Distributed Overlay Construction to Support Policy-based Access Control

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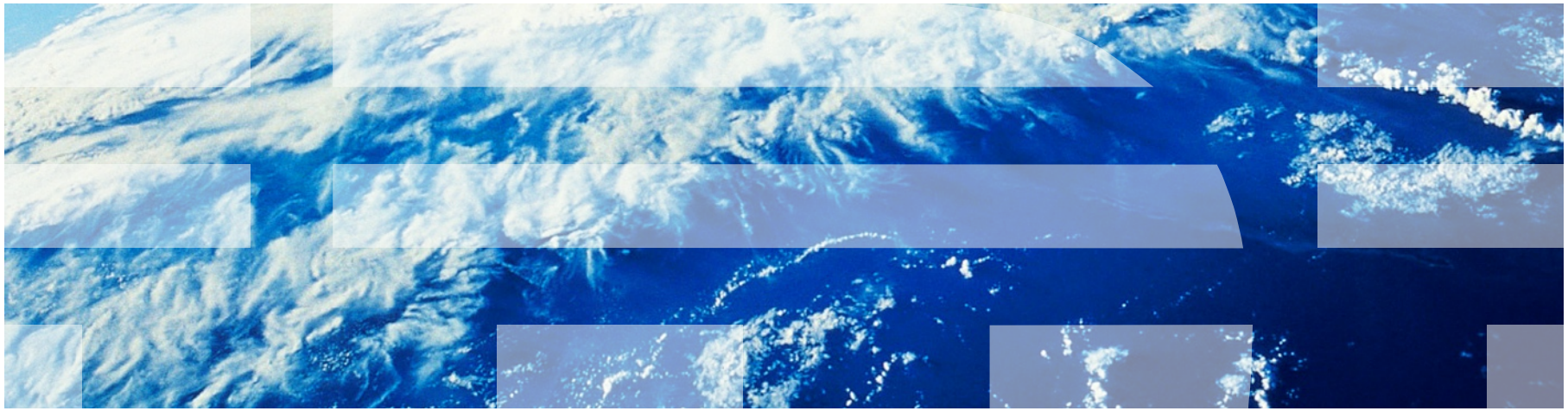

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A Tale of Two: “Once upon a time …”

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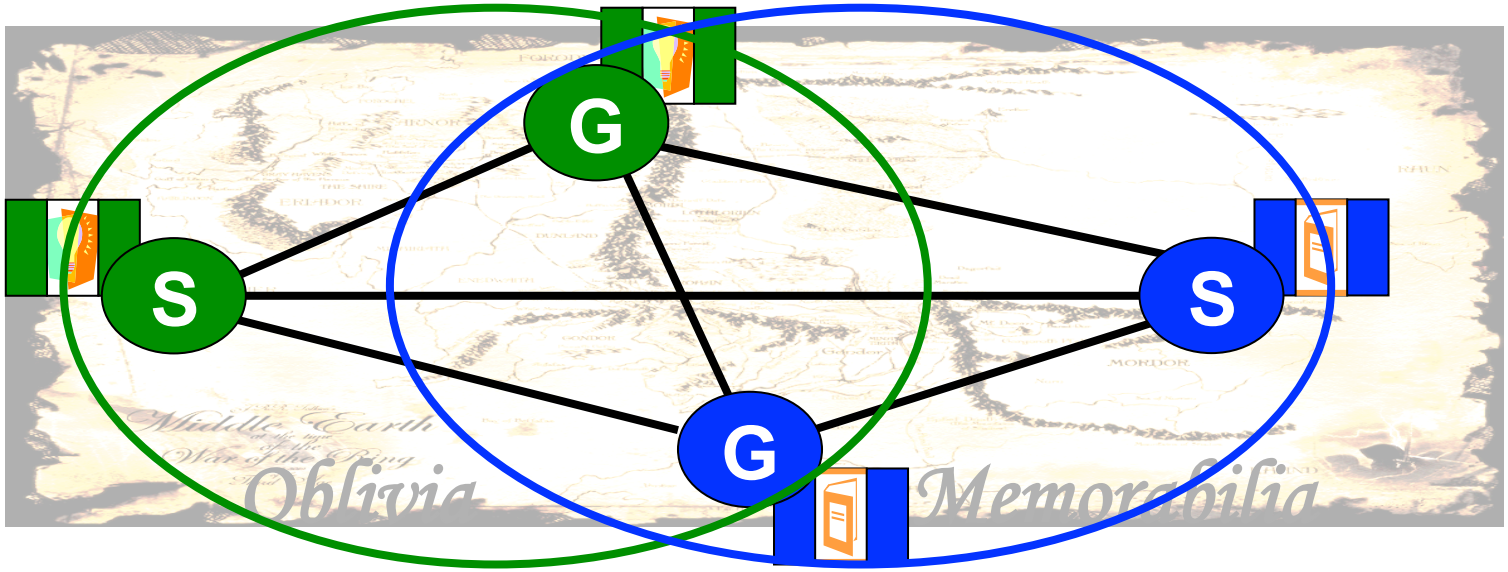
A Tale of Two: Building an information sharing network



- Rules of information sharing
  - *"Everyone is permitted to access the information of his/her country."*
  - *"Generals are permitted to access the information of the other country."*
  - *"Soldiers are not permitted to access the information of the other country."*
- Trust
  - *Authorized personnel will not send the information to unauthorized personnel, but will send and forward the information to other authorized personnel over multi-hop paths.*
- Mission: ***"Construct a network of secure links that can be used to pass the information around, without violating the policies."***
- Mission#2: ***"Don't create too many links. They are expensive."***

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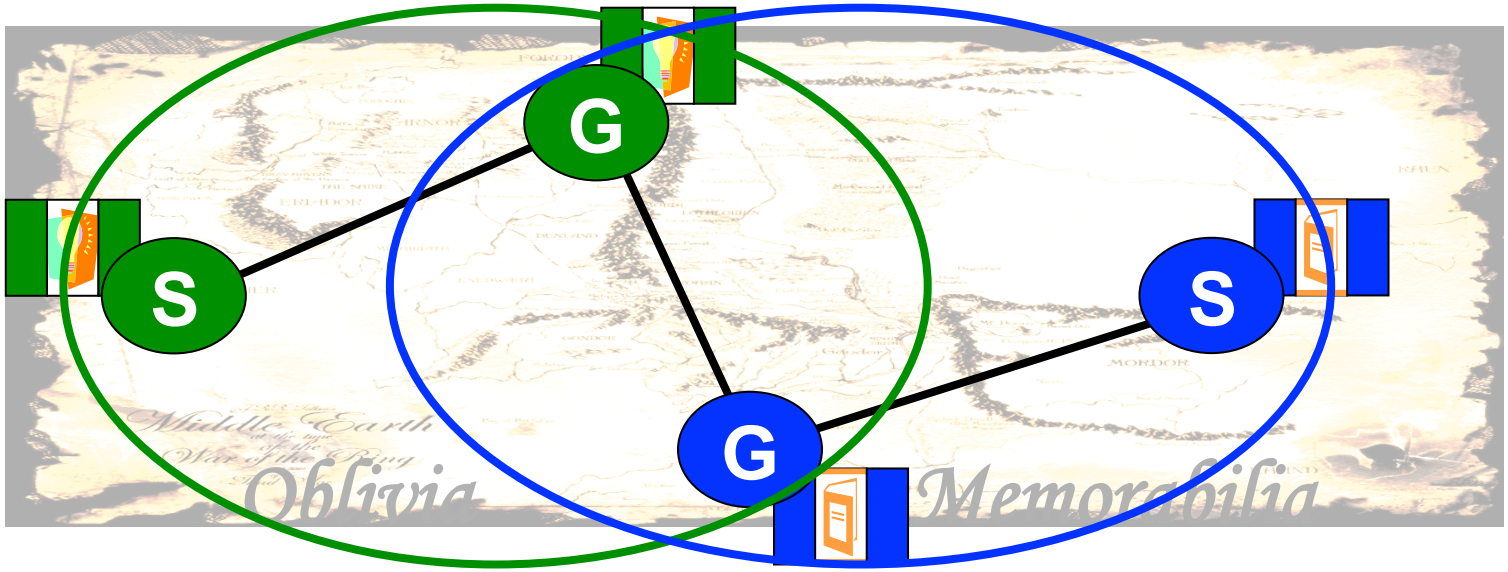
A Tale of Two: Building an information sharing network



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Node grouping by access control policy

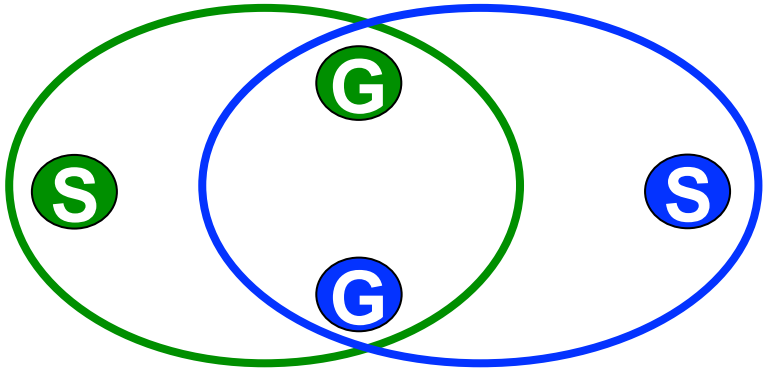
Access-control policy statement to node grouping

"**If** $f_k(r)$ = *true* and $g_k(n)$ = *true*, **then permit** *n*'s access to *r*".

→ $N_k = \{n \mid g_k(n) = true\}$: **access-control group** *k*

If {origin(**data**)=*Oblivia*} AND
{ {country(**person**)=*Oblivia*} OR {rank(**person**)=**General**} },
then
Permit the **person**'s access to the **data**

If {origin(**data**)=*Memorabilia*} AND
{ {country(**person**)=*Memorabilia*} OR {rank(**person**)=**General**} },
then
Permit the **person**'s access to the **data**



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Node grouping by access control policy (modern example)

Access-control policy statement to node grouping

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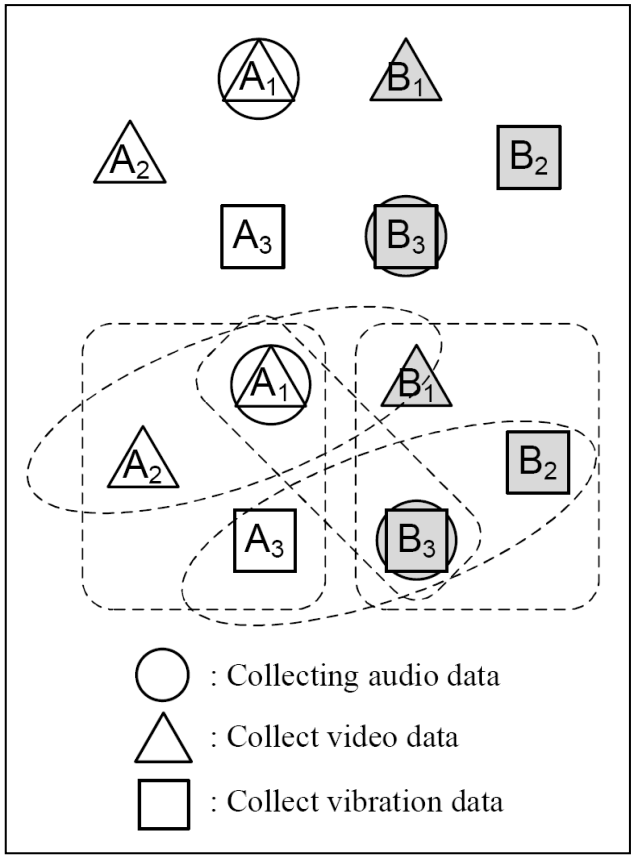
- If organization(n) == organization(s), then permit n's access to data from s.
- If roles(n) includes dataType(s), permit n's access to data from s..

Permit n's access to data from s:

- If organization(s) == A and organization(n) == A,
- If organization(s) == B and organization(n) == B,
- If dataType(s) == AUDIO and AUDIO ∈ roles(n),
- If dataType(s) == VIDEO and VIDEO ∈ roles(n), or
- If dataType(s) == VIBR and VIBR ∈ roles(n)



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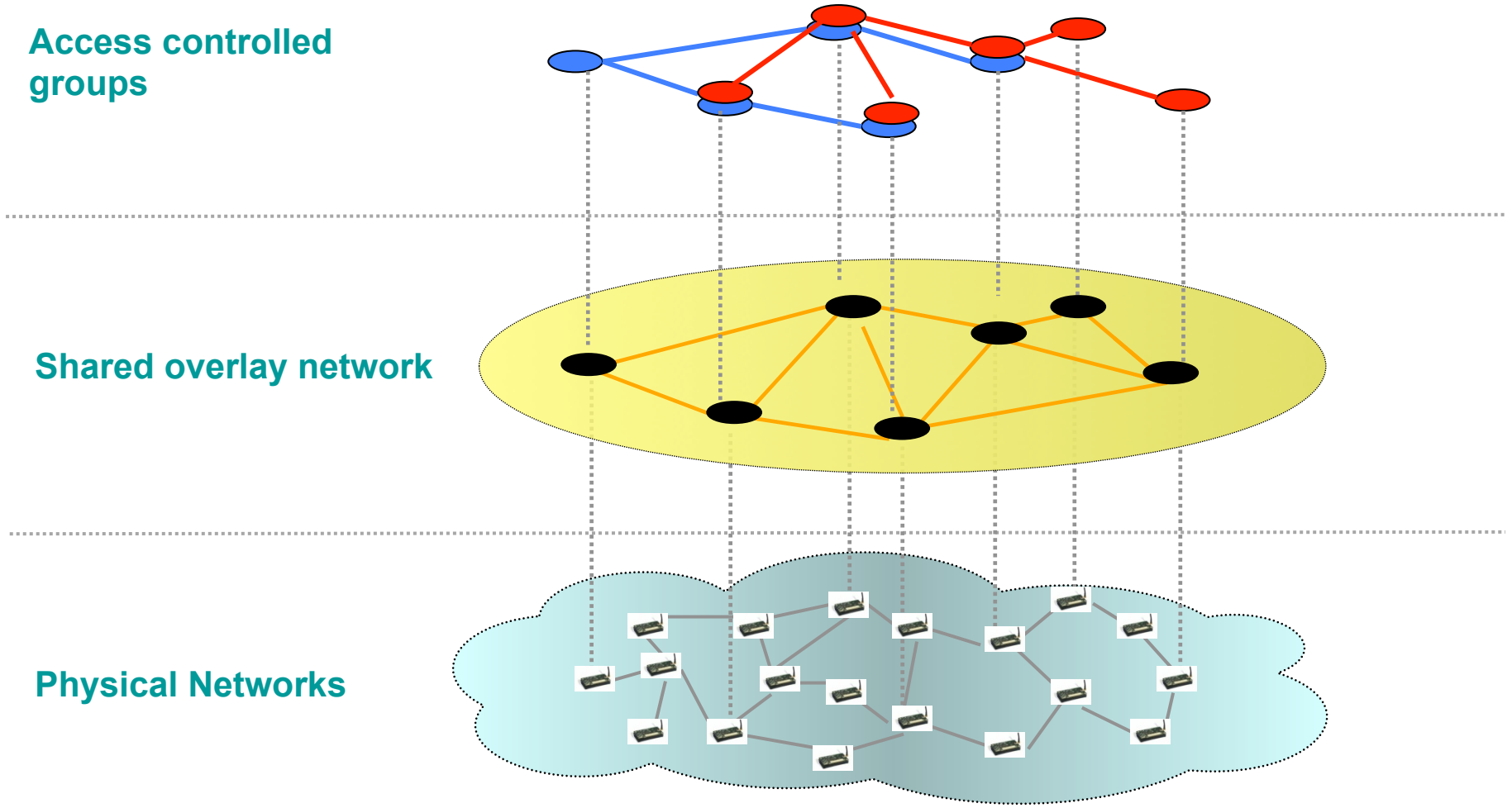
System architecture



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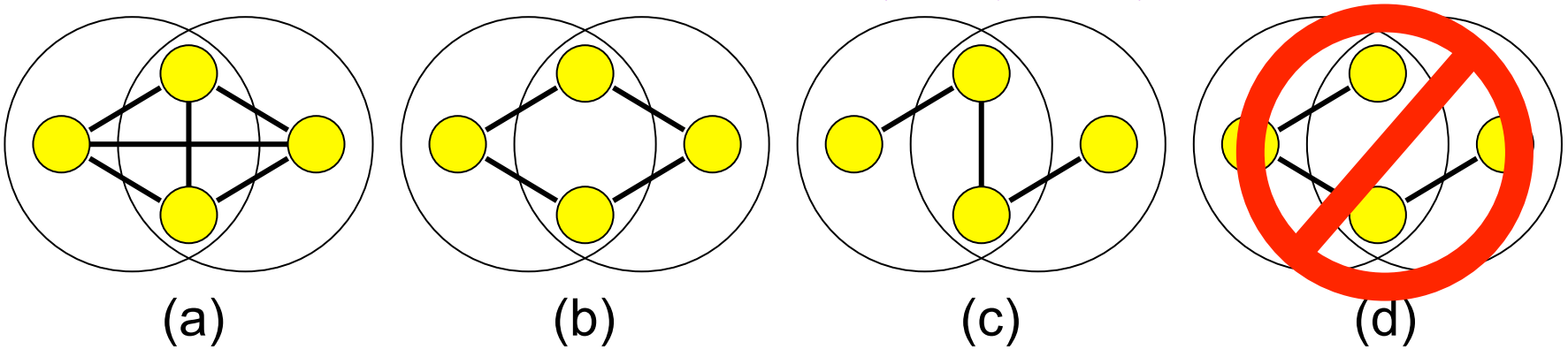
Policy-compatible Overlay Construction (PoCO) Problem

- Given
  - Set of nodes: $N = \{1, 2, \ldots, n\}$
  - Set of groups of nodes: $\Omega = \{N_1, N_2, \ldots N_K\}$, N_k *is a subset of* N
- A graph $G=(N,E)$ is *policy-compatible* w.r.t. Ω if, for each group N_k, the subgraph $G_k = (N_k, E_k)$ in G is a connected graph.
- Find a policy-compatible graph $G^*=(N,E^*)$ such that $|E^*| \leq |E|$ for all policy-compatible graphs $G = (N,E)$.
- NP-Complete problem

Q: Which of the followings is NOT policy-compatible?



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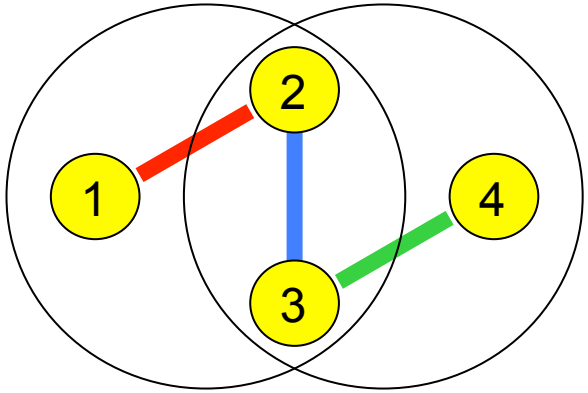
Centralized Overlay Construction

- **Group-connectedness**
  - $C_i = \{(u,v) |\ u$ and v are **not** connected in N_i, $u \in N_i$, $v \in N_i\}$
  - $C = \Sigma_i\ |C_i|$
- **Greedy addition of links**
  - At each step, a link that decreases C the most is selected (until $C = 0$).



N_1= {1,2,3},

N_2= {2,3,4}

Start: C_1 = {{1,2}, {2,3}, {1,3}}, C_2 = {{2,3}, {3,4}, {2,4}}

Step1: C_1 = {{1,2}, ~~{2,3}~~, {1,3}}, C_2 = ~~{{2,3}~~, {3,4}, {2,4}}

Step2: C_1 = ~~{{1,2}, {2,3}, {1,3}}~~, C_2 = ~~{{2,3}~~, {3,4}, {2,4}}

Step3: C_1 = ~~{{1,2}, {2,3}, {1,3}}~~, C_2 = ~~{{2,3}, {3,4}, {2,4}}~~

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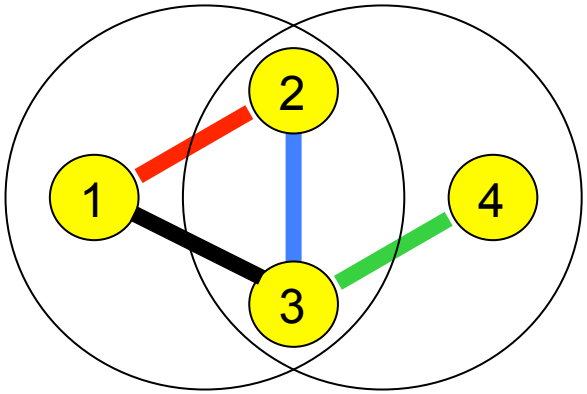
Distributed Overlay Construction

- Each node adds a link that maximizes group-connected pairs in its respective groups.
- Each node also deletes *redundant* links in its groups.
  - A link (*u*,*v*) is redundant if deleting it does not render *u* and *v* disconnected in their group(s).
- Each node exchanges ***its local link information*** with other nodes that belong to the same group via distributed protocols.



$N_1 = \{1,2,3\}$,
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Start: $C_1 = \{\{1,2\}, \{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{3,4\}, \{2,4\}\}$

Node 1: $C_1 = \{\{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{3,4\}, \{2,4\}\}$

Node 4: $C_1 = \{\{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{2,4\}\}$

Node 1: $C_1 = \{\{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{2,4\}\}$

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$C_1 = \{\{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{2,4\}\}$

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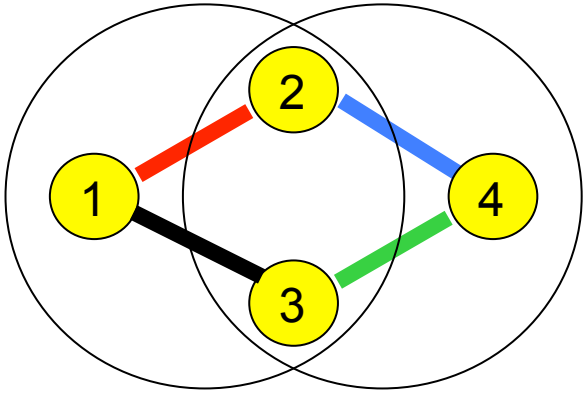
Distributed Overlay Construction: Convergence



$N_1 = \{1,2,3\}$,
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Node 2: $C_1 = \{\{1,2\}, \{2,3\}, \{1,3\}\}$, $C_2 = \{\{2,3\}, \{3,4\}, \{2,4\}\}$

Convergence :

*Starting from an arbitrary graph G_0, the evolving sequence of the graphs $(G_0, G_1, G_2, \cdots)$ generated by the distributed process converges to a **stable** graph $G = (N, E)$ which is compatible w.r.t. the policy grouping in finite number of steps.*

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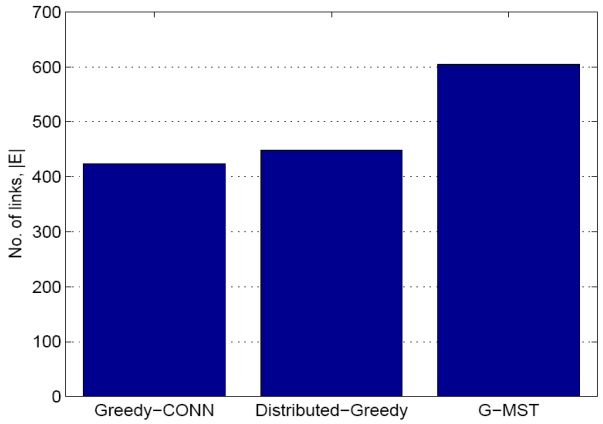
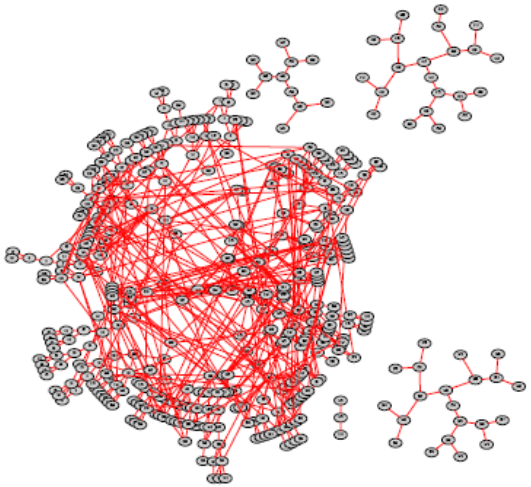
Performance (Empirical Data)

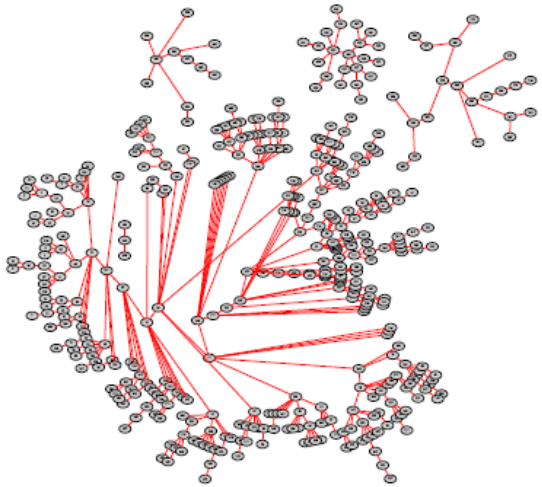


- Conference program committee membership data
- 482 individuals in 32 conference PCs in 2006.
- Policy: “Data can be shared among members in the same PC”.

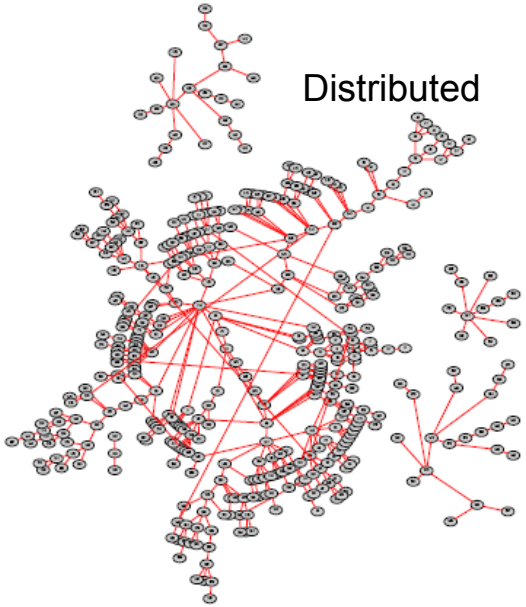
G-MST



Centralized



Distributed



** G-MST (Generalized Minimum Spanning Tree): Similar to Reverse-delete algorithm for MST, but deletes redundant edges*

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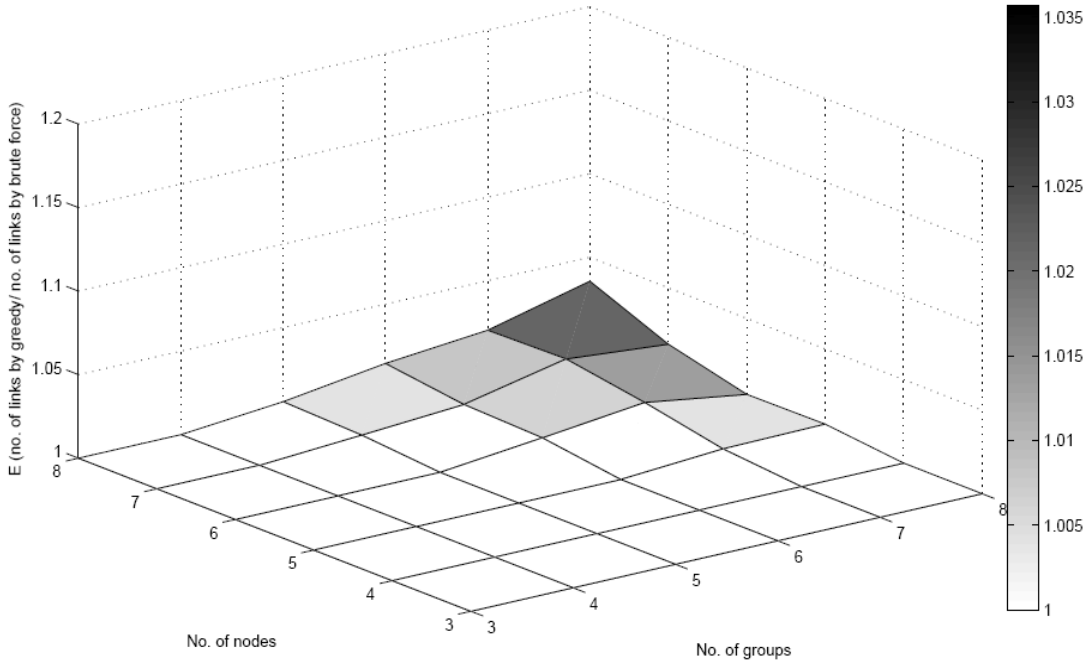
Performance (Synthetic Input)

- |*N*|: # of nodes (10 ~ 50)
- |Ω|: # of groups (10, 20)
- *p*: Probability that a node belongs to a group



Centralized vs Optimal

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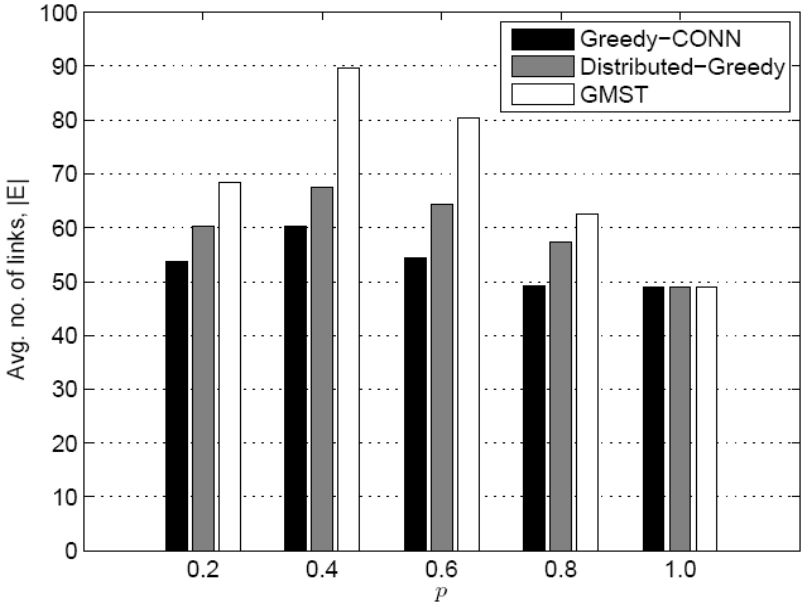
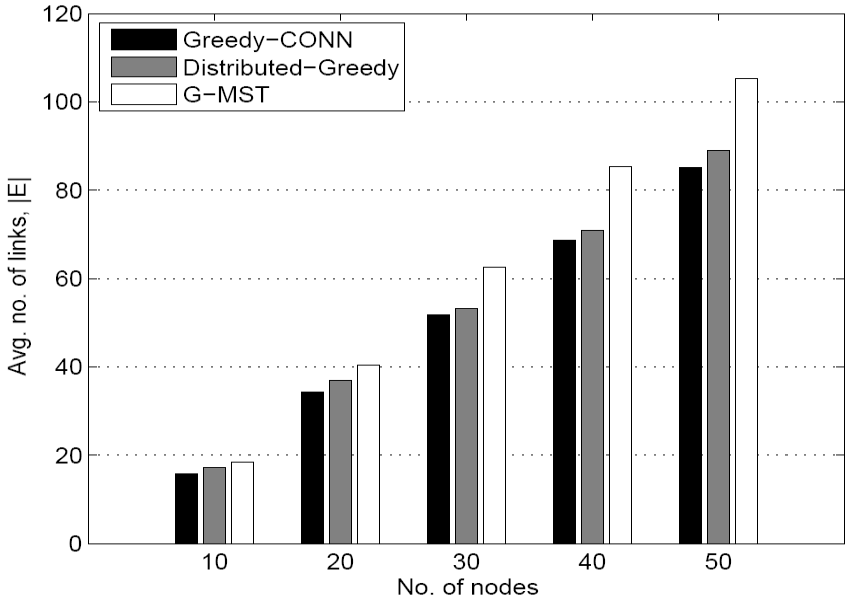


|N| = 50, |Ω| = 10



|Ω| = 20, p = 0.5

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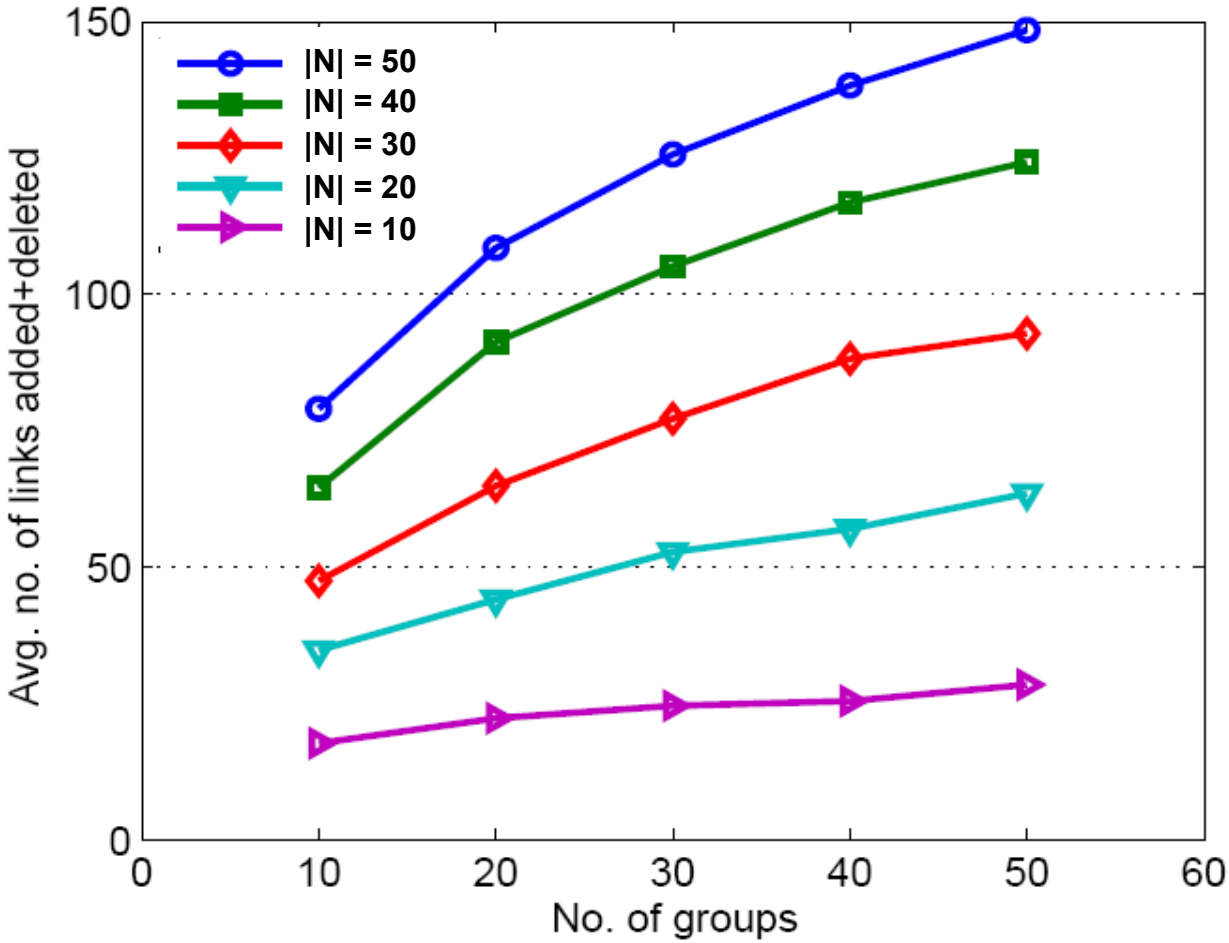
Performance: Dynamics of distributed algorithm



Total # of link additions/deletion by distributed algorithm

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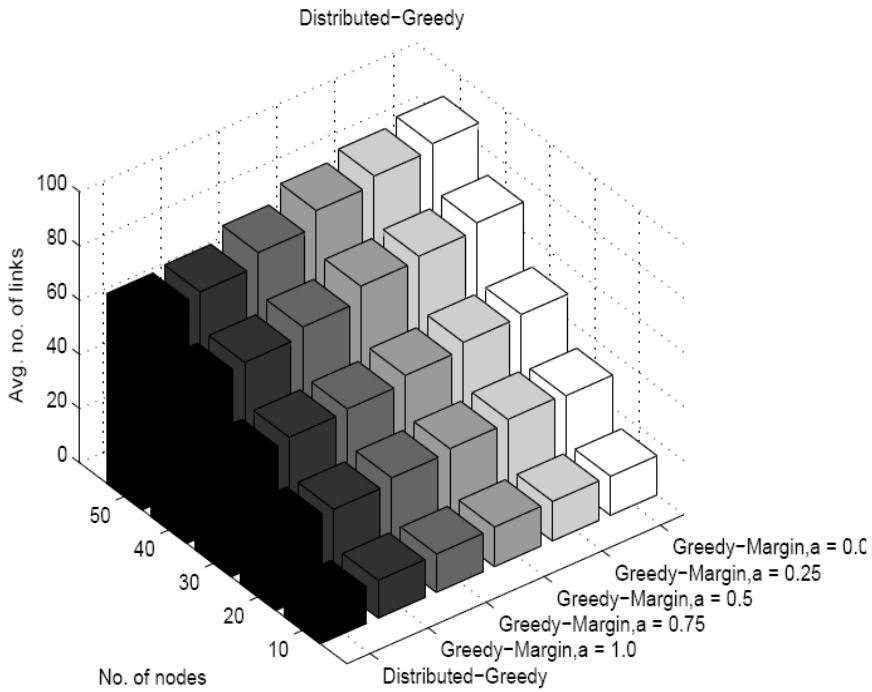
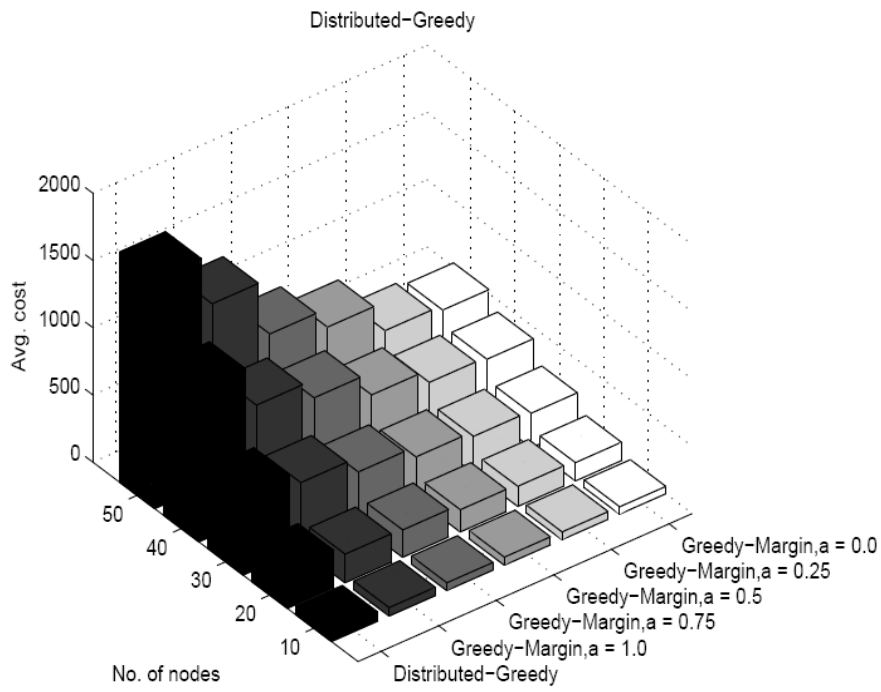
Extension for link cost optimization

- Link cost function: $c: N \times N \rightarrow R^{+}$
  - Accounts for node distance, trust level, etc.
- Construct overlay that minimizes the total cost: $c(E)=\Sigma_{(u,v)\in E}\, c(u,v)$



$|E|$



$c(E)$

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Conclusion

- A new problem of building a network constrained by access control policy.
- Build a shared overlay used across multiple access-control groups.
- Optimize over the number of links in the shared overlay
  - Greedy heuristics (centralized and distributed) work pretty well.
- Open problems
  - Partial knowledge in the distributed construction
    - Nodes may not have complete knowledge of group topology.
  - Risk-aware overlay
    - Some nodes are more trustworthy than others.
  - Resilient, efficient, and robust overlay
    - Small diameter
    - Dynamics: Node join/leave; policy updates
    - Compromised nodes; nodes under attack

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