Characterizing Selfishly Constructed Overlay Routing Networks

INFOCOM 2004

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2004/4/7

Outline

- Introduction
- Overlay Routing Network
- Routing Network Creation Game
- Experiment
- Conclusions
- Future Work

Introduction

- We analyze the characteristics of overlay routing networks generated
  - by selfish nodes playing competitive network construction games.
  - by modeling network formation as a non-cooperative game.
- Each node chooses its overlay neighbors
  - to maximize its benefit
  - to minimize its linking cost.

Introduction

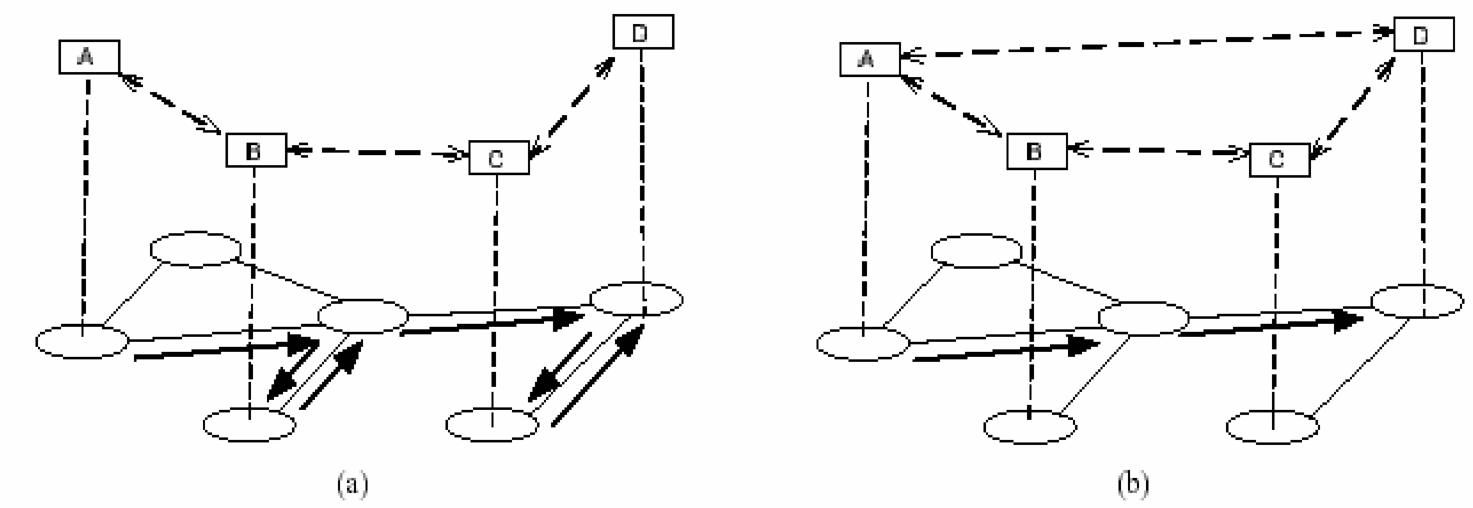
- They want to have low cost paths to other nodes in the network
  - by establishing more links.
  - not want to establish many links, which may turn out to be costly.

- The outcome of the game is a network topology, which is a Nash equilibrium.

- Nash equilibrium
  - a set of strategies that no player can benefit by changing its strategy, while the other players keep their strategies unchanged

Overlay Routing Network

- The ellipses are physical nodes and the rectangles are overlay nodes labeled A, B, C, and D.
  - In (a) has virtual links AB, BC, and CD.
  - In (a), the path length is 6 physical hops.
  - When A decides to add a link to D, the resulting network is the network (b).
  - A incurs cost to establish this new link, but the distance reduces to 2 physical hops due to the virtual link AD.

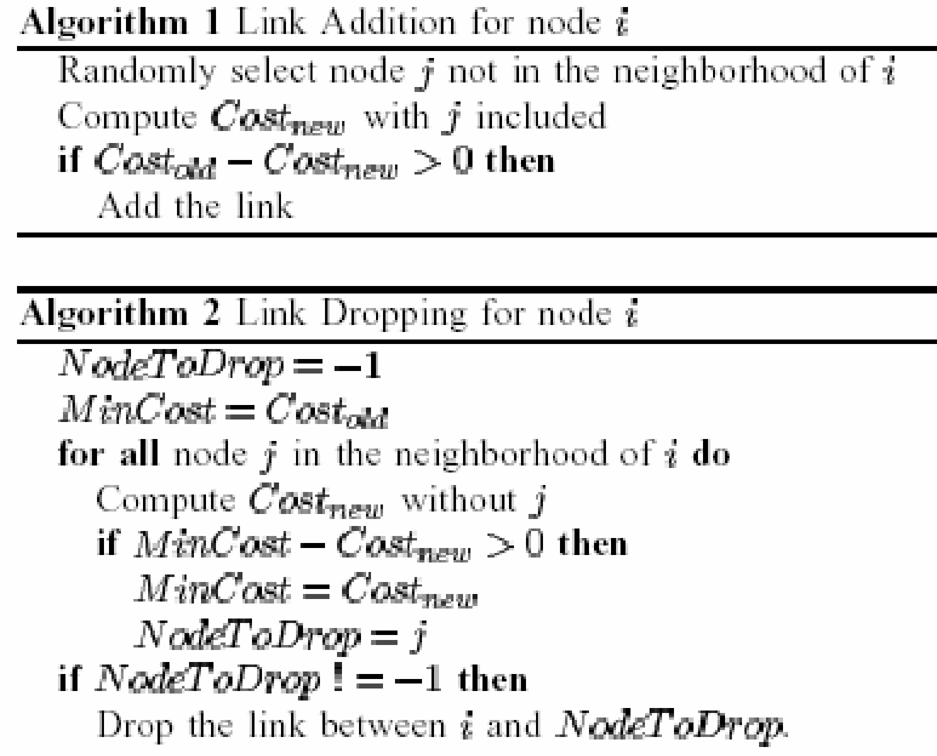


Routing Network Creation Game

- The cost model is the most important part of the game.
- The “distance” between two nodes may be represented by other functions than the number of hops (include the cost of the path or the latency).

Routing Network Creation Game

- From a connected random graph, and in each round, each player changes its link configuration to minimize its cost as given.



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Algorithm 1 Link Addition for node $i$
    Randomly select node $j$ not in the neighborhood of $i$
    Compute $Cost_{new}$ with $j$ included
    if $Cost_{old} - Cost_{new} > 0$ then
        Add the link
```

```
Algorithm 2 Link Dropping for node $i$
    $NodeToDrop = -1$
    $MinCost = Cost_{old}$
    for all node $j$ in the neighborhood of $i$ do
        Compute $Cost_{new}$ without $j$
        if $MinCost - Cost_{new} > 0$ then
            $MinCost = Cost_{new}$
            $NodeToDrop = j$
    if $NodeToDrop\ != -1$ then
        Drop the link between $i$ and $NodeToDrop$.
```

Routing Network Creation Game

- *Exhaustive search:*
  - The node should verify all possible configurations of the edges existing or not, to all other neighbors.
  - There are **$2^{(n-1)}$**different strategies.
  - The time complexity of running the game in this fashion is **exponential** in the number of nodes.

Routing Network Creation Game

- *Randomized local search:*
  - Runs the link state (LS) protocol.
  - Each node periodically performs the link drop and link addition procedures.
  - Randomly selects a node that
    - is not the previously dropped link.
    - is not in the neighborhood.

Routing Network Creation Game

- We randomly choose one node that is not in the neighborhood of node i , and fetch its link state and cost t_j.
- We add the link if the cost of node i is reduced by linking to node j .

$$Cost_{old} - Cost_{new} > 0$$

$$\text{iff} \quad \sum_{j=0}^{n-1} \left(d_{G_{old}}(i,j) - d_{G_{new}}(i,j)\right) > \alpha\, t_j$$

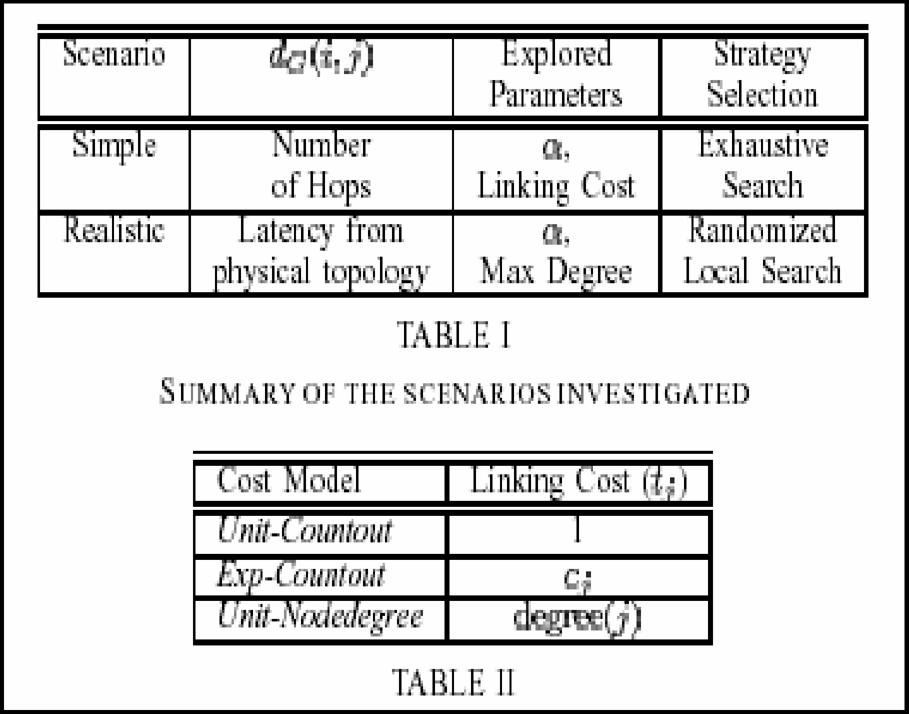
Routing Network Creation Game

- It computes the node’s cost of a new graph when a particular link is dropped.
- It chooses the neighbor that leads to the minimum cost value that is less than the old value.

$$
\begin{aligned}
& Cost_{old} - Cost_{new} > 0 \\
\text{iff} \quad & \sum_{j=0}^{n-1} \left(d_{G_{new}}(i,j) - d_{G_{old}}(i,j) \right) < \alpha \, t_j
\end{aligned}
$$

Routing Network Creation Game

- *Unit-Countout*:
  - Node that initiates the connection pays the total cost of the connect.
- *Exp-Countout*:
  - The linking costs are generated from an exponential distribution of mean 1.0.
- *Unit-Nodedegree*:
  - cost incurred by a node to create a link depends on the node degree of the node to connect to.



Scenario	$d_G(i,j)$	Explored Parameters	Strategy Selection
Simple	Number of Hops	α, Linking Cost	Exhaustive Search
Realistic	Latency from physical topology	α, Max Degree	Randomized Local Search

TABLE I

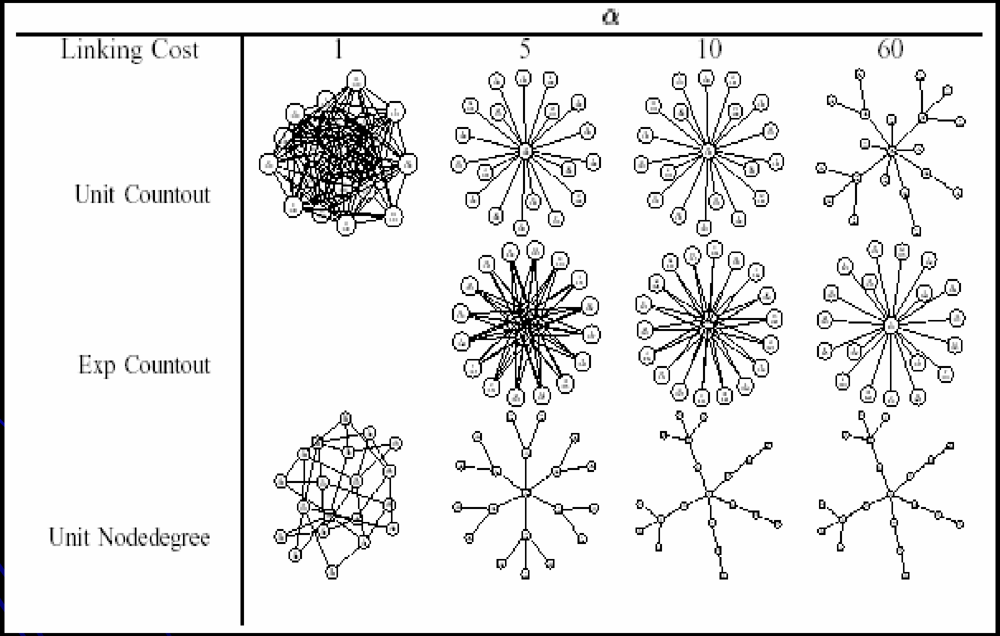
SUMMARY OF THE SCENARIOS INVESTIGATED

Cost Model	Linking Cost (l_j)
Unit-Countout	1
Exp-Countout	c_j
Unit-Nodedegree	degree(j)

TABLE II

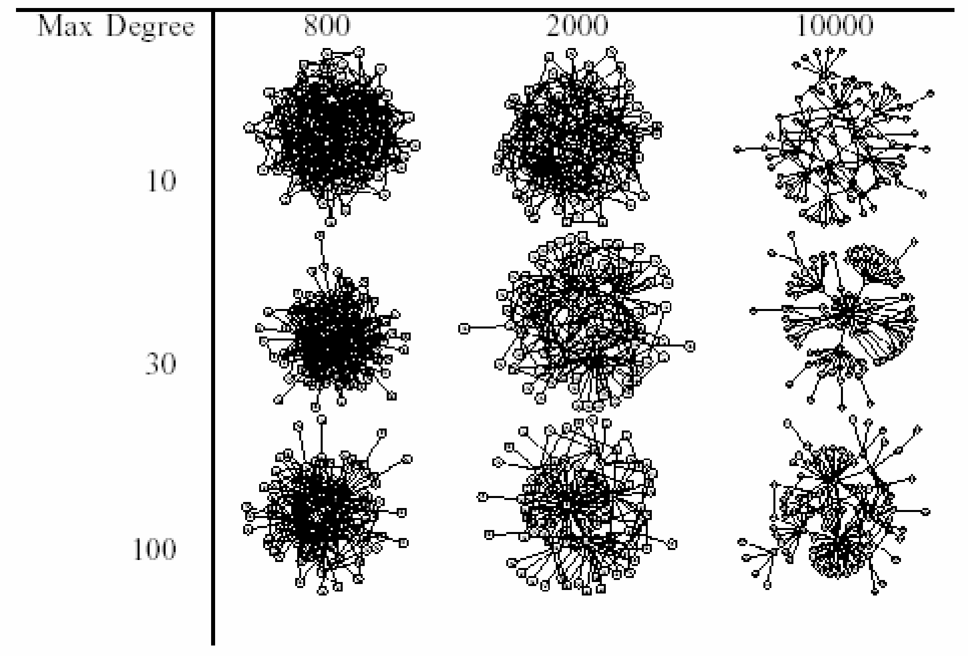
Routing Network Creation Game

- Simple Scenario
  - Sample equilibrium graphs for the simple scenario with 20 nodes, for the different cost models and values of α.



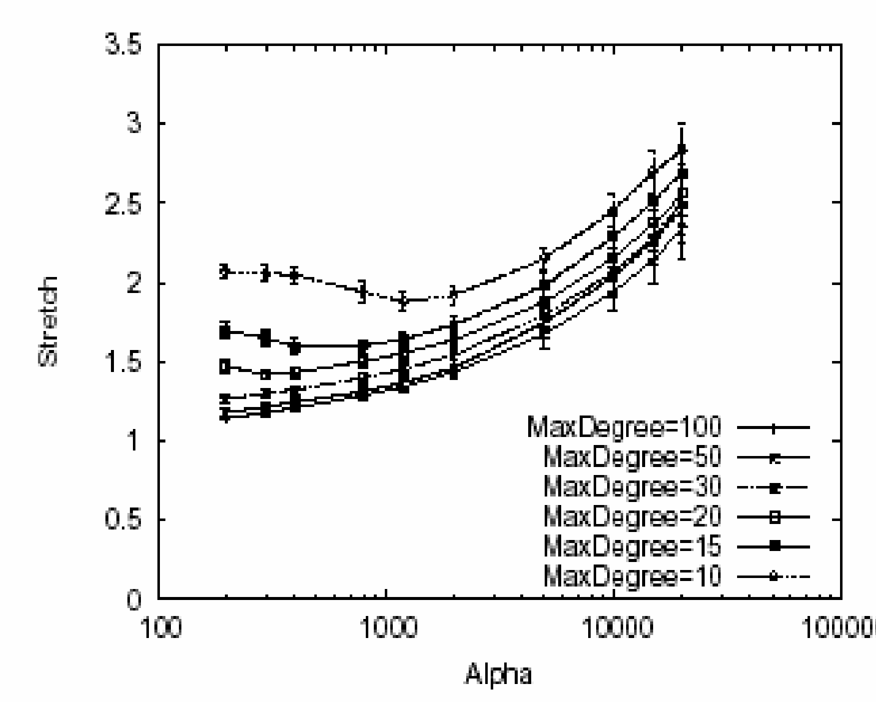
Routing Network Creation Game

- Realistic Scenario
  - We present simulation results for 100 nodes.
  - We varied α from 800 to 10000 and we varied *MaxDegree* between 10 and 100.



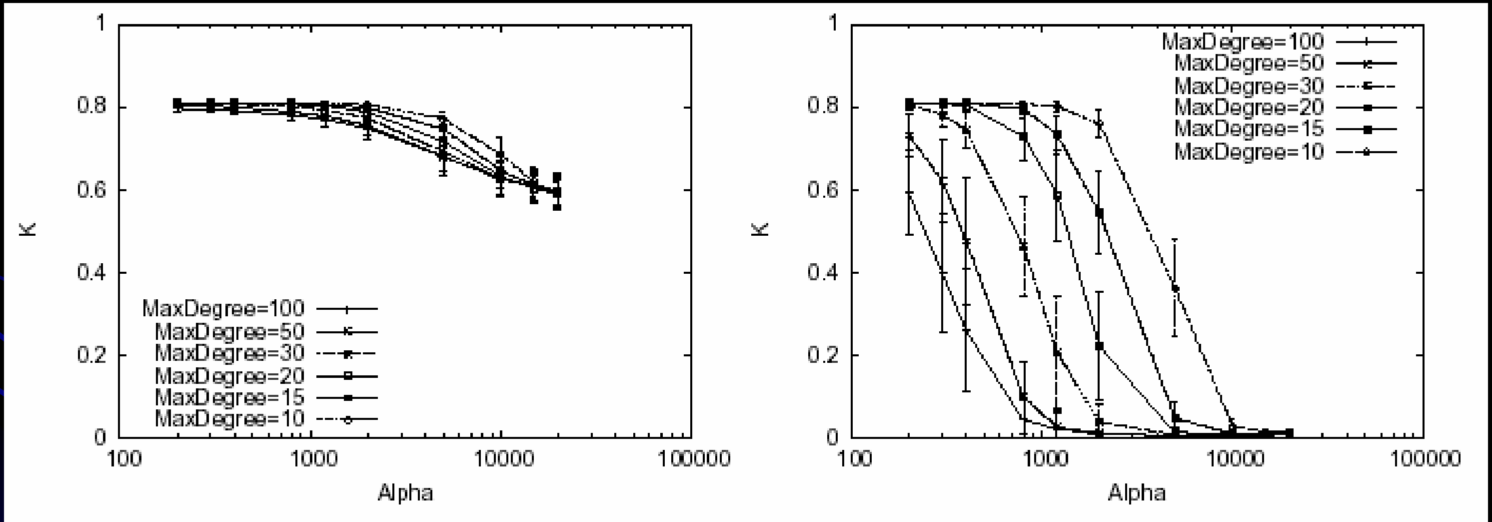
Experiment

- The stretch decreases as α decreases and it decreases as *MaxDegree* increases.
- Specifically, when α is small and *MaxDegree* is large.
- If α is small, the node is likely to add links, if is large, the node is not likely to add links,



Experiment

- Failure and attack tolerance (a) K when 10 of nodes fail, (b) K when 10 of nodes are attacked



(a) Failure

(b) Attack

Conclusions

- We use a non-cooperative game model to evaluate such networks and examine the effects of the underlying topology and different linking cost functions in the resulting Nash equilibria of the game.
- We find that the games can produce widely different networks, from complete graphs to trees with different properties.
- We also find that there is a fundamental tradeoff between these two metrics, and that it can be controlled by restricting the maximum node degree.

Future Work

- We want to examine the game in a dynamic network where the total number of nodes changes over time due to node joins and leaves.
- Another interesting area is to take traffic into consideration.