Best-effort Group Service in Dynamic Networks

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Plan

Best-effort Group Service

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Dynamic networks howto

Basic definitions

- Network
  - computing nodes
  - communication links
  - topology $\rightsquigarrow$ graph $G(V, E)$
- Ad hoc network
  - uniformity of the nodes :
    all equivalent, all routers
- Wireless network
  - mutual exclusion in the neighborhood :
    a message sent by a neighbor is received only if no other neighbor is sending
  - message passing or register model
- Wireless ad hoc networks

Dynamic networks howto

Definition

- Dynamic network : the topology is not fixed
  ⇝ sequence of graphs
  $G_0(V_0, E_0), G_1(V_1, E_1), G_2(V_2, E_2), G_3(V_3, E_3)\ldots$

1. Dynamic links $V_i = V_0, i \in \mathbb{N}$
   - adding links
   - deleting links temporarily or definitively
2. Dynamic nodes
   - adding nodes
   - deleting nodes temporary or definitively
   - ⇝ adds and deletes links
3. Moving nodes
   - $\neq$ deleting node + adding node elsewhere
     memory of the node
   - ⇝ adds and deletes links temporarily
4. Dynamic and moving nodes...

Dynamic networks howto

Metric of the dynamic

- Percentage of nodes or links affected
- Mean percentage of a neighborhood affected
- Frequency of changes Unit of time ?
- Frequency of changes vs. efficiency of the com.
  Nodes could move very fast without impact on the algorithm if the communication protocol is efficient.
- Algorithmic metric
  - δ-dynamic system : any node that experiments a neighborhood change is able to send a message to all its neighbors until δ hops before the next topology change
  - 1-dynamic system : a minimal requirement for allowing local exchange in a dynamic network

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Dynamic networks howto

Examples of dynamic networks

- Large networks are generally dynamic
- Social networks
- Peer-to-peer networks
- Network of laptops
  IEEE working group MANET : Mobile Ad hoc NETworks
- Network of pedestrian with personnal devices
- Network of embedded computers
  - Robots networks
  - Vehicular networks

Dynamic networks howto

Building applications : virtual structures

- Backbones, spanning trees, clusters...
  - using such structures as in non-dynamic networks
  - updating the structures when the topology changes
- But :
  - require control messages to be updated
  - when the dynamic increases, too much control messages are required
  - diverge
- Thus :
  - useful only when the dynamic is low

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Dynamic networks howto

Building applications : redundancy

- Important data are replicated
  - critical system
  - A node's disappearance is then supported
- But :
  - replicated data should be coherent
  - pessimistic replication requires consensus
    - consensus is unsolvable in unreliable asynchronous networks [FLP85]
    - alternative : failure detectors [CT96]
  - optimistic replication will eventually converge
    - working with non up-to-date data
- Thus :
  - strong conditions on the network
  - or weak conditions on the replicas

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Dynamic networks howto

Building applications : self-stabilization

- Self-stabilizing algorithms :
  - recover after a transient fault
    affecting a memory, a message
  - neighborhood change
    $\rightsquigarrow$ some memories are not up-to-date
  - topology change $\leftrightarrow$ transient fault
- But :
  - duration of the convergence phase vs. dynamic
  - the system doesn't know whether the stabilized phase is reached or not
- Thus :
  - useful only when the dynamic is low
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Best-effort algorithms

Principle

- The dynamic affects the algorithms
  When the dynamic increases, it becomes illusory to expect that an application continuously ensures the service for which it has been designed.
  - impossibility results ?
  - weak specifications ?
  - conditions on the dynamic
- What we can only expect from the distributed algorithms is to behave as "the best" as possible, the result depending on the dynamic.
- A best effort algorithm fulfills its specifications if the dynamic of the network allows it, and fulfills them few time after the network allows it, otherwise.

Best-effort algorithms

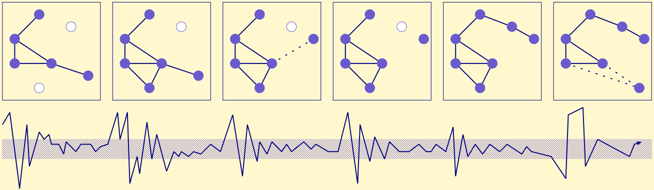
Using self-stabilization ?

- Self-stabilization can help face to the dynamic

  Neighborhood change

  ⇝ some memories do not reflect the neighborhood

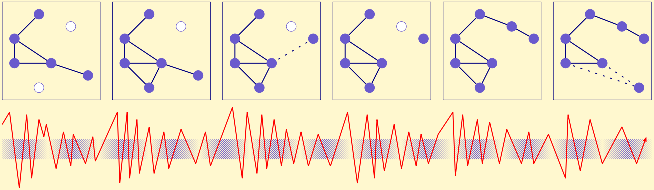
  ⇝ similar to a transient failure



Best-effort algorithms

Using self-stabilization ?

- Self-stabilization can help face to the dynamic
  Neighborhood change
  ⇝ some memories do not reflect the neighborhood
  ⇝ similar to a transient failure
- However, it is implicitly assumed that the convergence time is smaller than the delay between two topology changes
- General case : self-stabilization property must be completed



Best-effort algorithms

Definition

- Continuity predicate Π_C on successive config. : False if the "quality of successive outputs" decreases
  depends on the problem
- Topological predicate Π_T on successive config. : False if the topological change is "important"
  depends on the problem
- Best-effort requirement : $\Pi_T \Rightarrow \Pi_C$
  While the system is converging to a correct behavior, the result is better and better, as long as the dynamic allows it.

Best-effort algorithms

Related work

- How to complete self-stabilization ?
  - Fault-containing network protocols
    Gosh, Gupta, Pemmaraju, SAC '97
  - Stabilizing time adaptive protocols
    Kutten, Patt-Shamir. Theor. Comp. Sci. 1999
  - Superstabilizing protocols for dynamic distributed systems Dolev, Herman. PODC 1995
- Superstabilization
  - self-stabilization + passage predicate
  - after a legitimate state is reached, if a single topology change occurs, the predicate passage holds until a new legitimate state is reached
  - but :
    - what before stabilization ?
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Best-effort algorithms

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Groups service

Requirements : groups in vehicular networks

- Intelligent Transport Systems
  - infrastructure oriented applications
  - vehicle oriented applications
  - driver oriented applications
  - passenger oriented applications
- Some services are based on collaboration
  - driving, diagnostic, perception, infotainment...
  - collaboration $\rightsquigarrow$ group
- Vehicular networks : a kind of dynamic networks

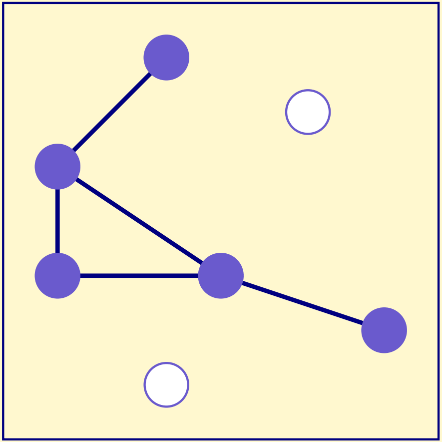
Groups service

Requirements : constraints on the groups

- Maintaining the running service
  - the aim is not to optimize the partition of the vehicles into groups
  - it is much more important to not split existing groups
  - ⇝ keeping the existing groups as long as possible
- Diameter constraint
  - delay vs. number of hops
  - no collaboration with far vehicles
    either useless (driving, diagnostic, perception...)
    or inefficient (chat, games...)
  - ⇝ bound on the diameter depending on the applications

Groups service for inter-vehicles applications

Example



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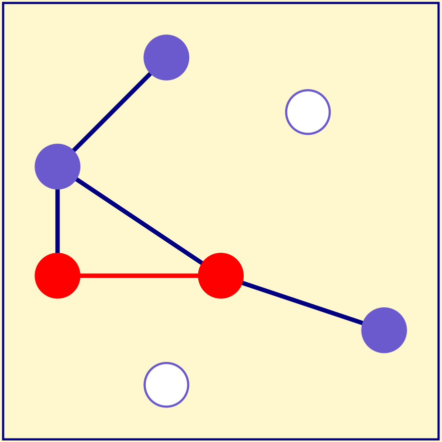

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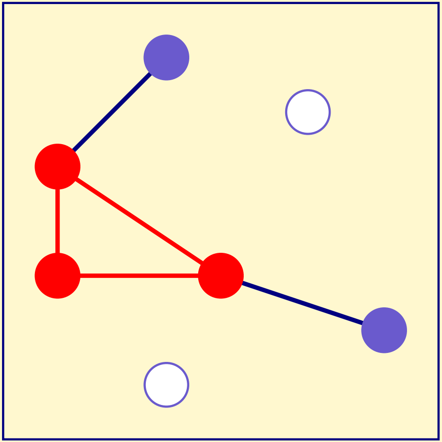

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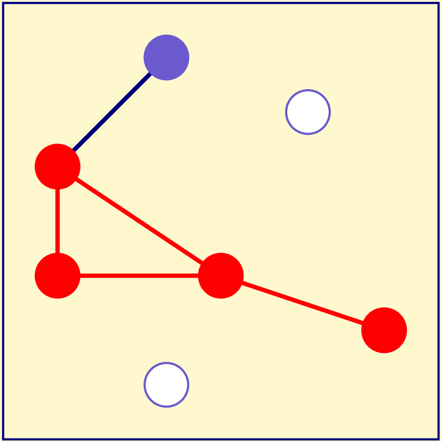

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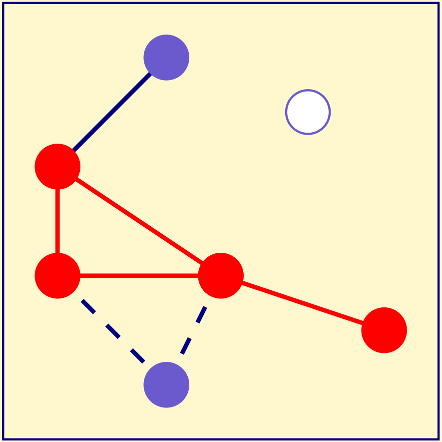

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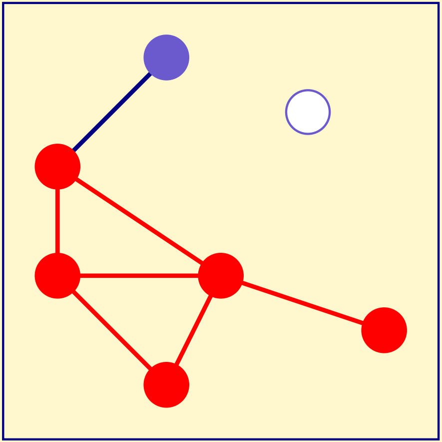

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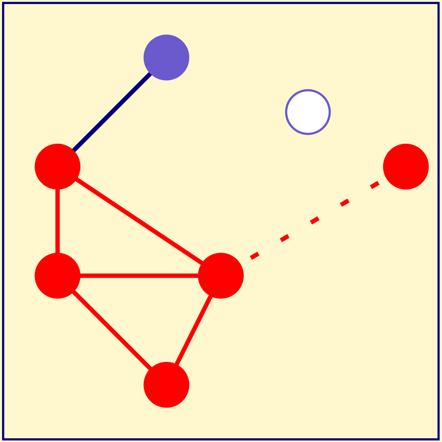

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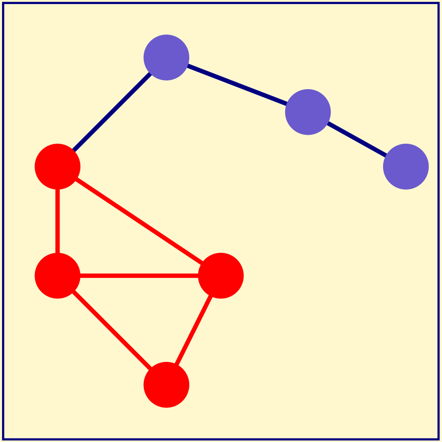

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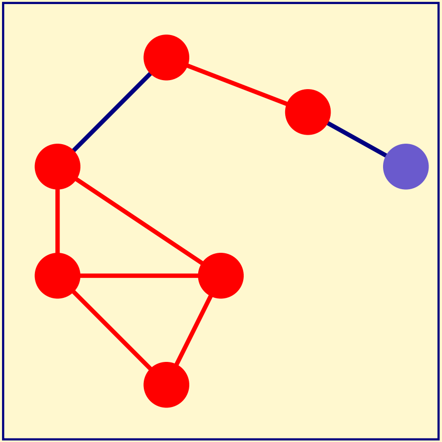

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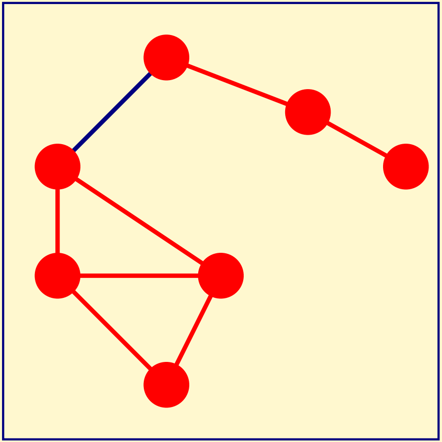

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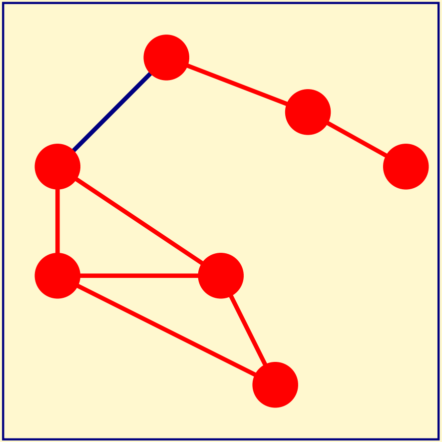

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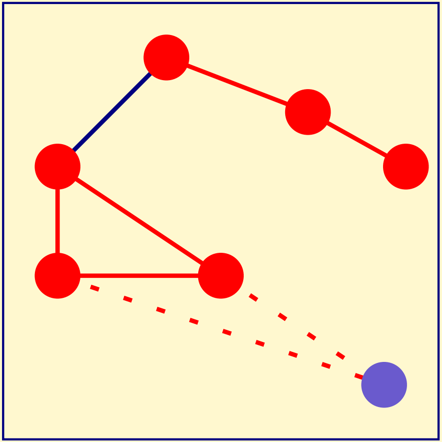

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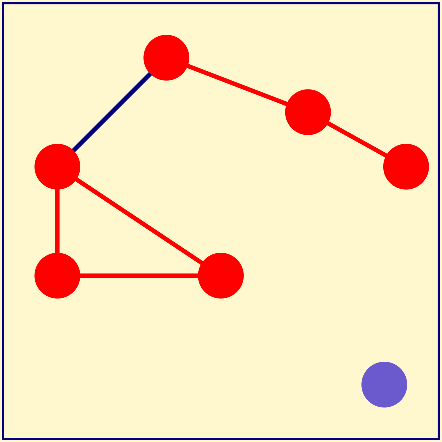

Groups service for inter-vehicles applications

Specifications

- Groups : disjoint subgraphs of $G(V, E)$
  - subgraphs $H_i(V_i, E_i)$ with $V_i \cap V_j = \emptyset$
    $V_i \subset V$ and $\forall (u, v) \in E, (u, v \in V_i) \Rightarrow (u, v) \in E_i$
  - view$_v^c$: knowledge of v about its own group
    at configuration c
- Agreement $\Pi_A(c)$: views define groups
  $(u \in V_i$ and $v \in V_i) \Leftrightarrow view_u^c = view_v^c = V_i$
  $\Omega_v^c = view_v^c$ if $\Pi_A(c)$ holds, $\emptyset$ else
- Safety $\Pi_S(c)$: groups are well formed
  connected and bounded diameter ($d_{\Omega_v^c}$: distance in Ω_v^c)
  $\forall v \in V, \max_{x,y \in \Omega_v^c} d_{\Omega_v^c}(x, y) \leq \mathtt{Dmax}$
- Maximality $\Pi_M(c)$: groups cannot merge more
  $\forall u, v \in V$ with $\Omega_u^c \neq \Omega_v^c$
  $\exists x, y \in \Omega_u^c \cup \Omega_v^c$ such that $d_{\Omega_u^c \cup \Omega_v^c}(x, y) > \mathtt{Dmax}$

Groups service for inter-vehicles applications

Best-effort specification

- Topological predicate $\Pi_T(c_i, c_{i+1})$:
  The distance between members of a group will remain smaller than Dmax
  $\forall v \in V, \max_{x,y \in \Omega_v^{c_i}} d_{\Omega_v^{c_i}}^{c_{i+1}}(x, y) \leq \texttt{Dmax}$
- Continuity property $\Pi_C(c_i, c_{i+1})$:
  No node disappears from a group
  $\forall v \in V, \Omega_v^{c_i} \subseteq \Omega_v^{c_{i+1}}$
- Best-effort specification :
  $\Pi_T(c_i, c_{i+1}) \Rightarrow \Pi_C(c_i, c_{i+1})$
  As long as the diameter of a group remains smaller than Dmax, the algorithm should ensure that no node will disappear
  $\leadsto$ An application can work with the current knowledge of the group (view) even if the convergence did not happend

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Groups service for inter-vehicles applications

Summary

- Self-stabilizing algorithm for $\Pi_A \wedge \Pi_S \wedge \Pi_M$
  - $\mathcal{C}$: set of all the configurations
  - $\mathcal{L} \subset \mathcal{C}$: set of configurations c satisfying $\Pi_A(c) \wedge \Pi_S(c) \wedge \Pi_M(c)$
  - prove, on a fixed topology, that
    - $\mathcal{L}$ is an attractor for $\mathcal{C}$
    - $\mathcal{L}$ is close
- Best-effort requirement
  - assuming a dynamic network
    sequence of graphs
  - considering two consecutive configurations c_i, c_{i+1} in any execution, prove that $\Pi_T(c_i, c_{i+1}) \Rightarrow \Pi_C(c_i, c_{i+1})$

Sommaire

Algorithm

Overview : diffusion of lists

- Candidates for a group : neighbors up to Dmax
- Lists of close nodes :
  - diffusion at timer expiration
  - merging of the received lists
  - lists of nodes ordered by the distance : $(\{d\},\{b\},\{a,c\})$
  - lists truncated to Dmax
- Lists filtering :
  - only symmetric links
    Three-way handshake by marking nodes : $\underline{v}$
  - malformed lists ignored
  - arrival list accepted only if the diameter remains smaller than Dmax after the merge
  - if merging is impossible, the neighbor is double-marked ($\underline{\underline{v}}$)

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Algorithm

Overview : merging lists

- $\mathbb{S}$: set of lists of nodes' sets
  $(\{d\},\{b\},\{a,c\}) \in \mathbb{S}$
- Operator $\oplus$ on $\mathbb{S}$ that merges two lists while deleting useless members :
  $(\{d\},\{b\},\{a,c\}) \oplus (\{c\},\{a,e\},\{b\}) =$
  $(\{d,c\},\{b,a,e\},\{a,c,b\}) = (\{d,c\},\{b,a,e\})$
- Endomorphism r of $\mathbb{S}$, that inserts an empty set at the beginning of a list
  $r(\{d\},\{b\},\{a,c\}) = (\emptyset,\{d\},\{b\},\{a,c\})$
- $l_1 \triangleleft l_2 = l_1 \oplus r(l_2)$, $l_1, l_2 \in \mathbb{S}$
  strictly idempotent r-operator

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self-stabilizing system	registers communications		message passing communications
	composite atomicity	read-write atomicity	read-write atomicity
strictly idempotent r-semi-group	partially ordered	totally ordered	totally ordered

[SSS'07, JACIC'06, TCS03, DC01]

Algorithm

Overview : priorities

- Conflict :
  - deciding between far nodes in a too large list
- Node priority :
  - oldness of the node in its group
  - local logical clock increased until the node belongs to a group
- Quarantine :
  - waiting for `Dmax` timers before entering into the view
  - allowing to broadcast its identity in the whole group, and then resolve conflicts (using priorities)

Algorithm

Sketch of proof - self-stabilization

1. lists bounded
2. lists contain only existing nodes
3. propagation until double-marked edges
4. if $d(u,v) >$ Dmax, each path from u to v contains a double-marked edge
5. if $d(u,v) >$ Dmax, u, v not in the same subgraph
6. Agreement : convergence to similar views inside each subgraph $\leadsto$ groups
7. Safety : group'diameters smaller than Dmax
8. The number of external edges does not increase
9. The number of external edges decrease
10. Maximality : if new merge, safety is false
11. Best-effort : a node leaves a group only if the safety becomes false

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8. The number of external edges does not increase
9. The number of external edges decrease
10. Maximality : if new merge, safety is false
11. Best-effort : a node leaves a group only if the safety becomes false

Algorithm

Sketch of proof - self-stabilization

1. lists bounded
2. lists contain only existing nodes
3. propagation until double-marked edges
4. if $d(u, v) > \texttt{Dmax}$, each path from u to v contains a double-marked edge
5. if $d(u, v) > \texttt{Dmax}$, u, v not in the same subgraph
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Sommaire

Conclusion

- Dynamic ad hoc network :
  - a next step in distributed computing ?
  - How to build distributed applications ?
- Best-effort approach :
  - algorithms do their best
  - the result depends on the dynamic
- Best-effort algorithm :

  self-stabilizing + continuity in the outputs depending on the dynamic
- Application : group service in vehicular networks

  Code and videos :

  http ://www.hds.utc.fr/∼ducourth/airplug