Nomadic Communications AA 2010/11

Vehicular Ad Hoc Networks

90% of this material is reproduced (with permission!) from a tutorial at MobiHoc 2007

thanks to the original authors:

Hannes Hartenstein
University of Karlsruhe
Karlsruhe, Germany
hartenstein@rz.uni-karlsruhe.de

Ken Laberteaux
Toyota Technical Center
Ann Arbor, USA
ken.laberteaux@tema.toyota.com

Agenda

- Vehicular networks are a very active research/development area
- Recent advances in location (GPS/Galileo) and communication techniques made them technically feasible
- Burst of interest
  - From authorities to reduce accidents and enhance infrastructure usage
  - From car factories to improve safety and increase vehicles appeal
- Possibility of Master theses
  - In Trento
  - With Erasmus Exchange in Carlsruhe (Hartenstein)

Agenda

1. Applications and recent projects
2. Mobility and radio channel
3. Communication technology and strategies
4. Architectural and application-specific issues
5. Security and privacy aspects
6. Discussion

Scope

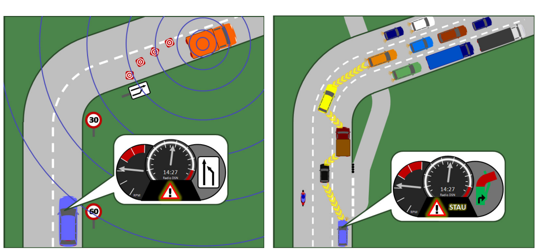
- **Networking-centric view to Vehicular Ad Hoc Networks**
- Focus is on wireless local area networking techniques for communication between vehicles and between vehicles and roadside units
  - Not on Inter-Vehicle Communications (IVC) based on wide area cellular networks
- We do not look at location techniques
- We do not look at services nor at transmission techniques and details

Agenda

1. Applications and recent projects

2. Mobility and radio channel
   incl. modeling and simulation
3. Communication technology and strategies
   incl. modeling and simulation
4. Architectural and application-specific issues
5. Security, privacy and incentives aspects
6. Discussion

Active safety



[Graphics by S. Labitzke]

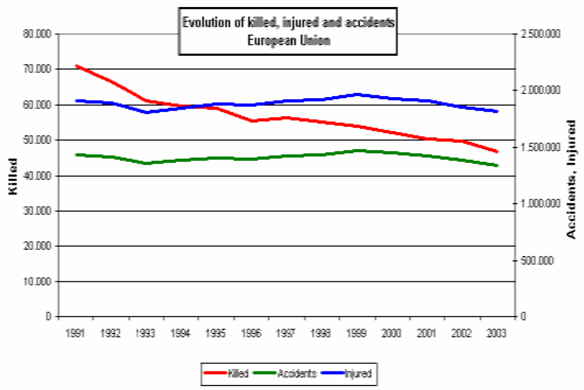
A digression on Fatalities (EU 2005)

- **Main Causes and driving errors:**
  - 95% of all road accidents involve some human error
  - In 76% of the cases the human is solely to blame
  - Misjudging, driving dynamics, weather (50%)
  - Distraction (38%)
  - **39% of passengers vehicles and 26% of trucks do not activate brakes before a collision**
  - Some 40% more do not brake effectively

- **Underlying Causes:**
  - Alcohol
  - Inexperience
  - Tiredness

- **Road Accidents**
  - 41.600 fatalities
  - 1.4 million accidents involving injury
  - 2.0 million injuries

A digression on Fatalities (EU 2005)



Cooperative-Driving or Info-Tainment

- The main "official" push for Vanets is safety/efficiency
- Industry (automotive) needs a revenue "golden fleece" to invest
- Industry (other) see a possible huge market for generic applications, from local info/ads to entertainment
- Technicians/scientists need to put it all together

Infrastructure and Equipment

- The average car life is 8-10 years ... with many lasting 20 or more
- Cooperative driving requires a very high penetration, say > 50%
- ... so what ...
- The chosen technology will peack in about 20 years and be still there after 40
- This is a different "pace" wrt the communication marketplace

Retrofitting & starting from the superflous

- Communications can be put on any car as an add-on feature
  - Just like GPS navigation, most of the installed systems are not "embedded"
- Building cooperative driving on top of add-on is not feasible, but safety is much more than CoDri and InfoTainment can be appealing
  - Accidents warnings can be given to the driver, not to the breaks
  - Dangerously small distances can trigger alarms (beware of too many false alarms!)
  - ...

Working together and ... the missing leg

- We're missing the road management from the picture
- Starting from a simple information delivery systems (cheap and incremental) can convince users of the utility of retro-fitting
  - Add a communication AP every time a mobile message system is added/maintained
- When the penetration is enough increment services with the safety goal
- Cooperative Driving ... will come by itself when times are mature

VSC ranking of safety-related applications

1. Traffic Signal Violation Warning
2. Curve Speed Warning
3. Emergency Electronic Brake Lights
4. Pre-Crash Warning
5. Cooperative Forward Collision Warning
6. Left Turn Assistant
7. Lane Change Warning
8. Stop Sign Movement Assistance

Communication requirements:

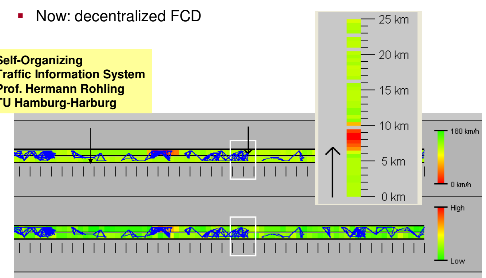
Periodic
10Hz
100ms latency
150m range

Vehicle Safety Communications Project – Final Report, DOT HS 810 591, April 2006

Traffic information system

- Floating Car Data (FCD): traffic information based on measurements of driving vehicles
  - Now: decentralized FCD

Self-Organizing
Traffic Information System
Prof. Hermann Rohling
TU Hamburg-Harburg



Roadside (commercial) services

- Electronic payments
- Drive-by info-fueling
  - DaimlerChrysler
- Drive-thru internet
  - Work by Ott und Kutscher
- Point of interest notifications
  - Location-based services
- ...

[Source: Network on Wheels project]

Overview

Wide variety of telematics services could benefit from VANETs:

- Fleet management (asset management)
- Vehicle remote diagnostics
- Entertainment
- Tolling
- Routing and information systems
- Safety
- ...

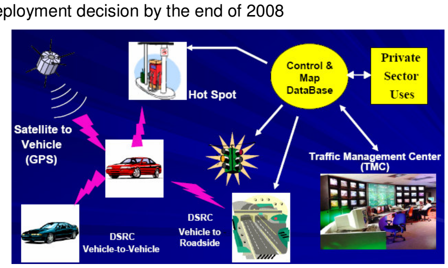
Our focus (Routing and information systems; Safety)

Safety versus efficiency

- Target could be efficiency, still it might be highly safety-critical
- Convention on Road Traffic
  - Vienna, Nov. 8, 1968
  - By Economic Commission for Europe
  - "Every moving vehicle ... should have a driver." (Article 8 (1))
  - "Every driver shall at all times be able to control his vehicle ..." (Article 8 (5))
- Our focus: driver assistance

Vehicle Infrastructure Integration

- Goals: reduce societal costs of crashes and traffic congestion
- Deployment decision by the end of 2008



Source: http://www.sigmobile.org/workshops/vanet2006/slides/Cops_VANET06.pdf

Agenda

1. Applications and recent projects
2. ***Mobility and radio channel incl. modeling and simulation***
   Basic building blocks for research
3. Communication technology and strategies incl. modeling and simulation
4. Architectural and application-specific issues
5. Security and privacy aspects
6. Discussion

Vehicular traffic flow modeling

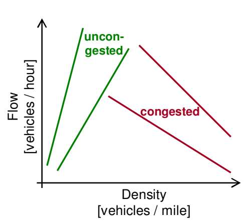
- More than 50 years of research
- Disciplines involved: civil engineering, physics
- Recommended overview paper (and reference used):

> State-of-the-art of vehicular traffic flow modelling,
> S. P. Hoogendoorn, P. H. L. Bovy,
> Journal of Systems and Control Engineering, 215(4):283-304,
> August 2001,
> Special Issue on Road Traffic Modelling and Control

- Level-of-detail classification:
  - (Sub-) Microscopic models
  - Mesoscopic models
  - Macroscopic models

Fundamental terms in traffic flow theory

- Traffic density
  - Number of vehicles per km
- Traffic flow
  - Number of vehicles per hour passing a specific cross-section
- Average velocity
- Time headway
  - Distance in time of two successive vehicles



Flow-density relation
'Fundamental diagram'

Characterization of traffic flow models

- Macroscopic models:
  - Do not look to individual entities
  - Feature of the aggregation
  - Typical features: flow-rate, density, average velocity
- Mesoscopic models:
  - Specify behavior on an individual level
  - But do not trace individual vehicles
  - Example: time-headway distribution
- Microscopic models:
  - Space-time behavior of vehicles and drivers
  - Their interactions
  - On individual level
  - Examples: car-following models, cellular automaton approaches

[Source: Hoogendorn, Bovy 2001, see previous slides]

Needed: accurate models of cities and freeways

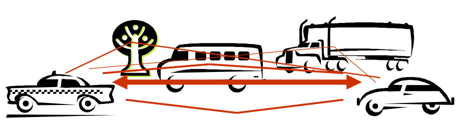
- Need for models, simulation tool is not enough
  - Topological data
  - Vehicular traffic flow data
  - Example: city scenario
    - Origin-destination pairs for vehicles, travel demand models
- Topological data
  - Example: TIGER database (Topologically Integrated Geographic Encoding and Referecing)

> Modeling mobility for vehicular ad hoc networks,
> A. K. Saha, D. B. Johnson,
> Proc. ACM VANET, 2004, p. 91-92

- Validation, calibration takes time
- We need more calibrated models of cities etc. for public use ...

Radio channel characterization

- 'Classical' experimental set-up:
  - Two cars in the desert
  - Results look great
- In reality:
  - Strong environmental influence
  - Typically, strong radio fluctuations



The classical path loss model: two-ray ground (1)

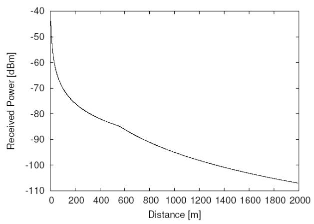
- Fundamental path loss model, lack of realism if used on its own
- Described based on NS-2 (combines free space with TRG)

Received power depending on distance *d*

$$P_r(d) = \begin{cases} \frac{P_t G_t G_r \lambda^4}{(4\pi)^2 d^2 L}, & d \leq d_c \\ \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}, & d > d_c \end{cases}$$

Transmit power

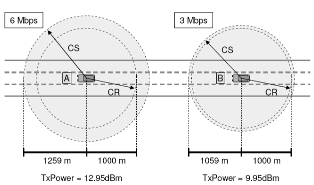
Crossover distance



Parameter	Value
Antenna gain (G_t and G_r)	4 dB (2.512)
Antenna height (h_t and h_r)	1.5 m
Carrier wavelength (λ)	50.85 mm
System loss (L)	1

The classical path loss model: two-ray ground (2)

- Reception and interference models:
  - Carrier Sense Threshold → Carrier sense range (CS)
  - Reception Threshold → Communication range (CR)
  - Capture Threshold



Parameter	Value
6 Mbps data rate: Reception Th. (RxTh) Capture Th. (CpTh)	 -92 dBm 7 dB
3 Mbps data rate: Reception Th. (RxTh) Capture Th. (CpTh)	 -95 dBm 4 dB
Carrier Sense Th. (CSTh)	-96 dBm
Noise	-99 dBm

Probabilistic models

- More realistic: include fading or shadowing model
- Notion of CS range and communication range has to be adapted
  - Mean value → 'Intended CS/communication range'
- Influential paper:

> Effects of Wireless Physical Layer Modeling in Mobile Ad Hoc Networks, M. Takai, J. Martin and R. Bagrodia, *Proc. ACM Int. Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc 2001)*, October 2001, pp. 87-94

- Log-normal shadowing (part of NS-2 release)
- Rayleigh and Ricean fading: modules for NS-2
  - http://www.ece.cmu.edu/~wireless/
  - http://web.informatik.uni-bonn.de/IV/BoMoNet/ns2.htm

Nakagami m-distribution (1)

- Empirical data and curve fitting by V. Taliwal et al. in 2004

> Empirical determination of channel characteristics for DSRC vehicle-to-vehicle communication, Vikas Taliwal, Daniel Jiang, Heiko Mangold, Chi Chen, Raja Sengupta, ACM VANET 2004, p. 88

- Nakagami: original work

> m-Distribution, a General Formula of Intensity Distribution of the Rapid Fading, M. Nakagami, in: Statistical Methods in Radio Wave Propagation, W.C. Homan, Ed. Oxford, England: Pergamon, 1960.

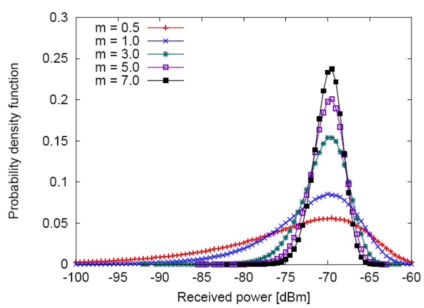
- Nakagami m-distribution: two-parameter family

$$f_{amp}(x;m;\Omega) = \frac{2m^m}{\Gamma(m)\Omega^m} x^{2m-1} \exp\left(-\frac{m}{\Omega}x^2\right); \quad m \geq \frac{1}{2}$$

Fading intensity

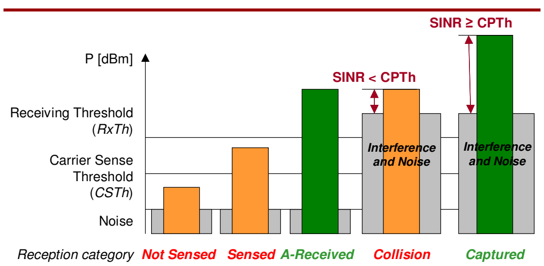
Average received power

Nakagami m-distribution (2)



- Various m-values, $\Omega \approx$ -70dBm

Reception modeling



- Additional category: 'Ignored' (packet arrival during sending)
- **Sophisticated capture model of modern chipsets**
  - **Almost independent of ordering of incoming packets**

Agenda

1. Applications and recent projects
2. Mobility and radio channel
   incl. modeling and simulation
3. ***Communication technology and strategies incl. modeling and simulation***
4. Architectural and application-specific issues
5. Security and privacy aspects
6. Discussion

Structure

3. Communication technology and strategies incl. modeling and simulation

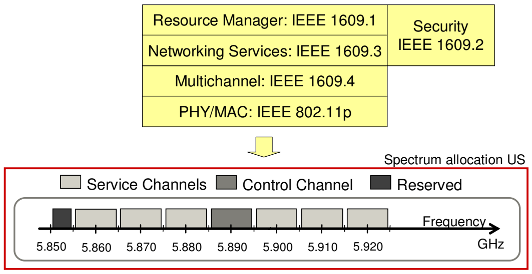
1. ***IEEE 802.11p MAC basics***
2. ***One-hop broadcasts ('beacons')***
   1. ***Performance analysis of 802.11p***
   2. ***Power control***
   3. ***Repetition strategies***
3. ***Multi-hop communication***
   1. ***Unicast position-based forwarding (PBF)***
   2. ***Unicast contention-based forwarding (CBF)***
   3. ***Information dissemination***
4. ***Multi-channel operation***

Standards

- Frequency allocation (specific for IVS) is now agreed upon in the 5.8-5.9 GHz band
  - Definitely short range (< 1000m range)
  - Licenced to avoid too much interference
  - Easy to make directional systems
- PHY is derived from OFDM WLANs
- MAC is mixed random/guaranteed access with priorities

The current IEEE WAVE standards landscape

- WAVE: 'Wireless Access in Vehicular Environments'



IEEE P1609

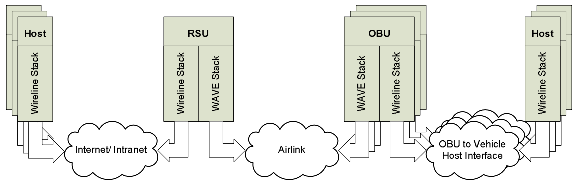
- **Wireless Access in Vehicular Environments (WAVE)**
- **IEEE P1609.1 - Resource Manager**
  - services and interfaces for resource management
  - Describes key components
  - Defines data flows and resources
  - Defines command message formats and data storage formats
  - Specifies the types of devices that may be supported by the On Board Unit (OBU)
- **IEEE P1609.2 - Security Services for Applications and Management Messages**
  - Defines secure message formats and processing
  - Defines the circumstances and purposes/contents for using secure message exchanges
  - Specify mandatory processing based for specific exchanges

IEEE P1609

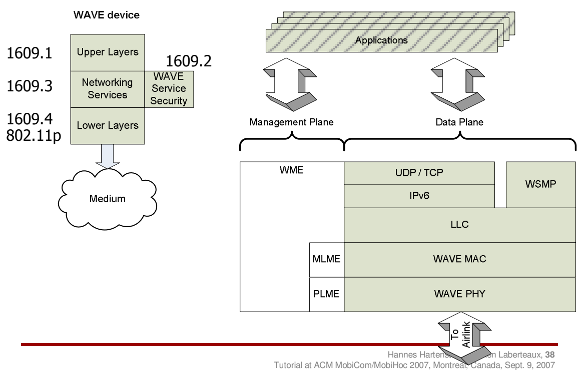
- **IEEE P1609.3 - Networking Services**
  - Network and transport layer services, including addressing and routing
  - Defines Wave Short Messages (WAVE-specific alternative to IPv6)
  - Defines the Management Information Base (MIB) for the WAVE protocol stack
- **IEEE P1609.4 - Multi-Channel Operations**
  - Enhancements to the IEEE 802.11 MAC to support WAVE operations

1609: system architecture

- Encompasses both CtC and ItCtI communications
- Defines also a subnet on the vehicle for info distribution and management



1609: protocol architecture



IEEE 802.11p

- Define 802.11 modes for
  - Rapidly changing PHY
  - Very short-duration communications exchanges
- Provide the minimum set of specifications to ensure interoperability
- Support transactions shorter (in time) than the minimum possible with infrastructure or ad hoc 802.11 networks
- Defines WAVE signaling and interface controlled by the MAC
- Describes functions and services required by WAVE-conformant stations

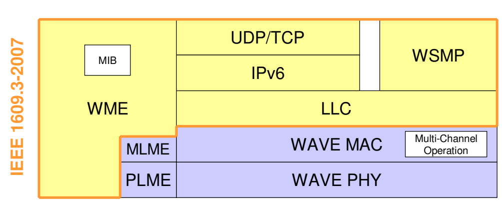
Agenda

1. Applications and recent projects
2. Mobility and radio channel
   incl. modeling and simulation
3. Communication technology and strategies
   incl. modeling and simulation
4. ***Architectural and application-specific issues***
5. Security and privacy aspects
6. Discussion

Structure

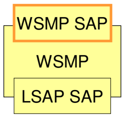
4. ***Architectural and application-specific issues***
   1. ***System architecture***
   2. ***Middleware***
   3. ***Application centric performance evaluation***
   4. ***Decision and control aspects***

WAVE protocol stack



- WAVE: Wireless Access in Vehicular Environments
- WSMP: Wave Short Message Protocol
- WME: Wave Management Entity

WAVE Short Message Protocol



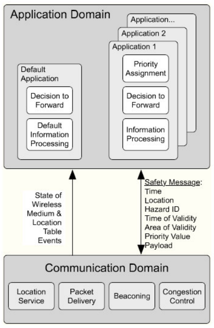
- WSM-WaveShortMessage.request

  Parameters of primitive contain 'ChannelInfo':
  - ChannelNumber
  - Adaptable
  - DataRate
  - TxPwr_Level
- Permits applications to control these transmit parameters for each individual frame
- WSM-WaveShortMessage.indication

WSM header format:

1	1	1	1	1	4	2	variable
WSM Version	Security Type	Channel Number	Date Rate	TxPwr_ Level	PSI	WSM Length	WSM Data

Data packets versus information



- Balance between 'networking services' and applications?
- Existence of 'dumb' nodes
  - Forwarding of packets, no understanding of 'semantics'

System design for information dissemination in VANETs,
M. Torrent Moreno, A. Festag, H. Hartenstein,
Proc. 3rd Int. Workshop on Intelligent Transportation,
Hamburg, Germany, 2006

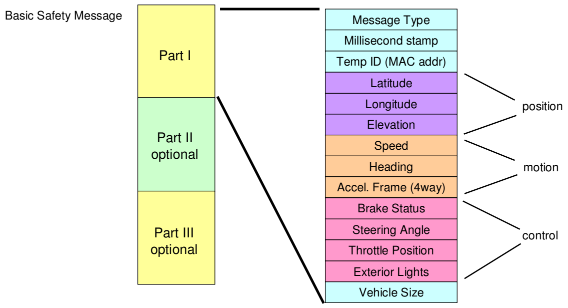
Middleware: message sets

- SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE Recommended Practice, Dec. 2006)
  - Goal: communication interoperability vehicle-vehicle and vehicle-infrastructure
  - Goal: support for innovation and product differentiation in applications
  - Therefore: standard, but flexible and extensible messages that are distinct from applications
  - More than 70 data elements: Acceleration to YawRate (e.g. anti-lock brake state, heading, latitude/longitude, rain sensor, vehicle length, wiper rate and status etc).
  - Messages composed of elements identified with light-weight tagging scheme

Name	DE_VehicleLatitude
Unique ID	70
Unit	microdegrees
Accuracy	LSB is 1 microdegree
Range	-900000000 to 900000000
Size	32bits
Description	The latitude position of the center of the vehicle, expressed in micro degrees and based on the WGS-84 coordinate system.

Example: latitude element

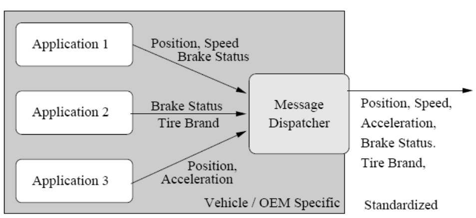
Middleware: message sets



A La Carte Messages are also defined, with arbitrary elements and ordering, using same tagging schema

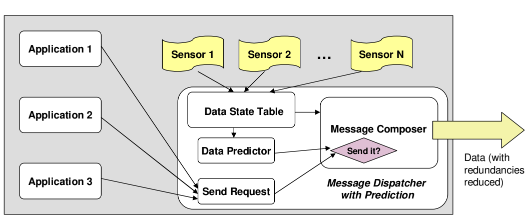
Middleware: message dispatcher

Efficient coordination and transmission of data for cooperative vehicular safety applications,
C.L. Robinson, L. Caminiti, D. Caveney, K. Laberteaux,
Proc. ACM VANET, 2006



Middleware: message dispatcher with prediction

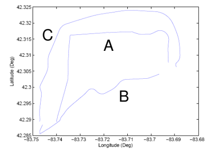
Efficient Message composition and Coding for Cooperative Vehicular Safety Applications,
C. L. Robinson, D. Caveney, L. Caminiti, G. Baliga, K. Laberteaux and P. R. Kumar
IEEE Transactions on Vehicular Technology, To Appear



Middleware: message dispatcher with prediction

Data Set Collected-Ann Arbor, MI, USA

Parameter	Data Set A	Data Set B	Data Set C
Environment	Urban	Urban	Highway
Sample Freq.	5Hz	5Hz	5Hz
Duration	8min 24sec	10min 34sec	6min 17sec
Length	6.1km	7.6km	9.1km
# of Stops	2	2	0
# Turns	7	5	0

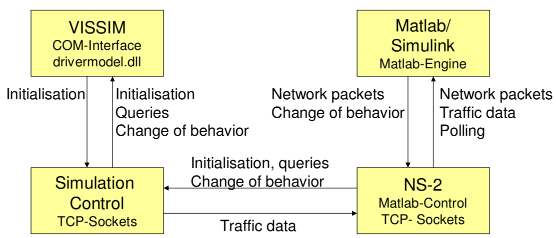


Data Element	*E[error] at end of 200 msec.*	*Data rate of predicted data, with 0.25 Hz lower bound*	*Data rate of predicted data*
Latitude (deg)	3.33 E-5	0.26	0.07
Longitude (deg)	2.77 E-5	0.27	0.10

With appropriate middleware design, the data-rate of safety messages may be much smaller than originally expected.

Application-centric performance evaluation

- Requires joint treatment of communication and vehicular traffic systems



Multiple simulator interlinking environment for IVC, Christian Lochert et al., Proc. ACM VANET, 2005

Selection of other coupling approaches

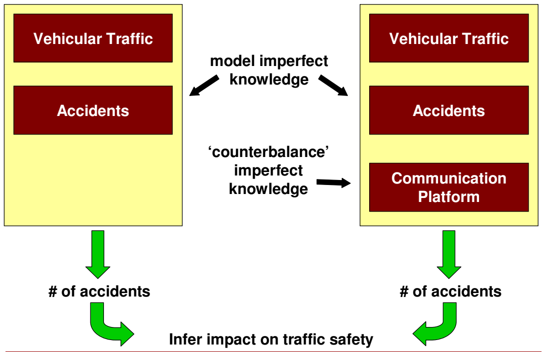
An Integrated Vehicular and Network Simulator for Vehicular Ad-Hoc Networks, C. Gorgorin, V. Gradinescu, R. Diaconescu, V. Cristea, L. Iftode, 20th European Simulation and Modelling Conference, 2006

- A 'monolithic' design: vehicular and network simulator parts are built together in one (new) simulator framework
  - Tiger topology, Wiedemann-74 traffic flow model
  - Nice: fuel consumption and pollutant emission estimation modules included

Simulation of car-to-car messaging: Analyzing the impact on road traffic, S. Eichler, B. Ostermaier, C. Schroth, and T. Kosch, Proc. 13th IEEE MASCOTS'05, 2005.

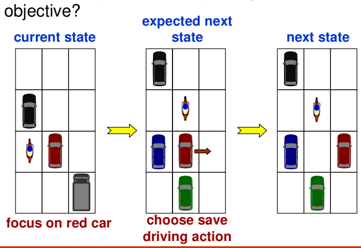
- Nice overview on coupling approaches, principles and a proposal for a Carisma and NS-2 coupling
- TraNS: Traffic and network simulation environment developed by EPFL, combines SUMO and NS-2

How to show the impact of VANETs on safety?



Decision and control

- Given the current road situation (car positions, velocities), what is the best maneuver (control action) from point of view of safety and driving objective?



Efficient Linear Approximations to Stochastic Vehicular Collision-Avoidance Problems, D. Dolgov, K. Laberteaux, ICINCO, 2005

Agenda

1. Applications and recent projects
2. Mobility and radio channel
   incl. modeling and simulation
3. Communication technology and strategies
   incl. modeling and simulation
4. Architectural and application-specific issues
5. ***Security and privacy aspects***
6. Discussion

Why Security and Privacy

- Security to guarrantee
  - **Integrity** (of messages)
  - **Identification** (of users or devices)
  - **Non-repudiation** (of messages)
- Privacy to enforce
  - **Users' protection** (violations notification)
  - **Anti-tracking** (avoid positioning cars an track movements)

Agenda

1. Applications and recent projects
2. Mobility and radio channel
   incl. modeling and simulation
3. Communication technology and strategies
   incl. modeling and simulation
4. Architectural and application-specific issues
5. Security and privacy aspects

6. Discussion

Where are we today?

- Dream of direct radio communication between vehicles has existed for decades
- Since the end of the 90's the ingredients (WLAN, GPS at 'reasonable' costs) are there
  - Triggered research in VANETs in the last 7 to 10 years
- What have we (as community) achieved so far?
  - Feasibility of VANETs has been shown
  - Basic building blocks (something to use, improve, extend, or replace) are available:
    - PHY/MAC
    - Communication strategies (beaconing, event-driven messages, info dissemination) based on repetitions, power control etc.
    - System architecture and middleware
    - Simulation methodology

... which grand challenges are waiting for us?

Links and Resources (some of them)

- Intelligent Transportation Society of America

http://www.itsa.org/

- CALM: Communications Architecture for Land Mobile environment

http://www.tc204wg16.de/

- Car 2 Car Communication Consortium

http://www.car-to-car.org/

VANET research in Europe: strategy and coordination

- White Paper submitted by the Commission on 12 September 2001: "European transport policy for 2010: time to decide"
  - COM(2001) 370
- **eSafety**: propose a strategy for accelerating the research, development, deployment and use of ICT-based intelligent active safety systems for improving road safety in Europe
  - Since 2002
  - http://ec.europa.eu/information_society/activities/esafety/index_en.htm
- **i2010 Intelligent Car Initiative**: policy framework to guide stakeholder efforts
  - Since 2006
  - "Save lives, save money, make cities and landscape more beautiful"
  - Three pillars: eSafety Forum, research and development activities, awareness raising actions
  - http://ec.europa.eu/information_society/activities/esafety/intelligent_car/index_en.htm