Cooperative Wireless Communications for Road Users

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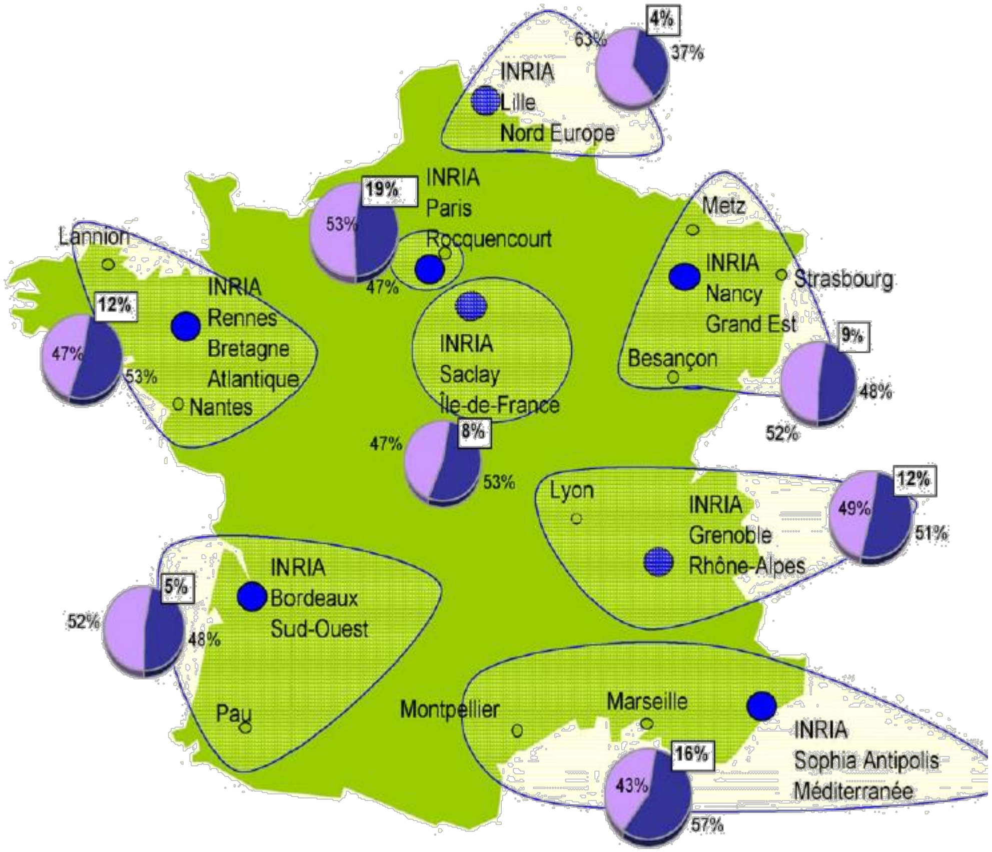
INRIA... at a glance

National **R**esearch **I**nstitute in **I**nformatics and **A**utomation

Director: Michel Cosnard

Staff : 2500

8 sites in France



INRIA

50% permanent INRIA staff
40% researchers vs. 60% ETA

180 Research Teams – lifetime : 12 years !

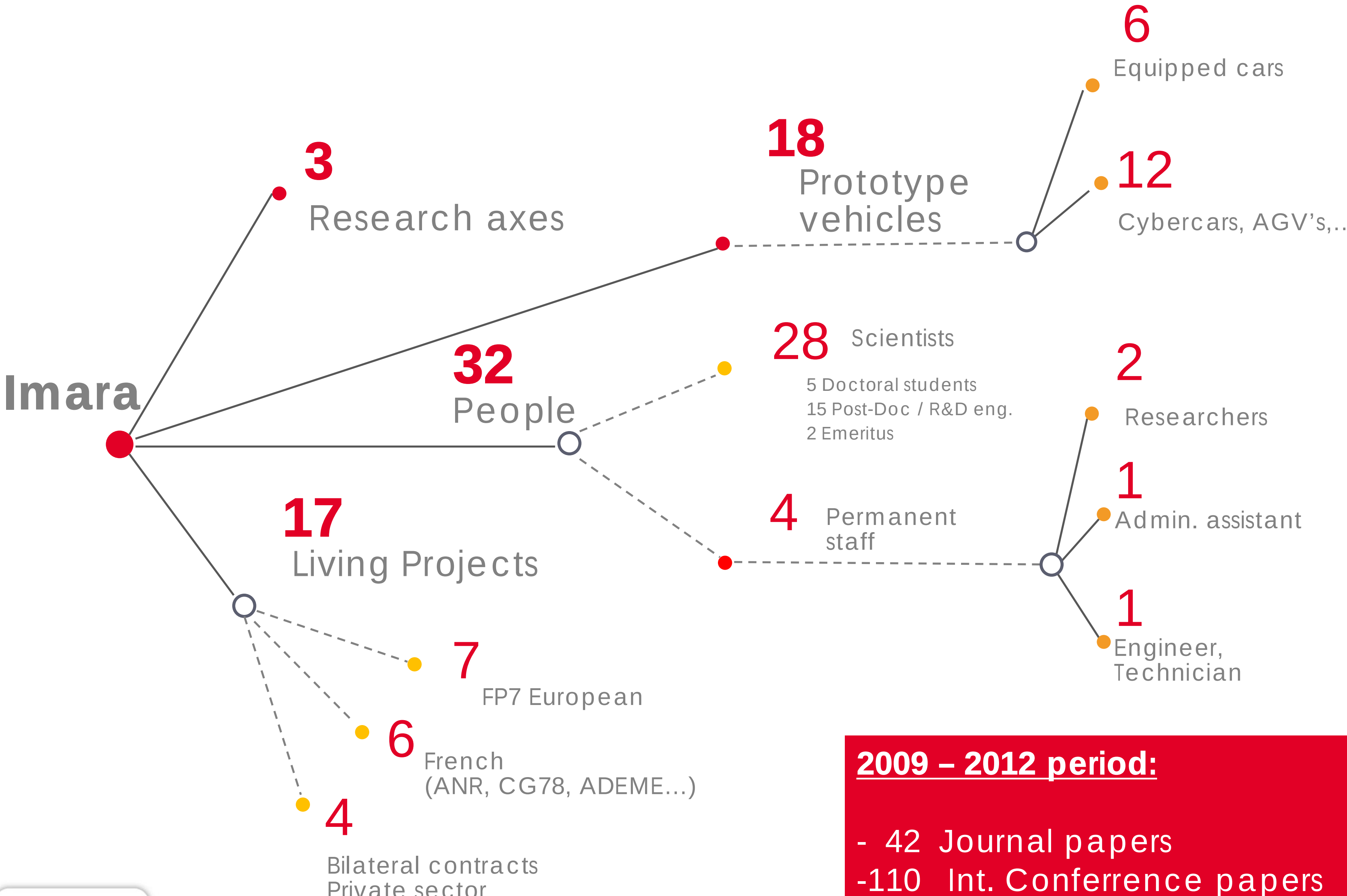
Activities:

Computer science
Robotics
Cognitive & digital sciences
Communicant systems

IMARA :

Informatique,
Mathématiques,
Automatique
pour la Route Automatisée

IMARA Key figures (today!)



2009 – 2012 period:

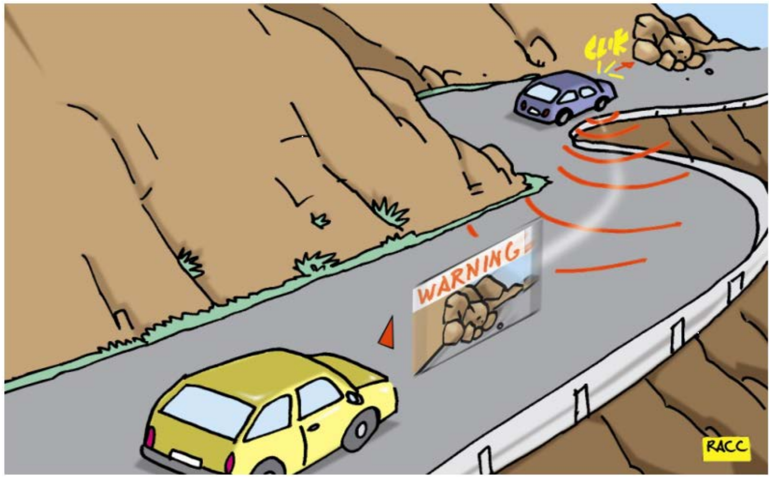
- 42 Journal papers
-110 Int. Conferrence papers
- 2 PhD / year

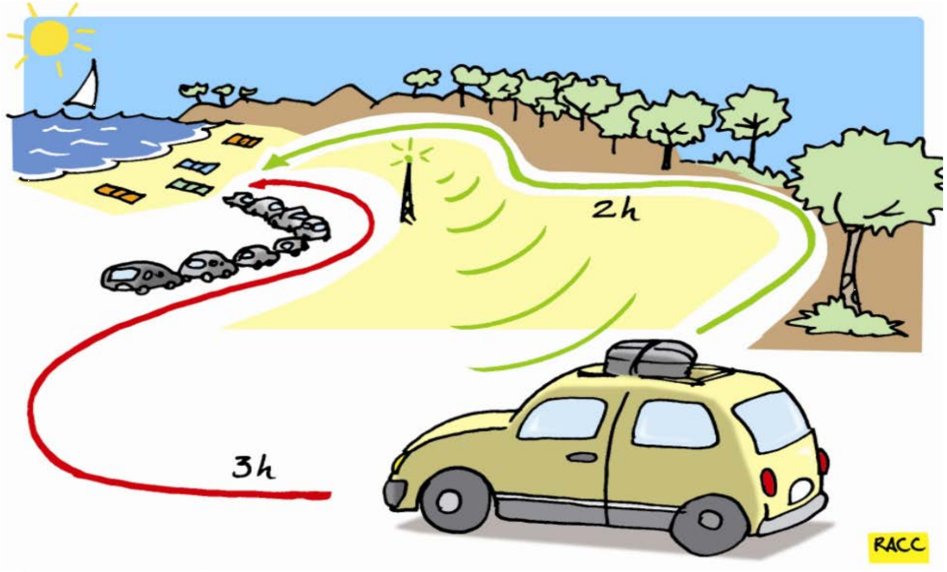
Overview of the talk

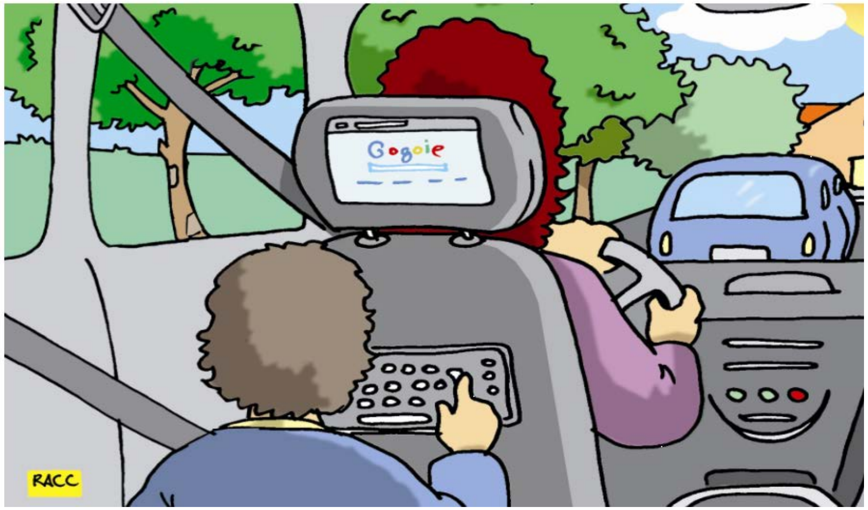
- ITS applications
  - Telecommunications for automative driving
- Telecommunication standards for ITS
  - Europe, USA, and Japan: IEEE 802.11p-like systems
  - Can IEEE 802.11p support road safety applications?
- Cooperative ITS for road safety
  - Visible light communications and RF communications
  - Cooperation between communications and control
  - Cooperation between communications and perception

ITS Applications

- Road safety applications
- Traffic efficiency applications
- Infotainment applications







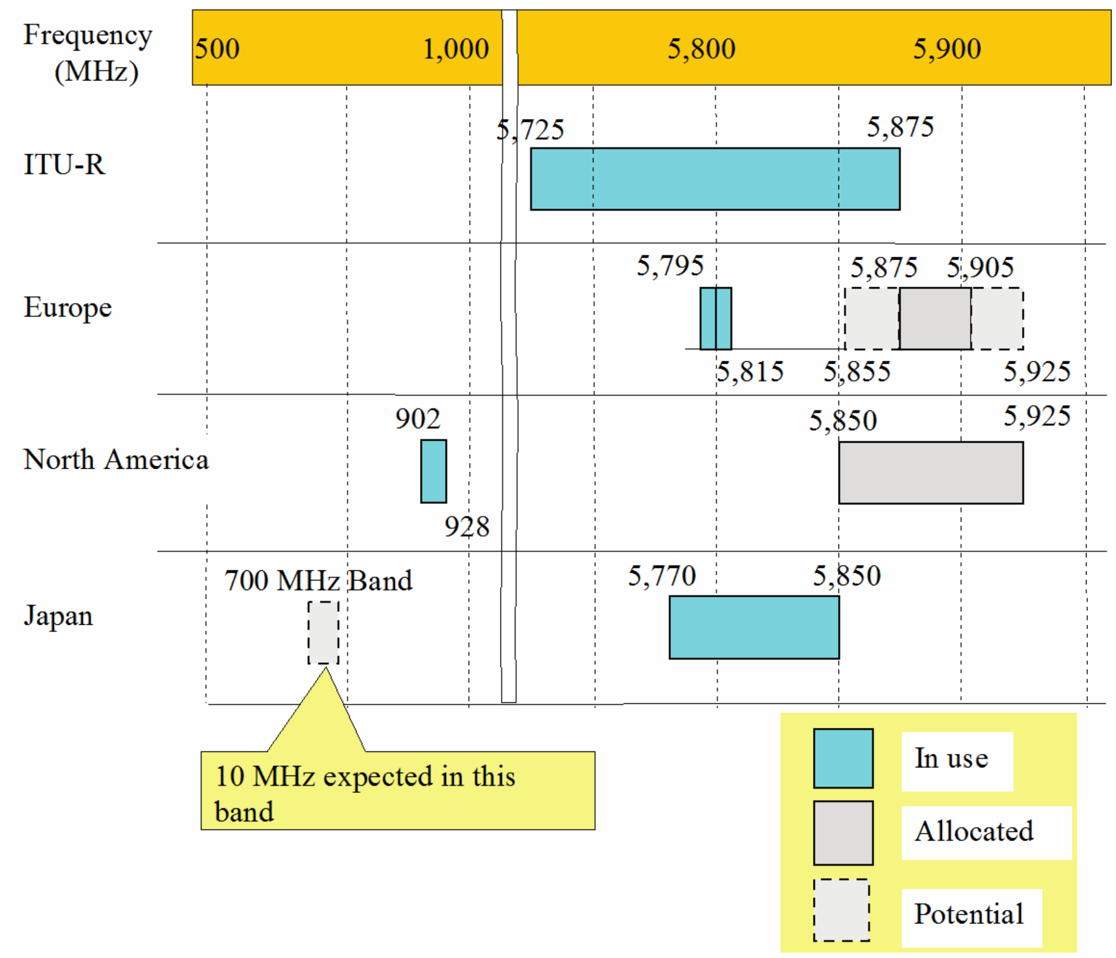
Telecommunications for automative driving
Vehicle negotiation

Telecommunications for automative driving
Platooning

ITS standards developing organizations (SDO)

- Regularity constraints (e.g., radio frequency) are different depending on the country/region.
- Standardization activities
  - USA: **IEEE, SAE** (Society of Automotive Engineers)
  - Japan: ITS Info-Communications Forum, **ARIB** (Association for radio industry and business)
  - Europe: CEN (European committee for standardization), **ETSI** (European telecommunications standards Institute)

Radio spectrum dedicated to ITS Communications



ITS standards in USA, Europe, and Japan

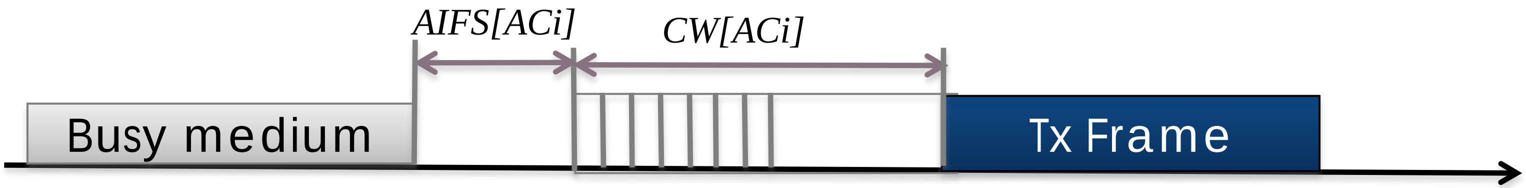
- Strong attention on safety applications
- Communications especially dedicated to V2V and V2I
  - IEEE 802.11p, ITS-G5, RC-005: Underling technology is IEEE 802.11

Can 802.11p support road safety?

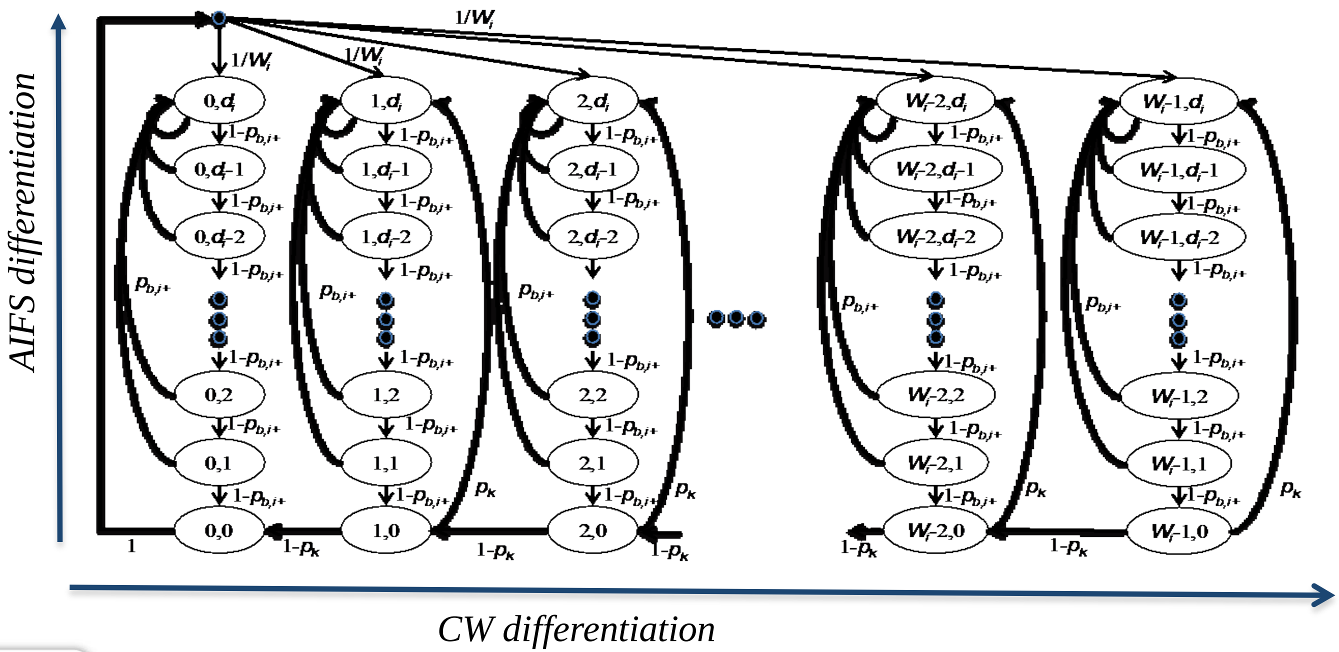
- Cooperative Adaptive Cruise Control
  - Platooning
  - Vehicle merging

IEEE 802.11p modeling based on 2D Markov chain

- MAC (Medium Access Control): Differentiated channel access to different traffic classes (i.e., different types of messages)



smaller AIFS and smaller CW → Higher-prioritized AC



IEEE 802.11p Performance

Probability of successful transmission at access category *AC[i]*

$$P_s[AC_i] = (1 - \tau_j)^{N_j}(1 - \tau_i)^{N_i - 1}$$

Ni: the number of transmitting nodes in the sensing range at *ACi*

$$\tau_i = q_i \square \tau_{si}$$

Channel access probability for non-saturated condition

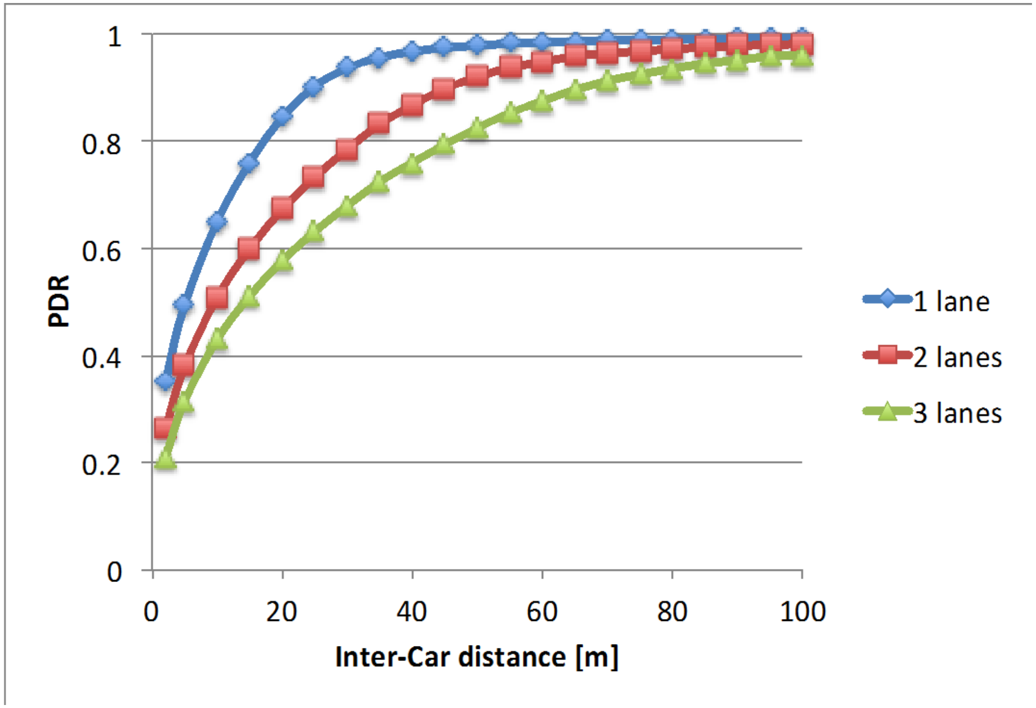
$$\tau_{si} = \Bigg[1 + \frac{1-(1-p_{b,i+})^{d_i}}{W_i p_{b,i+}(1-p_{b,i+})^{d_i}} + \frac{W_i - 1}{2(1-p_k)} + \frac{(1-(1-p_{b,i+})^{d_i})(2+3(W_i-2)p_k+(W_i-2)^2 p_k^2)}{2W_i(1-p_k)P_{b,i+}(1-p_{b,i+})^{d_i}}\Bigg]^{-1}.$$

Channel access probability for saturated condition

$$p_{b,i+} = 1 - \prod_{j=i+1}^{M-1}(1-\tau_j)^{N_j} \qquad p_k = 1 - (1-\tau_i)^{N_i - 1}\prod_{j=0, j \neq i}^{M-1}(1-\tau_j)^{N_j}$$

IEEE 802.11p performance for platooning

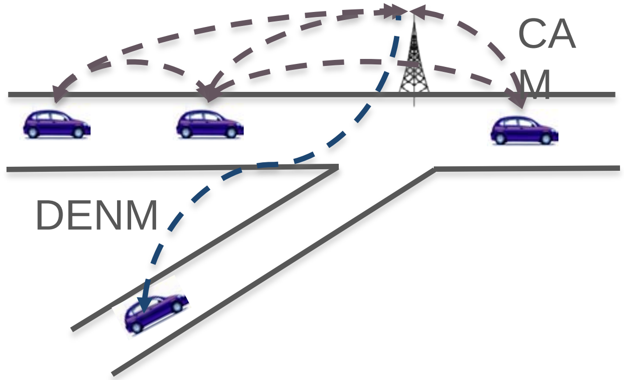
- Vehicles exchange their information in every 0.1seconds using a single access category



A mechanisms for scalable communications is required!

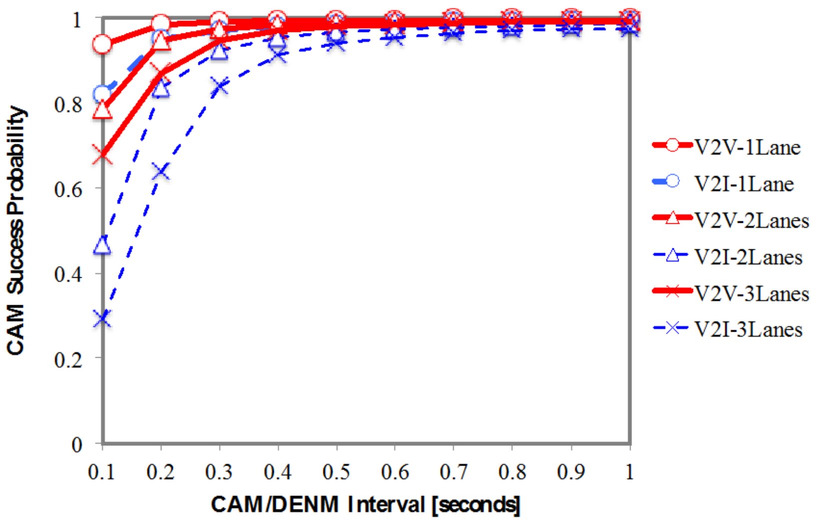
IEEE 802.11p for merging control

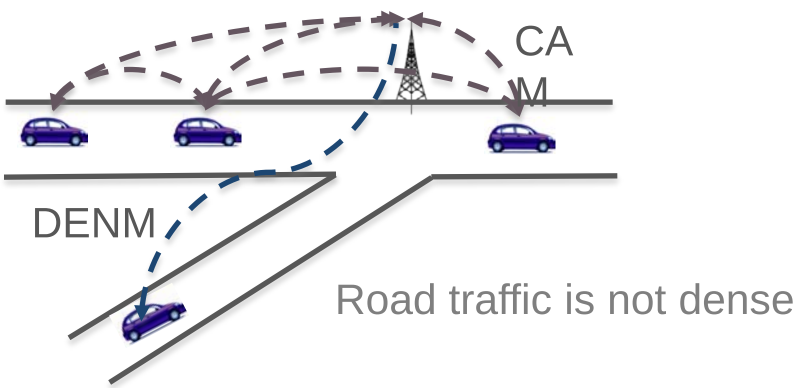
- Main road vehicles periodically exchange motion state info using CAMs.
- A vehicle (RSU if exists) at the junction informs main road state (speed, position of individual vehicles) to the merging vehicle using DENMs.
- DENM has higher priority over CAM.
- Control
  - Based on DENM information, the merging vehicle controls its velocity for safe merging

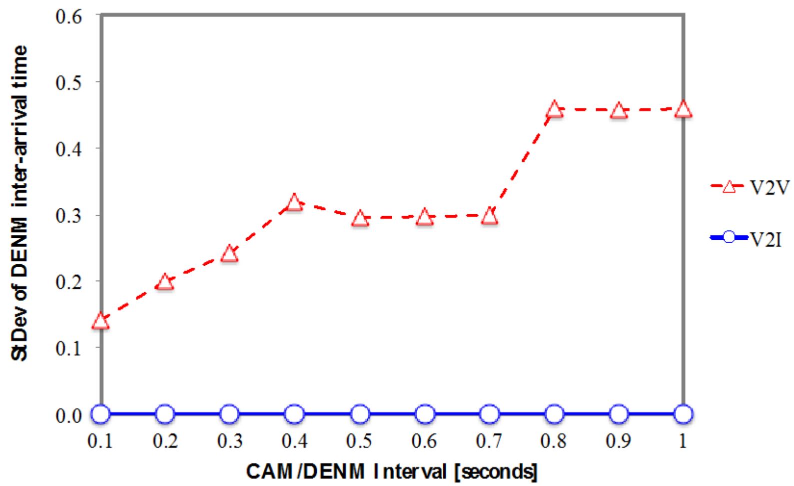


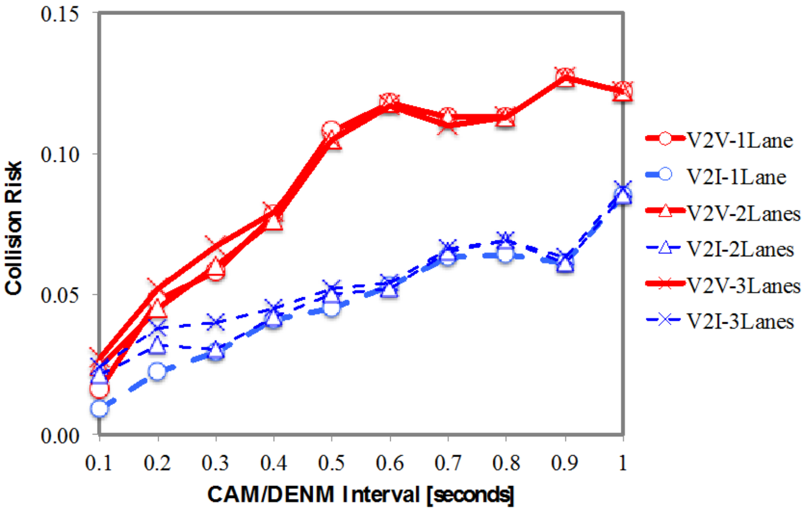
- Communications quality: Packet delivery ratio, packet inter-arrival time, throughput..
- Control quality: Collision risk: 0 if a collision can be avoided even the relative speed is non-zero at the merging time.

IEEE 802.11p for merging control









High throughput, fixed message inter-arrival time are the major requirement.
Due to road dynamics, V2I communication is preferred.

Visible Light Communications:
Communications for highly dense networks

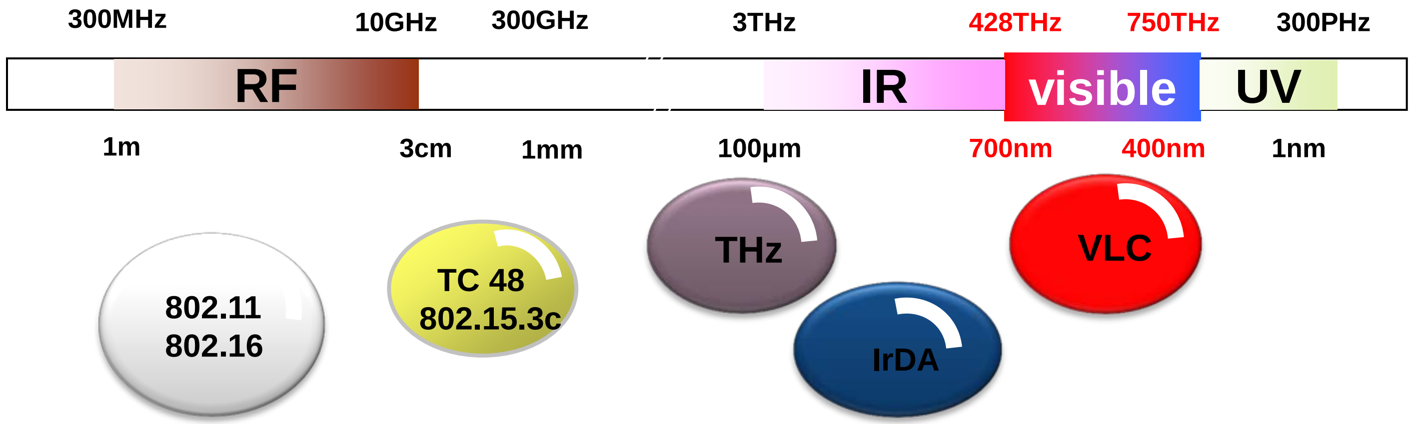
Cooperation between communications and control

Communications for highly dense road scenarios

- Traffic congestion
  - Increasing fuel consumption
  - Air and noise pollutions
- Automated vehicles platooning
  - Vehicle driver with reasonable high speed with only few meters of inter-vehicle gap
  - Reducing congestion (improves throughput)
  - Networking point of view: high dense

We look for a short-distance communications technology

Visible Light communications (VLC)



- No interference with radio
- Cheap and green
- Short distance line of sight communications

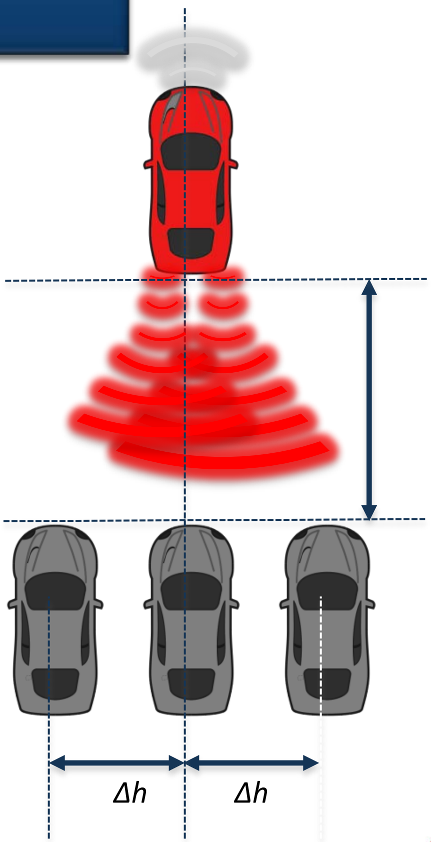
VLC Channel Modeling

- Channel gain

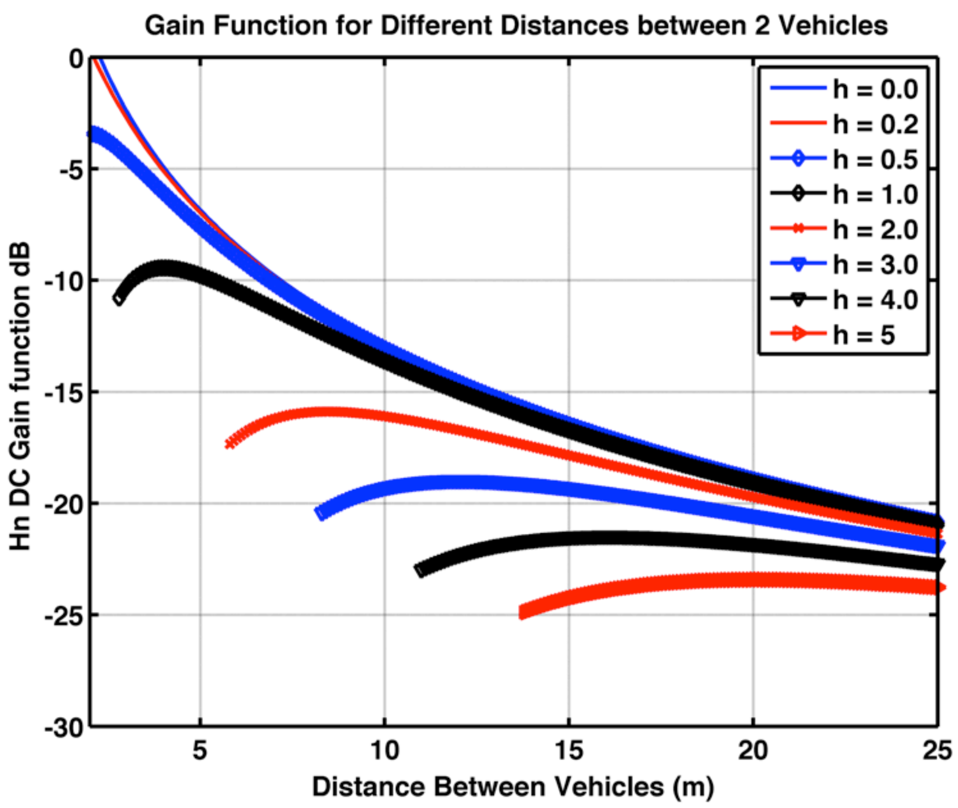
$$H(0)_{LOS} = \begin{cases} \frac{A_d}{d^2} R_0(\varphi) T_s(\lambda)\, g(\lambda)\, cos(\sigma), & 0 \le \sigma \le FOV \\ 0 & \psi > FOV \end{cases}$$

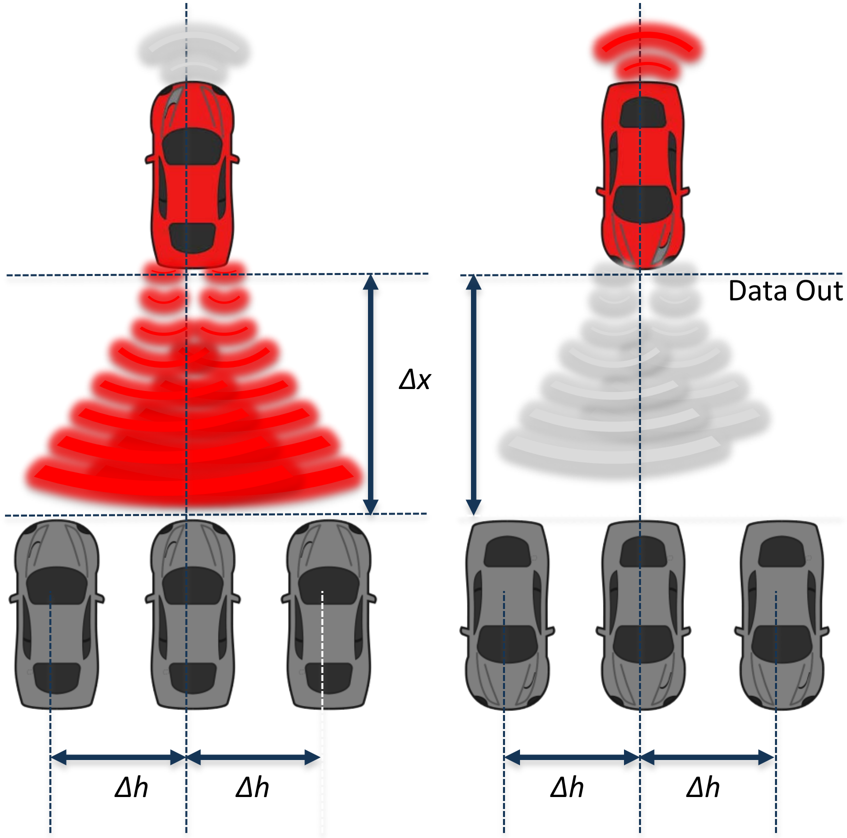
$$H_n(\phi,\theta,x,h) = \frac{m+1}{2\pi} \frac{\cos^m\left(\frac{\pi}{2} - \tan^{-1}\left(\frac{x}{h}\right) - \phi\right)\cos\left(\tan^{-1}\left(\frac{x}{h}\right) - \theta\right)}{h^2 + x^2}$$

$$m = -\frac{ln2}{ln\left(cos(\theta_{1/2})\right)}$$



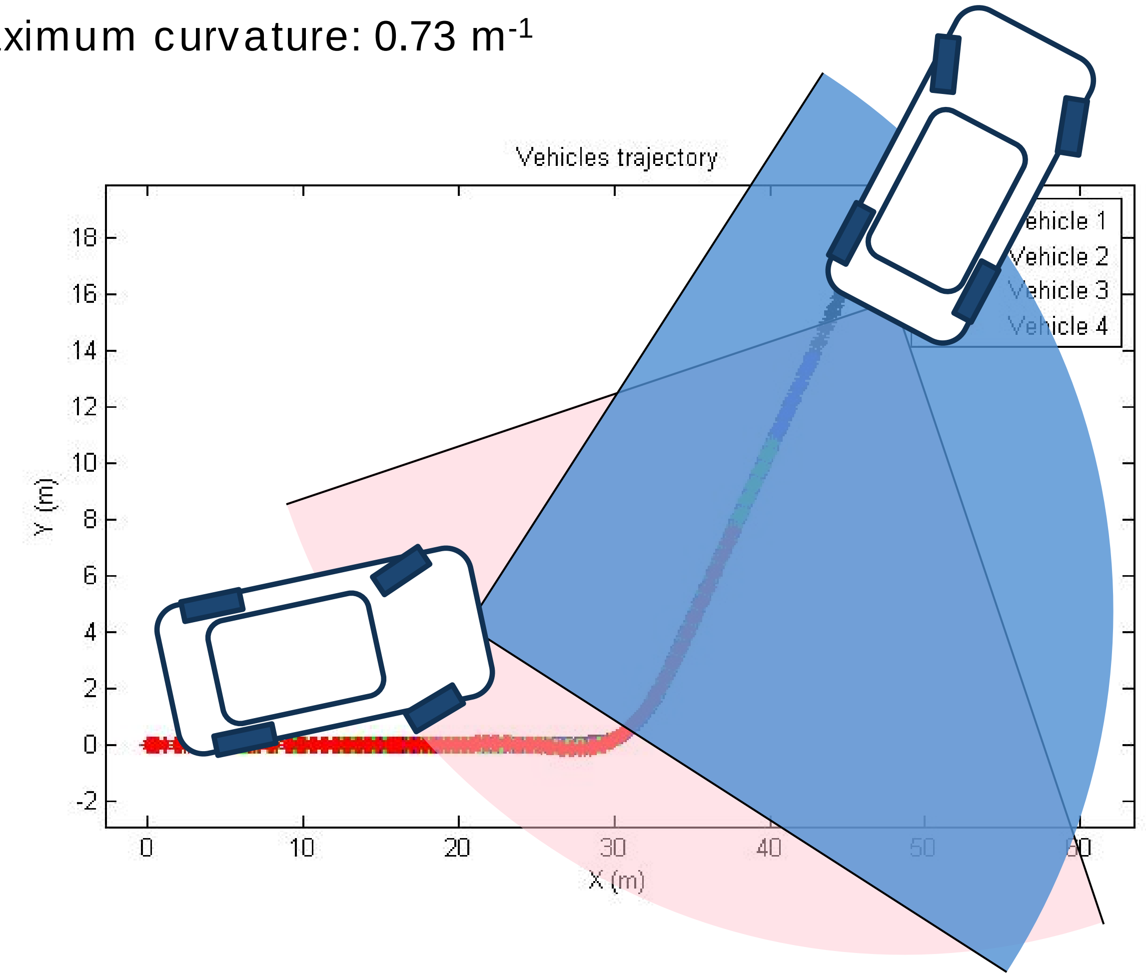
VLC Channel Performance





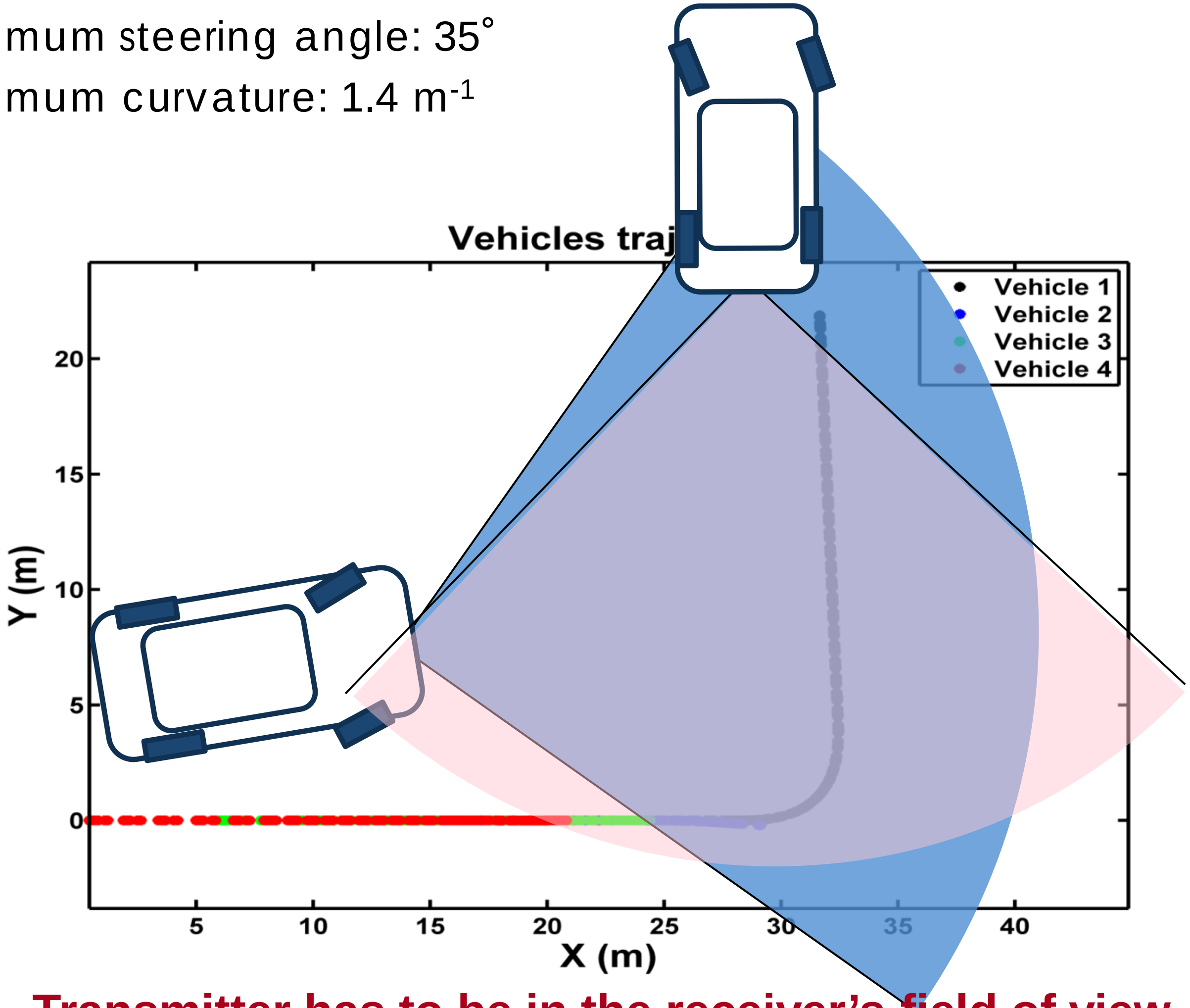
Simulations results

- Inter-vehicle distance: 2m
- Maximum steering angle: 20°
- Maximum curvature: 0.73 m^{-1}



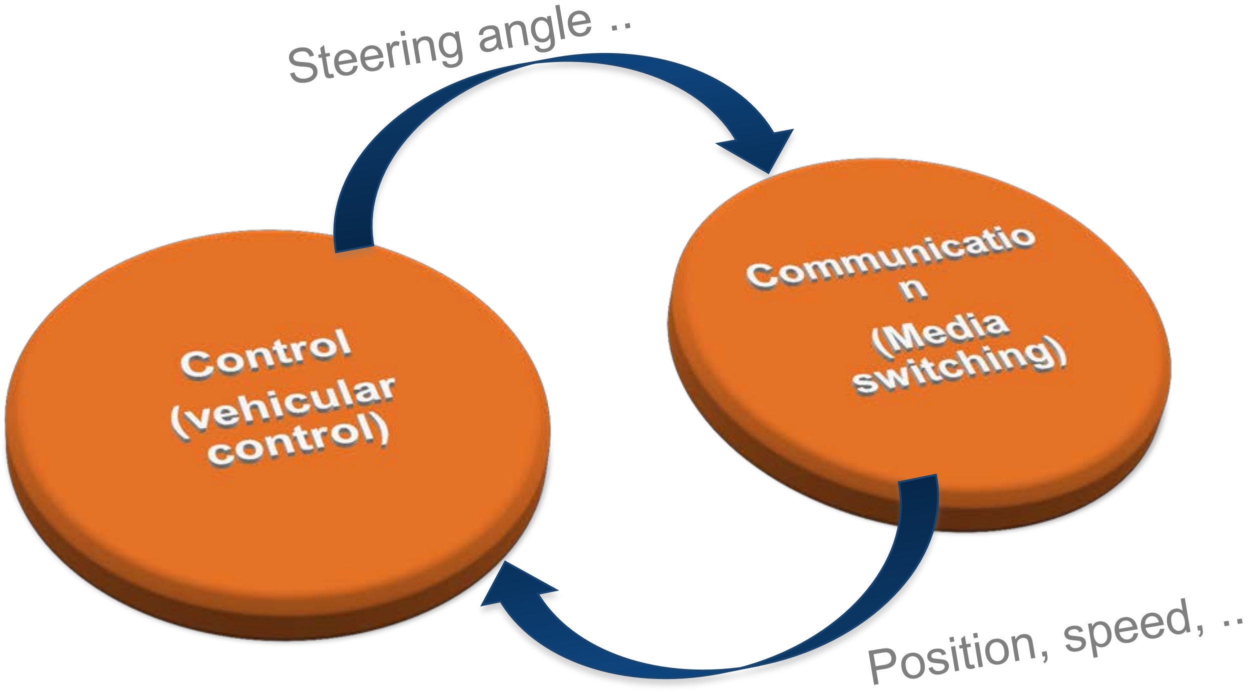
Simulations results

- Inter-vehicle distance: 2m
- Maximum steering angle: 35°
- Maximum curvature: 1.4 m^{-1}



Transmitter has to be in the receiver's field of view

Cooperation between Control & Communication
Ongoing research

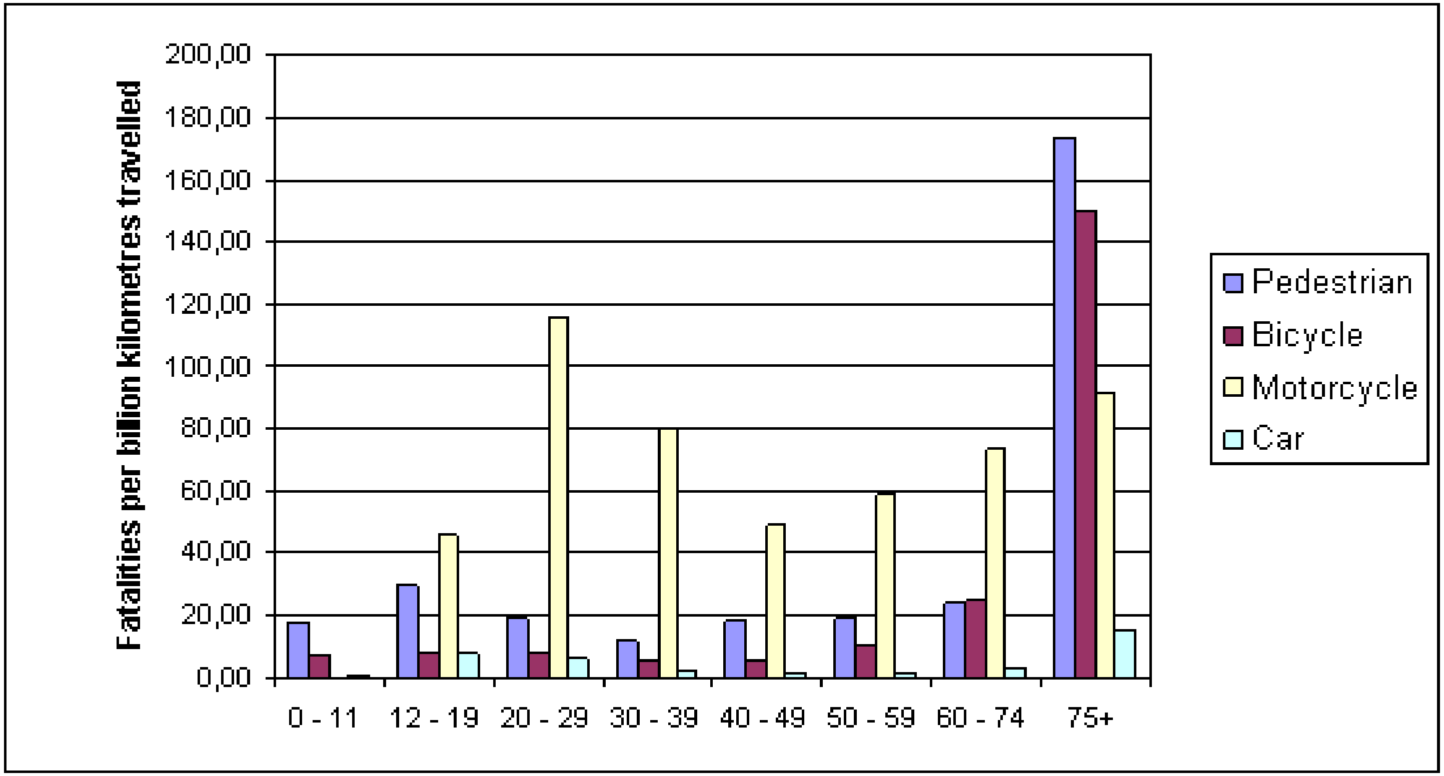


- Communications and control modules exchange their information
- Adaptive communications based on information from control module
  - Switching between RF and VLC

Protection of vulnerable road users

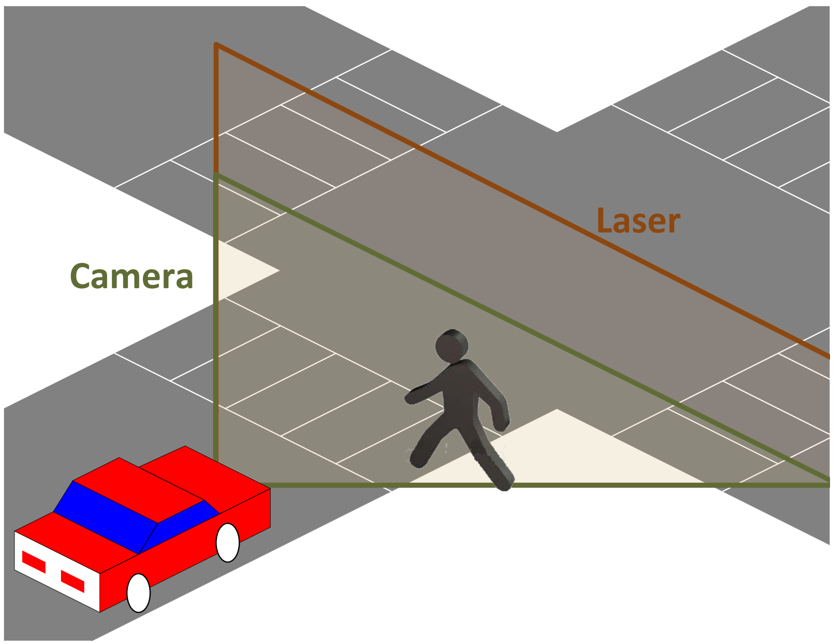
Cooperation between communications and perception

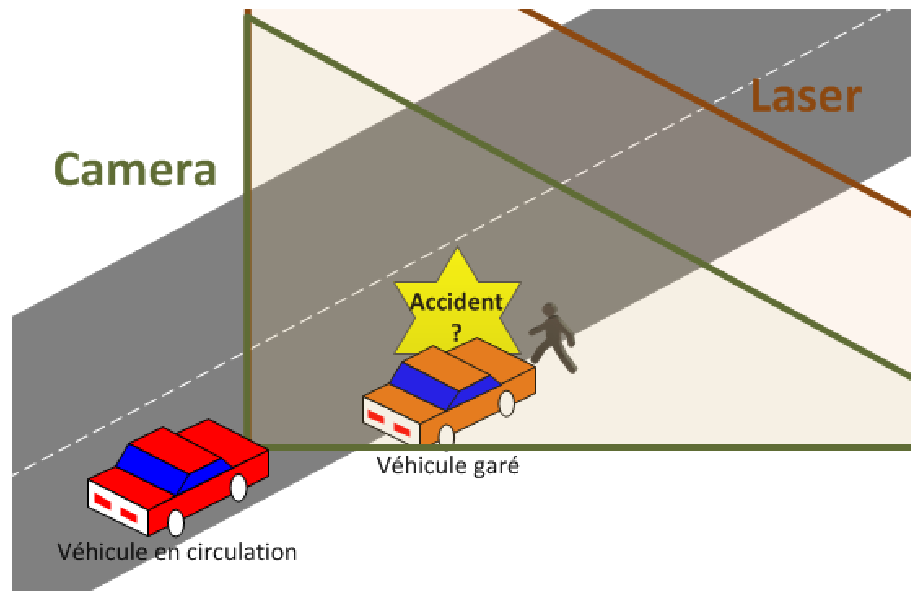
Fatalities for Pedestrians and cyclists



http://ec.europa.eu/transport/road_safety/specialist/knowledge/pedestrians/crash_characteristics_where_and_how/data_considerations.htm

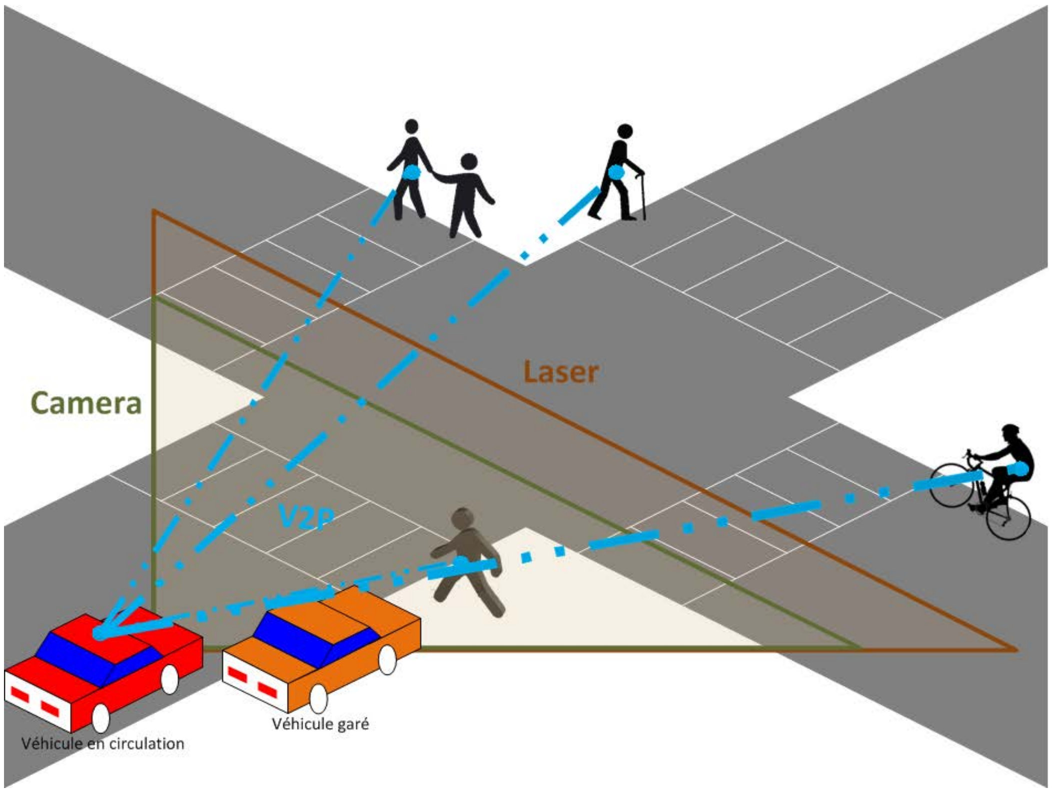
Pedestrian detection using local sensors (perception technology)





Local sensors cannot serve for NLOS scenarios or longer distance scenarios

Collabration between communications and perception technologies for pedestrian safety (ongoing research)



Using both communications and perception for pedestrian detection (ongoing research)

Summary

- Road safety applications are the primary concern of the ITS communications systems
  - IEEE 802.11p (like) communications systems have been standardized in major standardization organisations
- Study of 802.11p for realistic applications
  - IEEE 802.11p does not serve in dense road scenarios
  - IEEE 802.11p's priority control does not necessary serve applications such as merging control
- Cooperative Communications and control
  - VLC for platooning control
  - Usage of VLC and RF based on information from the control
- Cooperative Communications and Perception
  - Pedestrian safety

Thank you