A Tutorial on Vehicular Networks

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1. Introduction to the tutorial
2. Intelligent Transport System overview
3. Protocols for a Challenging Network
4. Designing New Protocols
5. Conclusion
1. Introduction to the tutorial
   Vehicular networks: Introduction
   Team
   Outlines

2. Intelligent Transport System overview

3. Protocols for a Challenging Network

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1 Introduction to the tutorial
Vehicular networks: Introduction
Team
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
Vehicular Networks: Introduction

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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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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:
Introduction to the tutorial

Vehicular networks: Introduction
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 mobile 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 conditional transmissions [IEEE TVT 2007]
- IEEE 802.11 fairness [MedHocNet 2006]
- Capacity of vehicular networks [VTC 2005]
By proofs
  for distributed algorithms
  require com. and synchronization models

By simulations
  for networking protocols
  require propagation and MAC model,
  packets traffic and node mobility model

By experiments
  for proof of concept and perf. measuring in situ
  require equipments and logistic

By emulation
  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
Introduction to the tutorial

Vehicular networks: Introduction

Team

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

1. **Introduction to the tutorial**

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

3. **Protocols for a Challenging Network**

4. **Designing New Protocols**

5. **Conclusion**
2 Intelligent Transport System overview

ITS Motivations

ITS Applications

Work-in-progress in Vehicular Networks

Research issues
Intelligent Transportation Systems
Motivations: Road safety

• ≈ 40,000 deaths per year in USA
  ➞ initiatives from Department of Transport (DoT) to reduce the fatalities on roads
  [http://www.its.dot.gov/its_overview.htm]

• Similar objectives in Europe
  ➞ 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
2 Intelligent Transport System overview

ITS Motivations

ITS Applications

Work-in-progress in Vehicular Networks

Research issues
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]
Peer-to-peer network invites drivers to get connected

CarTorrent could smarten up our daily commute, reducing accidents and bringing multimedia journey data to our fingertips

Laura Parker
The Guardian, Thursday 17 January 2008
Article history
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 safetyincident management, crash prevention, collisionavoidance, driver assistance...
  - for automatic/adaptive settings
- Driver oriented services
  - for improving the road usagetraffic jam, road work information, travelerpayment, ride duration estimate...
- Passengers oriented applications
  - for offering new services on boardInternet access, distributed games, chats, touristinf., city leisure inf., movies announces downloads
2 Intelligent Transport System overview

ITS Motivations

ITS Applications

Work-in-progress in Vehicular Networks

Research issues
[H. Hartenstein, K.P. Laberteaux, Wiley]
• 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]
• **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]
• 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]
• **CVIS** Cooperative Vehicle Infrastructure Systems [http://www.cvisproject.org/]
• **SAFESPO**T [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

• ...
• 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
  • 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
- **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]

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<table>
<thead>
<tr>
<th>WG1</th>
<th>WG2</th>
<th>WG3</th>
<th>WG4</th>
<th>WG5</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>Architecture and Cross Layer</td>
<td>Transport and Network</td>
<td>Media and Medium related</td>
<td>Security</td>
</tr>
<tr>
<td>Application Requirements</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
• **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

• ...
ISO/ETSI Reference Architecture

[T. Ernst]
2 Intelligent Transport System overview

ITS Motivations
ITS Applications
Work-in-progress in Vehicular Networks
Research issues
• ITS require a broad range of communications and electronics technologies both in the infrastructure and the vehicle.

• 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
Research issues
Dynamic ad hoc networks

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Dynamic ad hoc networks

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    \[\Rightarrow\] highly unstable neighborhoods
Research issues
Dynamic ad hoc networks

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  - apparition/disappearance of nodes
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  \[\leadsto\] highly unstable neighborhoods
Research issues
Next step in networking?

- Wired networks
- Partially wired networks
- Networks without infrastructure
- Highly dynamic ad hoc networks

Wired network  mobile user  mobile terminal  mobile network  mobile ad hoc networks
dynamic ad hoc networks

with infrastructure  without infrastructure

routers, fixed servers  hand-over...  virtual structures management (tree...)?

Internet, IP  MobileIP  Cellular  MANET  VANET
• A kind of dynamic networks
  VANET: Vehicular Ad hoc NETwork

• 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

1. Introduction to the tutorial

2. Intelligent Transport System overview

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

4. Designing New Protocols

5. Conclusion
3 Protocols for a Challenging Network

Time constraints

Road Tests
Physical layer
Medium Access Control Layer
IEEE 1609 WAVE
IP
CALM
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
Large study by the US Vehicle Safety Communication consortium

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
• **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

<table>
<thead>
<tr>
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<th>Freq.</th>
<th>Lat.</th>
<th>Range</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>I²V, one-way, one-to-many, periodic</td>
<td>10 Hz</td>
<td>100 ms</td>
<td>250 m</td>
<td>traffic signal status, timing, directionality, position of the stopping location, weather condition, road surface type</td>
</tr>
</tbody>
</table>
Time constraints
Traffic signal violation warning application

Time constraints
Traffic signal violation warning application

Time constraints

Traffic signal violation warning application

Time constraints

Traffic signal violation warning 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.

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<tbody>
<tr>
<td>V2I and l2V,</td>
<td>10 Hz</td>
<td>100 ms</td>
<td>300 m</td>
<td>vehicle position, velocity, heading</td>
</tr>
<tr>
<td>one-way, one-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to-many, peri-</td>
<td></td>
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Time constraints
Stop sign movement assistance application 2/2

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Stop sign movement assistance application 2/2

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Stop sign movement assistance application 2/2

Time constraints

Stop sign movement assistance application 2/2

[Vehicular Networks]

Bertrand Ducourthial

Introduction
Vanet & ITS Team
Outlines
ITS overview
Motivations
Applications
In-progress
Issues
Protocols
Time const.
Road Tests
PHY layer
MAC Layer
WAVE
IP
CALM

Design
Design rules
Examples
Validation
Airplug

Conclusion

• **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)

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<tbody>
<tr>
<td>V2V, one-way, one-to-many, event-driven</td>
<td>10 Hz</td>
<td>100 ms</td>
<td>300 m</td>
<td>position, heading, velocity, deceleration</td>
</tr>
</tbody>
</table>

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 vehicle-to-vehicle communications
- larger for infrastructure-to-vehicle communications
- maximum of \( \sim 430 \) bytes for left turn assistant application

Protocols for a Challenging Network

Time constraints

Road Tests

Physical layer

Medium Access Control Layer

IEEE 1609 WAVE

IP

CALM
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](http://www.hds.utc.fr/airplug)

- **Hardware:**

  Heudiasyc & Orange Labs vehicles
• 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)
  \[ \text{external events, distance (\neq radio)} \]
  \[ \neq \text{simulation} \]
Road test

Results: reception rate with repeated packets

- Vehicle reached (number of hops) for a given reception rate, function of the number of repetitions
A reasonable number of repetitions can be done without exceeding the security delay (2 s).
3 Protocols for a Challenging Network

Time constraints

Road Tests

Physical layer

Medium Access Control Layer

IEEE 1609 WAVE

IP

CALM
Vehicular Networks

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Introduction
Vanet & ITS Team
Outlines

ITS overview
Motivations
Applications
In-progress Issues

Protocols
Time const.
Road Tests
PHY layer
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IP
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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 multipath
• **DSRC**: Dynamic Short Range Communications
  Not the same signification in US and EU

• **ITS**: Intelligent Transportation Systems
• Channels of 5, 10 and 20 MHz instead of 20 MHz:
  • Doppler spread up to 2 kHz  
  • RMS delay spread up to 0.8 µs
  • 20 MHz channel in 802.11a  \(\rightarrow\) 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  \(\rightarrow\) advanced receiver or specific OFDM

[Mittag et al. in VANET, Wiley 2009]
Protocols for a Challenging Network

- Time constraints
- Road Tests
- Physical layer
- Medium Access Control Layer
- IEEE 1609 WAVE
- IP
- CALM
- **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 Environment
  - WAVE covers OSI layers 2 (MAC), 3 and 4
  - *MAC extension for multi-channel operation*

Note: protocols still under discussion
IEEE 802.11 Distributed Coordinated Function 1/2

DIFS

Contention Window

DIFS

Backoff-Window

Next Frame

Slot time

Defer Access

Select Slot and Decrement Backoff as long as medium is idle

DIFS

PIFS

SIFS

Busy Medium

IEEE 802.11, 1999
IEEE 802.11 Distributed Coordinated Function 2/2

DIFS

Station A: Frame → CWindow
Station B: Defer → Backoff
Station C: Defer → Frame → CWindow
Station D: Defer → Frame
Station E: Defer → Frame → CWindow

CWindow = Contention Window

= Backoff
= Remaining Backoff

[IEEE 802.11, 1999]
**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
[ANSI/IEEE Std 802.11, 1999]
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
Communication outside 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
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
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]
### EDCA parameters for CCH

<table>
<thead>
<tr>
<th>AC</th>
<th>CWmin</th>
<th>CWmax</th>
<th>AIFSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>aCWmin</td>
<td>aCWmax</td>
<td>9</td>
</tr>
<tr>
<td>Best effort</td>
<td>(aCWmin + 1)/2 - 1</td>
<td>aCWmin</td>
<td>6</td>
</tr>
<tr>
<td>Video</td>
<td>(aCWmin + 1)/4 - 1</td>
<td>(aCWmin + 1)/2 - 1</td>
<td>3</td>
</tr>
<tr>
<td>Voice</td>
<td>(aCWmin + 1)/4 - 1</td>
<td>(aCWmin + 1)/2 - 1</td>
<td>2</td>
</tr>
</tbody>
</table>

### EDCA parameters for SCH

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<td>3</td>
</tr>
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</table>
Protocols for a Challenging Network

Time constraints
Road Tests
Physical layer
Medium Access Control Layer
IEEE 1609 WAVE
IP
CALM
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 1609.2

IEEE 1609.3

IEEE 802.11p

IEEE 802.11

MAC Sublayer

Networking Services

Higher Layers

Security Services

PHY Layer

Medium

Medium

OSI Reference Model

Application, Presentation, Session

Transport

Network

Data Link

Physical

WAVE Model

ITSI overview

Motivations

Applications

In-progress Issues

Protocols

Time const.

Road Tests

PHY layer

MAC Layer

WAVE

IP

CALM

Design

Design rules

Examples

Validation

Airplug

Conclusion

Vehicular Networks

Bertrand Ducourthial

Introduction

Vanet & ITS Team

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

[IEEE Std 1609-3, 2007]
• 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.
3 Protocols for a Challenging Network

Time constraints
Road Tests
Physical layer
Medium Access Control Layer
IEEE 1609 WAVE
IP
CALM
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]
• 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
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
- 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 al.]
  - SLAAC (*Stateless Address Autoconfiguration*)
    using NDP (*Neighbour Discovery Protocol*) to check the unicity of IP
  - C2C-CC geographic routing for local broadcast
3 Protocols for a Challenging Network

Time constraints

Road Tests

Physical layer

Medium Access Control Layer

IEEE 1609 WAVE

IP

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]

<table>
<thead>
<tr>
<th>SWG 16.0</th>
<th>CALM Architecture</th>
</tr>
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<tbody>
<tr>
<td>SWG 16.1</td>
<td>CALM Media (low layers)</td>
</tr>
<tr>
<td>SWG 16.2</td>
<td>CALM IPv6 networking</td>
</tr>
<tr>
<td>SWG 16.3</td>
<td>Probe Data</td>
</tr>
<tr>
<td>SWG 16.4</td>
<td>Application Management</td>
</tr>
<tr>
<td>SWG 16.5</td>
<td>Emergency notifications (eCall)</td>
</tr>
<tr>
<td>SWG 16.6</td>
<td>CALM non-IP networking</td>
</tr>
<tr>
<td>SWG 16.7</td>
<td>Security, Lawful intercept</td>
</tr>
</tbody>
</table>
- 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

Combined CALM host and router
(SWG16.2: ISO 21217)

- CME
- NME
- IME

Management Information Base (MIB)
(SWG16.1 ISO 24102)

CALM networking layer

- CALM FAST
- Geo-routing
- Others

Internet IPv6
(SWG16.2: ISO 21210)

CALM CI layer
(SWG16.1: ISO 21218)

CI wireless
CI wired

CALM service layer

- CALM FAST
- Non-CALM-aware
- CALM IP-based

(SWG16.3: Probe data)
(SWG16.4: Application management)
(SWG16.5: eCall)

CALM Communications Kernel

[ISO TC 204 Draft Business Plan, 2008]
• CALM is not developing handover protocols
• Relies on IETF IPv6 protocols for vertical handovers
• Relies on medium-specific protocols for horizontal handover
1. Introduction to the tutorial

2. Intelligent Transport System overview

3. Protocols for a Challenging Network

4. Designing New Protocols
   - Designing rules for new protocols
   - Design examples
   - Validating new protocols
   - The Airplug Software Distribution

5. Conclusion
4 Designing New Protocols

Designing rules for new protocols

Design examples

Validating new protocols

The Airplug Software Distribution
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

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The relation for remote knowledge:

Dynamic $\Rightarrow$ cost $\Rightarrow$ usefulness

Dynamic $\Rightarrow$ preciseness $\Rightarrow$ usefulness
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...
• **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?
4 Designing New Protocols
   Designing rules for new protocols
   Design examples
   Validating new protocols
   The Airplug Software Distribution
• Conditions instead of addresses: more adapted to dynamic networks [IEEE TVT 07]

• CUP: upward condition
  eg. being back on the sender
  (evaluation by GPS positions correlations)

• CFW: upward condition
  eg. being not so far from the sender
Design examples
Conditional transmissions 1/2

- Conditions instead of addresses: more adapted to dynamic networks
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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.
V2I opportunistic communications

- Sending data from the vehicles to a web server

  - GTW
    - V2V: conditional transmission
    - V2I: IPv4, IPv6, WiFi hot-spot, 3G

[CFIP 2009]
V2I opportunistic communications

- Sending data from the vehicles to a web server

- **GTW**
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![Diagram of V2I communications](image)
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Diagrams of traffic flow and network connections.
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[CFIP 2009]
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]
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.
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 vehicle
    - 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 aggregation before exploitation
    
    - Local exploitation
    - Dissemination in the close neighborhood
    - Sending to the infrastructure...
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.
4 Designing New Protocols

Designing rules for new protocols
Design examples
Validating new protocols
The Airplug Software Distribution
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
  - ⇝ 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
  • Implementation of the protocol

• Advantages
  • Prove the usability
  • Give real measures

• Disadvantages
  • Only for few vehicles
  • Limited scenarios
  • Not reproducible

• Main usages
  • Distributed applications, networking protocols...
  • Proof of concept
  • Performance issues
  • 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
  - 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**
4 Designing New Protocols
   Designing rules for new protocols
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   The Airplug Software Distribution
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
• **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
  - in Michelin circuit, France
  - test-bed with 6 cars with France Telecom R&D
  - 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
- In the laboratory: airplug-lab
  - GPS position replaying
  - new trajectories derived \(\mapsto\) convoys
  - out of range messages filtered (soon)

On the road: airplug-road
- GPS position replaying
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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
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
- In Network Simulator: airplug-ns [VTC 2010]
The Airplug Software Distribution
Complete research platform

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- In all these usages, the same codes are used
Introduction to the tutorial

Intelligent Transport System overview

Protocols for a Challenging Network

Designing New Protocols

Conclusion
• **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?
• **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
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-emulator can be found at http://www.hds.utc.fr/airplug

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