A Tutorial on Vehicular Networks

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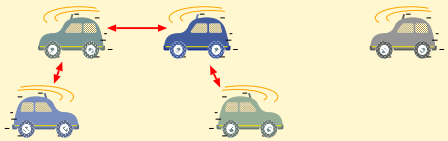
Agenda

Outlines



Outlines

Vehicular Networks: Introduction

Intelligent Transportation Systems

- Intended to improve the transportation in terms of safety and efficiency
  mobility, ressource usage, productivity...
  impact on the environment...

Save lives,

- Encompass a broad range of sciences and technologies: mechanics, automatic control, electronic, signal, networking, computer science...
  integrated in the transportation system's infrastructure as well as in vehicles themselves

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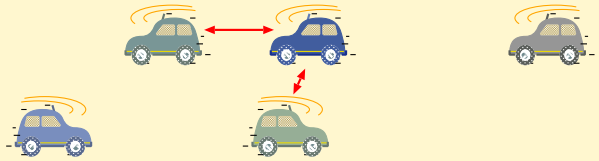
Vehicular Networks: Introduction

ITS and networking

- ITS development rely mainly on communication networks:
  - vehicle-to-infrastructure (V2I)
  - infrastructure-to-vehicle (I2V)
  - vehicle-to-vehicle (V2V or C2C)
    vehicular ad hoc networks (VANET)
- Ad hoc network: no infrastructure



The term Vanet sometimes includes the infrastructure as well depending on the authors

- Vehicular networks:
  new interesting research problems

Vehicular Networks: Introduction

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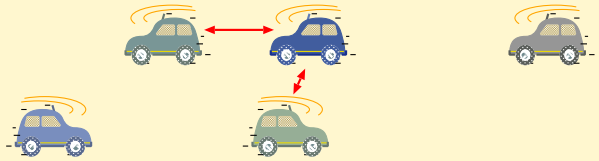

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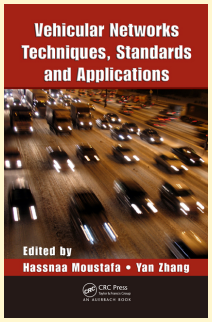
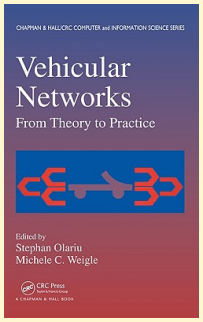
Vehicular Networks: Introduction

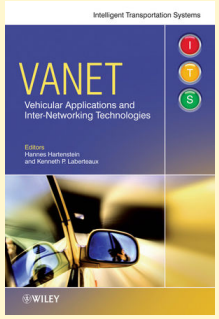
Research field

- Well identified research field
- Conferences:
  - Workshops
  - Topics in CFP of networking conferences
  - ACM International Workshop on VehiculAr Inter-NETworking (VANET)
  - IEEE Vehicular Networking Conference (VNC)
  - IEEE Conference on Intelligent Transportation Systems (ITSC)

- Books:







Outlines

Introduction

UTC/Heudiasyc Team

- Université de Technologie de Compiègne
  ∼4500 students, master degree (engineer diploma), PhD
  http://www.utc.fr
  - one of the first French engineering school for computer science
  - close to Paris and Charles de Gaulle airport

- Heudiasyc Lab. from the UTC & CNRS
  Automatic, Computer Science, Networking, Knowledge...
  http://www.hds.utc.fr
  Equipex Robotex, Labex MS2T

- Intelligent vehicles team
  several equipped cars
- Vehicular networks team

Introduction

Some of the UTC/Heudiasyc projects

- Road anticipating
  Regional grant DIVA, Heudiasyc - CREA 2004-2007
- Network services for com. between mobiles objects
  Industrial grant FTR&D 2004-2008
- Co-operative Systems for Road Safety
  "Smart Vehicles on Smart Roads"
  IP SafeSPOT, 6th PCRD / IST / eSafety 2006-2010
- Distributed applications for dynamic networks
  Regional grant Heudiasyc - LaRIA 2007-2010
- Data gathering from VANET to infrastructure
  Industrial grant FTR&D 2008-2010
- Distributed system for vehicle dynamic evaluation
  Regional grant Heudiasyc - MIS 2008-2011
- Inter-vehicles cooperative perception for road safety
  National project ANR JC, (Heudiasyc) 2008-2011

Introduction

Some of the UTC/Heudiasyc contributions

- Performances in a convoy of vehicles [VTC 2011]
- Vehicular networks emulation [ICCCN 2010]
- Distributed dynamic group service [SPAA 2010]
- V2I architecture [Mobiwac 2010]
- Simulation of vehicular networks [VTC 2010]
- Road experiments [VTC 2009]
- Messages forwarding [IEEE TVT 2007]
  conditional transmissions
- IEEE 802.11 fairness [MedHocNet 2006]
- Capacity of vehicular networks [VTC 2005]

Introduction

UTC/Heudiasyc contributions validation

- By proofs
  - for distributed algorithms
  - require com. and synchronization models
- By simulations ⇝ Airplug-ns
  - for networking protocols
  - require propagation and MAC model, packets traffic and node mobility model
- By experiments ⇝ Airplug-live
  - for proof of concept and perf. measuring *in situ*
  - require equipments and logistic
- By emulation ⇝ Airplug-emu
  - between analytical studies and experiments
  - require valid emulation of low layers
- The Airplug Software Distribution
  - Programs and libraries for comprehensive studies
  - Many prototypes for protocols and applications

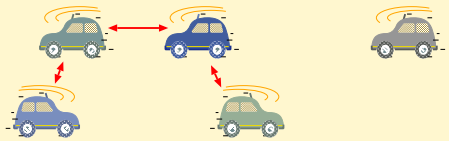
http://www.hds.utc.fr/airplug

Outlines

Tutorial outlines

- Overview of Vehicular Networks
  - ITS motivations
    Intelligent Transportation Systems
  - ITS applications
  - Work in Progress
  - Vehicular networks research issues
- A Challenging Network
  - Time Constraints in vehicular networks
  - Measures from road tests
  - Communication Protocols
- Vehicular Networks HowTo
  - Designing rules for new protocols
  - Examples of design
  - Validating new protocols
  - The Airplug Software Distribution
- Conclusion

Outlines

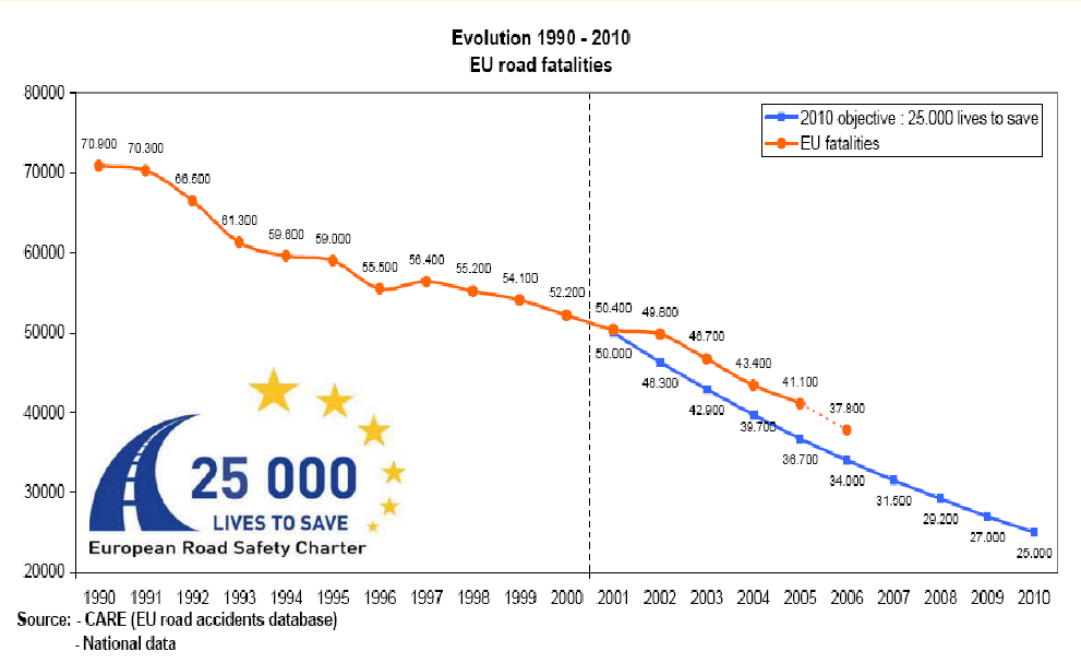


Outlines

Intelligent Transportation Systems

Motivations: Road safety

- $\approx 40,000$ deaths per year in USA
  $\rightsquigarrow$ initiatives from Department of Transport (DoT) to reduce the fatalities on roads
  [http://www.its.dot.gov/its_overview.htm]
- Similar objectives in Europe
  $\rightsquigarrow$ large ITS projects launched
  [The eSafety initiative http://www.esafetysupport.org/]



Intelligent Transportation Systems

Motivations: Resources

- Better resource management
  ⇝ transport productivity increases
  - infrastructure
  - car fleets
  - intermodal freight...
- Environmental preservation
  - better road management
    both by the infrastructure and the drivers
  - avoiding traffic congestion
  - optimizing the car speed
  - easing public transportation
    intermodality
  - organizing car sharing services...

Intelligent Transportation Systems

Motivations: New Business 1/2

- Consumers are more and more concerned by safety and environmental issues
  ⇝ all these services became marketing arguments for car manufacturers
- Some of the ITS applications are studied by car manufacturers to propose well equipped vehicles
- A new business related to on board services is expected in few years

Intelligent Transportation Systems

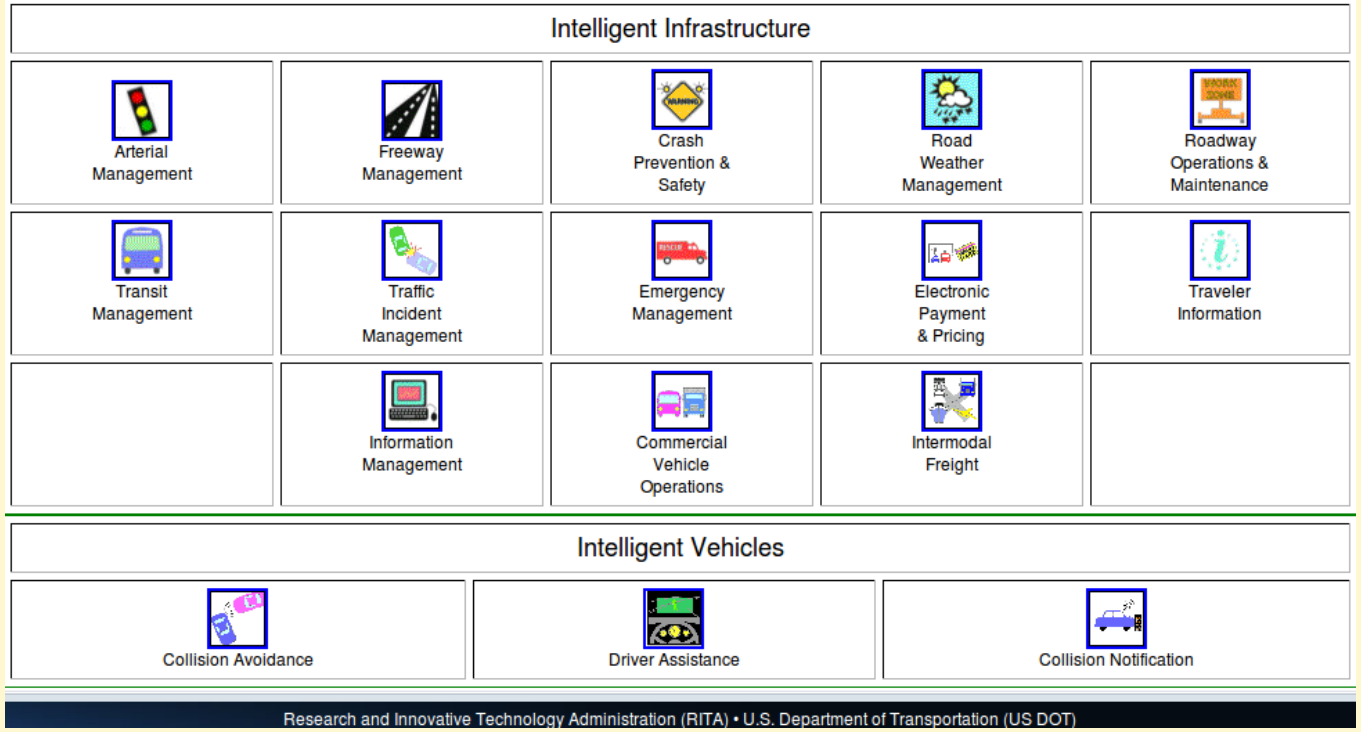
Motivations: New Business 2/2

- US Federal Communications Commission (FCC) allocated 75MHz of DSRC spectrum at 5.9 GHz for vehicular networks
  - public safety applications that save lives and improve vehicular traffic flow.
  - private services to lower the network deployment and maintenance costs to encourage DSRC development and adoption.
- Note: still some questions regarding the deployment

Outlines

Intelligent Transportation Systems

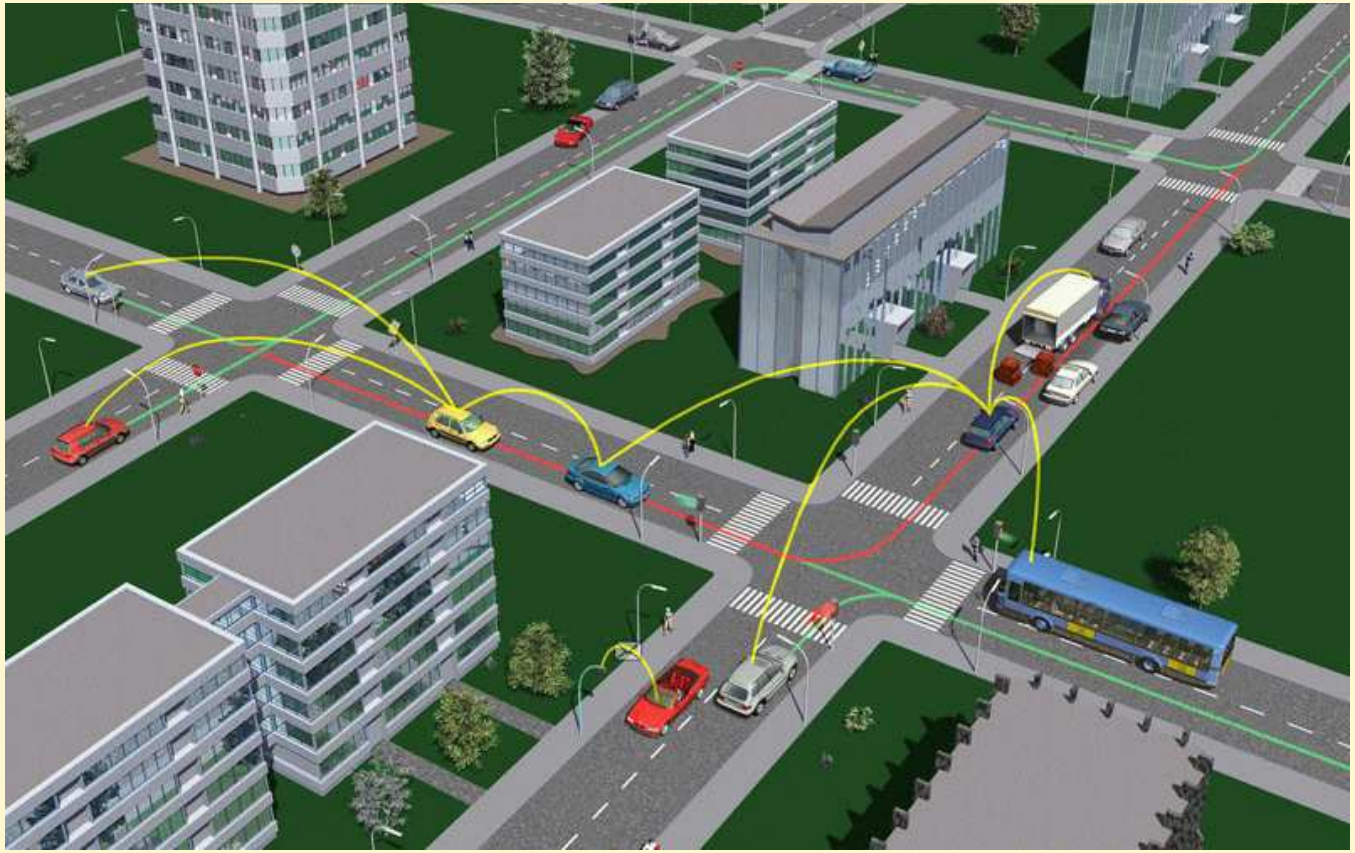
Applications: overview



[http://www.itsoverview.its.dot.gov/]

Intelligent Transportation Systems

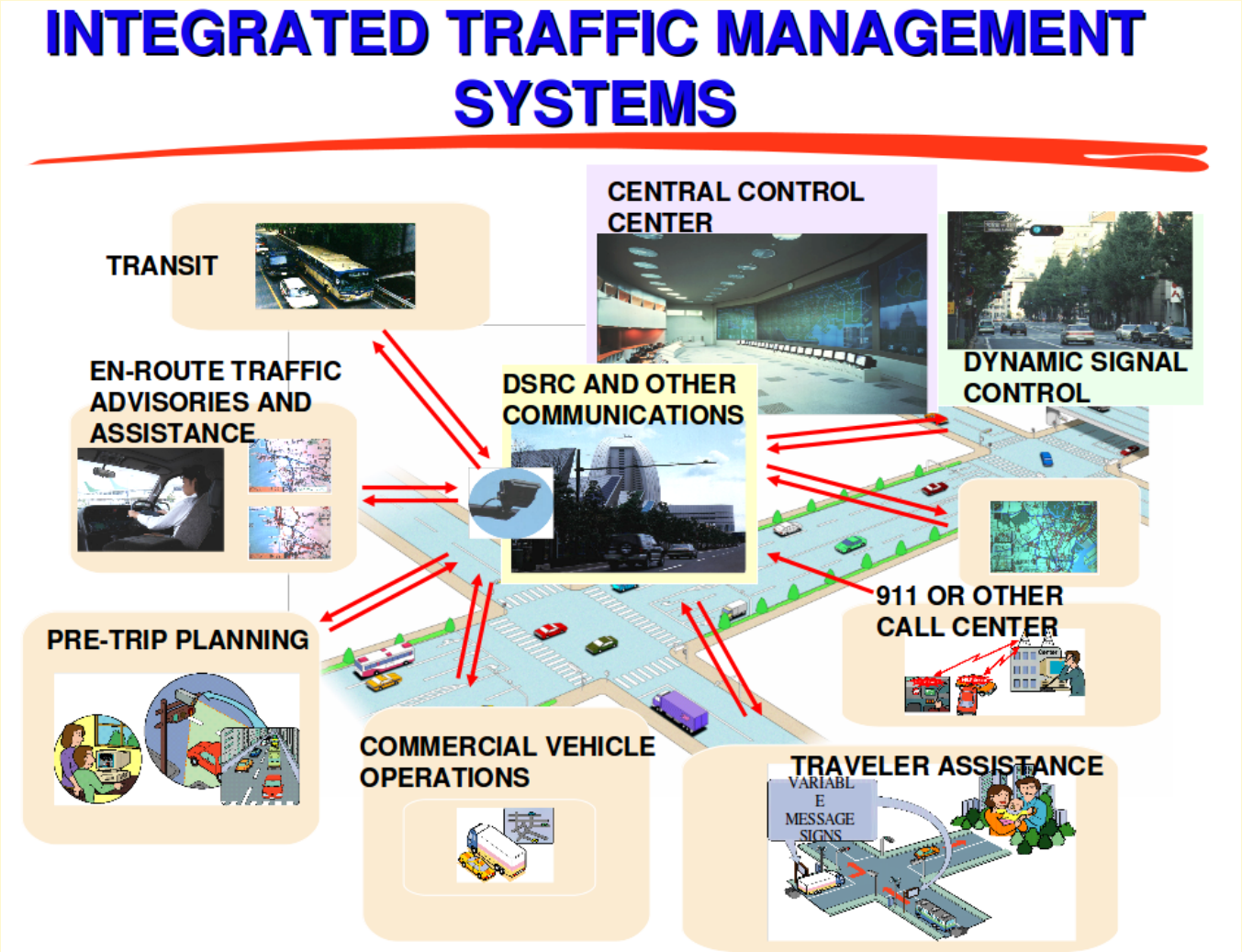
Applications: V2V in city



[C2C Communication Consortium http://www.car-to-car.org]

Intelligent Transportation Systems

Applications: infrastructure management



[L. Armstrong, “Classes of Applications”, 2002]

Intelligent Transportation Systems

Applications: Road safety improvement

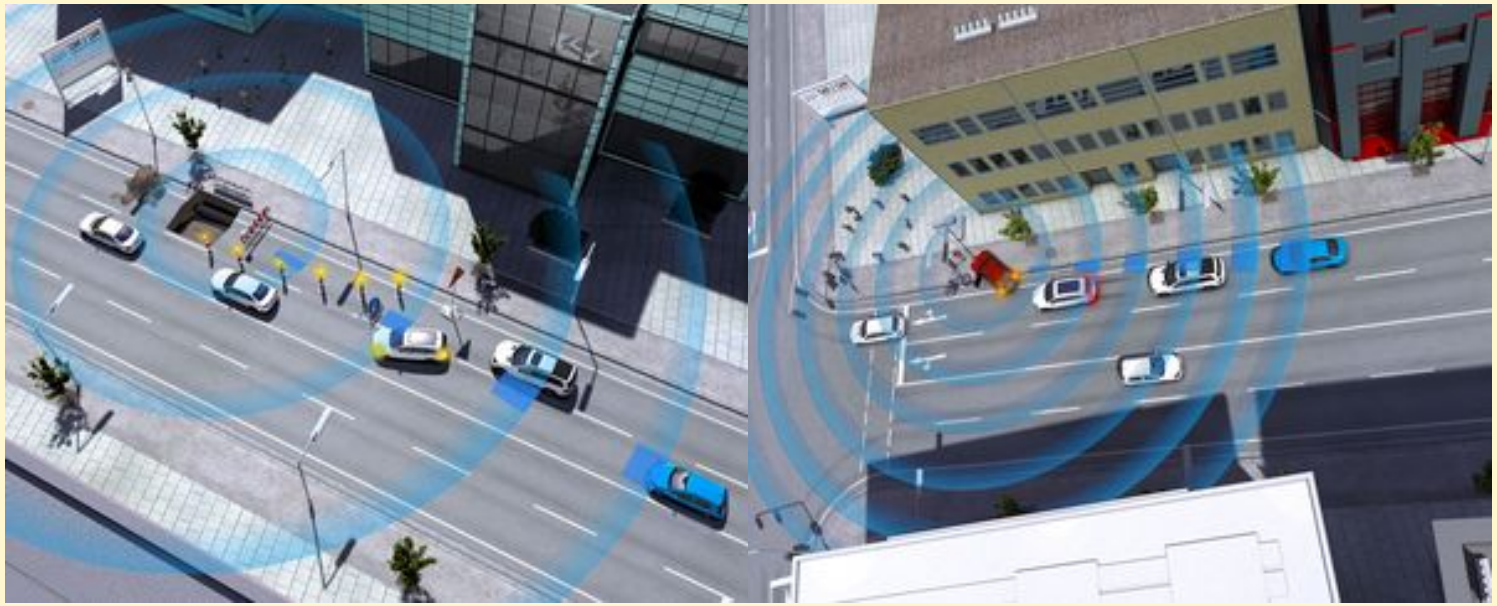
- Communication with emergency vehicles
- Motorcycle warning

[C2C Consortium, web ITS Croatia]

Intelligent Transportation Systems

Applications: Services for the driver

- Warning of roadworks
- Incident detection

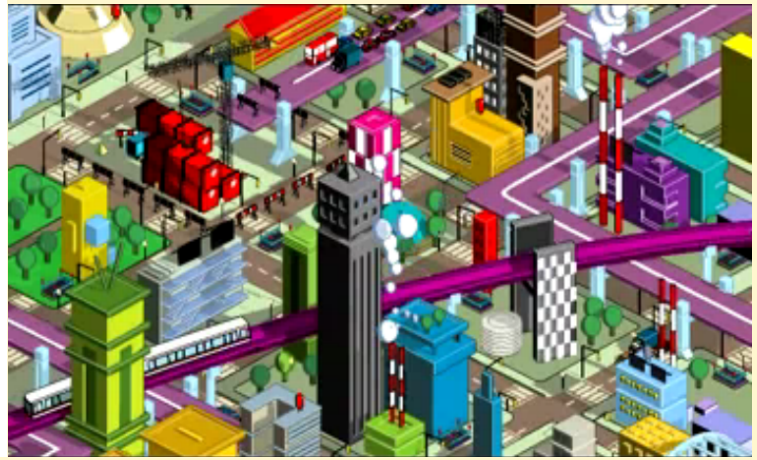


[C2C Consortium, web ITS Croatia]

Intelligent Transportation Systems

Applications: Services for travellers

- A day in the life of Eddie [Ertico]
- Intermodality, railways and cars [ITrans]



Intelligent Transportation Systems

Applications: infotainment 1/2

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Laura Parker
The Guardian, Thursday 17 January 2008
Article history

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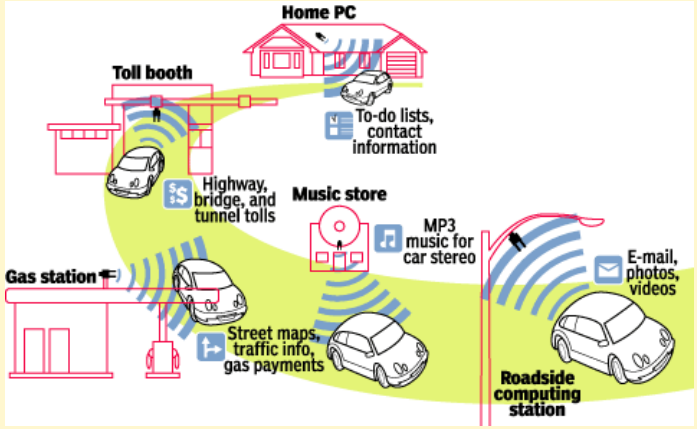
Intelligent Transportation Systems

Examples – Infotainment 2/2



- DaimlerChrysler DriveBy InfoFueling Car
  [http://www.pcmag.com/article2/0,2817,417233,00.asp]
- Demo at Fall Comdex trade show in Las Vegas
- 802.11b and next 802.11a (DSRC) with Atheros
- Shell Oil has partnered with IBM to build wireless hubs at its gas stations
  to pay for gas wirelessly and download information (maps, traffic information).

Intelligent Transportation Systems

Applications – Categorization

- Infrastructure oriented applications
  - optimizing their management
    transit management, freeway management, intermodal freight...
  - emergency organization...
- Vehicle oriented applications
  - for increasing the road safety
    incident management, crash prevention, collision avoidance, driver assistance...
  - for automatic/adaptive settings
- Driver oriented services
  - for improving the road usage
    traffic jam, road work information, traveler payment, ride duration estimate...
- Passengers oriented applications
  - for offering new services on board
    Internet access, distributed games, chats, tourist inf., city leisure inf., movies announces downloads

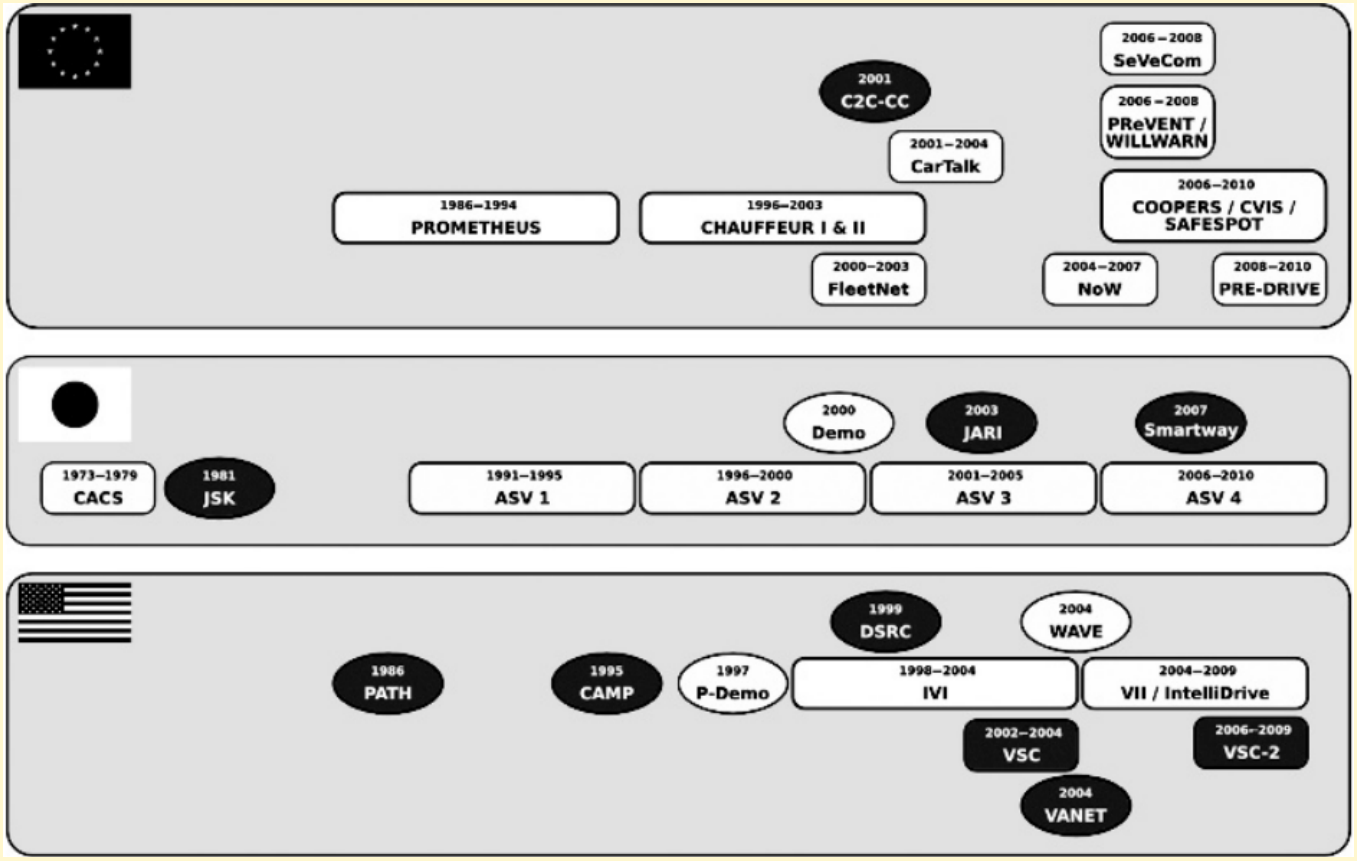
Outlines

2 Intelligent Transport System overview
- ITS Motivations
- ITS Applications
- Work-in-progress in Vehicular Networks
- Research issues

Work in progress

Projects overview

[H. Hartenstein, K.P. Laberteaux, Wiley]



ASV	Advanced Safety Vehicle Program	JARI	Japan Automobile Research Institute	Smart way	Smartway Public Road Test
CACS	Comprehensive Automobile Traffic Control System	JSK	Association of Electronic Technology for Automobile Traffic and Driving	VANET	ACM VANET Workshop
C2C-CC	Car-to-Car Communication Consortium	NoW	Networks on Wheels	VII	Vehicle Infrastructure Integration
CAMP	Crash Avoidance Metrics Partnership	PATH	California Partners for Advanced Transit and Highways	VSC	Vehicle Safety Communications Consortium
IVI	Intelligent Vehicle Initiative	P-Demo	PATH-Demo	VSC-2	Vehicle Safety Communications Two Consortium
				WAVE	Wireless Access in Vehicular Environments

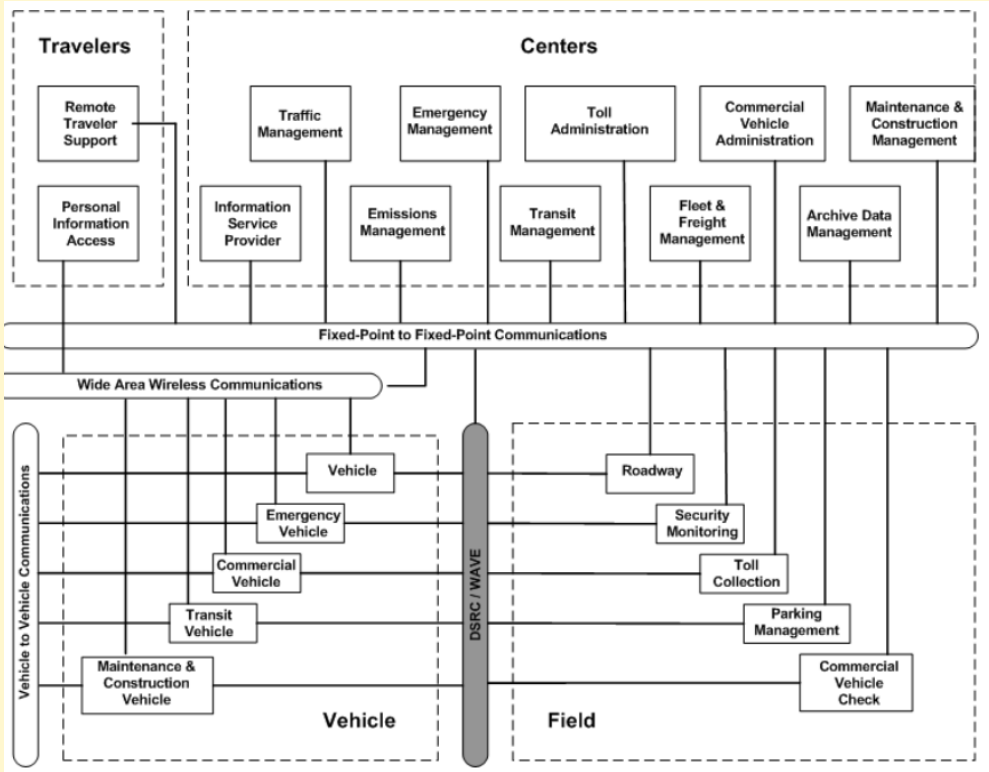
specific event e.g. demo, foundation

project / project period

Work in progress

Projects in USA 1/2

- The Intelligent Transportation System
  [http://www.its.dot.gov/its_overview.htm]
- The national ITS architecture
  functionnal architecture for the overall system
  [http://www.its.dot.gov/arch/index.htm]



[cited by IEEE draft standard 1609.0, 2009]

Work in progress

Project in USA 2/2

- Vehicle Safety Communications Project
  Goal: identifying intelligent safety applications enabled by DSRC
- The Cooperative Intersection Collision Avoidance Systems (CICAS) initiative
  Improving the road safety by enhancing driver decision-making at intersections
  [http://www.its.dot.gov/cicas/]
- Intellidrive [http://www.intellidriveusa.org]

Work in progress

Projects in Europe 1/2

- Major R&D projects supported by the EC
  - to constitute the basis of an European-wide intelligent transportation system
- The eSafety Forum
  - supported by the COMeSafety project
  - dedicated to the improvement of road safety using ITS [http://www.esafetysupport.org/]
- The Car-to-Car Communication Consortium (C2C-CC)
  - European car manufacturers and related industries + institutions [http://www.car-to-car.org]

Work in progress

Projects in Europe 2/2

- CVIS Cooperative Vehicle Infrastructure Systems [http://www.cvisproject.org/]
- SAFESPOT [http://www.safespot-eu.org/]
- COOPERS Cooperative Systems for Intelligent Road Safety [http://www.coopers-ip.eu/]
- PReVENT [http://www.prevent-ip.org/]
- GST Global System for Telematics [http://www.gstforum.org/]
- Sevecom security
- GeoNet IPv6 and geocast
- ...

Work in progress

Standardization efforts 1/4

- IEEE
  - Wireless Access in Vehicular Environments (WAVE)
  - IEEE 802.1p: extensions of the 802.11 protocols for ITS, based on DSRC
- ISO
  - CALM: Communication Architecture for Land Mobile
    previously *Continuous Air-Interface for Long and Medium range telecommunication*
  - ISO Technical Committee 204, Work Group 16
    ISO TC204 WG16
- IETF
  - extensions of IP: Mobile IP, IPv6, Nemo...
  - autoconfiguration in Manet
    Autoconf working group
    Manet: *Mobile Ad hoc NETwork*

Work in progress

Standardization efforts 2/4

- CEN (Comité Européen de Normalisation)
  - Intelligent Transport Systems Steering Group (ITSSG)
  - Road Transport and Traffic Telematics CEN/TC 278 [http://www.cen.eu]
- ETSI (European Telecom. Standards Institute)
  - Technical Committee on ITS ETSI TC ITS [http://www.etsi.org]

WG1	WG2	WG3	WG4	WG5
User Application Requirements	Architecture and Cross Layer	Transport and Network	Media and Medium related	Security

Work in progress

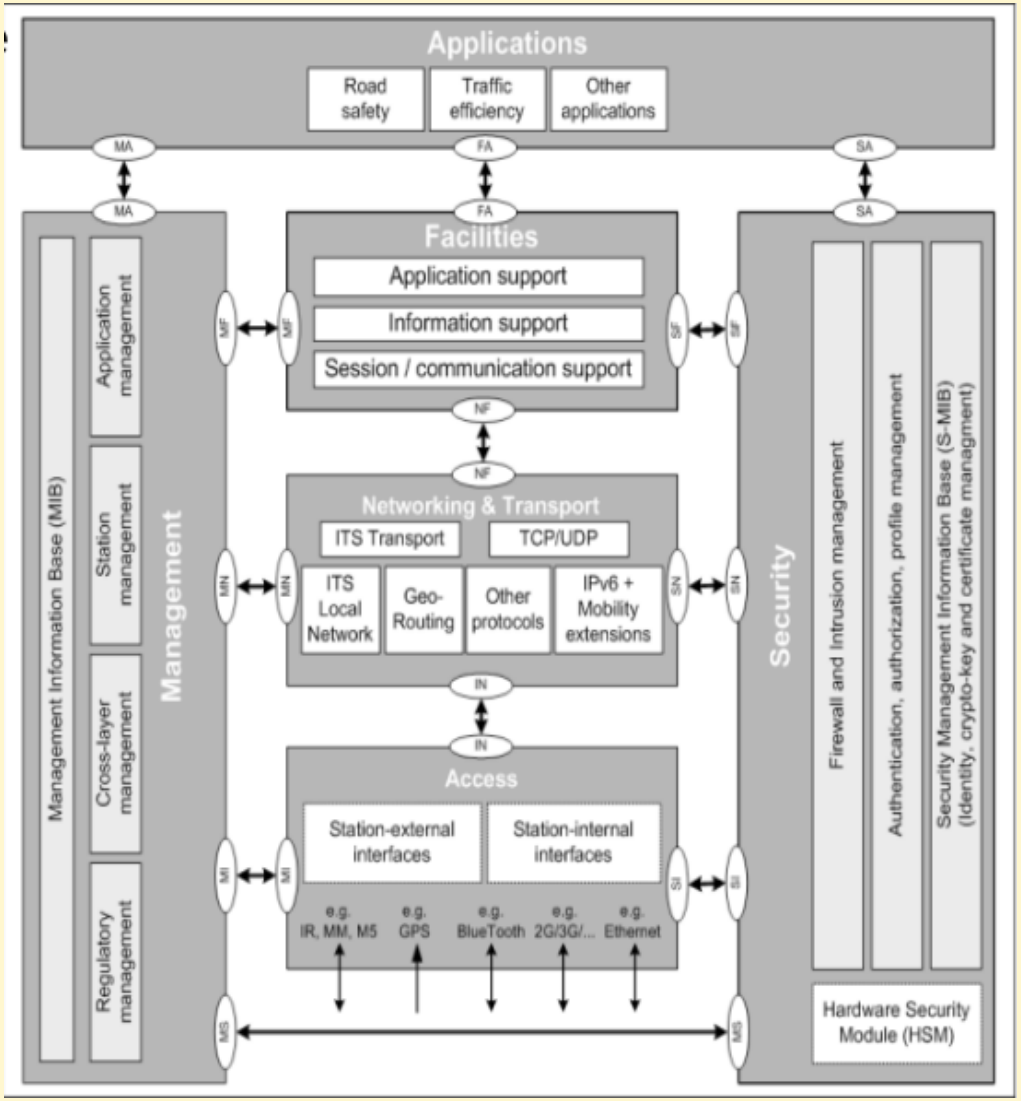
Standardization efforts 3/4

- C2C-CC (Car-to-Car Com. Consortium)
  - specifies and experiments vehicular communication
  - promotes the harmonization of vehicular communication standards worldwide [http://www.car-to-car.org]
- OMA (Open Mobile Alliance)
  - protocols for data management among mobile nodes
- OSGi (Open Services Gateway initiative)
  - Wire admin service: OSGi package for sensors inside vehicles
- ...

Work in progress

Standardization efforts 4/4

ISO/ETSI Reference Architecture [T. Ernst]



Outlines

Research issues

Technologies

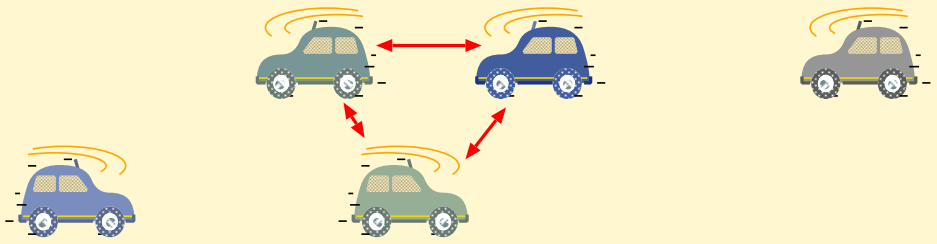
- ITS require a broad range of communications and electronics technologies
  both in the infrastructure and the vehicule
- Almost all ITS applications will rely on software embedded in the vehicles
- Many of them will require vehicular networks
- Terminology
  - ITS: Intelligent transportation systems
  - IVC: Inter-vehicular communication
  - MANET: Mobile ad-hoc network
  - VANET: Vehicular ad-hoc network
  - V2V: Vehicle-to-vehicle communication
  - V2I: Vehicle-to-infrastructure communication

Research issues

Dynamic ad hoc networks

- Unstable neighborhood
  - apparition/disappearance of nodes
  - large node mobility

  ⇝ highly unstable neighborhoods



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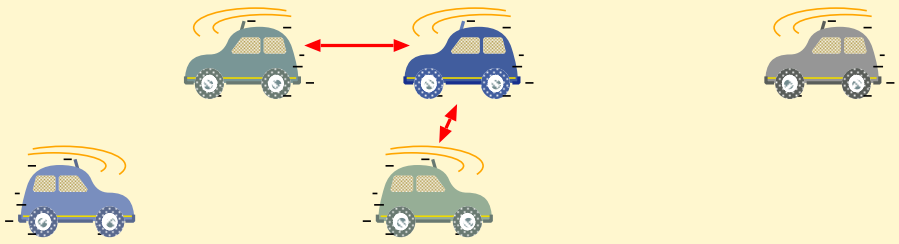

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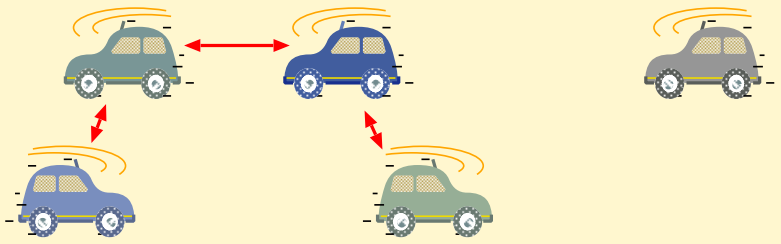

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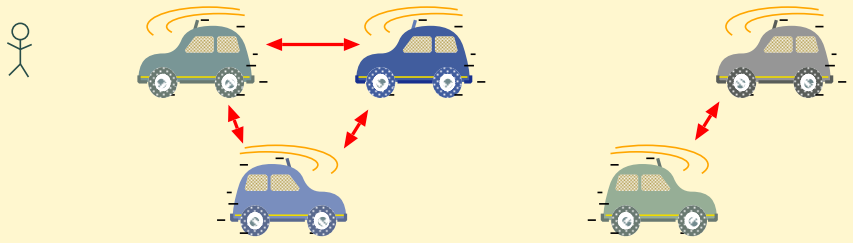

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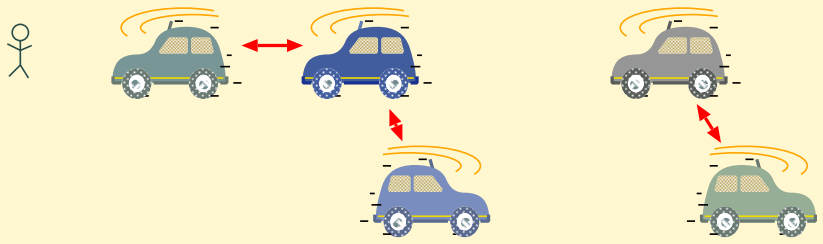

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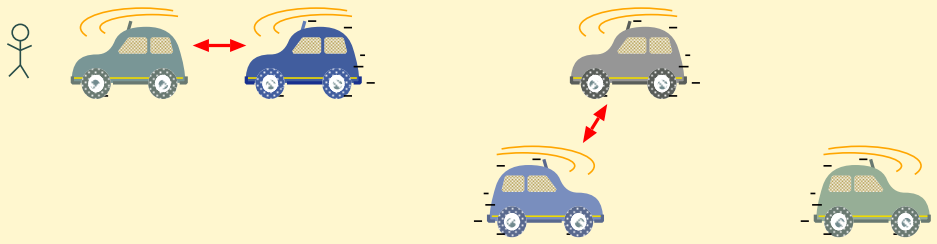
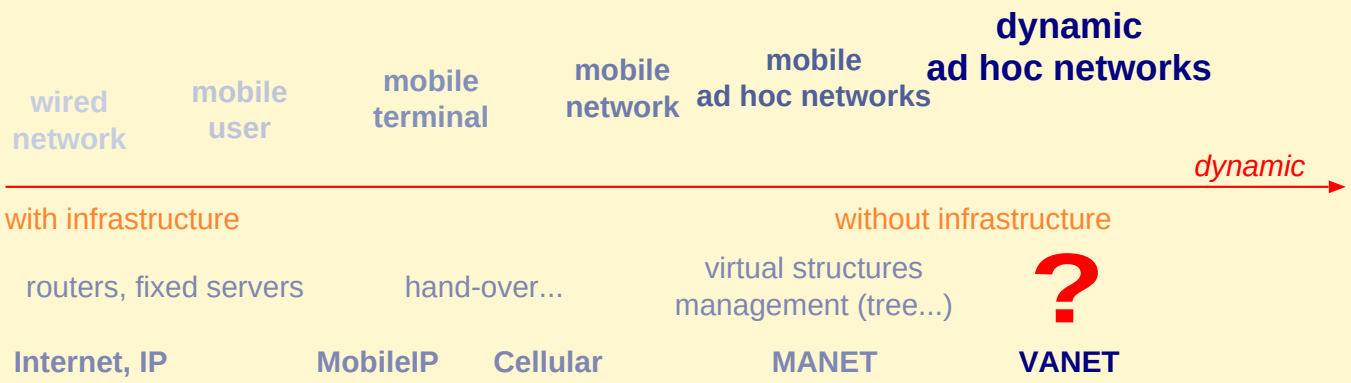


Research issues

Next step in networking?

- Wired networks — Internet core
- Partially wired networks — cellular networks
- Networks without infrastructure — MANET
- Highly dynamic ad hoc networks — VANET



Research issues

VANET characteristics

- A kind of dynamic networks
  VANET: Vehicular Ad hoc NETtwork
- Some mobility patterns can be identified
  Depending on the area, the time, the weather...
- Irregularity
  - of the dynamic
    in some cases, the network is not dynamic
  - of the road traffic
    depending on the area, time, weather...
  - of the architecture
    with or without infrastructure access
- Global knowledge assumed
  on-line or embedded
  not always!

Research issues

A summary

- Impact on network layers
  - physical layer
  - link layer
  - networking layer
  - transport layer
- Impact on the applications
  - robustness, fault tolerance
  - data sharing schemes
  - how to build applications
  - well known basic problems still have sense?
- Impact on trusty and security
  - who believe?
  - what information is reliable?
  - sensible applications!
- Algorithms necessary embedded
  - online optimizations required
  - adaptive algorithms
  - context aware optimizations

Outlines

Outlines

Time constraints

Safety application

According to the Car-to-Car Consortium, applications can be sorted into:

[C2C Manifesto 2007]

- Safety applications
  - Cooperative Forward Collision Warning
  - Pre-crash sensing/warning
  - Hazardous Location V2V Notification
- Efficiency applications
  - Enhanced Route Guidance and Navigation
  - Green Light Optimal Speed Advisory
  - V2V Merging Assistance
- Infotainment
  - Internet Access in Vehicle
  - Point of Interest Notification
  - Remote Diagnostics

Time constraints

Safety application

Large study by the
US Vehicle Safety Communication consortium

[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]
National Highway Traffic Safety Administration

- List of potential safety related applications
- Summary of crash types and causal factors
- Estimation of the applications ability to reduce vehicle crashes and functional years lost
- Ranking based on their potential safety benefits and when they may become feasible
  technical feasibility, stringency of system/communications requirements, economic viability, estimated market penetration, estimated effectiveness...
- Analysis of best applications

Time constraints

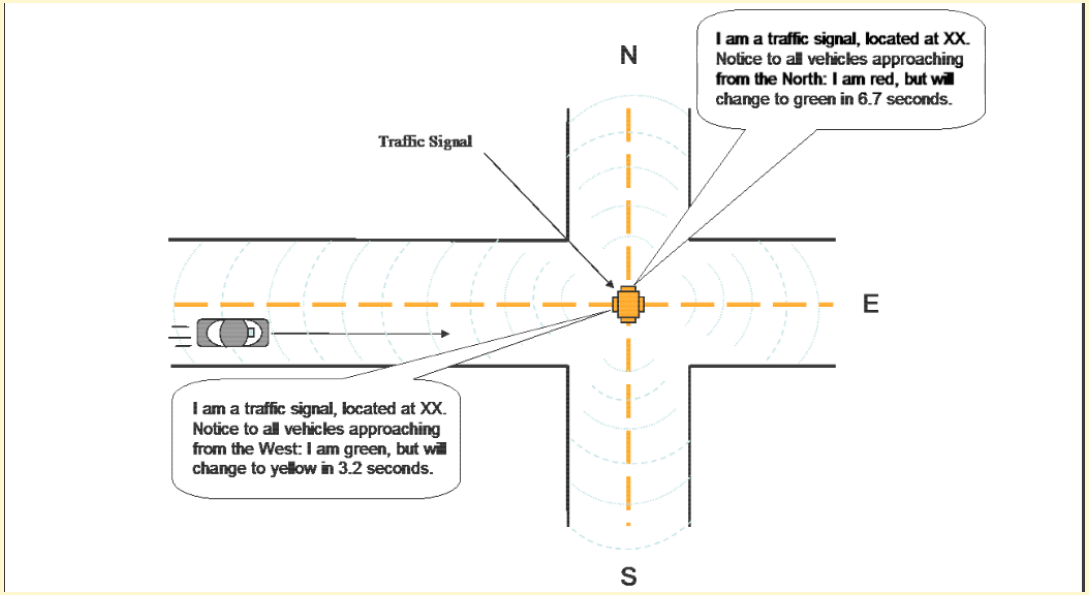
Traffic signal violation warning application

- Traffic signal violation warning
  Warn the driver to stop at the legally prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation

Communication	Freq.	Lat.	Range	Data
I2V, one-way, one-to-many, periodic	10 Hz	100 ms	250 m	traffic signal status, timing, directionality, position of the stopping location, weather condition, road surface type

Time constraints

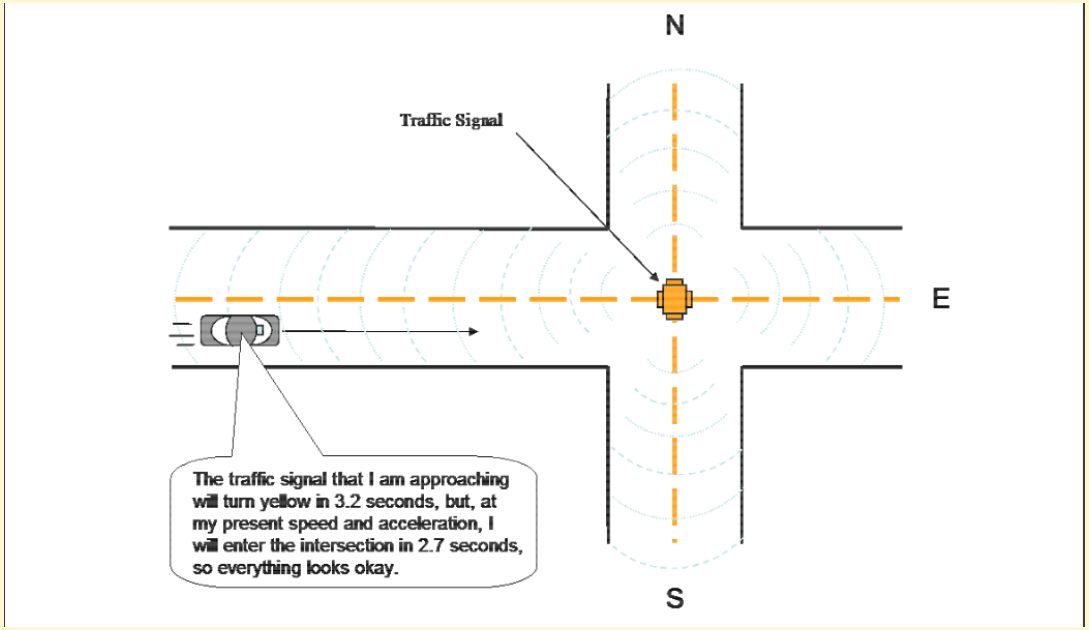
Traffic signal violation warning application



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

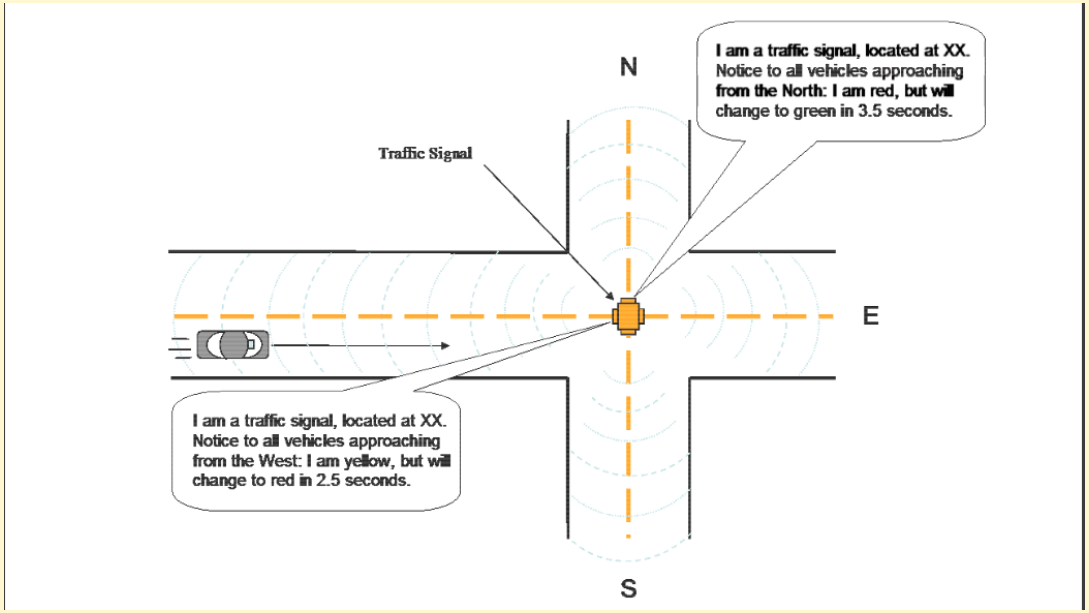
Traffic signal violation warning application



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

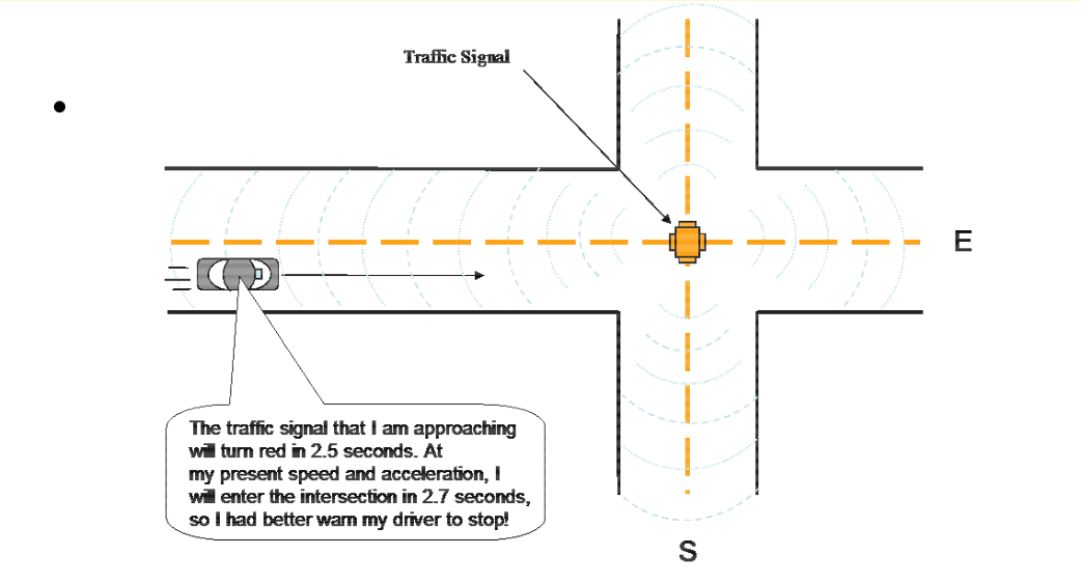
Traffic signal violation warning application



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

Traffic signal violation warning application



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

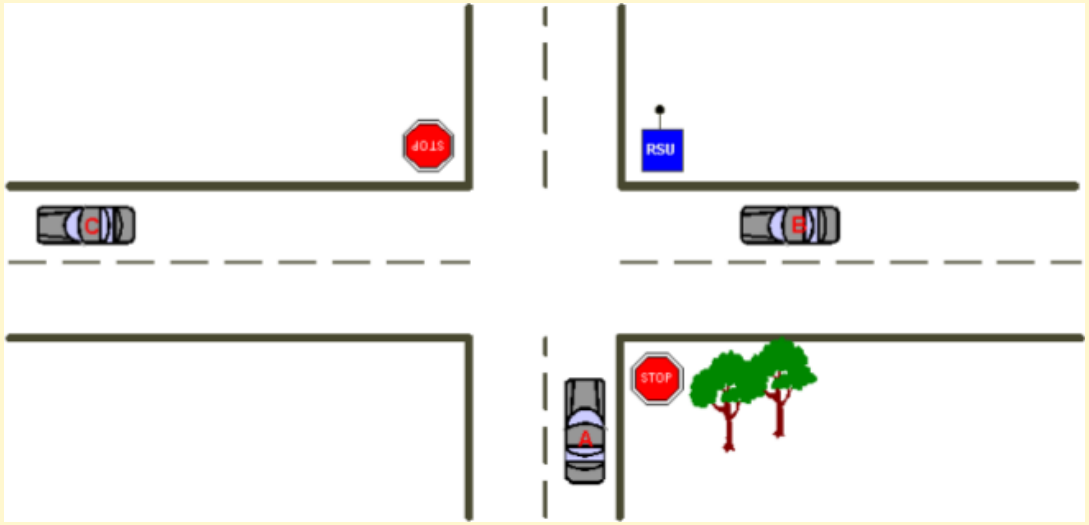
Stop sign movement assistance application

- Stop sign movement assistance
  Provides a warning to a vehicle that is about to cross through an intersection after having stopped at a stop sign in case a collision may occur due to traffic approaching the intersection.

Communication	Freq.	Lat.	Range	Data
V2I and I2V, one-way, one-to-many, periodic	10 Hz	100 ms	300 m	vehicle position, velocity, heading

Time constraints

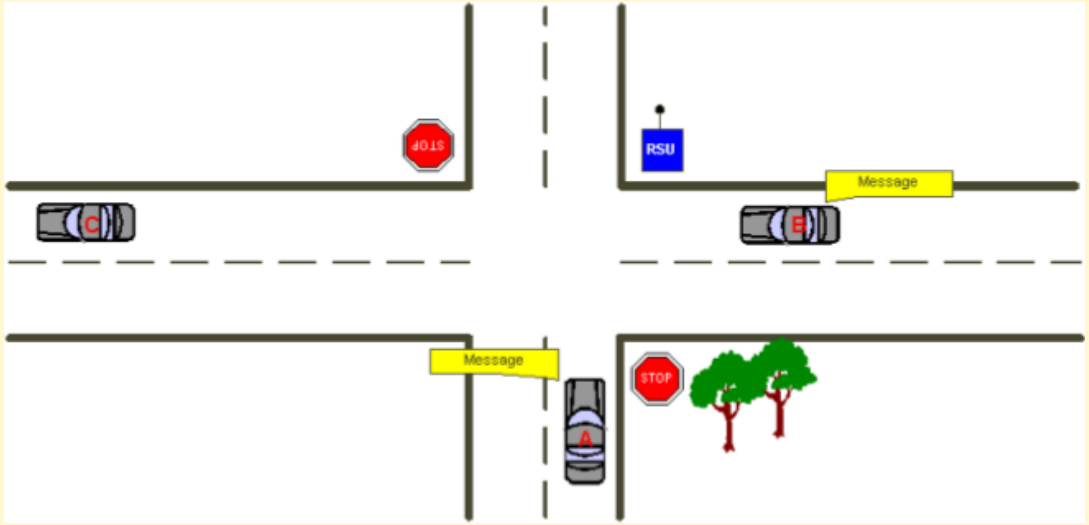
Stop sign movement assistance application 2/2



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

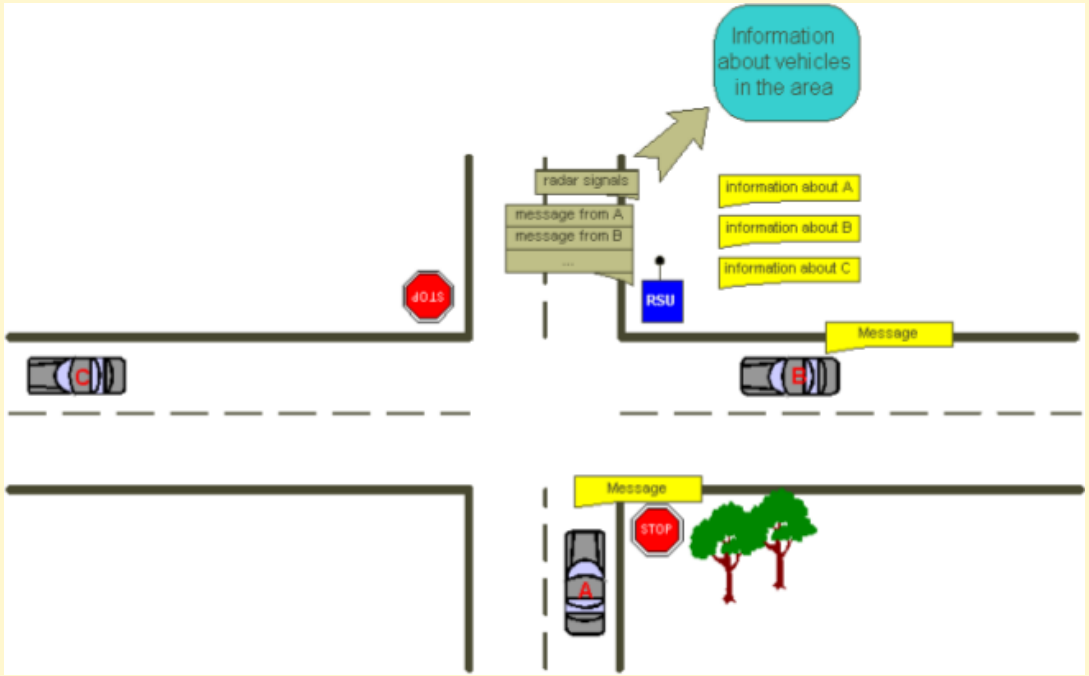
Stop sign movement assistance application 2/2



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

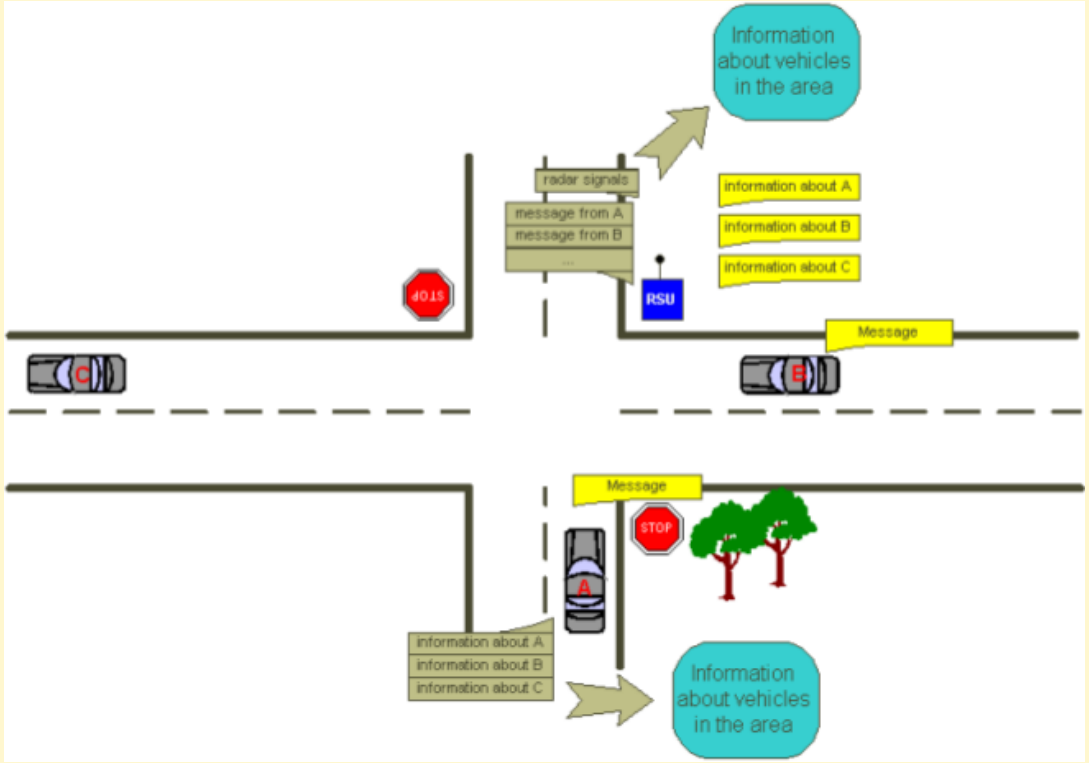
Stop sign movement assistance application 2/2



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

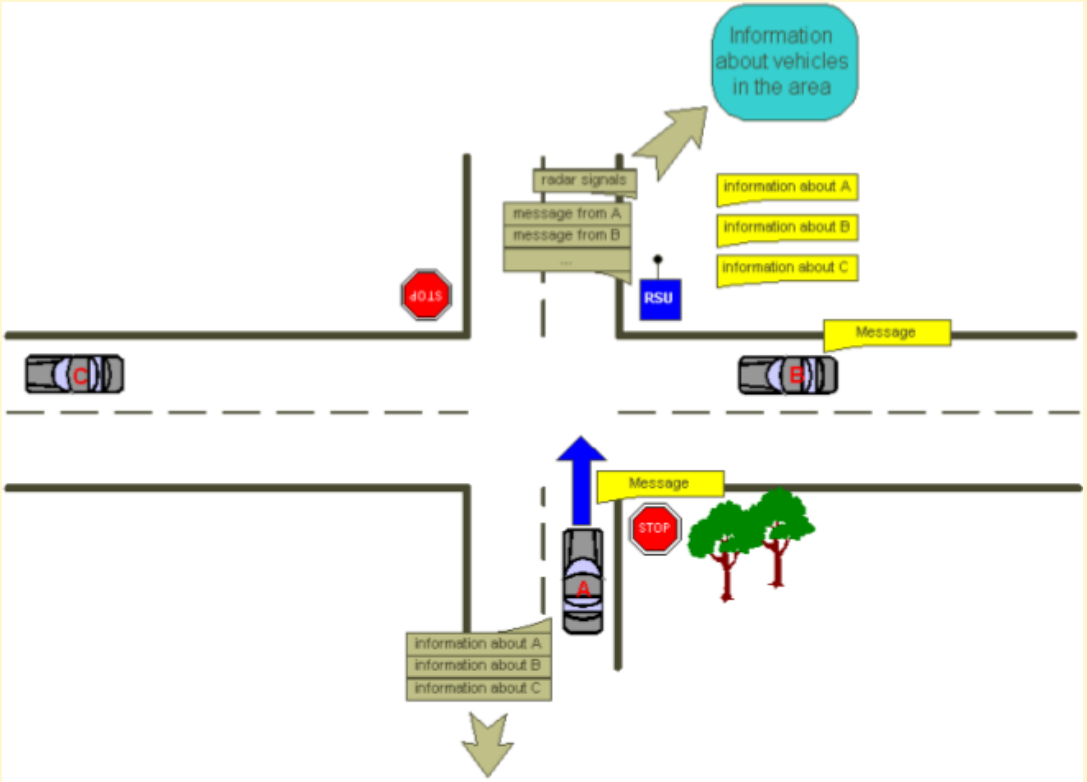
Stop sign movement assistance application 2/2



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

Stop sign movement assistance application 2/2



Vehicle	Velocity	Accel	Projected position	Time stamp	Distance	Time to expire	Relative position
B	60	1	Xx:xx:xx ; xx:xx:xx	Hh:mm:ss.ss	10	3	45
C	62	0	Yy:yy:yy yy:yy:yy	Hh:mm:ss.ss	45	2	300
...	...	...	...	...	...	...	...

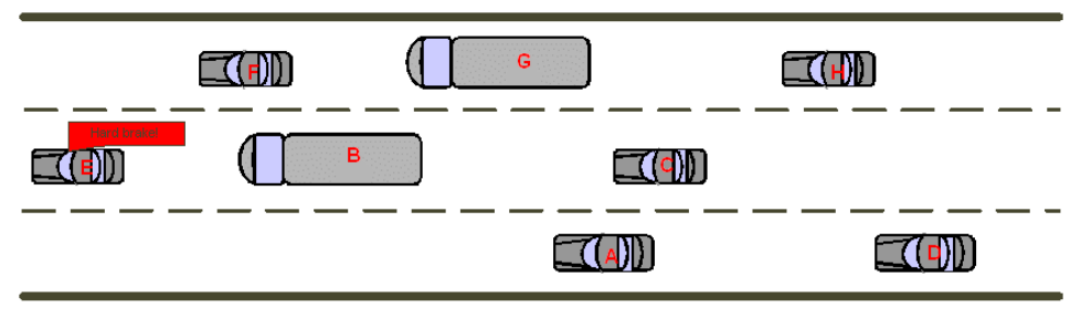
[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

Emergency electronic brake lights application

- Emergency electronic brake lights
  Enhances the driver visibility by giving an early notification of a vehicle braking hard even when the driver's visibility is limited (e.g. heavy fog, rain, snow, other large vehicle in between)

Communication	Freq.	Lat.	Range	Data
V2V, one-way, one-to-many, event-driven	10 Hz	100 ms	300 m	position, heading, velocity, deceleration



[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Time constraints

Summary: qualitative properties

- Type of communication
  - V2V, V2I, I2V
  - one-way, two-way
  - one-to-one, one-to-many
  - local broadcast
- Transmission mode
  - periodic messages
    - for awareness of the environment
  - Event driven
    - in case an unsafe situation is detected
    - high priority
    - high importance of delivery

Time constraints

Summary: quantitative properties

- 100 ms latency
- less than 100 bytes per packets for vehicule-to-vehicle communications
- larger for infrastructure-to-vehicle communications
  - maximum of $\sim$ 430 bytes for left turn assistant application

[Vehicle Safety Com. Project, NHTSA, US DoT, 2005]

Outlines

Road test

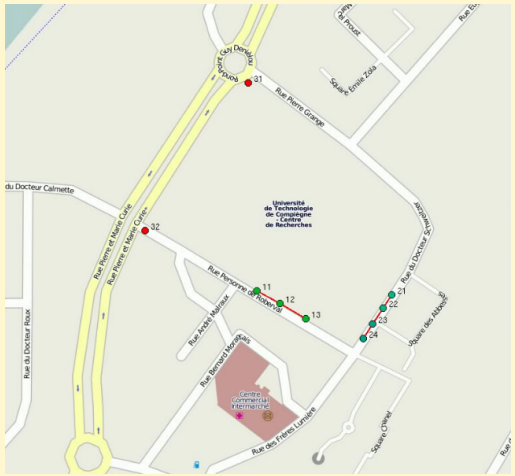
Methodology: scenario

- 802.11 broadcast, no retransmission
- convoi of seven vehicles

- speed about 76 km/h
- inter-vehicle distance about 400 m

- real environmental conditions
- measures at the application level

[IEEE VTC 2011]



Road test

Methodology: experimental platform

- Software:

  The Airplug Software Distribution

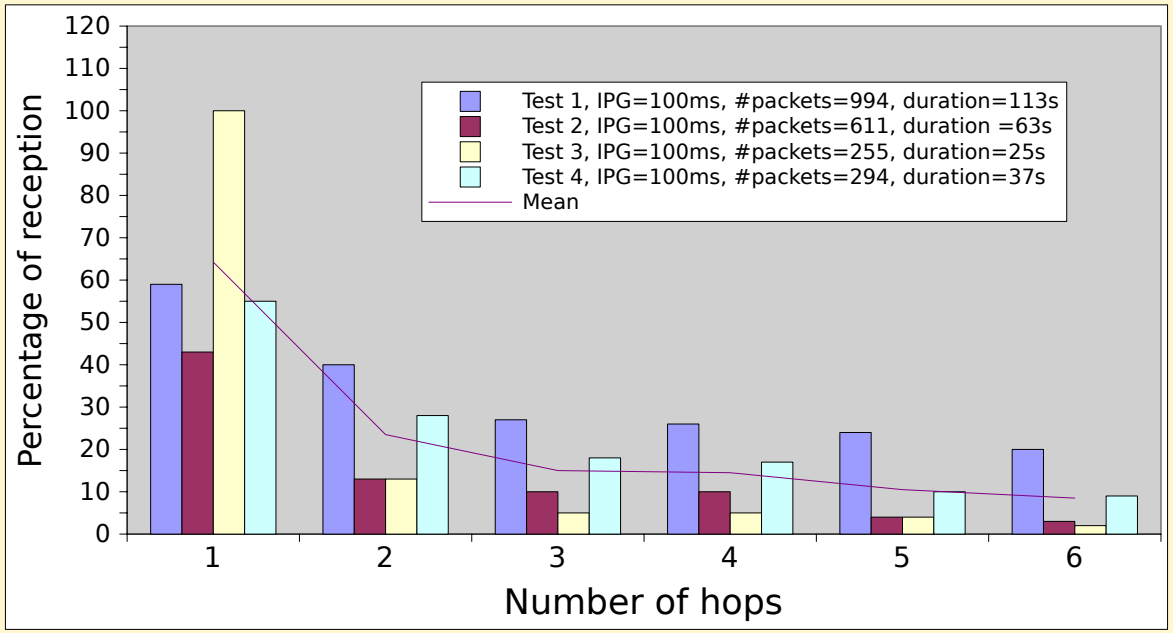
  http://www.hds.utc.fr/airplug

- Hardware:

Heudiasyc & Orange Labs vehicles

Road test

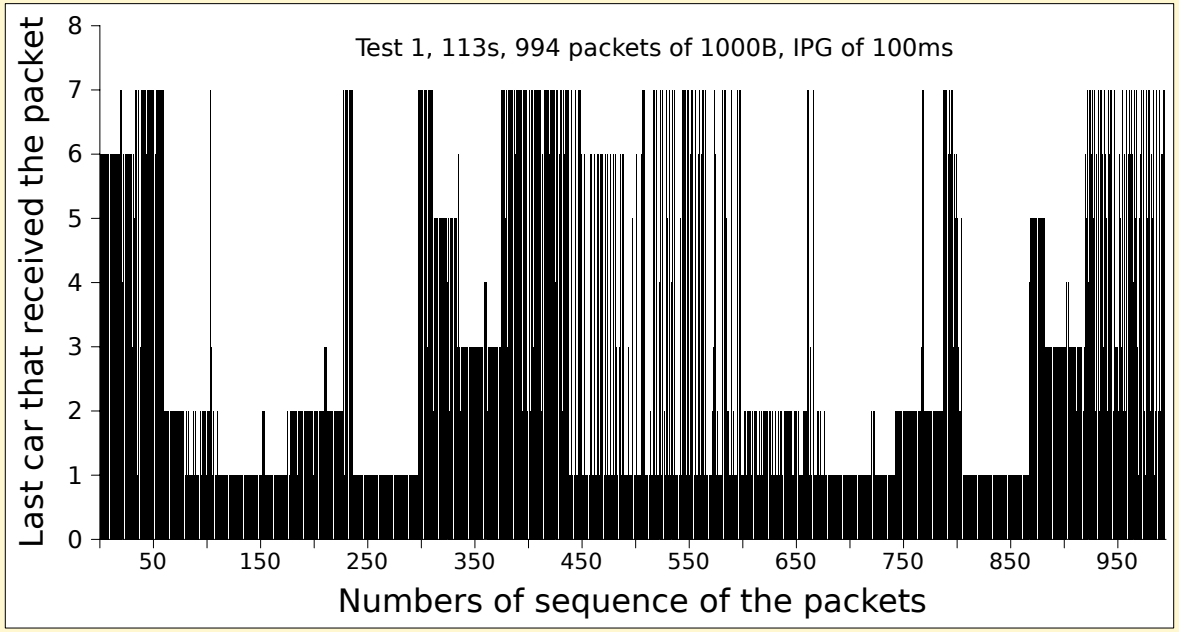
Results: losses



- Performances measured without acknowledgment nor retransmissions
- After 5 hops, 10% of reception

Road test

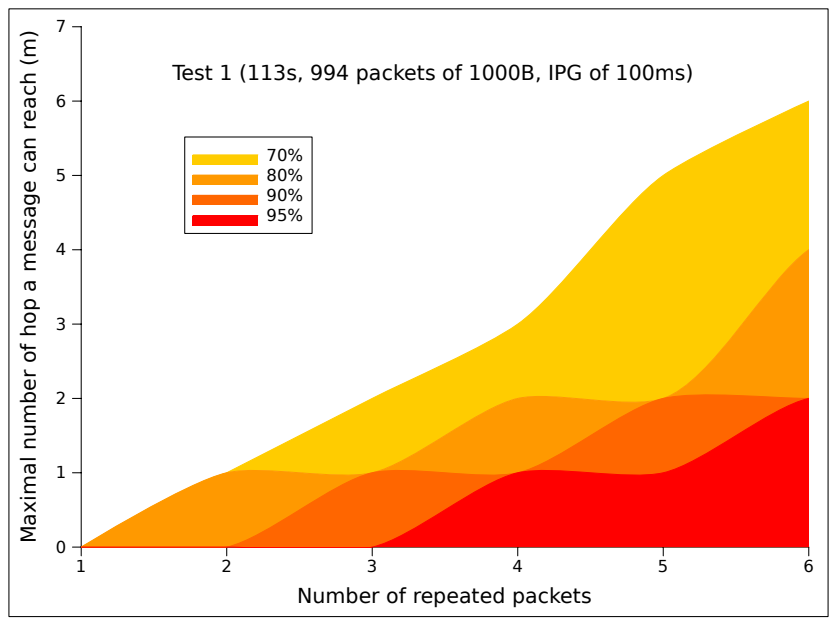
Results: loss events



- Loss event: a loss after good receptions
- Most frequently 1 to 5 packets lost successively
- Events grouped by 50 packets (5 s)
  $\rightsquigarrow$ external events, distance ($\neq$ radio)
  $\neq$ simulation

Road test

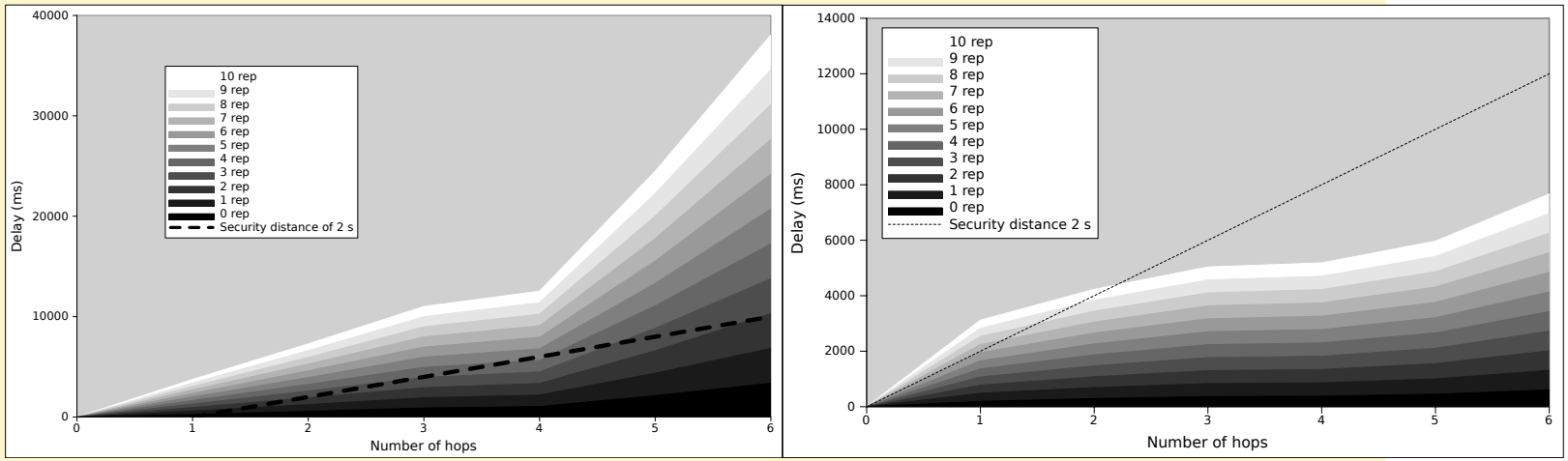
Results: reception rate with repeated packets



- Vehicle reached (number of hops) for a given reception rate, function of the number of repetitions

Road test

Results: with repeated packets 1/2



- A reasonnable number of repetitions can be done without exceeding the security delay (2 s).

Outlines

PHY Layer

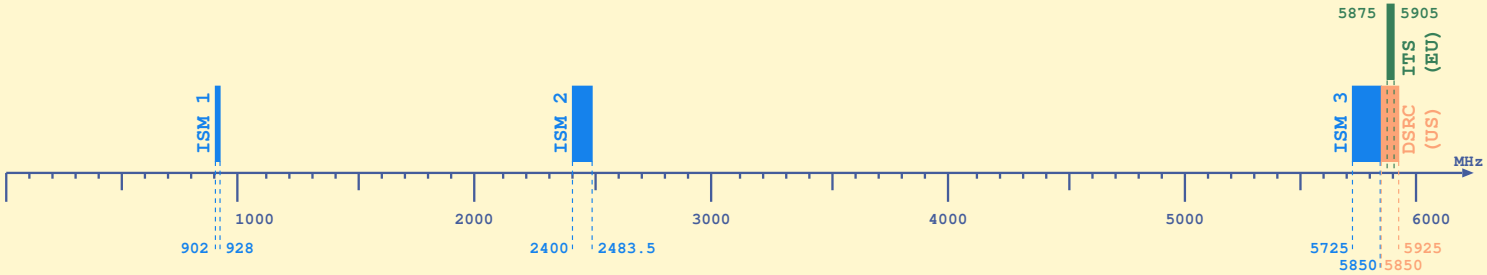
Overview

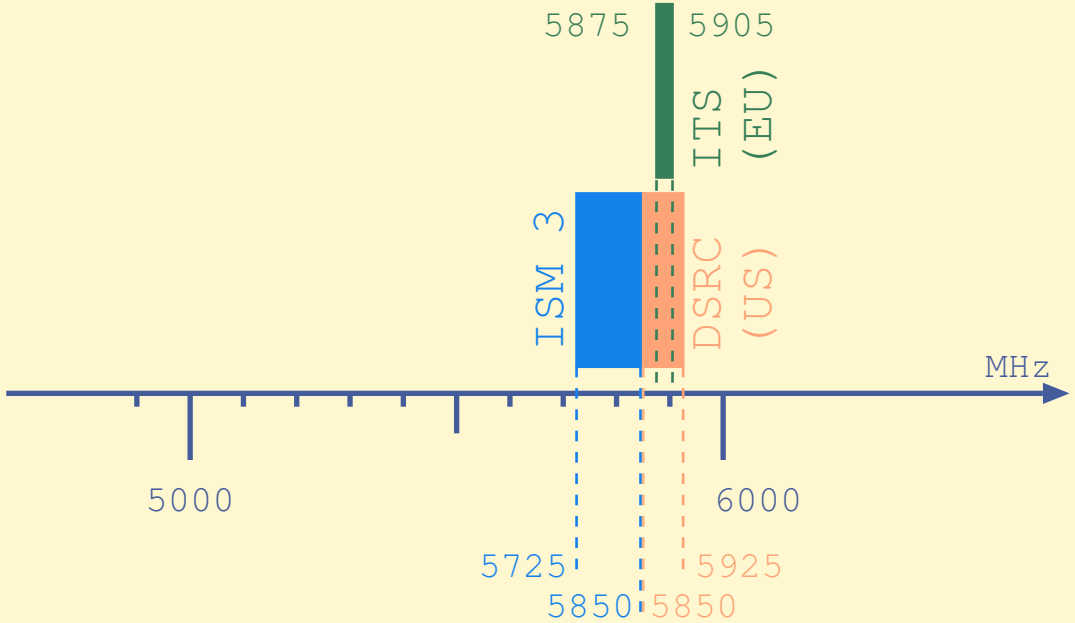
- IEEE 802.11p
- Frequencies
  - DSRC band 5.9 GHz
    Dedicated Short Range Communications
  - Not the same band in USA, Europe and Japan
- Channel sharing
  - Code Division Multiple Access
  - $\in$ IEEE 802.11
- Modulation
  - OFDM
    Orthogonal Frequency Division Multiplexing
  - Adaptation to be more robust to Doppler and mutlipath

PHY Layer

DSRC frequencies

- DSRC: Dynamic Short Range Communications
  Not the same signification in US and EU
- ITS: Intelligent Transportation Systems





PHY Layer

From 802.11a to 802.11p

- Channels of 5, 10 and 20 MHz instead of 20 MHz:
  - Doppler spread up to 2 kHz — fast moving nodes
  - RMS delay spread up to 0.8 μs — multipath
  - 20 MHz channel in 802.11a $\rightsquigarrow$ guard of 0.8 μs
  - Guard interval of 1.6 μs instead of 0.8 μs
    Larger than the measured delay spread
    Inter-Symbol Interference reduced (ISI)
  - Doppler effect much smaller than half the subcarrier separation distance (156.25 kHz)
    Inter-Carrier Interferences (ICI) reduced
  - Duration of a symbol doubled (6.4 μs)
    The channel estimation performed during preamble reception may become invalid at the end of the frame $\rightsquigarrow$ advanced receiver or specific OFDM

[Mittag et al. in VANET, Wiley 2009]

Outlines

MAC Layer

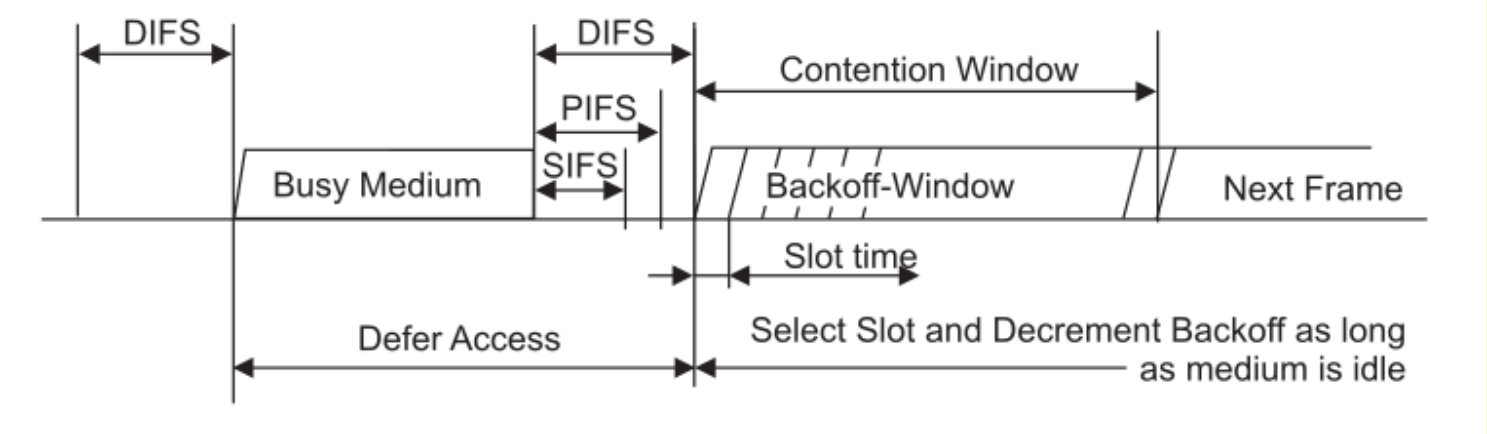
Overview

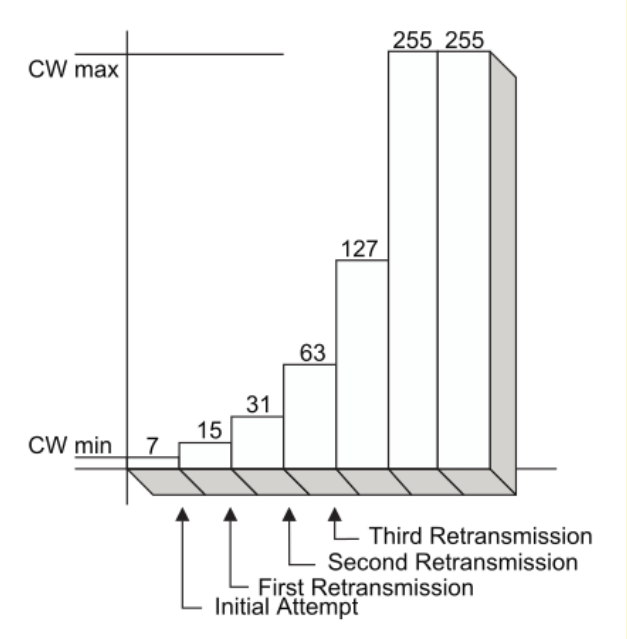
- 802.11p: part of the 802.11 family
  - Frame-by-frame rules unchanged
  - Session-based rules modified
- IEEE 1609.4
  - part of the IEEE 1609 WAVE standard
    Wireless Access for vehicular Environnement
  - WAVE covers OSI layers 2 (MAC), 3 and 4
  - *MAC extension for multi-channel operation*

Note: protocols still under discussion

MAC Layer

IEEE 802.11 Distributed Coordinated Function 1/2

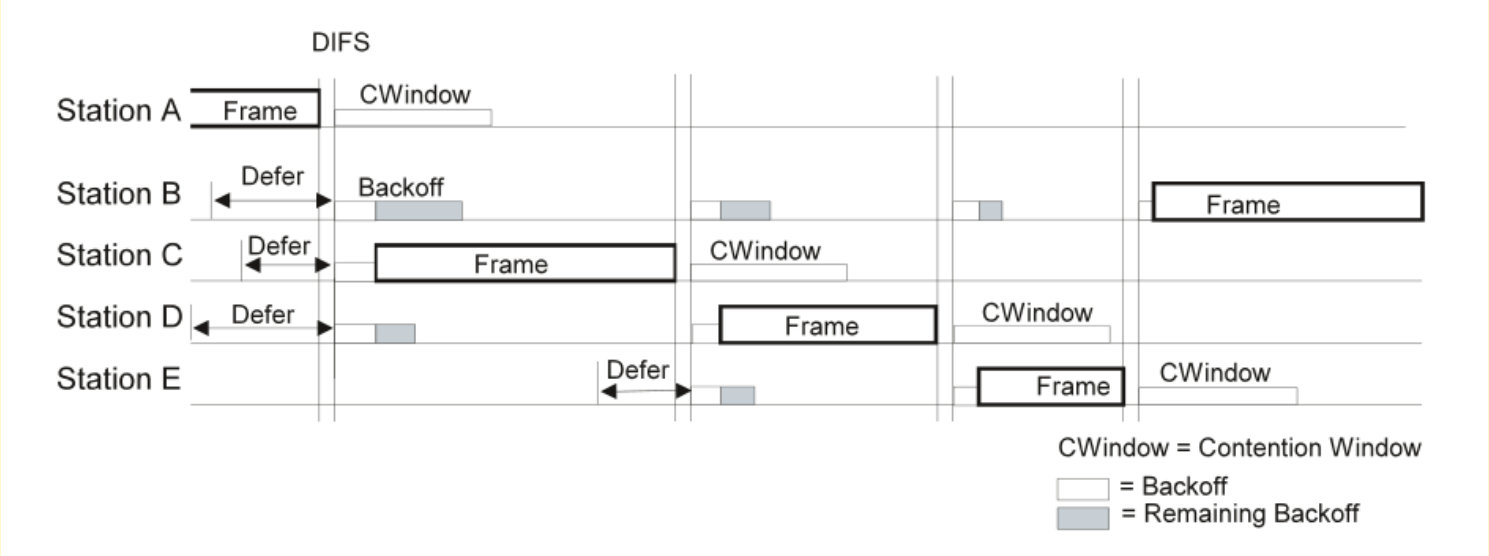




[IEEE 802.11, 1999]

MAC Layer

IEEE 802.11 Distributed Coordinated Function 2/2



[IEEE 802.11, 1999]

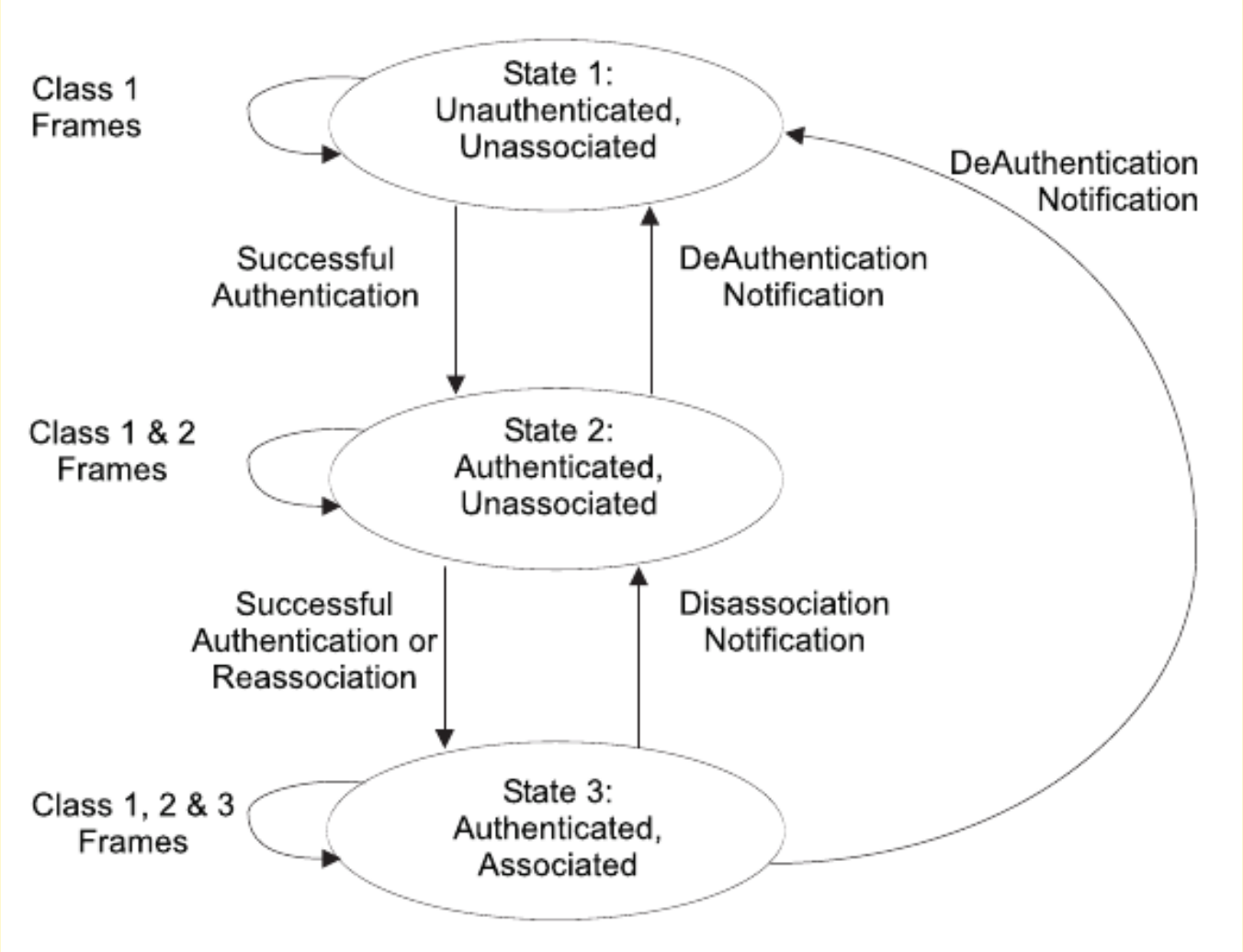
MAC Layer

IEEE 802.11 Basic Service Set 1/2

- Infrastructure Basic Service Set
  - Announced by an Access Point
    AP STA: Access Point STAtion
  - AP ⇝ gateway for the *Distribution System* DS
  - An entering station STA:
    - Hears a beacon
    - Joins
      clock synchronizing with the AP STA'clock
    - Authenticates
    - Associates
- Independent Basic Service Set
  - No Distribution System
  - For communication between STA in the BSS
  - The stations announce the BSS
  - An entering station: hears and synchronizes with the announcing station

MAC Layer

IEEE 802.11 Basic Service Set 2/2



[ANSI/IEEE Std 802.11, 1999]

MAC Layer

New session-based rules 1/2

Adaptation for vehicular networks:

- Very short-duration communications exchanges
- Not enough time to perform standard authentication and association to join a BSS

- Main motivation for the 802.11p WAVE Amendment
- Adding a new type of communication:
  - Communication outside the context of a BSS
  - BSS-based communications remain available

MAC Layer

New session-based rules 2/2

Communication outisde a BSS:

- No beacon
  - No BSS to be announced
  - Use predetermined parameters values
  - Use the TA frame to convey parameters
- No STA synchronization before communication
  - Mainly for energy saving purpose
  - In VANETs, STA are supposed to be supplied
- No authentication at the MAC level
  - Will rely on higher layers IEEE 1609.2
- No association before communication
  - No Distribution System (DS) in the MAC layer

MAC Layer

Multichannels 1/4

- Communication in vehicular networks
  ⇝ broadcast
  A message should be received by all surrounding vehicles
- No communication coordinator
  Some applications do not involve the infrastructure
  ⇝ a single shared channel

- To ensure time constraints
  - dedicated control channel
  - services channels
- Defined in IEEE WAVE 1609.4
- Impacts the MAC layer
- Could be different in Europe

MAC Layer

Multichannels 2/4

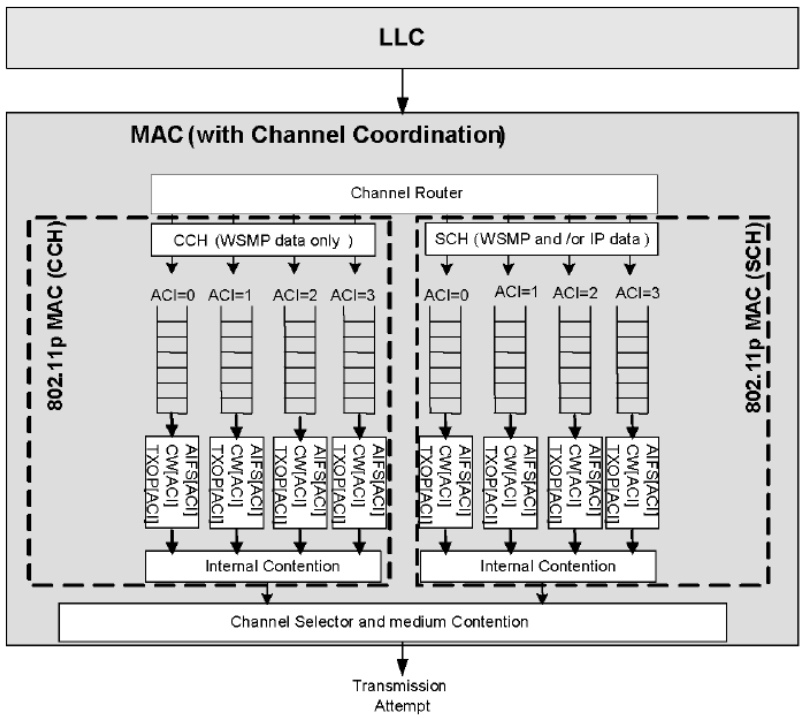
- Two classes of radio channel:
  - a single control channel (CCH) (default channel)
  - multiple service channels (SCH)
- CCH reserved for short, application and system control messages
- SCH supports general-purpose application data transfers
  announced via a WAVE Service Advertisement (WSA)

- IPv6 only allowed on SCHs
- Wave Service Advertisements on the CCH
- Wave Short Messages on any channel

MAC Layer

Multichannels 3/4

- At the arrival of MSDU MAC Service Data Unit
  - channel routing
  - User Priority mapped to Access Category
- Internal contention for Access Category (AC)
  - EDCA mechanism to prioritize AC
  - The AC with the smallest back-off wins
  - It then contends externally for the medium



[IEEE Std 1609.4, 2006]

MAC Layer

Multichannels 4/4

- EDCA parameters for CCH

AC	CWmin	CWmax	AIFSN
Background	aCWmin	aCWmax	9
Best effort	(aCWmin + 1)/2 - 1	aCWmin	6
Video	(aCWmin + 1)/4 - 1	(aCWmin + 1)/2 - 1	3
Voice	(aCWmin + 1)/4 - 1	(aCWmin + 1)/2 - 1	2

- EDCA parameters for SCH

AC	CWmin	CWmax	AIFSN
Background	aCWmin	aCWmax	7
Best Effort	aCWmin	aCWmax	3
Video	(aCWmin + 1)/2 - 1	aCWmin	2
Voice	(aCWmin + 1)/4 - 1	(aCWmin + 1)/2 - 1	2

Outlines

IEEE 1609 WAVE

Goal

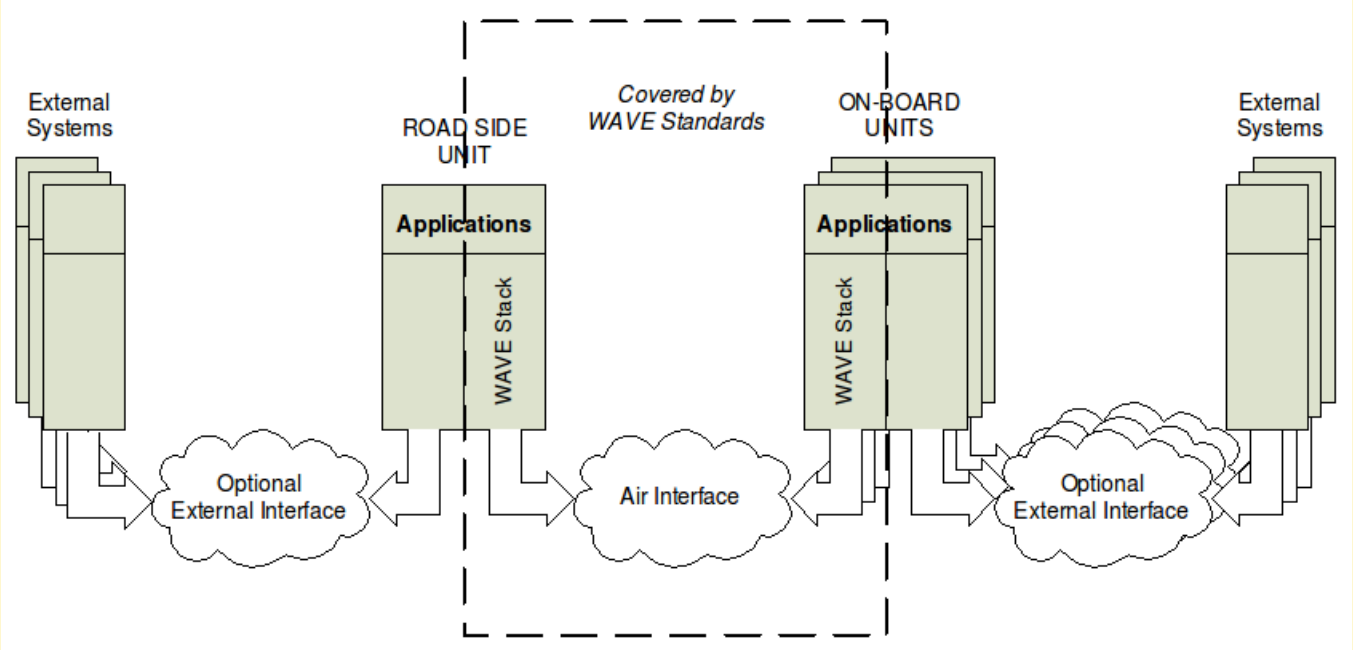
Wireless Access for Vehicular Environment

The WAVE system provides connectivity in support of pedestrian and in-vehicle applications offering safety and convenience to their users, while at the same time offering a level of confidentiality and data security.

- Provide a networked environment supporting very high speed transactions for V2V, V2I, and V2D
  hand-held devices
- For transportation services such as alerting drivers to potential hazards and notifying them of services of interest even at high speed or in high traffic density
- Enhancing the safety, mobility and convenience of everyday transportation.

IEEE 1609 WAVE

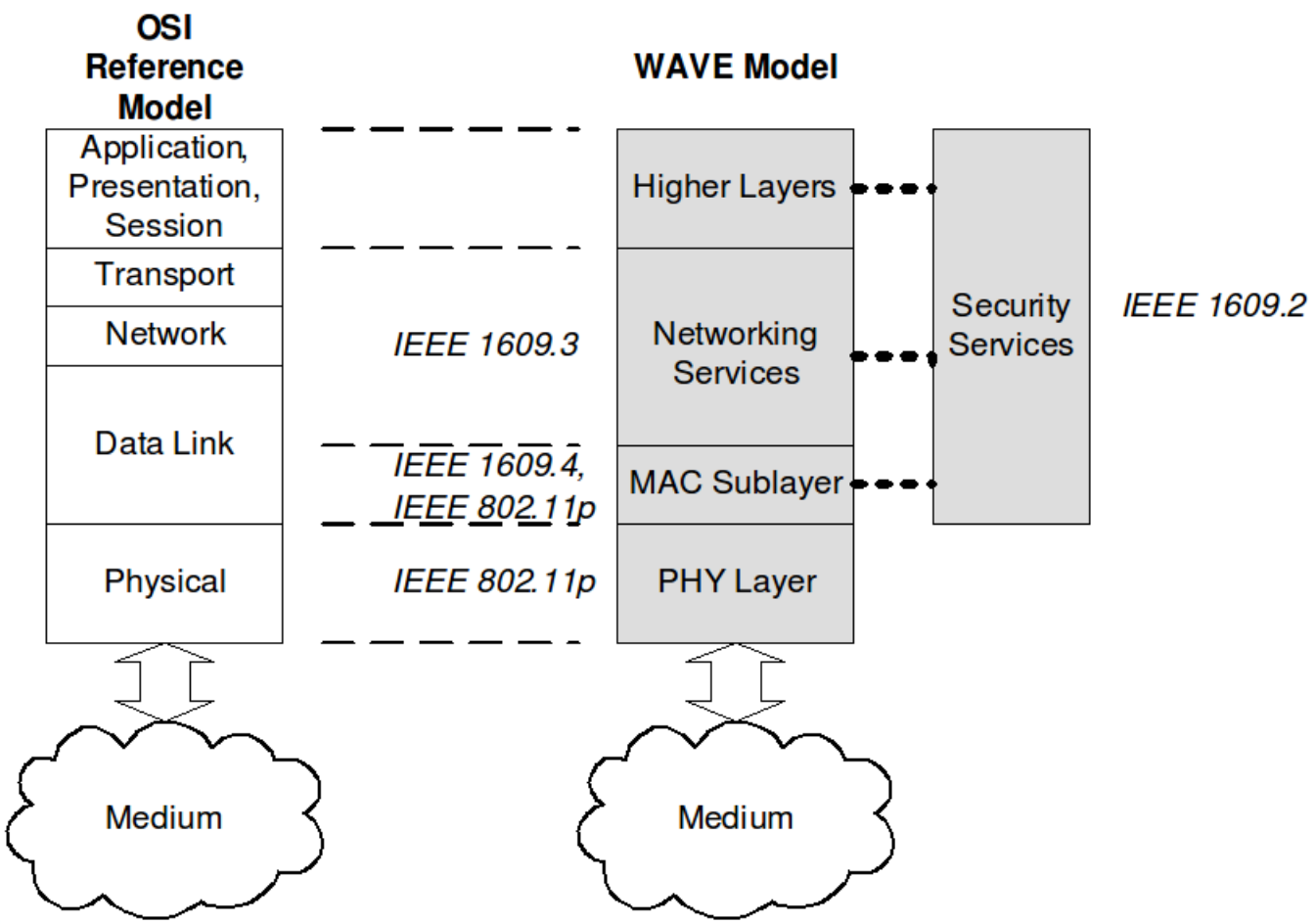
Covered area



[IEEE P1609.0/D0.7, January 2009]

IEEE 1609 WAVE

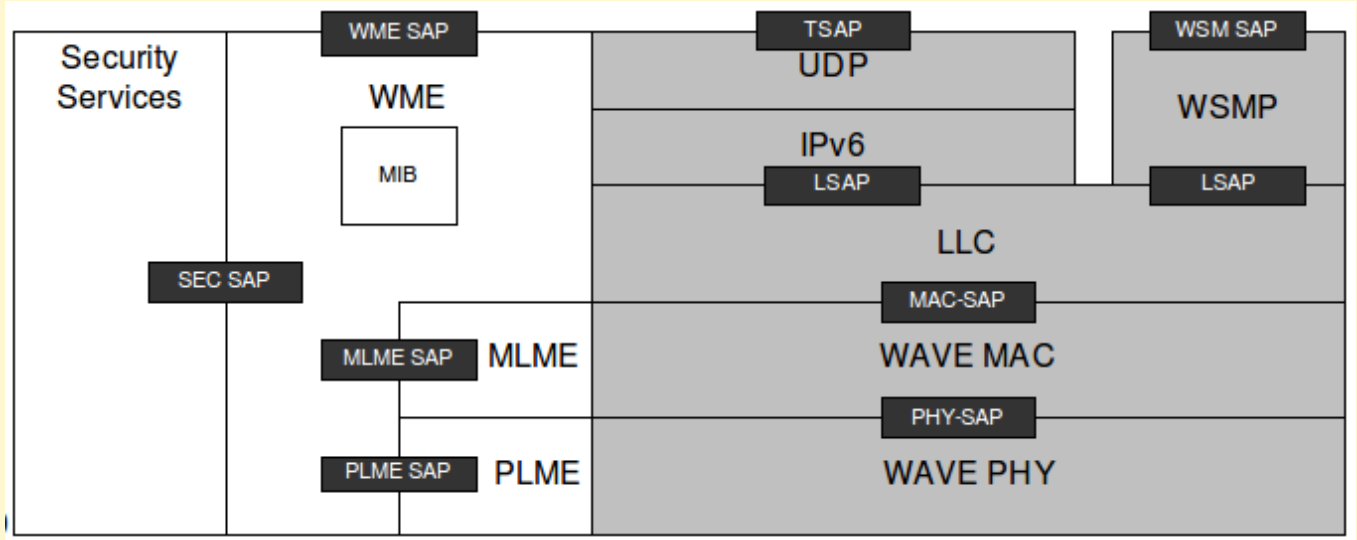
OSI comparison



IEEE 1609 WAVE

Protocols stack and relationship

- IETF IPv6 vertical handover
- IETF UDP
  match well with the connectionless nature of WAVE
- WSMP: WAVE short messages protocols



[IEEE Std 1609-3, 2007]

IEEE 1609 WAVE

Short Messages

- Wave Short Messages Protocol (WSMP)
- Designed to consume minimal channel capacity
  Thus allowed on both CCH and SCHs.
- Sending applications can directly control physical characteristics
  Channel number, transmitter power...
- MAC address of the destination is required
  Or group of addresses.
- Messages delivered to the correct application thanks to Provider Service Identifier (PSID)
  Unique values managed by the IEEE Registration Auth.

Outlines

Internet Protocol

Overview

- IETF Internet Engineering Task Force
- Towards a large deployment of IP
  Using several IP per vehicles
- IPv6
  - to be able to assign one address per object
  - while maintaining a end-to-end connexion without translation
  - improvements and extensibility

- IP in highly mobile networks ?

- IP in MANET Mobile Ad hoc NETworks
- Address assignation: Autoconf WG
  Ad hoc Network Autoconfiguration Working Group

[Vehicular Networks, Techniques, Standards and Applications, CRC Press 2009]

Internet Protocol

Mobile IPv6

- Two addresses per mobile nodes: permanent and temporary
  - home agent (HA) in the origin network
  - care-of address (CoA) in the visited network
- When the node joins a new network,
  - a new care-of address is assigned
  - it is sent to the home agent
- When a message arrives to the home agent
  - it is forwarded to the care-of address
- Routing optimization with Mobile IPv6 vs. IPv4
  not all messages have to reach the home agent

Internet Protocol

NEMO: Network Mobility

- Mobile IPv6 does not support network mobility
  eg. in case of several IP per vehicles
- Nemo Basic Support [RFC 3963]
  - based on Mobile IPv6
  - does not change addresses of Mobile Network Nodes (MNN) behind the Mobile Router (MR)
  - only the Mobile Router updates its home-agent
  - this home-agent forwards every messages with the suffix of the MR network to the MR
- Nemo Extended Support [Ernst, 2009]
  - optimization for multidomiciles, routing
  - does not rely on Mobile IPv6
  - in case the MR admits several interfaces while the HA registers a single care-of address

Internet Protocol

Address autoconfiguration

- RFC 4861 et 4862 for fixed networks cannot be used in mobile ad hoc networks
- No standard for the moment
- VAC [Fazio et al. 2007]
  - small linear clusters of vehicles
  - one leader per cluster runs a DHCP server
- GeoSAC [Baldessari et a.]
  - SLAAC (*Stateless Address Autoconfiguration*) using NDP (*Neighbour Discovery Protocol*) to check the unicity of IP
  - C2C-CC geographic routing for local broadcast

Outlines

3. Protocols for a Challenging Network
   - Time constraints
   - Road Tests
   - Physical layer
   - Medium Access Control Layer
   - IEEE 1609 WAVE
   - IP
   - CALM

CALM

What is it?

- ISO Technical Committee 204
  Intelligent Transportation Systems
  [http://www.iso.org/iso/iso_technical_committee.html?commid=54706]
- WG 16 Wide Area Communication
  Communication Architecture for Land Mobile
  [http://www.calm.hu]

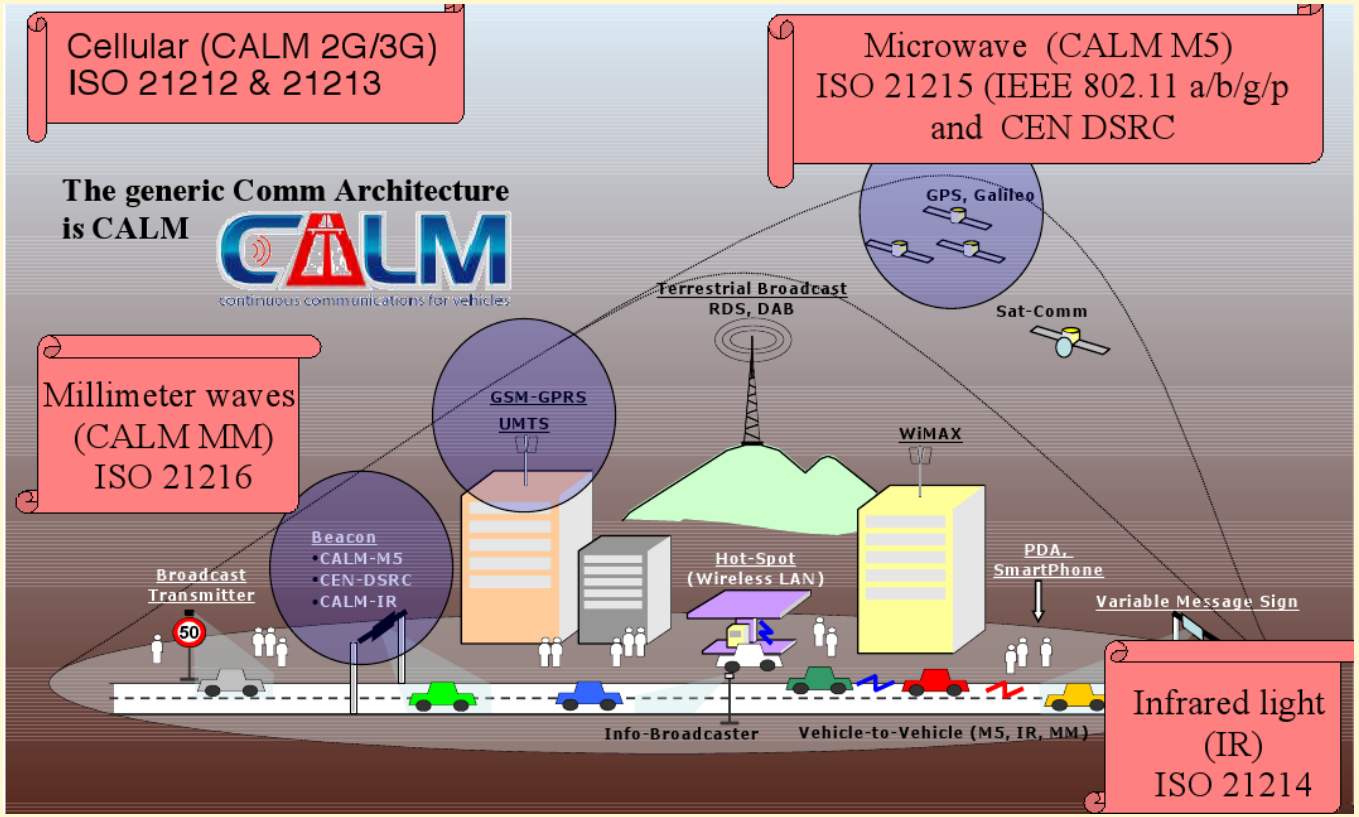
SWG 16.0	CALM Architecture
SWG 16.1	CALM Media (low layers)
SWG 16.2	CALM IPv6 networking
SWG 16.3	Probe Data
SWG 16.4	Application Management
SWG 16.5	Emergency notifications (eCall)
SWG 16.6	CALM non-IP networking
SWG 16.7	Security, Lawful intercept

CALM

Media Diversity

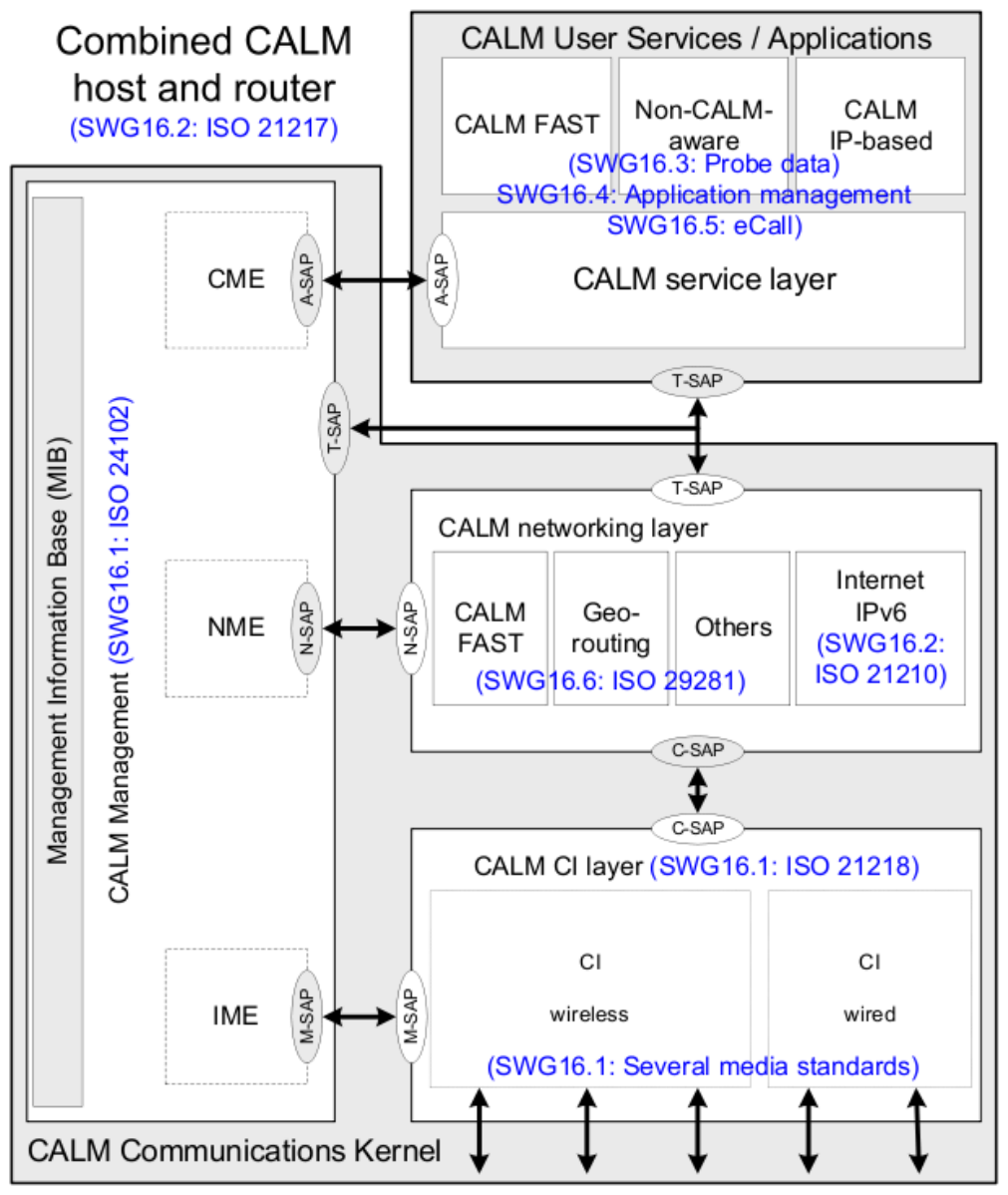
- V2V, V2I with multiple radio technologies

Cellular (CALM 2G/3G)	ISO 21212, 21213	ITU, ETSI
Infrared light (IR)	ISO 21214	Germany
Microwave (CALM M5)	ISO 21215	802.11p
Millimeter waves (CALM MM)	ISO 21216	



[cited by T. Ernst, Architectures IPv6, 2009]

CALM Architecture

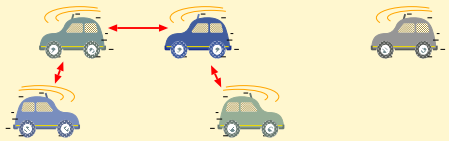


[ISO TC 204 Draft Business Plan, 2008]

CALM

- CALM is not developing handover protocols
- Relies on IETF IPv6 protocols for vertical handovers
- Relies on medium-specific protocols for horizontal handover

Outlines



Outlines

Design rules for dynamic networks

Global knowledge

- Do not rely on the topology
  By definition, it is unstable
- Virtual structures are costly
  A main difference with MANET
  - Spanning trees, clusters...
  - Help for algorithms
  - Consumes resources to be maintained
- More generally, any global knowledge should not be used
  Except if it does not change

Design rules for dynamic networks

Local knowledge

- Neighborhood is unstable
- Learning from the neighborhood is costly
- Sender-side:
  - Exchange messages to learn about the neighbors
  - Select a neighbor
  - Send the message to the selected neighbor
  - Consume bandwidth
  - The neighborhood may have change
- Receiver-side:
  - Send the message to all neighbors
  - Each neighbor decides whether it is concerned or not
  - Several neighbors may decide to be concerned

Design rules for dynamic networks

Local knowledge

- Neighborhood is unstable
- Learning from the neighborhood is costly
- Sender-side:
  - Exchange messages to learn about the neighbors
  - Select a neighbor
  - Send the message to the selected neighbor
  - Consume bandwidth
  - The neighborhood may have change
- Receiver-side:
  - Send the message to all neighbors
  - Each neighbor decides whether it is concerned or not
  - Several neighbors may decide to be concerned

Design rules for dynamic networks

Divergence

The relation for remote knowledge:

$$\text{Dynamic} \nearrow \quad \Rightarrow \quad \begin{array}{l} \text{cost} \nearrow \\ \text{preciseness} \searrow \end{array} \quad \Rightarrow \quad \text{usefulness} \searrow$$

Design rules for VANET

Particularities of VANET

- VANET are a special case of dynamic networks
  - Unstable topology
  - Unstable neighborhood
  - Disconnected network
- However in some situations, we can find:
  - Regular patterns
  - Access to the infrastructure
- Variety of network dynamic, density, regularity...

Design rules for VANET

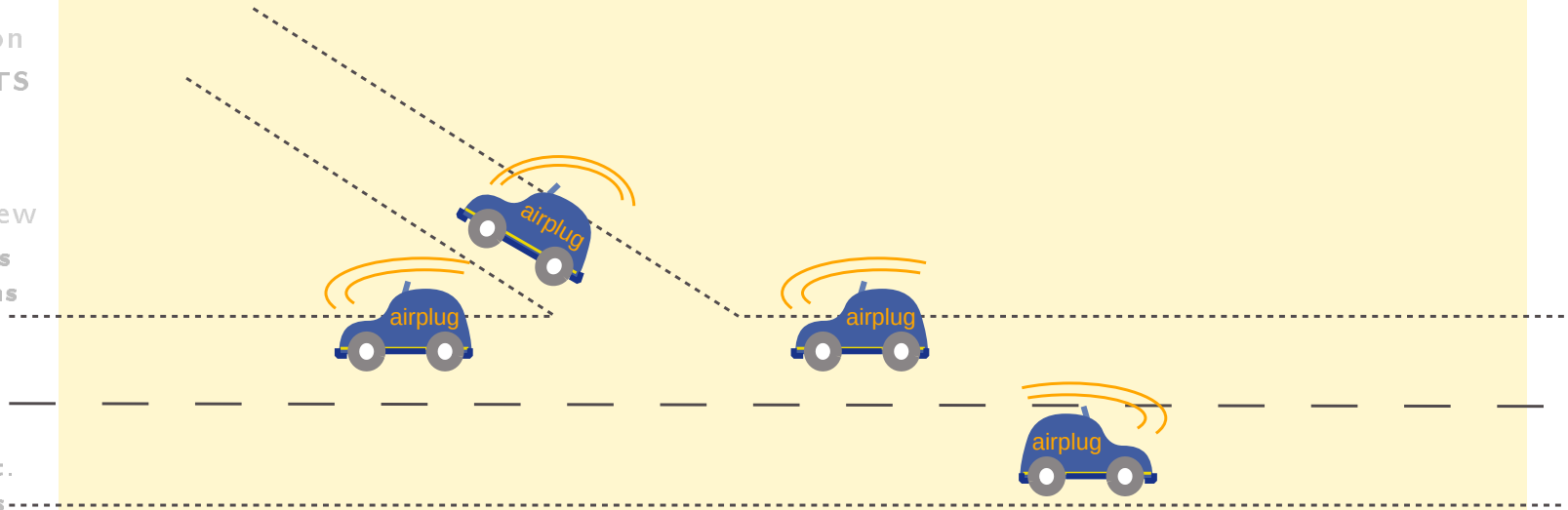
Summary and discussion

- Summary
  - A special case of dynamic networks...
  - Sometimes some facilities...
  - Variety of situations
  - Adaptive algorithms required
- Discussion
  - Should VANET be considered as classical networks?
    - known networking solutions to be adapted?
    - new networking solutions to be imagined?
  - A general purpose network?

Outlines

Design examples

Conditional transmissions 1/2



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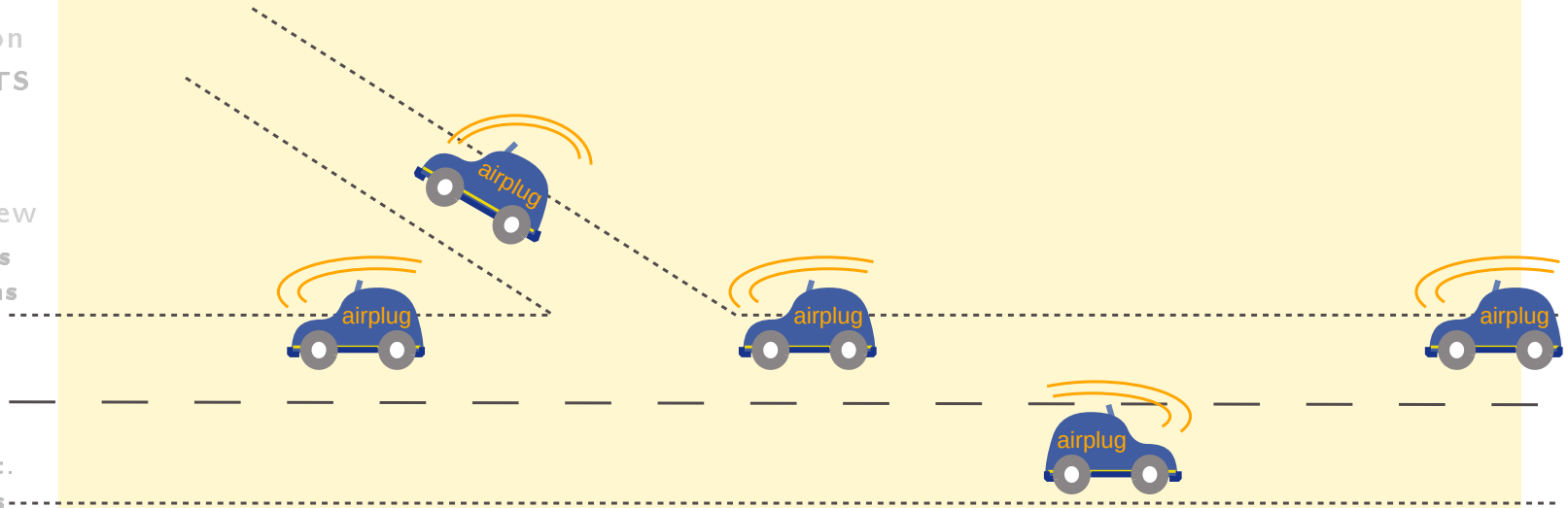
Design examples

Conditional transmissions 1/2



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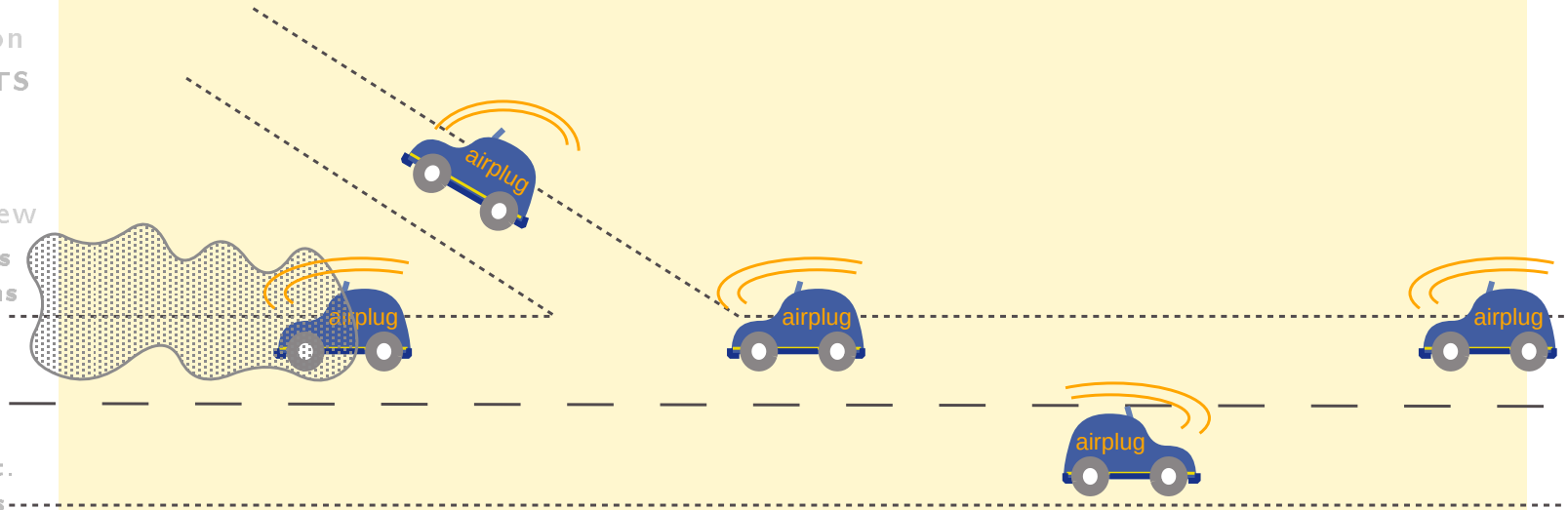

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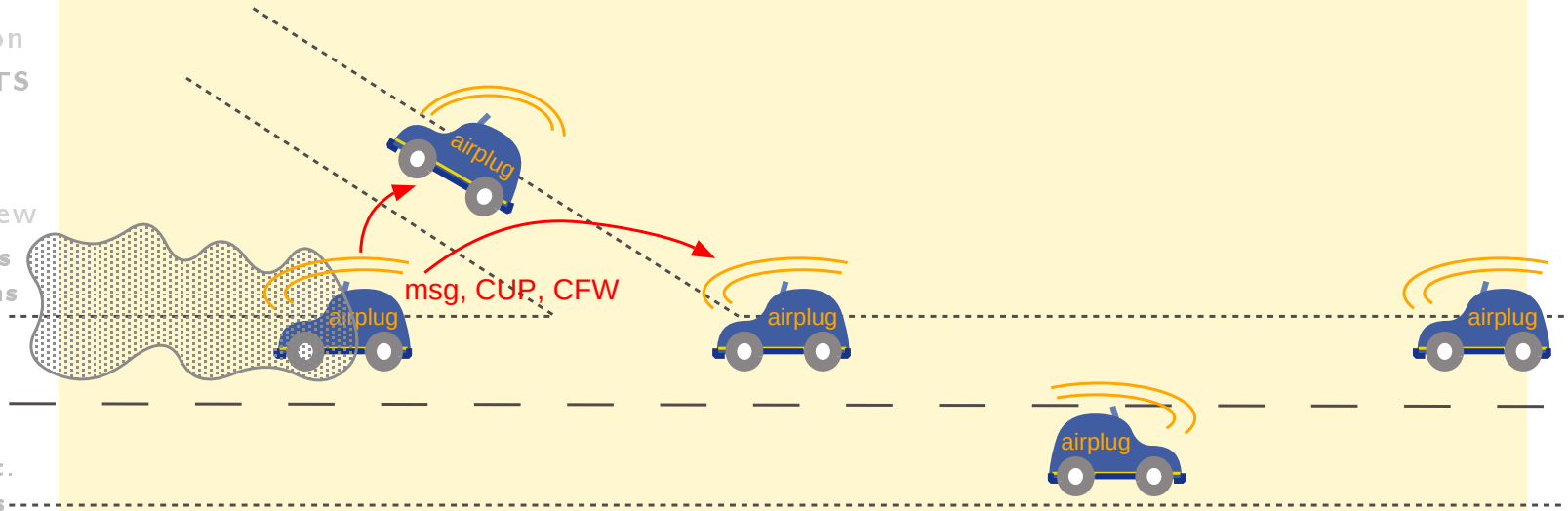

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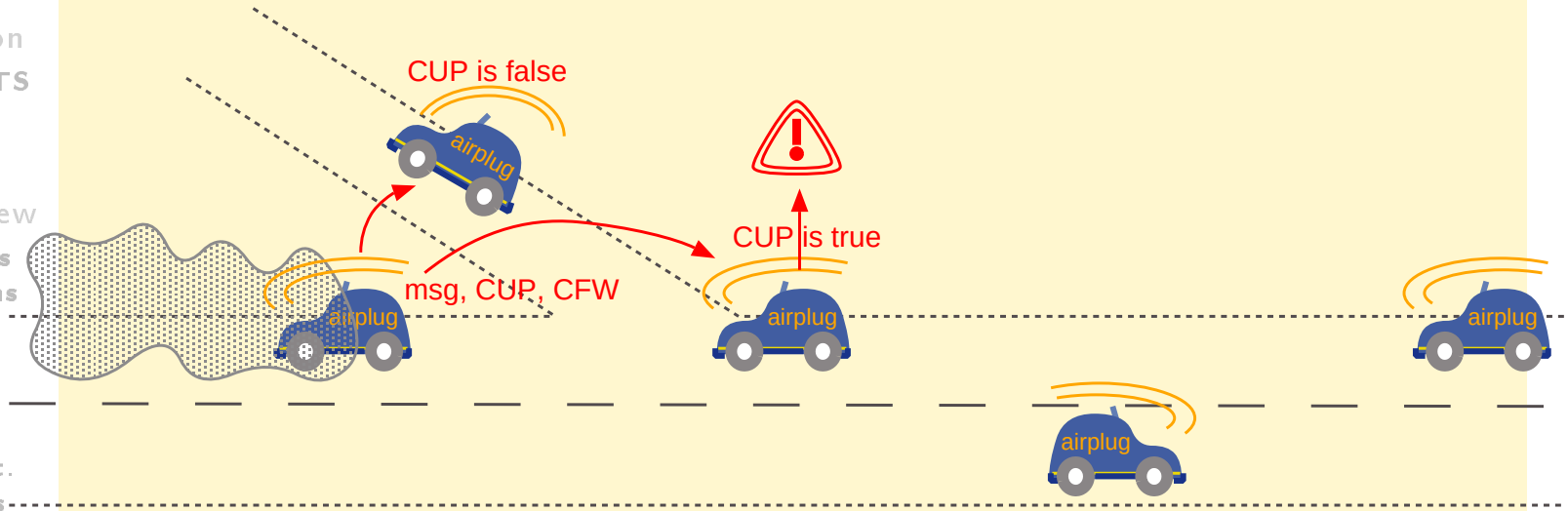

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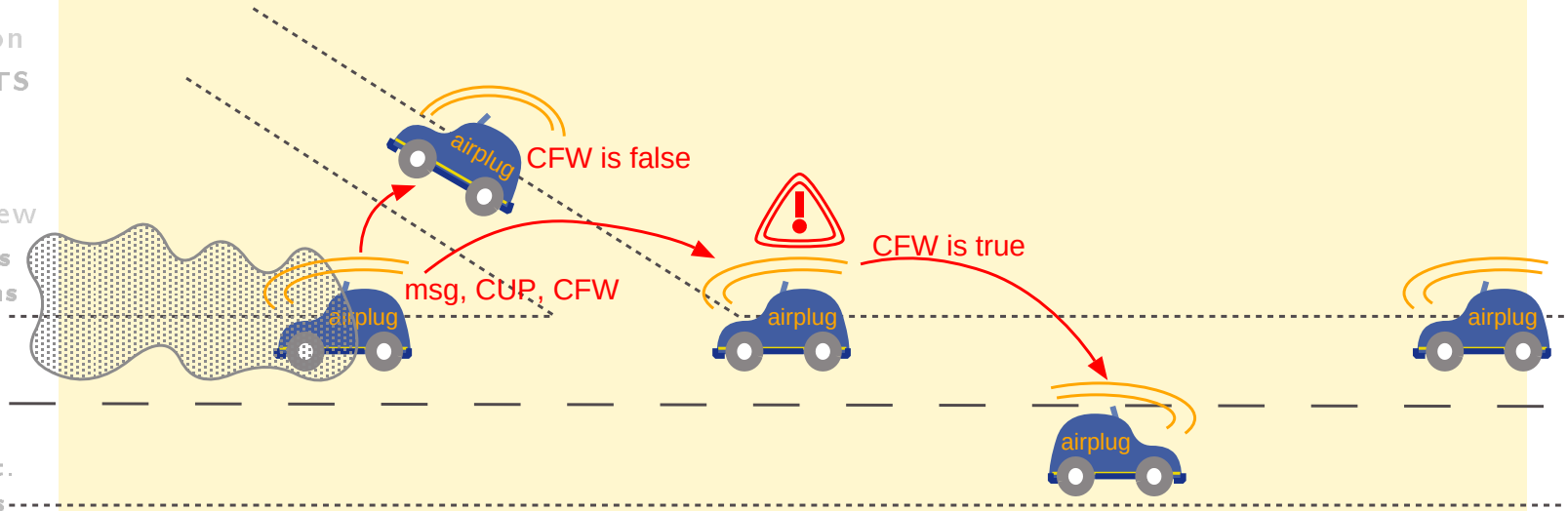

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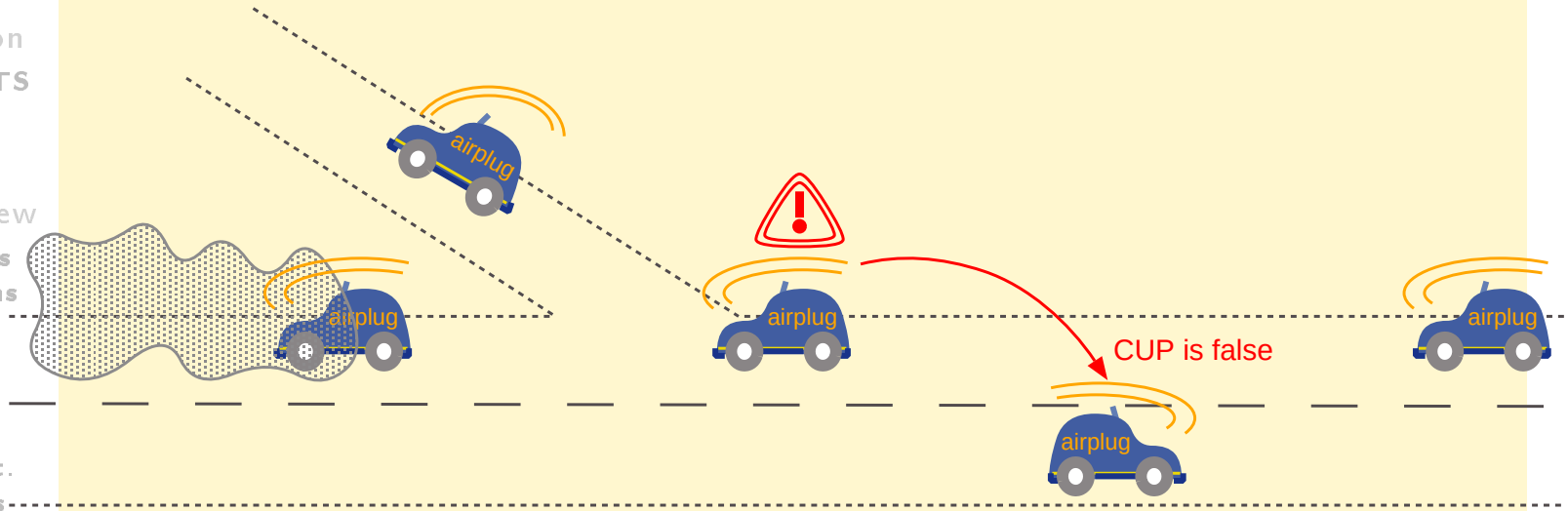

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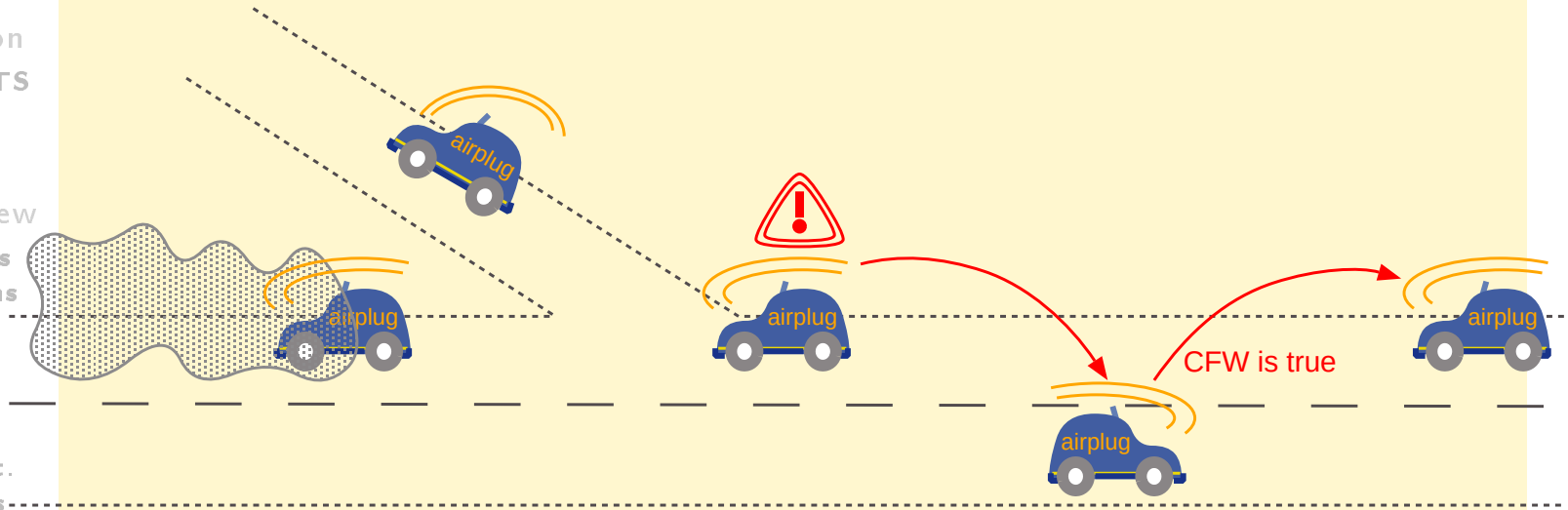

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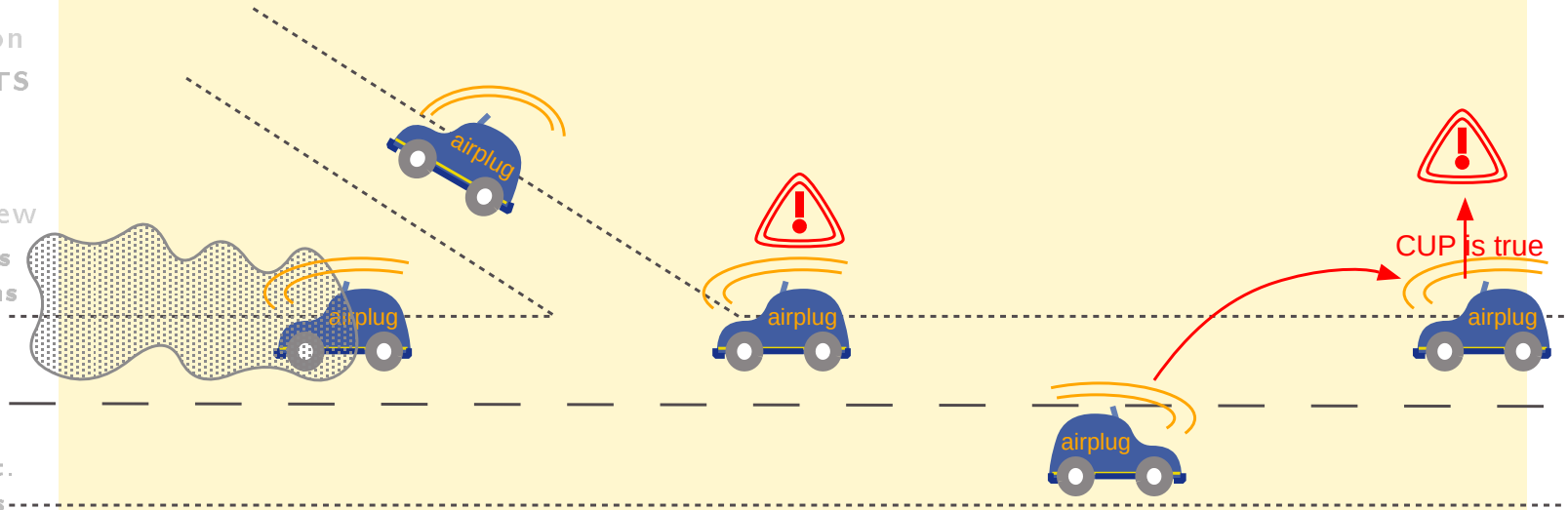

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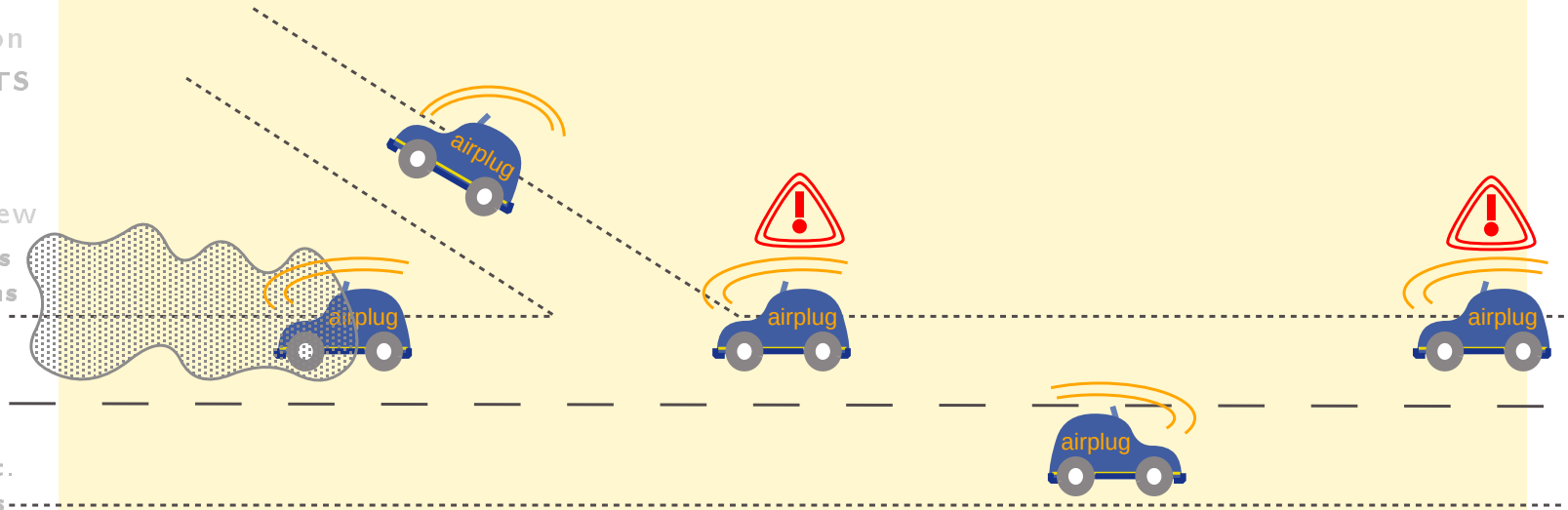

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Design examples

Conditional transmissions 2/2

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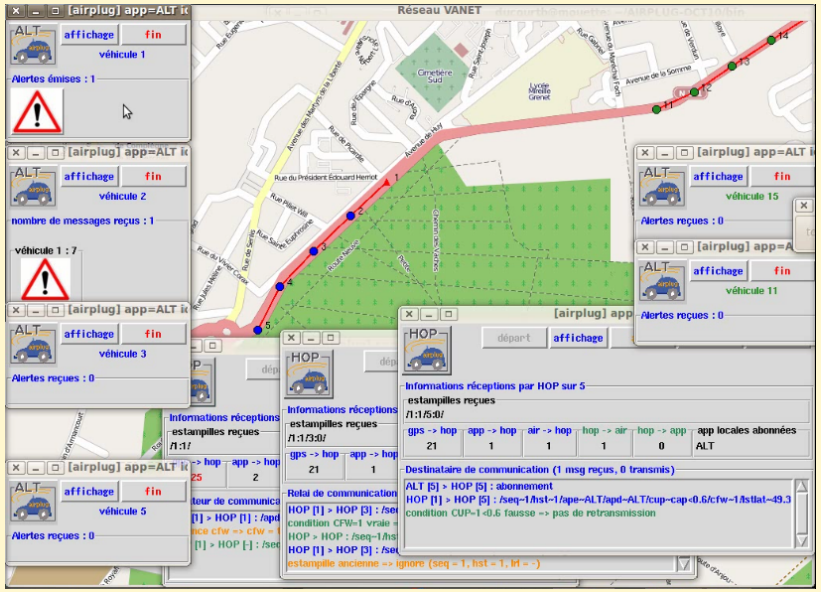
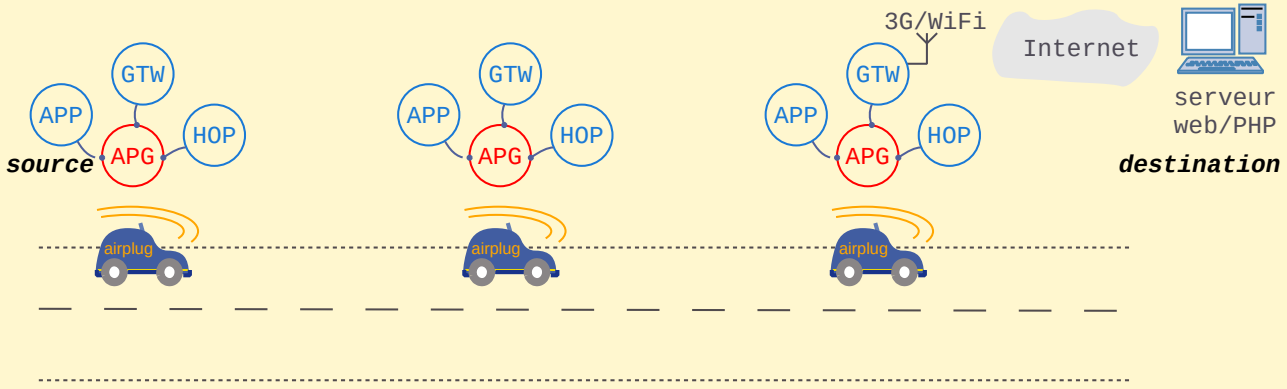


V2I oportunistic communications

- Sending data from the vehicles to a web server

- GTW [CFIP 2009]
  - V2V: conditional transmission
  - V2I: IPv4, IPv6, WiFi hot-spot, 3G



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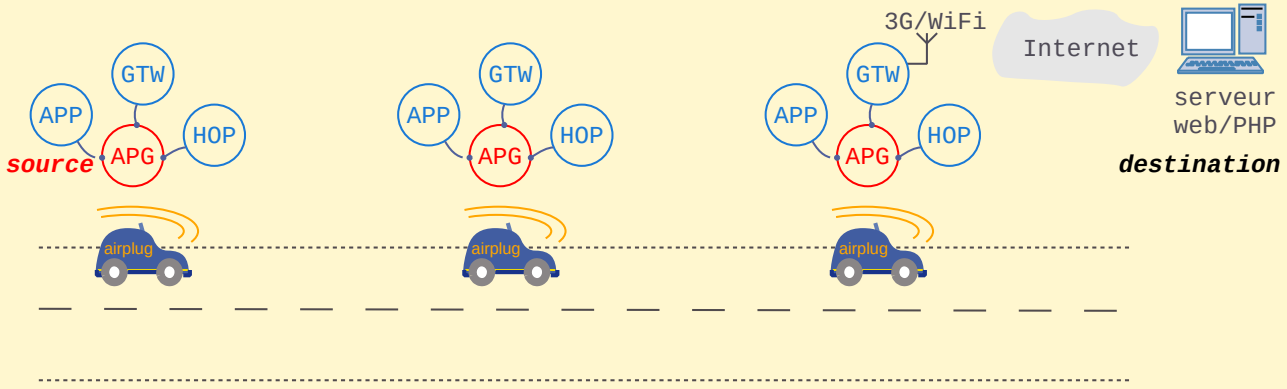

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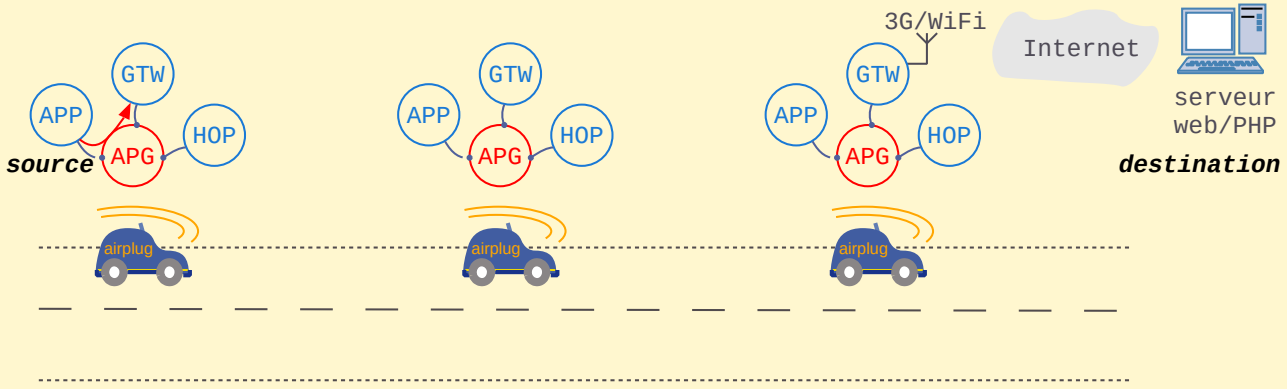

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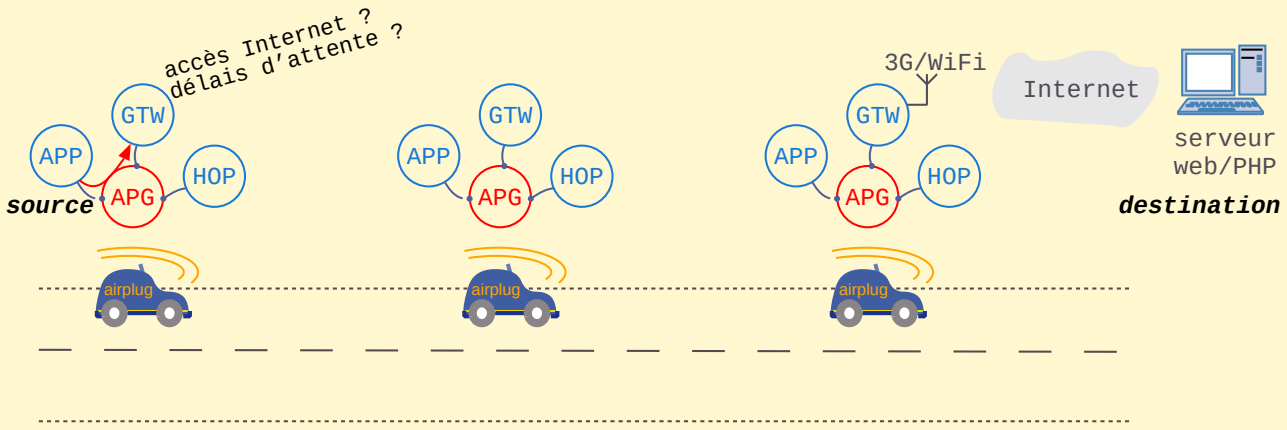

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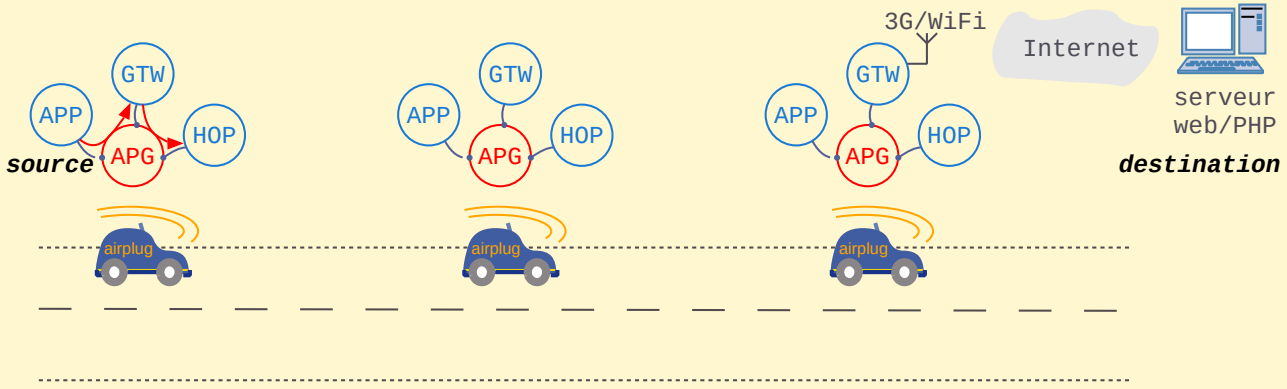

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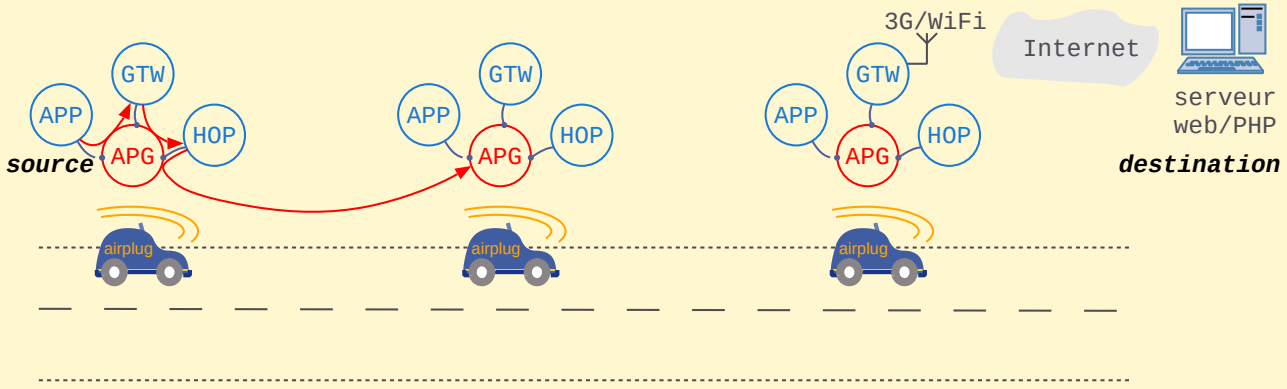

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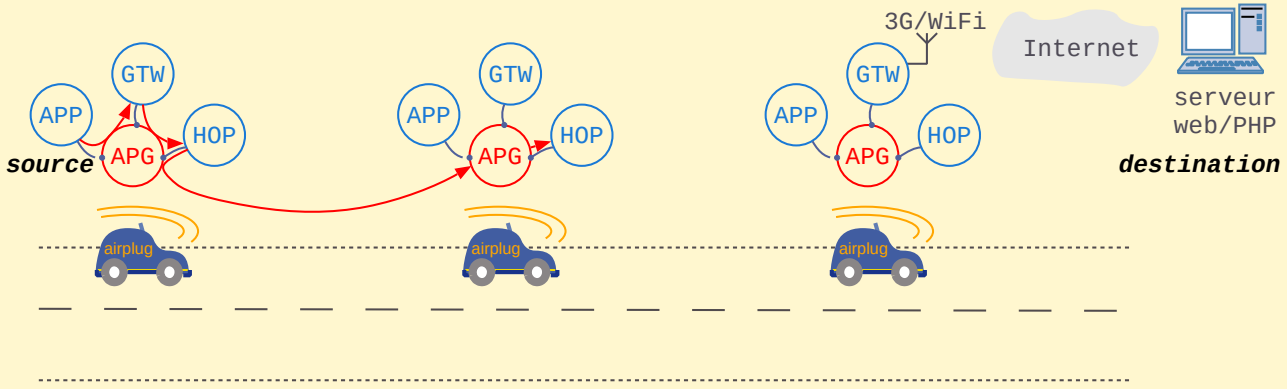

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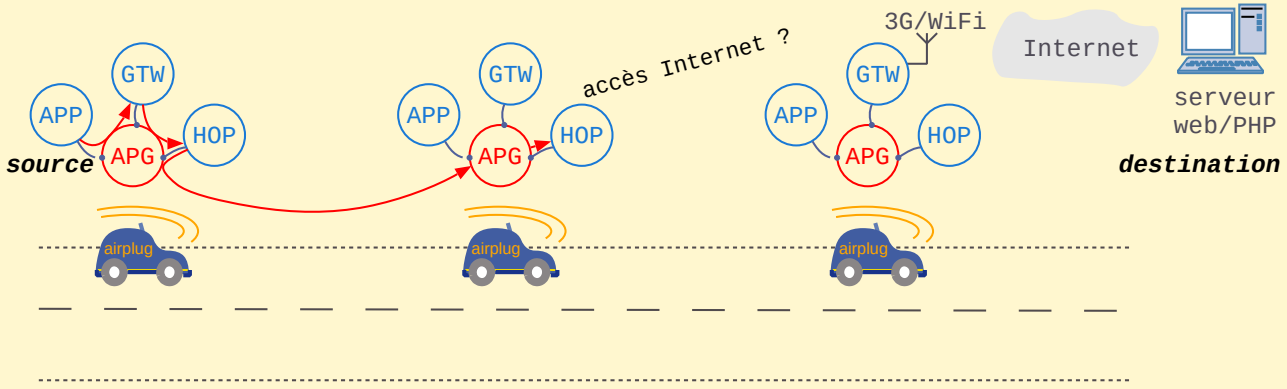

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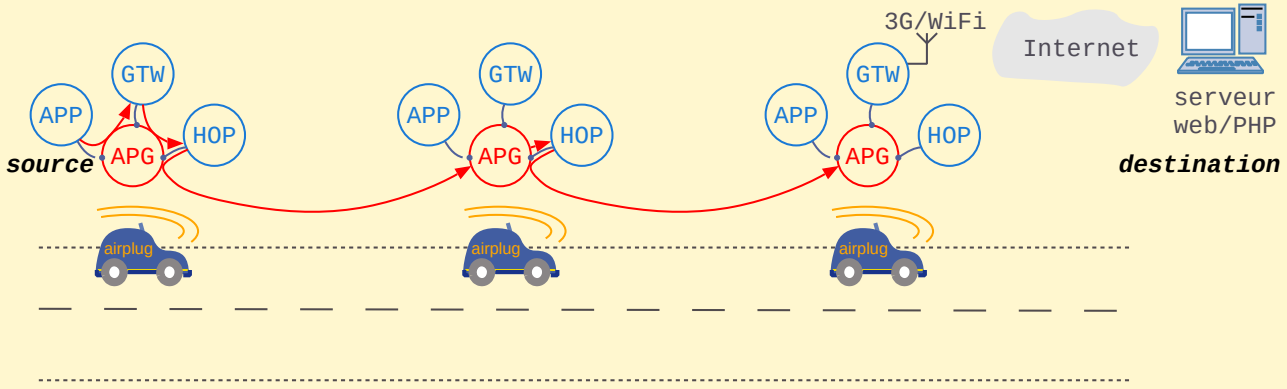

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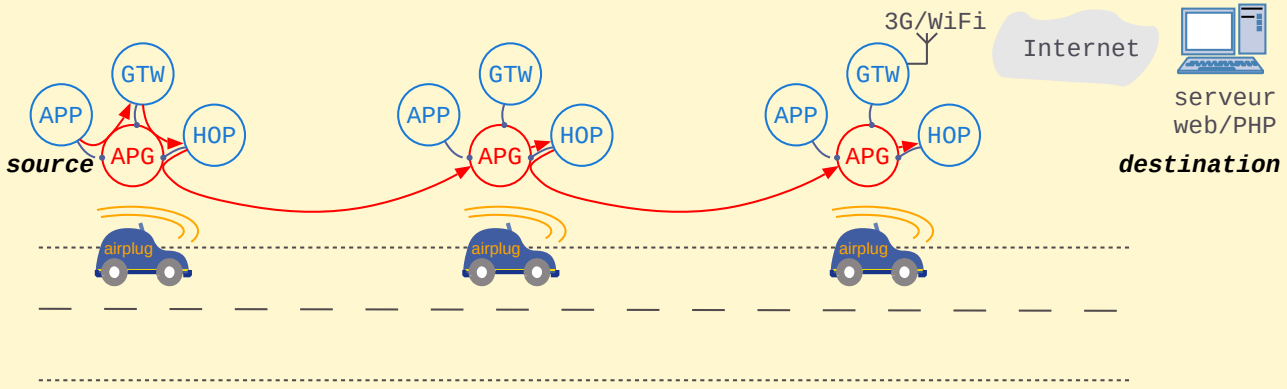

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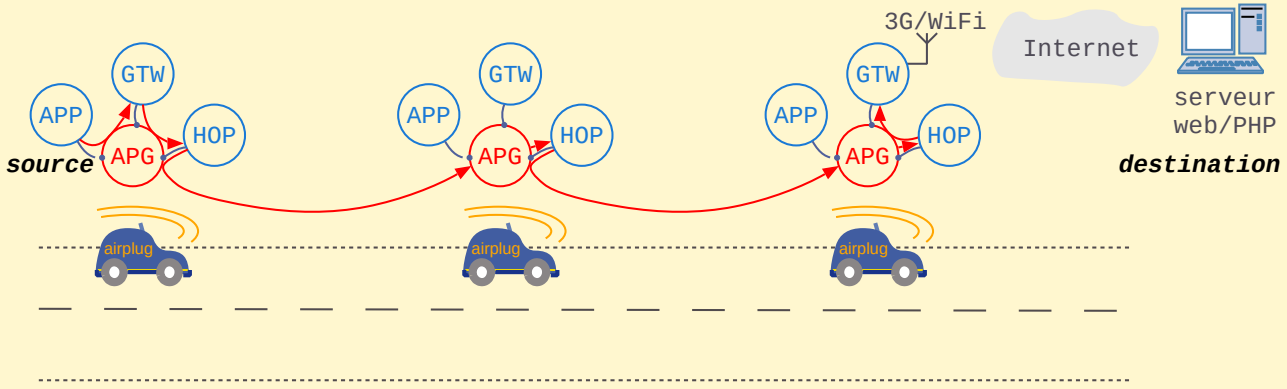

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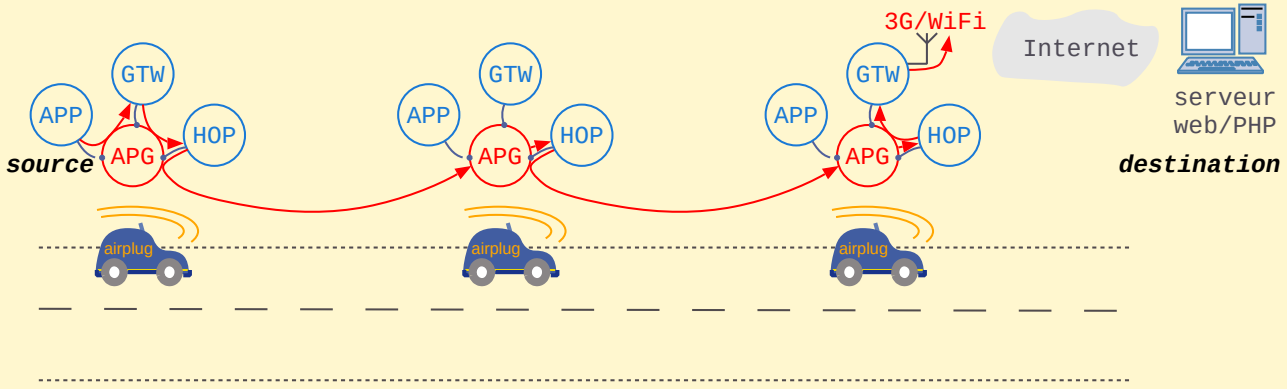

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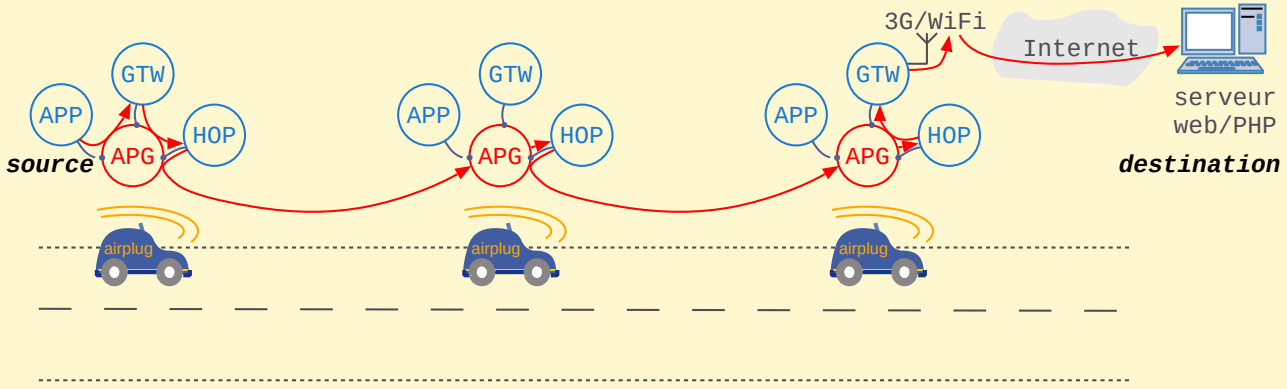

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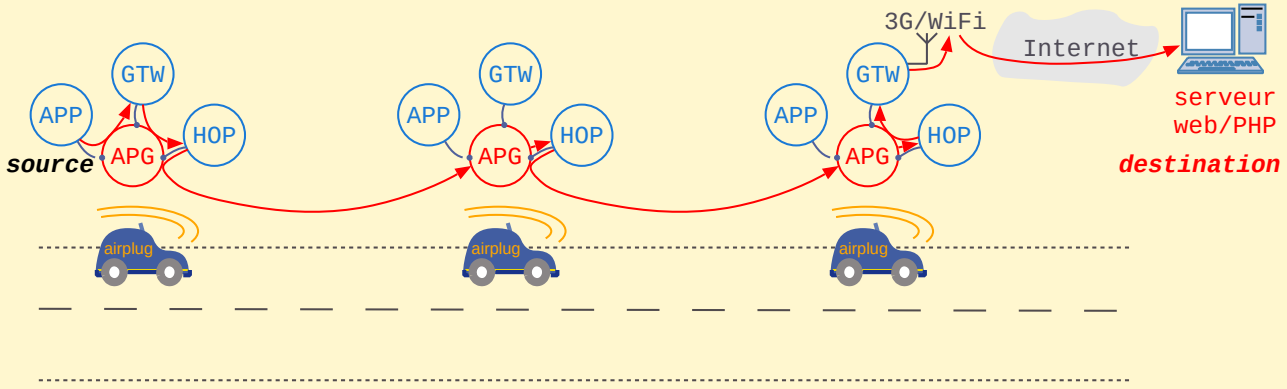

Design examples

Groups service for inter-vehicles applications 1/2

- Specific groups based applications
  - some services are based on collaboration
    driving, diagnostic, perception, infotainment...
  - collaboration ⇝ group
    ⇝ to be maintain as long as possible
  - no collaboration with far vehicles
    either useless (driving, diagnostic, perception...)
    or inefficient (chat, games...)
    ⇝ constraint on the diameter
- GRP: best-effort group service [SPAA 2010]

Design examples

Groups service for inter-vehicles applications 2/2

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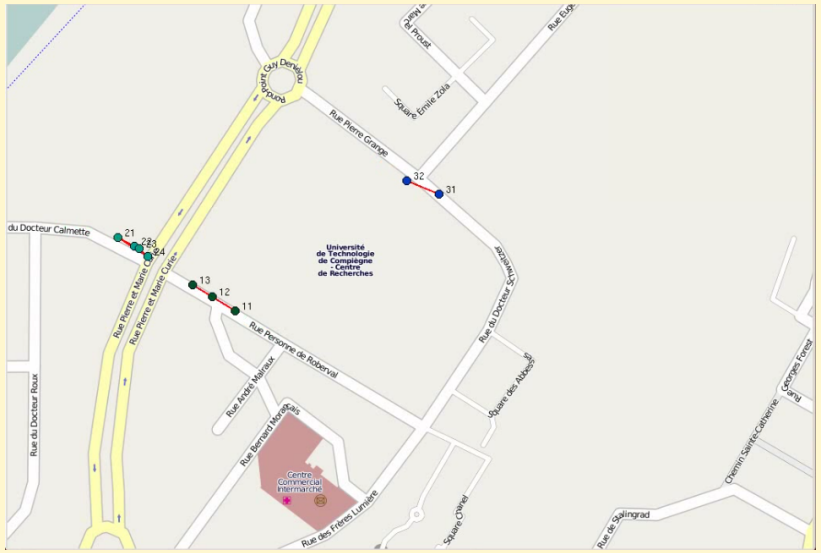


Design examples

Data collect in VANET 1/3

- Motivations
  - Many data produced by vehicles
    Produced by embedded sensors and calculators
  - Could feed intelligent applications
    - infrastructure
    - vehicle-oriented, driver oriented
- Problem to solve
  - Large amount of data
  - Limited network resources
- Literature
  - Dissemination...
  - Request based: require connected network
- Our contribution: protocol COL
  - Self-stabilizing protocol supporting network disconnection

Design examples

Data collect in VANET 2/3

- Start on some *initiators*
  - Any vehicule
    Periodically, or on request (local/infrastructure)
  - Service vehicles
  - Road side unit
- Collect
  - Data in vehicles up to a given distance
  - Update of dynamic data
- Termination
  - Maximal duration
  - Stability of the result
- Result
  - Ordered by the distance to the initiator
  - Allow agregation before exploitation
    Local exploitation
    Dissemination in the close neighborhood
    Sending to the infrastructure...

Design examples

Data collect in VANET 3/3

To show the animation, click on the image if your computer is connected to Internet.

See the video page on the Airplug web site for more details.

Outlines

How to validate new protocols

By proofs

- Validation by proof
  - Prove that a protocol admits some properties
- Requirements
  - Formal modeling
    communication, nodes synchronization, fault...
  - Models for dynamic networks? [SPAA2010]
- Advantages
  - Exact result regarding the model
  - Long term study
- Disadvantages
  - Many different models
  - Model far from reality $\rightsquigarrow$ practical applications?
- Main usages
  - Distributed algorithms [SPAA2010,CFIP2011]
  - Networking performance issues

How to validate new protocols

By simulation

- Validation by simulation
  - Simulate the behavior of the protocol
- Requirements
  - Accurate simulator... [MWCN2005,VTC2010]
  - Packet traffic model
  - Mobility model
- Advantages
  - Allow comparisons between protocols
  - Scalability studies
- Disadvantages
  - Implemented protocols different from reality
  - Simulators and models far from the reality
  - $\rightsquigarrow$ Give only trends
- Main usages
  - Networking performance issues [VTC2011]
  - Protocols comparisons [TVT2007]

How to validate new protocols

By experiments

- Validation by experiments
  - Run the protocol in a real scenario
- Requirements
  - Vehicles, computers, friends...
  - Experimental environment [VTC2009]
  - Implementation of the protocol
- Advantages
  - Prove the usability
  - Give real measures
- Disadvantages
  - Only for few vehicles
  - Limited scenarios
  - Not reproducible Road traffic always different
- Main usages
  - Distributed applications, networking protocols...
  - Proof of concept
  - Performance issues [VTC2011]
  - Comparison/Calibration of simulation/emulation

How to validate new protocols

Emulation 1/2

- Validation by emulation
  - Run the real protocol in an emulation of the network:
    - parts are real
      applications, protocols, mobility, traffic
    - parts are artificially reproduced
      layers 1 and 2
- Requirements
  - Accurate emulator [ICCCN2010]
  - Implementation of the protocol
  - Traffic packets if related to users
- Advantages
  - Real protocol
  - Prove the usability
  - Give accurate measures
  - Reproducible experiments
    Allow to study the influence of a given parameter, of a variant of the algorithm

How to validate new protocols

Emulation 2/2

- Disadvantages
  - More difficult to obtain measures than simulation similar to experiments
  - Inputs required for accurate results [ICCCN2010]
  - Less comparisons...
    Other protocols often not available in the emulator
- Main usages
  - Distributed applications, networking protocols...
  - Proof of concept
  - Performance issues

Emulation: powerful tool for vehicular networks

Outlines

The Airplug Software Distribution

Presentation

- Motivations
  - Experiments useful for guiding the theory
  - Complementarity of validation means
    Proofs, simulation, experiments, emulation
  - Need for an integrating tools
    - Designing new protocols can be fastidious
    - Implementation and tests are time consuming
- The Airplug Software Distribution
  - Prototyping environment — Airplug-term
  - Experiment environment — Airplug-live
  - Emulation environment — Airplug-emu
  - Remote execution — Airplug-remote
  - Simulation environment — Airplug-ns
    for ns-2 only

The Airplug Software Distribution

Designing for dynamic networks

- Addressing for dynamic networks [WINITS 2007]
  - *area*: LCH, AIR, ALL
  - *applications*:
    - a given application
    - all those that subscribed to the sender app
  - Note: similarities with
    - IEEE WAVE Short Messages Protocol
    - messages-oriented frameworks (eg. JMS)
- Three types of communication
  - to simplify the development
  - *what*, *whatwho*, *whatwhowhere*
  - extensible at runtime
  - automatic guessing or safe mode

The Airplug Software Distribution

Components

- Distribution skeleton
  - Libraries and other stuffs for Airplug-term
    Including version management, application packaging, message formatting...
  - Template applications
- Complements for other usages
  - Airplug core program + libraries for Airplug-live
  - EMU application + libraries for Airplug-emu
  - RMT applications + libraries for Airplug-remote
  - Adds-on for ns-2 for Airplug-ns
- Many applications
  - Connection to GPS, Bluetooth, socket...
  - Protocols for routing, transport...
  - Distributed services: group, collect...
  - Applications: chat, games, alert...
  - Teaching applications...
  - ...

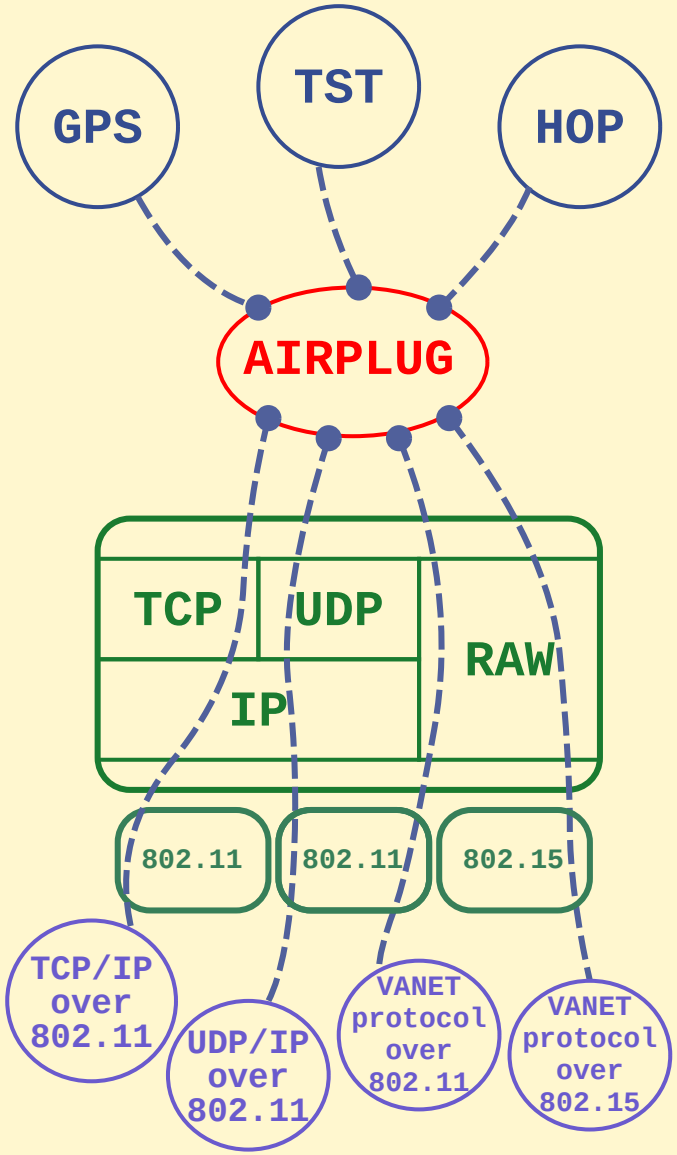
The Airplug Software Distribution

Usage

- Requirements
  - POSIX computer
  - Any language can be used
  - Libraries mainly for Tcl/Tk
- Modular
  - Only parts can be used
  - Or all the applications togethers
- Portable
  - any POSIX OS
  - embedded computers
- Any dynamic network
  - Vehicular networks
  - UAV
  - ...

The Airplug Software Distribution

Process-based architecture

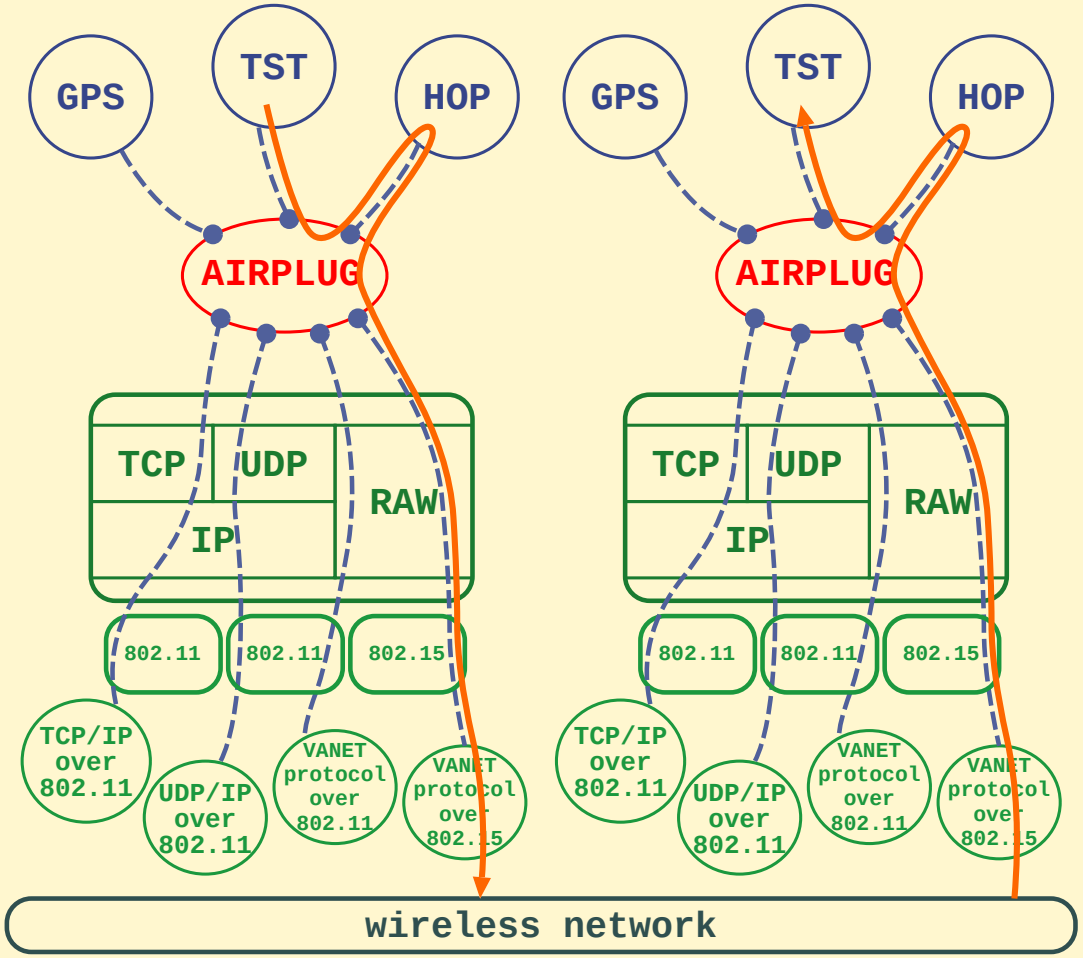


- Posix OS
- core program
  - user-space process
  - networking
- applications
  - user-space process
  - read on stdin
  - write on stdout
  - API close to IEEE WSMP
- ensure tasks and OS independence for robustness
- open to any programming language

The Airplug Software Distribution

Facilities for developing new protocols

- New protocols developed in user space processes
  - open to new networking solutions
  - cross-layer solutions facilitated

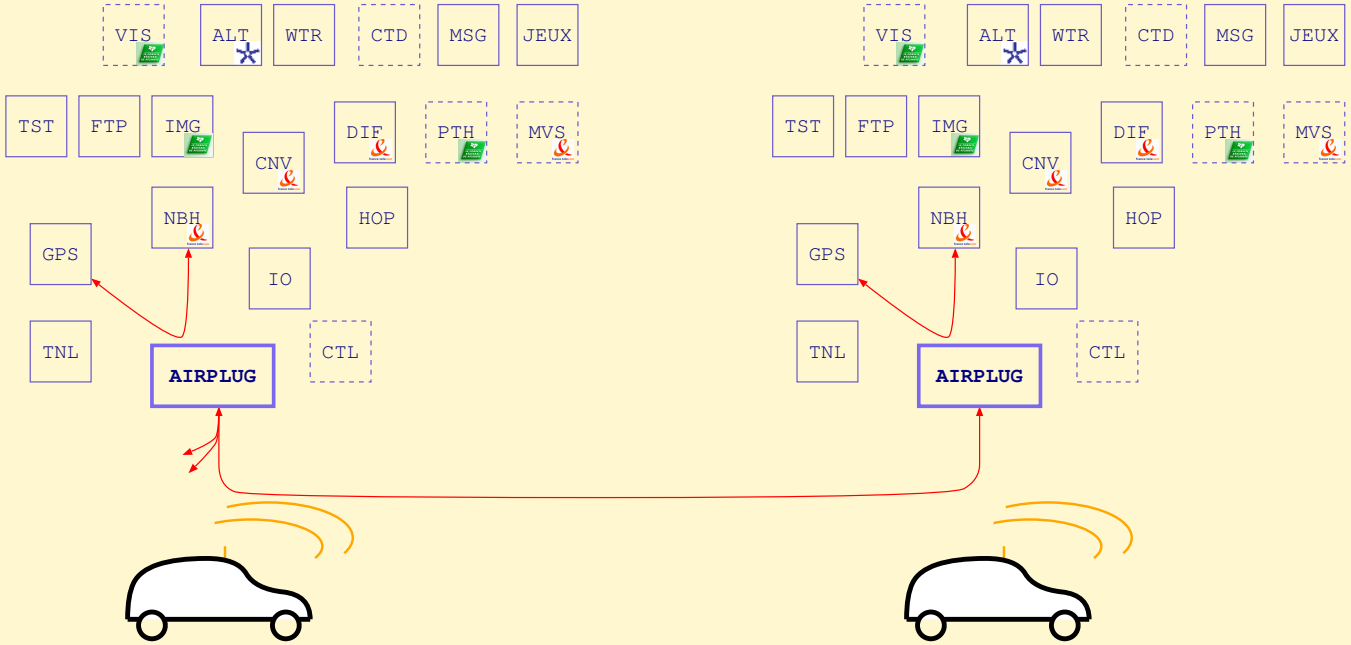


The Airplug Software Distribution

Modularity

- Modular architecture

  Applications for infrastructure, vehicles, drivers, passengers...



http://www.hds.utc.fr/airplug

The Airplug Software Distribution

Complete research platform

- On the road : airplug-road [VTC 2009]
  - in Compiègne, France
  - 2005 in Michelin circuit, France
  - 2007 test-bed with 6 cars with France Telecom R&D
  - 2009 test-bed with 7 cars with France Telecom R&D

  [see movies on-line
  http://www.hds.utc.fr/airplug]

The Airplug Software Distribution

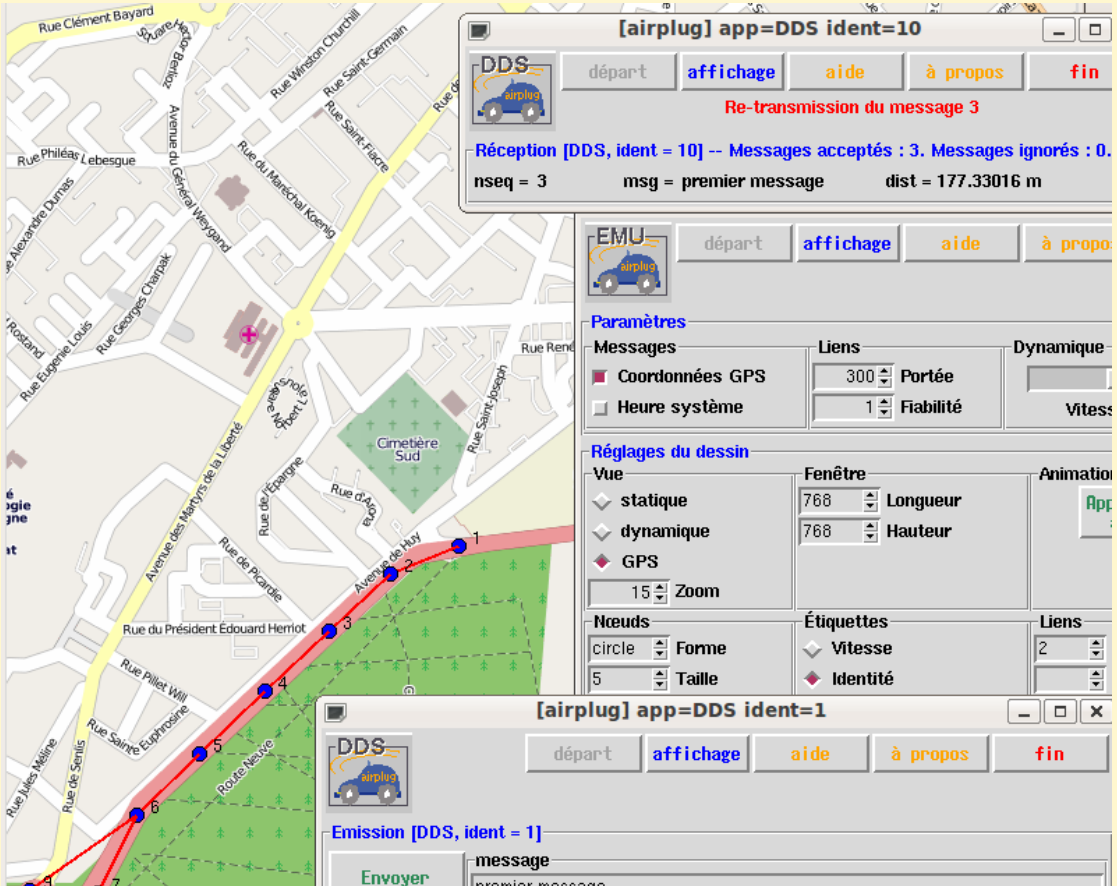
Complete research platform

- On the road : airplug-road [VTC 2009]
- In the laboratory : airplug-lab
  - GPS position replaying
  - new trajectories derived ⇝ convoys
  - out of range messages filtered (soon)

The Airplug Software Distribution

Complete research platform

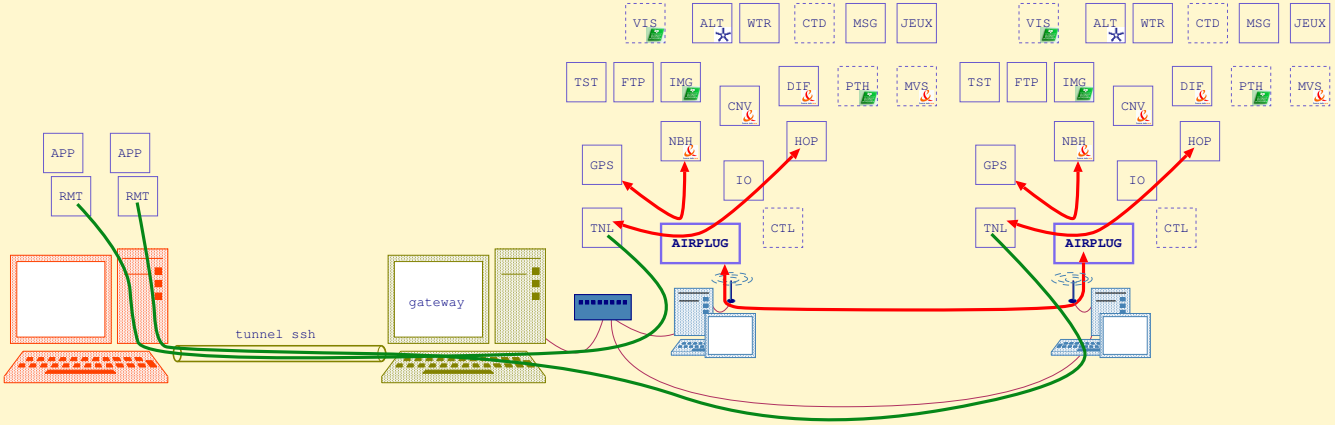
- On the road : airplug-road [VTC 2009]
- In the laboratory : airplug-lab
- In a computer : airplug-emu [ICCCN 2010]
  - using shell facilities
  - emulation of vehicular networks



The Airplug Software Distribution

Complete research platform

- On the road : airplug-road [VTC 2009]
- In the laboratory : airplug-lab
- In a computer : airplug-emu [ICCCN 2010]
- Remotely : airplug-rmt
  - a specific application controls remote access from external applications
  - portability of the applications
    transparent usage stand-alone / remotely / locally
  - heterogeneous vehicular networks emulation



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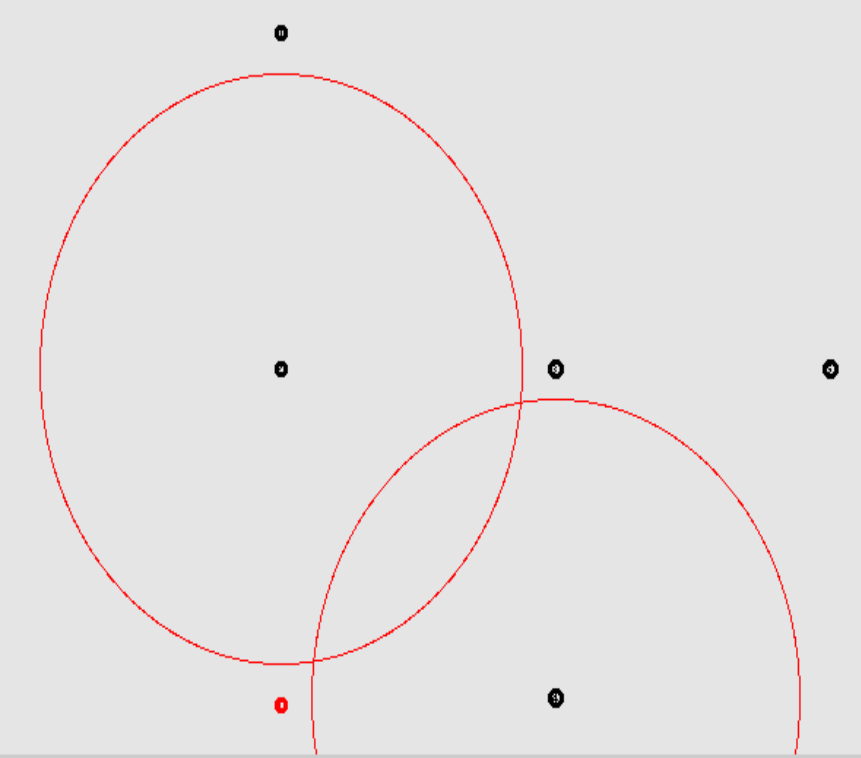

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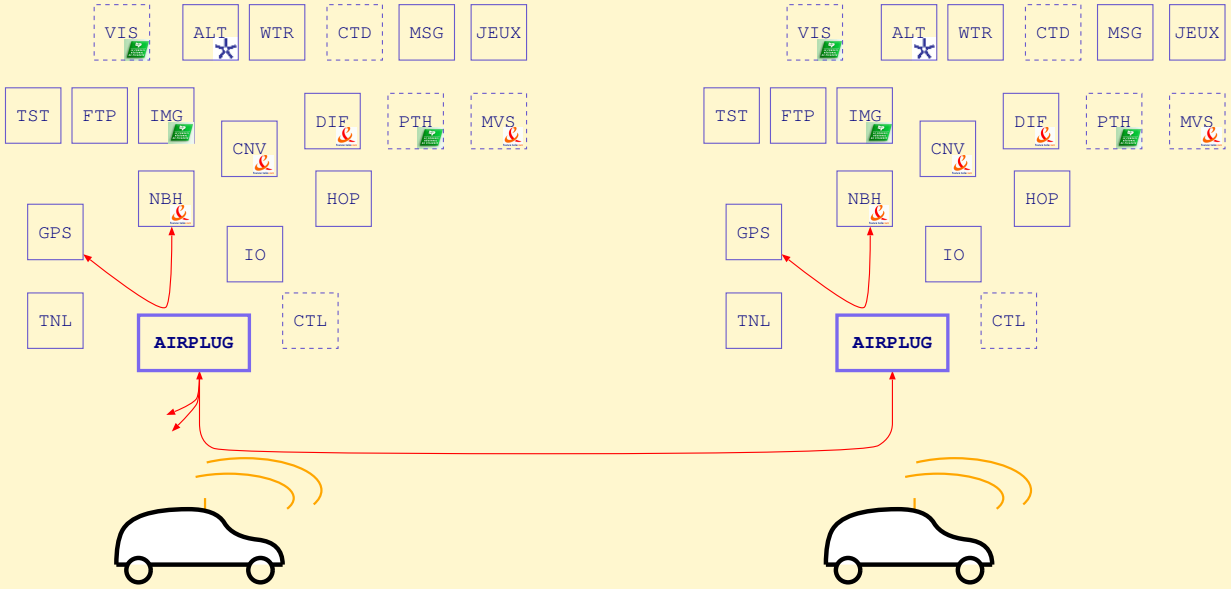
- In all these usages, the same codes are used



Outlines

A Tutorial on Vehicular networks

Conclusion 1/2

- Vehicular Networks
  - Part of the Intelligent Transport Systems
  - Strong motivations
  - Many applications have been imagined
  - Large projects in USA, Europe, Japan...
  - Many research issues
    Networking protocols, Cooperative applications...
- A Challenging Network
  - Strong applications requirements
  - Poor real networking conditions
  - Low layers: 802.11p + WAVE
  - Higher layers: WAVE, IP, CALM
  - Protocols still under discussion
  - Will they reach expected performances?

A Tutorial on Vehicular networks

Conclusion 2/2

- Designing rules for new protocols
  - Vanet: a case of dynamic networks...
    - Dynamic neighborhood, disconnected network
    - Do not rely on remote/global knowledge
  - With some peculiarities
    - Sometimes, regular patterns, infrastr. access
    - A large variety of regularity/density/dynamic
    - Adaptive and embedded solutions required
- Vehicular networks:
  - A general purpose network?
    The case of unicast communication
  - Similar to already known networks?
    - Adapting already known networking solutions
    - vs. designing new ones
- Advantage of an integrative environment
  - The Airplug Software Distribution
  - http://www.hds.utc.fr/airplug

Further information

References of the author' publications cited in this tutorial can be found at
http://www.hds.utc.fr/~ducourth

Movies of the road experiments and screenshots of the protocols in the Airplug-emu emulator can be found at
http://www.hds.utc.fr/airplug

Fill free to contact the author for any question, remark or correction.