Vehicular Communications: How important is to see who you are talking to?

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Instituto de Telecomunicações

- National Laboratory for Telecommunications
- More than 30 research groups with about 150 PhDs
- Four fundamental areas:
  - Basic Sciences
  - Wireless Technologies
  - Optical Communications
  - Networks and Multimedia
- Currently 6 sites (Aveiro, Coimbra, Covilhã, Leiria, Lisboa, Porto)
- Special funding by the Portuguese Foundation for Science and Technology

Instituto de Telecomunicações - Porto

- Personnel: 59 researchers, including 11 researchers with a Ph.D., 30 Ph.D. students 10 M.Sc. students and 8 research assistants.
- Two locations: FCUP and FEUP

IT- Porto: Research Highlights

- Information Theory
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  - Rate-Distortion Theory
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- Information Security
  - Information-Theoretic Security
  - Cooperatively Secure Routing
  - Secure Network Coding
  - Secret Key Agreement

IT- Porto: Research Highlights

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  - Distributed Inference
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  - **Vehicular Ad-hoc Networks**

Vehicular Communications Systems

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    - Roadside Units.

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  - In 2008, approximately 37000 persons died and 2.35 million were injured on U.S. roadways in approximately 5.8 million crashes.
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  - Data from Autoridade Nacional de Segurança Rodoviária: In 2007, traffic related accidents killed 854 people and injured 43202. And in 2008, there were 772 fatalities e 40745 injuries.

Vehicular Communications: Potential Applications

- Safety
  - Road Work Ahead

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- Mobility
    - Traffic Information

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  - Weather Conditions
  - Emergency Vehicle Approaching
- Mobility
  - Traffic Information
  - Traffic Smoothing
  - Dynamic Route Guidance
- Other
  - Internet Access
  - E-Payment
  - Games
  - Travel Related Info (gas stations, maps)
  - Telediagnosis
  - Etc...

Vehicular Communications: Access Technologies

- DSRC - 5.9GHz:
  - Specially designed for C2X applications;
  - Supports the most stringent safety applications
  - Dedicated Spectrum;
  - Penetration challenge for C2C approach (introduction cost)
  - Infrastructure will concentrate on traffic hotspots;
- Cellular Systems:
  - Infrastructure available;
  - Reuse of in-car equipment;
  - Variety of providers;
  - All safety apps. possible?

Vehicular Communications: Access Technologies

- DSRC - 5.9GHz:
  - IEEE 802.11p: DSRC physical layer & lower MAC sublayer - Passed 2nd recirculation ballot with 89% approval rate in 2009 (draft standard)
  - IEEE 1609.4: DSRC upper MAC sublayer (multi-channel coordination) - Approved as trial use standard in 2006 IEEE 1609.3
  - WAVE Short Message Protocol (WSMP) - Approved as trial use standard in 2007
  - IEEE 1609.2: Security functions - Approved as trial use standard in 2006
  - SAE J2735: Common message set and data dictionary - Already in sponsor ballot

Vehicular Communications: Lots of open issues

- DSRC:
  - What are introduction scenarios with and without infrastructure?
  - Security issues in the ad-hoc domain.
  - Other technical details: transmission power control, congestion control, etc.
- Cellular Systems:
  - Is the additional acceptable in the mobile network?
  - How will roaming / internationalization / harmonization be handled?
  - What is the price projection?
  - How will different network providers cooperate?

DRIVE-IN Project

- Distributed Routing and Infotainment through VEhicular Inter-Networking.
- Partners: Carnegie Mellon, IT-Aveiro, IT-Porto, N-Drive.
- *The goal of DRIVE-IN project is to investigate how vehicle-to-vehicle communication can improve the user experience and the overall efficiency of vehicle and road utilization.*

DRIVE-IN Project

DRIVE-IN Project: Task 1

- Goal: devising protocols capable of seizing the best transmission opportunities and disseminating vital information towards the right locations in the road network.
- Explore new ways of exploiting positioning and context information in the communications architecture
  - Geo-Optimized Physical Layer
  - Geo-Optimized Medium Access
  - Distribution Storage and Information Dissemination

DRIVE-IN Project: Task 2

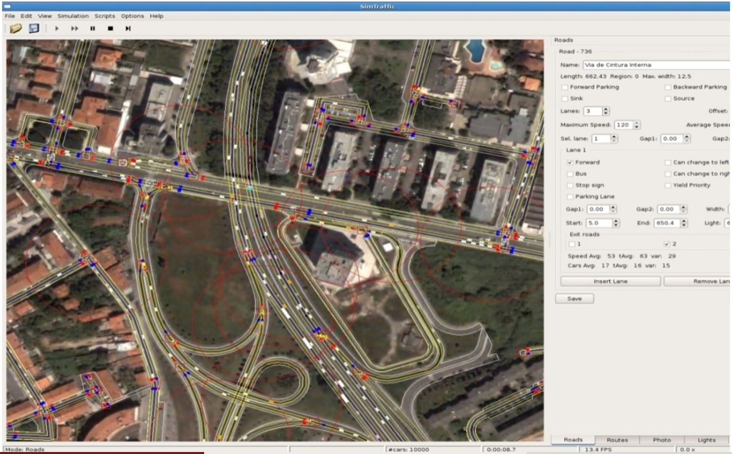
- This task targets the optimization of traffic flow through inter-vehicle communication.
- The current state-of-the-art of deployed traffic information sharing systems (e.g. TomTom HDTraffic) is based on Floating Car Data, where cars act as sensors to collect traffic data and communication is based on a centralized client/server architecture.

DRIVE-IN Project: Task 3

- Goal: produce a variety of applications and services aimed at improving the user experience while in the car.
- Example:
  - See Through System
- Infotainment: Multiplayer games over VANET
- Plan: implement game prototypes on the network of taxis.

DRIVE-IN Project: Task 4

- Provides feedback from extremely complex scenarios
- Enable insights, identify critical problems, and test solutions throughout the project.



DRIVE-IN Project: Task 5

- Goal: deploy the largest example of a real VANET, using 500 taxis in the city of Porto.
- Deployment finished by the end of 2010.
- At the end of deployment, 5% of vehicles in Porto will be VANET-enabled
- Will be used to evaluate:
  - Geo-optimized routing protocols
  - Car routing techniques
  - Applications
- Cooperation with N-Drive

Impact of Vehicles as Obstacles

- Joint work with:
  - Mate Boban (Carnegie Mellon University, FEUP)
  - Michel Ferreira (IT-Porto,FEUP), João Barros (IT-Porto,FEUP)
  - Ozan Tonguz (Carnegie Mellon University)

Motivation

- State-of-the-art simulators used for VANETs (e.g., NS-2 , JiST/SWANS/STRAW , NCTU-NS) consider the vehicles as dimensionless entities that have no influence on signal propagation.

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- Mobile obstacles increase the complexity even further.

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- Realistic propagation models (e.g., ray tracing): computationally expensive
- Mobile obstacles increase the complexity even further.
- Simplified stochastic radio models (Shadowing): rely on the statistical properties of the chosen environment and do not account for the specific obstacles in the region of interest
- Do not provide satisfying accuracy for typical VANET scenarios.

Desired VANET Propagation Model

- Realistic
  - Modeling both static and dynamic obstacles
    - Static: buildings, trees, overpasses, hills, parked vehicles,...
    - **Mobile: other vehicles on the road**
- As topology/location independent as possible
- Computationally manageable
  - Propagation model is only one of several simulated models in VANETs (mobility, MAC, routing, application,...)
  - Modeling vehicles is only one part of propagation modeling
  - Has to execute within certain time, otherwise is not useful

Model for evaluating the impact of vehicles

- Impact on line of sight (LOS)
- Impact on signal propagation
- Time complexity of the model

Problem Setup

- Spatial characteristics of vehicular networks that are of interest:
    - Exact position of each vehicle and the inter-vehicle spacing
    - Vehicle dimensions (height, width, length)
    - Speed distribution of vehicles
    - To obtain these data, we used stereoscopic aerial photography
    - Data from A28 and A3 collected by FCUP group.
    - 404 vehicles on a 12 km highway strip and 55 vehicles over 7.5 km respectively.

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- Widths and heights of vehicles?
  - Automotive Association of Portugal
  - 18 brands comprising 92% of vehicles
  - Both H & W normally distributed

Speed Distribution A28

Speed Distribution A3

Inter-vehicle spacing A28

Inter-vehicle spacing A3

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- Per-link probability of LOS $\rightarrow$ Average probability of LOS for a given vehicle $\rightarrow$ Macroscopic probability of LOS behavior.
- To calculate $P(LOS)_{ij}$ (the probability of LOS for the link between vehicles i and j) with N_o vehicles as a potential obstacles,given Tx and Rx heights h_i and h_j:

$$P(LOS|h_i, h_j) = \prod_{k=1}^{N_o} \left[1 - Q\left(\frac{h_k}{\sigma_k}\right)\right] \quad (1)$$

- Averaging over the transmitter and receiver antenna heights we obtain the unconditioned $P(LOS)_{ij}$:

$$P(LOS)_{ij} = \int\int P(LOS|h_i, h_j)p(h_i)p(h_j)dh_i dh_j \quad (2)$$

How do we evaluate probability of LOS?

- Probability of line of sight for a given vehicle i, $P(LOS)_i$, and all its N_i neighbors is defined as:

$$P(LOS)_i = \frac{1}{N_i} \sum_{j=1}^{N_i} P(LOS)_{ij} \qquad (3)$$

- System-wide ratio of LOS paths blocked by other vehicles: average $P(LOS)_i$ over all N vehicles on the considered road segment:

$$\overline{P(LOS)} = \frac{1}{N} \sum_{i=1}^{N} P(LOS)_i \qquad (4)$$

Effect on Received Signal Power

- Obstructing vehicles are approximated as knife-edge obstacles;
- Additional attenuation due to multiple knife-edge obstacle calculation.

Computational Complexity

- The described model can be regarded as a special case of geometric intersection problem
- Well know problem in computational geometry that occurs in various environments:
  - Computer graphics (is an object visible or occluded?),
  - Circuit design (are any conductors crossing?)
- Red-Blue intersection problem:
  - Given a set of red line segments r and blue line segments b in the plane, report all K intersections of red with blue segments
  - Time complexity of the algorithm: $O(N^{4/3} \log N + K)$
  - $N = r + b$
  - Additional time for multiple knife-edge: $O(K)$
  - Overall $O(N^{4/3} \log N + K)$

Results: Probability of LOS

- Macroscopic probability of LOS.
- A28: 32.3 vehicles/km, A3: 7.3 vehicles/km.

	Transmission Range (m)		
Highway	100	250	500
A3	0.8445	0.6839	0.6597
A28	0.8213	0.6605	0.6149

Results: Obstructed Neighbors

- Neighbors with unobstructed and obstructed LOS
- Half of the neighbors will not have LOS due to vehicles only at 500 m of observed range.

Stationarity of Poisson Process

- Stationarity of the generating Poisson process
- Important for characterizing the moving network (i.e., over time)
- Important for determining the refresh rate for vehicles-as-obstacles model

	$\Delta P(LOS)_i$ (%)			
Time offset	$<$ 5%	5-10%	10-20%	$>$20%
1ms	100%	0%	0%	0%
10ms	99%	1%	0%	0%
100ms	82%	15%	3%	0%
1s	35%	33%	22%	10%
2s	31%	25%	29%	15%

Results: Truck/Bus Routing

- Big vehicles have much better LOS conditions
- Selecting big vehicles as next hops, messages are:
  - More likely to reach larger distances
  - More likely to reach larger number of neighbors within a certain

Results: Received Signal Power

$P_T = 20$ dBm, $G_T = G_R = 1$ dBi, Tx Range $= 750$ m.

Results: Received Signal Power

Results: Packet Reception - Requirements for DSRC Receiver Performance

Data Rate (Mb/s)	Modulation	Minimum sensitivity (dBm)
3	BPSK	-85
4.5	BPSK	-84
6	QPSK	-82
9	QPSK	-80
12	QAM-16	-77
18	QAM-16	-70
24	QAM-64	-69
27	QAM-64	-67

Results: Packet Reception

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- Credibility of simulation results
  - 9.2 dB attenuation and 20% packet loss on average are far from negligible!
  - If vehicles are not accounted for, optimistic results are obtained
  - In reality, routing protocols will behave worse, network reachability will be reduced, delay will be incorrect.

Thank You!

- Questions?
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