# Cooperative alert generation and propagation in vehicular networks

*Cooperative Mobility for the Service of the Future*

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with D. Bloquel, S. Bonnet, V. Cherfaoui and T. Fuhrmann

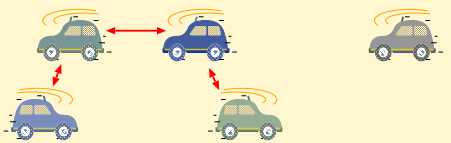
Sorbonne universités
Université de Technologie de Compiègne
UMR CNRS UTC 7253 Heudiasyc

Decembre 2016

# Agenda







# Summary

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# Comosef project

## Cooperative Mobility for the Service of the Future



- European Celtic Plus project
  - Coordinator: Pekka Eloranta
  - 9 million euros, 94 person-years
  - 7 countries, 21 partners
  - 11 pilots

- Mobisoft Oy
- Finnish Meteorological Institute
- Infotripla Oy
- Taipale Telematics
- VTT
- Centria

- CRP Henri Tudor
- HITEC Luxembourg S.A.
- Entreprise des Postes et Telecommunications Luxembourg

- Technical University of Cluj-Napoca
- AROBS Transilvania Software

- UBRIDGE

- IKUSI – Angel Iglesias S.A.
- CBT Comunicación & Multimedia
- INNOVALIA

- ISBAK A.S.
- KocSistems
- Otokar

- UTC Lab. Heudiasyc
- Viveris Technologies
- Thales Communication & security

CoMoSef

Celtic-Plus

# French consortium

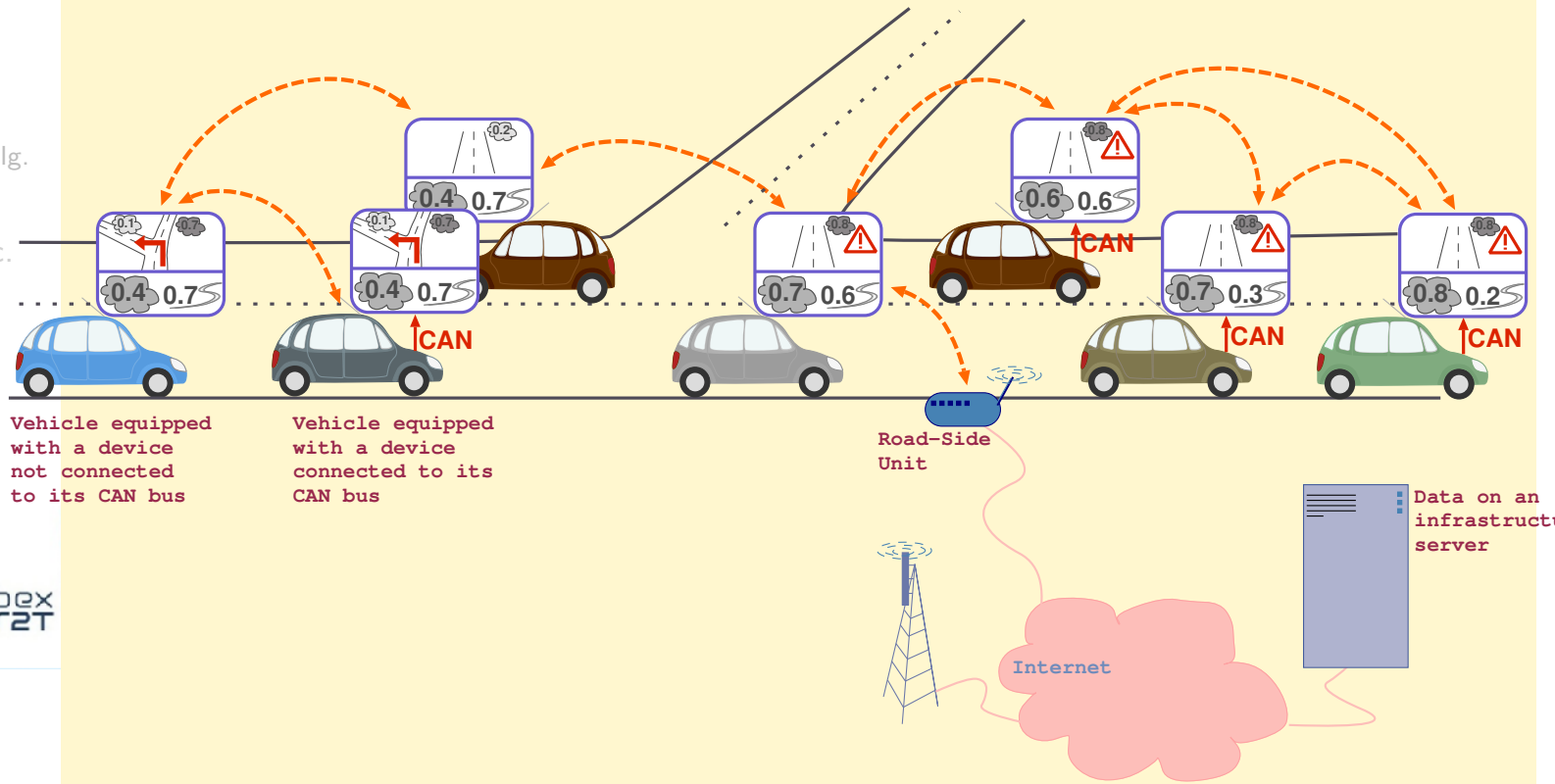
- Viveris Technologies
  CAN bus decoding, embedded architecture
- Thales Communication and Security
  Optimizing data diffusion from RSU, network coding
- Université de Technologie de Compiègne
  CNRS Heudiasyc 7253
  Cooperative alert generation and propagation in VANET

# Sommaire

# French pilot



- Inputs from CAN bus of vehicles
- Distributed data fusion
- Alert propagation to vehicles/infrastructure



# Sommaire

# Université de Technologie de Compiègne

## CNRS Heudiasyc

- 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
  Equipex Robotex, Labex MS2T
  https://www.hds.utc.fr

- Dynamic networks team
  https://airplug.hds.utc.fr

# Université de Technologie de Compiègne

## Team approach

- Dynamic networks are differents
  - Very short communication timer
  - Unknown neighbors
- Example:
  - Confidence in the information
  - Security
  - Data sharing, data collect
  - Messages routing
- Impact
  - Protocol design
  - Modeling and proofs
  - Embedded architecture
  - Evaluation methodology
- Our tools:
  - Airplug Software Distribution
  - Communicating embedded disposals

https://www.hds.utc.fr/airplug

# Université de Technologie de Compiègne

## Research projects

- Collecting water meters data using vehicles
  Grant Aceda with Amiens city 2016-2017
- Cooperative architecture for smart cities
  Agreement with Compiègne city 2015-
- Cooperation in a fleet of drones
  FUI Airmès (I. Fantoni) 2015-2018
- Modeling and proofs in dynamic networks
  Regional grant Toredy 2015-2018
- European Celtic-Plus project Comosef (2013-2016)
- Cooperative perception for road safety
  ANR Percoive (A. Victorino) 2008-2011
- Co-operative Systems for Road Safety
  European project SafeSPOT (M. Shawky) 2006-2010
- Data gathering from VANET to infrastructure
  Industrial grant FTR&D 2008-2010
- Distributed applications for dynamic networks
  Regional grant Toredy 2007-2010
- Network services for com. between mobiles objects
  Industrial grant Orange lab 2004-2008

# UTC/CNRS Heudiasyc

## Scientific contributions

- Dynamic p-graphs [Ad Hoc Networks 2016]
- Detecting icy roads [IEEE ITS 2016]
- Adaptive inter-messages delay [WiMob 2016]
- Robustness of distributed data fusion [SRDS 2016]
- Mobile measure of the pollution [IWCMC 2015]
- Cooperative approach near RSU [IWCMC 2014]
- Keepalive service in VANET [WCNC 2014]
- Distributed data fusion [SSS 2012]
- Data collect on the road [IV 2012]
- 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 [IEEE TVT 2007]

# Summary

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## 2 Pilot in Compiègne

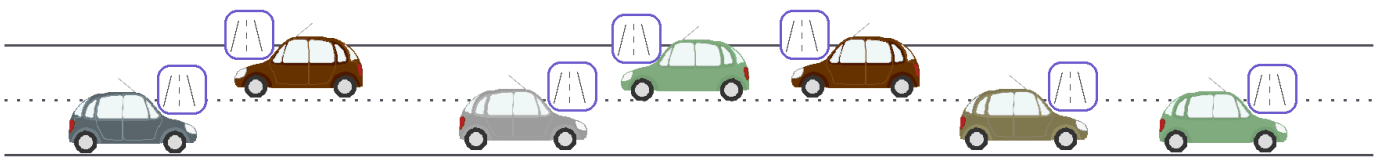
- Aim
- Architecture
- Airplug framework
- Hardware




# Pilot in Compiègne

## Aim

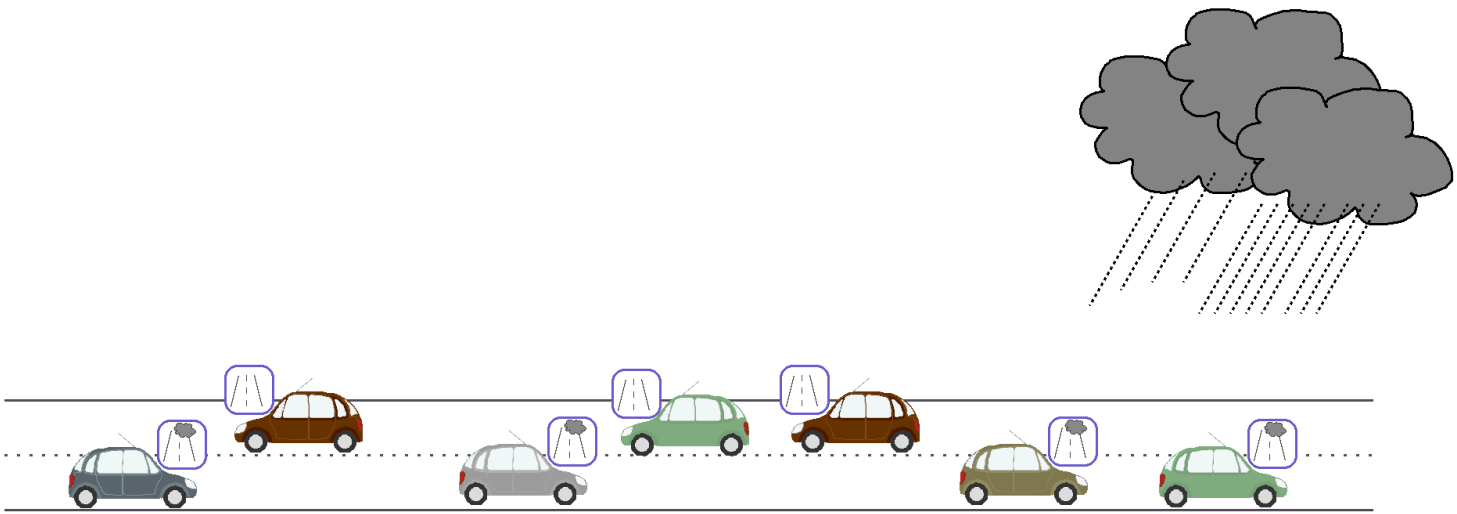




- Vehicular network

# Pilot in Compiègne

## Aim



- Vehicular network
- Detecting potential danger

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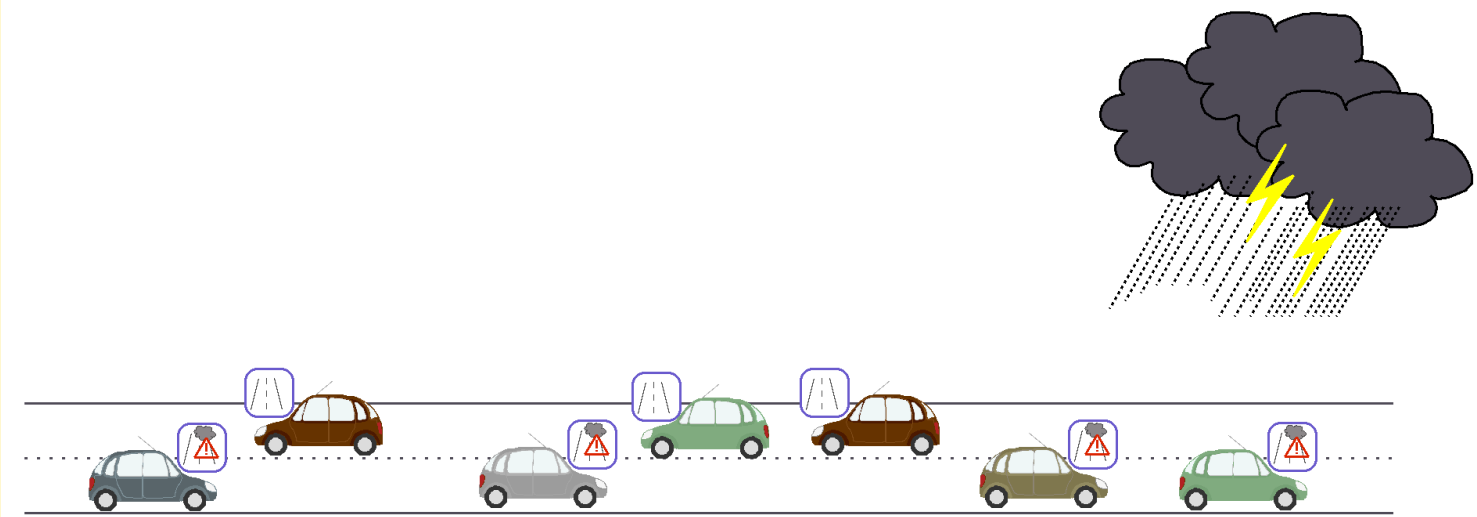
# Pilot in Compiègne

## Aim





- Vehicular network
- Detecting potential danger
- Warning only concerned vehicles

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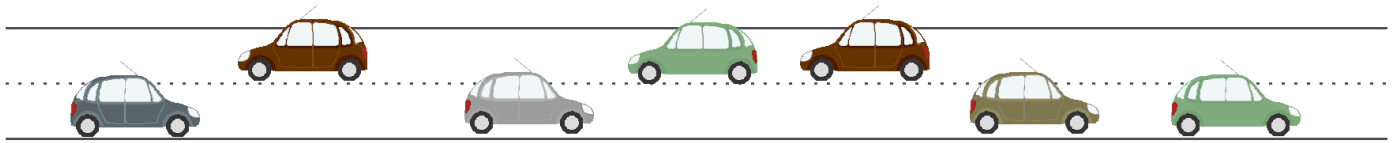
## 2 Pilot in Compiègne

- Aim
- Architecture
- Airplug framework
- Hardware




# Pilot in Compiègne

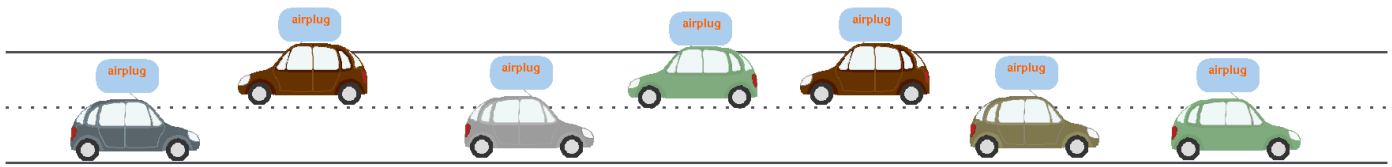
## Architecture: vehicle as a source



- Vehicle as a source of information

# Pilot in Compiègne

## Architecture: vehicle as a source

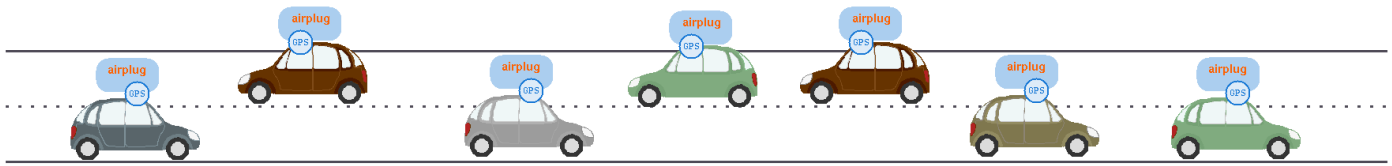



- Vehicle as a source of information
  - Airplug framework

# Pilot in Compiègne

## Architecture: vehicle as a source






- Vehicle as a source of information
  - Airplug framework
  - GPS device and app

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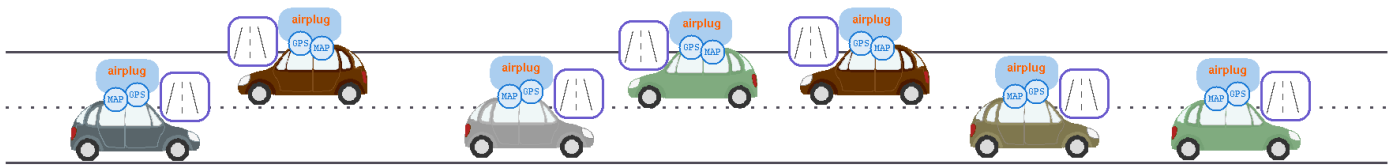
# Pilot in Compiègne

## Architecture: vehicle as a source






- Vehicle as a source of information
  - Airplug framework
  - GPS device and app
  - MAP app

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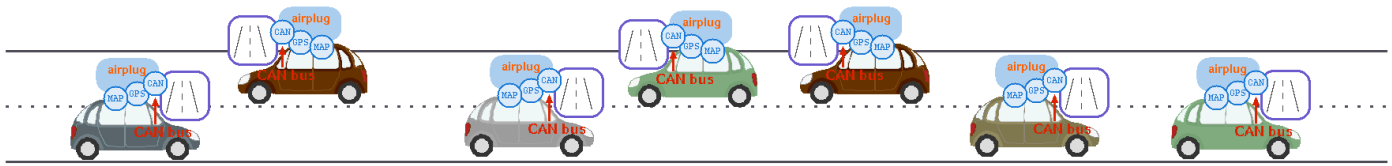
# Pilot in Compiègne

## Architecture: vehicle as a source

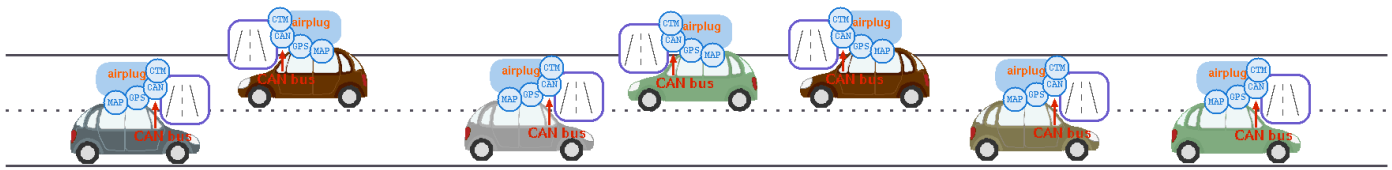



- Vehicle as a source of information
  - Airplug framework
  - GPS device and app
  - MAP app
  - CAN app

Viveris & Heudiasyc

# Pilot in Compiègne

## Architecture: vehicle as a source

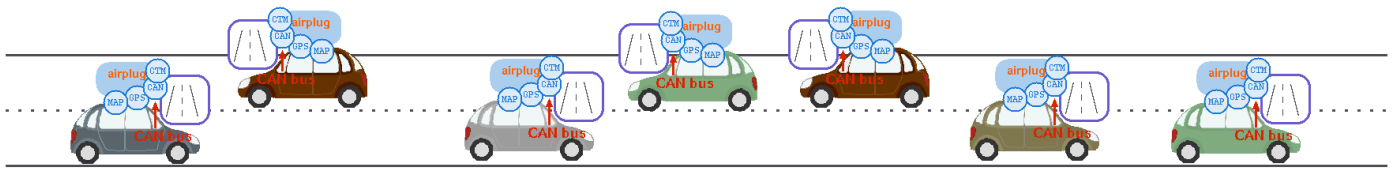



- Vehicle as a source of information
  - Airplug framework
  - GPS device and app
  - MAP app
  - CAN app
  - CTM app: local confidence in the danger

Viveris & Heudiasyc

# Pilot in Compiègne

## Architecture: cooperative detection of danger




- Cooperative detection of a danger

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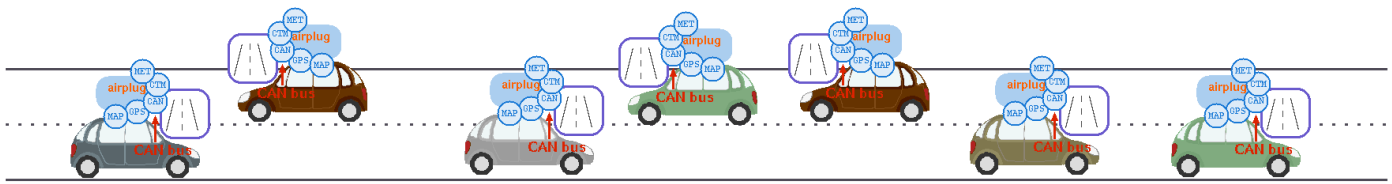
# Pilot in Compiègne

## Architecture: cooperative detection of danger






- Cooperative detection of a danger
  - MET app: robust distributed data fusion

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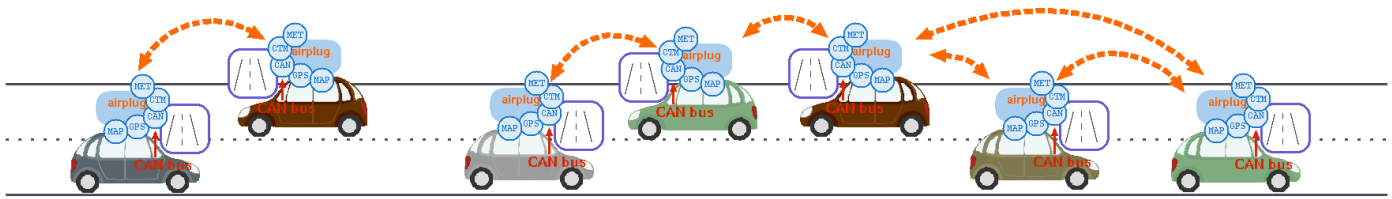
# Pilot in Compiègne

## Architecture: cooperative detection of danger




- Cooperative detection of a danger
  - MET app: robust distributed data fusion

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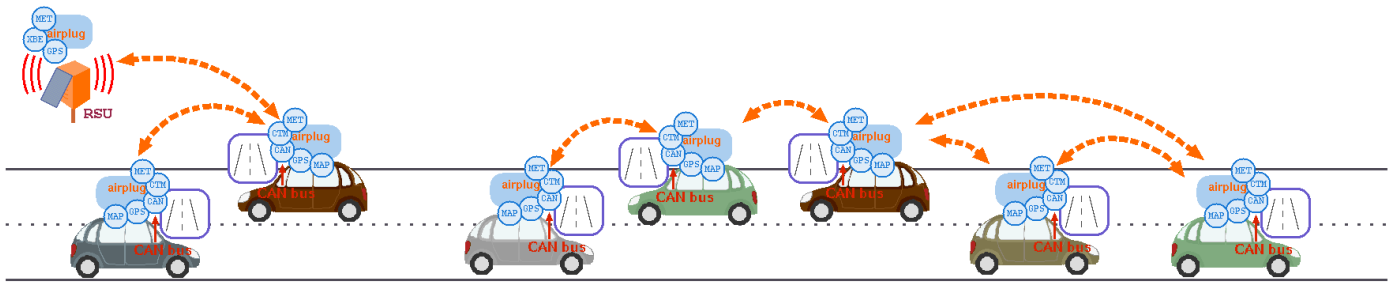
# Pilot in Compiègne

## Architecture: cooperative detection of danger






- Cooperative detection of a danger
  - MET app: robust distributed data fusion

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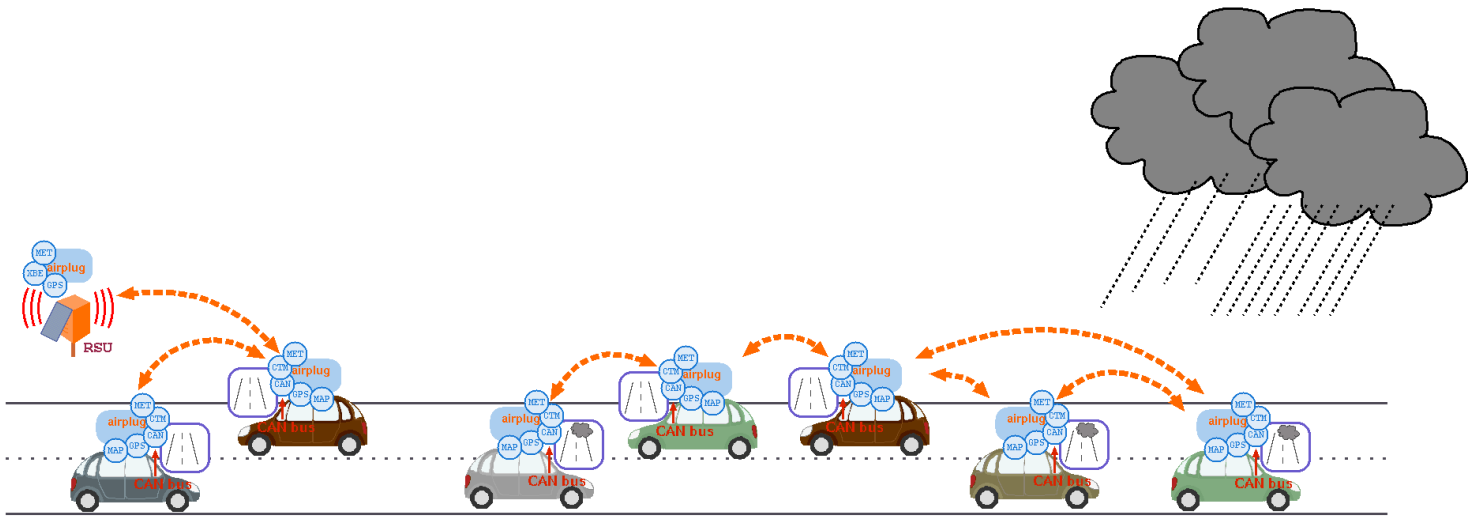
# Pilot in Compiègne

## Architecture: cooperative detection of danger






- Cooperative detection of a danger
  - MET app: robust distributed data fusion
  - Updating the local confidence
    Reading the windscreen wipers speed on the CAN bus

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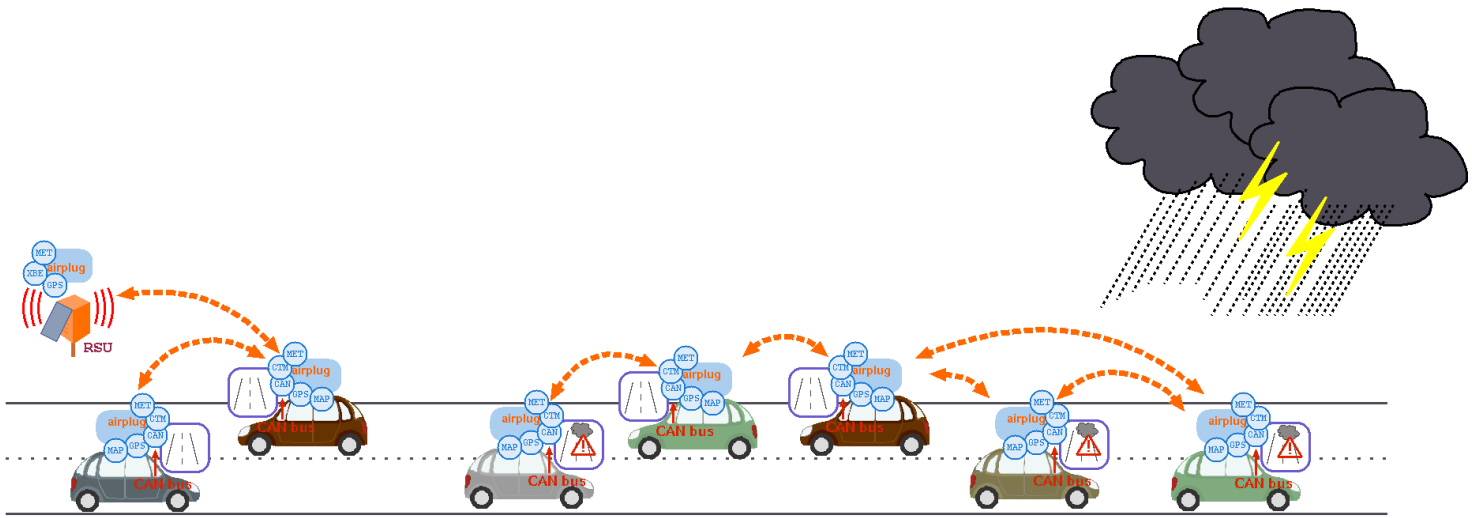
# Pilot in Compiègne

## Architecture: cooperative detection of danger






- Cooperative detection of a danger
  - MET app: robust distributed data fusion
  - Updating the local confidence
    Reading the windscreen wipers speed on the CAN bus
  - Detecting a danger
    Computed distributed confidence larger than a threshold

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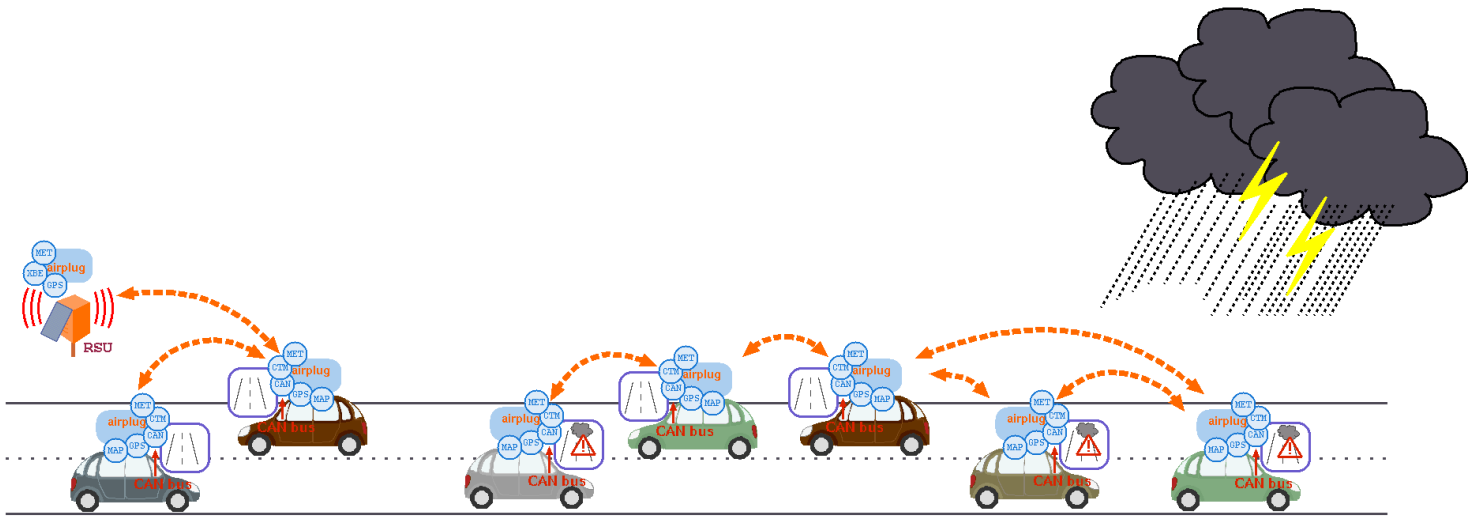
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger

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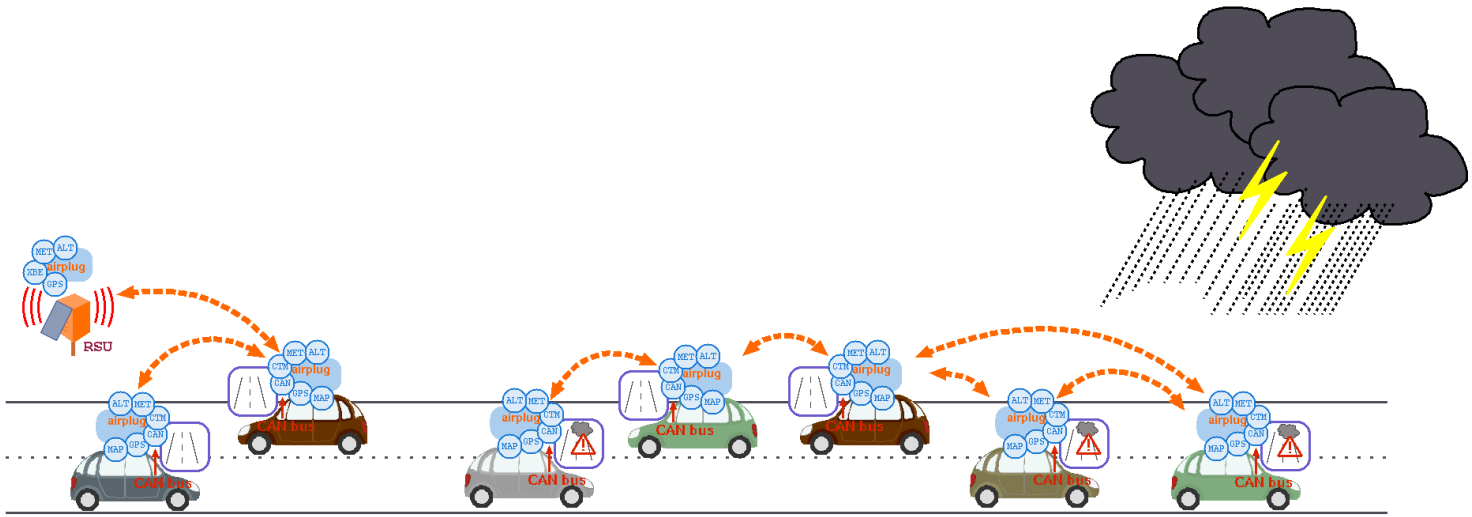
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert

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# Pilot in Compiègne

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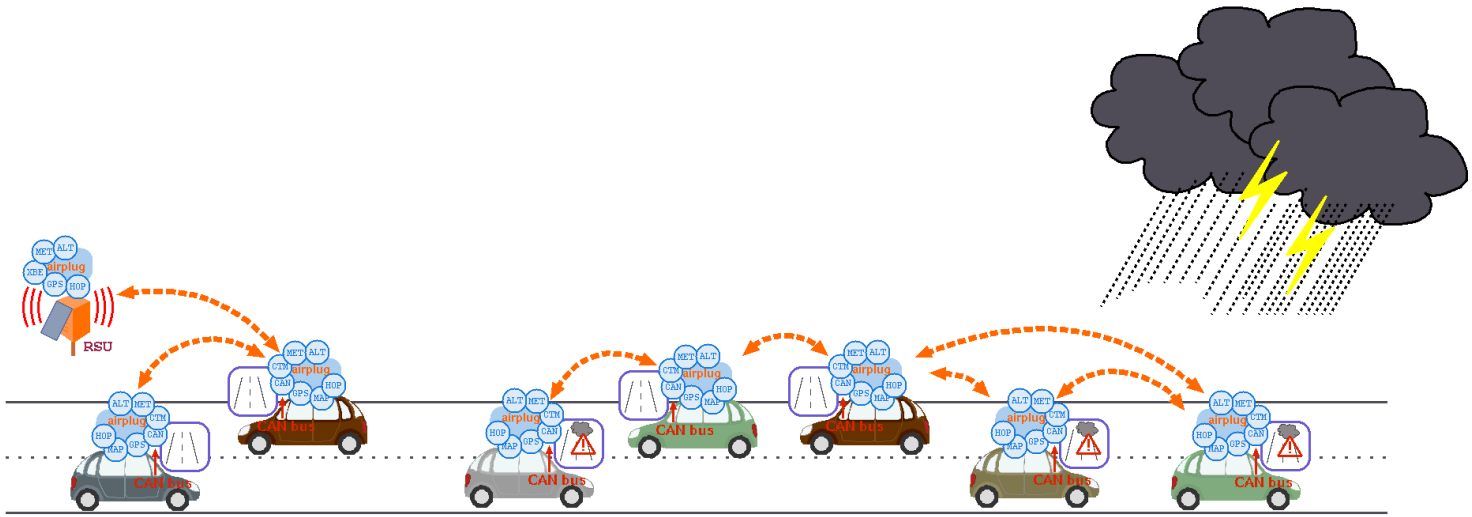


- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
  - HOP app: smart conditionnal retransmission

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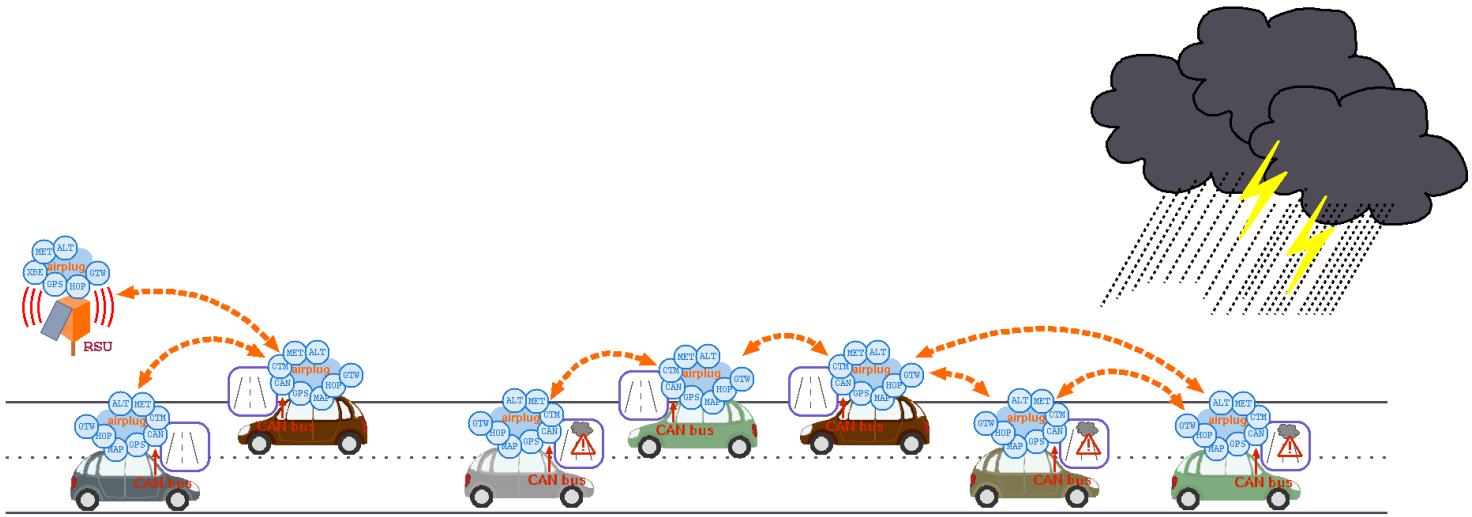


- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
  - HOP app: smart conditionnal retransmission
  - GTW app: searching for Internet gateway

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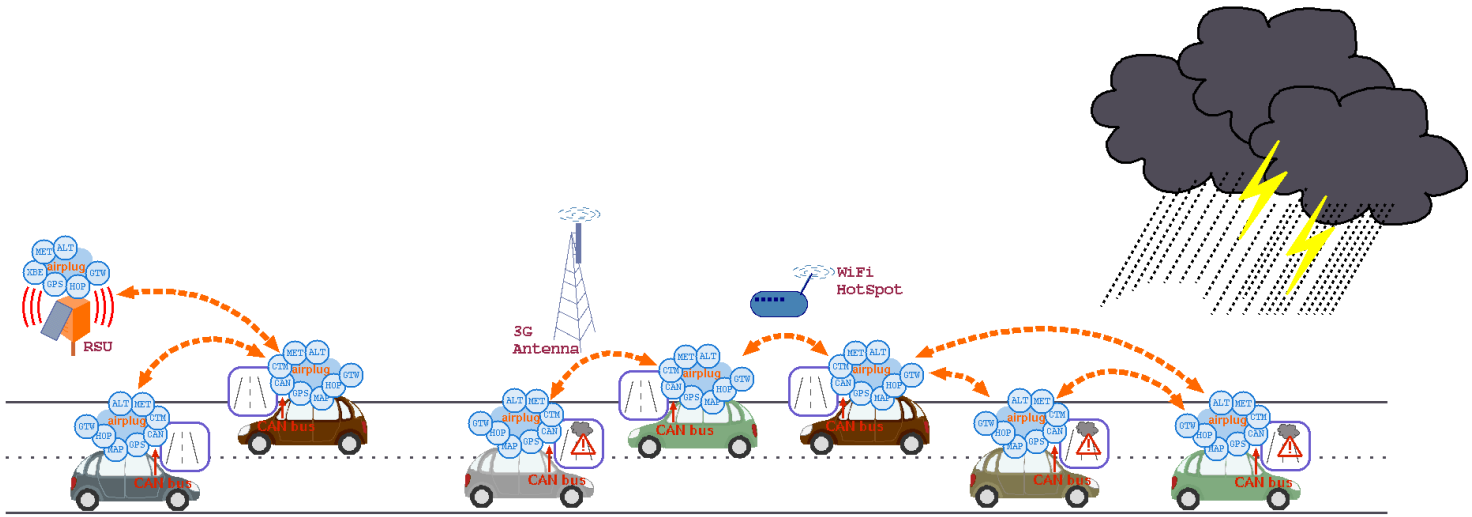
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger
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# Pilot in Compiègne

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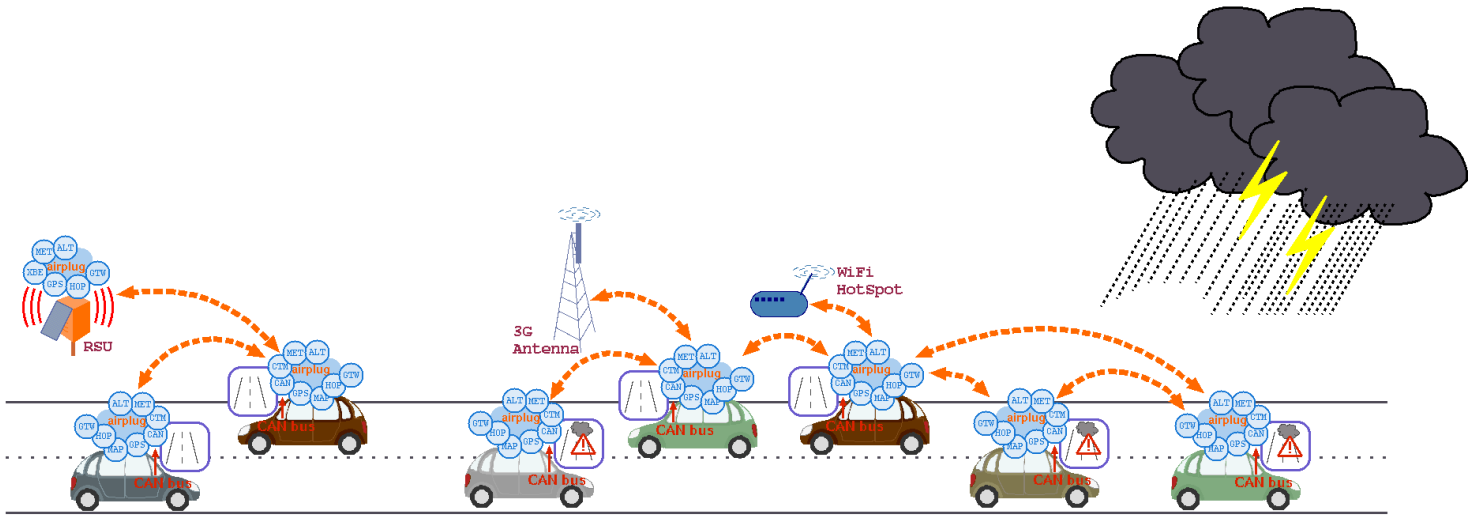


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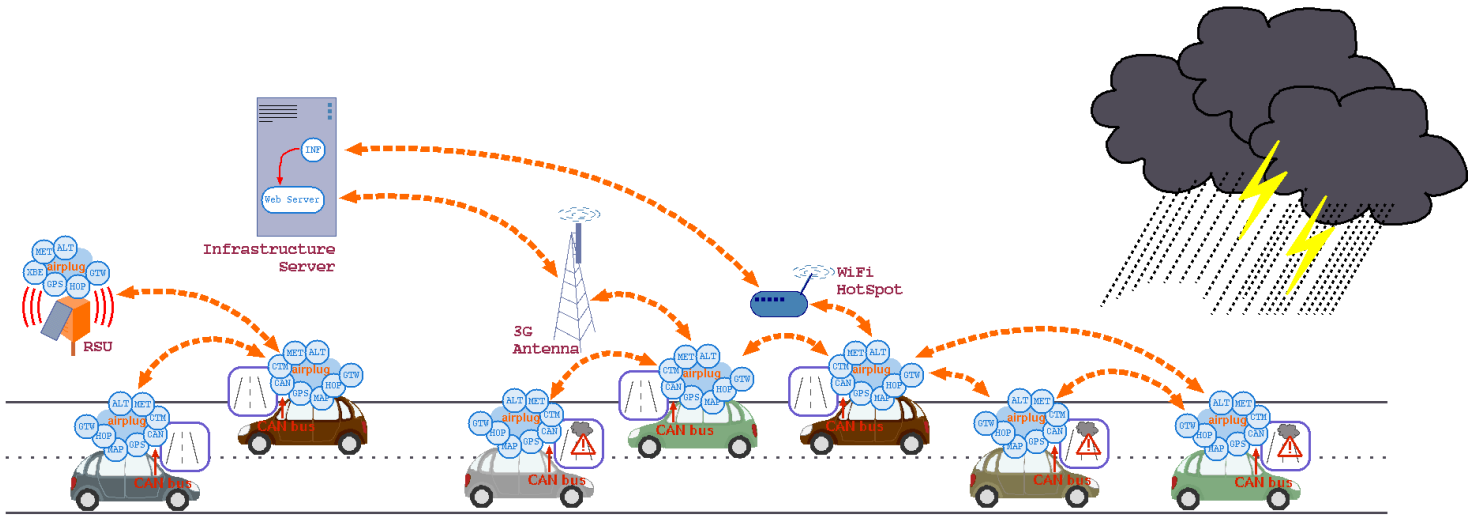
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
  - HOP app: smart conditionnal retransmission
  - GTW app: searching for Internet gateway
  - Web app: warning web clients

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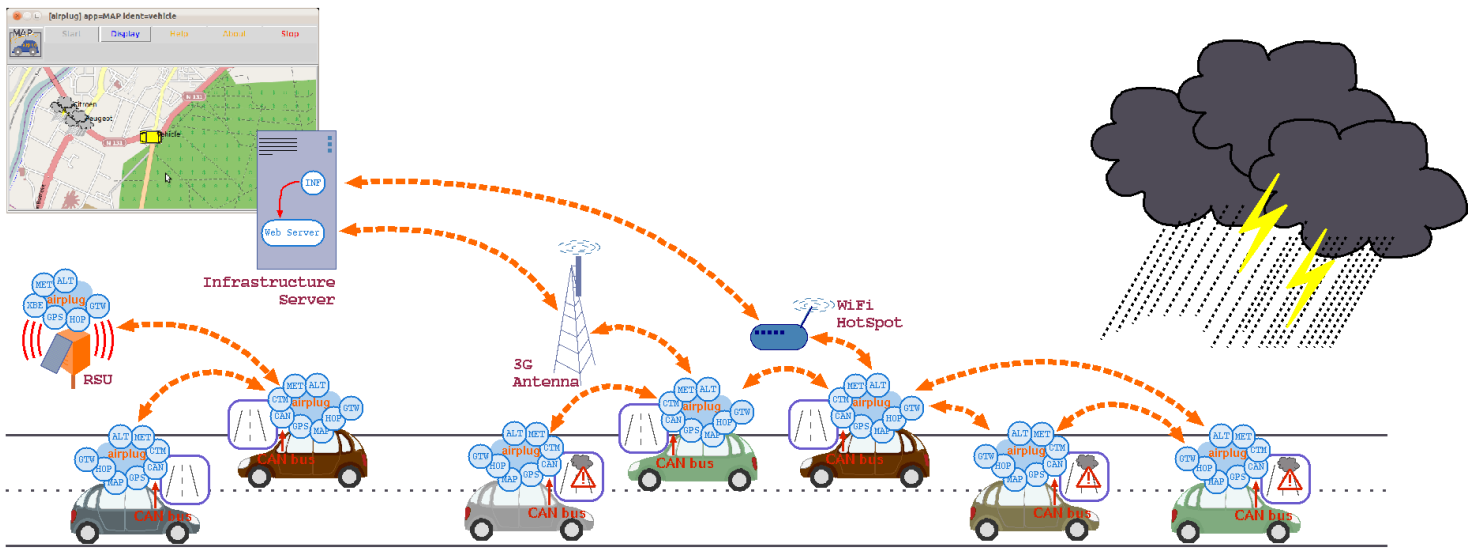
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
  - HOP app: smart conditionnal retransmission
  - GTW app: searching for Internet gateway
  - Web app: warning web clients
  - Web clients warned

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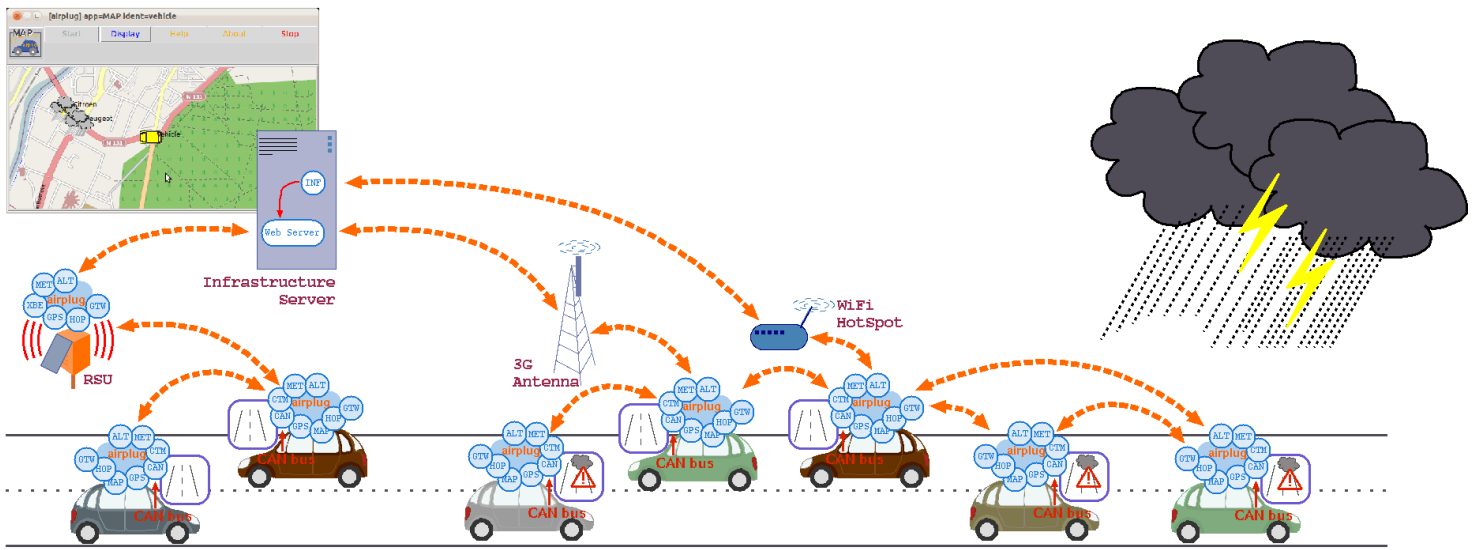
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert






- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
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  - GTW app: searching for Internet gateway
  - Web app: warning web clients
  - Web clients warned

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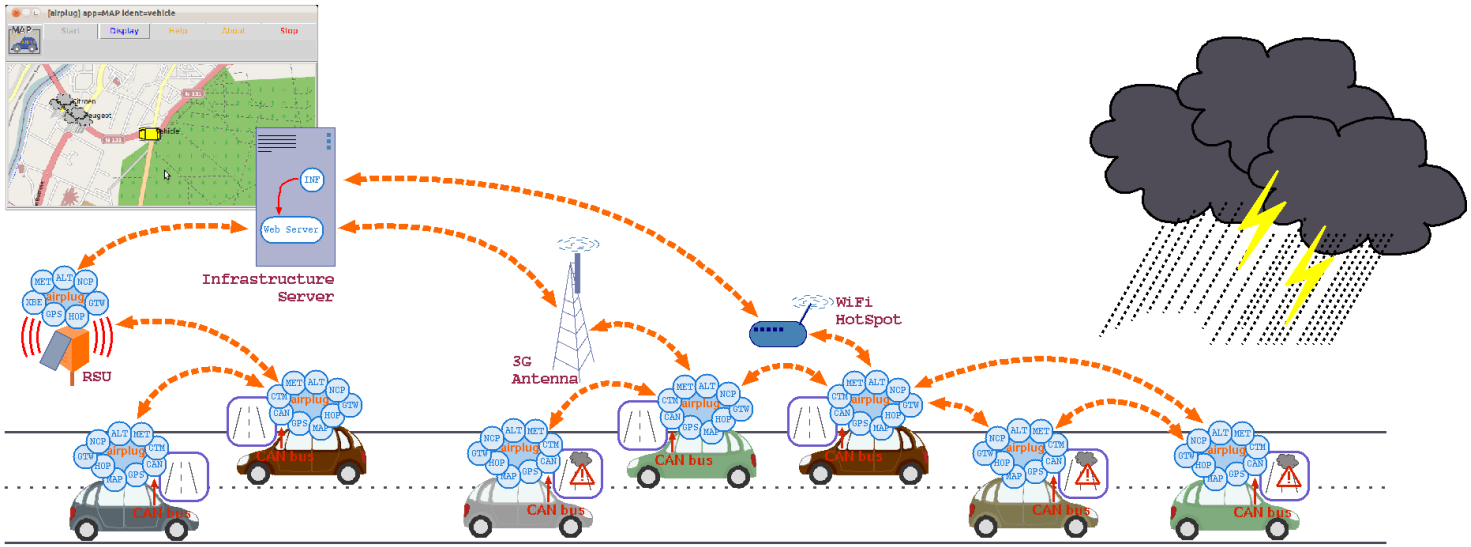
# Pilot in Compiègne

## Architecture: cooperative propagation of an alert




- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
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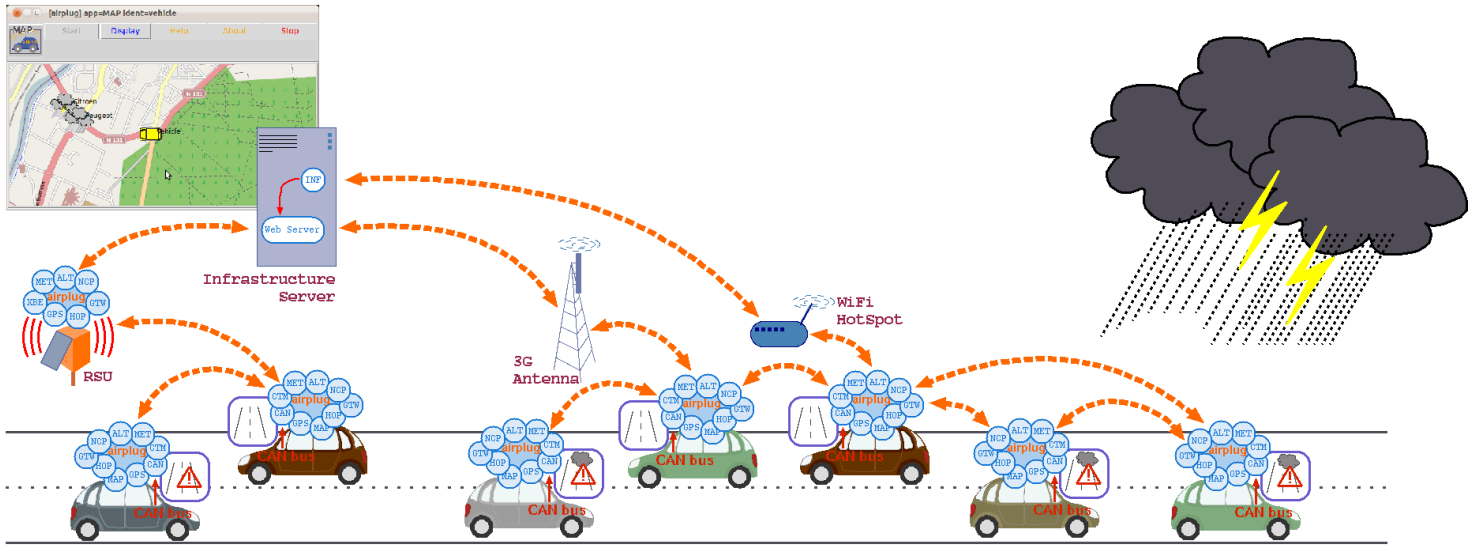
  - Web app: warning web clients
  - Web clients warned

# Pilot in Compiègne

## Architecture: cooperative propagation of an alert




- Cooperative propagation of the danger
  - ALT app: generating an propagating an alert
  - HOP app: smart conditionnal retransmission
  - GTW app: searching for Internet gateway
  - Web app: warning web clients
  - Web clients warned
  - Far vehicles warned using road side units

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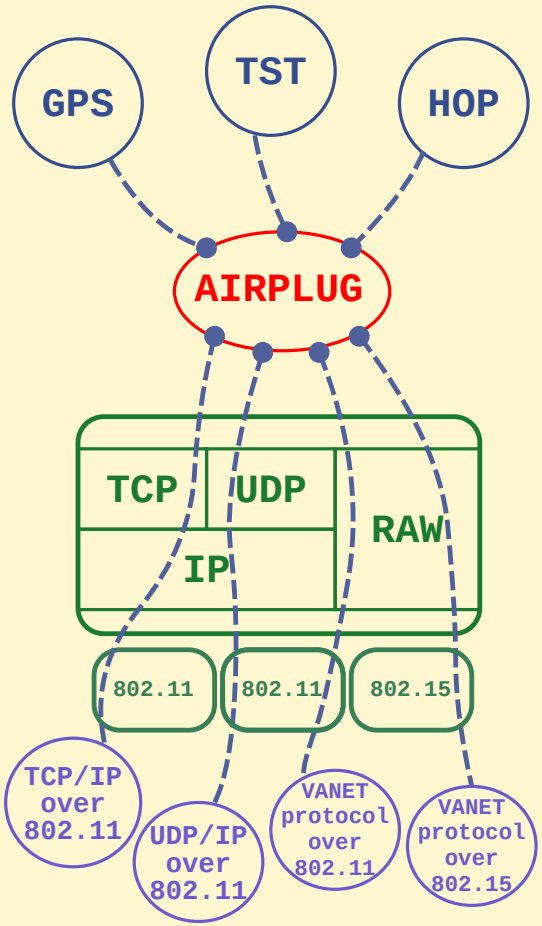
# Pilot in Compiègne

## Airplug framework 1



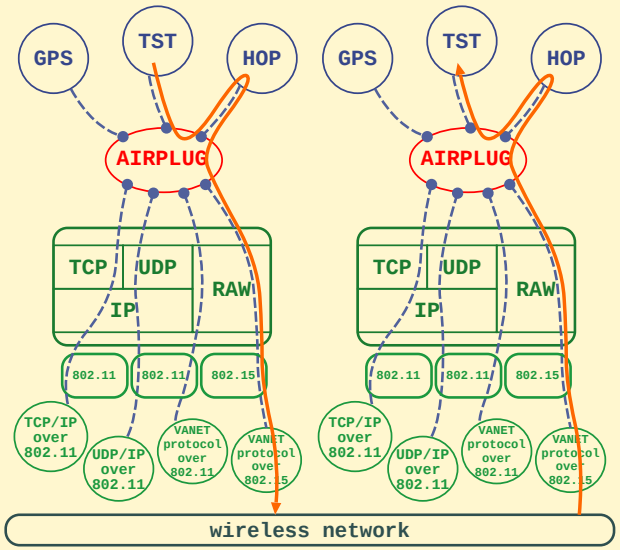

- Core program
  - User-space process
  - Networking
- Applications
  - User-space process
  - Any language
  - Read on stdin
  - Write on stdout
  - API close to IEEE WSMP
- Robustness
  - Tasks and OS independence
- Portability
  - GNU/Linux

# Pilot in Compiègne

## Airplug framework 2



- Designing new protocols
  - Developed in user space processes
  - Cross-layer solutions facilitated




- Airplug software distribution
  - LEGO: many applications that can be combined
  - Tools to ease packaging, prototyping and studies

https://www.hds.utc.fr/airplug

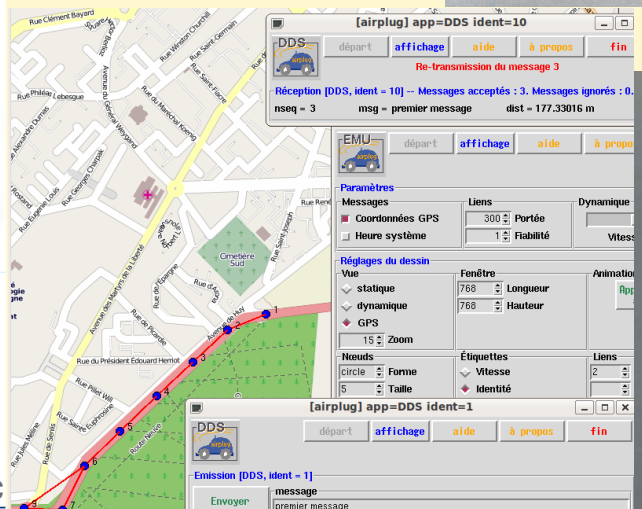
# Pilot in Compiègne

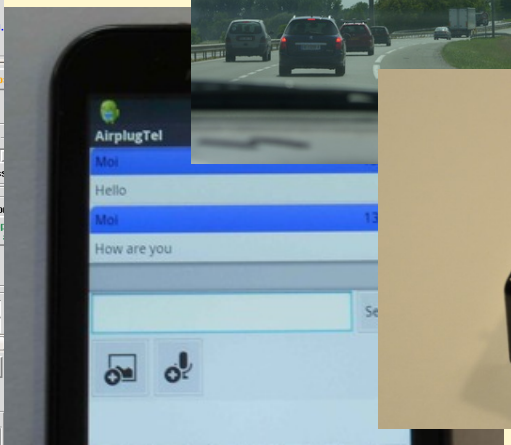
## Airplug framework 3

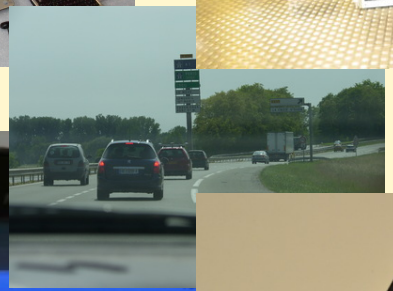


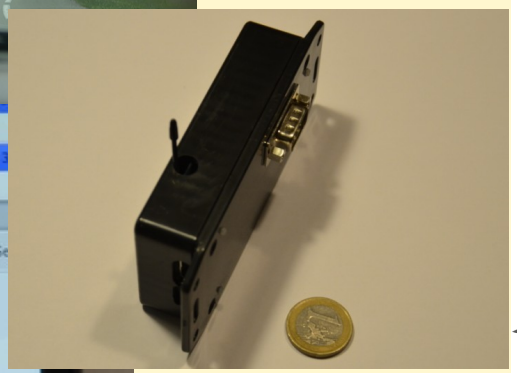
- Airplug-term $\rightsquigarrow$ rapid prototyping
- Airplug-emu $\rightsquigarrow$ study by emulation
- Airplug-live $\rightsquigarrow$ real experiments (vehicles, UAV)

$+$ remote, notk...





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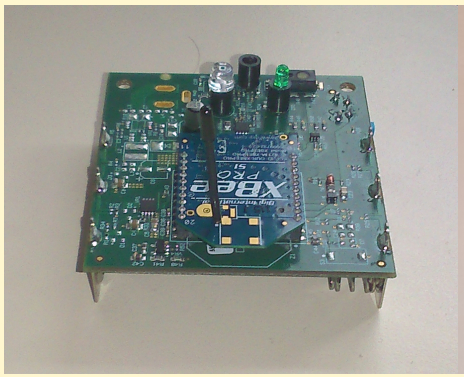
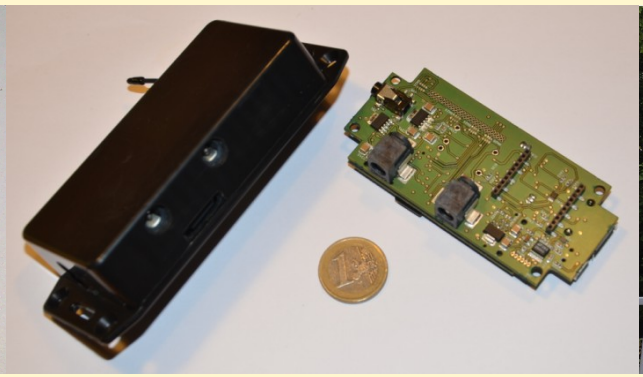
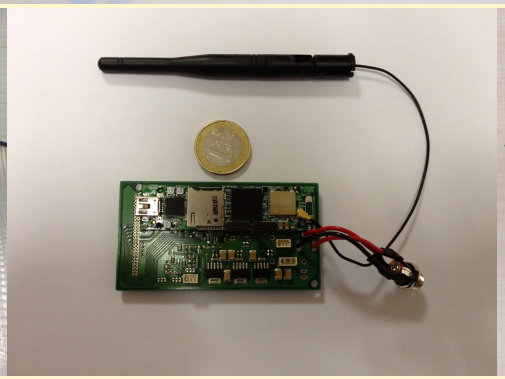
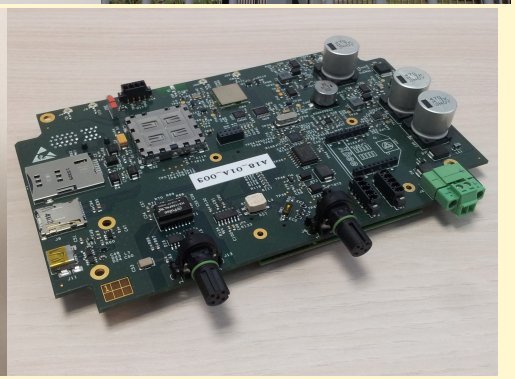
# Research plateform

## Road tests





# Summary



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# Distributed data fusion

## Data fusion introduction

- Several sources of information
  - How to deal with?
  - Could disagree
  - Take benefit of all of them
- Imperfect measures
  - Can we trust data?
  - Imprecision
  - Uncertainty
  - Ambiguity






# Distributed data fusion

## Data fusion introduction



- How to deal with imprecise and uncertain data?
  - Imprecision :
    Set Membership Approach uncertainty?
  - Aleatory uncertainty :
    Probability theory imprecision?
  - Theory of Belief Function: generalizes both
    Also known as Dempster-Shafer Theory of Evidence

- Belief Function Framework
  - Information modeling
  - Combination rules

[Dempster 1968, Shafer 1976, Smets 1990s]

# Distributed data fusion

## Data fusion introduction



- Data $X$ with value in $\Omega$
- Representation of $X$
  - (value, confidence)
  - value: subset of $\Omega$
  - confidence: indication on the reliability of the item of information
- Interest:
  - Imprecision of $X \rightsquigarrow$ value
  - Uncertainty of $X \rightsquigarrow$ confidence

[Dubois, Prade 1988]

| | | Confidence | |
|---|---|---|---|
| | | certain | uncertain |
| Value | precise | 20 | probably 20 |
| | imprecise | between 15 and 25 | probably between 15 and 25 |

# Distributed data fusion

## Data fusion introduction



- Frame of discernment: set $\Omega$
- Basic belief assignment
  - Mass function
    - $m^{\Omega} : \mathcal{P}(\Omega) \rightarrow [0,1]$
    - $\sum_{X \subset \Omega} m^{\Omega}(X) = 1$
  - Our algorithm: vector of weights
- Dempster operator
  - Emphases the agreement of reliable and independent sources [Smets 1990,Shafer 1976]
    $m_{1 \textcircled{\cap} 2}(A) = \sum_{B \cap C = A} m_1(B) \cdot m_2(C)$
  - Spread the conflict over other sets [Dempster]
- Cautious operator [Denoeux 2008]
  - Do not assume independent sources
  - Least commitment principle
  - Avoid the *data incest*

# Sommaire



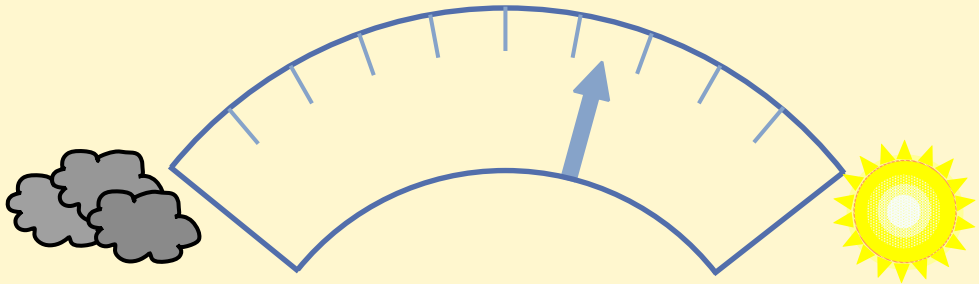





# Distributed data fusion

## Example of Basic Belief Assignment 1/3

- Pressure measurement



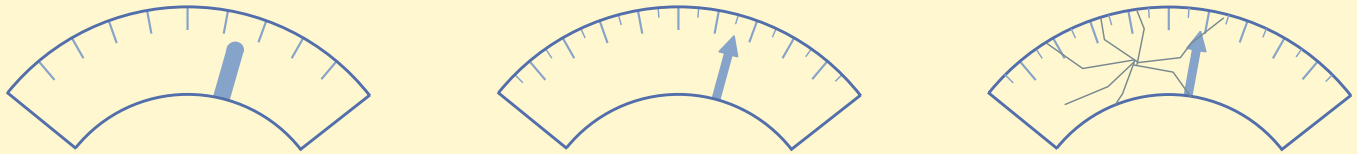
- Weather forecast
  - Compare current measure with the last one

# Distributed data fusion

## Example of Basic Belief Assignment 2/3



- Barometer?



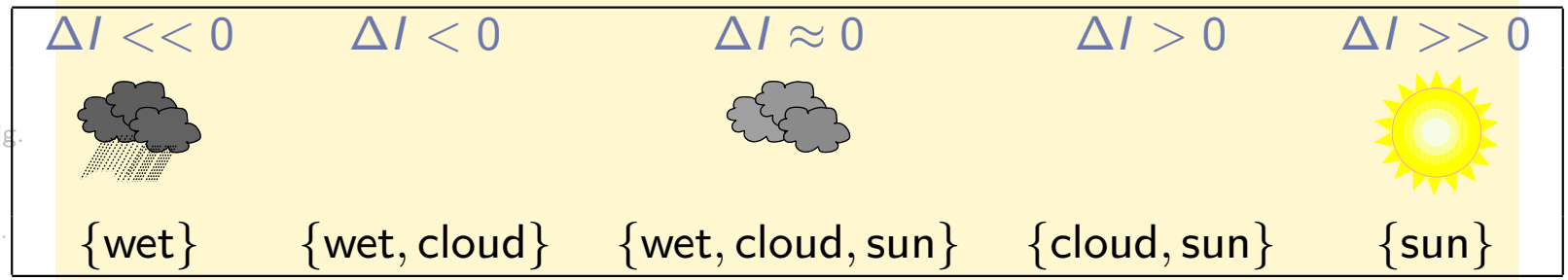
- Measure:
  - Pressure measurement: interval $I \subset \mathbb{R}^+$
  - Pressure gradient: interval $\Delta I \subset \mathbb{R}$
  - *Simple* mass function:
    - Only two subsets: $\Delta I$ and $\mathbb{R}$
    - $\mathbb{R}$: lack of knowledge
    - $m^{\mathbb{R}}(\Delta I) = 1 - \alpha$
    - $m^{\mathbb{R}}(\mathbb{R}) = \alpha$
    - $\alpha$: uncertainty of the barometer

# Distributed data fusion

## Example of Basic Belief Assignment 3/3



- Coarsening
  - Finite frame of discernment instead of $\Delta I \subset \mathbb{R}$
  - Example: $\Omega = \{wet, cloud, sun\}$
  - Mass function:




- Combination
  - Several independent measures can be combined using the Dempster rule
- Decision
  - From mass to *pignistic* probability
    $P(A) = \sum_{\emptyset \neq B \subset \Omega} m(B) \frac{|A \cap B|}{|B|}$

# Sommaire







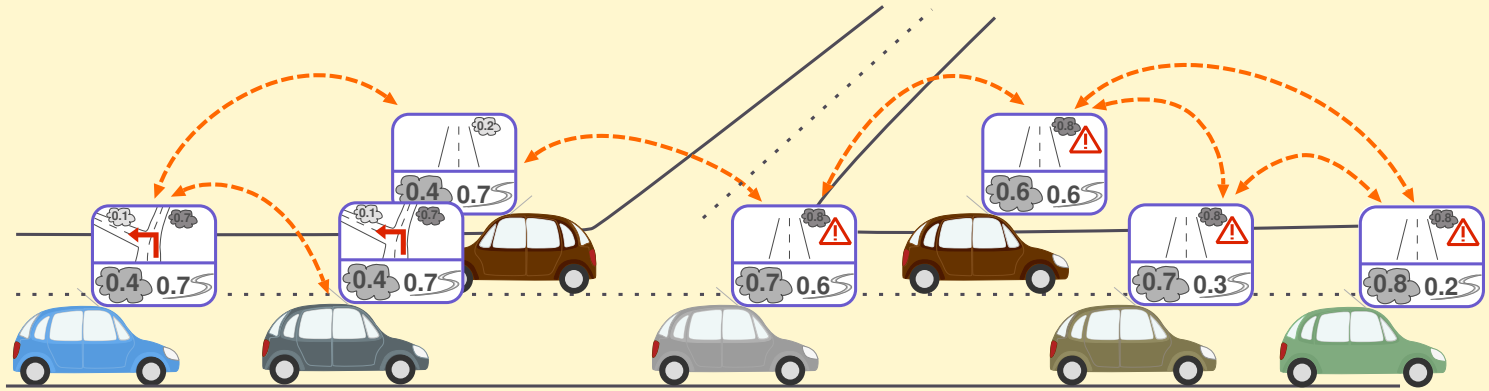

# Distributed data fusion

## Distributed algorithm: motivation



- Distributed approach for data fusion
  - Direct confidence (regularly) produced locally
    Using an external uncertain device
  - Node's confidence computed using other values

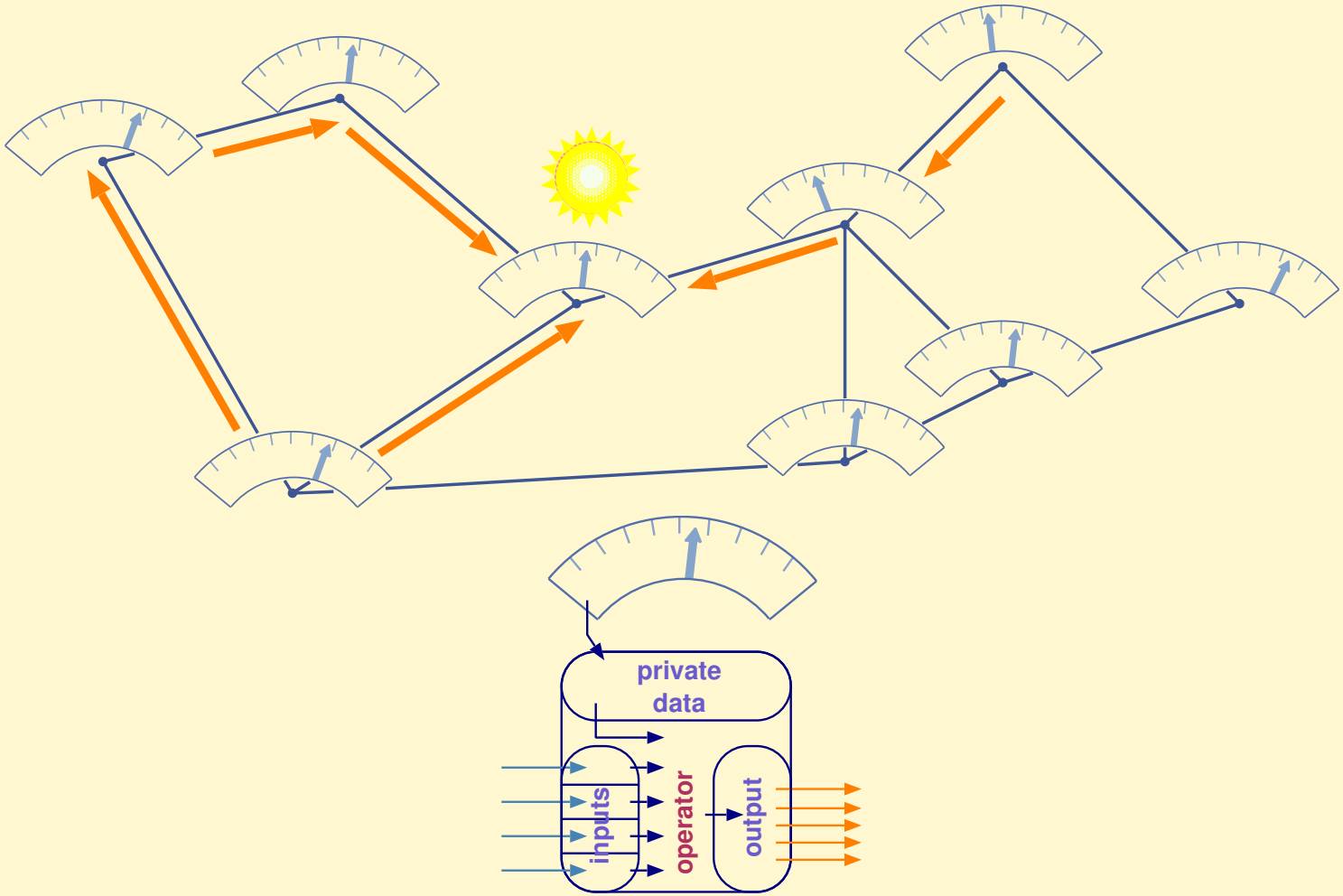
  - Avoiding data collection
  - Locality
    - One result per node
    - Depends on its position in the network



# Distributed data fusion

## Distributed algorithm: example

- Result on any node $v$ now depends on all other nodes, not only its neighbors.



# Distributed data fusion

## Distributed algorithm: characteristics



- Our distributed data fusion algorithm [SSS2012]
  - Combine all direct confidences of the system
  - Relies on local periodic broadcast
  - Discount received information
    $\rightsquigarrow$ confidence decreases according to the distance

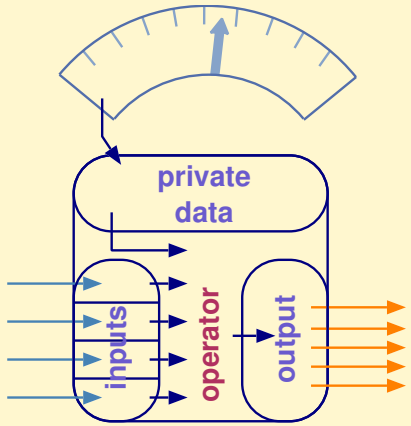
- Characteristics
  - Finite data set
    Discretization + adapted operators
  - Asynchronous and anonymous system
  - Unreliable message passing system

  - Intermittent faults on memories/messages
  - Crash faults on nodes

# Distributed data fusion

## Distributed algorithm: details






### Upon (local) timer expiration

$\mathtt{PRIV}_v \leftarrow$ current direct confidence

$\mathtt{OUT}_v \leftarrow \mathtt{PRIV}_v$

**for each** entry $u$ in $\mathtt{IN}_v$ **do**

  $\mathtt{OUT}_v \leftarrow \mathtt{OUT}_v \barwedge r(\mathtt{IN}_v[u])$

**end for**

**push(** $\mathtt{OUT}_v$ **)**

Reset $\mathtt{IN}_v$

Restart the timer

# Sommaire





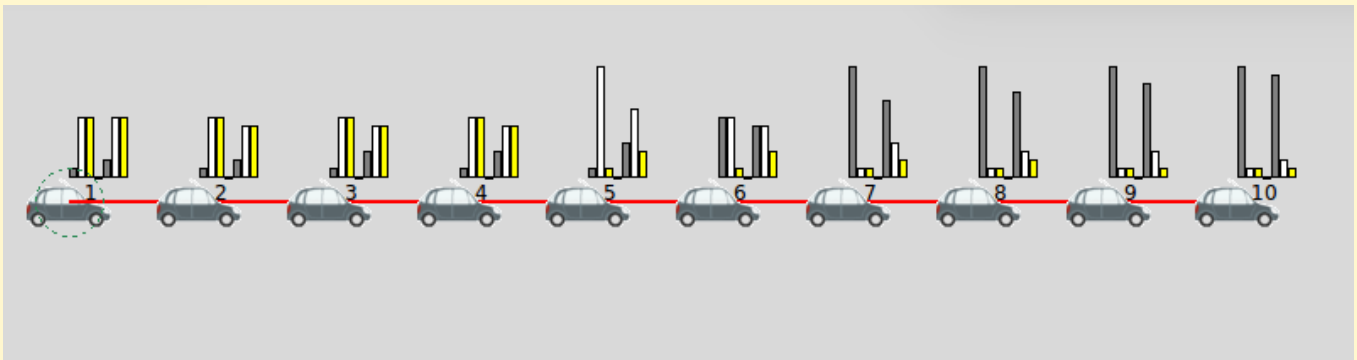



# Distributed data fusion

## Properties: locality



- Discounting **r**
  - Local computation: $\mathtt{OUT}_v \leftarrow \mathtt{OUT}_v \circledcirc r(\mathtt{IN}_v[u])$
  - $\circledcirc$: cautious operator defined on weights
  - $r$ : discounting function
    - Decreases the information
    - Application-dependent
- Without discounting
  - A single result per connected component
- With discounting
  - Limited influence of a node
  - Locality of the result



# Distributed data fusion

## Properties: robustness



- Self-stabilization [SSS2005, SSS2007]
  - $\triangleleft$: r-operator defined by $x \triangleleft y = x \mathbin{\textcircled{\scriptsize A}} r(y)$
  - Condition 1: endomorphism
    $\mathbf{r}(\mathbf{w}_1 \mathbin{\textcircled{\scriptsize A}} \mathbf{w}_2) = \mathbf{r}(\mathbf{w}_1) \mathbin{\textcircled{\scriptsize A}} \mathbf{r}(\mathbf{w}_2)$
  - Condition 2: expansion
    $\mathbf{w} \prec_{\textcircled{\scriptsize A}} \mathbf{r}(\mathbf{w})$
- Without discounting
  - No convergence after a fault
    In a message, in a memory or in the input device
- With discounting
  - Convergence in finite time after the transient failure ceases

# Distributed data fusion

## Properties: complexity



- Stabilization time — supposing a synchronous system
  - $O(k + D)$
  - $k$: defined by $r^k(\text{smallest value}) = \text{largest value}$
  - $D$: diameter of the stabilized topology

# Summary








# Sommaire








# Cooperative communication architecture

## Strategy for dynamic networks 1/2



- Dynamic network: topology? address?
- One-to-one communication (V2-1V)
  - Known receiver? $\rightsquigarrow$ fix or already encountered
  - Maintaining a path
- One-to-many communication (V2-nV)
  - Sending a message without knowing the receiver ...and without trying to know it
  - Sending to receiver(s) defined by conditions
- Vehicle-to-infrastructure communication (V2I)
  - Sharing the gateways toward Internet
  - Enlarging their range
  - Cooperative approach
    - First try by yourself (waiting for a gateway)
    - Else request help from others

# Cooperative communication architecture

## Strategy for dynamic networks 2/2



- Choosing the next hop
  - 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
    Solutions to avoid several retransmission if required

# Sommaire

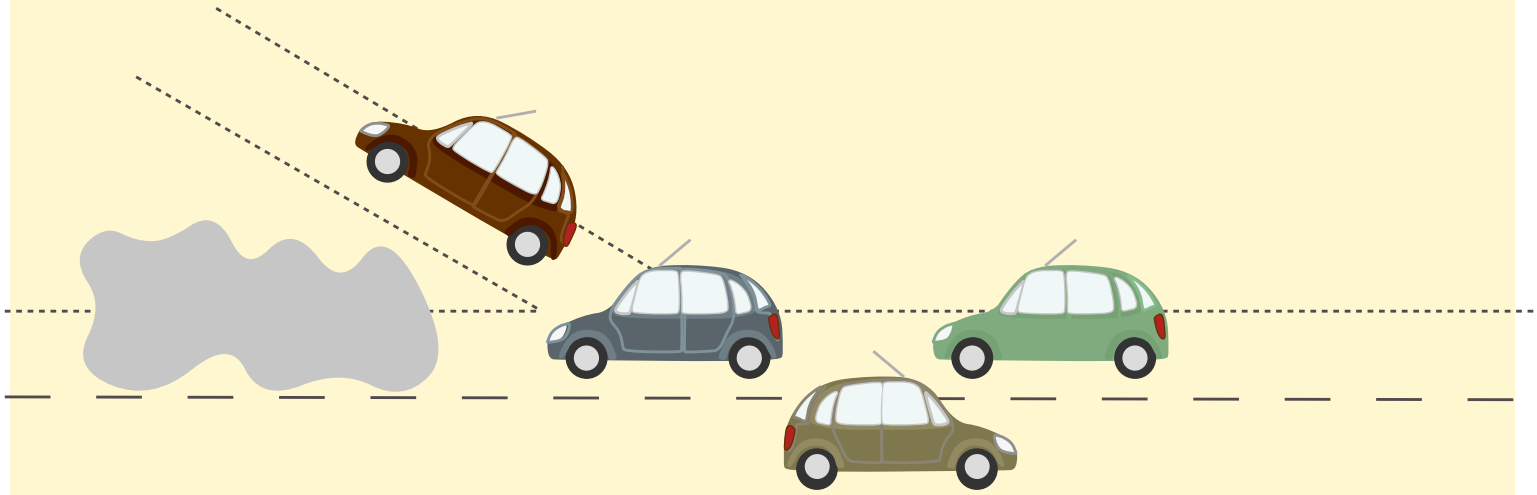







# Cooperative communication architecture

## One-to-many communication (V2V)



- Conditions instead of addresses
  More adapted to dynamic networks
  - CUP: upward condition $\rightsquigarrow$ applications
  - CFW: forward condition $\rightsquigarrow$ local broadcast
- Conditions
  - Identity, address, GPS cf. geocast
  - Distance, duration, trajectory correlation...
    Eg. being back to the sender

# Cooperative communication architecture

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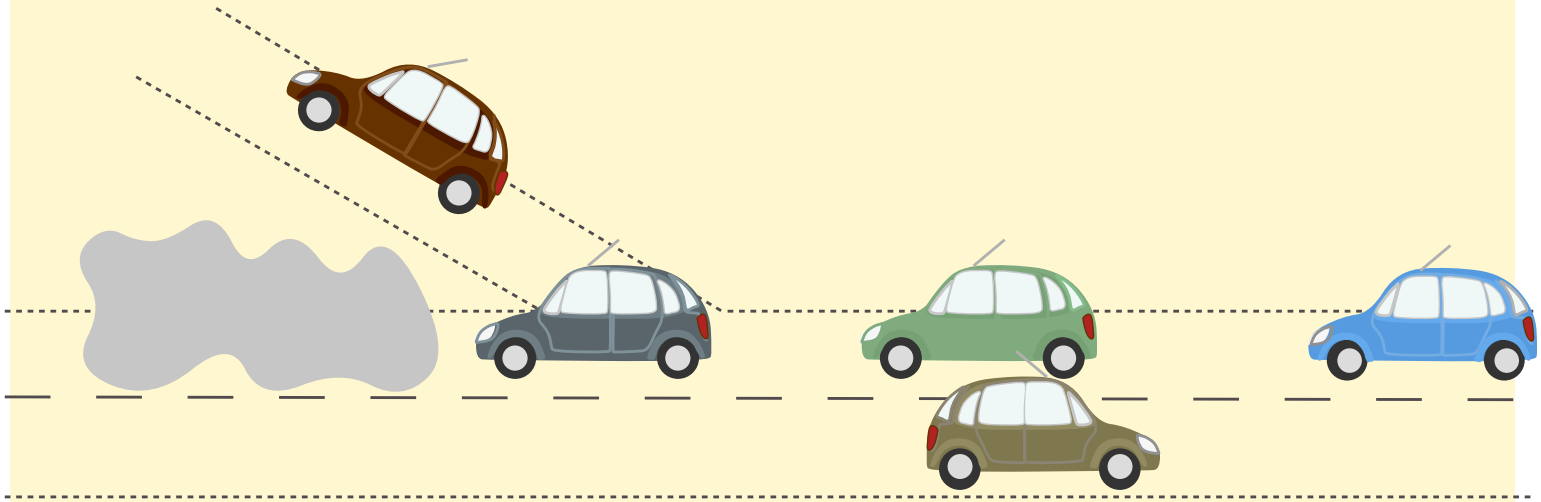

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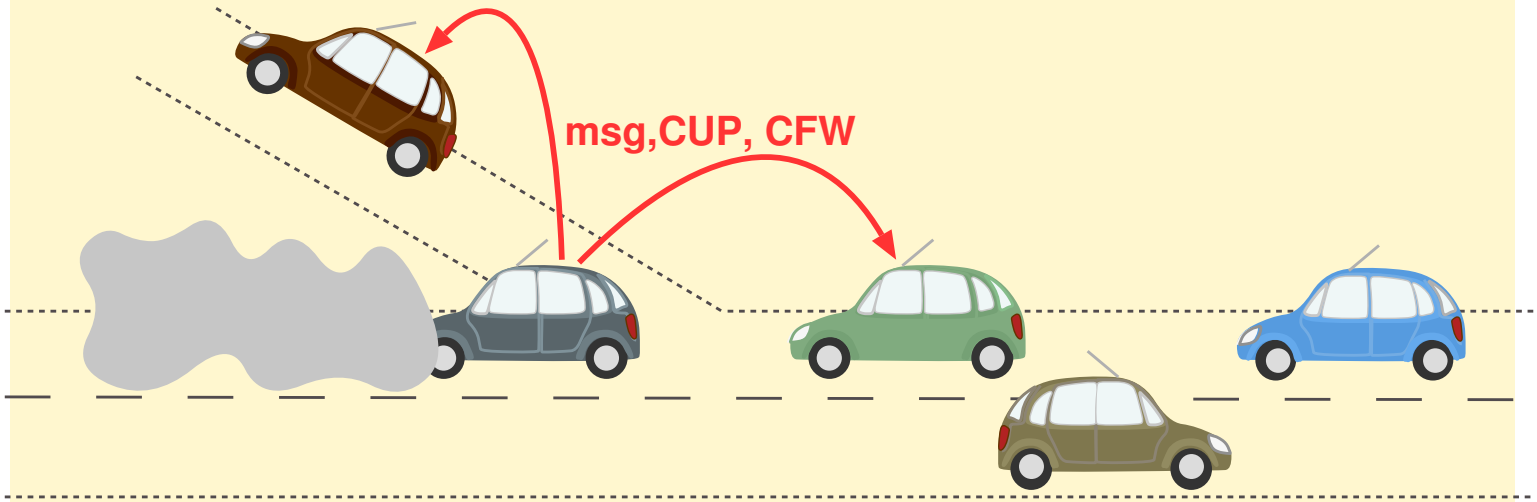


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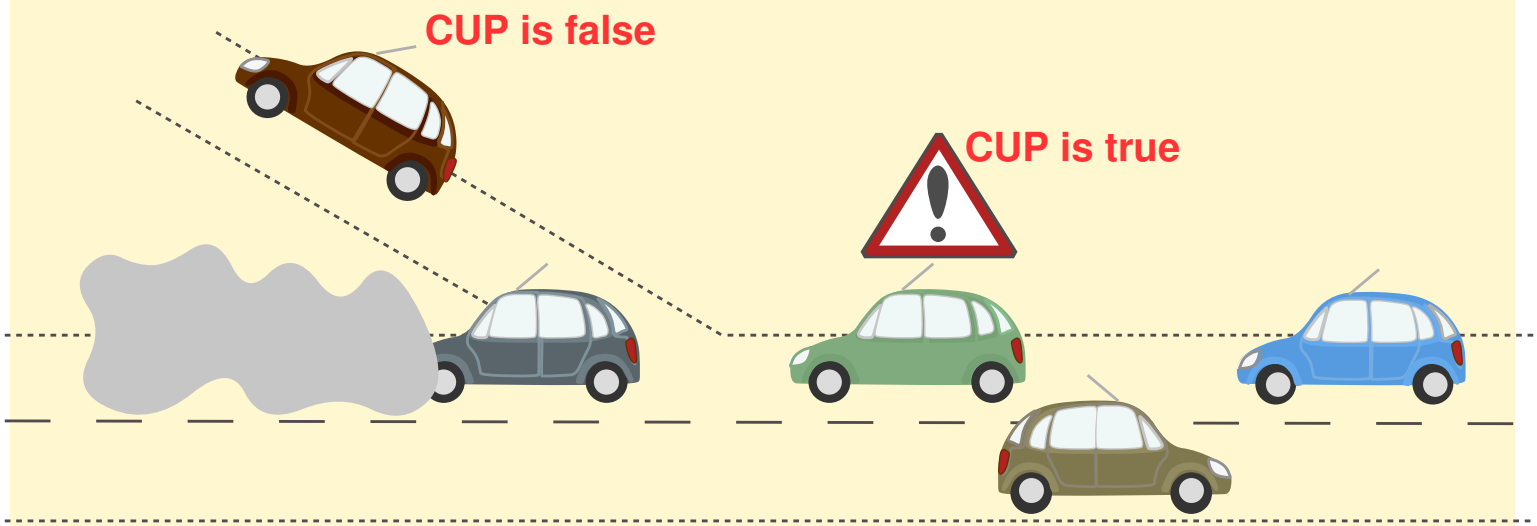


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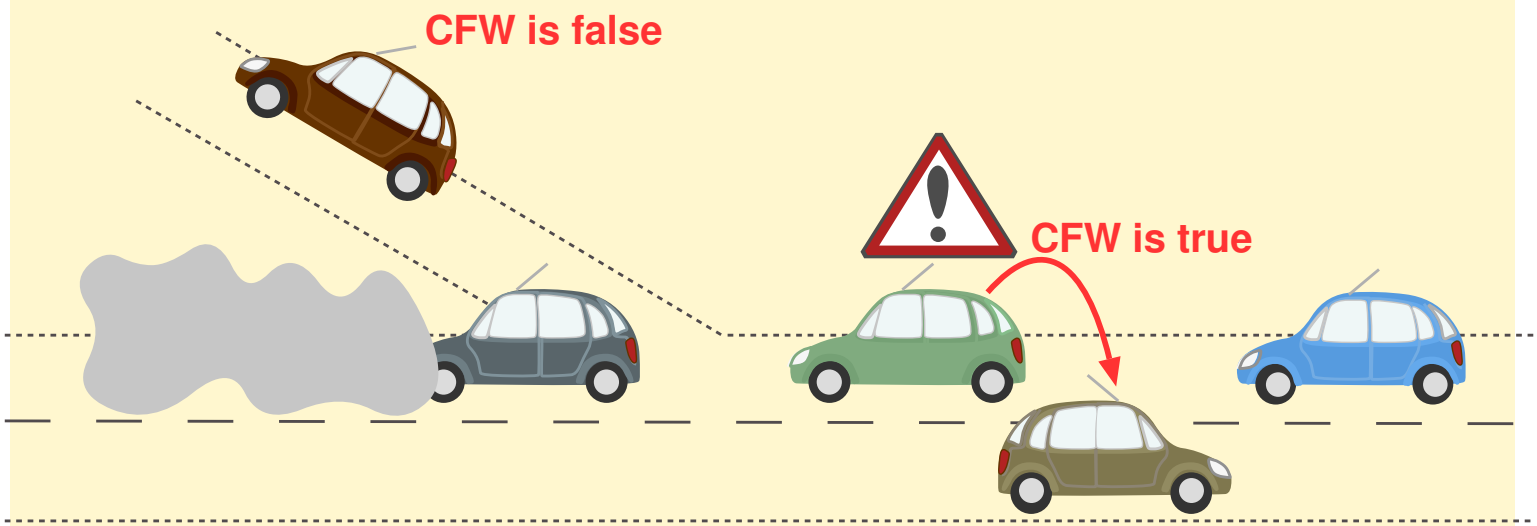


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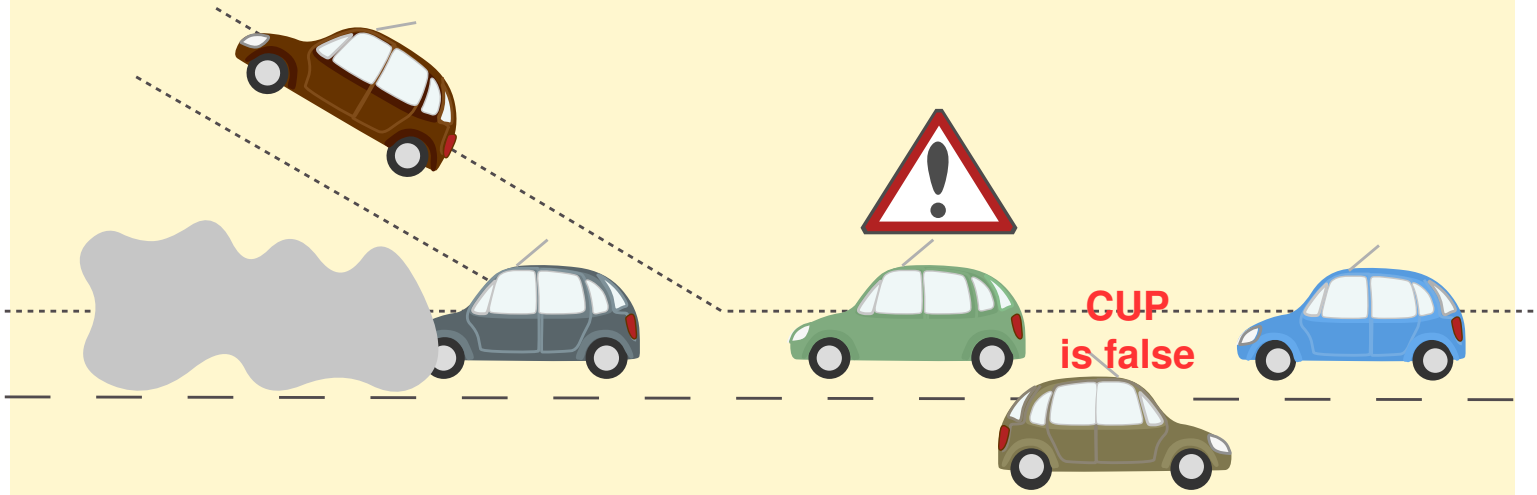


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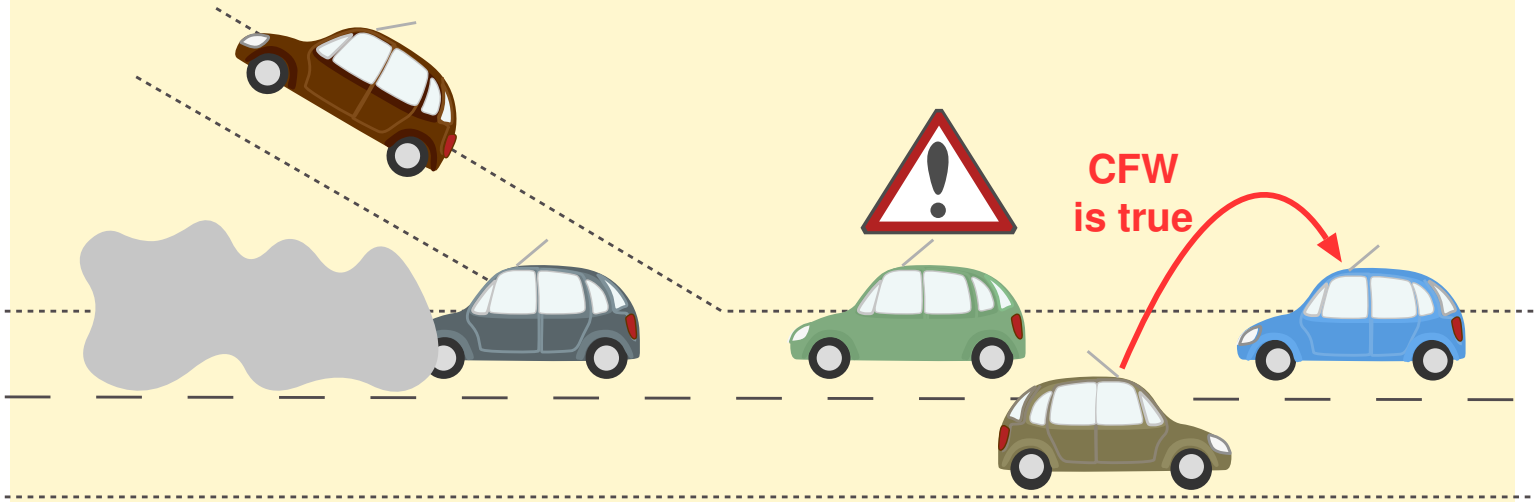


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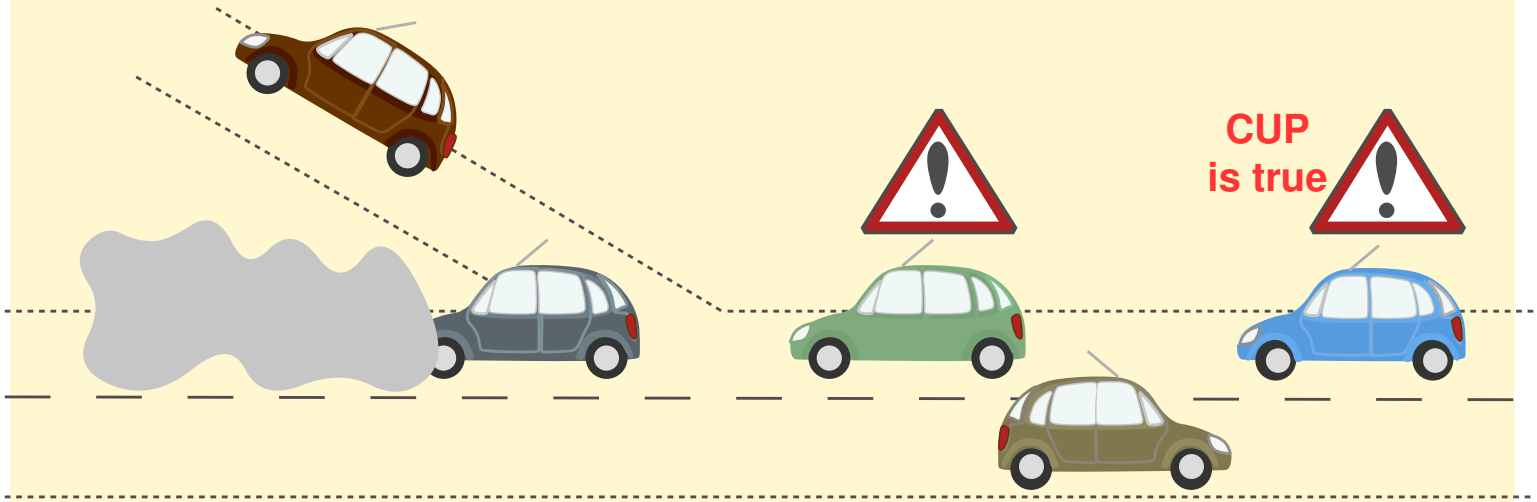


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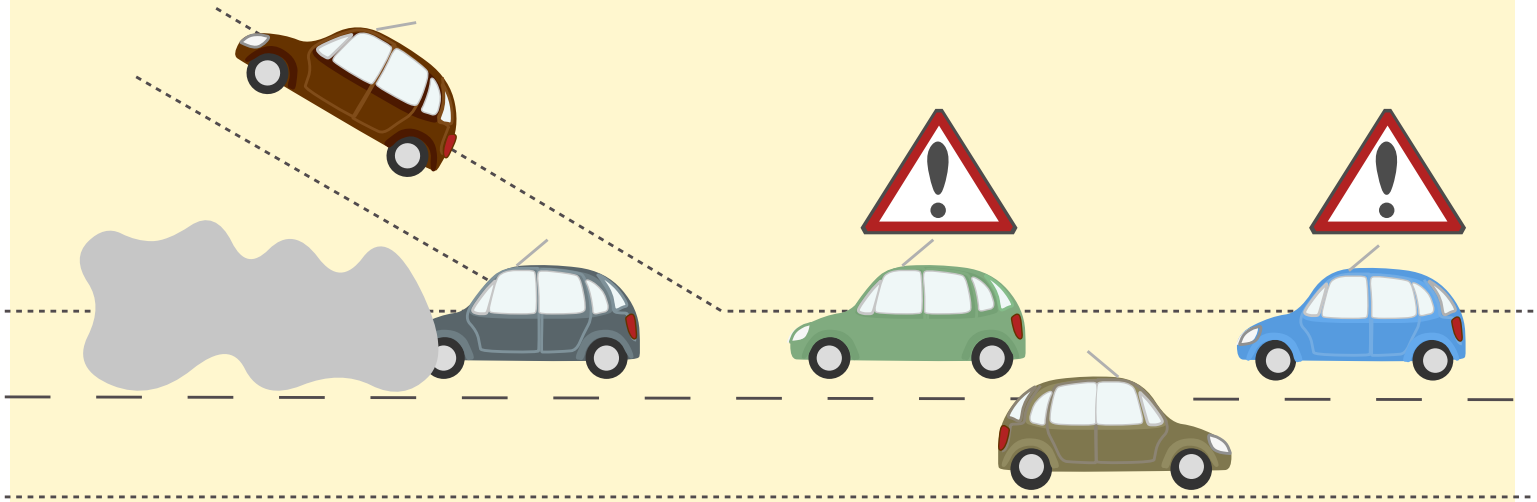

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# Sommaire



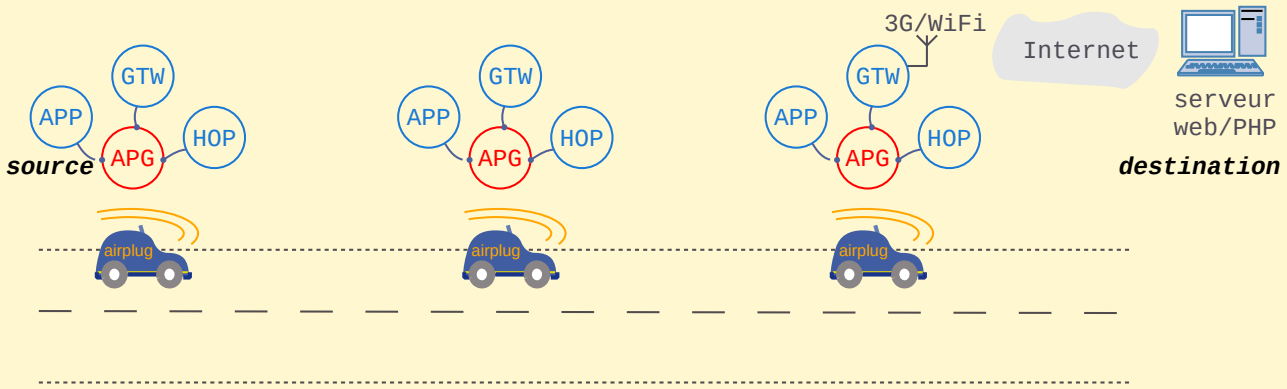
4 Cooperative communication architecture
- Strategy for dynamic networks
- One-to-many communication (V2V)
- Vehicle to Infrastructure communication (V2I)




# Cooperative communication architecture

## Vehicle to Infrastructure (V2I)

- Cooperative strategy
  - Relies on conditional transmissions
    New condition: gateway discovered
  - Messages contains:
    - Lifetime
    - Number of attempt for robustness
    - Delay before forwarding to other nodes

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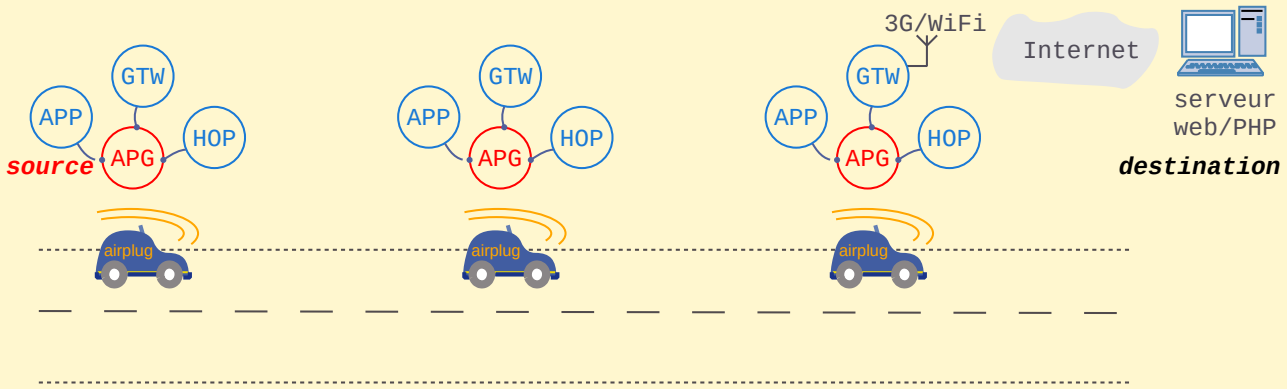


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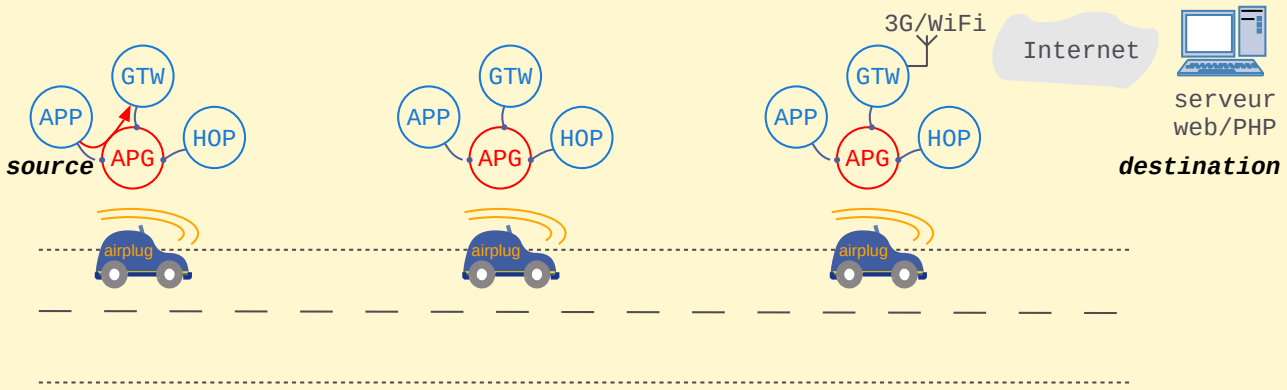


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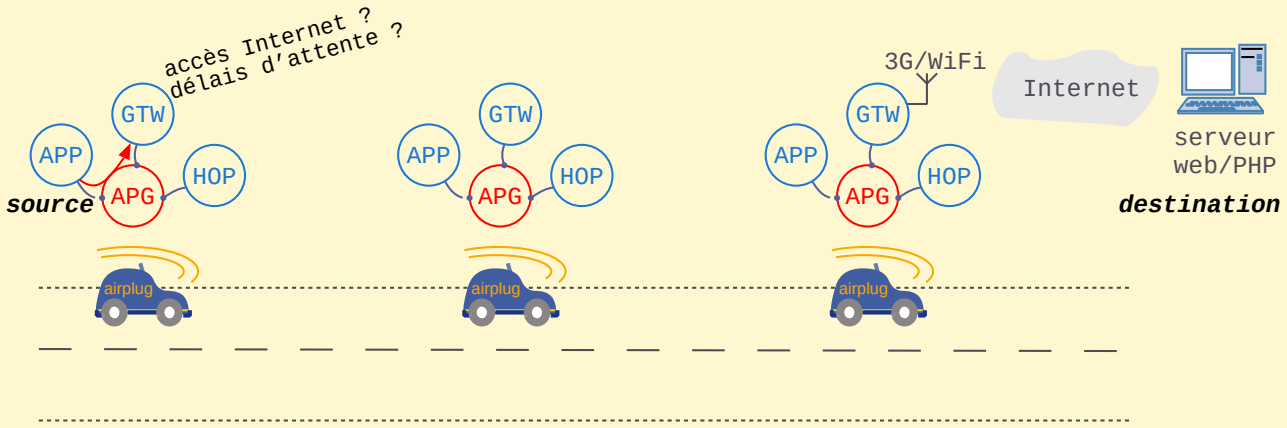

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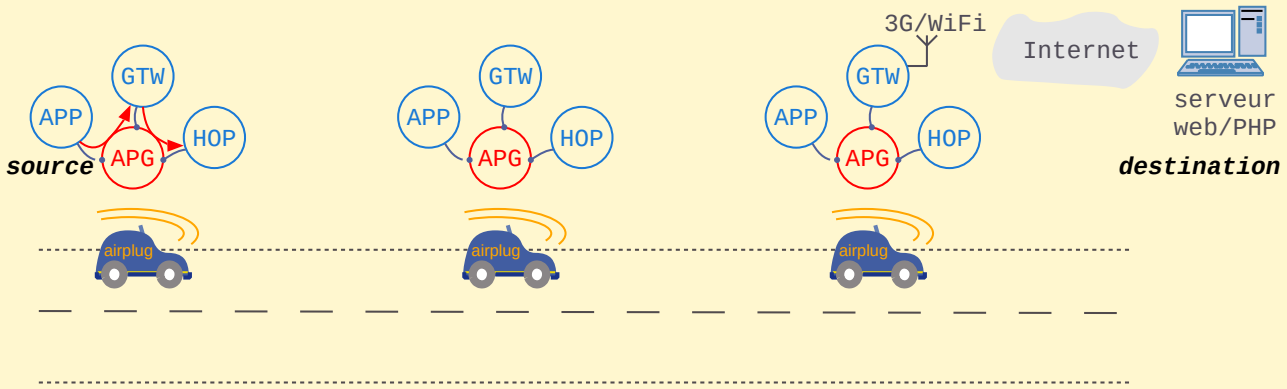


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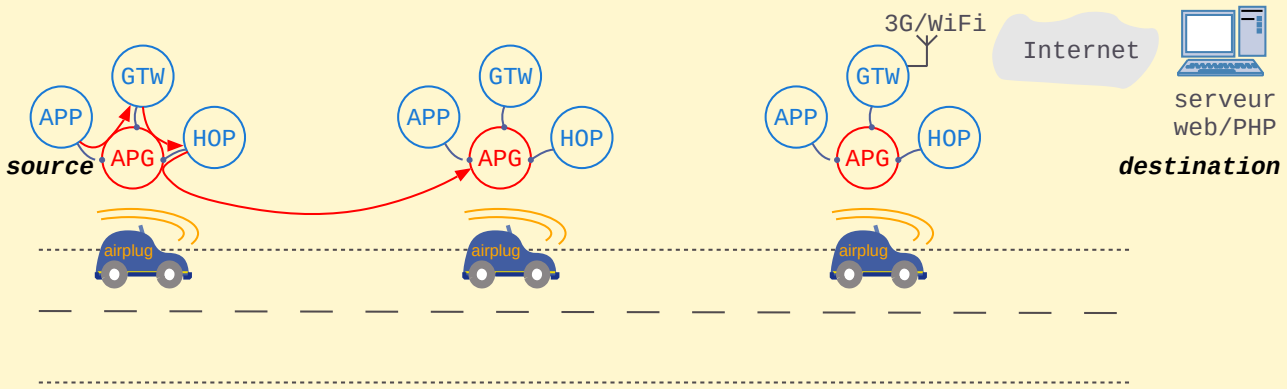


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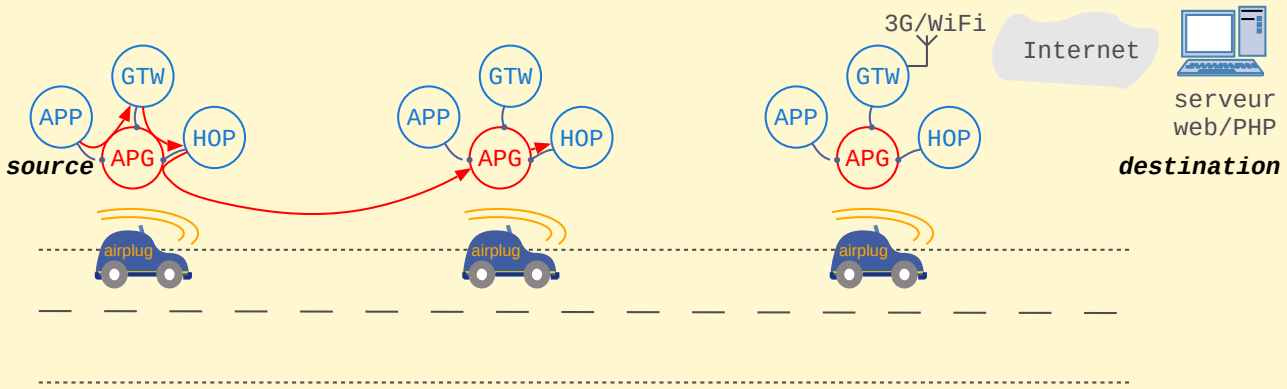


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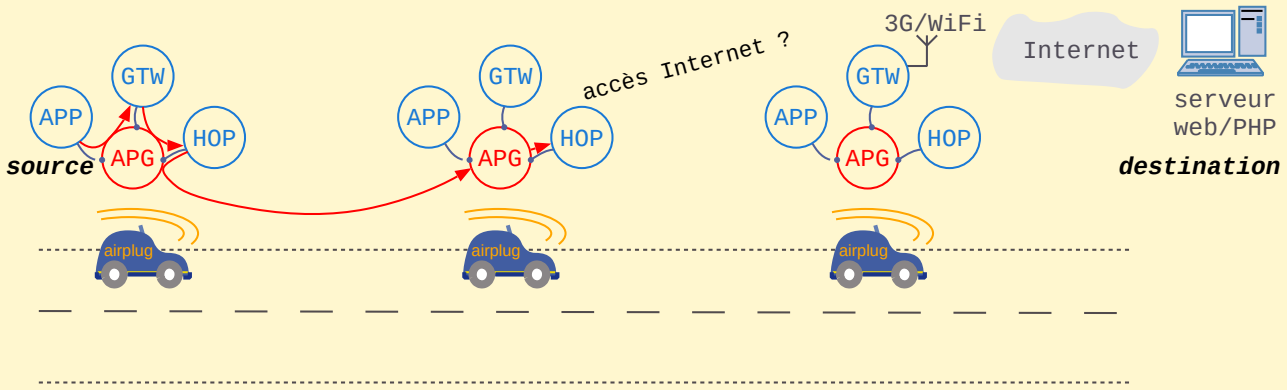


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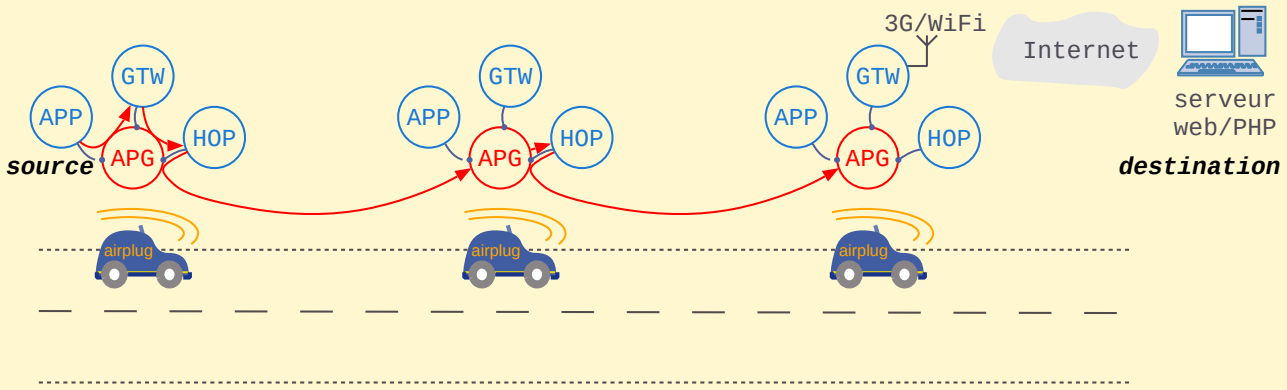


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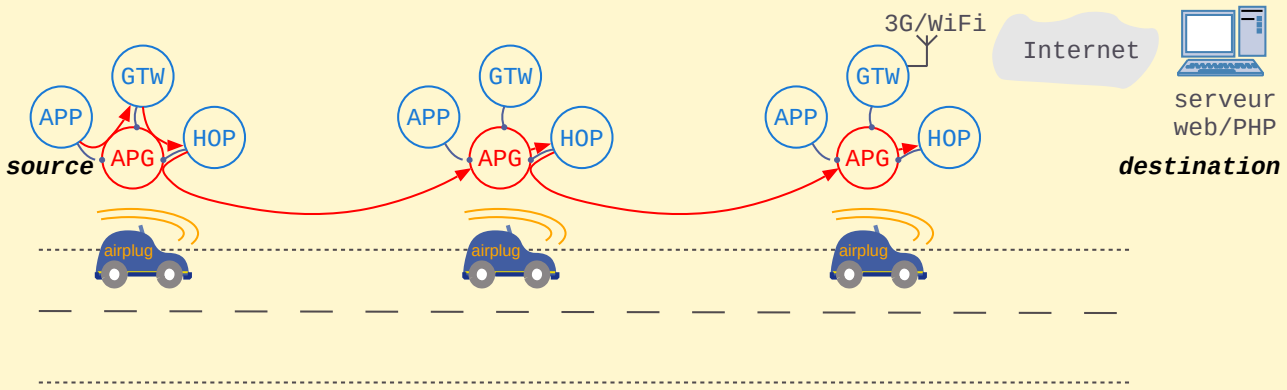


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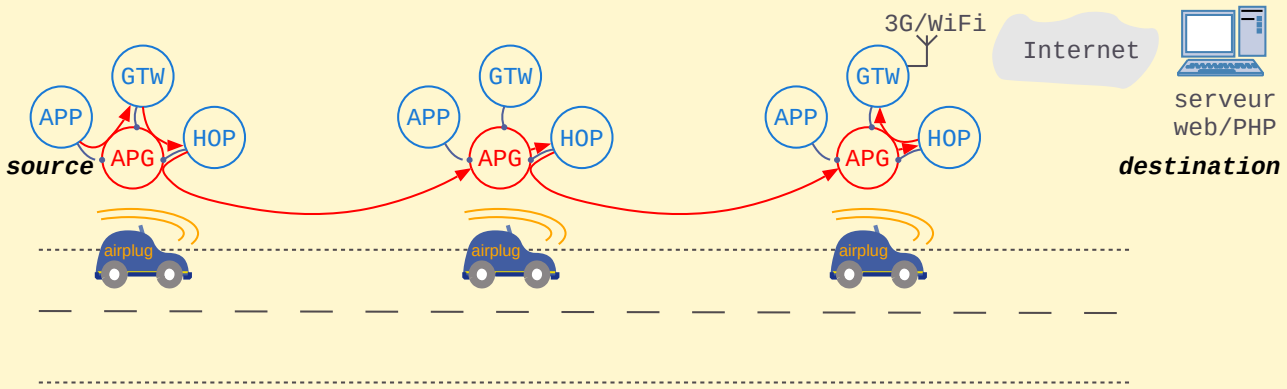


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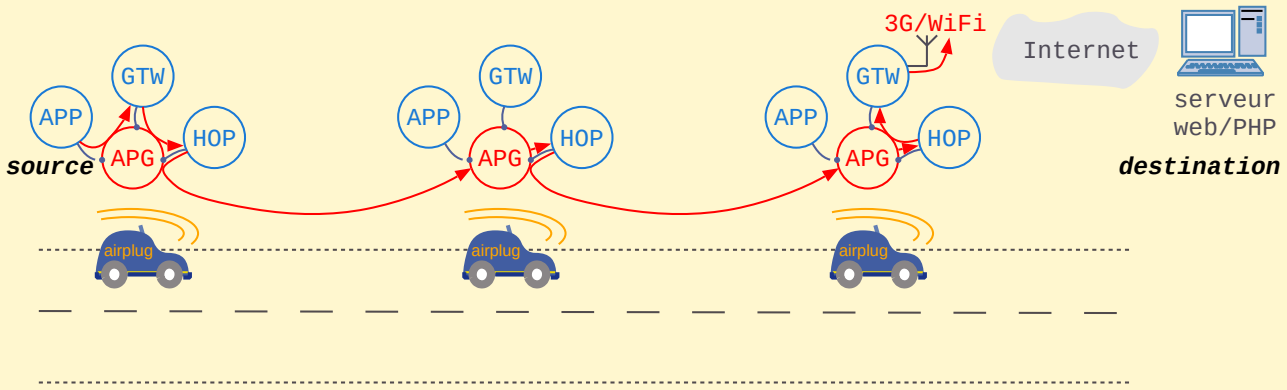


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# Cooperative communication architecture

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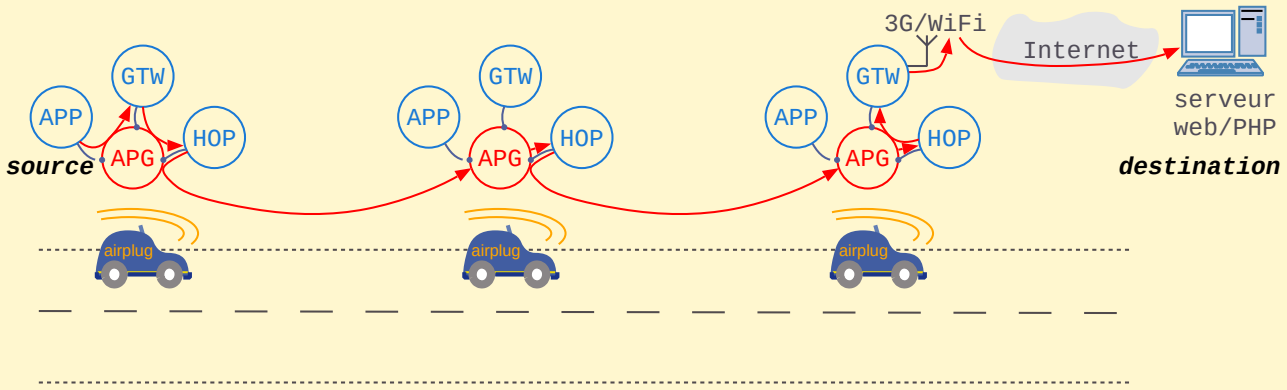


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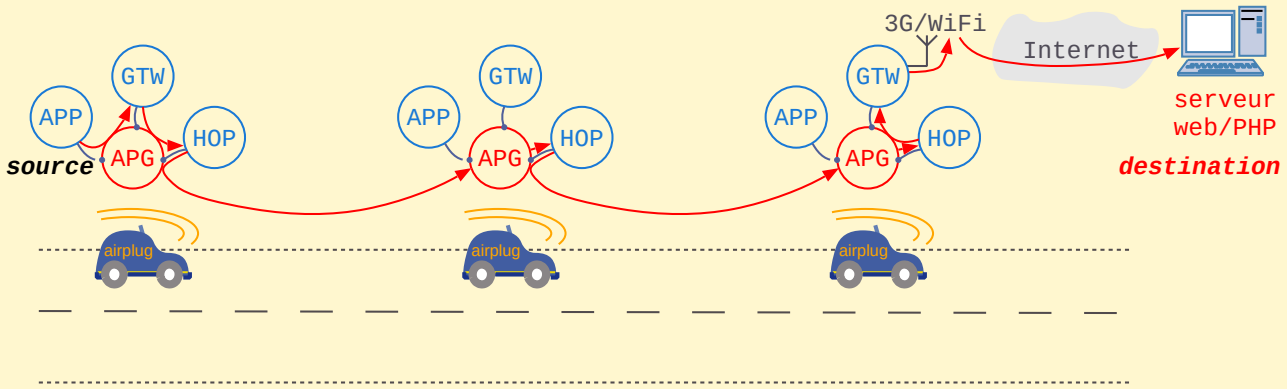


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# Summary

# Cooperative alert generation and propagation in vehicular networks

- Distributed data fusion
  - Avoiding the data collection phase
  - One result per node depending on its position
  - Robust algorithm
- Cooperative communication architecture
  - Adapted to dynamic networks
  - V2V and V2I
- CoMoSeF project
  - From theory to practice
  - Special thanks to:
    - Pekka Eloranta
    - the Celtic-Plus Office and the DGE
    - and all the Heudiasyc team!

# Experiment



- Distributed data fusion
  - Enforce confidences in the rain event
- Decision phase
  - Pignistic probability $>$ threshold $\rightsquigarrow$ alert
- Alert propagation
  - Message forwarding based on conditions