

Hazard
detection

Ducourthial

UTC

French pilot

Team

Aim

Scenario

Architecture

Data fusion

Introduction

Example

Algorithm

Experiments

Pilot

Hardware

Airplug

Fusion

Alert

Conclusion

Road Hazard Detection Using Distributed Data Fusion Comosef pilote in Compiègne, France

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V. Conan, D. Lim (Thales Communication & Security)

ITS World Congress Bordeaux 2015
October, 7th 2015



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2 French pilot

3 Distributed data fusion

4 French CoMoSeF pilot

5 Conclusion



- **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**
<http://www.hds.utc.fr>
Equipex Robotex, Labex MS2T



- Point of view
 - Dynamic networks are different!
- Methodology
 - ① Real applications
 - ② Designing new algorithms
 - ③ Proof of concept
 - Road tests
 - Performances issues Tests or network emulation
 - Analytic proofs Distributed algorithms
- Tools
 - **Airplug** Software Distribution
 - **Airbox** Communicating embedded disposals
 - On-Board-Units, Road-Side-Units in Compiègne

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



- **Cooperative Mobility for Services of the Future**
European Celtic Plus project 2013-2015
- **Inter-vehicles cooperative perception for road safety**
National project 2008-2011
- **Distributed system for vehicle dynamic evaluation**
Regional project 2008-2011
- **Data gathering from VANET to infrastructure**
Industrial project Orange lab 2008-2010
- **Distributed applications for dynamic networks**
Regional project 2007-2010
- **SafeSPOT European IP project** 2006-2010
- **Network services for com. between mobiles objects**
Industrial project Orange lab 2004-2008
- **Road anticipating** Regional project 2004-2007



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- Mobile sensing [IWCMC 2015]
- Experiments with dist. data fusion [VNC 2014]
- Experiments with sensors [WiSARN 2014]
- I2V experiments [ITSC 2014]
- V2I experiments [IWCMC 2014]
- V2V unicast communication [WCNC 2014]
- Distributed data fusion [SSS 2012]
- Data collection on the road [IV 2012]
- Performances in a convoy of vehicles [VTC 2011]
- V2I architecture [MobiWac 2010]
- Distributed dynamic group service [SPAA 2010]
- Vehicular networks emulation [ICCCN 2010]
- Simulation of vehicular networks [VTC 2010]
- Experimenting on the road [VTC 2009]
- Messages forwarding [IEEE TVT 2007]



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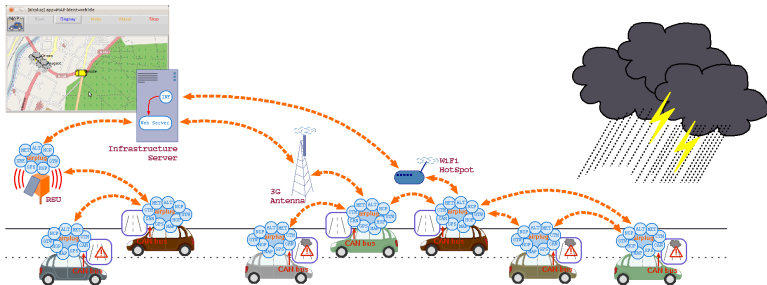
- 1 Université de Technologie de Compiègne
- 2 French pilot
- 3 Distributed data fusion
- 4 French CoMoSeF pilot
- 5 Conclusion



- **Université de Technologie de Compiègne (UTC)**
 - PhD & engineering diploma ~5000 students
 - CNRS lab Heudiasyc ~50 researchers + PhD
 - Computer science, theory and experiments
- **Viveris Technologies**
 - IT services in the technology services area
 - Automotive, aeronautic and medical...
 - 53 M€revenues, 750 employees
- **Thales Communication & Security**
 - Aerospace, Space, Defence, Security, Transportation
 - 60000 employees with 50000 in Europe
 - R&D activities: 1.9 Billions euro



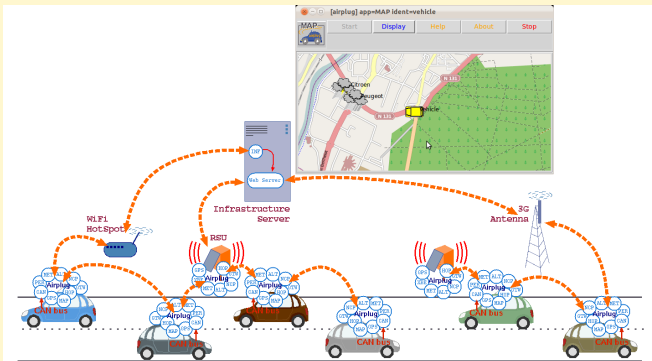
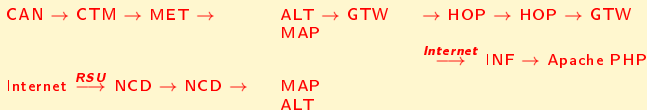
- Inputs from CAN bus [Viveris]
- Distributed data fusion [UTC]
- Alert management [UTC]
- Information diffusion from RSU [TCS]



- Weather alert scenario
 - Convoy of several vehicles
 - Some of them start windscreen wipers
Information read on CAN bus
 - Strong rain alert detected and propagated
(V2V, V2I)
Distributed data fusion
 - Efficient data dissemination from RSU
Based on network coding



- Hardware architecture
 - Airbox (UTC & Viveris)
- Software architecture



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- Motivation
 - From data to information
 - Avoiding to collect when possible
 - Can we trust data?
- Imperfect measures
 - Imprecision
 - Uncertainty
 - Ambiguity



- How to deal with imprecise and uncertain data?
 - Imprecision :
Set Membership Approach uncertainty?
 - Aleatory uncertainty :
Probability theory imprecision?
 - **Theory of Belief Function**: generalizes both
Transferable Belief Model
Dempster-Shafer Theory of Evidence
- Belief Function Framework
- Information modeling + combination rules

[Dempster 1968, Shafer 1976, Smets 1990s]



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

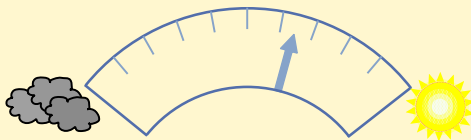
[Dubois, Prade 1988]

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

- Frame of discernment Ω finite or infinite
- Basic belief assignment (bba)
 - Mass function
 - $m^\Omega : \mathcal{P}(\Omega) \rightarrow [0, 1]$
 - $\sum_{X \subset \Omega} m^\Omega(X) = 1$
 - Other representations: commonalities, **weights**
- **Conjunctive operator**
 - Combines two mass functions by emphasizing the agreement, providing they are reliable and independent [Smets 1990, Shafer 1976]
 - $m_{1 \otimes 2}(A) = \sum_{B \cap C = A} m_1(B) \cdot m_2(C)$
 - Conflict is the mass obtained on $\emptyset \subset \Omega$
- **Dempster operator**
 - Conflict ignored
 - Spread over other sets
- Other operators: disjunctive, **cautious...**



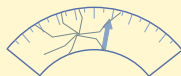
- Pressure measurement



- Weather forecast
 - Compare current measure with the last one



- Barometer?

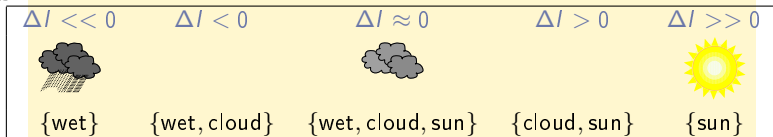


- Measure:

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



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



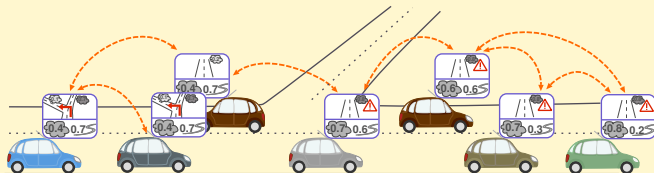
- Several independent measures can be combined using the Dempster rule.
- Decision: from mass to *pignistic* probability

$$P(A) = \sum_{\emptyset \neq B \subset \Omega} m(B) \frac{|A \cap B|}{|B|}$$

- **Centralized approach** [Cherfaoui et al. 2008]
 - Geographic distance between sources of information
 - Age of information
- **Distributed approach**
 - **Spanning tree** [Gasparri et al. 2011]
 - **Vehicular networks** [El Zoghby et al. 2012]
 - Spanning tree?
 - Loops \rightsquigarrow data incest
 - Idempotent combination rule
 - \rightsquigarrow **Cautious operator** [Denoeux 2008]
Defined on weights functions
- **Network always supposed to be reliable**



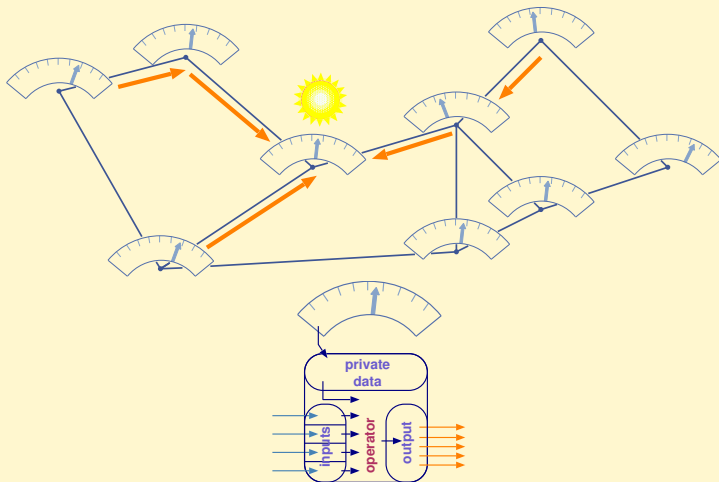
- Problem to solve
 - **Direct confidence** (regularly) produced locally
 - **Distributed confidence** computed by each node using other values
- Locality
 - One result per node
 - Depend on the position of the node in the network



- Self-stabilizing distributed data fusion algorithm
 - Combine all direct confidences of the system
 - Discount information regarding the distance
Confidence decreases at each hop
- Properties
 - Finite data set
Discretization + adapted operators
 - Asynchronous and anonymous system
 - Unreliable message passing system
 - Intermittent faults on memories/messages
 - Crash faults on nodes



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

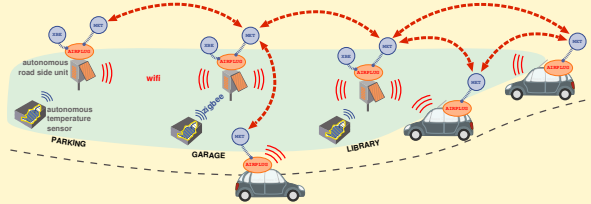


- Testbed
 - 3 RSU, 6 sensors + vehicles

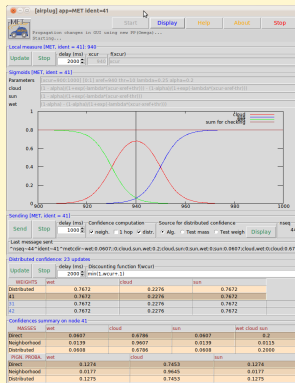


[WiSARN 2014, VNC 2014]

- Proof of concept



- Live demo



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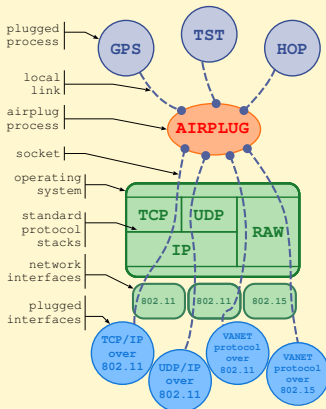


- **Airbox**

- New device
- On-Board Units in our vehicles
- Road-Side Units in Compiègne
Agreement with the city of Compiègne

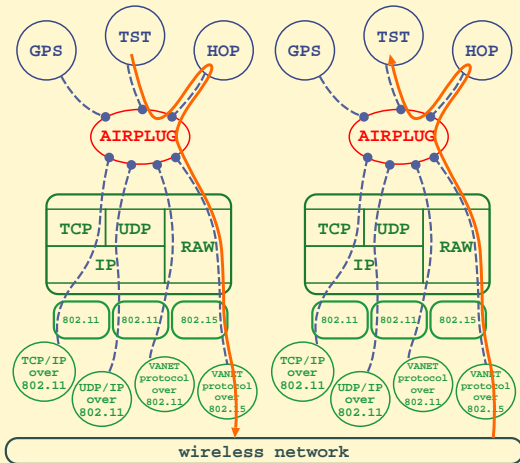
UTC & Viveris





- POSIX OS
- **Core program**
 - user-space process
 - networking
- **Applications**
 - user-space process
 - read on stdin
 - write on stdout
 - API close to IEEE WSMP
- Ensure tasks and OS independence for robustness
- Open to any programming language

- New protocols developed in user space processes
 - Open to new networking solutions
 - Cross-layer solutions facilitated



Hazard detection

Airplug Software Distribution

Complete platform

Ducourthial

UTC

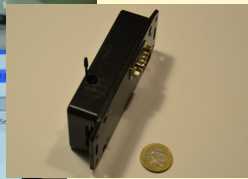
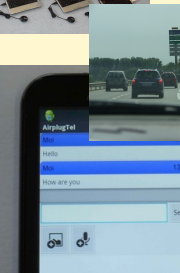
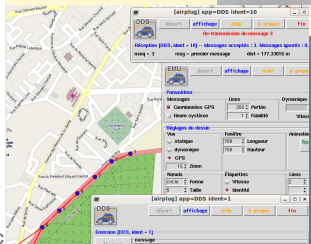
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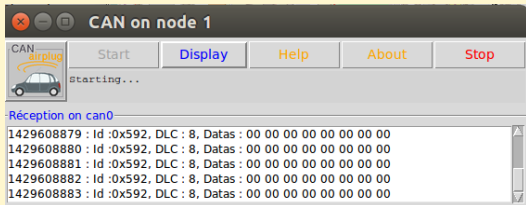
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- Airplug-term \rightsquigarrow rapid prototyping
 - Airplug-emu \rightsquigarrow study by emulation
 - Airplug-live \rightsquigarrow real experiments (vehicles, UAV)
- + remote, notk...



- CAN app: Viveris & UTC
 - Reading the CAN bus
- Specific tool for initializing a vehicle Viveris



- CTM app

UTC

- CAN bus \rightsquigarrow direct confidence
- Inputs from the CAN bus, the GPS...
- Local knowledge sent to the MET app

```

CTM on node 1
CTM airplug Starting...
Réception [CTM, ident = 1]
Dernier message reçu de : ^cansn~170^canwiper-off^
Emission [CTM, ident = 1]
Dernier message émis vers MET : ^metpl~0^
  
```




- MET app

UTC

- Distributed data fusion
- Convert local knowledge to mass functions
- Exchange messages with neighbors
- Convergence despite network failures

MET on node 2

MET  Start Display Help About Stop

Propagation changes in GUI using new PP(Omega)...
Starting...

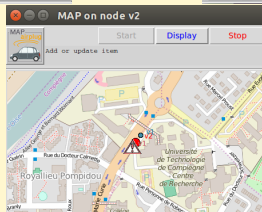
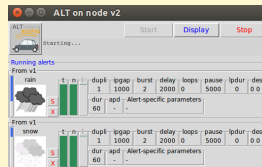
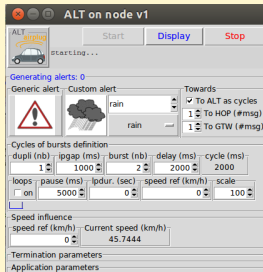
Confidences summary [MET, ident = 2]

MASSES	nofall	lowfall	fall	highfall	nofall lowfall fa
Direct	0.8000	0.0000	0.0000	0.0000	0.2
Neighborhood	0.0000	0.0000	0.0000	0.0000	0.0000
Distributed	0.8000	0.0000	0.0000	0.0000	0.2000
PIGN. PROBA.	nofall	lowfall	fall	highfall	
Direct	0.8500	0.0500	0.0500	0.0500	0.0500
Neighborhood	0	0	0	0	0
Distributed	0.8500	0.0500	0.0500	0.0500	0.0500



- ALT app
 - Alert generation
 - Alert local management

UTC



- HOP app
- Multihop communication based on conditions

UTC

```

HOP on node v1
Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/

gps -> hop -> app -> hop -> air -> hop -> hop -> air -> hop -> app | local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd~ALT^cfw--^cup--^msg--^altsid~v1^altp~rain^altseq~
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [1]: ^seq~1^hst~v1^ape~ALT^apd~ALT^cup~1^cfw~1^msg~^altsic
GTW [v1] > HOP [v1]: ^apd~GTW^cfw~1^cup~1^msg~^gtwid~v1~ALT~0^gtwid~58^
HOP [v1] > HOP [1]: ^seq~2^hst~v1^ape~GTW^apd~GTW^cup~1^cfw~1^msg~^gtwid~58^
  
```



- HOP app UTC
 - Multihop communication based on conditions

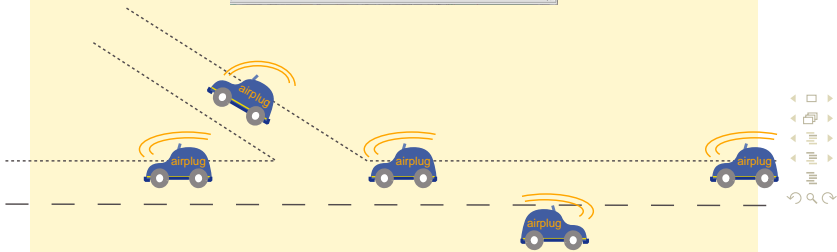
```

HOP on node v1
Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/

gps -> hop -> app -> hop -> air -> hop -> hop -> air -> hop -> app local registered app
47      3      6      2      0      GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^msg--^altsid-v1^alttyp-rain^altseq-1
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg--^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg--^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg--^gtwid-58^
  
```



- HOP app
- Multihop communication based on conditions

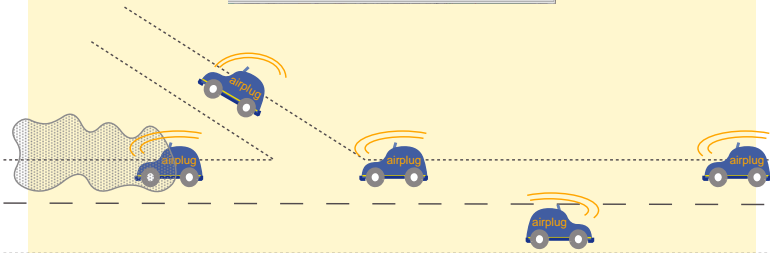
UTC

```

HOP on node v1
Start Display Help About Stop
Starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
gps-> hop -app-> hop--air-> hop -hop-> air -hop-> app -local registered app
47 | 3 | 6 | 2 | 0 | GTW
-----|-----|-----|-----|-----|-----
-|-|-|-|-|-|

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^msg--^altsid-v1^alttyp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
yop [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg-^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg-^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg-^gtw
  
```



- HOP app
- Multihop communication based on conditions

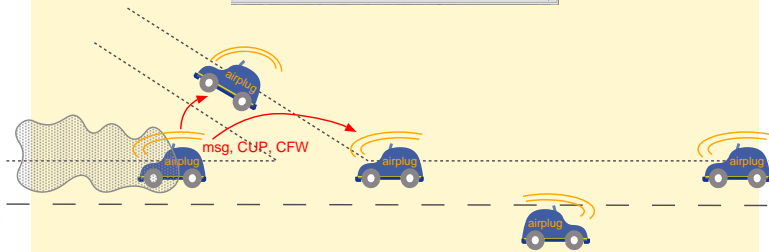
UTC

```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
gps -> hop -> app -> hop -> air -> hop -> hop -> air -> hop -> app - local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^msg--^altsid-v1^alttyp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg-^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg-^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg-^gtw
  
```



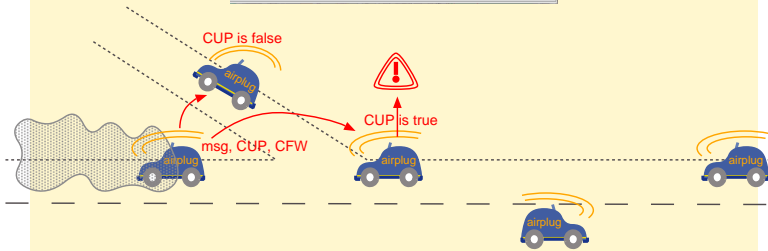
- HOP app UTC
- Multihop communication based on conditions

```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
gps-> hop -app-> hop--air-> hop--hop-> air--hop-> app -local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^altsid-v1^alttyp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg--^altsid
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg--^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg--^gtwid
  
```



- HOP app
- Multihop communication based on conditions

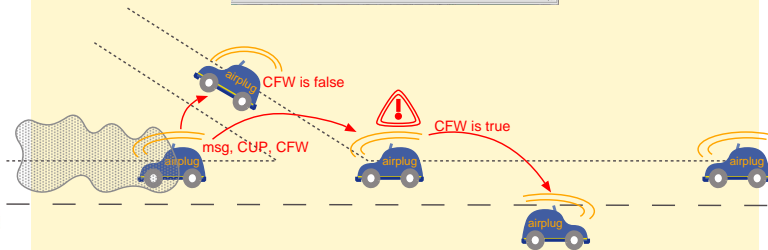
UTC

```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
-gps-> hop -app-> hop -air-> hop -hop-> hop -air-> hop -app -local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^msg--^altsid-v1^altp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg-^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg-^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg-^gtw
  
```



- HOP app
- Multihop communication based on conditions

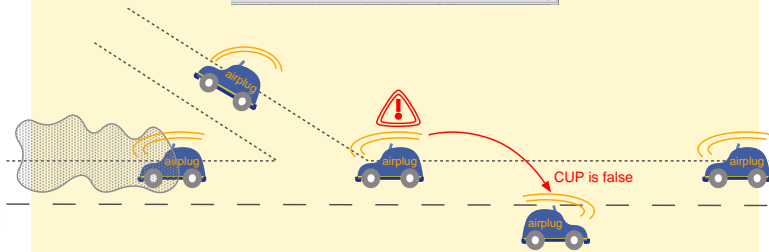
UTC

```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
-gps-> hop -app-> hop -air-> hop -hop-> air -hop-> app -local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^altsid-v1^altp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg-^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg-^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg-^gtw
  
```



- HOP app
- Multihop communication based on conditions

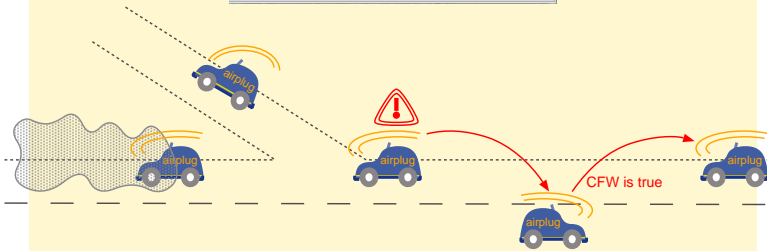
UTC

```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

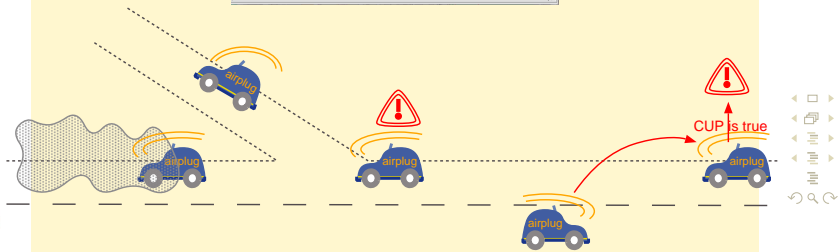
Information about receptions (HOP on v1)
-received timestamps
N1:2/
-gps-> hop -app-> hop -air-> hop -hop-> hop -air-> hop -app -local registered app
47 | 3 | 6 | 2 | 0 | GTW

Initiator of communication (3 received msg, 2 transmitted)
ALT [v1] > HOP [v1]: ^apd-ALT^cfw--^cup--^altsid-v1^alttyp-rain^altseq-
lack of cup => cup = true, lack of cfw => cfw = true
HOP [v1] > HOP [v1]: ^seq-1^hst-v1^ape-ALT^apd-ALT^cup-1^cfw-1^msg-^altsic
GTW [v1] > HOP [v1]: ^apd-GTW^cfw-1^cup-1^msg-^gtwid-v1-ALT-0^gtwid-58^
HOP [v1] > HOP [v1]: ^seq-2^hst-v1^ape-GTW^apd-GTW^cup-1^cfw-1^msg-^gtw
  
```



- HOP app
- Multihop communication based on conditions

UTC



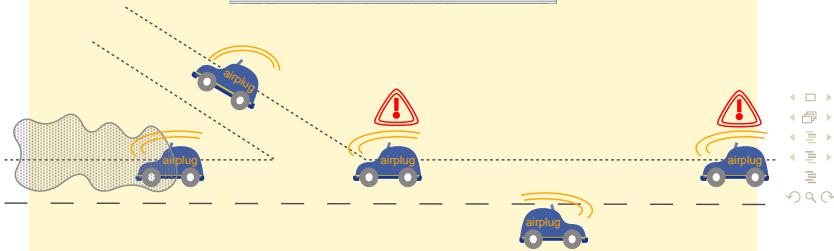
- HOP app
- Multihop communication based on conditions

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```

HOP on node v1
HOP [airplug] Start Display Help About Stop
starting...

Information about receptions (HOP on v1)
-received timestamps
N1:2/
gps-> hop -app-> hop -air-> hop -hop-> air -hop-> app -local registered app
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```



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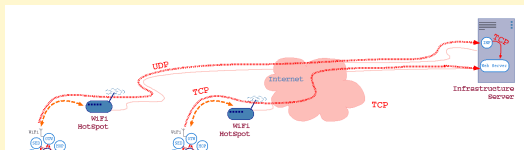
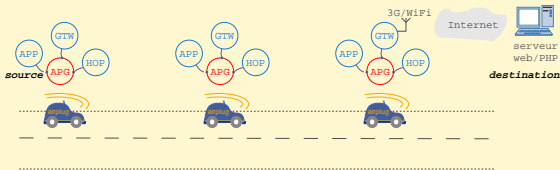
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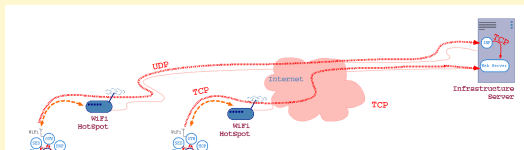
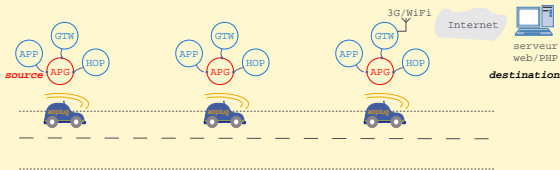
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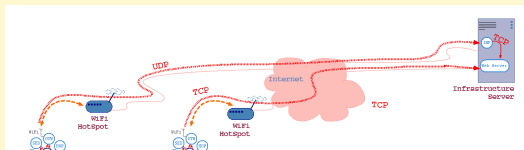
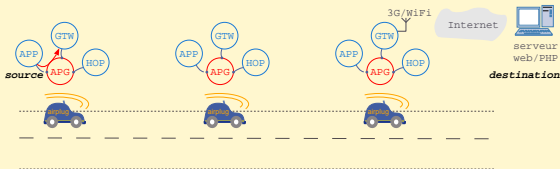
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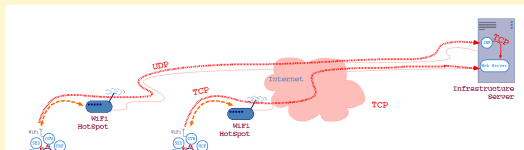
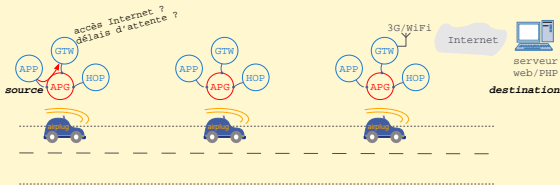
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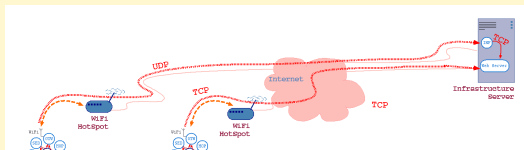
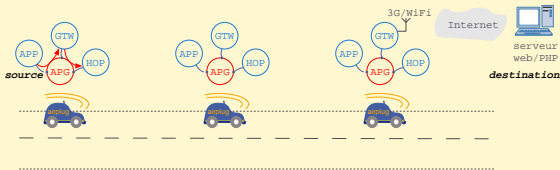
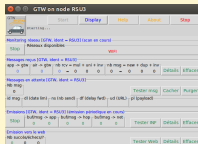
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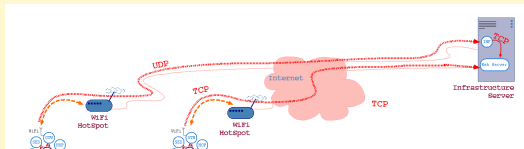
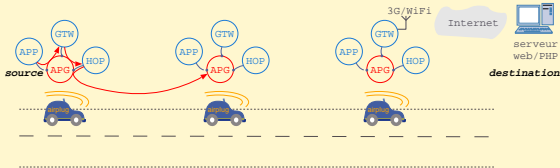
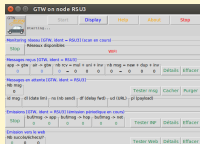
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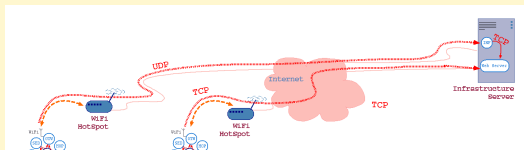
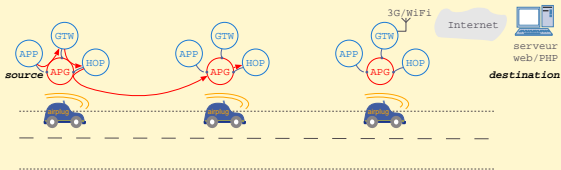
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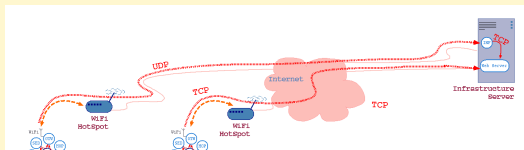
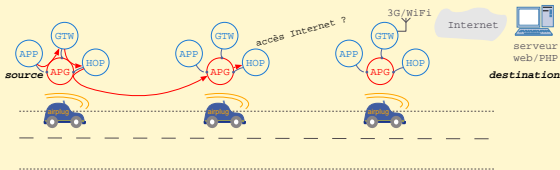
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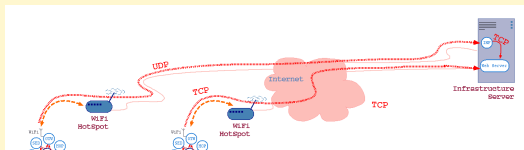
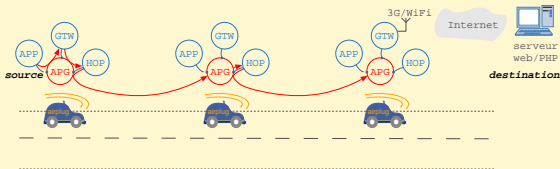
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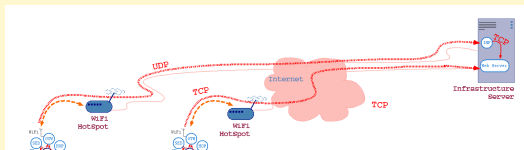
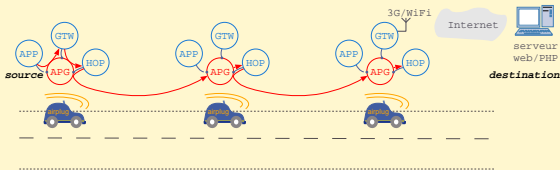
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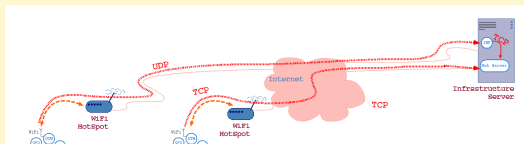
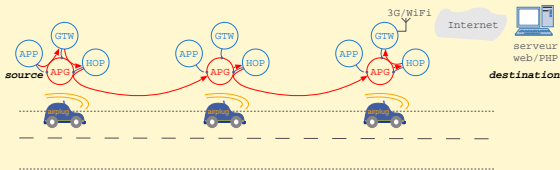
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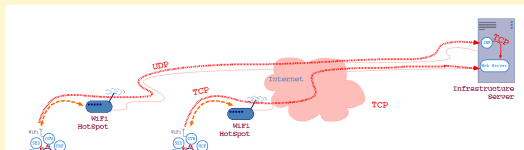
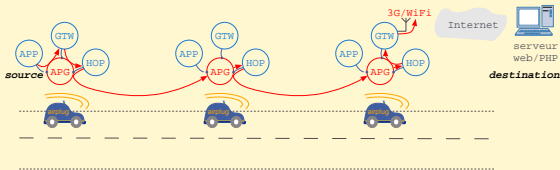
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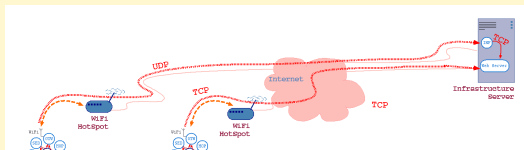
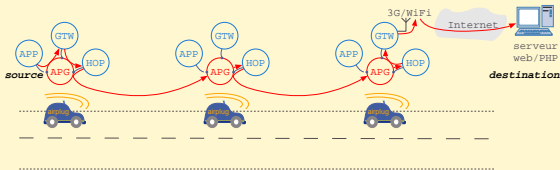
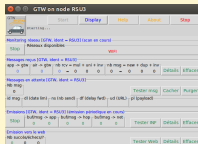
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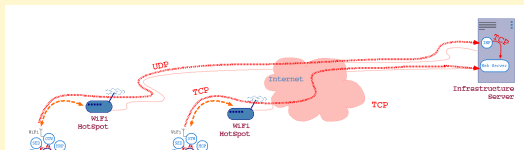
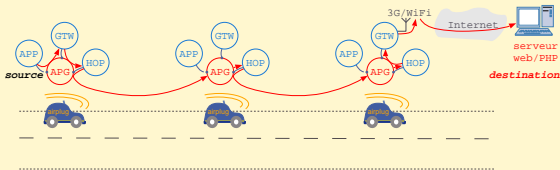
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- INF app
 - Infrastructure components
 - UDP proxy
 - LAMP server
Linux, Apache, Mysql, PHP
 - Map

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- NCD app Thales Communication & Security
 - Network coding
 - Combination method
 - Very efficient for (large) data diffusion
 - Information combined before sending
 - Linear combination for the simple method
 Other possible methods exists
 - Increase robustness, security and efficiency



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- ① Université de Technologie de Compiègne
- ② French pilot
- ③ Distributed data fusion
- ④ French CoMoSeF pilot
- ⑤ Conclusion



- Distributed data fusion
 - Original and robust algorithm
 - Application to hazard detection
Freezing road, rain alert...
- Experiments
 - The French CoMoSeF pilot
 - Hardware: **Airbox** new communicating device
 - Software: **Airplug** software distribution
 - Airplug apps: CAN, CTM, MET, ALT, HOP, GTW, INF, NCD
- Future work
 - Large testbed in Compiègne
 - New applications

