Autonomous cars navigation: from standalone to cooperative systems

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Autonomous cars navigation

Sometimes people think that things happen like that.

But, the navigation space is constrained and there are interactions between cars.

Outline

1. Level of autonomy of autonomous vehicles
2. Key elements for cooperative autonomous navigation
3. Usefulness of cooperative navigation
4. Autonomous navigation in a System of Systems
   1. Infrastructure-aided Localization Systems
   2. Infrastructure-aided Perception Systems
   3. Cooperative Localization Systems in Mutual Cooperation
5. Conclusion and perspectives

Level of autonomy of autonomous vehicles

Part 1

Autonomous Vehicles: Trends

- Driverless vehicles
  - New Mobility Services
  - Shuttles and Robot taxis

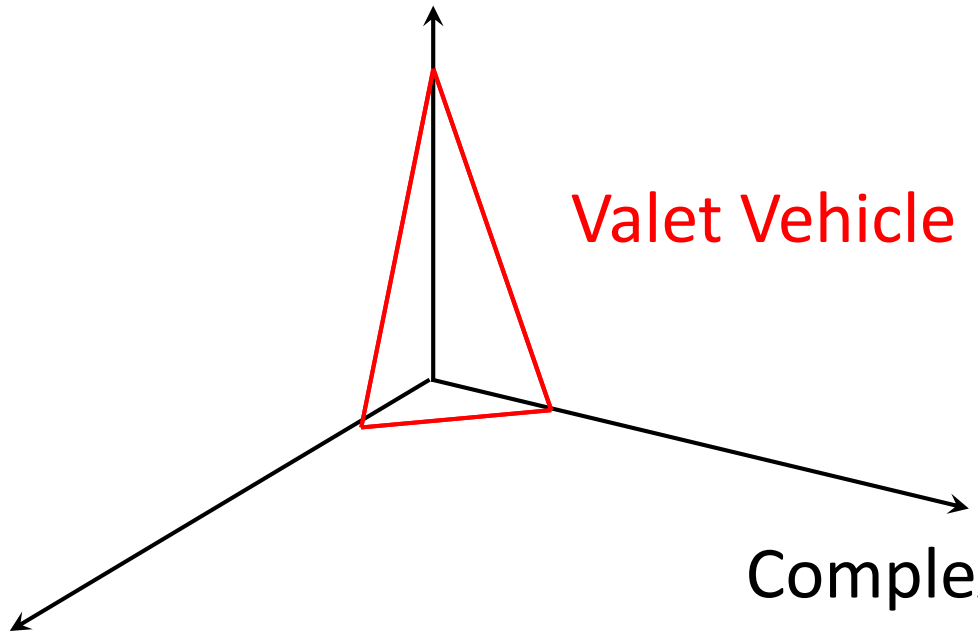
- Autonomous cars
  - Traditional customers
  - Valet vehicle
  - Traffic Jam Assist

automotive
robotics
Converge

Example of autonomous car: Valet Vehicle (PAMU Renault)

The three Roboticist Axes

Autonomy capacity
Independence with respect to human



Complexity of the mission or task

Complexity of the environment and of the navigation area

Robot vehicle

Ability to function independently of a human operator in any context

Operational autonomy

- Feedback mechanisms to control behavior to follow a predefined trajectory, while rejecting disturbances
- No need for user monitoring

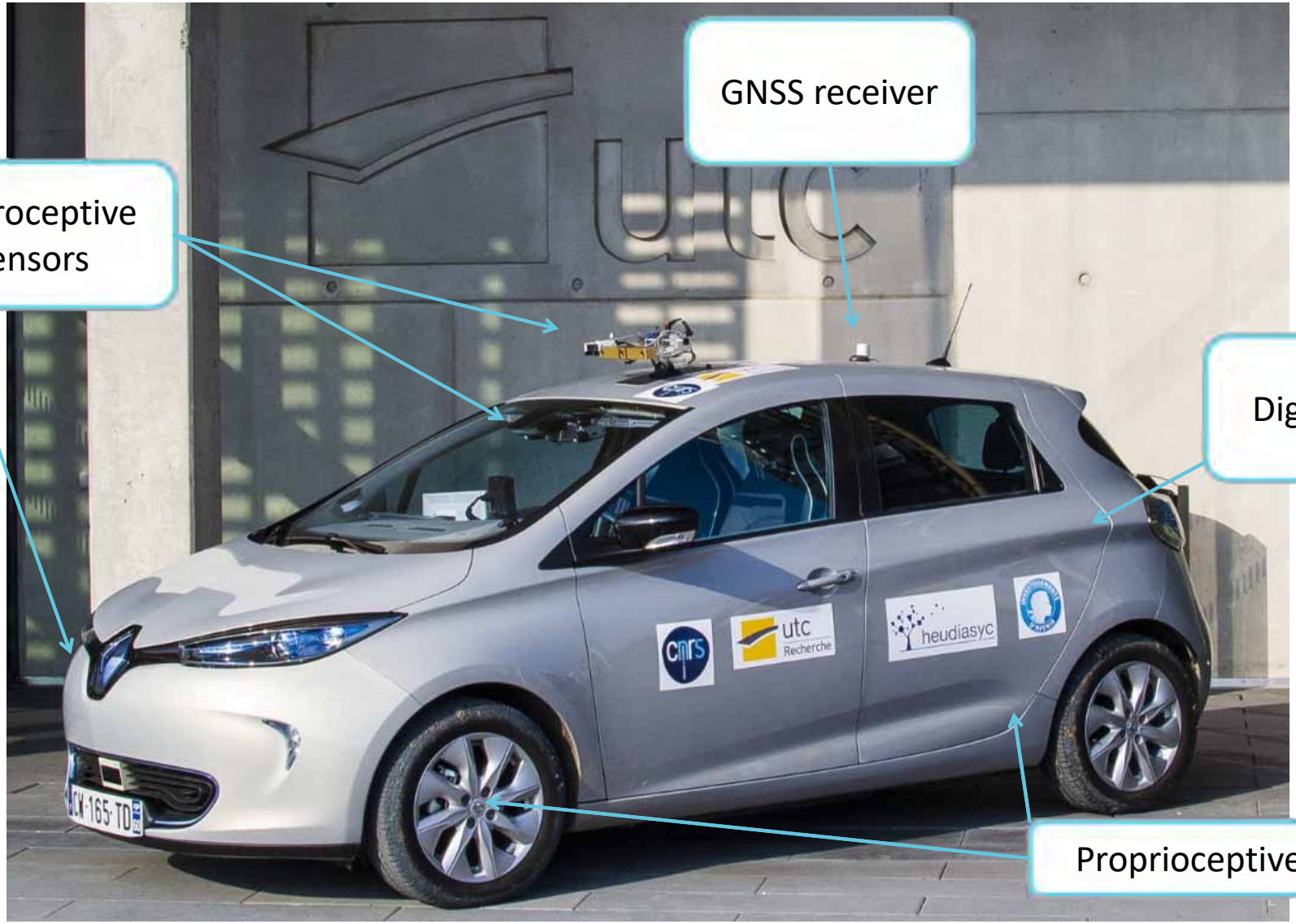
Decisional autonomy

- The machine has the ability to understand despite the uncertainties of perception and localization as well as incomplete information about the environment
- Decision making to ensure safe behavior of the vehicle interacting with its environment

Key elements for cooperative autonomous navigation

Part 2

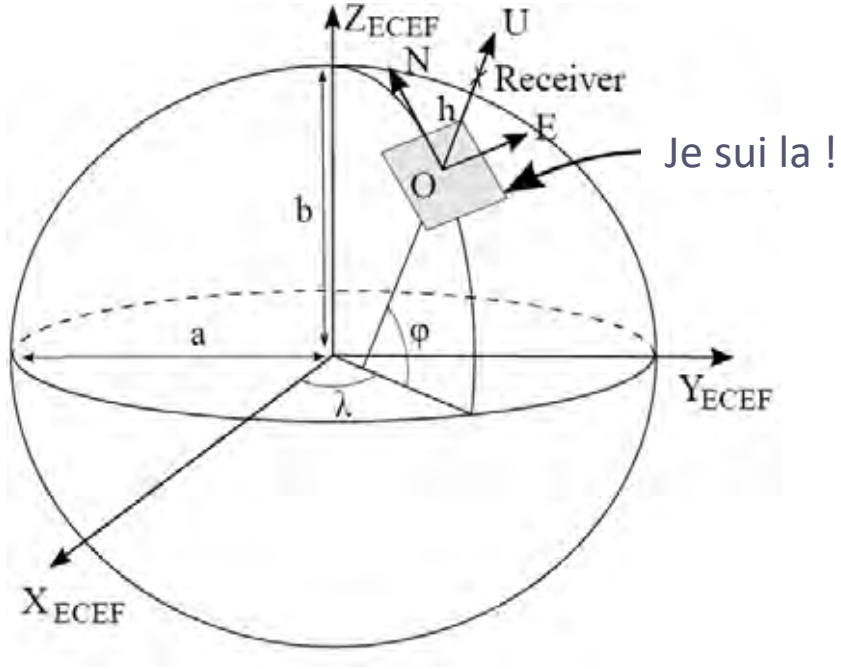
Sources of information for autonomous navigation



Localization and perception

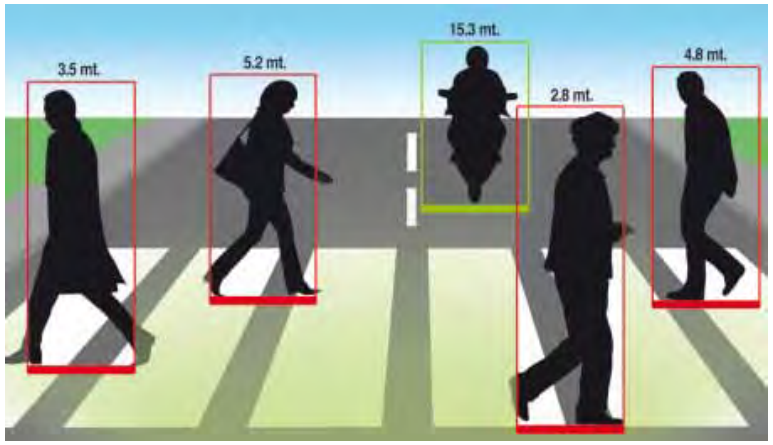
Localization system

— allows the vehicle to position itself spatially, absolutely or relatively, in its evolution environment

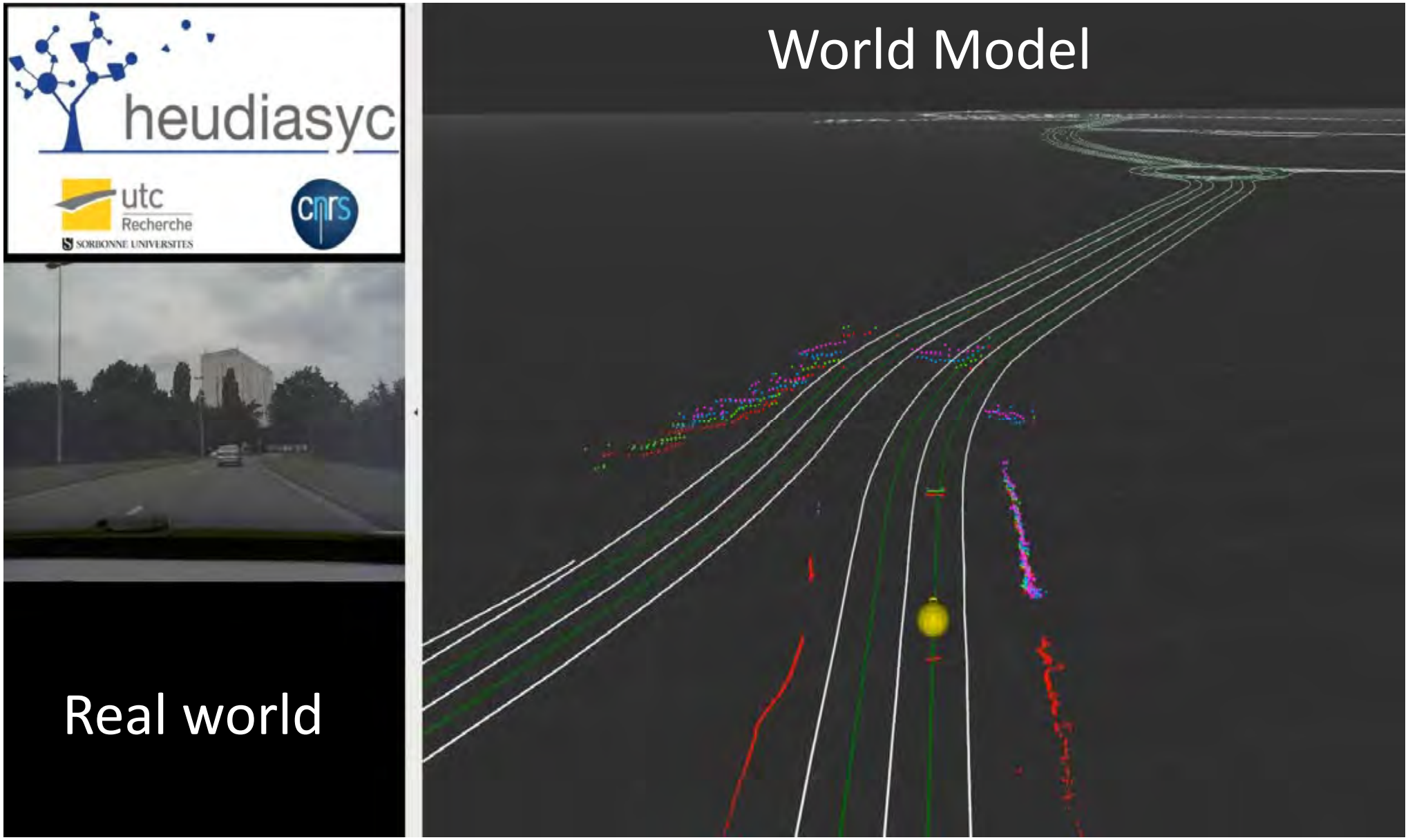


Perception system

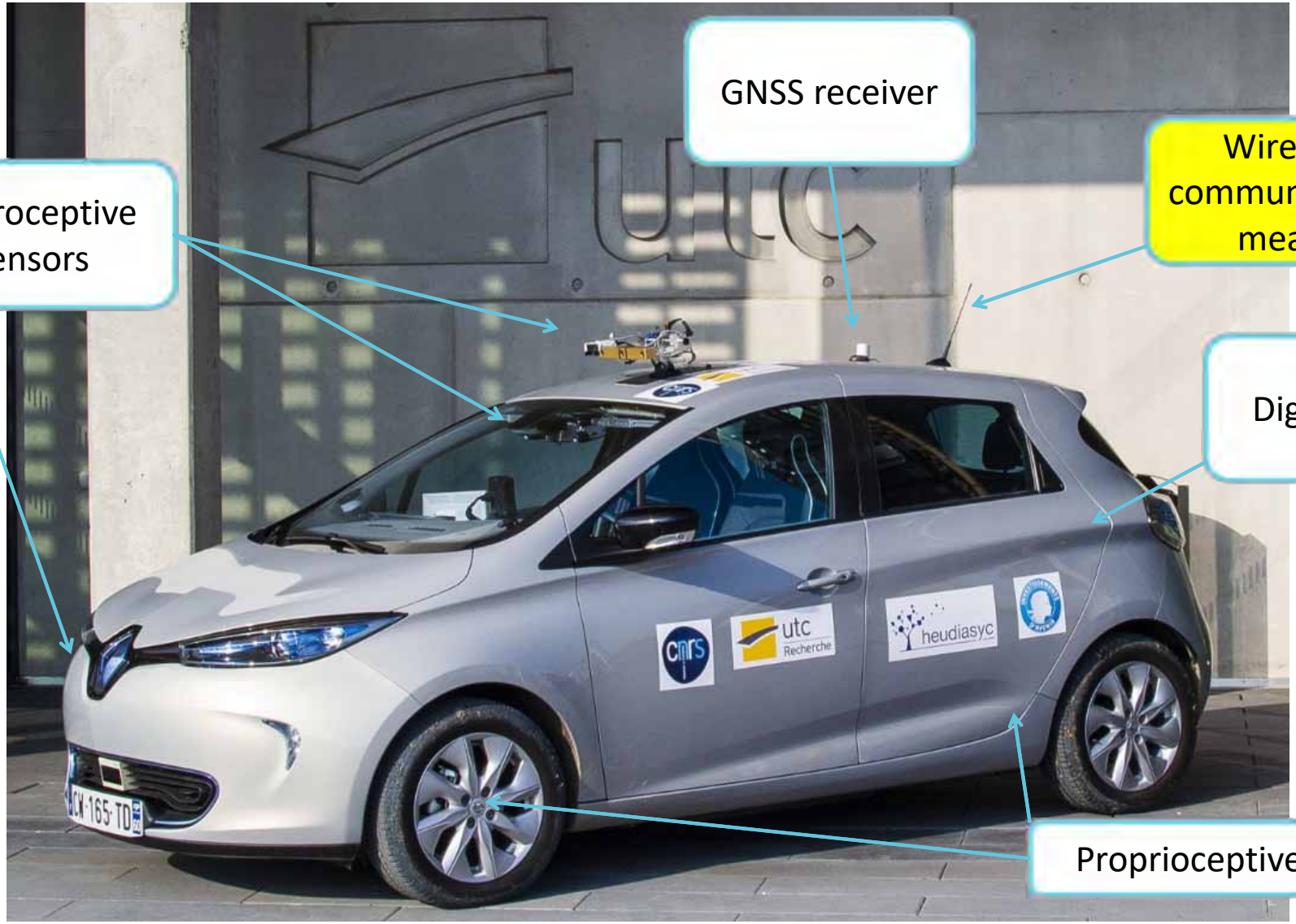
— equips the vehicle with understanding and prediction capabilities of its immediate environment. From the sources of information available, the vehicle builds a representation of the environment that allows it to navigate



Localization and perception



Wireless communication for cooperative autonomous navigation



Wireless Networks for data exchange

Vehicular ad hoc networks (VANETs) allow an augmented perception of the dynamic environment by using wireless communications:

- Vehicle-to-Vehicle (V2V)
- Infrastructure to Vehicle (I2V)

Some typical messages (ETSI standard)

- CAM (Cooperative Awareness Message)
- DENM (Distributed Environment Notification Message)
- CPS (Collective Perception Service - ETSI TR 103 562 under preparation)

Features

- short range radio technologies (Wifi mode), 5.9 GHz band (802.11p)
- Broadcast frequency: 1-10 Hz

CAM Message

Vehicle information

- ID
- Vehicle type (car, truck, etc.)
- Vehicle role (emergency, roadwork)
- Vehicle size (length and width)

Time Stamp

- UTC time (in ms, ~1 minute ambiguity)

Pose

- Position (geo) + 95% confidence bound
- Heading

Kinematics

- Speed, drive direction, yaw rate
- Acceleration

DENM Message

Typically sent by Road Side Units (RSU)

Data :

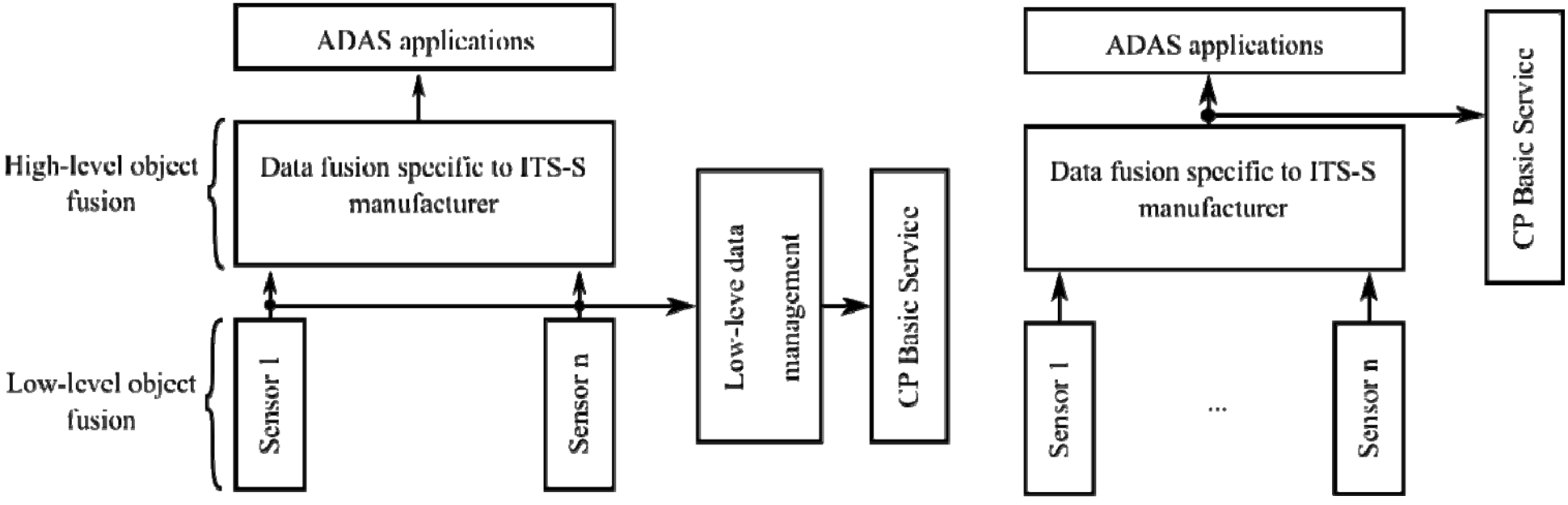
- Station type
- Time Stamp
- Event type
  - Roadworks,
  - Stationary vehicle,
  - Emergency vehicle approaching,
  - Dangerous Situation, etc.
- Lane position
- Lane is closed or not

CPS Message

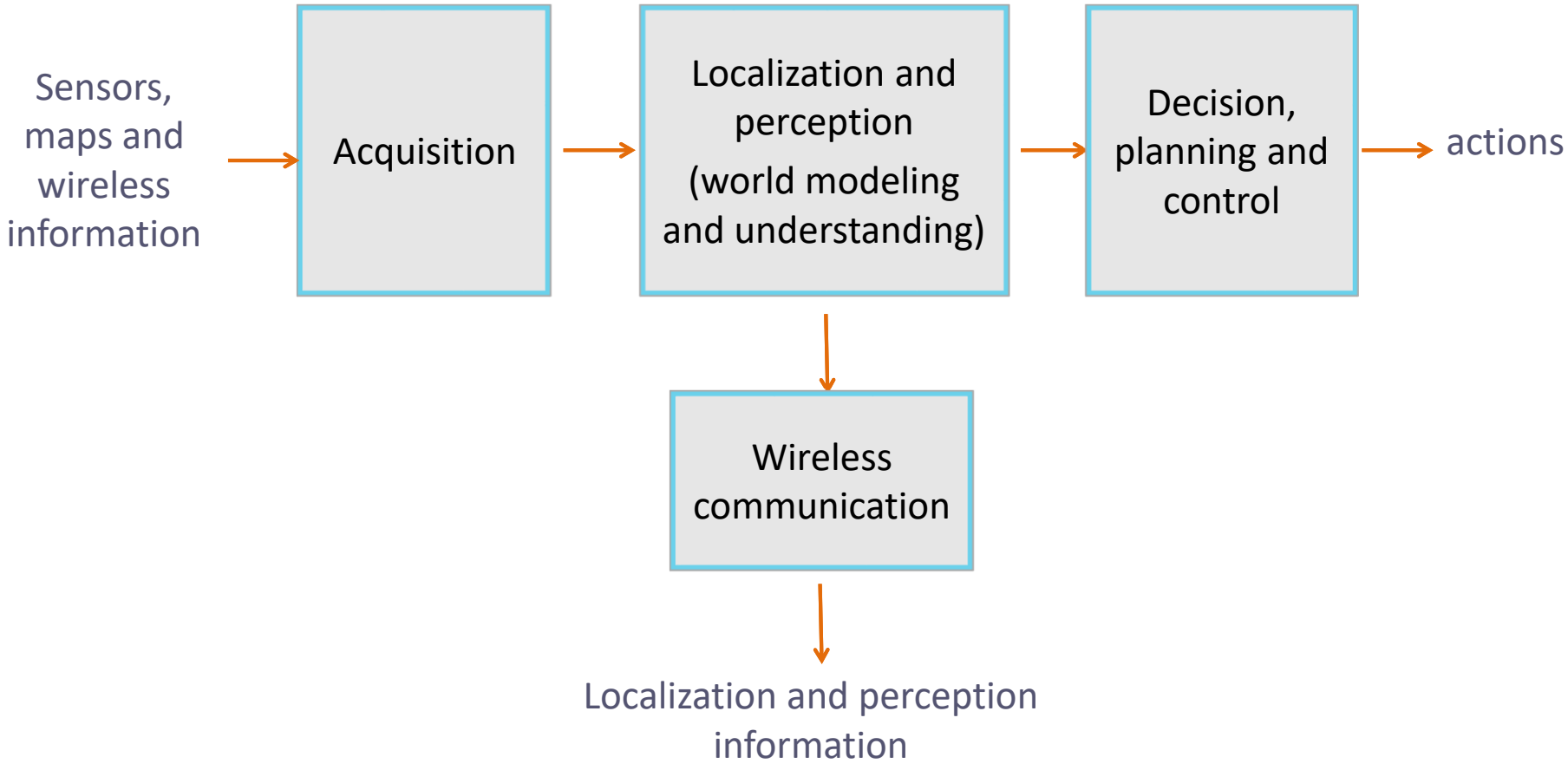
Can be emitted by the infrastructure or the vehicles.

Information:

- List of detected objects
- Position, speed, acceleration
- ID and type of the sensor which provided the measurement data



Typical processing loop



For what kind of tasks, is cooperative navigation useful?

Part 3

Grand Cooperative Driving Challenges

GCDC 2011

- A270 highway between Helmond and Eindhoven.
- Cooperative platooning (sensor based-control with speed and acceleration exchange)
- 9 teams (with cars and trucks)

GCDC 2016

- Same place
- May 28-29, 2016
- Autonomous driving with interactions with vehicles and infrastructure
- Three different traffic scenarios
- 10 European teams.

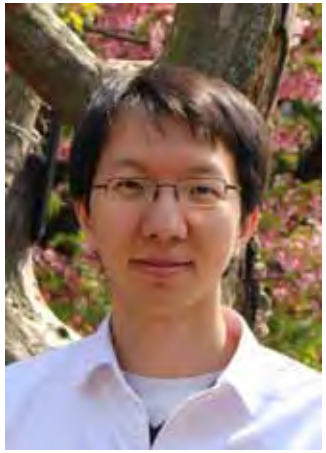
Main Challenge

- Cooperation between heterogeneous systems implementing different algorithms

Heudiasyc team

Team Leader:

Philippe XU



People involved

- 5 Profs and Researchers
- 3 Engineers
- 2 Phd students
- 2 interns
- 12 Master students

Experimental vehicle

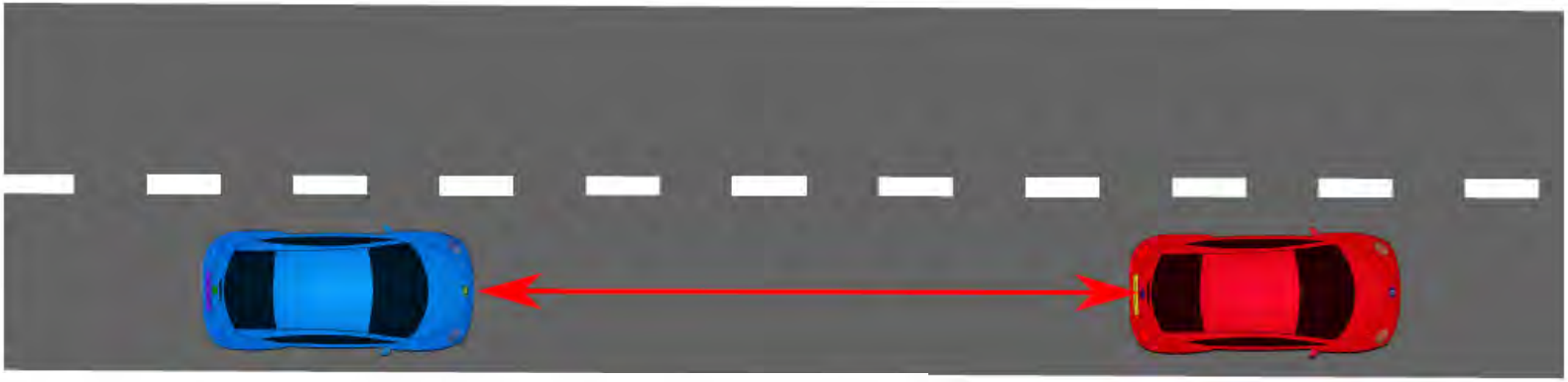
Fully electric car (Renault Zoé)

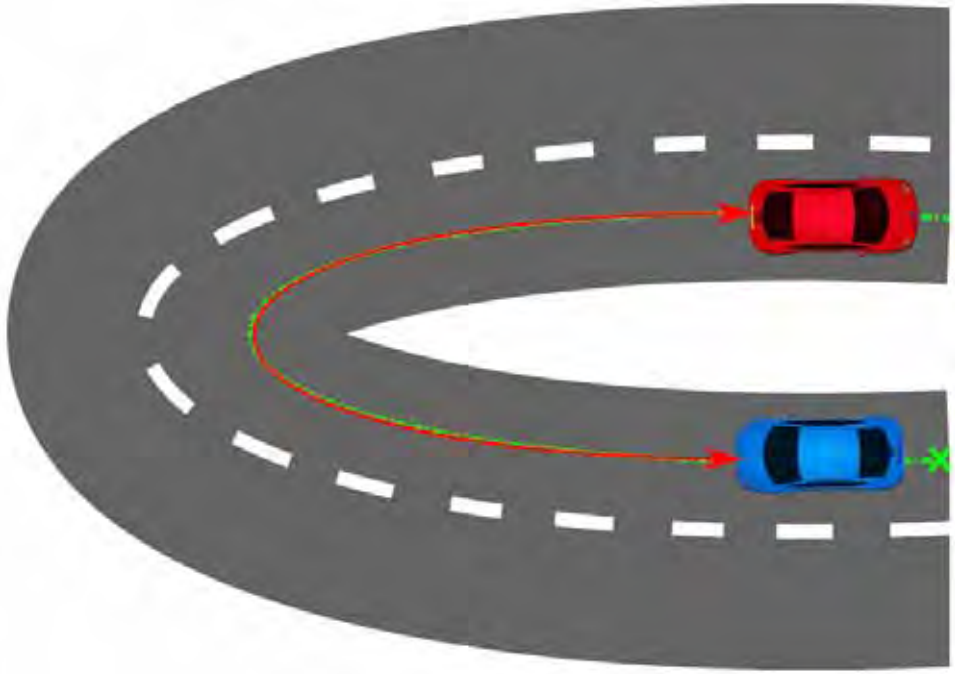
Maximum speed of 50 km/h while driving autonomously

Snapshot of the GCDC 2016

Inter-distance for platooning

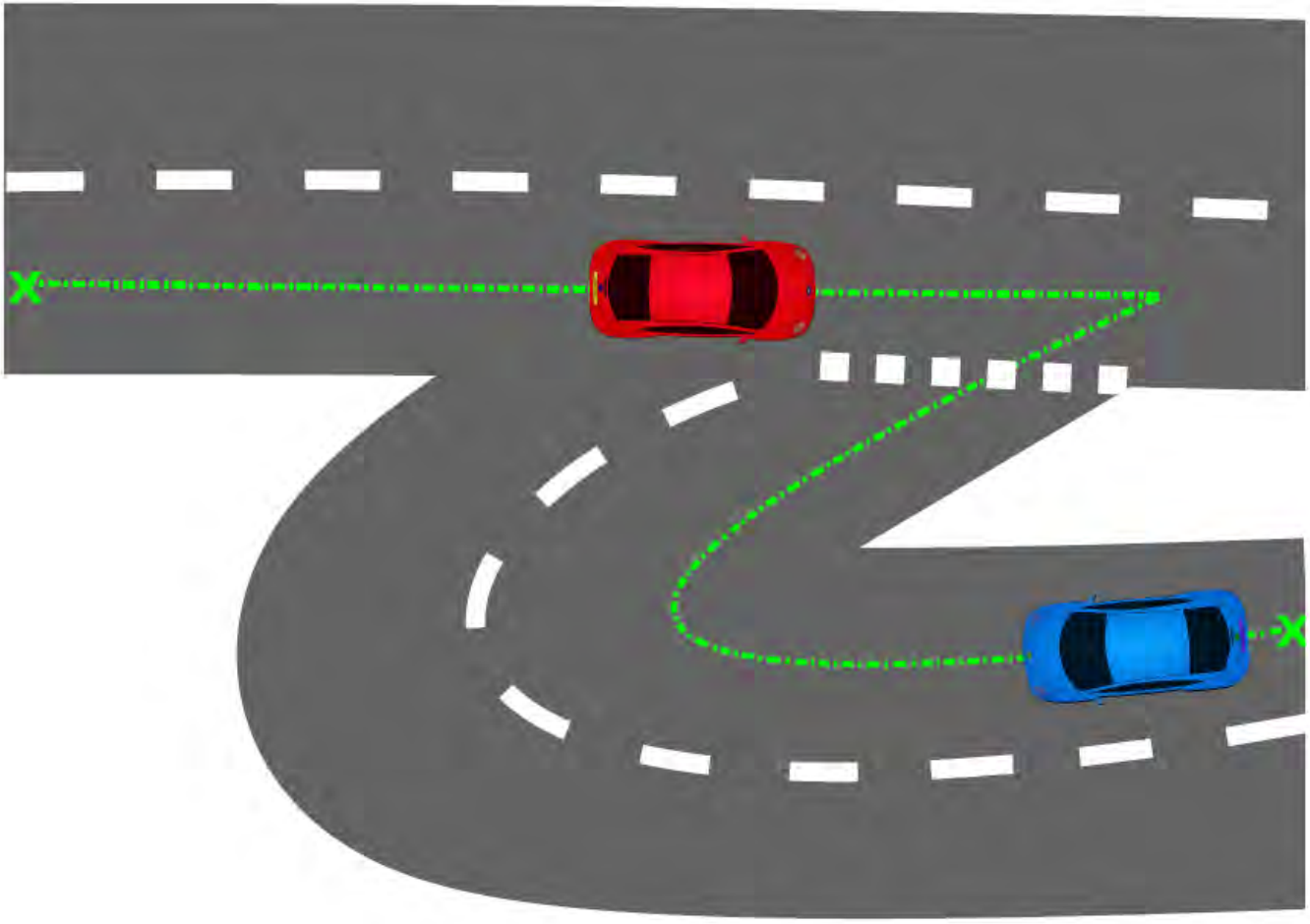
In straight road, inter-distance is easy to measure (e.g. Lidar)





In curved road, compute the inter-distance along the map by using positions exchanged by wireless communication

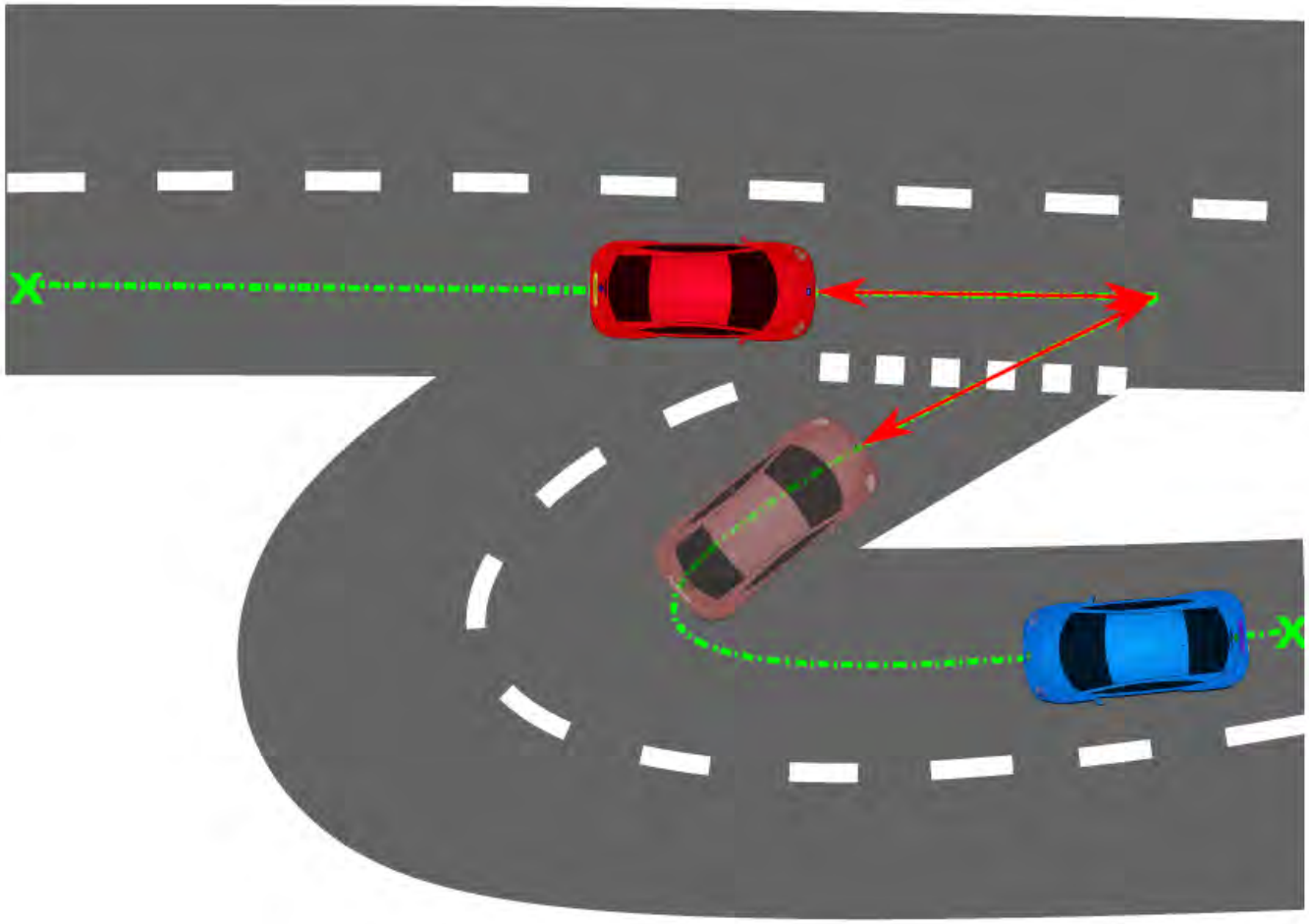
Cooperative merging using virtual platooning



The virtual platooning concept

Every vehicle

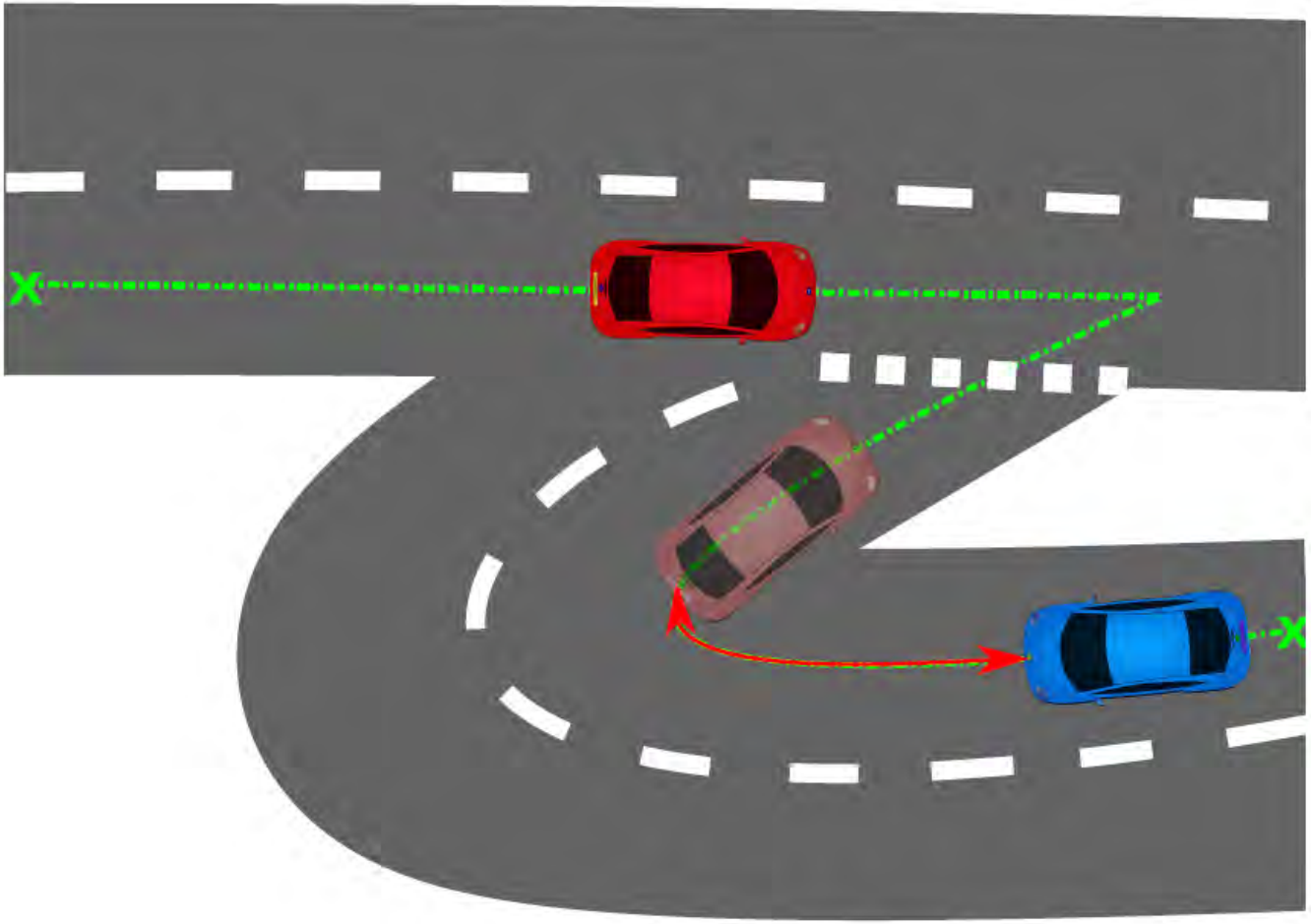
- Computes its distance to the crossing point
- Such that the others can locate it on their own path



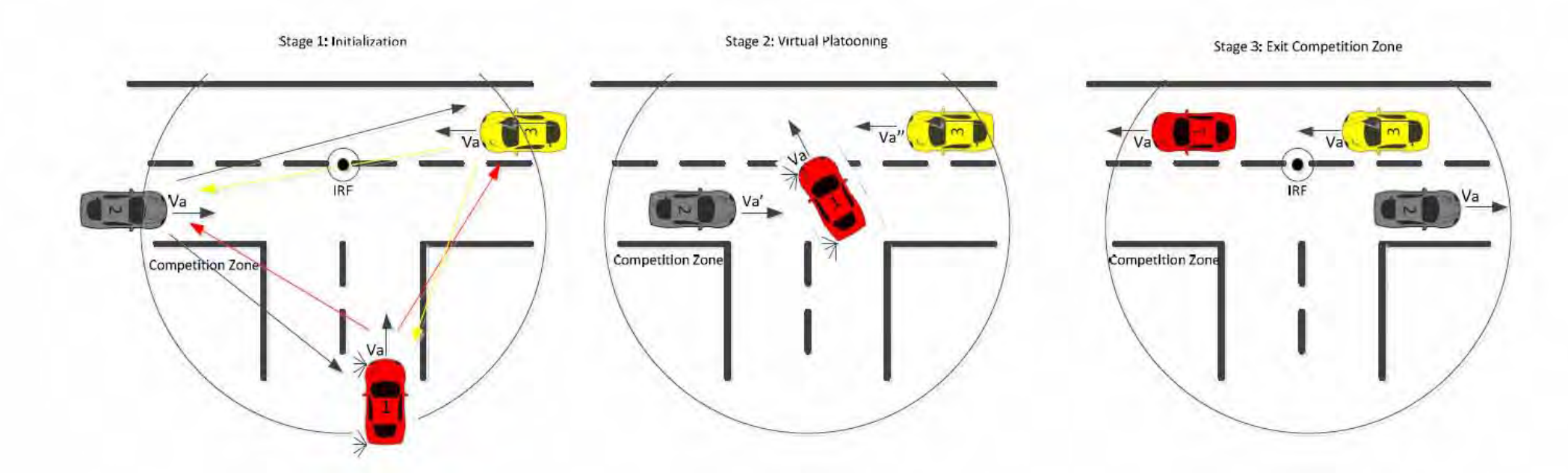
The virtual platooning concept

In this example, the red vehicle is the closest to the intersection point and becomes the (virtual) leader

Then the blue one does platooning



Crossing Scenario at the GCDC



Vehicle 1 is a car of the organizers, the challengers are 2 and 3

Goal:

- Vehicles have to reach the competition zone at a given time with a given speed
- Vehicles 2 and 3 have to let vehicle 1 cross the intersection at constant speed
- The goal of each challenger is to exit the CZ as fast as possible (with no collision)

Intersection Crossing Strategy

Method used:

— virtual platooning with the vehicle of the organizers

We used its transmitted position

— because we knew it was reliable

Procedure:

— Set the origin of the working frame at the center of the intersection

— Convert the geo-positions in this frame

— The norm of the position is the distance to the center

— Do virtual platooning with the organizer's car until it has crossed the intersection

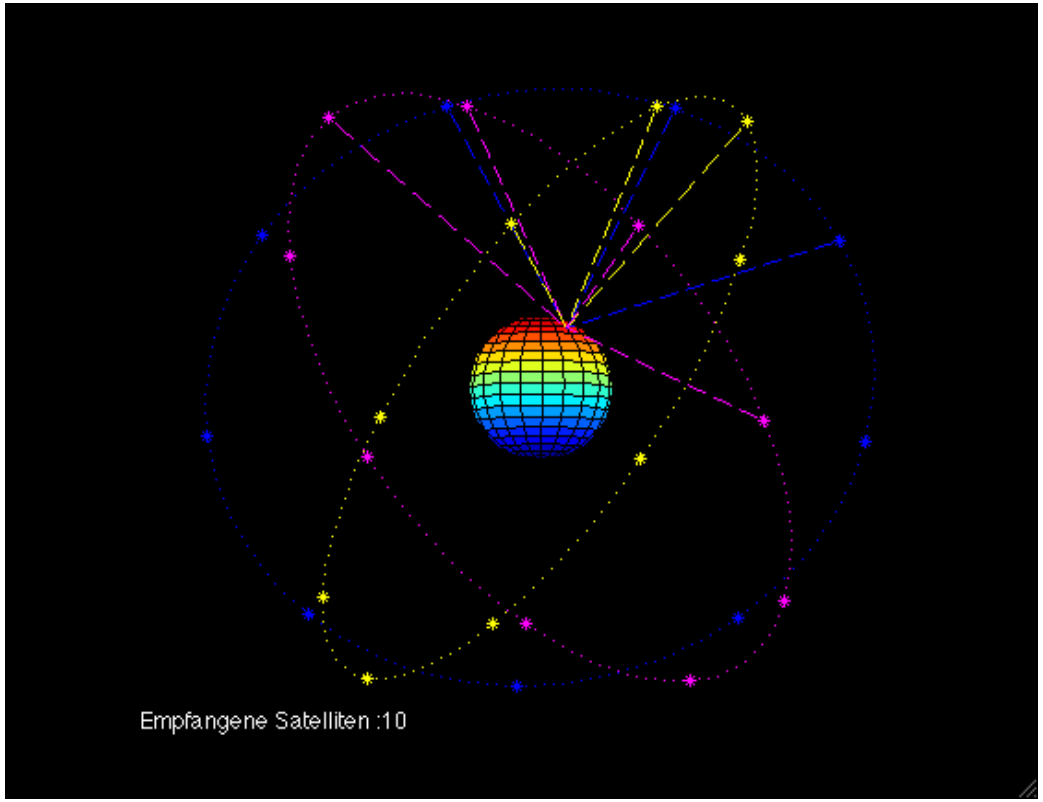
Snapshot of an intersection crossing during the GCDC

Infrastructure-aided localization systems

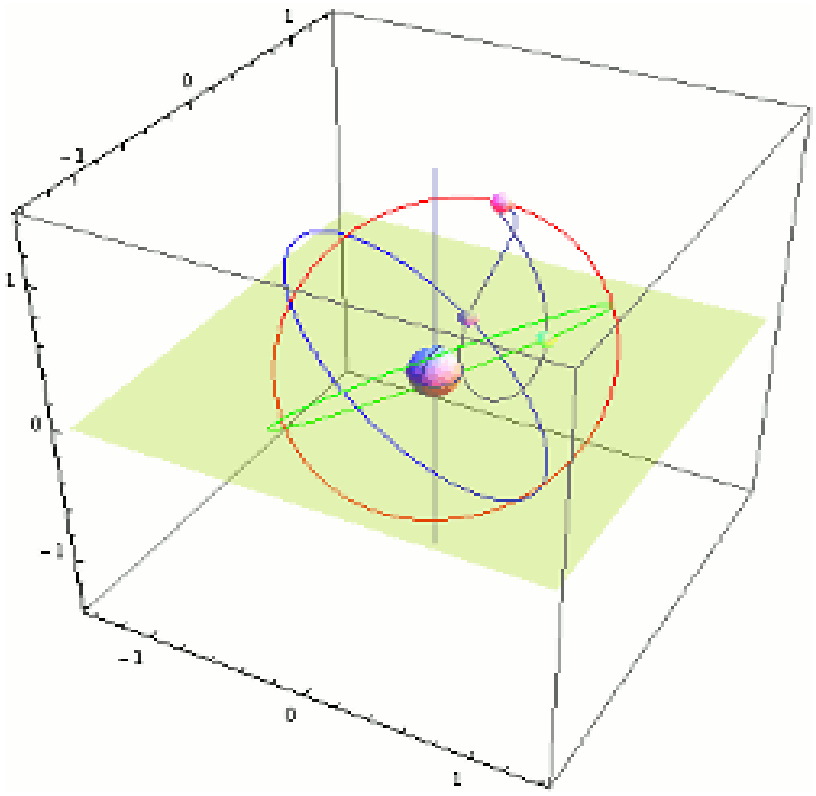
The GNSS example

GNSS technology

GPS (USA), GLONASS (Russia), BeiDou (China) and Galileo (EU)



Medium Earth Orbit (MEO)



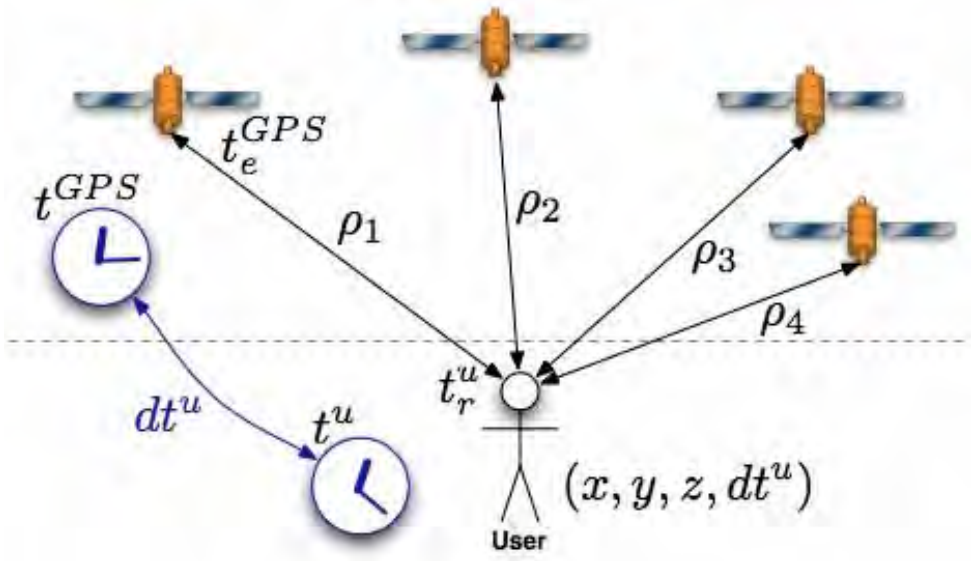
Quasi-Zenith Satellite System (QZSS) Japan

Classical GNSS positioning problem

—Receiver measures *pseudoranges:*
range + offset

—4 unknowns: *x, y, z, dtu*

—Pseudorange observation model:

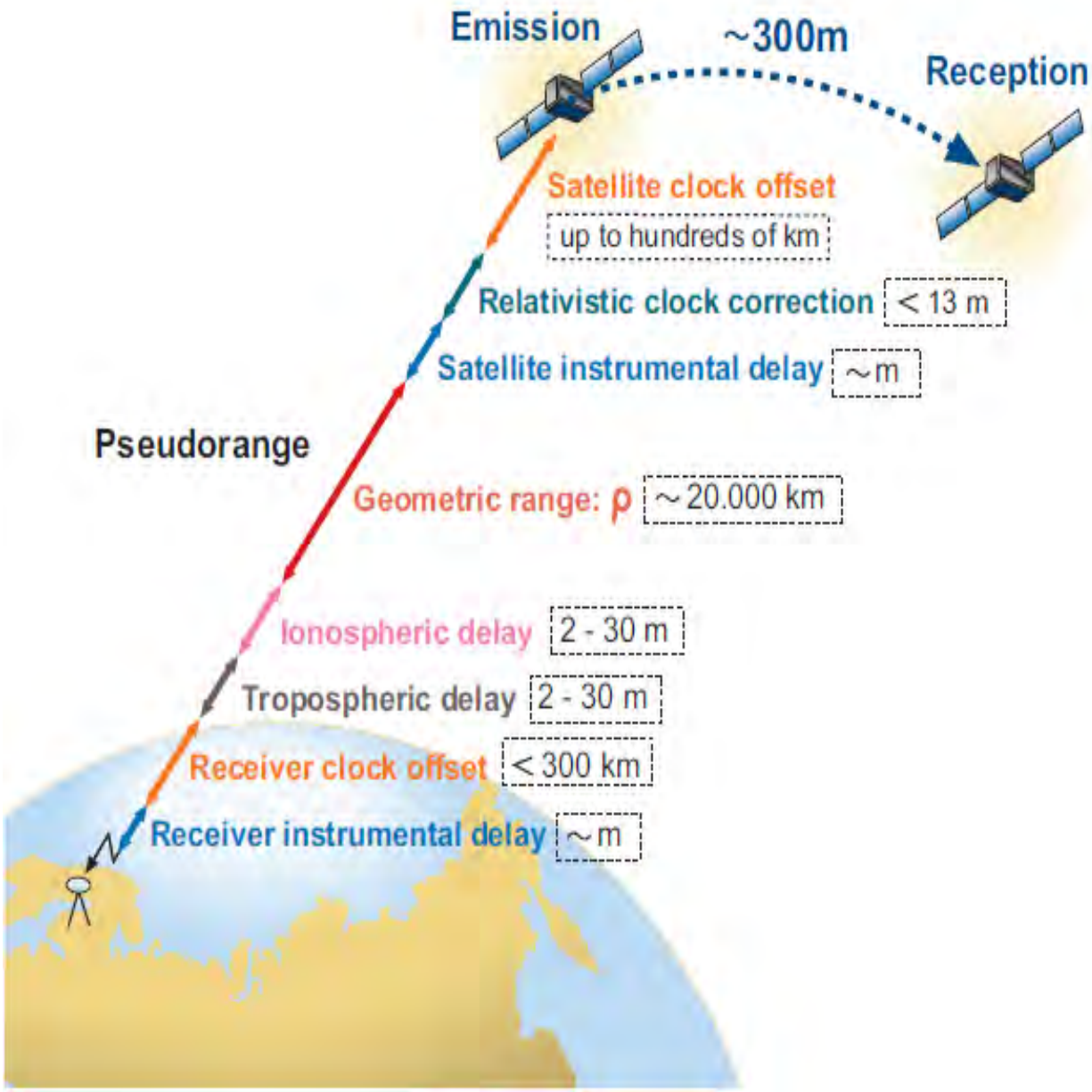


$$\begin{cases} \rho_1 = \sqrt{(x-x_{s1})^2+(y-y_{s1})^2+(z-z_{s1})^2} + c \cdot dtu \\ \rho_2 = \sqrt{(x-x_{s2})^2+(y-y_{s2})^2+(z-z_{s2})^2} + c \cdot dtu \\ \quad \dots \\ \rho_p = \sqrt{(x-x_{sp})^2+(y-y_{sp})^2+(z-z_{sp})^2} + c \cdot dtu \end{cases}$$

$x_{s_i}, y_{s_i}, z_{s_i}$ are satellite positions (broadcast)

ρ_i are corrected pseudoranges:

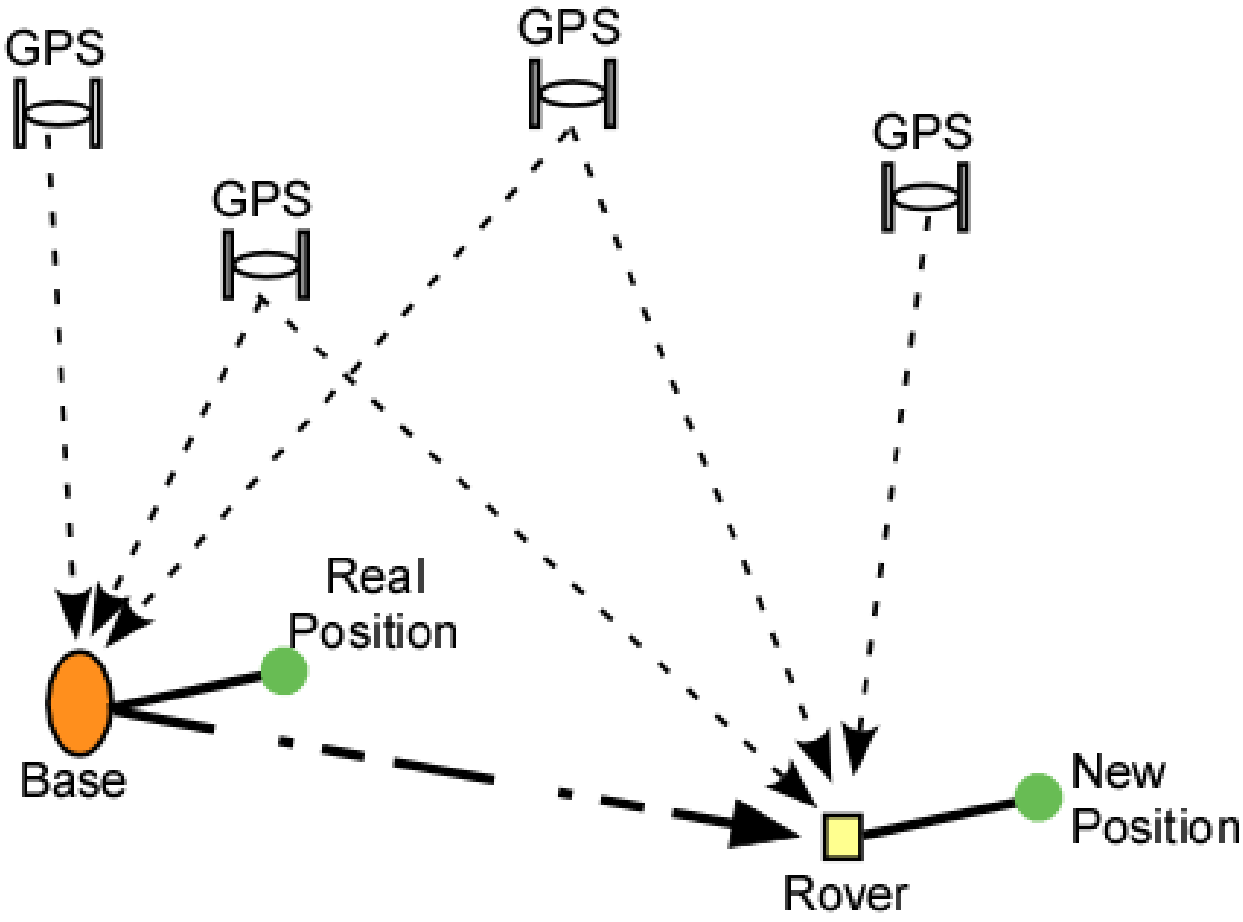
GNSS sources of errors



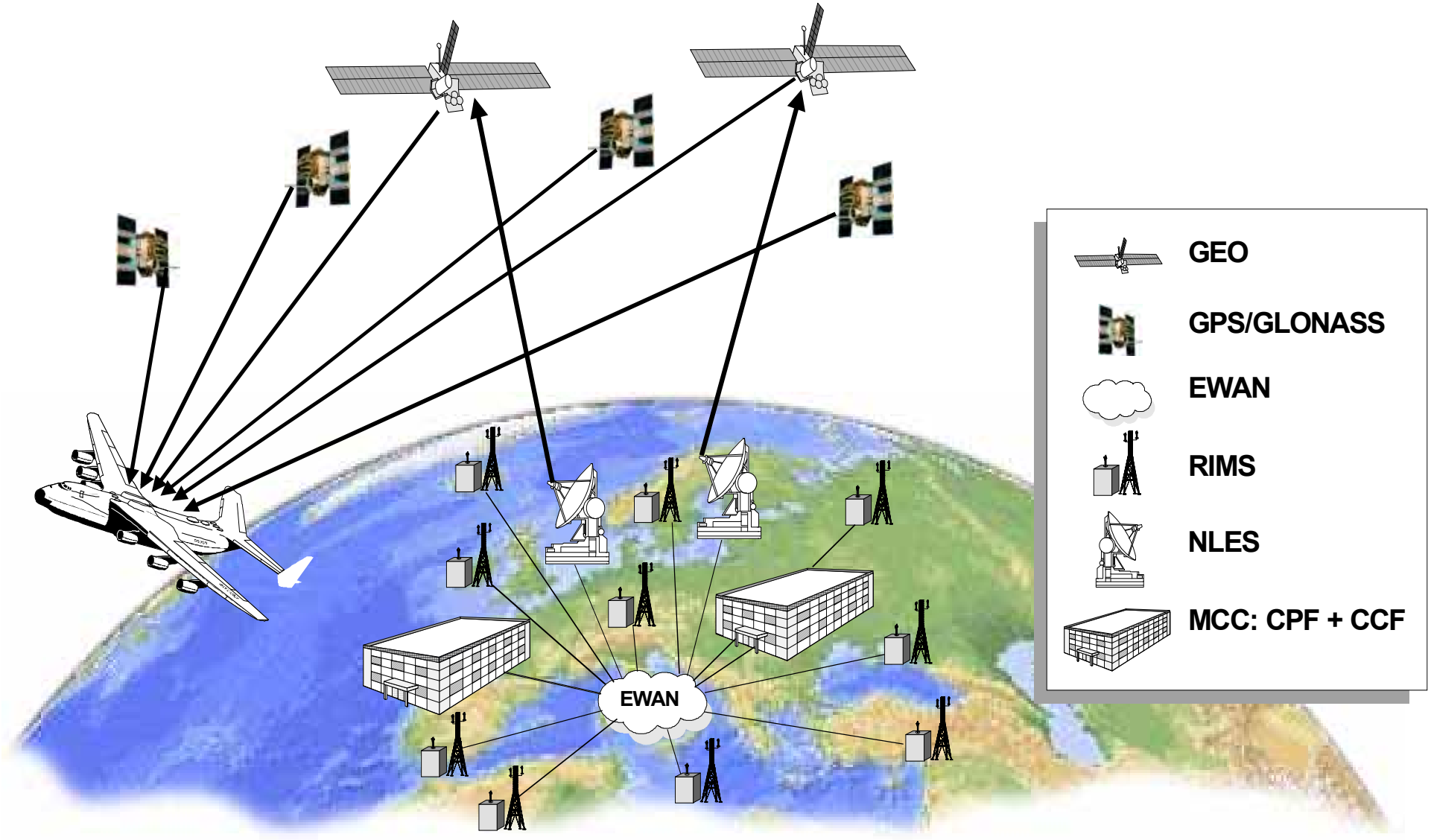
Accuracy and integrity improvement:

- DGPS and RTK
- EGNOS/WAAS
- PPP

Differential and Real-Time Kinematic

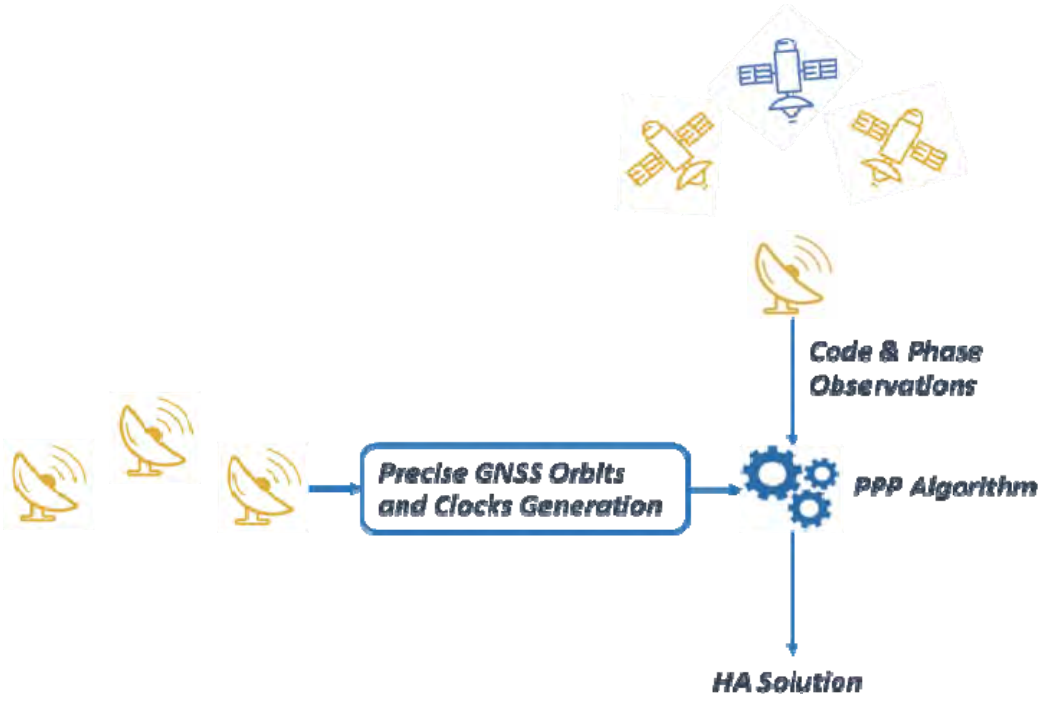


EGNOS (European Service)



Precise Point Positioning

- PPP combines precise satellite positions and clocks with GNSS receivers
- PPP requires fewer reference stations globally distributed rather than classic differential approaches (e.g. RTK)
- PPP corrections are disseminated through the internet to connected users



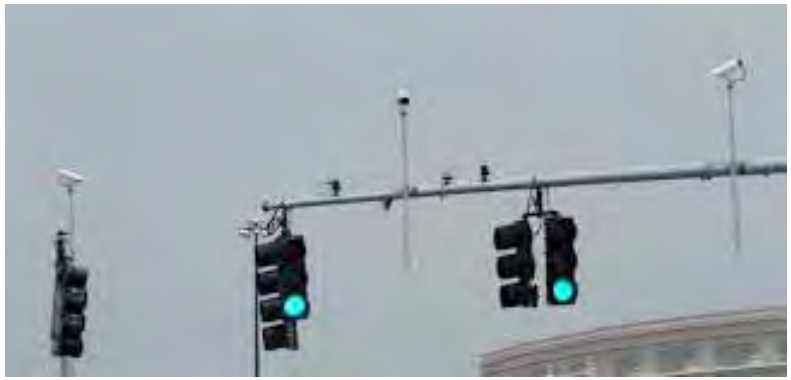
Cooperative Wireless platooning with CAM Messages and RTK GNSS (GPS and Glonass)

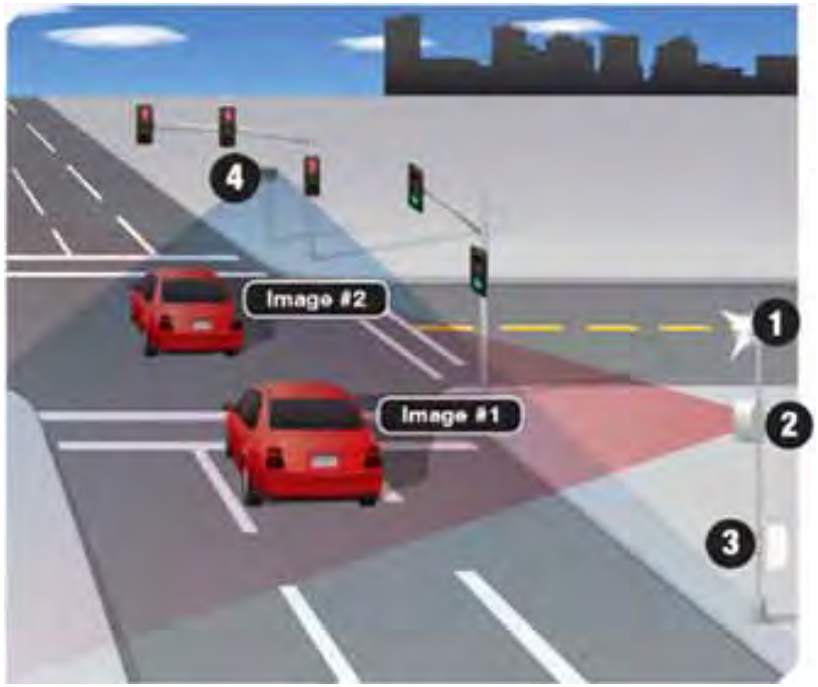
Experiments at Compiègne

Infrastructure-based perception systems

The roundabout crossing example

Infrastructure-based perception systems





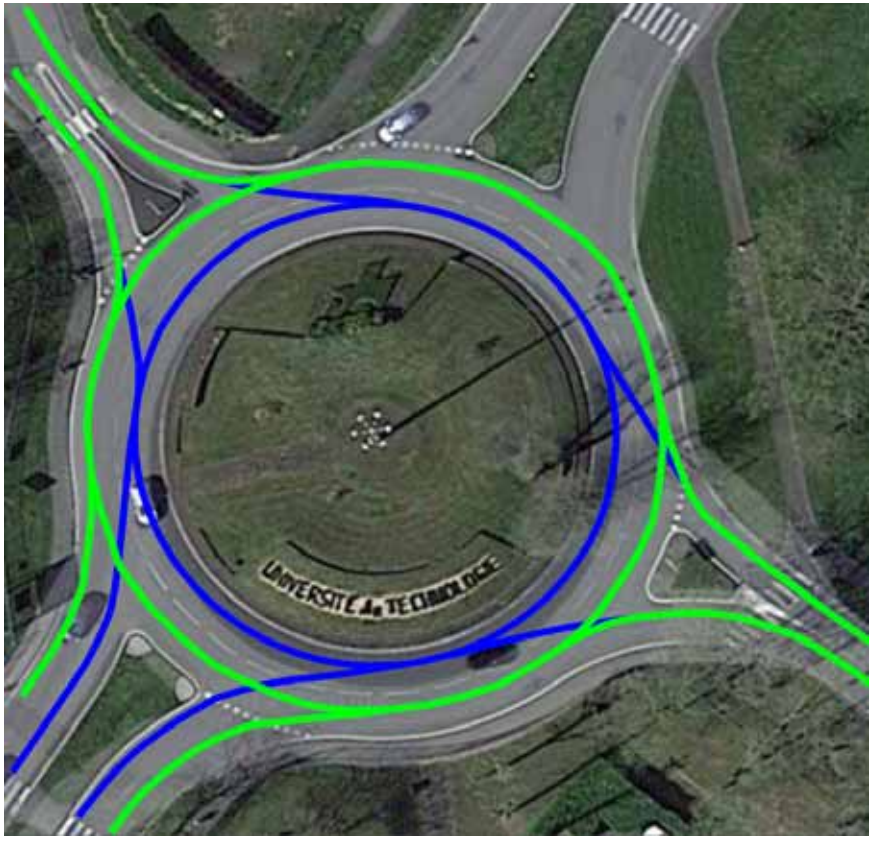
The infrastructure scans the environment and

It shares information about the current traffic participants by broadcasting the locations and speeds of the mobile objects

This reduces the ambient uncertainty by providing contextual information

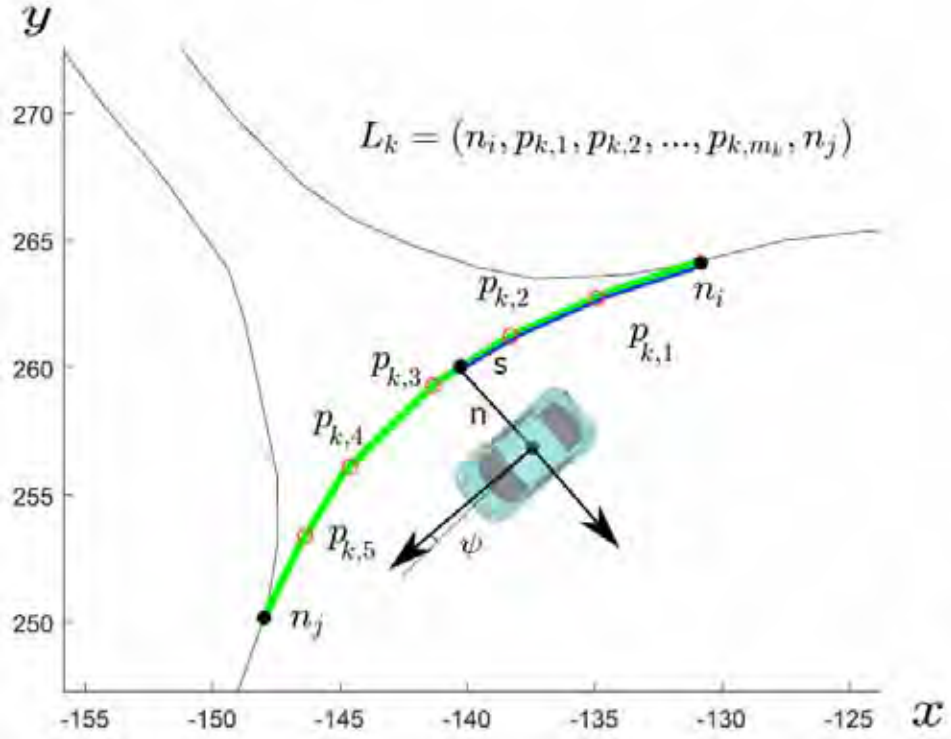
Case study: Roundabout crossing

- Infrastructure can assist autonomous cars to cross roundabouts by detecting and broadcasting CPM messages with vehicles positions and speeds inside the roundabout
- Thanks to this, autonomous vehicles can anticipate crossing the roundabout by adapting their speed



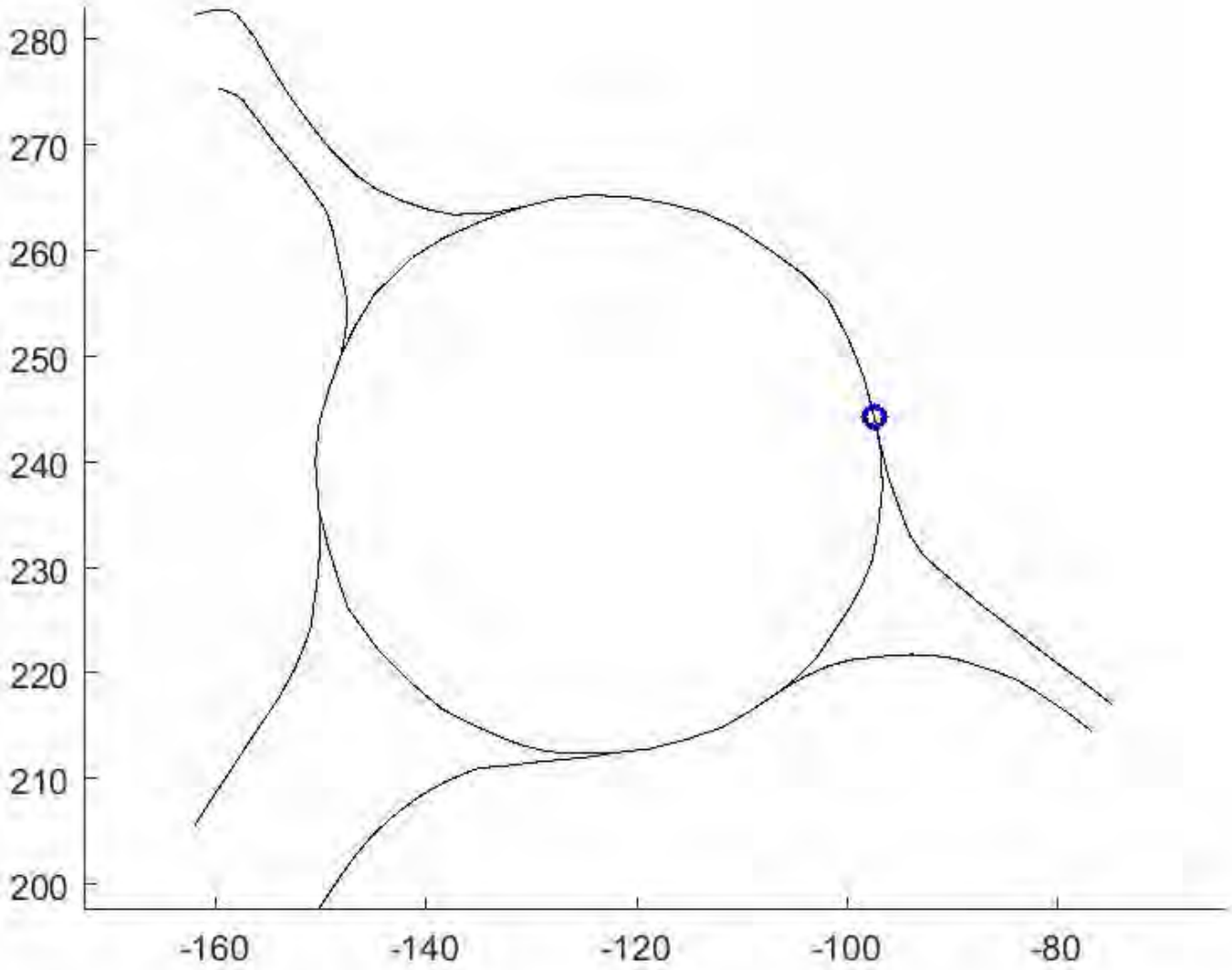
Adapting the Virtual Platooning Concept to Roundabout Crossing

- Use a high-definition map (HD map)
- Map-match every estimated position

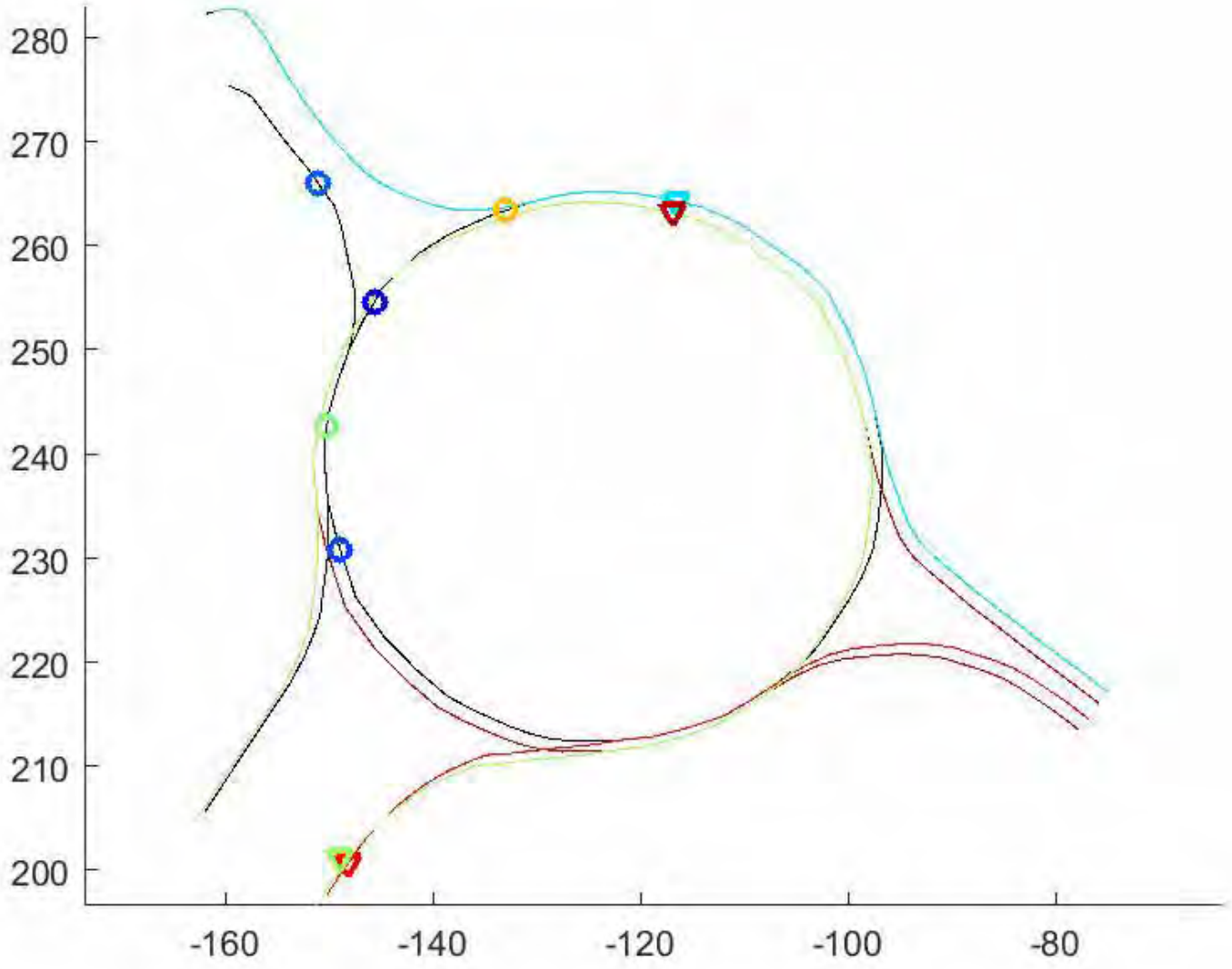


- Compare distances between vehicles and common node
- Do platooning according to the decided order

Example with cooperative autonomous cars



A solution to solve the problem of non cooperative driven cars



Cooperative Localization Systems in Mutual Cooperation

Objectives

Cooperate

—To help the others

—To be assisted by the others

—To reduce uncertainties

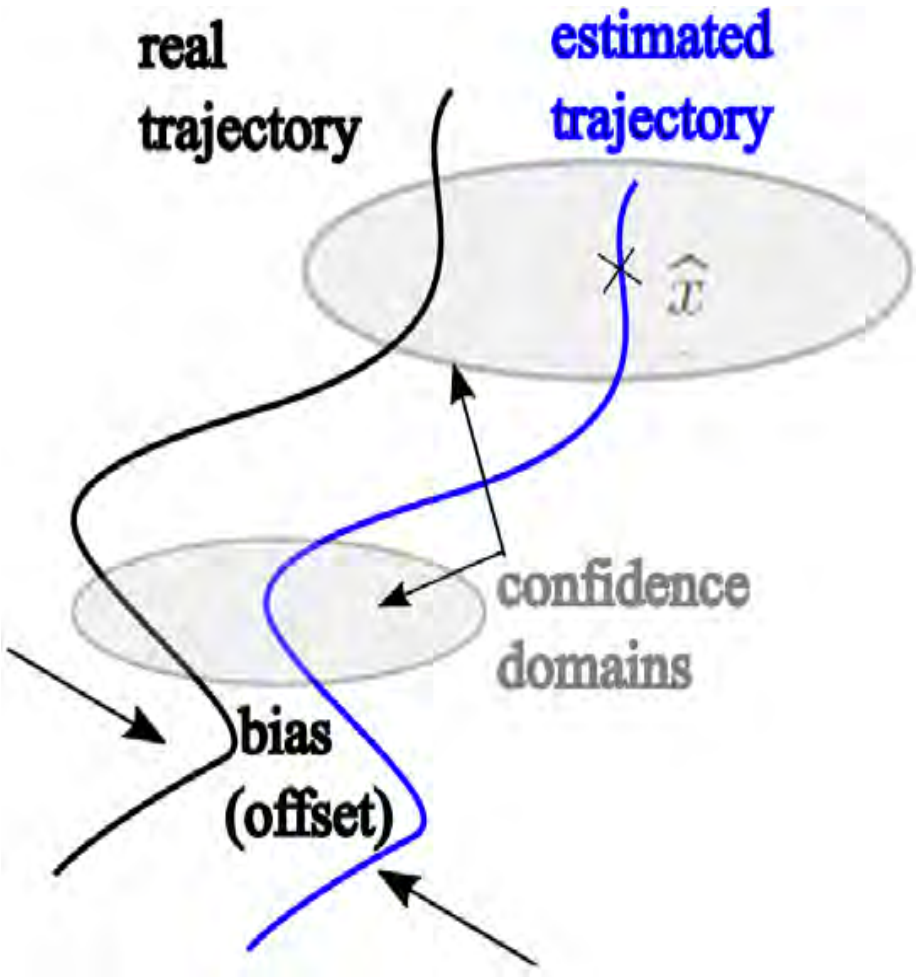
—To reduce the pessimism of confidence bounds

—To increase system availability

The data incest issue

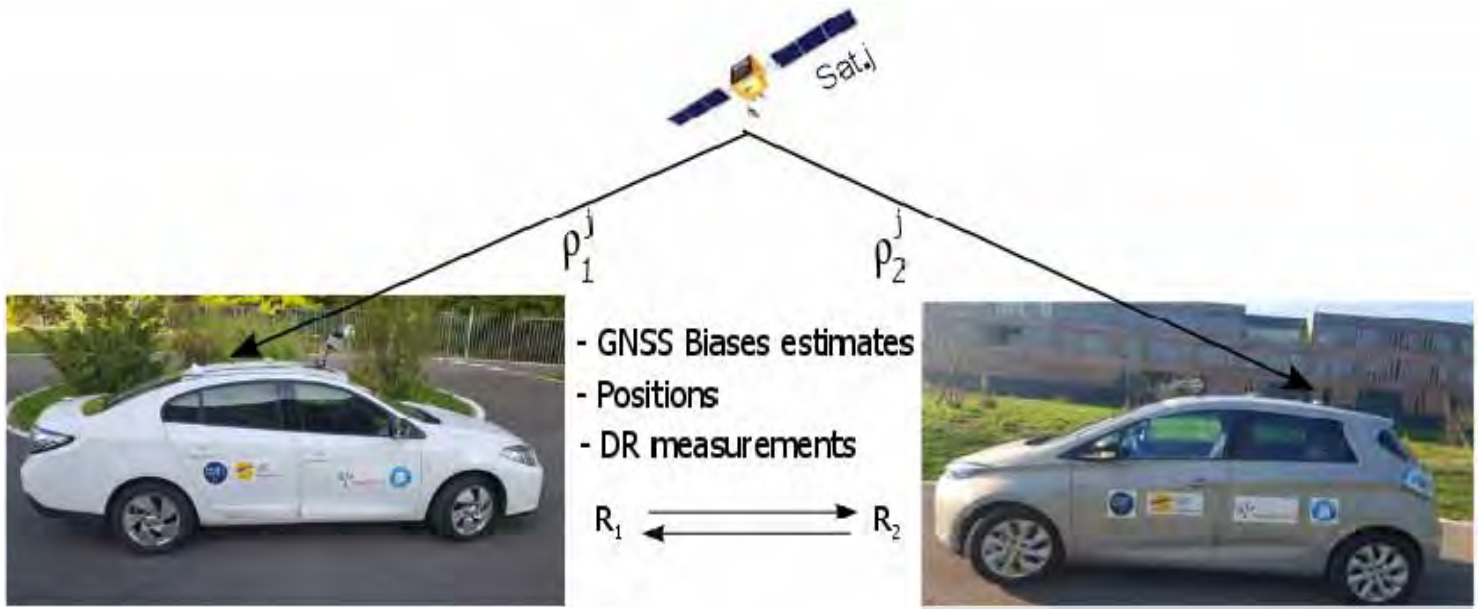
Cooperative Localization to reduce biases

Low cost GNSS receivers without corrections from the infrastructure lead to systematic offsets



Cooperative Localization by distributed state observation

Estimation of the pseudoranges biases with no base station



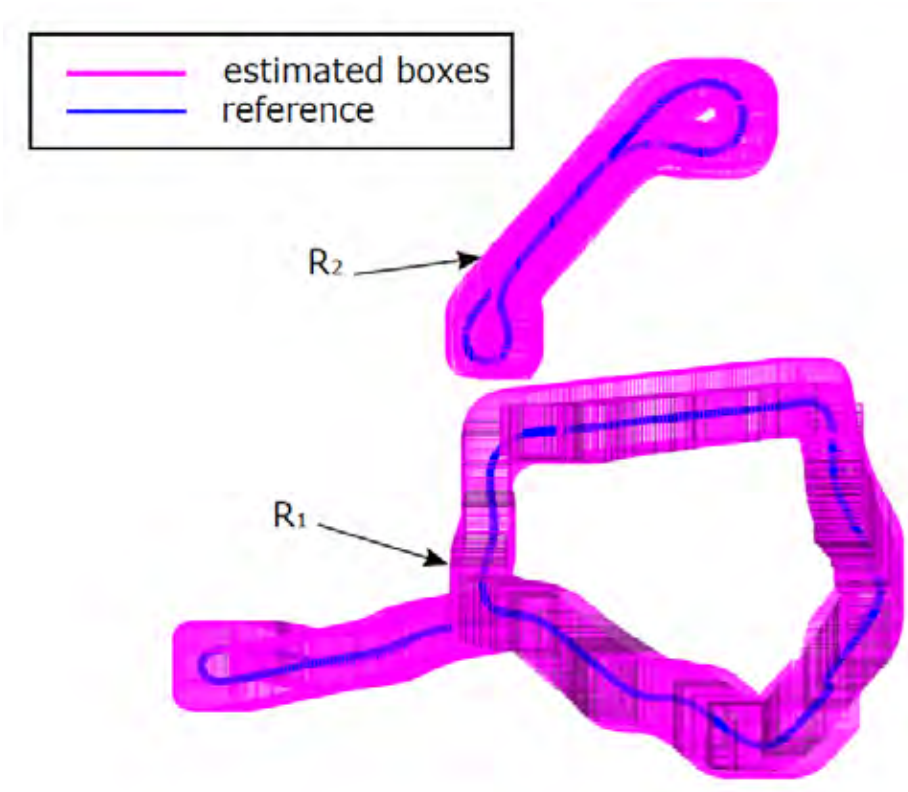
Methods:

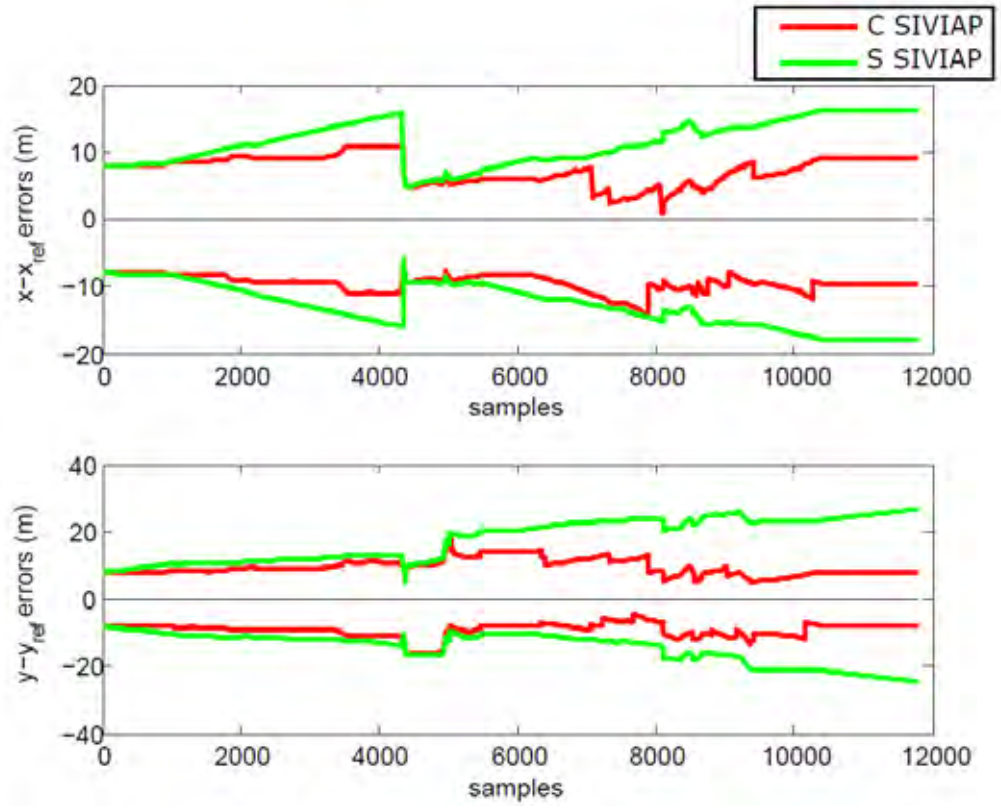
— Set-membership methods based on Constraints Propagation and Set inversion

— Bayesian methods based on EKF and covariance intersection for data fusion

Results

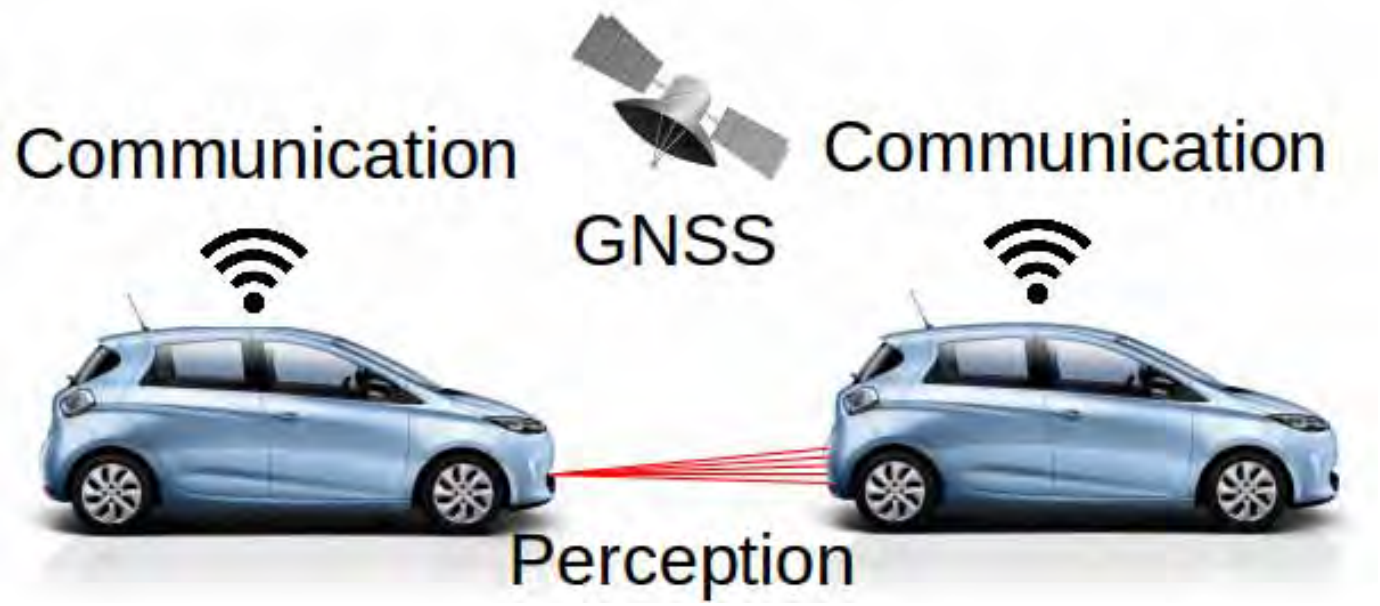
- Mutual cooperation reduces uncertainty and improves accuracy
- No data incest (overconfidence in this case)





Cooperative localization using perception

- Low cost GNSS receivers and proprioceptive measurements
- Embedded perception sensors for inter-distances (lidar)

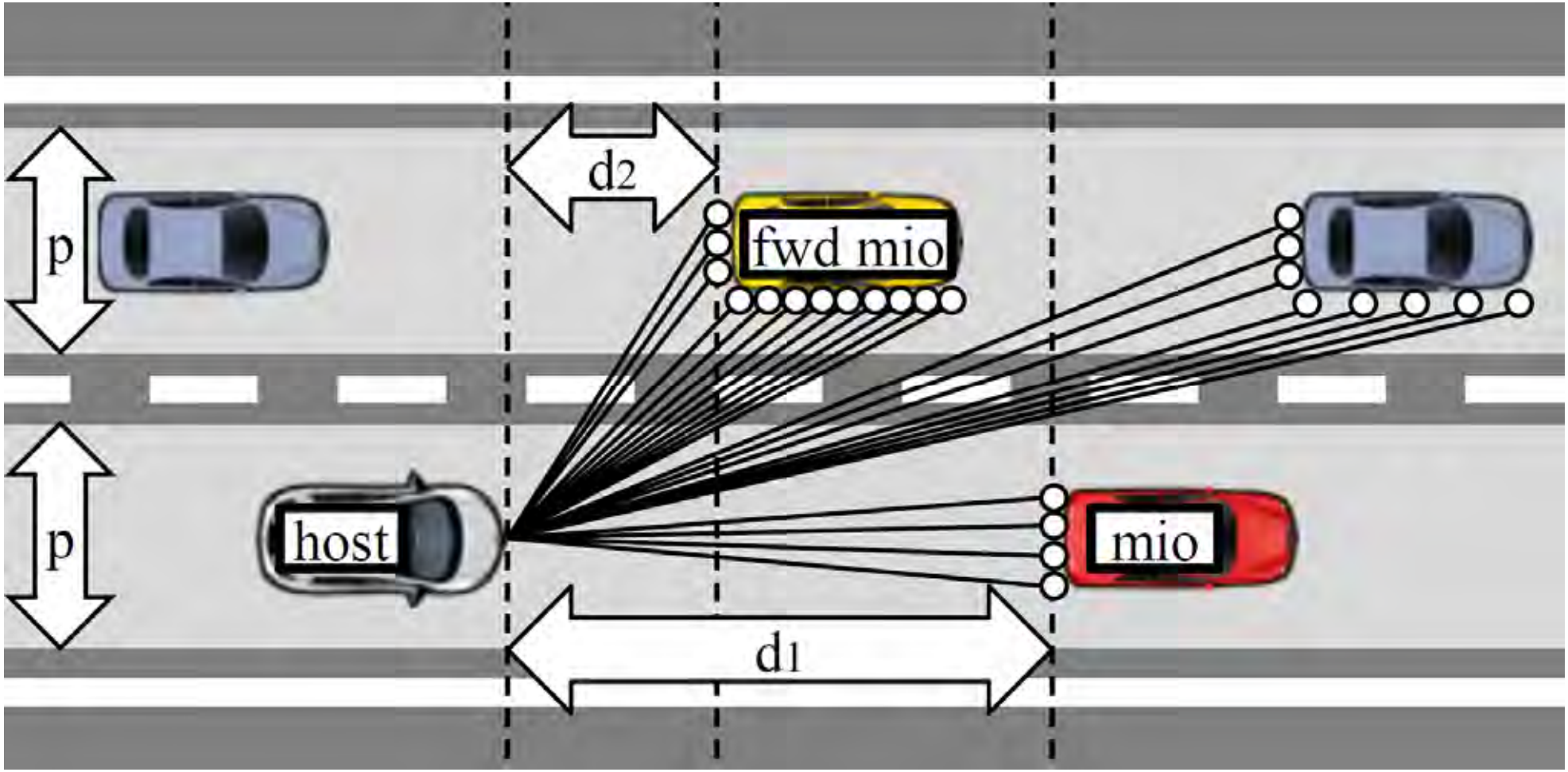


Lidar installation

Four-layer Sick LD-MRS LiDAR installed in the front bumper

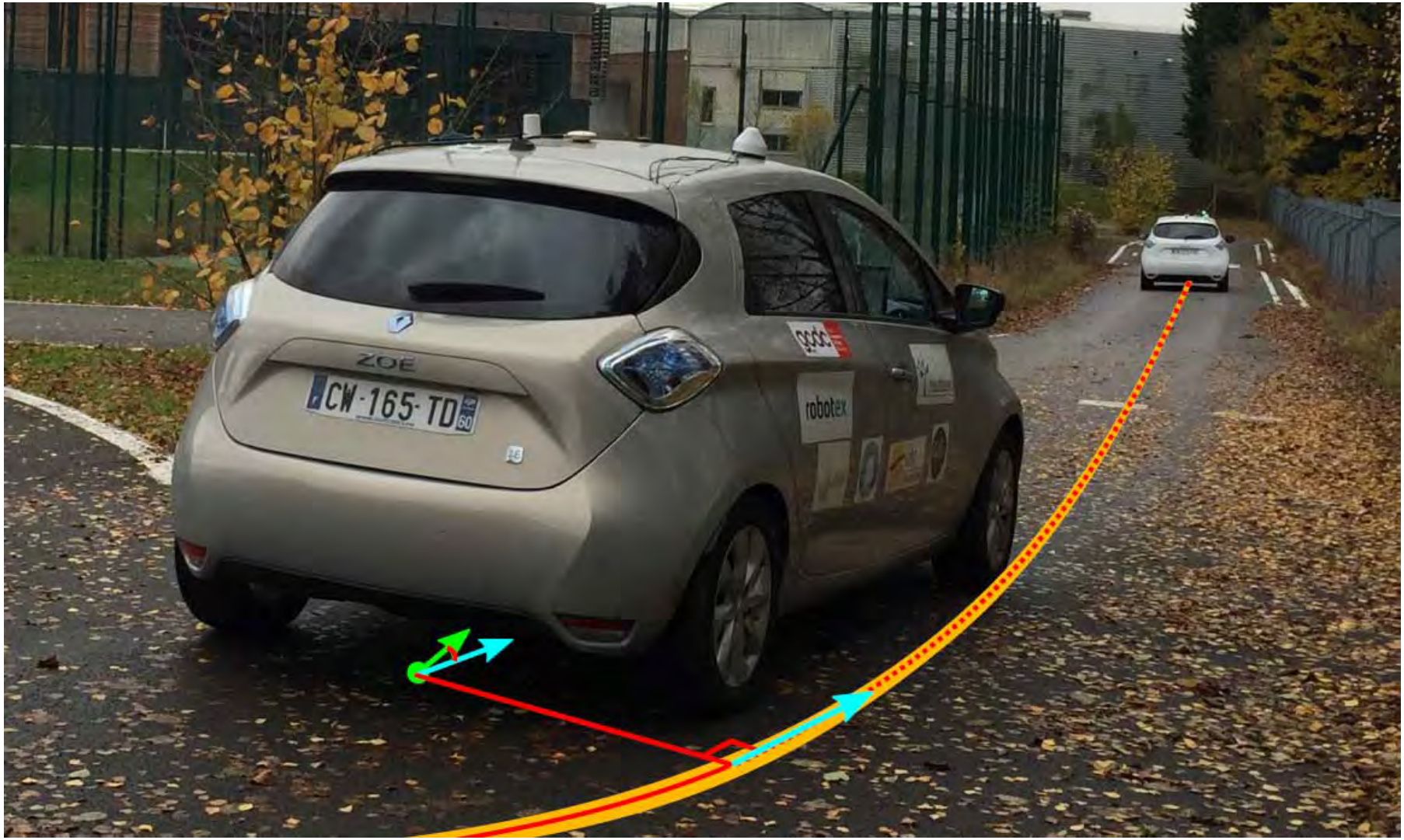
Lidar processing

Clustering of the point cloud and bounding box computation



Curvilinear coordinates

Curvilinear coordinates



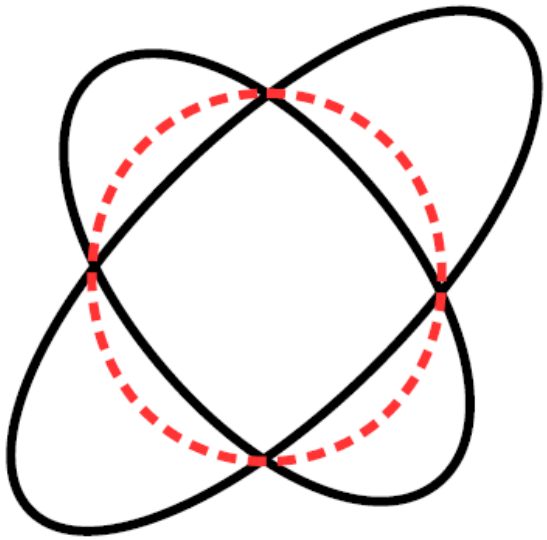
One dimensional cooperative data fusion

Covariance intersection filter

$$\hat{\sigma}^2_{k|k} = \left(\omega / \hat{\sigma}^2_{k|k-1} + (1-\omega) / \sigma^2_{z,k}\right)^{-1}$$

$$\hat{s}^2_{k|k} = \hat{\sigma}^2_{k|k}\left(\omega\, \hat{s}_{k|k-1} / \hat{\sigma}^2_{k|k-1} + (1-\omega)\, z_k / \sigma^2_{z,k}\right)$$

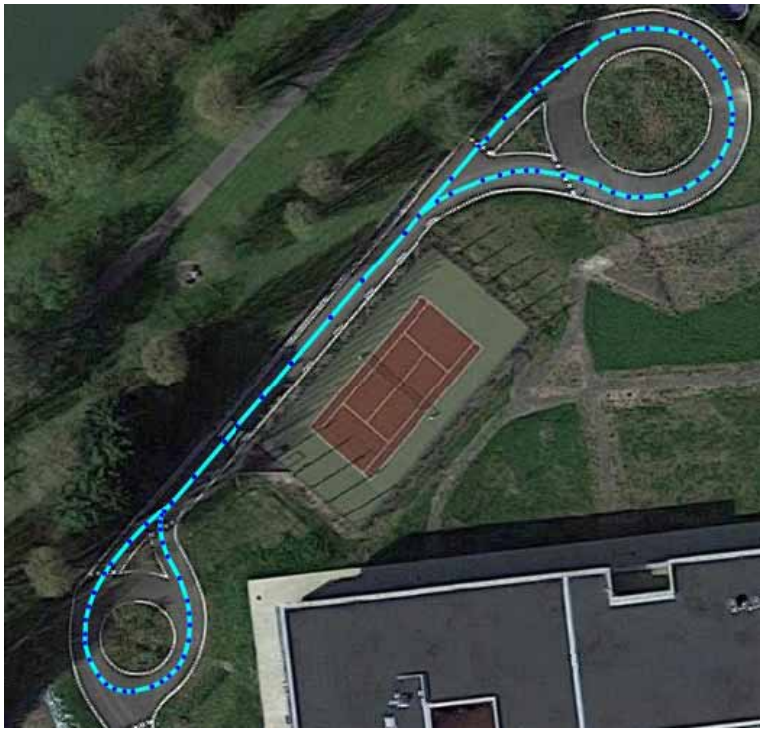
Such as $\hat{\sigma}^2_{k|k}$ is minimum with $\omega \in [0,1]$



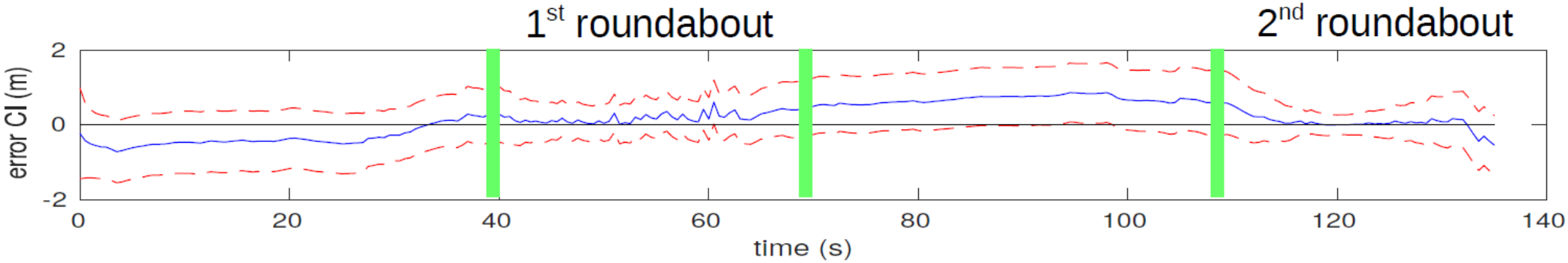
In one dimension, the covariance intersection filter is straightforward

Experimental results

Mutual cooperation in curved lane



Error and confidence bound computed for the follower



Conclusion and perspectives

Conclusion

Cooperation is new paradigm for autonomous vehicles navigation

— Receive information from the infrastructure

— Exchange highly dynamic information with each other

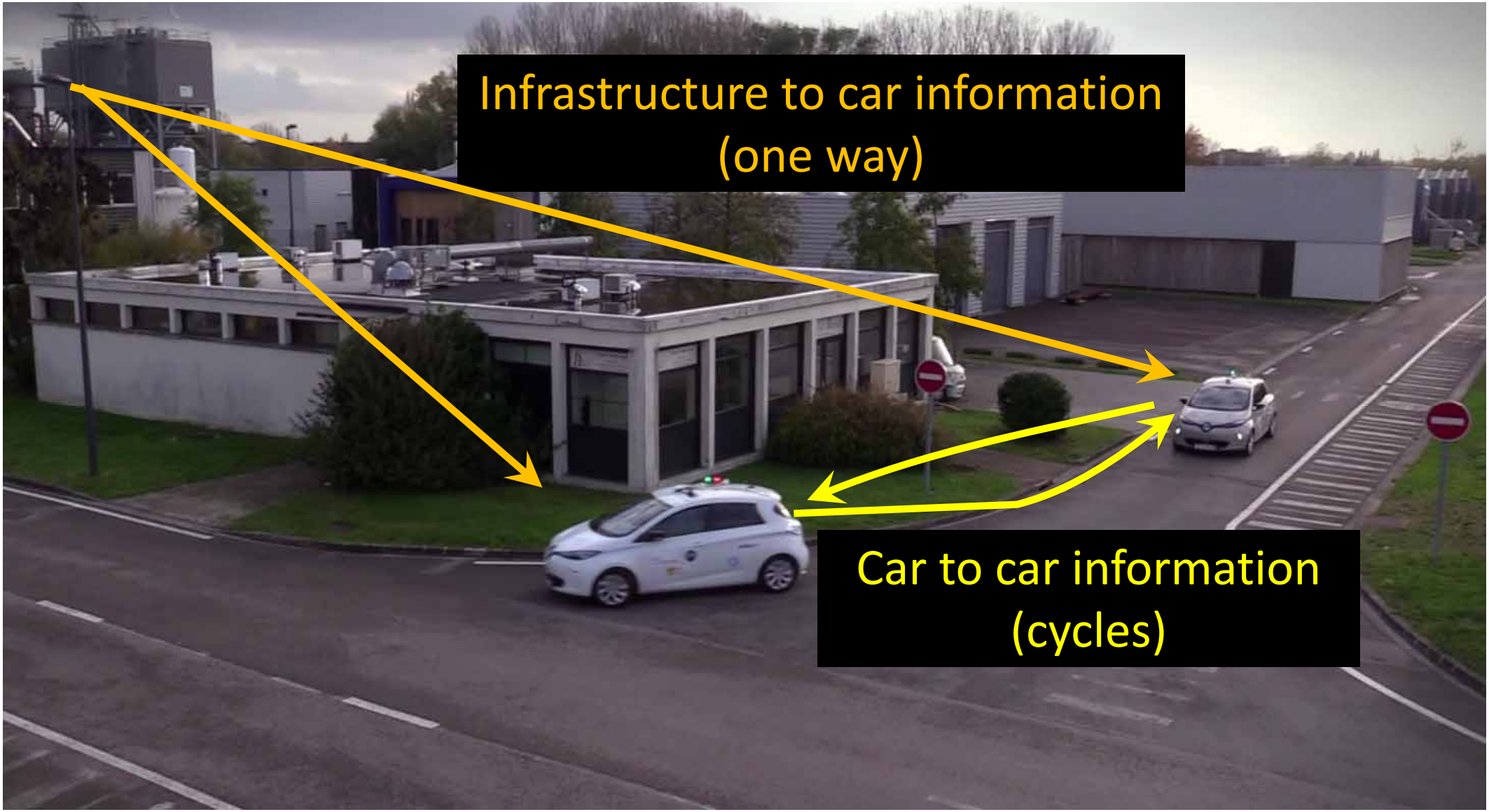
Useful

— To reduce the number of embedded sensors for navigation (even if they remain mandatory)

— To improve the accuracy and the integrity

— For augmented perception

Cooperation is useful for autonomous cars



Localization for cooperative systems

Localization is crucial at the tactical level because most of the decisions are based on the location of the vehicle itself and of other vehicles in its vicinity

It improves crossing procedures in case the vehicles can't see each other

Localization for cooperative control

Localization is useful for cooperative systems at the control level when the others traffic participants are out of view

— Lane changes, overtaking, intersection crossing

Requirements

— Accuracy has to be “lane level”

— Uncertainty has to be consistent (the estimation of the error has to be not underestimated)

Localization errors may lead to dangerous situations for cooperative control when the others traffic participants are in the vicinity

— Inter-distances in platoons have to be regulated with embedded perception sensors

— When crossing junctions, embedded perception sensors are necessary for safe navigation

Perspective

Progress to be made

- Methods that guaranty the integrity of the information exchanged and control the propagation of errors and faults
  - In particular, cycles of exchange inducing data incest problems have to be taken into account
- Methods able to compute in real-time reliable bounds of the errors
- Data exchange standards
  - In particular, regarding the uncertainty representation

Thank you for your attention !

Associated publications

- Ph. Xu, G. Dherbomez, E. Héry, A. Abidli, and Ph. Bonnifait. "System architecture of a driverless electric car in the grand cooperative driving challenge." IEEE Intelligent Transportation Systems Magazine, January 2018.
- E. Héry, Ph. Xu and Ph. Bonnifait. "Along-track localization for cooperative autonomous vehicles". IEEE Intelligent Vehicles Symposium, Redondo Beach, California, June 2017.
- K. Lassoued, Ph. Bonnifait, and I. Fantoni (2017). "Cooperative Localization with Reliable Confidence Domains between Vehicles sharing GNSS Pseudoranges Errors with no Base Station" IEEE Intelligent Transportation Systems Magazine, January 2017

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