Exploiting data in dynamic networks

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April 2014

Agenda

1. Context
2. Distributed data collect
3. Distributed data fusion
4. Conclusion
5. Jobs position

Summary

Context : dynamic networks

A definition

- Dynamic network
  - Short communication link duration
  - Short amount of data exchanged

  - Unstable neighborhood
  - Do not rely on topology
  - Avoid using any remote knowledge
- Modeling ?
  - Nodes speed $\leftrightarrow$ communication protocol
  - p-Dynamic graphs
  - Metric

Context : dynamic networks

Applications

- Applications
  - Large networks are generally dynamic
  - Social networks
  - Peer-to-peer networks
  - Network of laptops Mobile Ad hoc NETworks
- Examples
  - Network of pedestrian with personal devices
  - Network of embedded computers
    - Robots networks
    - Vehicular networks (VANET)

Context : dynamic networks

Challenges

- Impact of the dynamic
  - Communication protocols
  - Distributed algorithms
  - Trusty, security
  - ...
- Distributed data ?

Context : distributed data

Collect

- Data spread out in a network
- Decision making
  - Data on each node ⇝ action decided
  - Using physical devices Alarm...
  - Using another (distributed) algorithm
- Require to know about the data

⇝ Data collection

Context : distributed data

Fusion

- Can we trust data ?
- Techniques for dealing with system faults
  - A fault could damage data
  - Self-stabilization
  - Redundancy
  - ...
- Fault : data $\neq$ legitimate data
  - What is a legitimate data ?
  - Data are supposed to be precise and certain
- Reality : information tainted with imperfection
  - Imprecision
  - Uncertainty
  - Ambiguity

$\leadsto$ Data fusion

Context : team

UTC/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
  http ://www.hds.utc.fr
  Equipex Robotex, Labex MS2T

Context : team

Team approach

- Our point of view :

  Dynamic networks are different !

- Our methodology :
  1. Real applications
  2. Designing new algorithms
  3. Proof of concept — Road tests

     Performances issues — Tests or network emulation

     Analytical proofs

- Our tools :
  - Airplug Software Distribution
  - Communicating embedded disposals

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

Context : team

Research projects

- 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

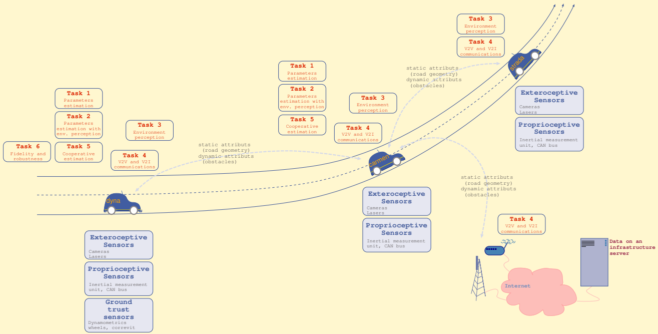
Context : team

Scientific contributions

- Experiments with sensors [WiSARN 2014]
- I2V experiments [IV 2014]
- V2I experiments [IWCMC 2014]
- V2V unicast communication [WCNC 2014]
- Distributed data fusion [SSS 2012]
- Data collect 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]
- ...

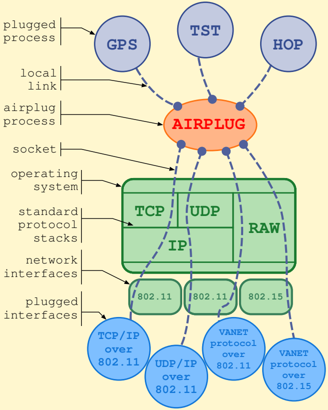
Context : team

Communication & intelligent vehicles



Context : Airplug Software Distribution

Process-based architecture

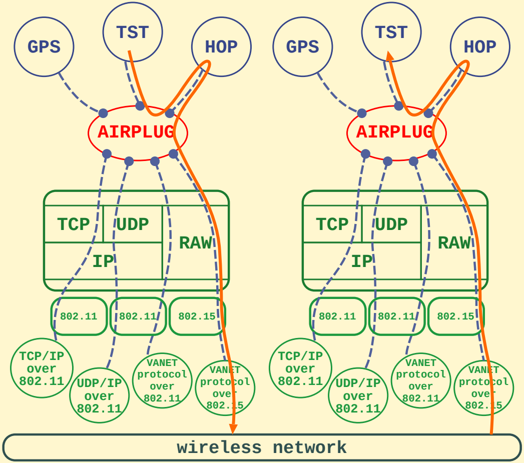


- POSIX OS
- Core program
  - user-space process
  - networking
- Applications
  - user-space process
  - read on stdin
  - write on stdout
  - API close to IEEE WSMP
- Ensure tasks and OS independence for robustness
- Open to any programming language

Context : Airplug Software Distribution

Facilities for developing new protocols

- New protocols developed in user space processes
  - open to new networking solutions
  - cross-layer solutions facilitated

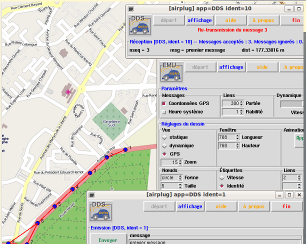


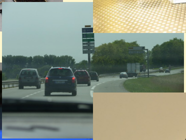
Context : Airplug Software Distribution

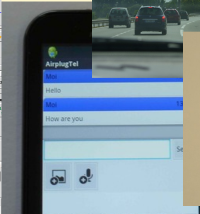
Complete research platform

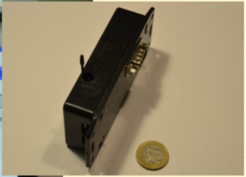
- Airplug-term ⇝ rapid prototyping
- Airplug-emu ⇝ study by emulation
- Airplug-live ⇝ real experiments (vehicles, UAV)
- Airplug-ns ⇝ adds-on for Network Simulator

+ remote, notk...









Summary

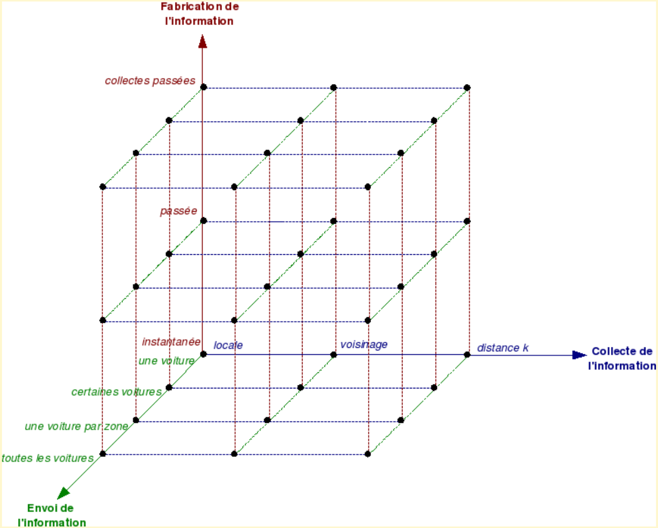
Data collect : introduction

Problem to solve

- Motivations
  - Many data produced by vehicles
    From embedded sensors and calculators
  - Could feed intelligent applications
    - infrastructure
    - vehicle-oriented, driver oriented
- Problem to solve
  - Large amount of data
  - Limited network resources
  - Dynamic network
- Kind of collect
  - Data production
    local, time/geographic aggregation...
  - Data sending
    a single, some, all vehicles...
  - Starting
    Push-based, pull-based...
  - Ending ?

Data collect : introduction

Taxonomy



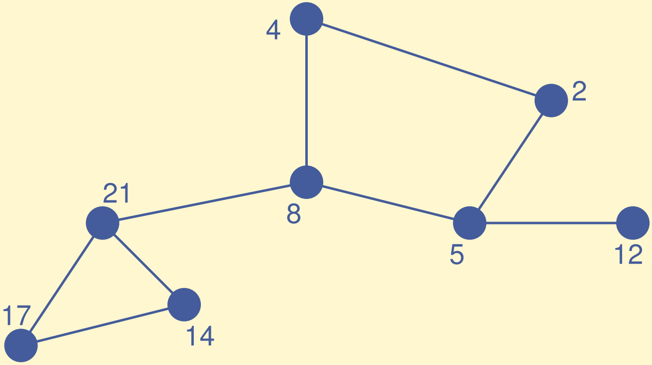
Data collect : introduction

Related work : a summary

- Dissemination
  - Opportunistic, geographic, peer-to-peer, cluster-based... [WU04,LEE06,BON07]
  - Kind of data to be sent ?
  - When to send data ?
- Request-based
  - Propagation of Information with Feedback [SEG83]
    For fixed networks
  - Wave for MANETs [CHE02]
    For networks without partitioning

Data collect : introduction

Related work : PIF



[Propagation of Information With Feedback, Segall 1983]

- Fix network
- A single node collects

Data collect : introduction

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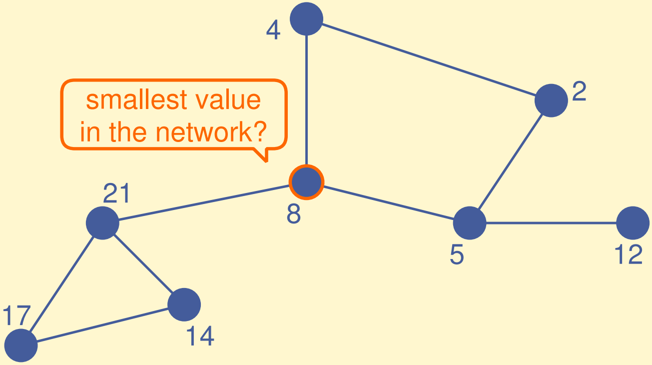

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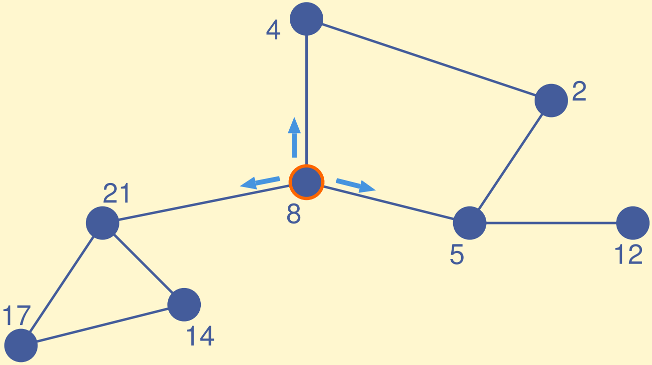

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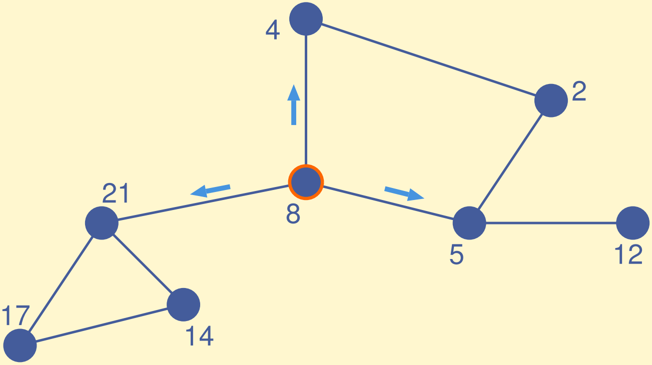

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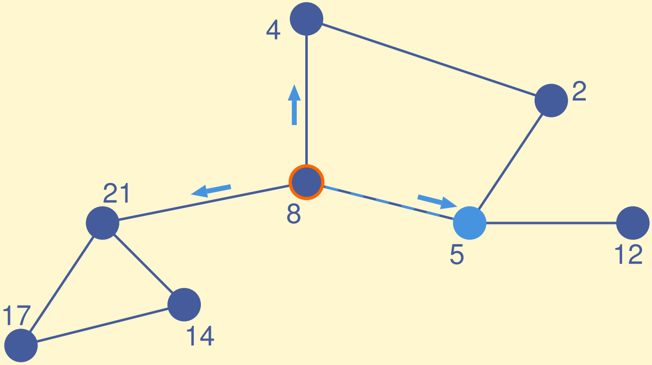

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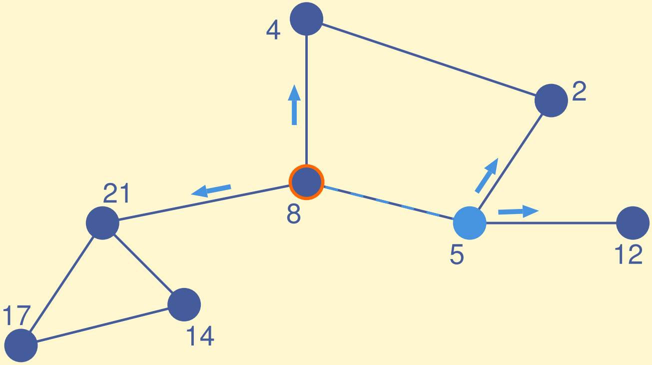

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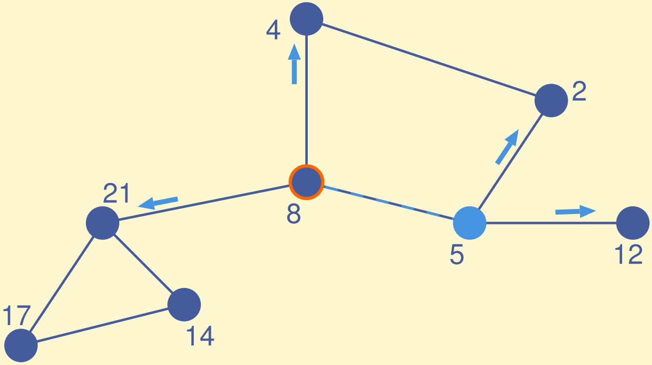

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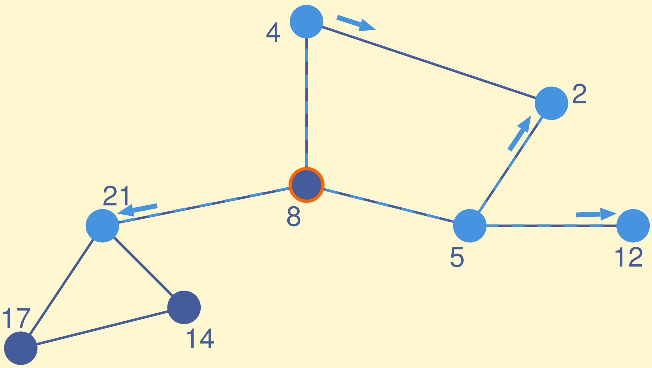

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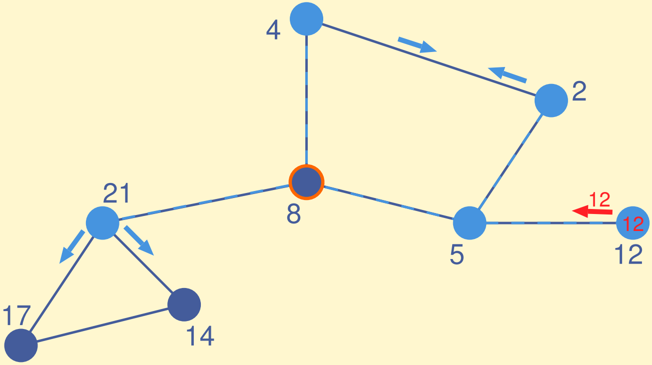

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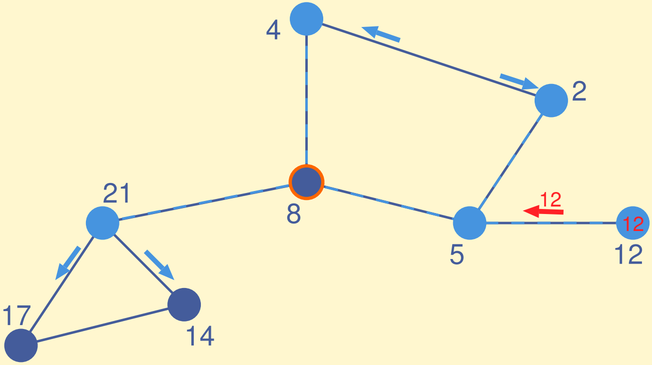

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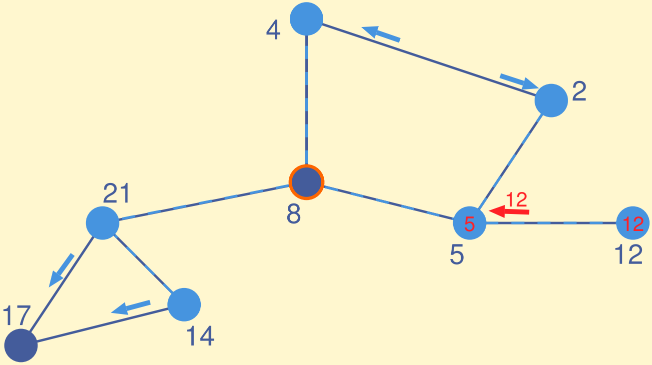

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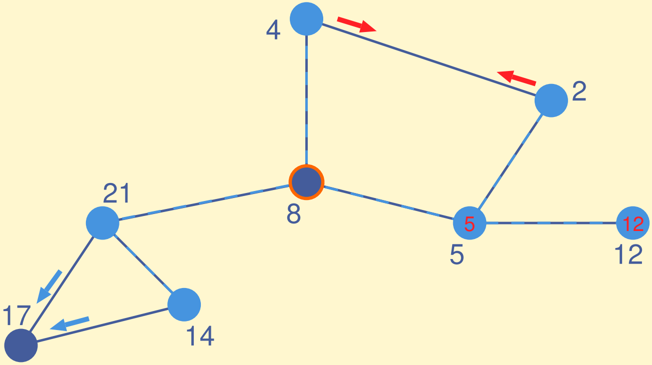

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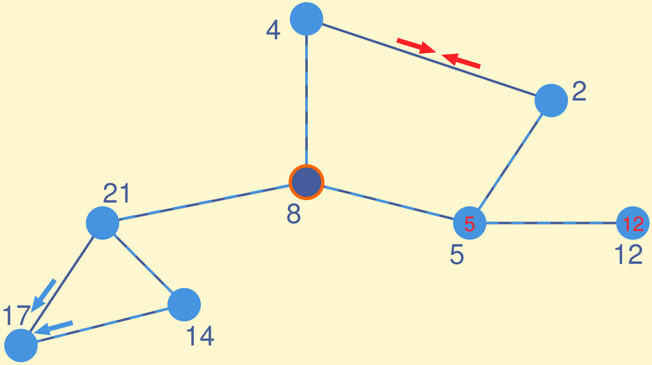

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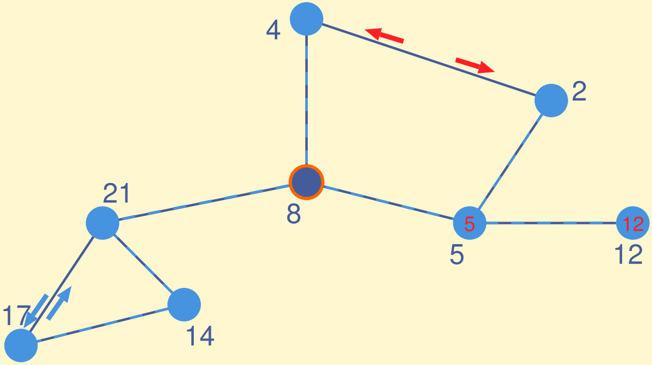

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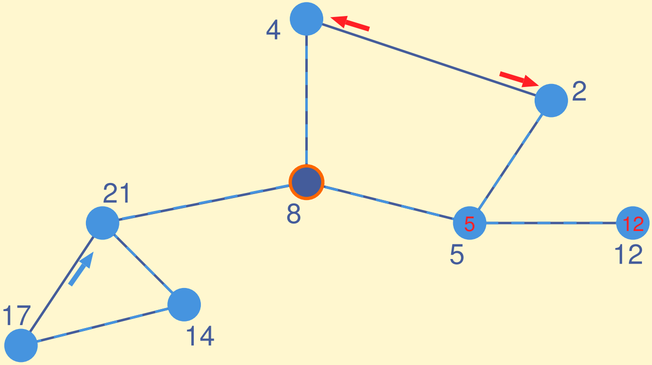

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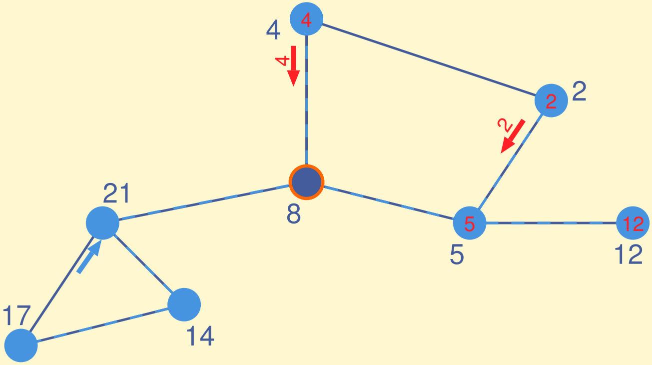

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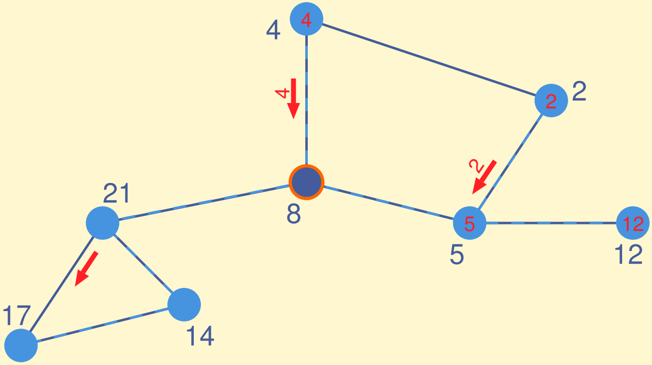

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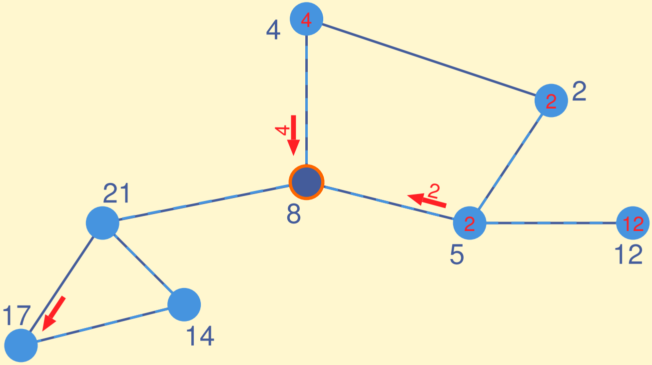

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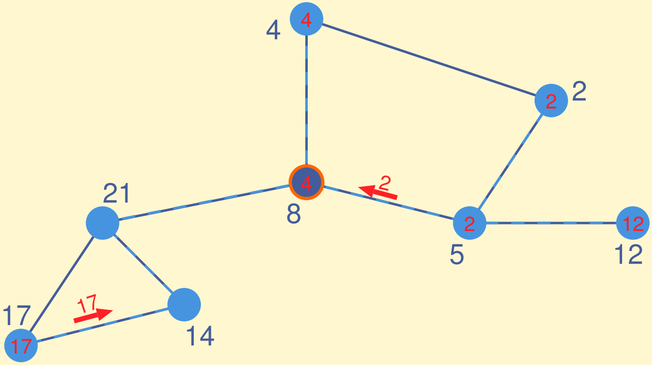

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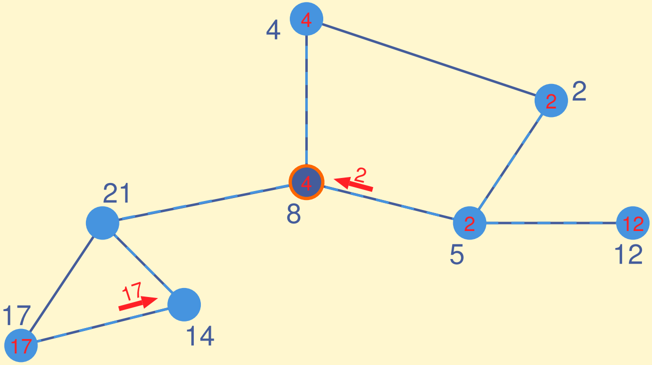

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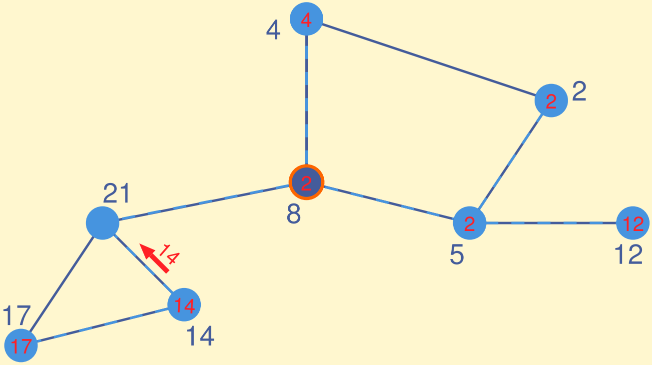

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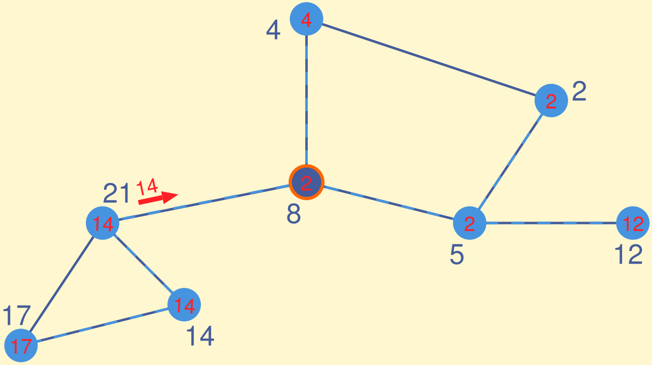

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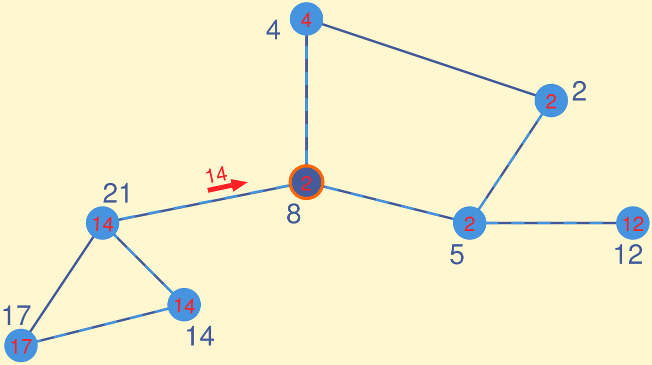

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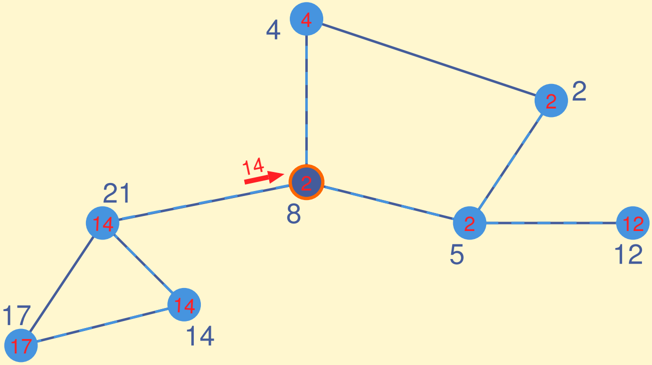

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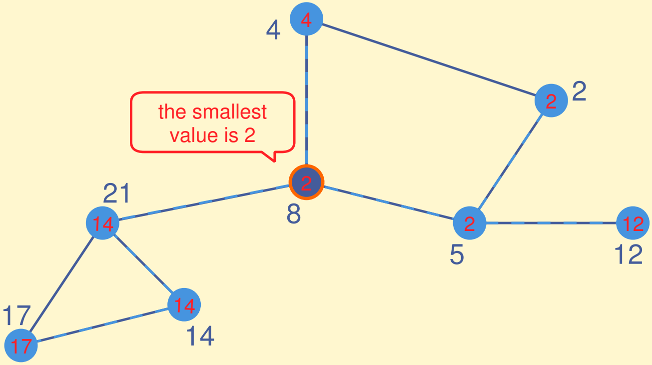

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- Fix network
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Data collect : introduction

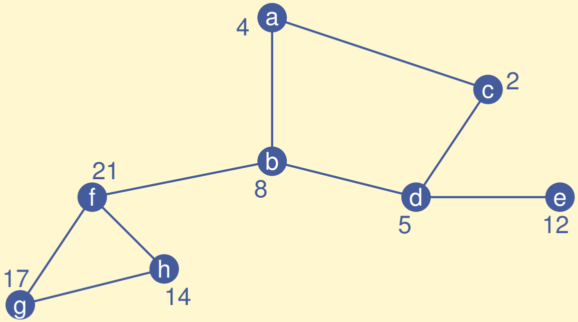
Proposed architecture

- Start on some *initiators*
  - Any vehicle
    Periodically, or on request (local/infrastructure)
  - Service vehicles
  - Road side unit
- Collect
  - Data in vehicles up to a given distance
  - Update of dynamic data
- Termination
  - Maximal duration
  - Stability of the result
- Result
  - Ordered by the distance to the initiator
  - Allow aggregation before exploitation

Data collect : distributed algorithm

Local view : definition

- Local view of a node :
  lists of (node_id, local_data) ordered by the distance to the node



Data collect : distributed algorithm

Local view : definition

- Local view of a node :
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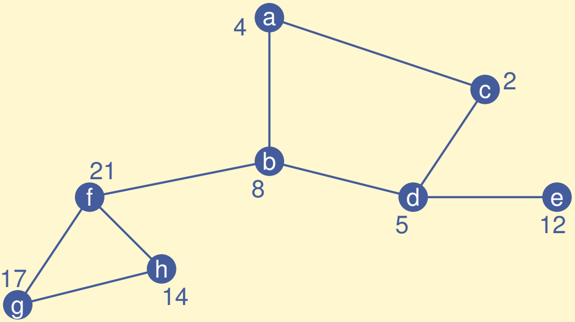
{(a,4)}



Data collect : distributed algorithm

Local view : definition

- Local view of a node :
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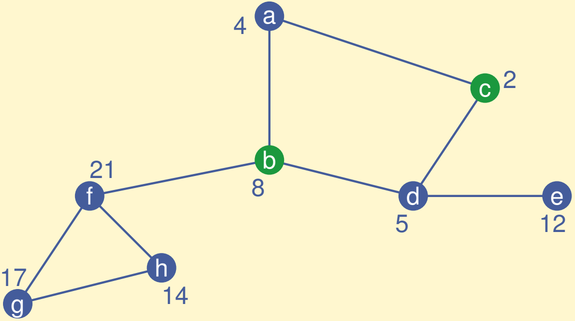
{(a,4)}, {(b,8), (c,2)}



Data collect : distributed algorithm

Local view : definition

- Local view of a node :
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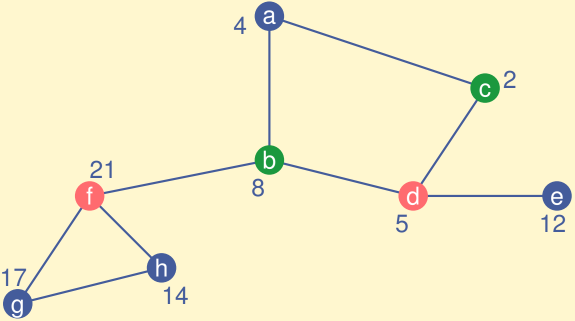

Data collect : distributed algorithm

Local view : definition

- Local view of a node :
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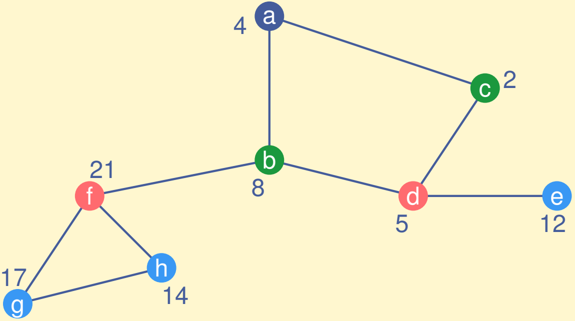


Data collect : distributed algorithm

Local view : operator ant

- Views $\mathcal{V}_1$ and $\mathcal{V}_2$:

$$\mathcal{V}_1 = \{(a,4)\},\{(b,8)\},\{(d,5),(f,21)\}$$
$$\mathcal{V}_2 = \{(c,2)\},\{(d,5)\},\{(b,8),(e,12)\}$$

- Shifting

$$\mathcal{V}_1 = \{(a,4)\},\{(b,8)\},\{(d,5),(f,21)\}$$
$$r(\mathcal{V}_2) = \{\}, \quad \{(c,2)\},\{(d,5)\}, \quad \{(b,8),(e,12)\}$$

- Merging

$$\mathcal{V}_1 \oplus r(\mathcal{V}_2) = \{(a,4)\},\{(b,8),(c,2)\},\{(d,5),(f,21)\},\{(b,8),(e,12)\}$$
$$\mathcal{V}_1 \oplus r(\mathcal{V}_2) = \{(a,4)\},\{(b,8),(c,2)\},\{(d,5),(f,21)\},\{(e,12)\}$$

- r-operator ant :

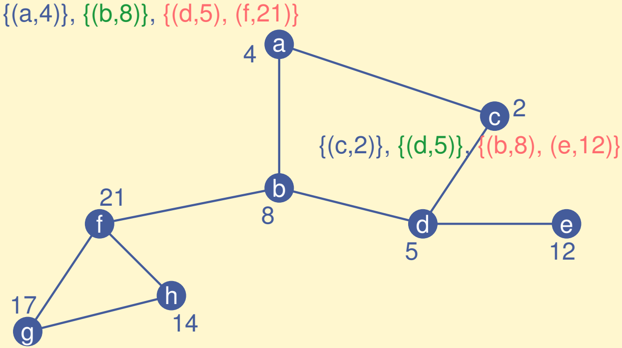
$$\text{ant}(\mathcal{V}_1,\mathcal{V}_2) = \mathcal{V}_1 \oplus r(\mathcal{V}_2)$$

$\leadsto$ self-stabilizing distributed algorithm

Data collect : distributed algorithm

Local view : example

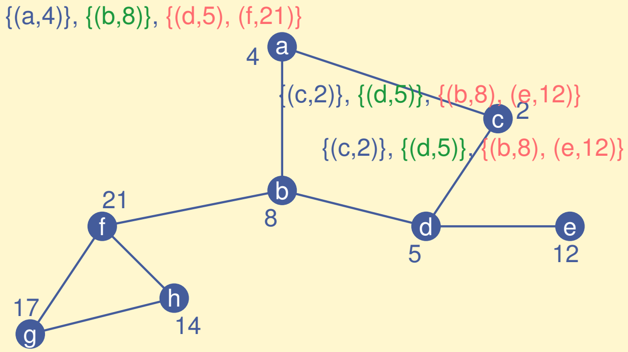
$$\mathcal{V}_1 \oplus r(\mathcal{V}_2) = \{(a,4)\},\{(b,8),(c,2)\},\{(d,5),(f,21)\},\{(e,12)\}$$



Data collect : distributed algorithm

Local view : example

$\mathcal{V}_1 \oplus r(\mathcal{V}_2) = \{(a,4)\},\{(b,8),(c,2)\},\{(d,5),(f,21)\},\{(e,12)\}$



Data collect : distributed algorithm

Local view : example

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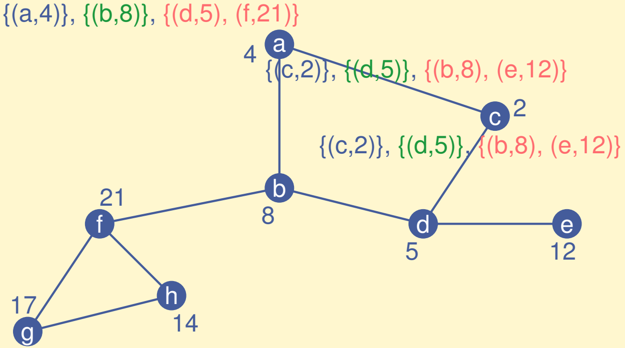

Data collect : distributed algorithm

Local view : example

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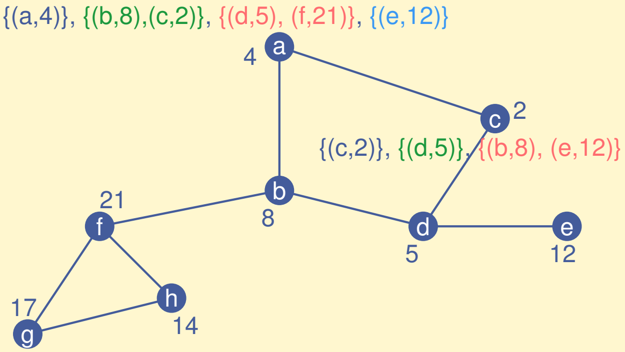


Data collect : distributed algorithm

Algorithm : receptions

Algorithm for message reception

receive(parameters, view **)**

if no current collect **then**

  Reset variables ; store the parameters

  Set the lifetime of the sender to `maxloss`

  Store the view of the sender

  Set the timer

else if message for current collect

  Set the lifetime of the sender to `maxloss`

  Store the view of the sender

else

  Drop the message

end if

Data collect : distributed algorithm

Algorithm : timer expiration

Algorithm for timer expiration

```
Decrement the lifetime of each known neighbor
Reset any data of neighbors with lifetime=0
Update local_view with local data
for each view previously stored do
    local_view ← ant(local_view, view)
end for
Truncate local_view to maxdst first elements
if local termination is false then
    set the timer
    send( parameters, local_view )
end if
```

Algorithm for Local termination detection

if initiator $\notin$ local_view **then return** true
count_dur $\leftarrow$ count_dur + 1
if count_dur == `maxdur` **then return** true
if old_local_view $\equiv$ local_view **then**
    count_stb $\leftarrow$ count_stb + 1
else
    count_stb $\leftarrow$ 0
end if
if count_stb == `maxstb` **then return** true
return false

Data collect : experiments

Using the Airplug Software Distribution

- Proof of concept on the road
  - 5 vehicles with Dell mini-9, WiFi devices and roof antenna
  - Ubuntu 8.04, Airplug, GPS and COL programs embedded
  - [see movie on-line http ://www.hds.utc.fr/airplug]
- Performance evaluation by emulations
  - 13 vehicles, series of 50 experiments
  - Variations of the timer duration, the links robustness and the life duration of a neighbor
- Demonstration

Data collect : experiments

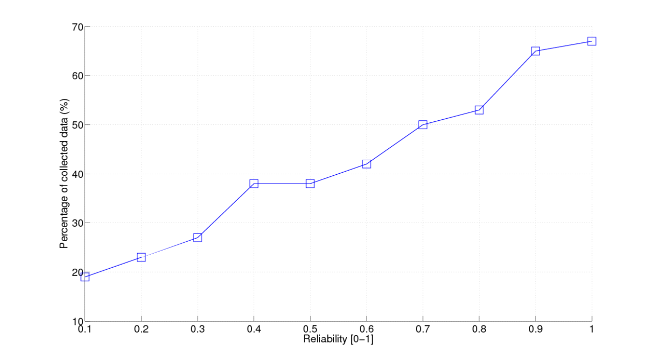
Road experiment replay

Click on the image for loading the video (in the web browser)

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

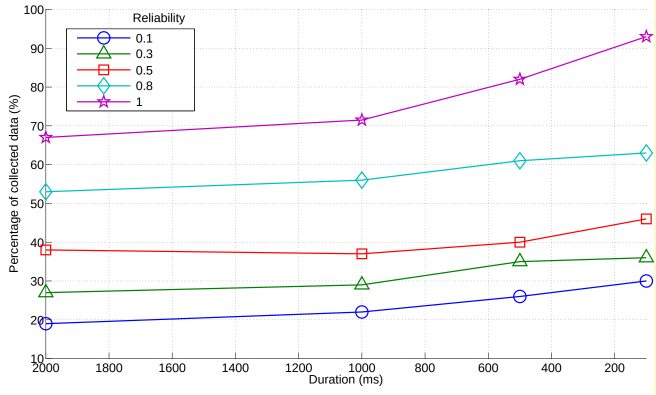
Data collect : experiments

Percentage of received data versus Link reliability



Data collect : experiments

Percentage of received data versus timer duration



Data collect : experiments

Results summary

- Qualitative result
  - Success of the proof of concept
  - Support the network dynamic
    Including network partitioning
- Quantitative results
  - $\nearrow$ link reliability $\Rightarrow$ % collected data $\nearrow$
  - Small influence of the timer duration
  - Auto-adaptation of `maxdst`
    Maximal distance
  - In highly dynamic network :
    - Increasing `maxloss` Neighbor lifetime
      To the detriment of up-to-date local view
    - Decreasing the timer duration
      To the detriment of bandwidth
  - Towards self-adaptation

Summary

Distributed data fusion

Introduction : data ?

- 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]

Distributed data fusion

Introduction : data representation

- 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

Distributed data fusion

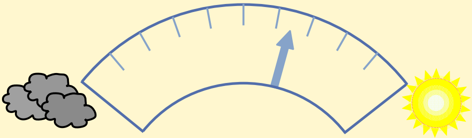
Introduction : fusion operators

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

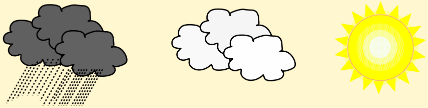
Distributed data fusion

Data fusion example : weather forecast (1)

- Pressure measurement



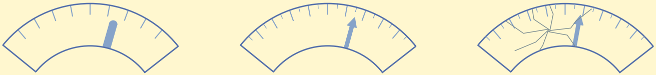
- Weather forecast
  - Compare current measure with the last one



Distributed data fusion

Data fusion example : weather forecast (2)

- Barometer ?

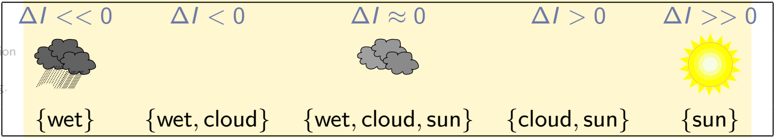


- Measure :
  - Pressure measurement : interval $I \subset \mathbb{R}^+$
  - Pressure gradient : interval $\Delta I \subset \mathbb{R}$
  - *Simple* mass function :
    - Only two subsets : ΔI and $\mathbb{R}$
    - $\mathbb{R}$: lack of knowledge
    - $m^{\mathbb{R}}(\Delta I) = 1 - \alpha$
    - $m^{\mathbb{R}}(\mathbb{R})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

Distributed data fusion

Data fusion example : weather forecast (3)

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

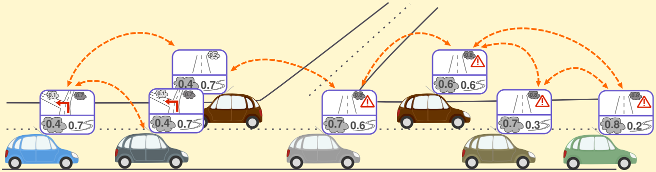


- Several independent measures can be combined using the Dempster rule.
- Decision : from mass to *pignistic* probability
  $P(A) = \sum_{\emptyset \neq B \subset \Omega} m(B) \frac{|A \cap B|}{|B|}$

Distributed data fusion

Motivation

- Problem to solve
  - Direct confidence (regularly) produced locally
    Using an external mean
  - Node's confidence computed using other values
- Avoiding data collection and centralized approach
- Locality
  - One result per node
  - Depend on the position of the node in the network



⤳ Distributed approach for data fusion

Distributed data fusion

Related work

- 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 ⇝ data incest
    - Idempotent combination rule
    - ⇝ Cautious operator [Denoeux 2008]
      Defined on weights functions
- Network always supposed to be reliable

Distributed data fusion

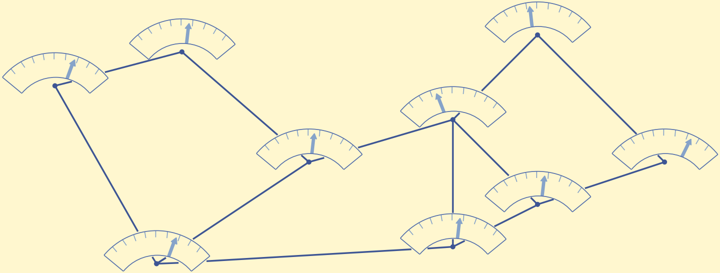
Contribution

- Problem to solve :
  - Direct confidence (regularly) produced locally
    Using an external mean
  - Node's confidence computed using other values
- Neighborhood confidence algorithm
  - Combine the direct confidences in the neighborhood
- Distributed confidence 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

Distributed data fusion

Neighborhood confidence algorithm : definition

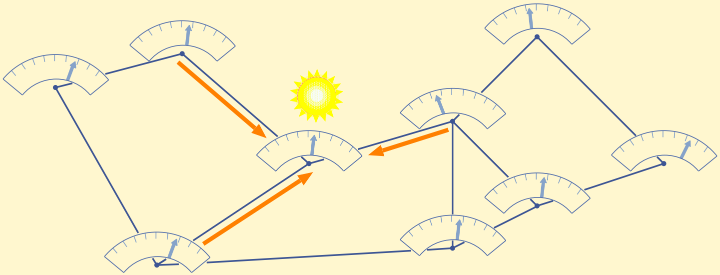
- Result on any node v depends on its neighbors only.



Distributed data fusion

Neighborhood confidence algorithm : definition

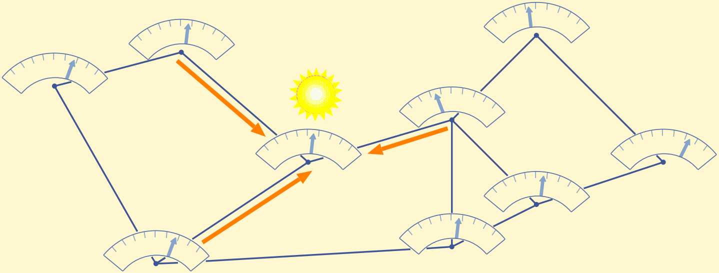
- Result on any node v depends on its neighbors only.

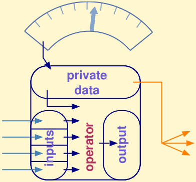


Distributed data fusion

Neighborhood confidence algorithm : definition

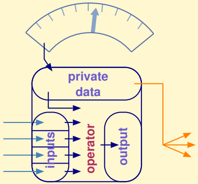
- Result on any node v depends on its neighbors only.





Distributed data fusion

Neighborhood confidence algorithm : algorithm



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**

  $\mathtt{OUT}_v \leftarrow \mathtt{OUT}_v \boxplus \mathtt{IN}_v[u]$

end for

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

Reset $\mathtt{IN}_v$

Restart the timer

Distributed data fusion

Neighborhood confidence algorithm : result

- Legitimate configuration
  - combination of the direct confidence with those of the neighbors
  - $\bigcirc\!\!\!\!\cap$: discretization of Dempster operator
    Commutative

$$\forall v \in \mathcal{S}, \quad \mathtt{OUT}_v(c) = \bigcirc\!\!\!\!\cap_{u \in \Gamma_v^{01}} \mathtt{PRIV}_u(c)$$

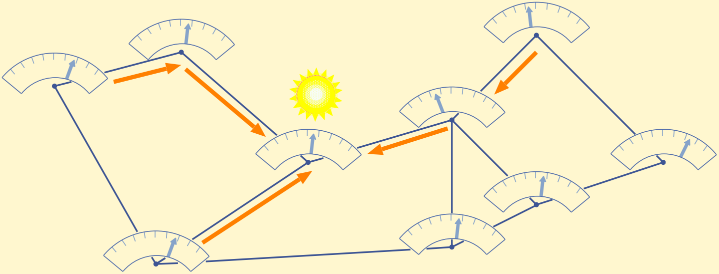
- Result

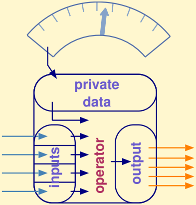
Convergence in finite time to a legitimate configuration after the last occurrence of a transient fault and the last modification of either the topology or the direct confidences (inputs).

Distributed data fusion

Definition

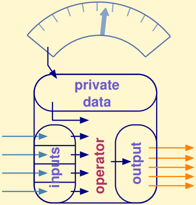
- Result on any node v now depends on all other nodes, not only its neighbors.





Distributed data fusion

Algorithm



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**

$\quad \mathtt{OUT}_v \leftarrow \mathtt{OUT}_v \oslash \mathtt{IN}_v[u]$

end for

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

Reset $\mathtt{IN}_v$

Restart the timer

Distributed data fusion

Result

- Legitimate configuration
  - combination of the direct confidence with those of all the nodes in the network
  - $\varowedge$: cautious operator defined on weights
    Associative, commutative, idempotent

$$\forall v \in \mathcal{S}, \quad \mathtt{OUT}_v(c) = \varowedge_{u \in \Gamma_v} \mathtt{PRIV}_u(c)$$

- Result

Stabilization in a fixed topology starting from an initial configuration where all memories have been reset, assuming the direct confidences (inputs) stabilizes.

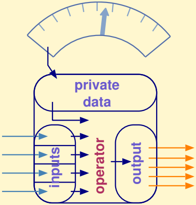
Distributed data fusion

Self-stabilizing algorithm : motivation

- The previous algorithm
  - Give one result per distributed component
  - Does not support erroneous messages
  - See demonstration
- What happens in large network ?
  - Convergence time ?
  - Interpretation of the result ?
- What hap-pends in case of erroneous message ?
  - Introduced accidentally
  - Introduced intentionally
  - Due to the dynamic

Distributed data fusion

Self-stabilizing algorithm : algorithm



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**

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

end for

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

Reset $\mathtt{IN}_v$

Restart the timer

Distributed data fusion

Self-stabilizing algorithm : discounting

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

- r is called a discounting
- It decreases the information in a given bba
  Basic belief assignment
- It is application-dependent

- Condition 1 : endomorphism
  $r(w_1 \circledwedge w_2) = r(w_1) \circledwedge r(w_2)$
- Condition 2 : expansion
  $w \prec_{\circledwedge} r(w)$

Distributed data fusion

Self-stabilizing algorithm : result (1/2)

- The cautious operator along with the discounting r defines an r-operator which ensures the self-stabilization of the algorithm.

[SSS 2005, SSS 2007]

- $\owedge$: cautious operator defined on weights
- r : discounting function
- $\lhd$: r-operator defined by $x \lhd y = x \owedge r(y)$

Distributed data fusion

Self-stabilizing algorithm : result (2/2)

- Legitimate configuration
  - combination of the direct confidence with those of all the nodes in the network, discounted as many time as their distance.
  - $\circledtriangleleft$: r-operator defined using $\circledwedge$ and r

$$\forall v \in \mathcal{S}, \quad \mathtt{OUT}_v(c) = \begin{array}{l} \circledtriangleleft_{u \in \Gamma_v} \mathtt{PRIV}_u(c) \\ \circledwedge_{u \in \Gamma_v} \mathbf{r}^{\mathrm{dist}(u,v)}(\mathtt{PRIV}_u(c)) \end{array}$$

- Result

Stabilizes in finite time to a legitimate configuration after the last occurrence of a transient fault and the last modification of either the topology or the direct confidences (inputs).

Distributed data fusion

Self-stabilizing algorithm : 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
  - Previous example : $k = 10$
- Message size
  - Depends on coarsening $\rightsquigarrow |\Omega|$
    Previous example : $|\Omega| = 3$
  - and the discretization
    Example : $(0, 1]$ discretized up to the thousandth
  - In the example : 60 bits per message

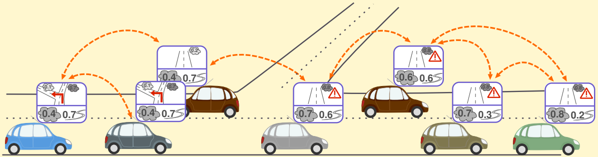
Distributed data fusion

Experiments : testbed

- Testbed
  - 3 RSU, 6 sensors + vehicles

[WiSARN 2014]

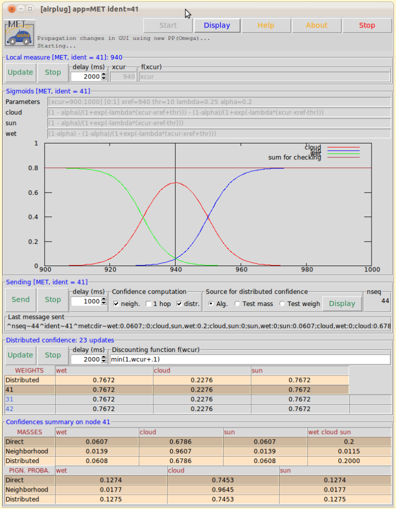
- Proof of concept



Distributed data fusion

Experiments : demonstration

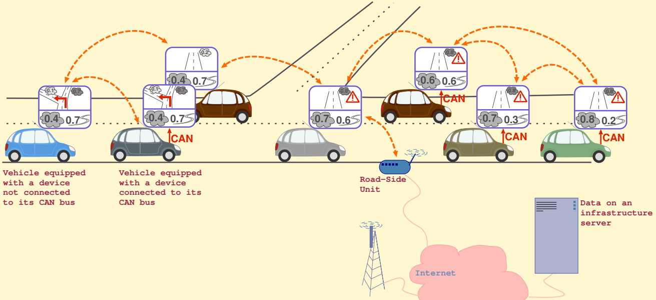
[on-line demonstration using Airplug-emu]



Summary

Data in dynamic networks

- How to exploit data in dynamic networks ?
  - Distributed data collect
    Self-stabilizing algorithm
  - Distributed data fusion
    Self-stabilizing algorithm
- Next steps
  - Modeling
  - Proofs of usability in dynamic networks
  - Adaptivity
  - Large testbed



Summary

Jobs positions

- Open postdoc position
  - Distributed algorithms and protocols
  - One year
- Open engineer position
  - Development and experiments
  - European project
  - Two years
- Heudiasyc Lab. UMR CNRS UTC 7253
  Equipex Robotex
  Labex MS2T
  https ://www.hds.utc.fr