%	1.5%	3%	5%	7.5%
Penetration required for initial effectiveness	0.2% - 5.0%				



Deployment Roadmap

2006

Standards complete
Base technology available



2009

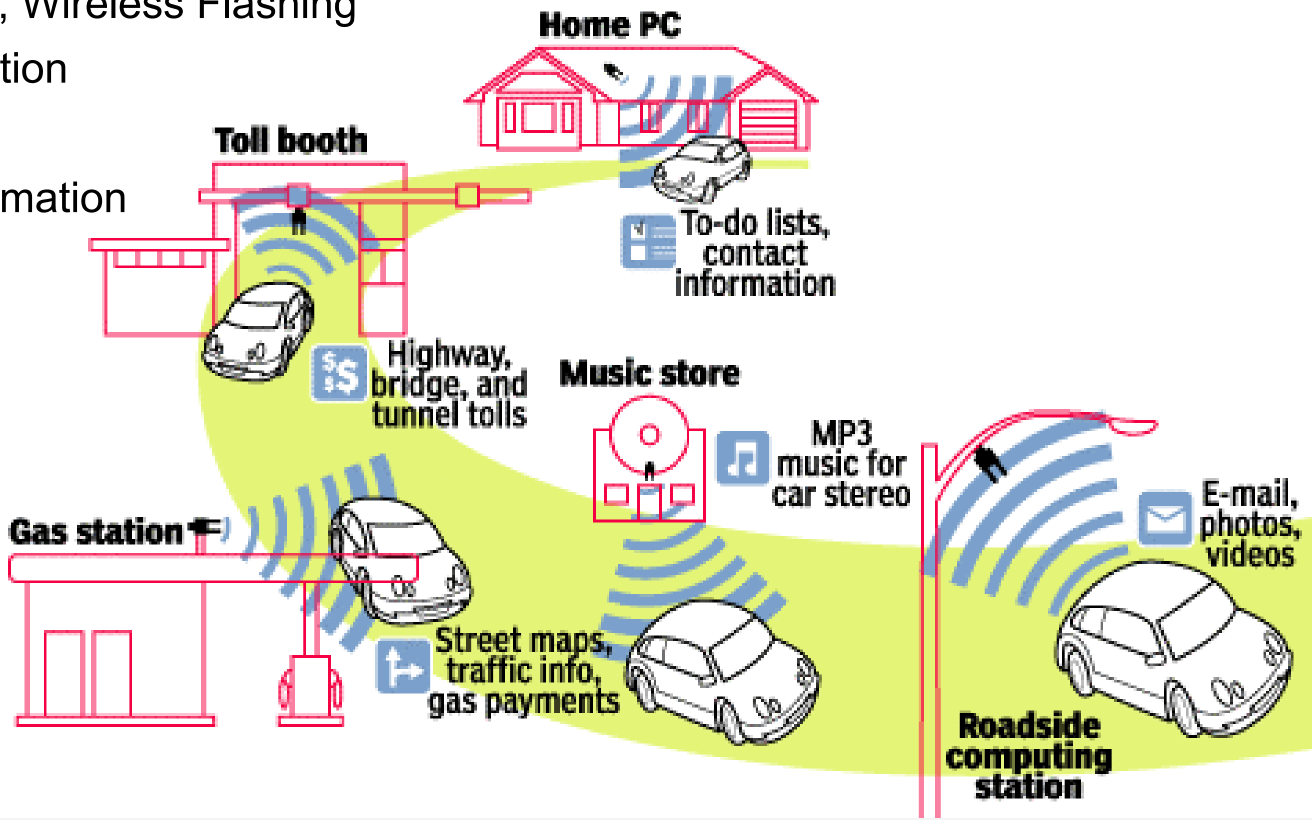
Single-vehicle applications

2012

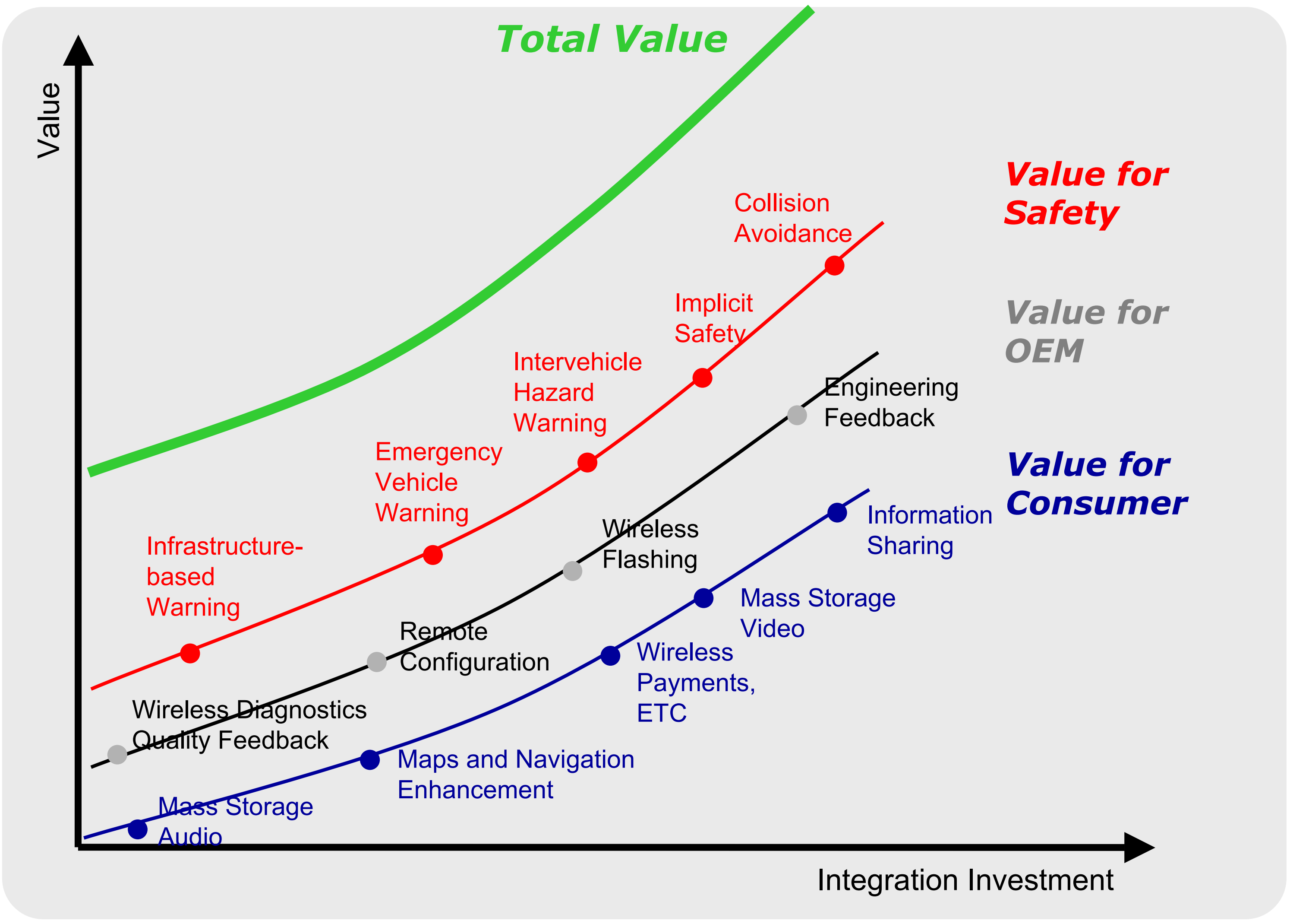
Multi-vehicle safety applications

Single-Vehicle Applications

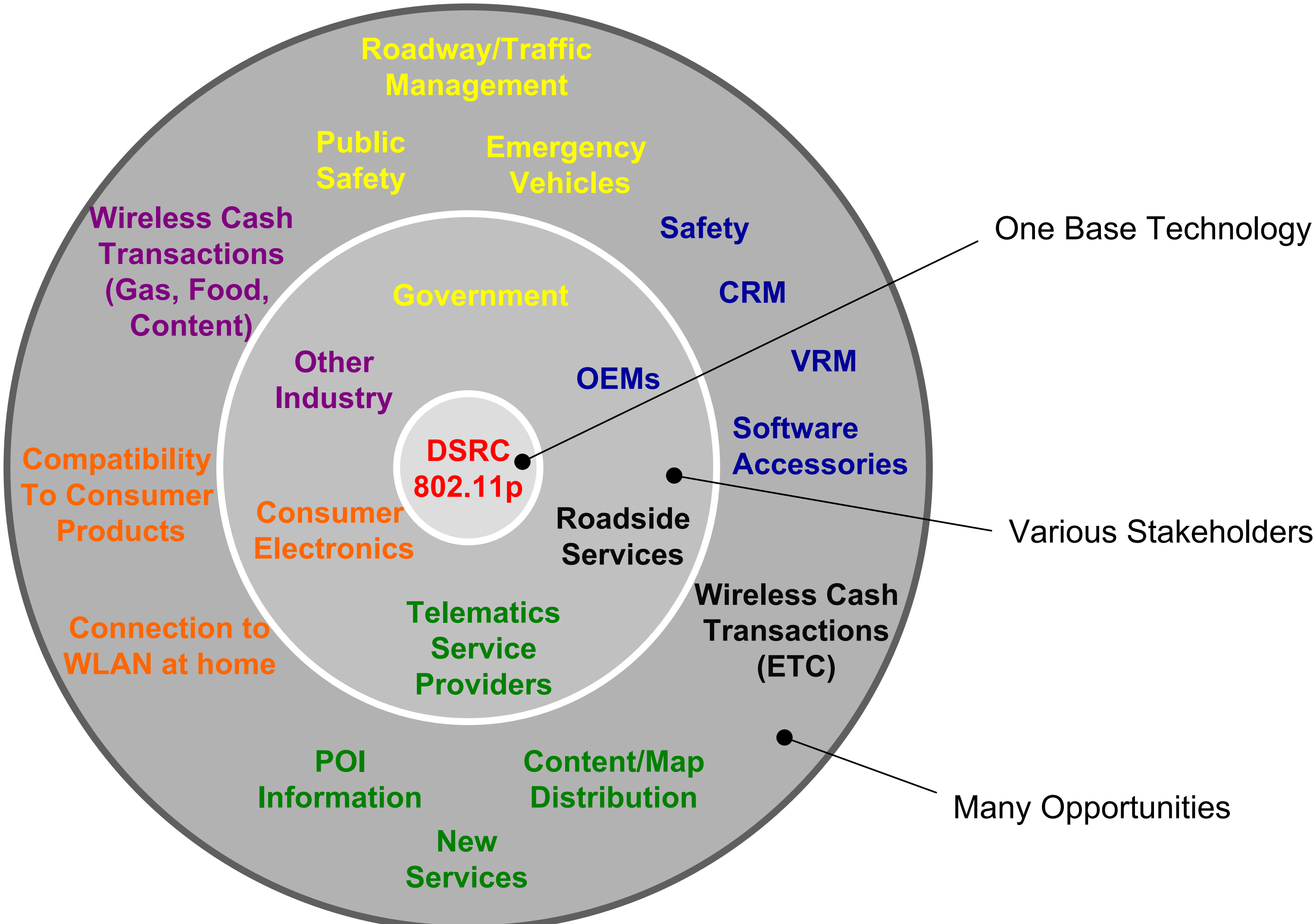
- If a short range communication device is installed on the vehicle, the following single-vehicle applications could be available to the customer at almost no extra cost:
  - Infrastructure-based warning (Traffic Lights, Traffic Signs, Curves, …)
  - Drive-through payments (gas station, parking garages, fast food, …)
  - Wireless Diagnostics, Wireless Flashing
  - Electronic Toll Collection
  - Digital Entertainment
  - Point of Interest Information
  - Digital Map updates
  - Traffic updates
  - Etc.



Value Generation of Communication-based Applications



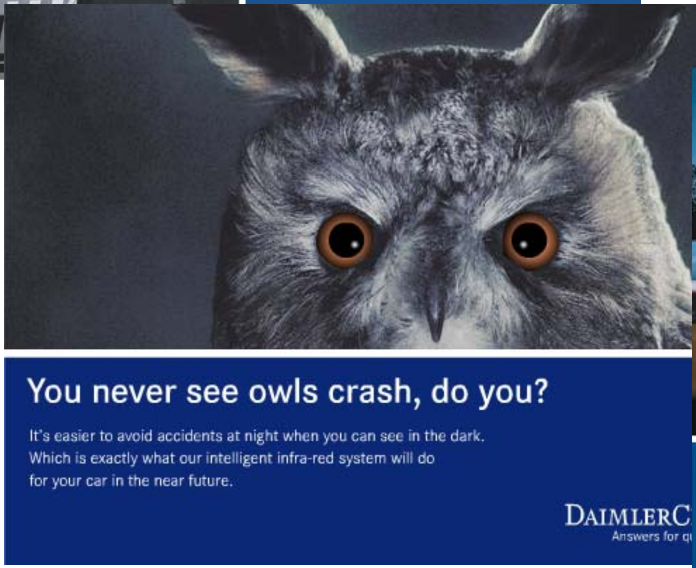
Many Opportunities – One Single Base-Technology



Summary and Conclusion

- Communication has offered many new opportunities for the automotive industry
- Cellular technology will continue to evolve, a flexibility communication architecture is required to keep up with the innovations
- Bluetooth gaining acceptance as the standard “cable replacement” technology
- Wireless LAN technology is currently the clear winner in the communication industry and is starting to penetrate into the consumer electronics and entertainment space
- It is inevitable that WLAN technology will also appear in the automobile
- The next generation of active safety systems will require additional sensor such as communication and efforts to re-use WLAN technology for this purpose are already well underway:
- Examples of open research issues include: security mechanisms, protocol stack and architecture design, message set definition, power level and scalability analysis, antenna design and vehicle integration
- Government, Academia and Industry are working on solving those issues

Safety as a DaimlerChrysler Goal



Thank You!