An Application-Level Network Mapper

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IPDPS 2005

Outline

Introduction (1/2)

Motivation

- Modern platforms (Grid, P2P systems) heterogeneous and dynamic.
- Distributed applications have to be reactive and network-aware.

- Quantitative information (bandwidth) well studied [NWS, RPS, ganglia].
- Qualitative information (topology) seldom known, but needed for:
  - Host siting and automatic configuration
  - Group communication

Definitions of topology

Almost as many as layers in the OSI model.

- Physical interconnexion map (wires in the walls)
- Routing infrastructure (path of network packets, from router to switch)
- Application level (focus on effects – bandwidth, latency – not causes)

Introduction (2/2)

Our context is at application level

Grid or P2P systems = multi-organization platforms.

- System heterogeneity ⇒ cannot rely on specific system feature
- Trust issue ⇒ no privileges for grid administrators ("root" or other)

Our Goal is...

Discover What Applications can Expect from the Platform

Given 4 hosts (a, b, c, d), determine whether $a \longrightarrow b$ impact $c \longrightarrow d$ (perfs).

Intuition: if they share a link, they share the bandwidth.

Our goal is not...

- Discover network bottleneck and configuration issues
- Discover packet paths

Topology discovery methodologies

State of the art

Method	Restriction	Focus	Routers	Notes
SNMP	authorized	path	all	passive, LAN
traceroute	ICMP	path	all	level 3 of OSI
pathchar	root	path	all	link bandwidth, slow
Other tomography	no	path	$d_{in} \neq d_{out}$	tree bipartite [Rabbat03]
ENV	no	interference	some	tree only
ALNeM	no	interference	?	complete graph

Outline

Model used

Definition: routed graph $G = (V, E, r)$

Non-oriented graph with *routing function* $(r : V \times V \to V)$.

$\left(u \underset{G}{\longrightarrow} v\right)$ is the path (set of vertices encountered in the graph G).

Definition: (ab) interfere with (cd) in G

$$(ab) \between_G (cd) \iff \left(a \underset{G}{\longrightarrow} b\right) \cap \left(c \underset{G}{\longrightarrow} d\right) \neq \emptyset$$

Symmetric relation: $(ab) \between_G (cd) \Leftrightarrow (cd) \between_G (ab)$

Routing not symmetric: $(ab) \between_G (cd) \not\Leftrightarrow (ab) \between_G (dc)$

Definition: (ab) does not interfere with (cd) in G

$$(ab) /\!/_G (cd) \iff \neg\Big((ab) \between_G (cd)\Big)$$

Measurement methodology

Notation

$bw(ab)$: bandwidth on $a \longrightarrow b$.

$bw_{/\!/ cd}(ab)$: bandwidth on $a \longrightarrow b$ when $c \longrightarrow d$ is saturated.

Definition of the **measured interference**

$(ab) \asymp_{mes} (cd) \iff \frac{bw_{/\!/ cd}(ab)}{bw(ab)} < 0.7$; $(ab) /\!/_{mes} (cd)$ if ratio > 0.9

Not symmetric: $a \xleftrightarrow{\text{10 Mo/s}} c \xleftrightarrow{\text{100 Mo/s}} b \xleftrightarrow{\text{100 Mo/s}} d$ $(ab) \asymp_{mes} (cd)$ and $(cd) /\!/_{mes} (ab)$.

Definition of the **"real" interference** (to reintroduce symmetry)

$$(ab) \asymp_{rl} (cd) \iff \begin{cases} (ab) \asymp_{mes} (cd) \\ (cd) \asymp_{mes} (ab) \end{cases} (or) \iff \neg (ab) /\!/_{rl} (cd)$$

Problem statement

Notations

$\mathcal{H}$: set of nodes

Interference matrix $I(\mathcal{H}, \between_{rl})$:

$$I(\mathcal{H}, \between_{rl})_{(a,b,c,d)} = \begin{cases} 1 & \text{if } (ab) \between_{rl} (cd) \\ 0 & \text{else} \end{cases}$$

Definition

InterferenceGraph: Given $\mathcal{H}$ and $I(\mathcal{H}, \between_{\tilde{G}})$, find a routed graph $G = (V, E, r)$ such that:

$$\begin{cases} \mathcal{H} \subset V \,; \\ I(\mathcal{H}, \between_{\tilde{G}}) = I(\mathcal{H}, \between_{G}) \,; \\ |V| \text{ is minimal.} \end{cases}$$

Outline

Mathematical tools: Total interference and separators

Definition of the **total interference**

$$a \perp b \Longleftrightarrow \forall (u,v) \in \mathcal{H},\ (au) \between_{rl} (bv)$$

Lemma (Separation)

$a \perp b \Longleftrightarrow \exists \rho \in \widetilde{V} \ \Big/\ \forall z \in \mathcal{H} : \rho \in (a \to z) \cap (b \to z)\,.$

Such a ρ is said to be a separator of a and b.

Theorem: $\perp$ **is an equivalence relation** **(under some assumptions)**

Moreover, $\forall$ equivalence class, $\exists$ common separator for all pair of elements.

Theorem (Representativity)

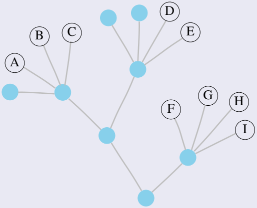
Let $\mathcal{C}$ be an equivalence class for $\perp$ and ρ a separator of its elements.

$$\forall a \in \mathcal{C},\ \forall b,u,v \in \mathcal{H},\ (a,u) \between_{rl} (b,v) \Leftrightarrow (\rho,u) \between_{rl} (b,v)$$

Reconstructing algorithm

Handling trees and cliques of trees

Equivalence class ⇒ greedy algorithm *eating* the leaves.



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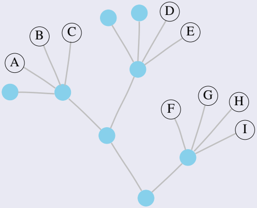

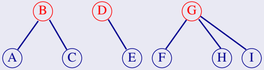

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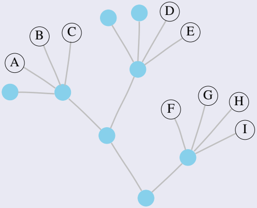

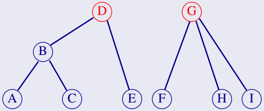

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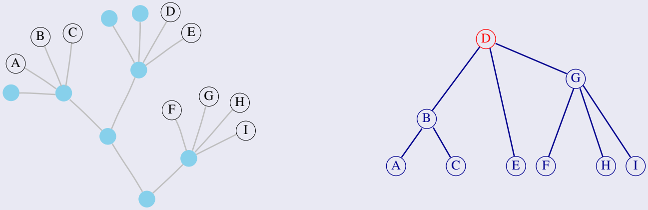

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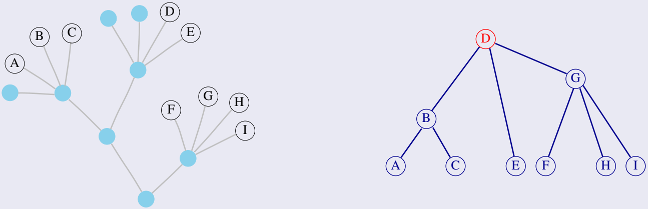

Theorem: When $|C_{\text{inf}}| = 1$, the graph built is a solution.
Theorem: If a tree being a solution exists, $|C_{\text{inf}}| = 1$.
Remark: The graph built is optimal (wrt $|V|$ since $V = \mathcal{H}$)

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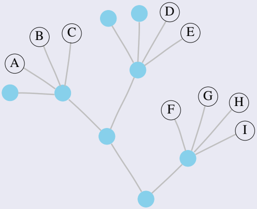

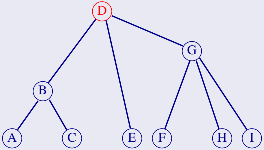

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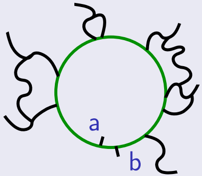
Theorem: If a tree being a solution exists, $|C_{\text{inf}}| = 1$.
Remark: The graph built is optimal (wrt $|V|$ since $V = \mathcal{H}$)

Theorem: When no interferences in I, clique of C_i is valid solution
Remark: It is also optimal

Reconstructing algorithm: Extension for cycles

Idea

- Find a and b close to each other on a cycle;
- cut the cycle in between;
- iterate previous algorithm;
- reintroduce the cycle: reconnect (a, b).



Finding out how to cut

a, b: nodes with the most interferences (*i.e.*, maximizing $\{u, v : au \between bv\}$)

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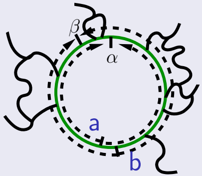

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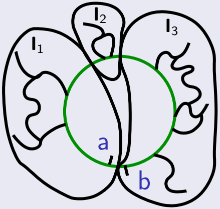

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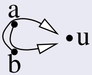
a, b: nodes with the most interferences (*i.e.*, maximizing $\{u, v : au \between bv\}$)

$$\begin{cases} I_1 = \{u \in \mathcal{C}_i : a \in (b \rightarrow u) \text{ and } b \notin (a \rightarrow u)\} \\ I_2 = \{u \in \mathcal{C}_i : a \notin (b \rightarrow u) \text{ and } b \in (a \rightarrow u)\} \\ I_3 = \{u \in \mathcal{C}_i : a \notin (b \rightarrow u) \text{ and } b \notin (a \rightarrow u)\} \\ I_4 = \{u \in \mathcal{C}_i : a \in (b \rightarrow u) \text{ and } b \in (a \rightarrow u)\} \end{cases}$$

$I_4 = \{a; b\}$ or 

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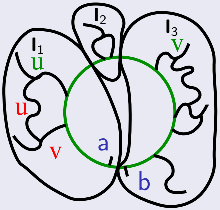

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v \ u	a … α	α … β	β … b	
a … α	1	1	1	} I_1
α … β	0	0\1	1	} I_2
β … b	0	0	1	} I_3

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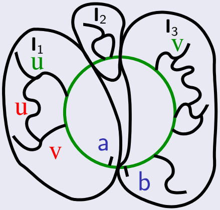

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v \ u	a–α	α–β	β–b	
a–α	1	1	1	} I_1
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β–b	0	0	1	} I_3

Topological sort on the graph associated to the matrix slice gives I_1, I_2, I_3

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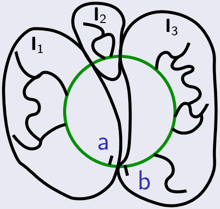

Finding out how to cut

. . .

How to connect parts afterward

Reconstructing algorithm: Extension for cycles

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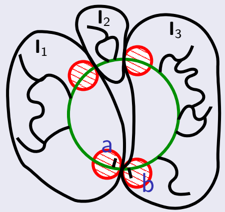

Finding out how to cut

...

How to connect parts afterward

First step on $I_1 \longrightarrow$ Finds 2 classes I_{1_a} and I_{1_α}; $a \in I_{1_a}$.
First step on $I_3 \longrightarrow$ Finds 2 classes I_{1_b} and I_{1_β}; $b \in I_{1_b}$.

Reconstructing algorithm: Extension for cycles

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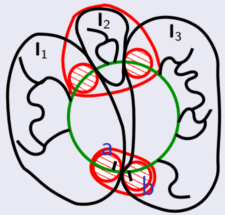

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Reconnect I_{1_a} and I_{1_b} ; Reconnect I_{1_α} and I_{1_β}.

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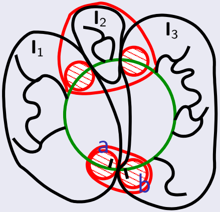

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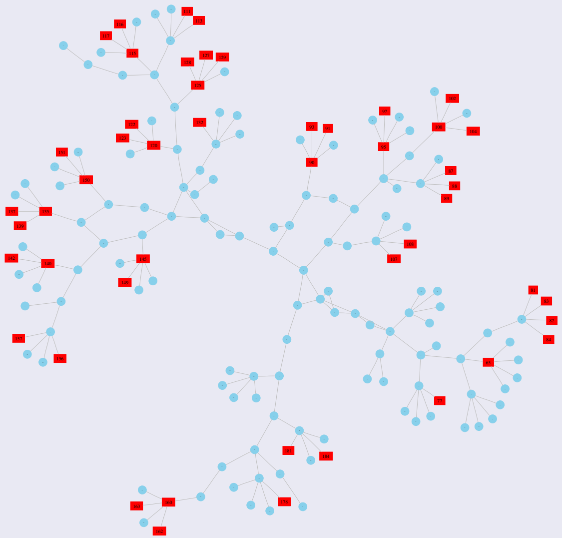
Reconnect I_{1_a} and I_{1_b} ; Reconnect I_{1_α} and I_{1_β}.

No demonstration of this...

Example of reconstruction



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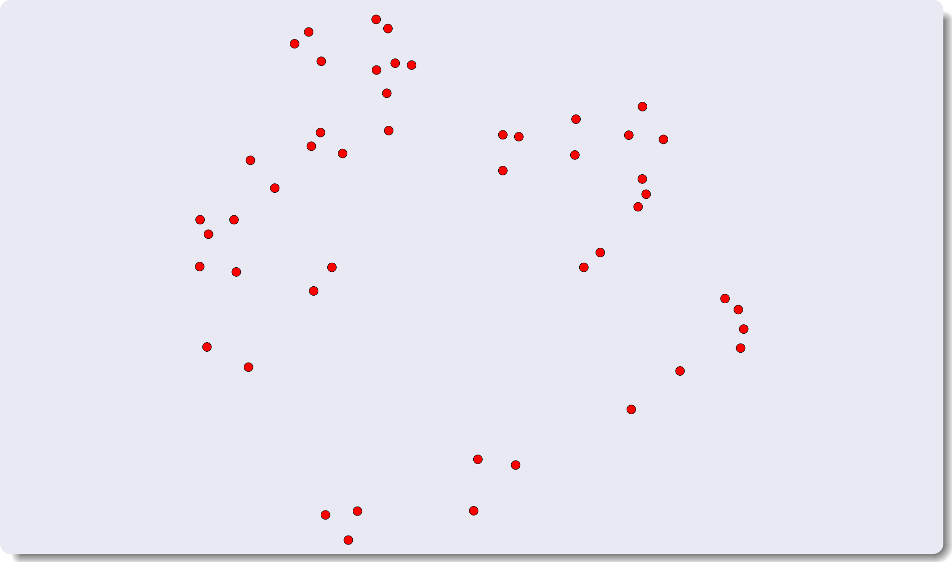

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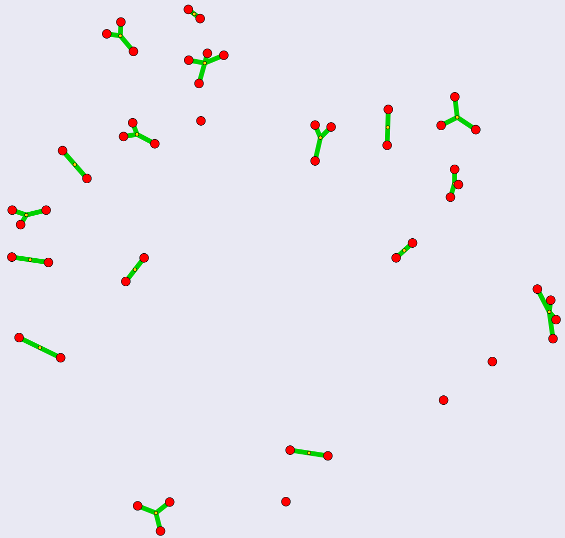

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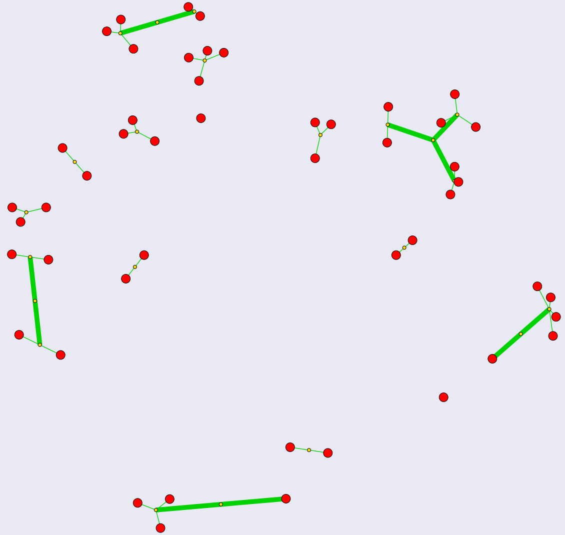

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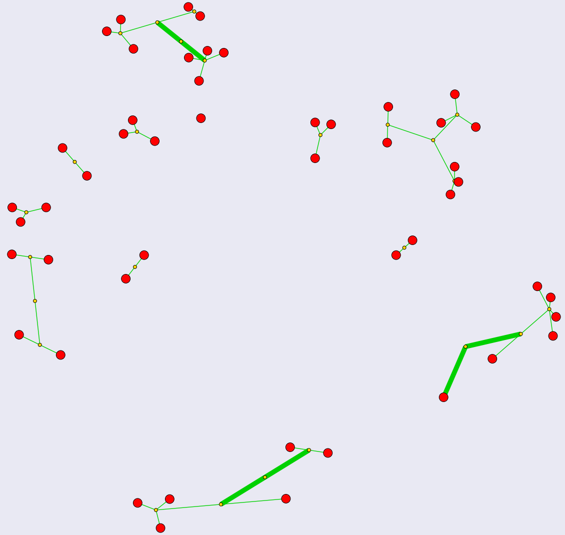

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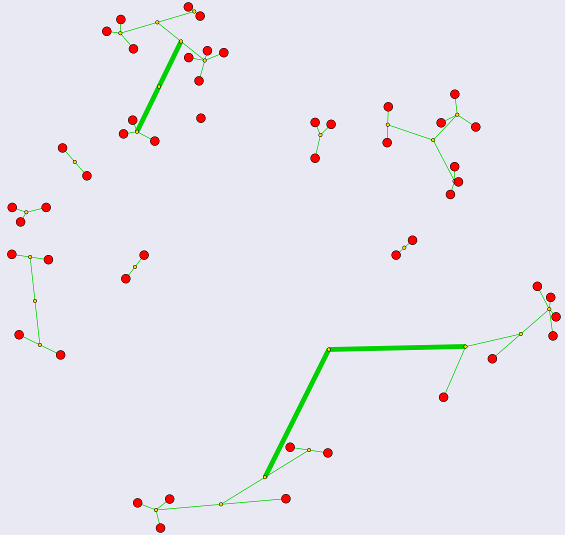

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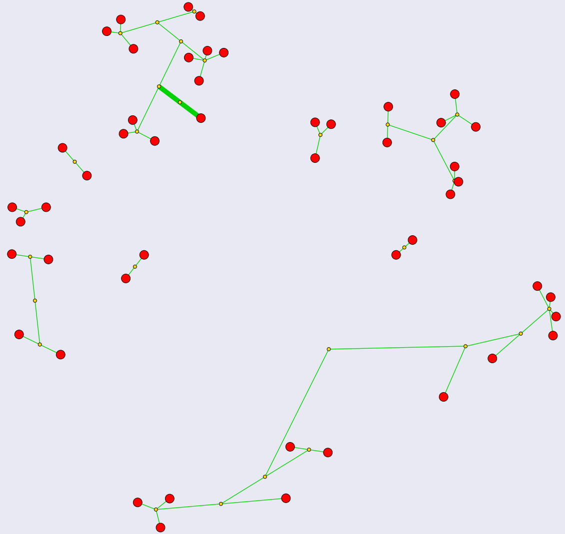

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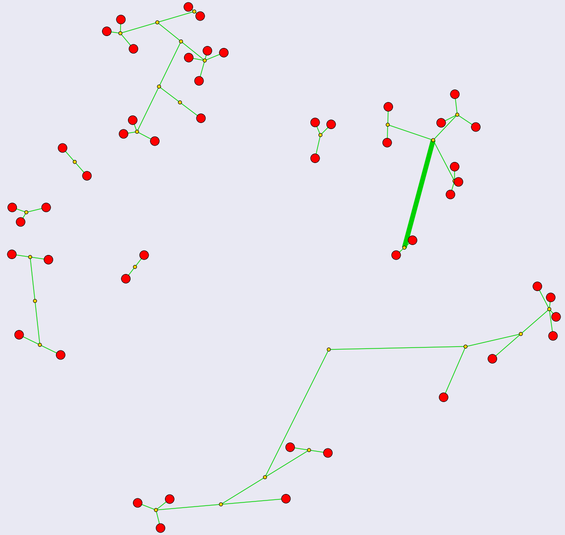

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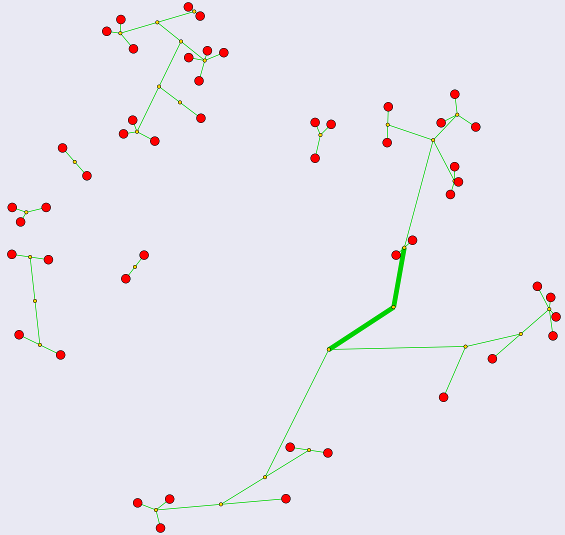

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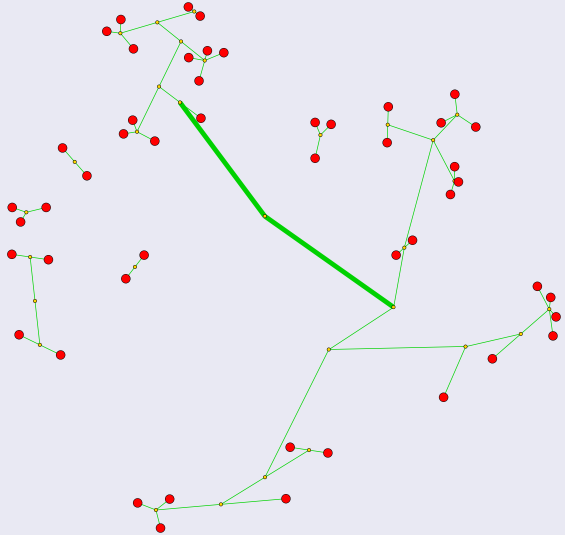

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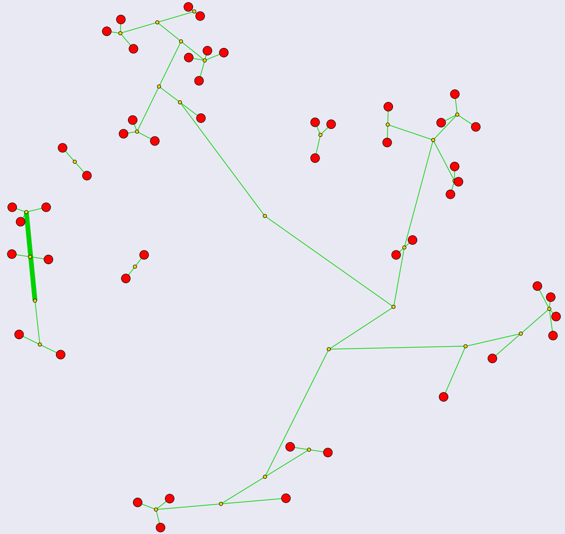

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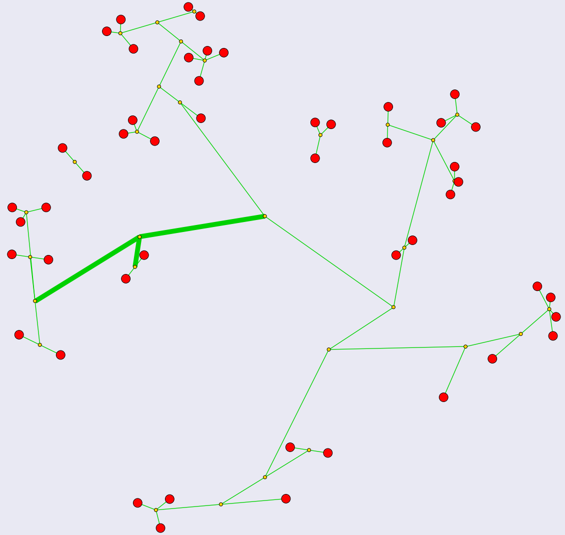

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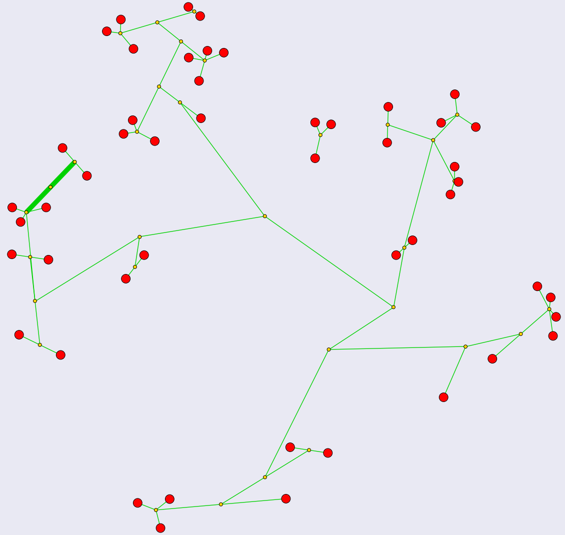

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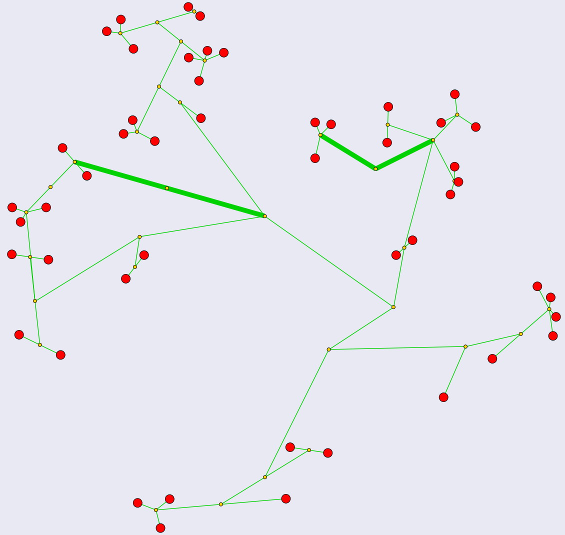

Outline

Data collection

Intuitive algorithm

1. Measure the bandwidth on (ab) ;
2. Measure the bandwidth on (ab) when the link (cd) is saturated ;
3. Compute the ratio.

N^4, 30s. per step $\Rightarrow$ 50 days for 20 hosts.

Speeding things up

Using traceroute or other tomography

- Independent tests in parallel
- Validation of information sets

Refinement of existing graph?

Outline

Conclusion

Contributions

- Retrieve the interference-based topology from direct measurements
- Strong mathemathical basements (optimal for cliques of trees)
- More generic than ENV (partial cycle handling)
- Based on GRAS (development of distributed applications on simulator)

Future work

- NP-hardness
- Experimentation on real platform (measurements optimization)
- Iterative algorithm (modification detection)
- Couple measurement and reconstruction phases
- Integration within the NWS (auto-configuration; provide information)