Taming Dynamic and Selfish Peers

Stefan Schmid

Distributed Computing Group

ETH Zurich, Switzerland

schmiste@tik.ee.ethz.ch

Talk based on our papers at IPTPS 2005 and 2006

SCHLOSS DAGSTUHL
INTERNATIONALES
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FORSCHUNGSZENTRUM
FÜR INFORMATIK

“Peer-to-Peer Systems and Applications”

Dagstuhl Seminar

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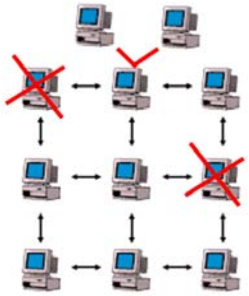
Outline of this Talk

- Current research of our group at ETH
  - Based on our papers at IPTPS 2005 and IPTPS 2006
  - Still many interesting open questions!

- Two challenges related to P2P topologies

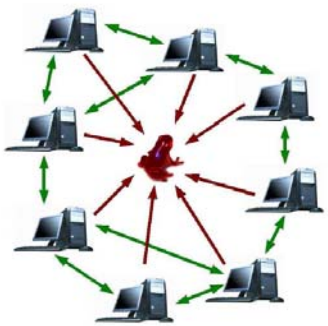


CHALLENGE 1: Dynamic Peers

•dynamics of P2P systems,

•i.e., joins and leaves of peers ("churn")

•our approach to maintain desirable properties in spite of churn



CHALLENGE 2: Selfish Peers

•impact of selfish behavior on P2P topologies

•How bad are topologies formed by selfish peers?

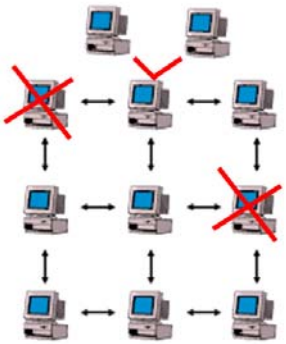
•Stability of topologies formed by selfish peers?

CHALLENGE 1:

Dynamic Peers

Motivation (1)

- P2P systems are
  - composed of unreliable desktop machines
  - under control of individual users



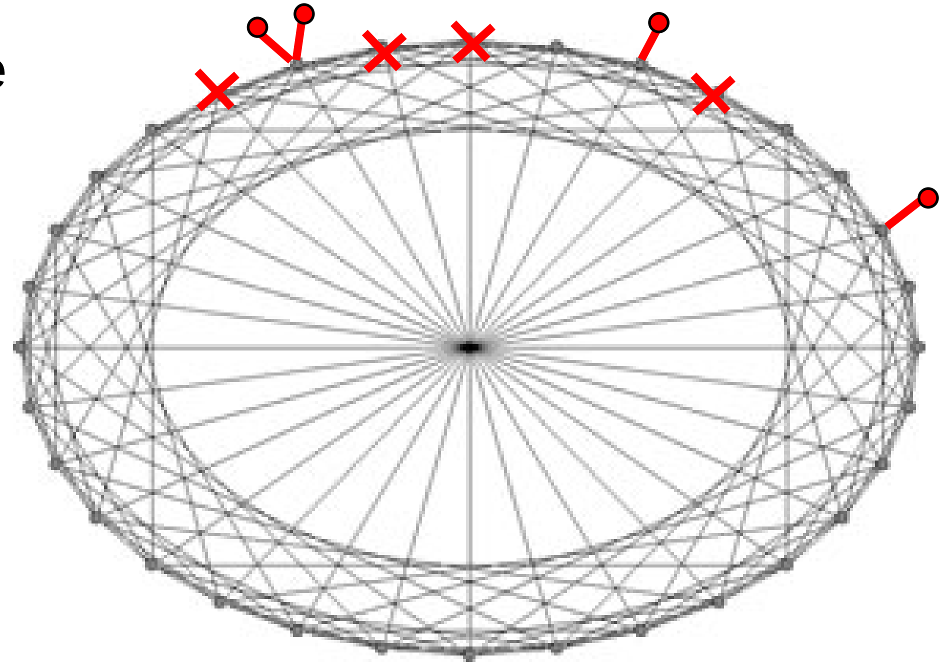
⇒ Peers may join and leave the network at any time and concurrently (“churn”)!

- However:
  - many systems maintain their properties only in static environments!

Motivation (2)

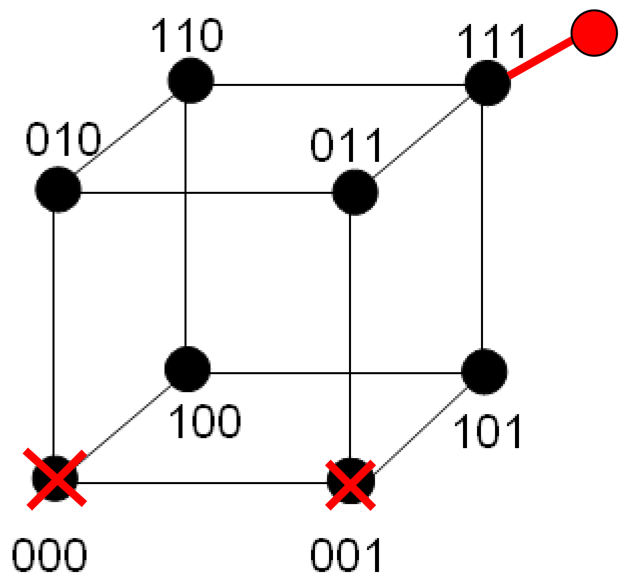
How to maintain desirable properties such as

- Connectivity,
- Network diameter,
- Peer degree?



A First Approach

- Fault-tolerant hypercube?
- What if number of peers is not 2^i?
- How to prevent degeneration?
- Where to store data?



Idea: Simulate the hypercube!

Simulated Hypercube System

Simulation: Node consists of several peers!

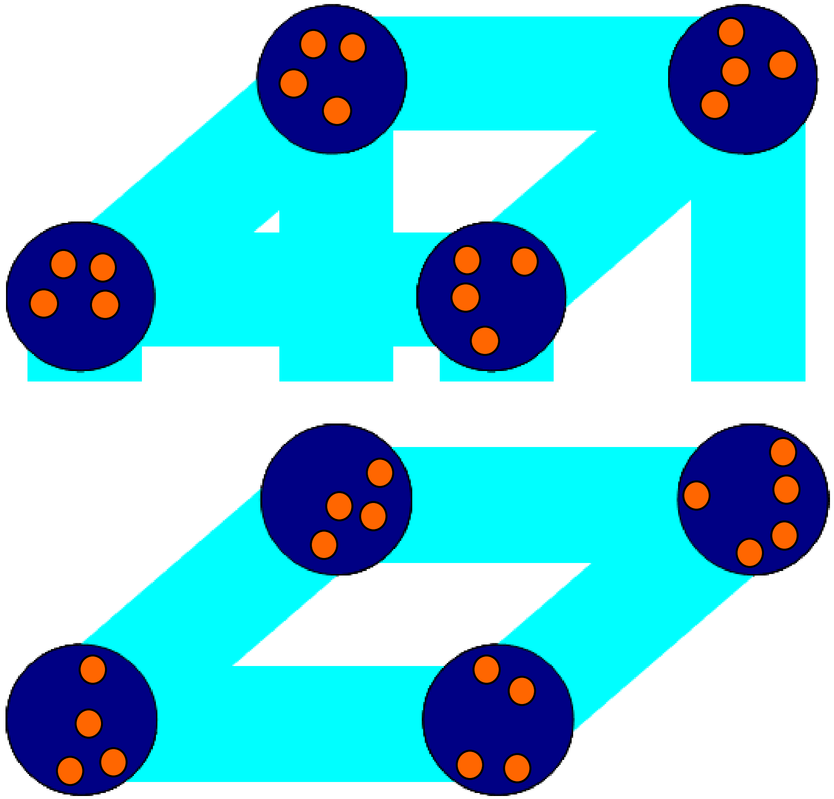
Basic components:

- Route peers to sparse areas

Token distribution algorithm!

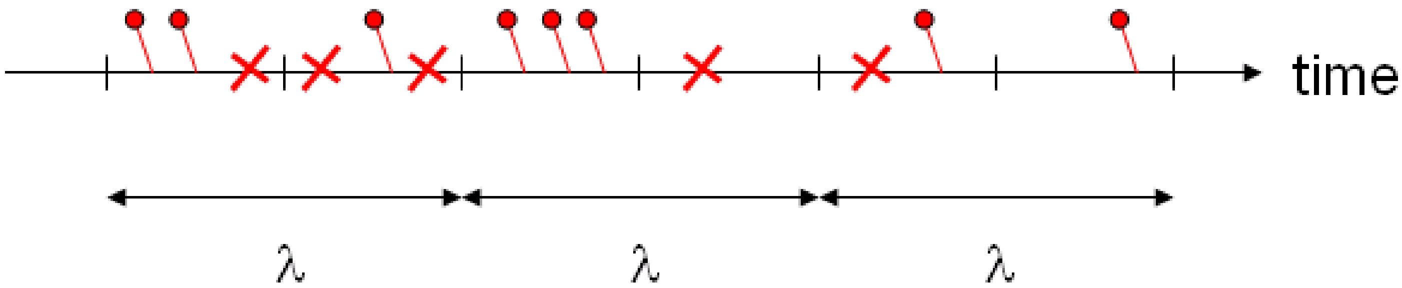
- Adapt dimension

Information aggregation algorithm!



The Adversary

- Model worst-case faults with an adversary *ADV(J,L,λ)*
- *ADV(J,L,λ)* has complete visibility of the entire state of the system
- May add at most *J* and remove at most *L* peers in any time period of length λ



- Note: Adversary is *not* Byzantine!

Results

- In spite of *ADV(O(log n), O(log n), 1)*:
  - always at least one peer per node (no data lost!),
  - peer degree *O(log n)* (asymptotically optimal!),
  - network diameter *O(log n)*.

Discussion

- Simulated topology: Taming dynamic peers by redundancy!
- Simulated topology: A simple blueprint for many P2P topologies!
  - Requires token distribution and information aggregation on the topology!
- A lot of future work!
  - A first step only: dynamics of P2P systems offer many research challenges!
  - E.g.: Other dynamics models, self-stabilization after larger changes, etc.!

CHALLENGE 2:

Selfish Peers

Challenge 1 -> Challenge 2

- Simulated hypercube topology is fine…
- … if peers act according to protocol!
- However, in practice, peers can perform selfishly!

Motivation (1)

Power of Peer-to-Peer Computing =

Accumulation of Resources of Individual Peers

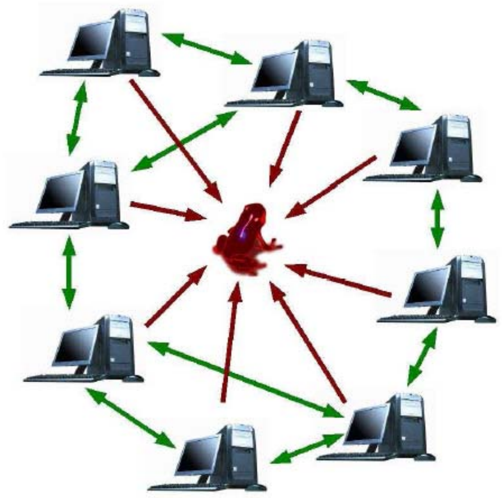
- CPU Cycles
- Memory
- Bandwidth
- …

Collaboration is of peers is vital!

However, many free riders in practice!

Motivation (2)

- Free riding
  - Downloading without uploading
  - Using storage of other peers without contributing own disk space
  - Etc.



- Our research: selfish neighbor selection in unstructured P2P systems

- Goals of selfish peer:

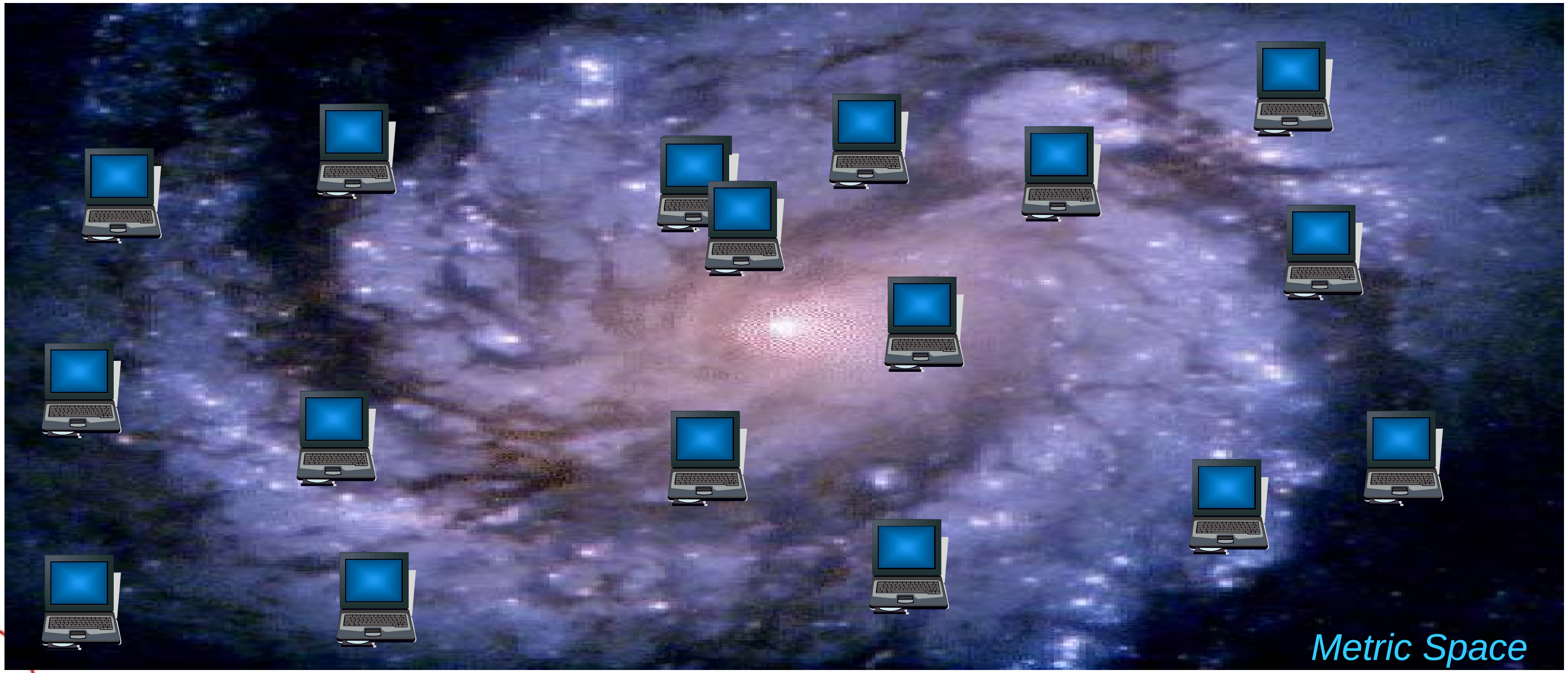
  (1) Maintain links only to a few neighbors (small out-degree)

  (2) Small latencies to all other peers in the system (fast lookups)

What is the impact on the P2P topologies?

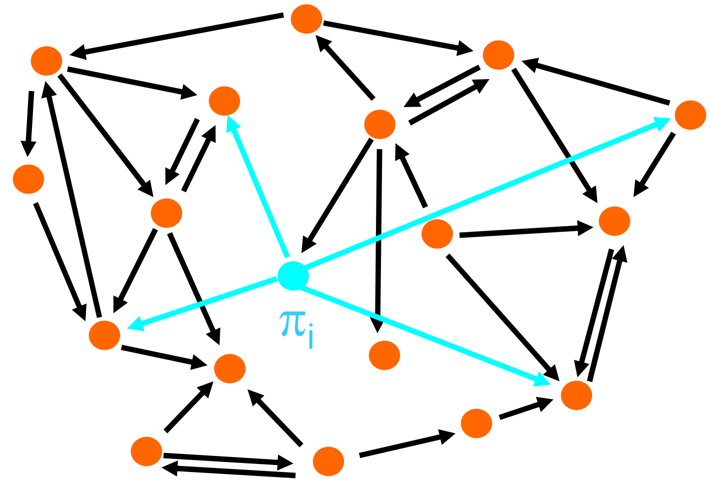
Problem Statement (1)

- n peers $\{\pi_0, \ldots, \pi_{n-1}\}$
- distributed in a metric space
  - Metric space defines distances between peers
  - triangle inequality, etc.
  - E.g., Euclidean plane



Problem Statement (2)

- Each peer can choose…
  - to which
  - and how many
  - … other peers its connects



- Yields a directed graph *G*

Problem Statement (3)

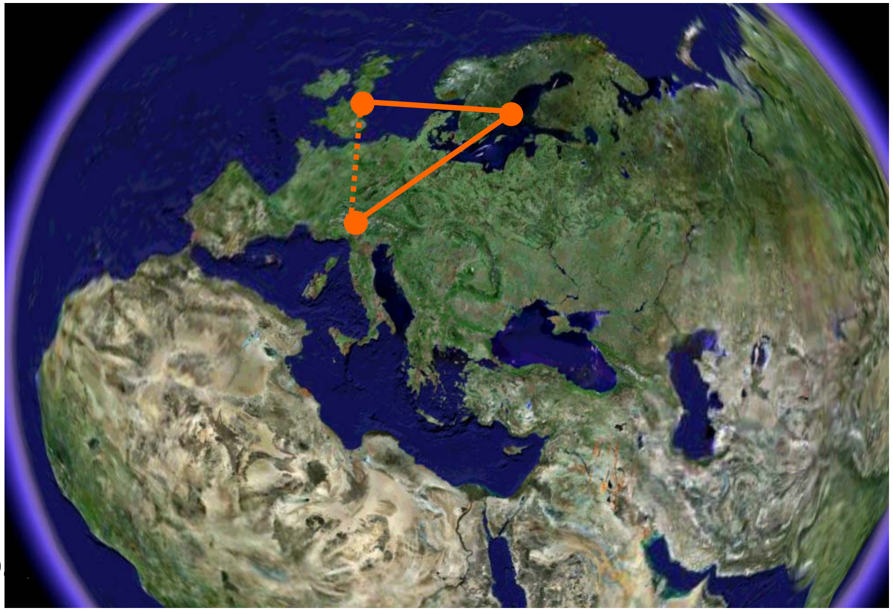
- Goal of a selfish peer:

(1) Maintain a small number of neighbors only (out-degree)

(2) Small stretches to all other peers in the system

- Only little memory used
- Small maintenance overhead

- Fast lookups!
- Shortest distance using edges of peers in G…
- … divided by shortest direct distance



Problem Statement (4)

- Cost of a peer:
  - Number of neighbors (out-degree) times a parameter α
  - plus stretches to all other peers
  - α captures the trade-off between link and stretch cost

$$cost_i = \alpha \; outdeg_i + \sum_{i \neq j} stretch_G(\pi_i, \pi_j)$$

- Goal of a peer: Minimize its cost!

Game-theoretic Tools (1)

- Social Cost
  - Sum of costs of all individual peers:
  - => Criterion to evaluate the overall efficiency of a P2P topology!

$$\text{Cost} = \sum_i \text{cost}_i = \sum_i \left(\alpha\ \text{outdeg}_i + \sum_{i \neq j} \text{stretch}_G(\pi_i, \pi_j)\right)$$

- Social Optimum OPT
  - Topology with minimal social cost of a given problem instance
  - => "topology formed by collaborating peers"!

- Nash equilibrium
  - "Result" of selfish behavior => "topology formed by selfish peers"
  - Topology in which no peer can reduce its costs by changing its neighbor set
  - In the following, let NASH be social cost of worst equilibrium

Game-theoretic Tools (2)

- How to compute the impact of selfish behavior?

- Price of Anarchy
  - Captures the impact of selfish behavior by comparison with optimal solution
  - Formally: social costs of worst Nash equilibrium divided by optimal social cost

$$PoA = \max_I \{NASH(I) / OPT(I)\}$$

Results: Price of Anarchy

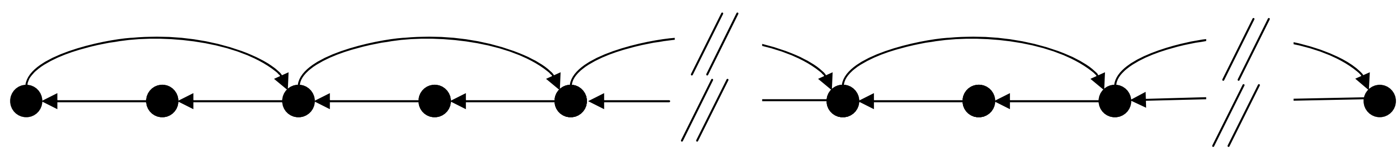
Theorem: The price of anarchy is

PoA $\in \Theta(\min\{\alpha, n\})$

=> PoA can grow linearly in the total number of peers

=> PoA can grow linearly in the relative importance of degree costs α

- This is already true in a 1-dimensional Euclidean space:
  - Is Nash equilibrium, at has large social costs compared to doubly linked list



Peer:	π_1	π_2	π_3	π_4	π_5	…	π_{i-1}	π_i	π_{i+1}	…	π_n
Position:	½	α	½ α^2	α^3	½ α^4	…	½ α^{i-2}	α^{i-1}	½ α^i	…	½ α^{n-1}

Results: Stability

How long thus it take until no peer has an incentive to change its neighbors anymore?

Theorem:

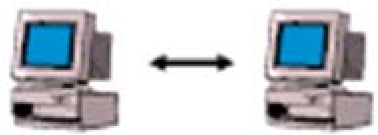
Even in the absence of churn, peer mobility or other sources of dynamism, the system may never stabilize (i.e., P2P system never reaches a pure Nash equilibrium)!

Discussion

- Unstructured topologies created by selfish peers
- Efficiency of topology deteriorates linearly in the relative importance of links compared to stretch costs, and in the number of peers
- Instable even in static environments
- Discussion
  - Relevance in practice?
  - If yes: How to tame the selfish peers?
  - Mechanism design?

Thank you for your attention!

Questions? Comments? Feedback?



Further reading:

1. "A Self-repairing Peer-to-Peer System Resilient to Dynamic Adversarial Churn", Kuhn, Schmid, Wattenhofer; *Ithaca, New York, USA, IPTPS 2005.*
2. "On the Topologies Formed by Selfish Peers", Moscibroda, Schmid, Wattenhofer; *Santa Barbara, California, USA, IPTPS 2006.*

Email: *schmiste@tik.ee.ethz.ch*

Website: *http://dcg.ethz.ch/members/stefan.html*