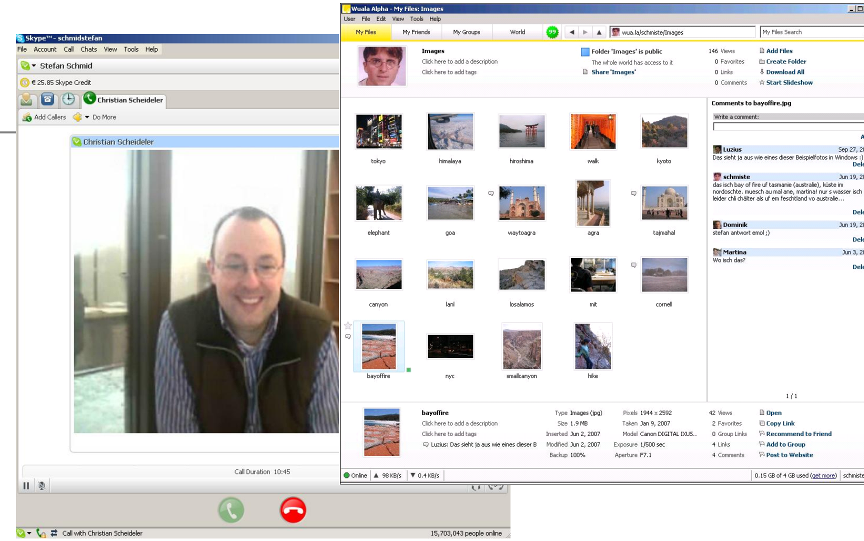
Some Peers Are More Equal than Others!

Stefan Schmid

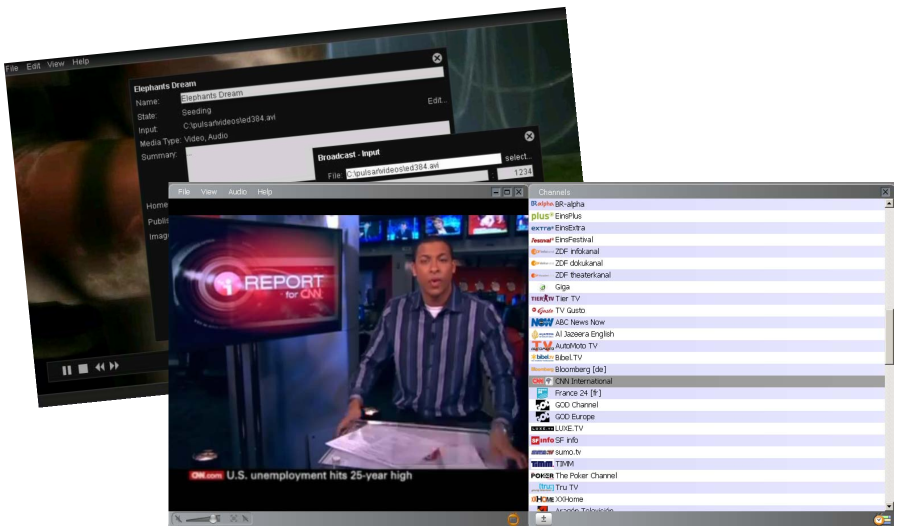
TECHNISCHE UNIVERSITÄT MÜNCHEN

MSR Cambridge, March 31, 2009

Peer-to-Peer Technology



- Well-known p2p systems
  - Internet telephony: *Skype*
  - File sharing: *BitTorrent, eMule, ...*
  - Streaming: *Zattoo, Joost, ...*

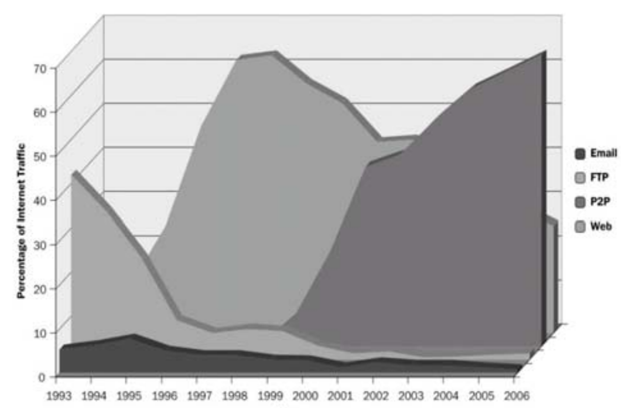


- Other (well-known?) systems
  - Pulsar streaming system (e.g., tilllate clips?)
  - Wuala: online storage system

Two startups!

- Impact: Accounts for much Internet traffic!

  (source: *cachelogic.com*)



The Paradigm

- Key concepts

  - Machines (peers) in the network: consumer and producer of resources (e.g., broadcast of Olympic Games 2008)

  - Use of decentralized resources on the edge of the Internet (e.g., desktops)

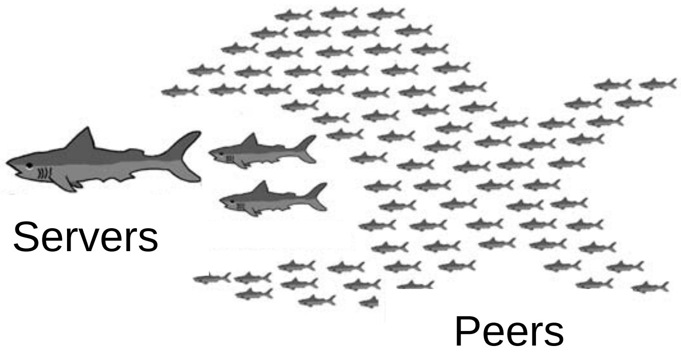
- Benefits

  - Scalability: More resources in larger networks („the cake grows")

  - Robustness: No single point of failure

  - Can outperform server-based solutions

  - Cheap: start-up vs Google



- Therefore:

  - No need for expensive infrastructure at content distributors

  - Democratic aspect: Anyone can publish media contents / speeches

A Challenge

- In practice, peer-to-peer is not synonym for „from equal to equal“
  - Rather some peers may be „more equal than others“!

- E.g.
  - Some peers want to be consumers only (but not producers) of resources
  - Some peers may be malicious
  - Some peers may be social
  - Different capabilities (e.g., better Internet connection)

- These differences must not be ignored
  - E.g., punish selfish behavior
  - E.g., ensure efficiency despite heterogeneity

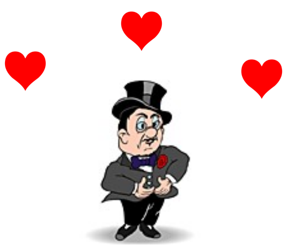
State of the Art

- Peer-to-peer systems: no effective solutions for many inequality problems today
- Example 1: BitThief client downloads entire files from BitTorrent without uploading
- Example 2: Censorship attacks in the Kad network (malicious peer)
  - Peer assumes corresponding IDs
- Example 3: Solutions for heterogeneity challenge often simplistic
  - Cheated incentive mechanism: *Kazaa Lite client* hardwires user contribution to maximum
  - Limited heterogeneity: two peer type approach of Gnutella or Kazaa

Talk Outline

- Case Study 1: Non-Cooperation in BitTorrent Swarms *(HotNets 2006)*

- Case Study 2: Malicious Peers in the Kad Network *(under submission)*



- Analysis of Social Behavior in Peer-to-Peer Systems *(EC 2008)*

- SHELL: A Heterogeneous Overlay Architecture *(under submission)*

- Conclusion

Case Study BitThief:
Free-riding Peers in BitTorrent

BitThief: BitTorrent

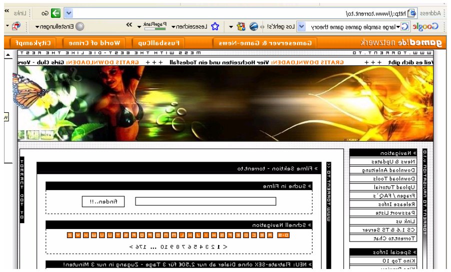
- BitTorrent = one of the most popular p2p systems
  - Millions of simultaneous users

- One of the few systems incorporating incentive mechanism

- Basic principle

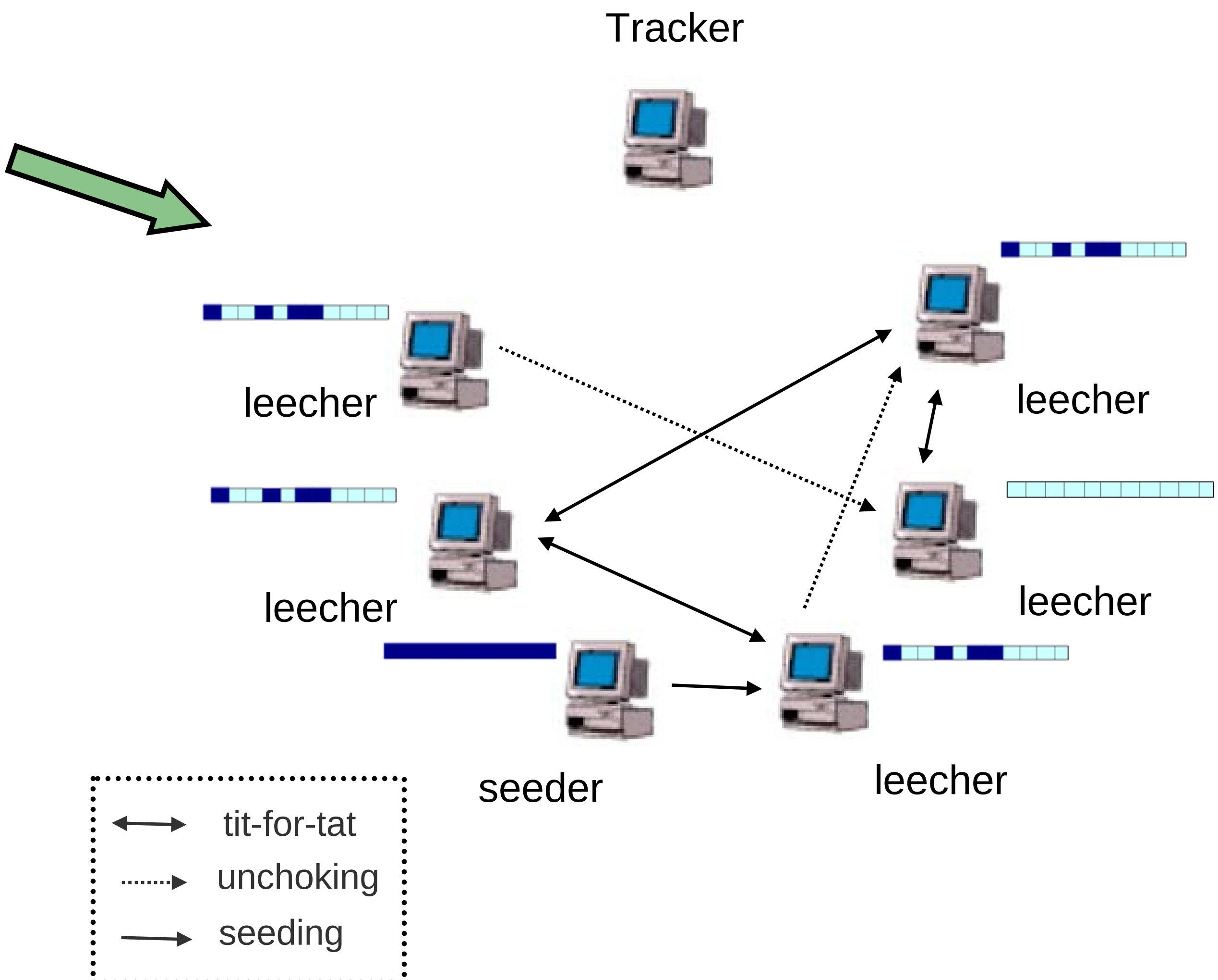
  - Peers interested in same file are organized by a tracker in a swarm
  - File is divided into pieces (or „blocks“)
  - Distinguish between seeders (entire file) and leechers (not all pieces)
  - Peers have different pieces which are exchanged in a tit-for-tat like manner
  - Bootstrap problem: peers optimistically unchoke neighbors (round-robin = give some pieces „for free“)

BitThief: BitTorrent Swarms



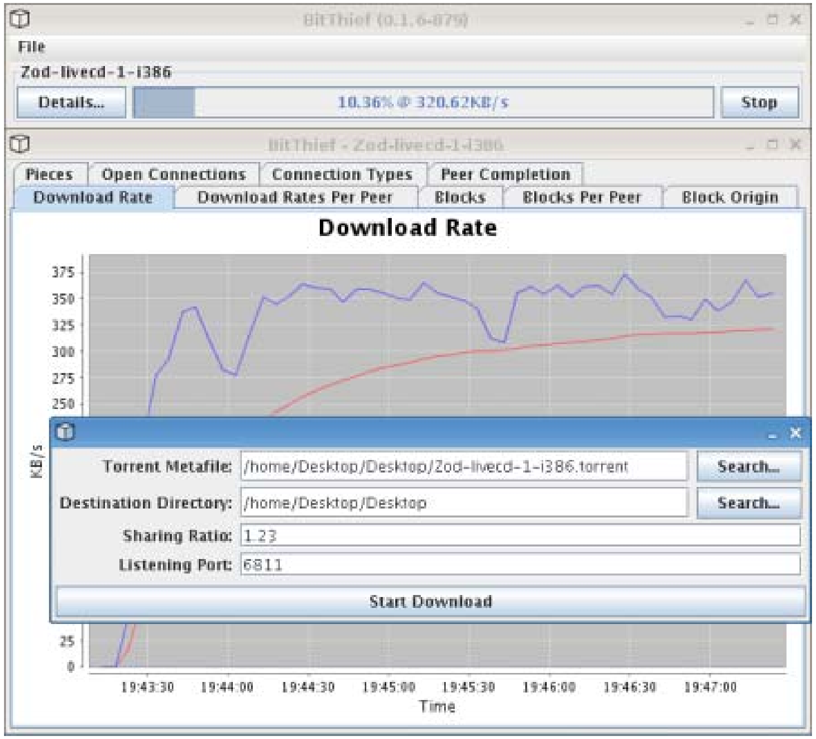
website with .torrent file

- tracker address
- verification data
- ....



BitThief: Goal

BitThief = proof of concept Java client (implemented from scratch) which achieves fast downloads without uploading at all – in spite of BitTorrent‘s incentive mechanism!



BitThief: Tricks

BitThief's three simple tricks:

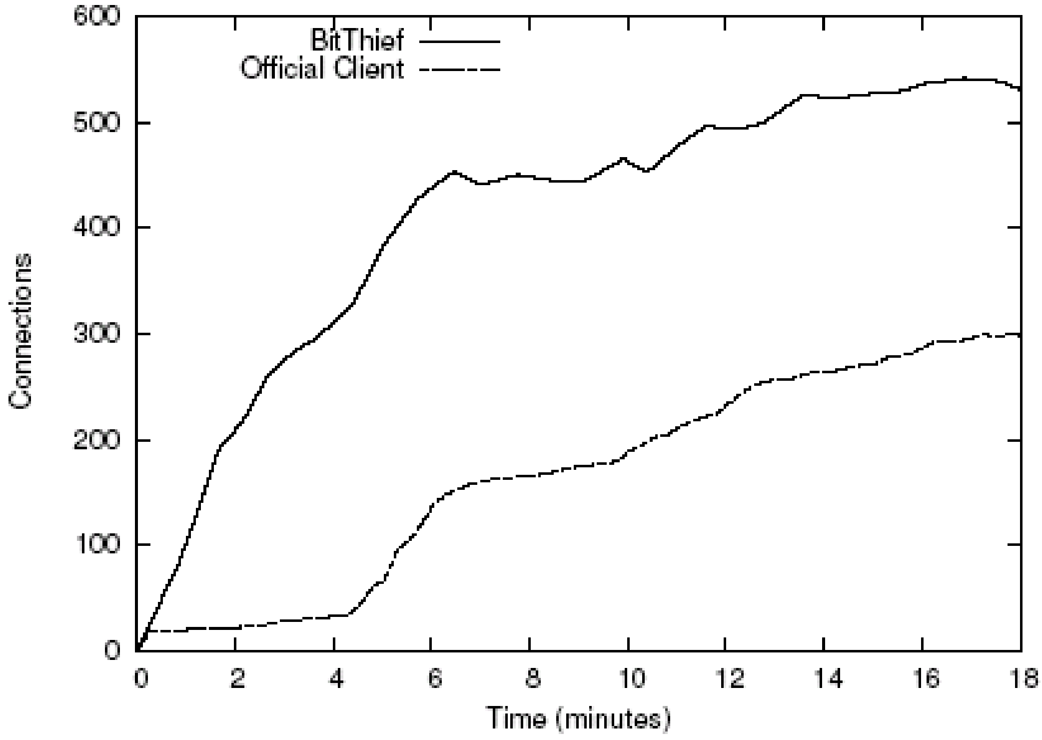
- Open as many TCP connections as possible
- Contacting tracker again and again, asking for more peers (never banned!)
- Pretend being a great uploader in sharing communities

⇒ Exploit optimistic unchoking slots (large view exploit)

⇒ „Exploit" seeders

⇒ Exploit sharing communities

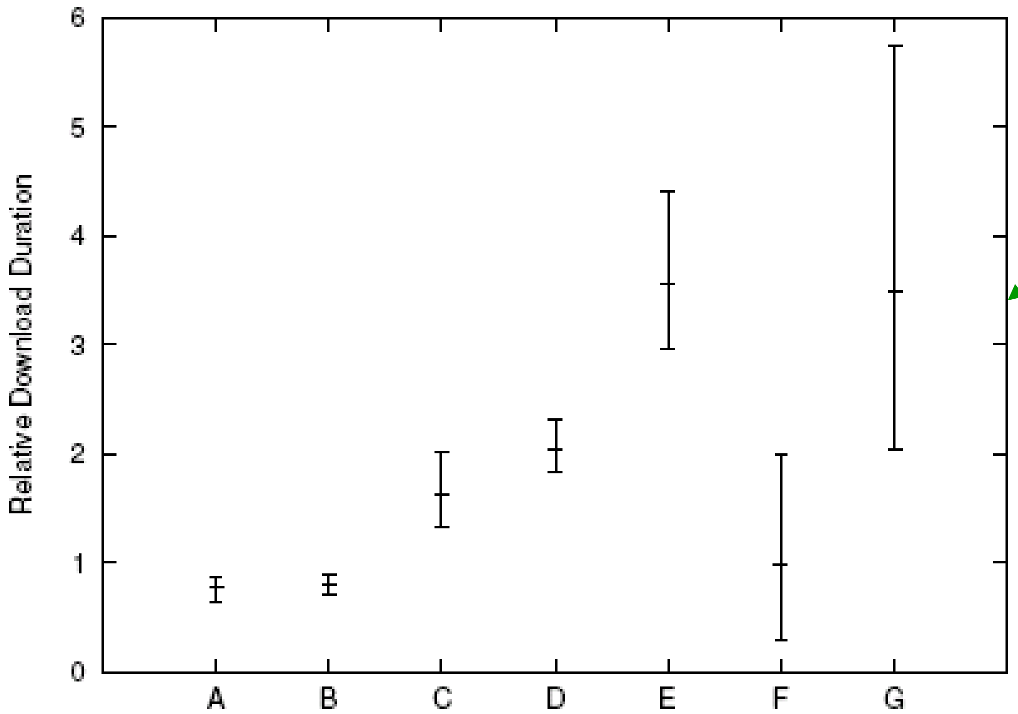
BitThief: Connect to More Neighbors…



BitThief: Results (with Seeders)

2

compared to official client (with unlimited number of allowed connections)



4 BitThief with public IP and open TCP port

number of peers announced by tracker

max peers found by BitThief

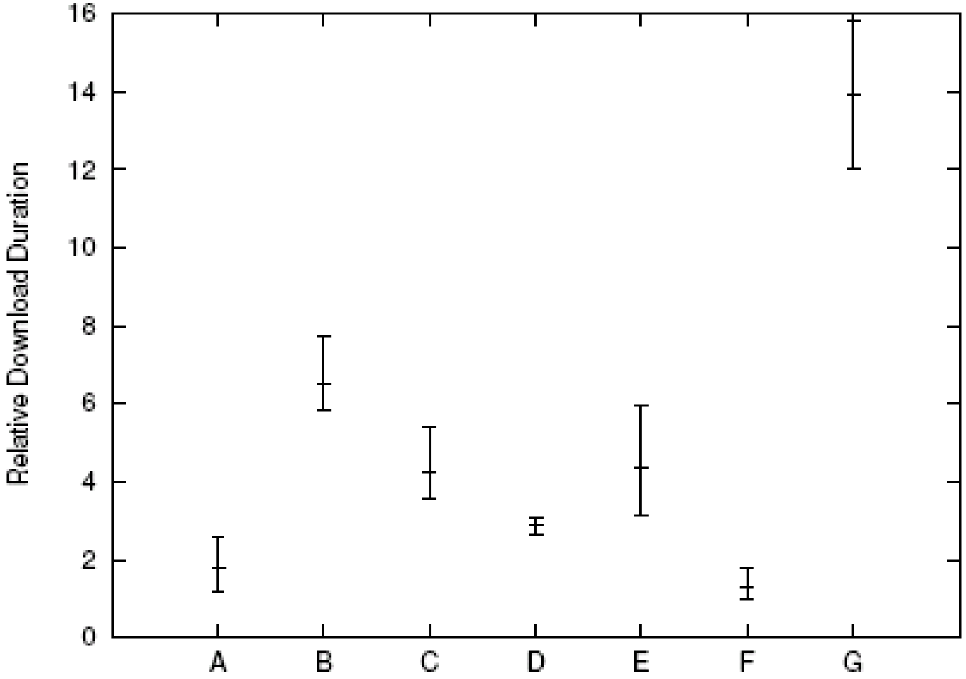
1

	Size	Seeders	Leechers
A	170MB	10518 (303)	7301 (98)
B	175MB	923 (96)	257 (65)
C	175MB	709 (234)	283 (42)
D	349MB	465 (156)	189 (137)
E	551MB	880 (121)	884 (353)
F	31MB	N/A (29)	N/A (152)
G	798MB	195 (145)	432 (311)

3

- All downloads finished!
- Fast for small files (fast startup), many peers and many seeders!

BitThief: Results (*without* Seeders)

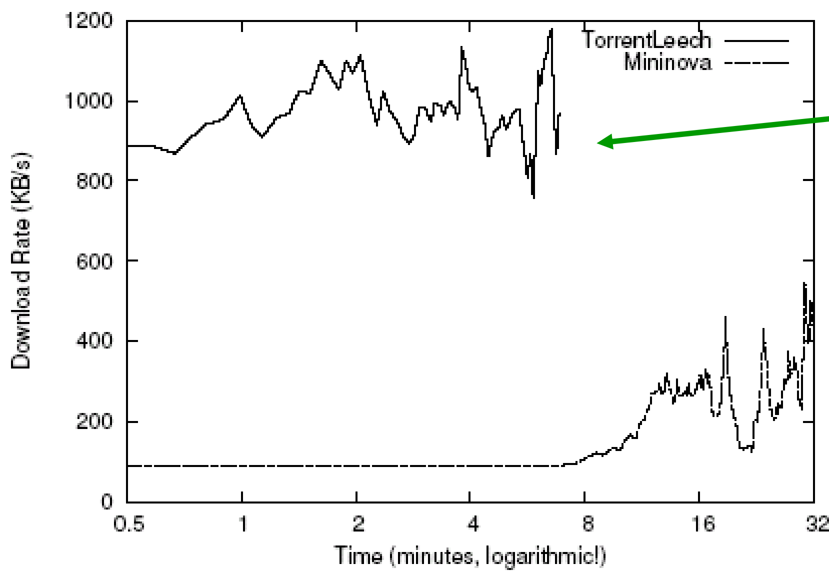


- Seeders detected with bitmask / have-message
- Even without seeder it's fast!
- Unfair test: Mainline client was allowed to use seeders!

	Size	Seeders	Leechers
A	170MB	10518 (303)	7301 (98)
B	175MB	923 (96)	257 (65)
C	175MB	709 (234)	283 (42)
D	349MB	465 (156)	189 (137)
E	551MB	880 (121)	884 (353)
F	31MB	N/A (29)	N/A (152)
G	798MB	195 (145)	432 (311)

BitThief: Sharing Communities (1)

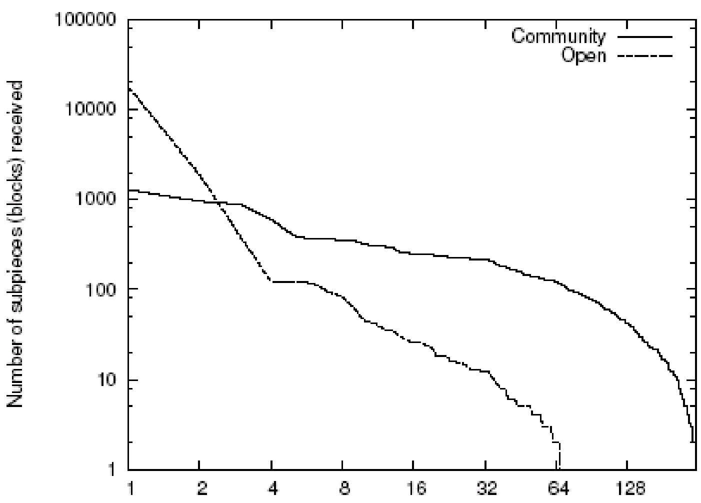
- Closed / private swarm
  - Tracker requires user registration
  - Monitors contributions, bans peers with low sharing ratios
- Client can report uploaded data itself! (tracker announcements)
  - As tracker does not verify, it‘s easy to remain in community...
  - ... and communities are often a cockaigne for BitThief.



4 x faster!
(BitThief had a faked sharing ratio of 1.4; in both networks, BitThief connected to roughly 300 peers)

BitThief: Sharing Communities (2)

- In communities, contribution is more balanced
- Reason?
  - Peers want to boost ratio?
  - Users more tech-savvy? (less firewalled peers? faster network connections?)



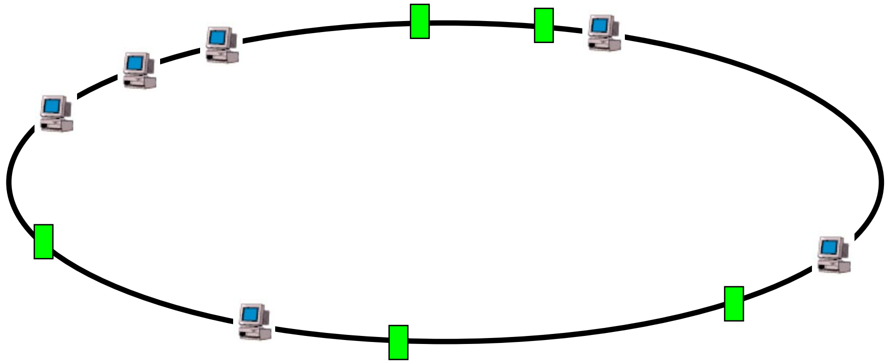
Case Study Kad:
Censorship in Kad

Under submission / PhD thesis

Kad: The Kad Network

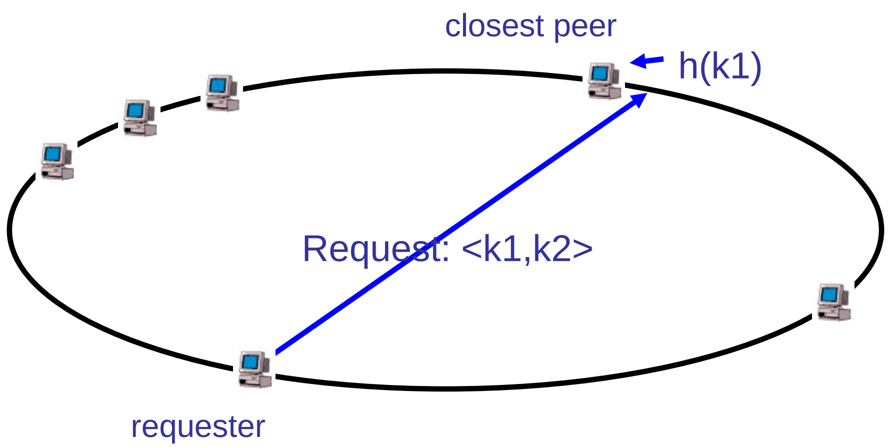
- Kad = one of the first widely used distributed hash tables (DHT)
  - A structured peer-to-peer system where the index is stored distributedly
  - In literature, DHTs have been studied for years (Chord, Pastry, etc.)

- Basic principle
  - Consistent hashing
  - Peers and data items with identifiers chosen from [0,1)
  - (Pointers to) data items stored on closest peers*



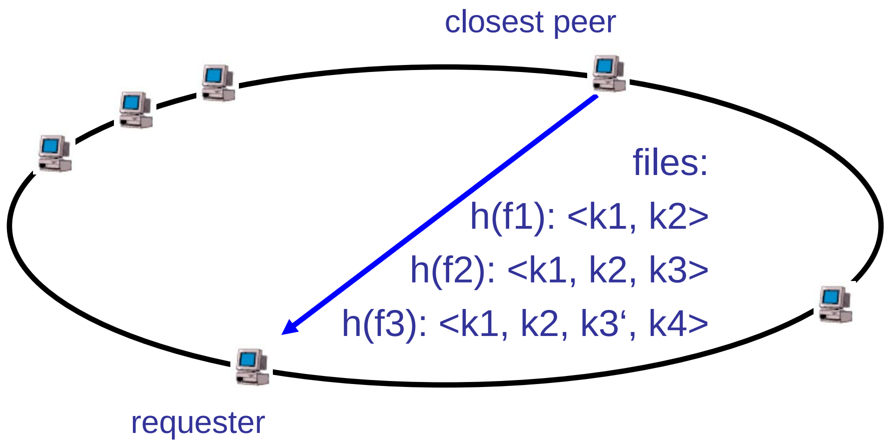
* Attention: this is a simplification (factor 10 replication in „close" tolerance zone)

Kad: Keyword Request



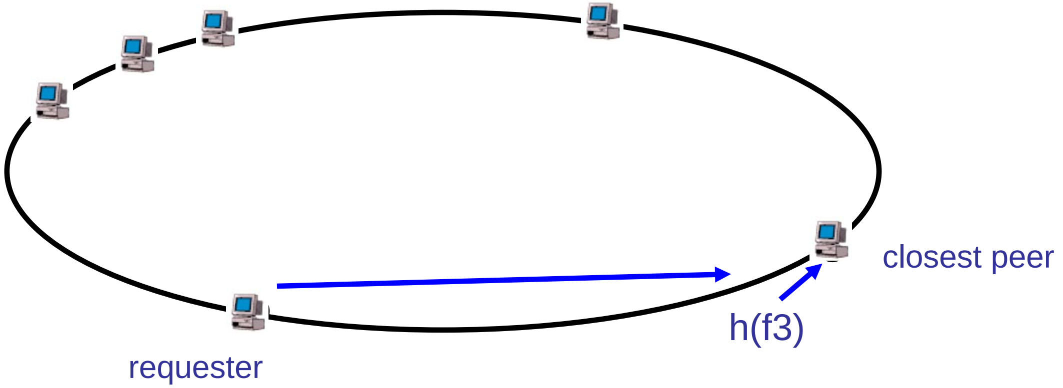
Lookup only with first keyword in list. Key is hash function on this keyword, will be routed to peer with Kad ID closest to this hash value. This peer is responsible for files stored with this first keyword.

Kad: Keyword Request



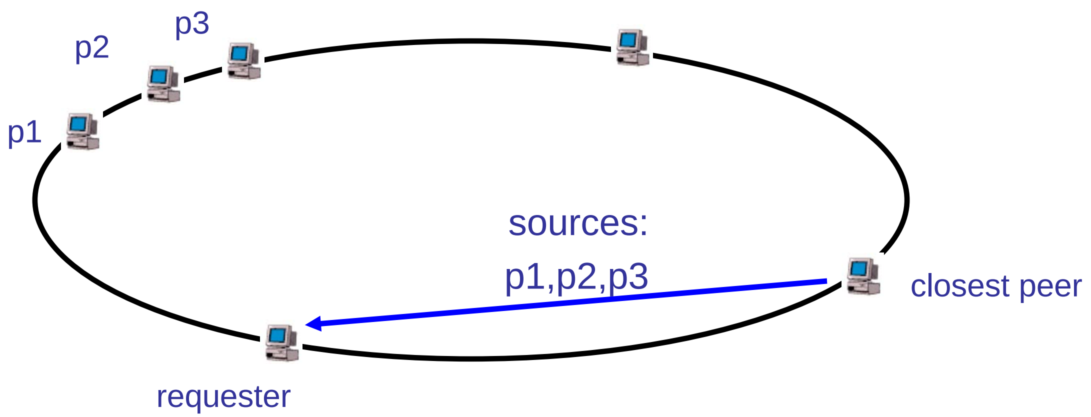
Peer responsible for this keyword returns different sources (hash keys) together with keywords.

Kad: Source Request



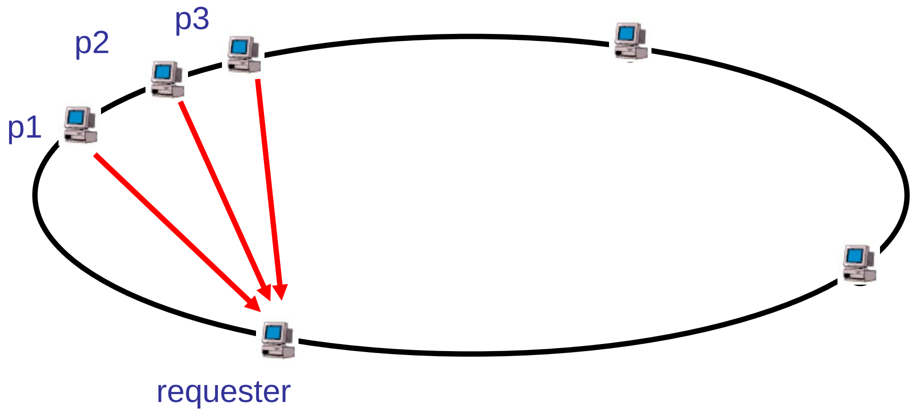
Peer can use this hash to find peer responsible for the file.

Kad: Source Request



Peer provides requester with a list of peers storing a copy of the file.

Kad: Download

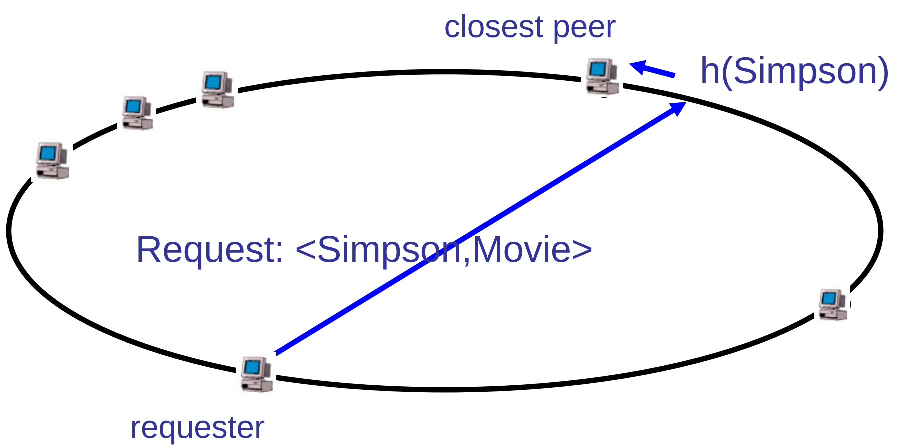


Eventually, the requester can download the data from these peers.

Kad: Censorship

- Kad network has several vulnerabilities

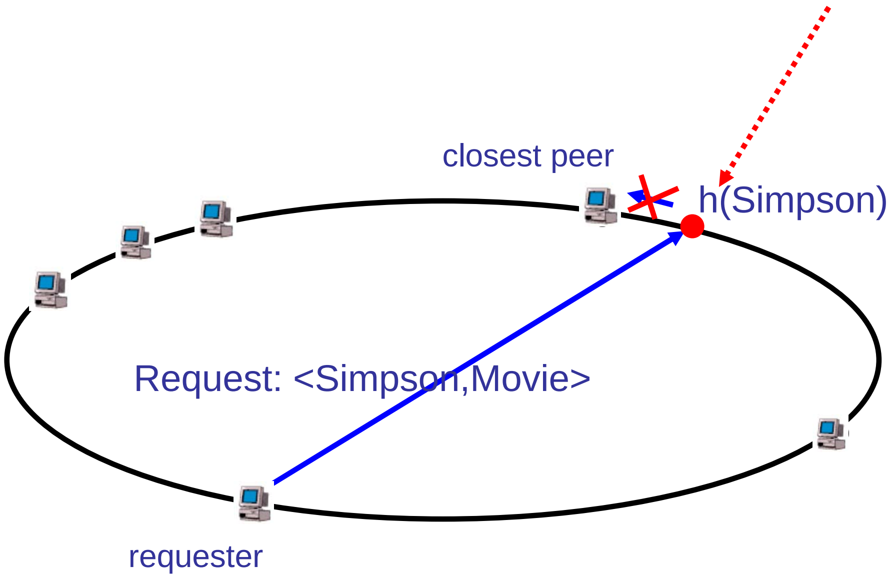
- Example: malicious peers can perform censorhip attack
  - Simply by assuming the corresponding IDs (peer insertion attack)
  - No prescribed ID selection method or verification



Kad: Censorship

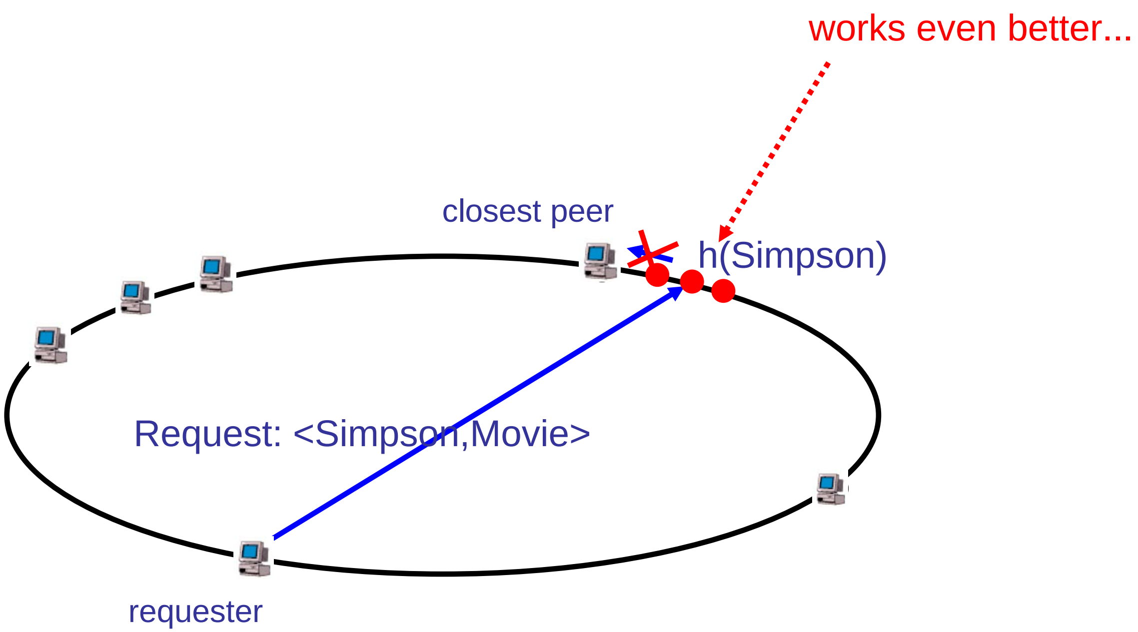
- Censoring contents in Kad

If peer is inserted here, it can block (or spy on) keyword requests for „Simpsons“, „Simpsons Movie“, etc.



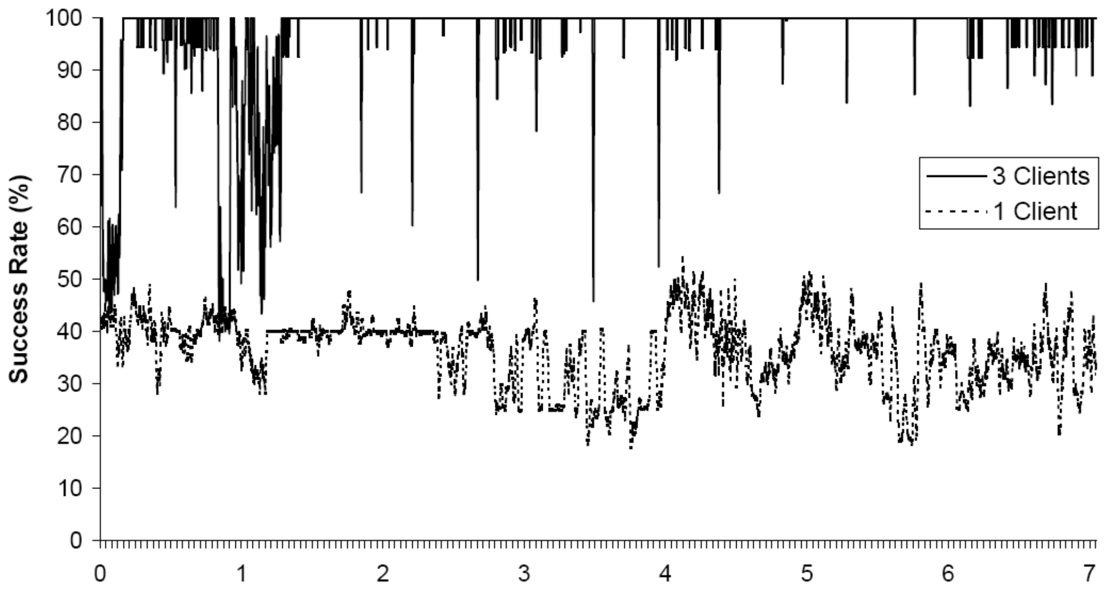
Kad: Censorship

- Censoring contents in Kad



Kad: Censorship

- Some results



- Similarly for source requests
- There are also other censorship attacks (e.g., pollute cache of other peers)
- Plus eclipse and denial of service attacks (e.g., pollute cache such that requests are forwarded to external peers)...

Easy to Fix?

BitThief and Kad Attacks

- BitThief
  - Optimistic unchoking can be exploited
  - Just do pure tit-for-tat? Bootstrap problem...
  - Fast extension: subset of pieces only (limited „venture capital")
  - What if participants are not directly interested in each other? E.g., inter-swarm incentives?

- Kad Attacks
  - Do not accept too much information from same peer (e.g., publish attack)
  - Bind ID to peer... But how?
  - Bind to IP? But what about NATs where many peers have same ID? And what about dynamic IP addresses? Lose credits?
  - Generate ID, e.g., by hashing a user phrase? But due to sparsely populated ID space, it's still easy to generate IDs close to the object...

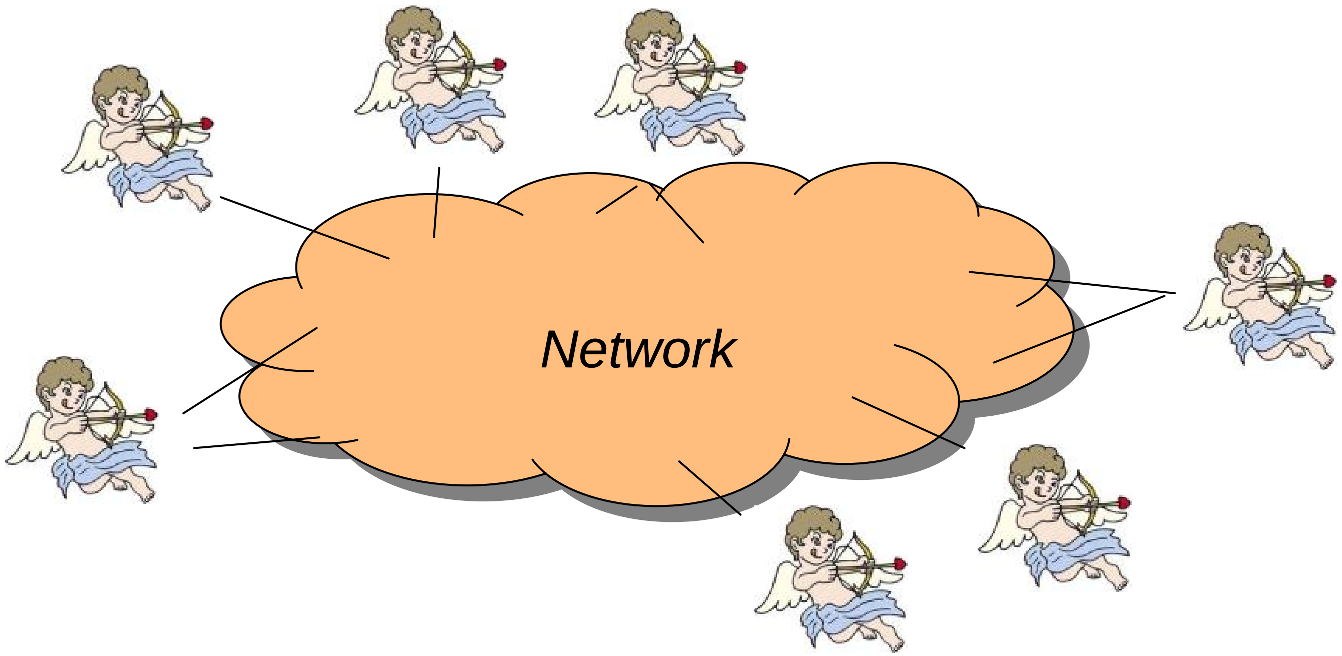
What is the Impact of such Non-cooperative Behavior? (Extended) Game Theory…

PODC 2006 / EC 2008

Modelling Peers (1)

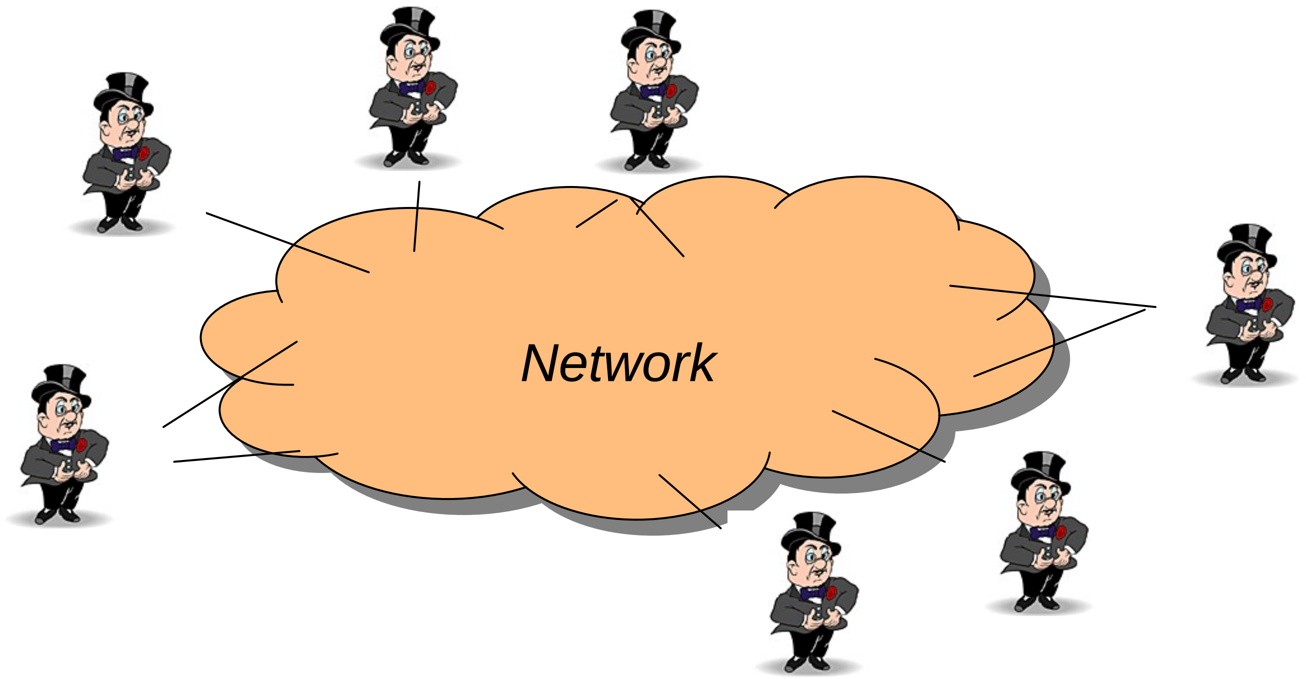
- Game theory is formalism to study uncooperative behavior
  - mainly selfish individuals (e.g., Price of Anarchy)

- Model for peer-to-peer network?



Modelling Peers (2)

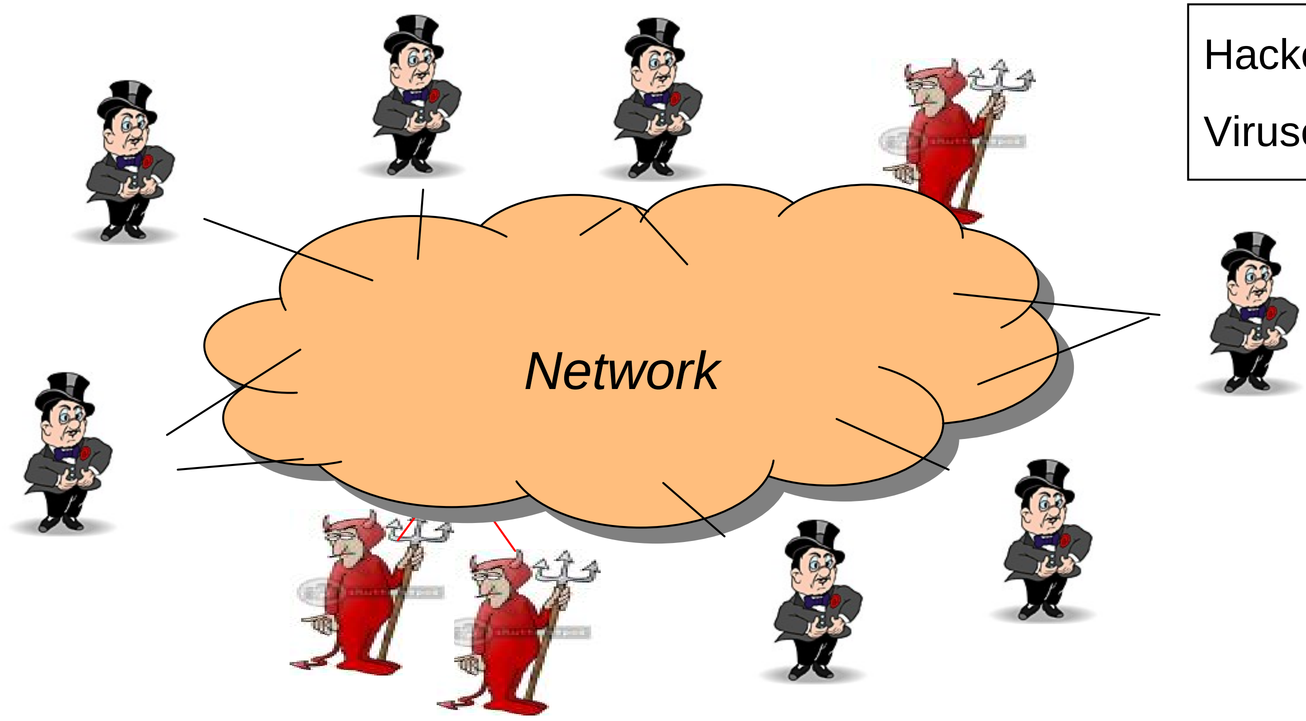
- Game theory models participants as selfish players
  - Seek to maximize their utility



Modelling Peers (3)

- We extended this model and introduced malicious players

  - seek to minimize social welfare



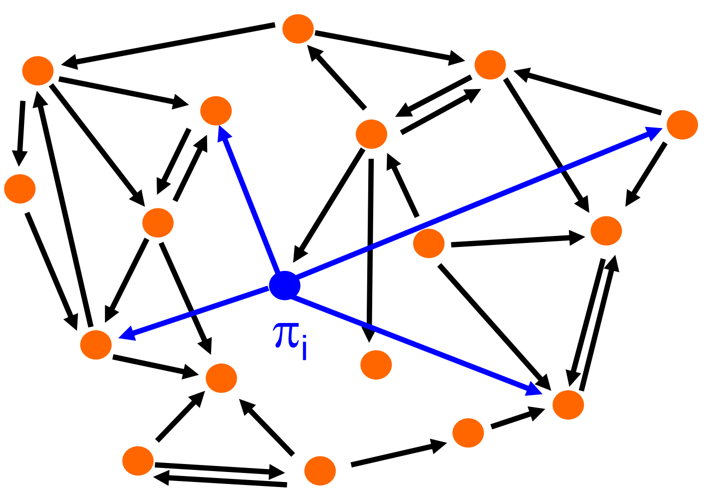
Hackers, Polluters,

Viruses, DOS attacks

Impact of Selfish Players

- Study of strategic behavior in unstructured peer-to-peer topologies

- Some results of network creation game (PODC 2006)
  - Price of Anarchy can be large
  - Nash equilibria may not exist (instability!)
  - NP-hard to decide whether a given network will stabilize



Impact of Malicious Players

- What is impact of malicious players in selfish networks?

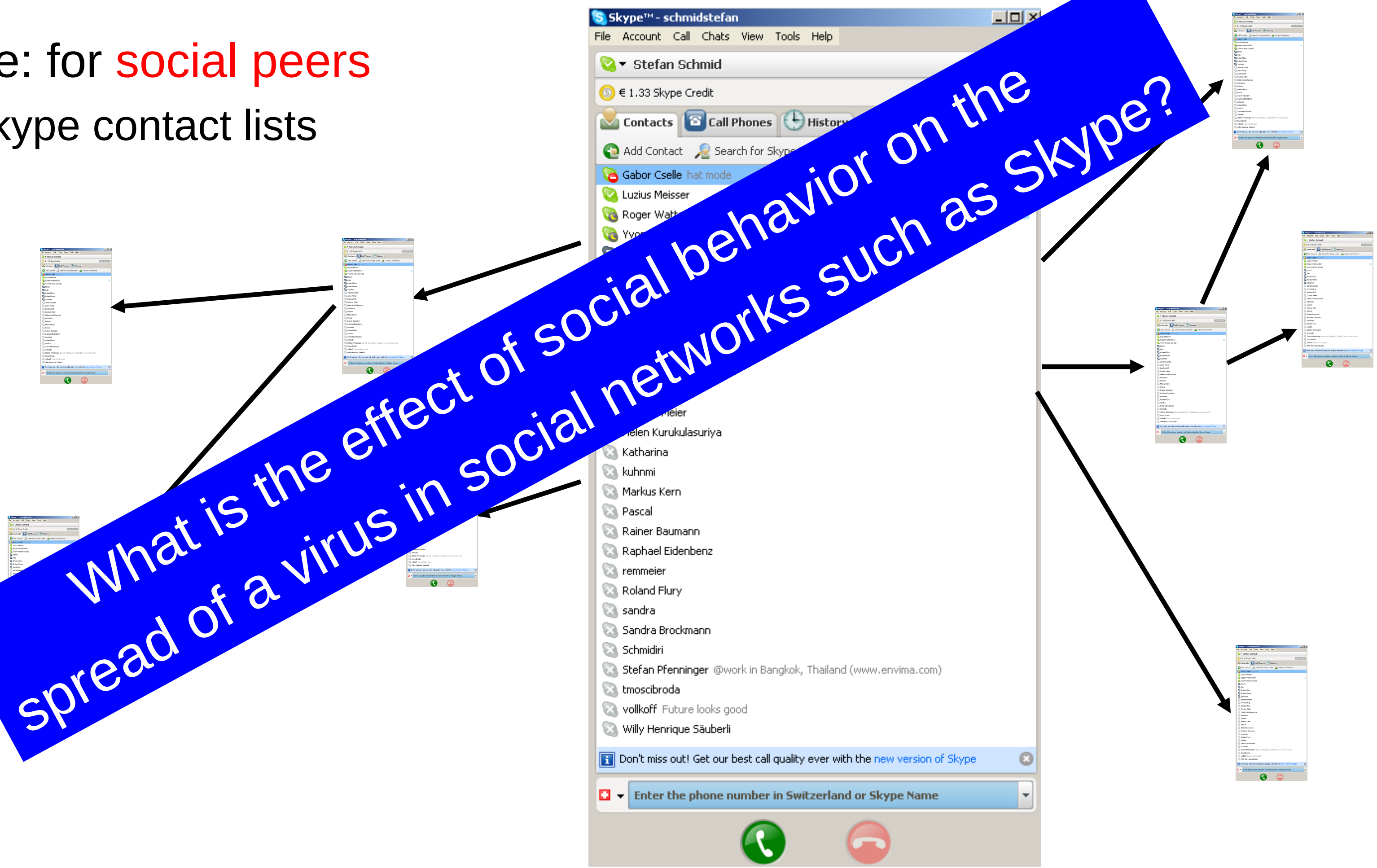
- Depends on
  - Knowledge of selfish players on malicious players
  - How selfish players react to this knowledge (neutral, risk-averse, etc.)

- Some results (PODC 2006) for a virus inoculation game
  - If selfish players are oblivious, malicious players reduce social welfare
  - If players non-oblivious and risk-averse, social welfare may improve!
  - Phenomenon called fear factor or windfall of malice

Impact of Social Players?

- We devised a framework to analyze uncooperative behavior

- Example: for social peers
  - E.g., Skype contact lists

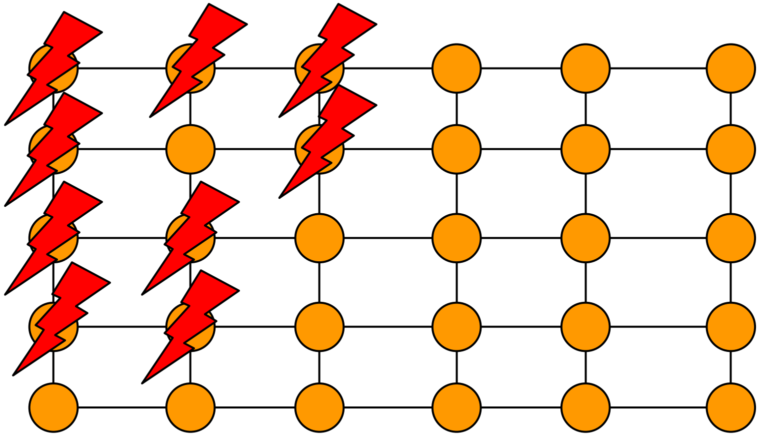


What is the effect of social behavior on the spread of a virus in social networks such as Skype?

A Sample Game

- Sample game: virus inoculation

- The game
  - Network of n peers (or players)
  - Decide whether to inoculate or not
  - Inoculation costs C
  - If a peer is infected, it will cost L>C

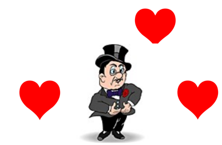


- At runtime: virus breaks out at a random player, and (recursively) infects all insecure adjacent players

Modelling Peers...

- Peers are selfish, maximize utility

- However, utility takes into account friends‘ utility
  - „local game theory“



- Utility / cost function of a player
  - Actual individual cost:

k_i = attack component size

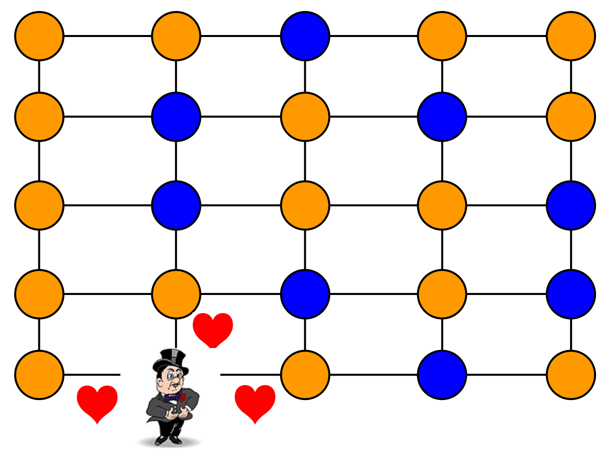
$$c_a(i,\vec{a}) = a_i \cdot C + (1-a_i)L \cdot \frac{k_i}{n}$$

a_i = inoculated?

  - Perceived individual cost:

$$c_p(i,\vec{a}) = c_a(i,\vec{a}) + F \cdot \sum_{p_j \in \Gamma(p_i)} c_a(j,\vec{a})$$

F = friendship factor,
extent to which players care about friends

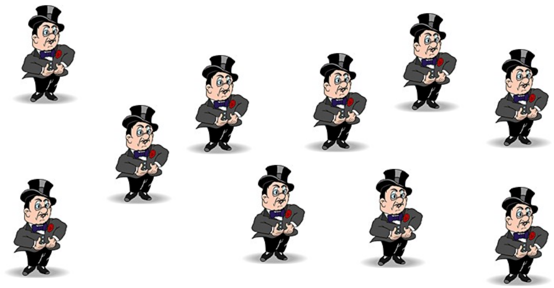


Social Costs and Equilibria

- In order to quantify effects of social behavior...

- Social costs

  - Sum over all players' actual costs



- Nash equilibria

  - Strategy profile where each player cannot improve her welfare...
  - ... given the strategies of the other players
  - Nash equilibrium (NE): scenario where all players are selfish
  - Friendship Nash equilibrium (FNE): social scenario
  - FNE defined with respect to perceived costs!
  - Typical assumption: selfish players end up in such an equilibrium (if it exists)

Evaluation

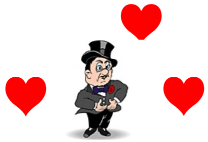
- What is the impact of social behavior?

- Windfall of friendship

  - Compare (social cost of) worst NE where every player is selfish (perceived costs = actual costs)...

  - ... to worst FNE where players take friends‘ actual costs into account with a factor F (players are „social“)

Windfall of Friendship

- Formally, the windfall of friendship (WoF) is defined as

$$\Upsilon(F, I) = \frac{\max_{NE} C_{NE}(I)}{\max_{FNE} C_{FNE}(F, I)}$$

instance I describes graph, C and L

- WoF >> 1 => system benefits from social aspect

  - Social welfare increased

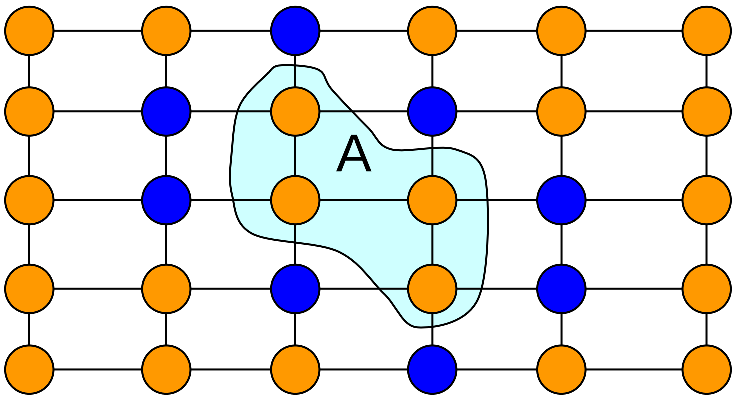
- WoF < 1 => social aspect harmful

  - Social welfare reduced

Characterization of NE

- In regular (and pure) NE, it holds that...

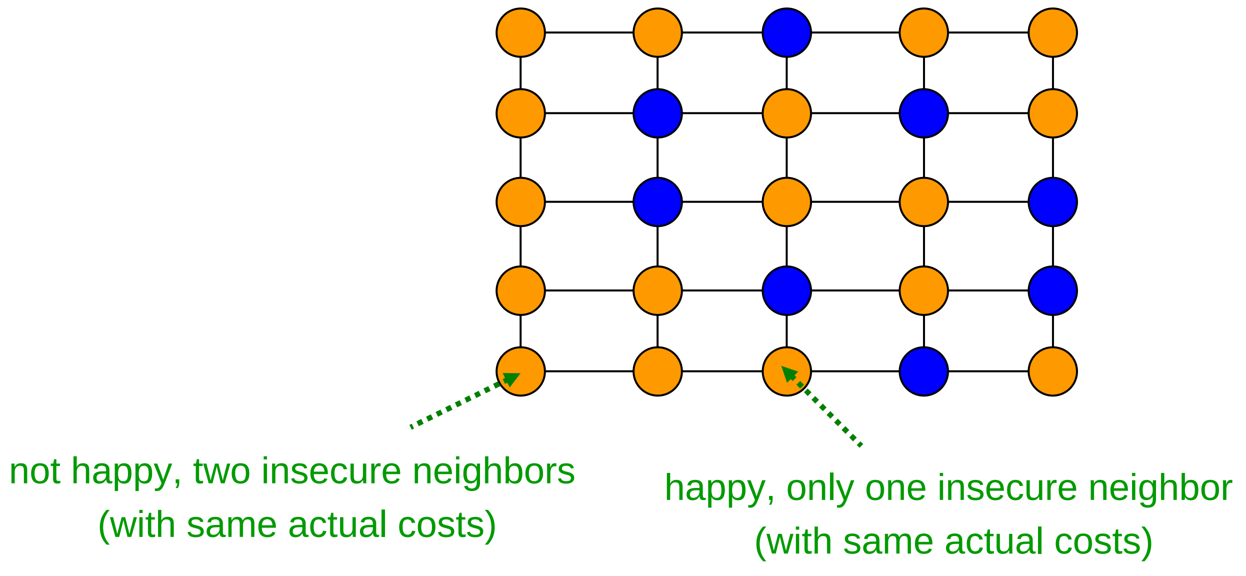
- Insecure player is in attack component A of size at most Cn/L
  - otherwise, infection cost
    > (Cn/L)/n * L = C



- Secure player: if she became insecure, she would be in attack component of size at least Cn/L
  - same argument: otherwise it‘s worthwhile to change strategies

Characterization of Friendship Nash Equilibria

- In friendship Nash equilibria, the situation is more complex
- E.g., problem is asymmetric
  - One insecure player in attack component may be happy...
  - ... while other player in *same component* is not
  - Reason: second player may have more insecure neighbors



Bounds for the Windfall

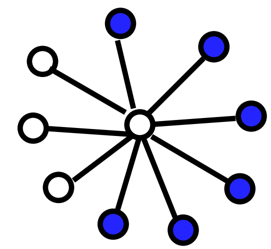
THEOREM 4.2. *For all instances of the virus inoculation game and* $0 \leq F \leq 1$*, it holds that*

$$1 \leq \Upsilon(F, I) \leq PoA(I).$$

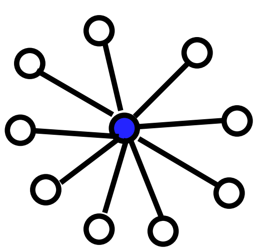
- It is always beneficial when players are social!
- The windfall can never be larger than the price of anarchy
  - Price of anarchy = ratio of worst Nash equilibrium cost divided by social optimum cost
- Actually, there are problem instances (with large F) which indeed have a windfall of this magnitude („tight bounds“, e.g., star network)

Example of Large Windfall: Star Graph

- In regular NE, there is always a (worst) equilibrium where center is insecure, i.e., we have n/L insecure nodes and n-n/L secure nodes (for C=1):



Social cost = (n/L)/n * n/L * L + (n-n/L) ~ n



- In friendship Nash equilibrium, there are situations where center *must* inoculate, yielding optimal social costs of (for C=1):

Social cost = „social optimum“
= 1 + (n-1)/n * L ~ L

WoF as large as maximal price of anarchy in arbitrary graphs (i.e., n for constant L).

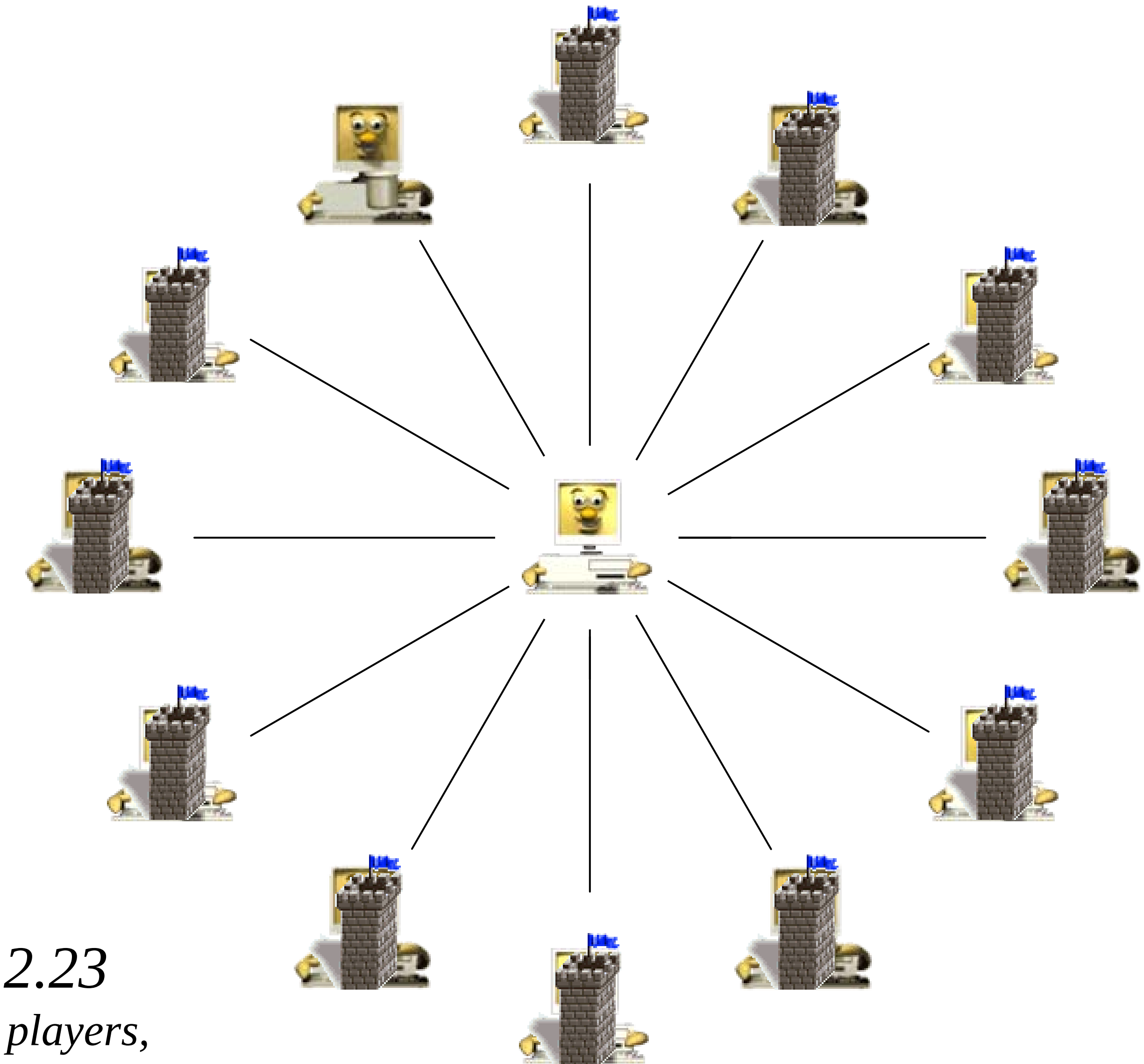
Monotonicity

But the windfall does not increase monotonously:
WoF can decline when players care more about their friends!

- Example again in simple star graph...

Monotonicity: Counterexample

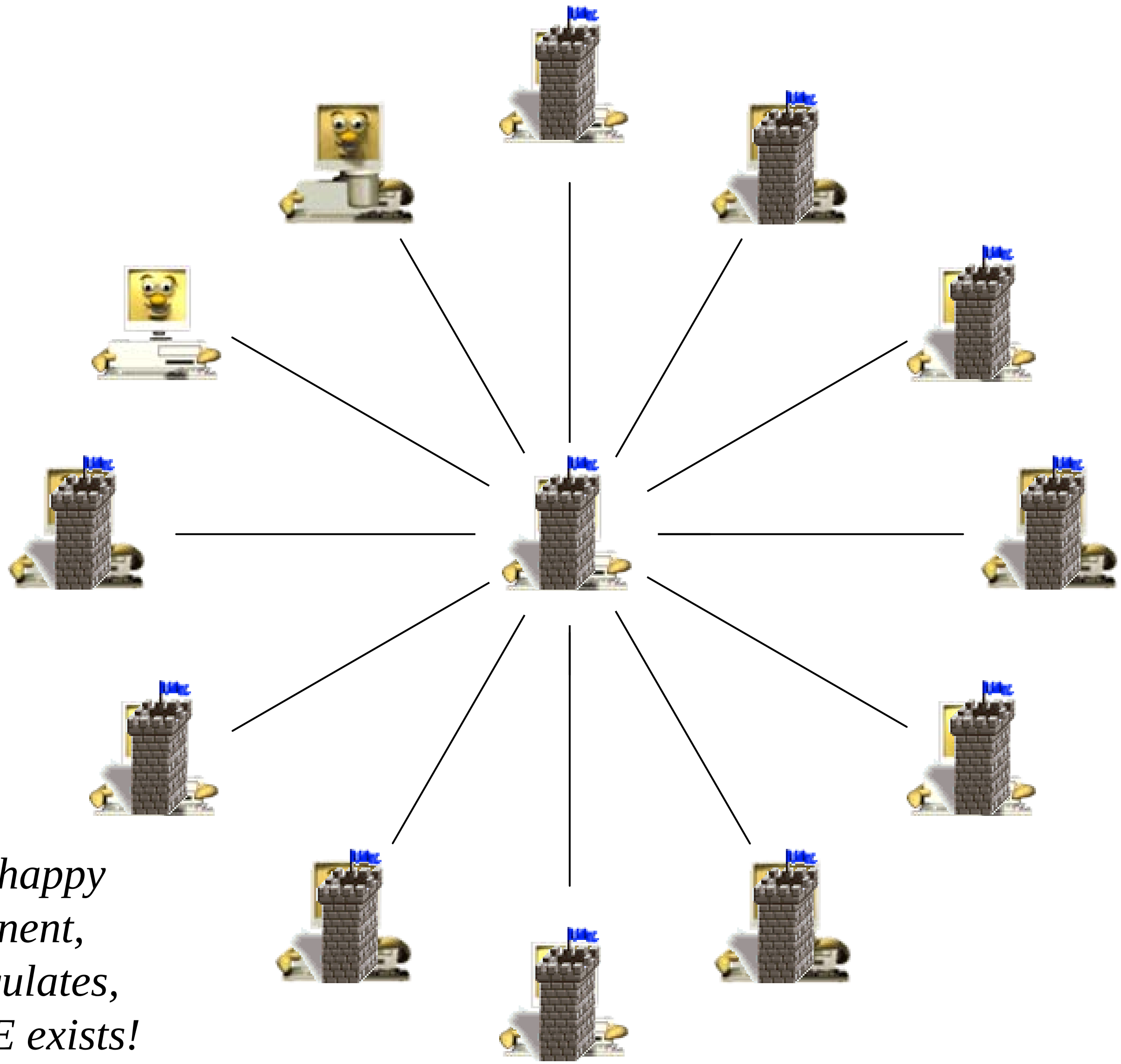
n = 13
C = 1
L = 4
F = 0.9



total cost = 12.23
(many inoculated players, attack component size two)

Monotonicity: Counterexample

n = 13
C = 1
L = 4
F = 0.1



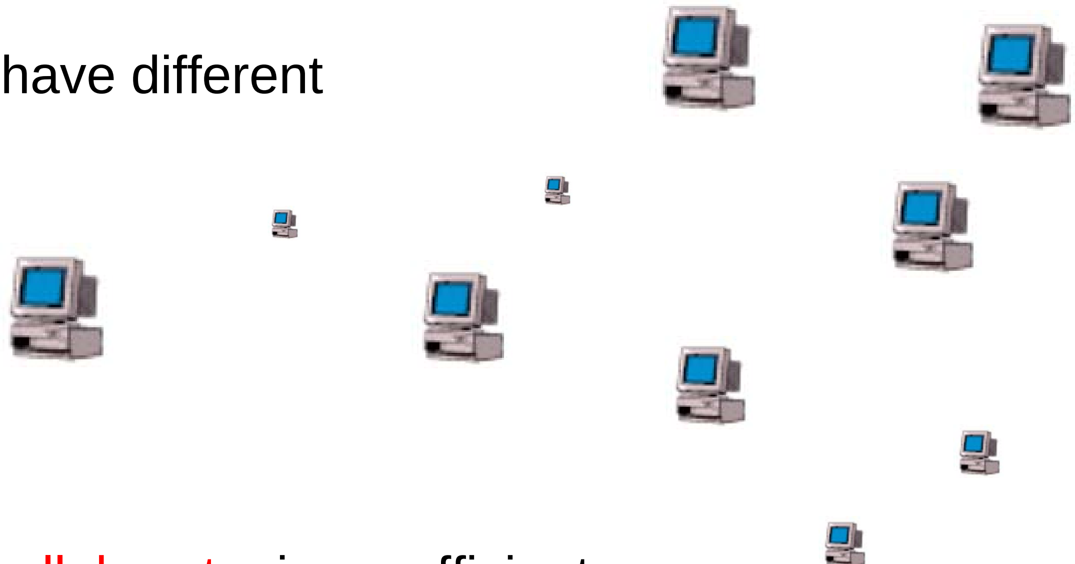
Boundary players happy with larger component, center always inoculates, thus: only this FNE exists! total cost = 4.69

Other Forms of Inequality?
Heterogeneous Capabilities…

Under submission

Heterogeneous Peers...

- Peer-to-peer machines have different
  - Internet connections
  - CPUs
  - Hard disks
  - Operating systems
  - ...

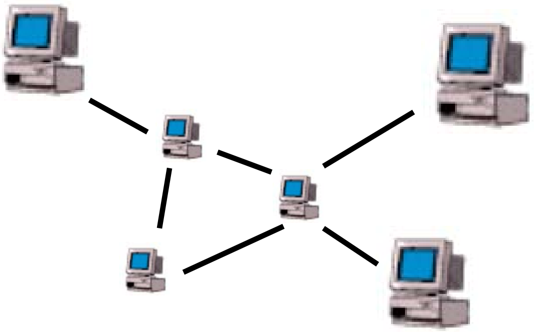


- But still, peers need to collaborate, in an efficient way

- Interesting problem
  - E.g., conflict with incentive compatibility
  - Should a (cooperative) weak peer be supported by stronger peers?
  - Threat: strategic behavior? Is peer weak or just selfish?

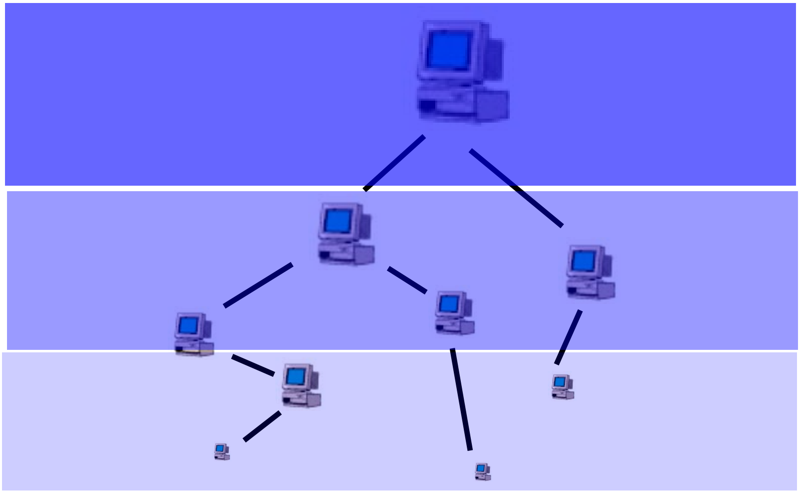
The Basic Problem

- Motivation: strong peers cannot make full use of the system if they can only interact indirectly via weak peers



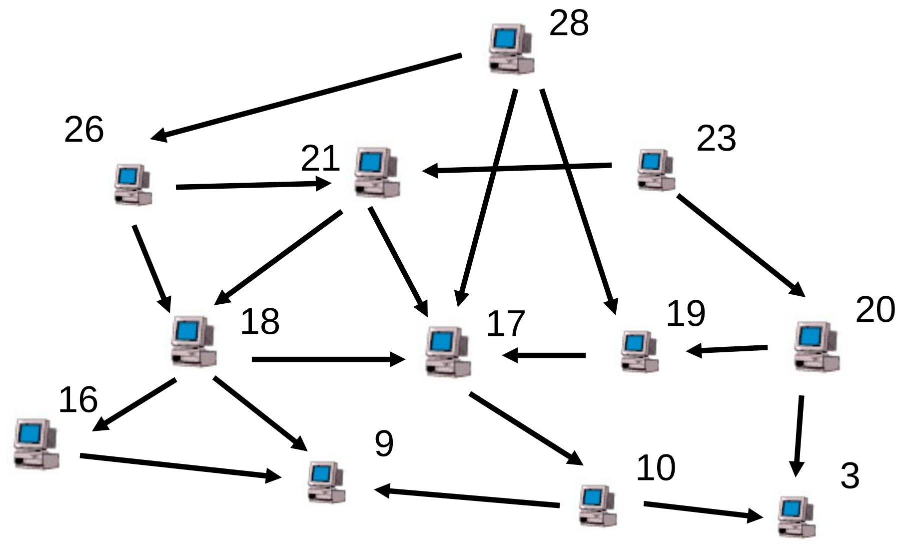
- Idea: clustering of peers with roughly same capability!

  - in a heap-like manner



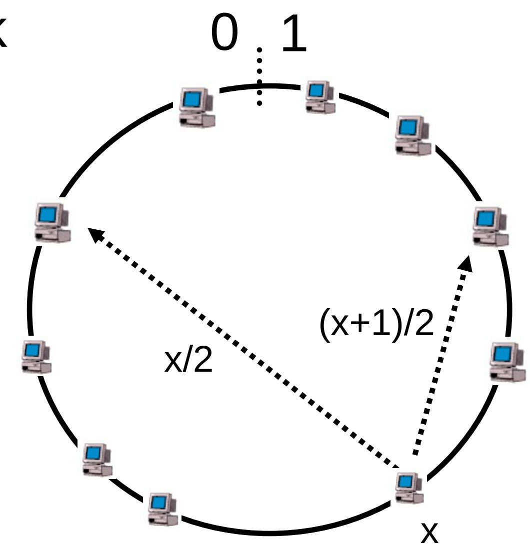
The Distributed SHELL Heap

- What is a distributed heap?
- We assume that peers have a key / rank / order / id
  - for example: inverse of peer capability
- (Min-) heap property: peers only connect to peers of lower rank
  - for example: peers only connect to stronger peers
  - SHELL constructs a directed overlay
    (routing along these edges only)

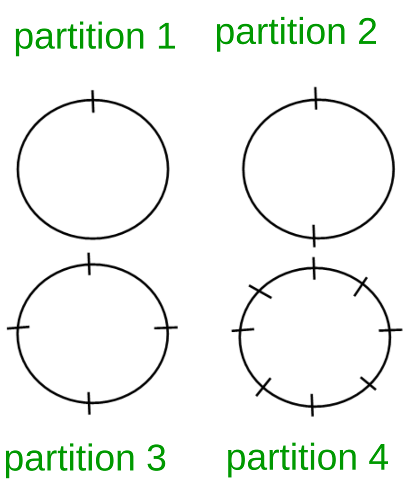


The SHELL Topology (1)

- Continuous-discrete approach: de Bruijn network



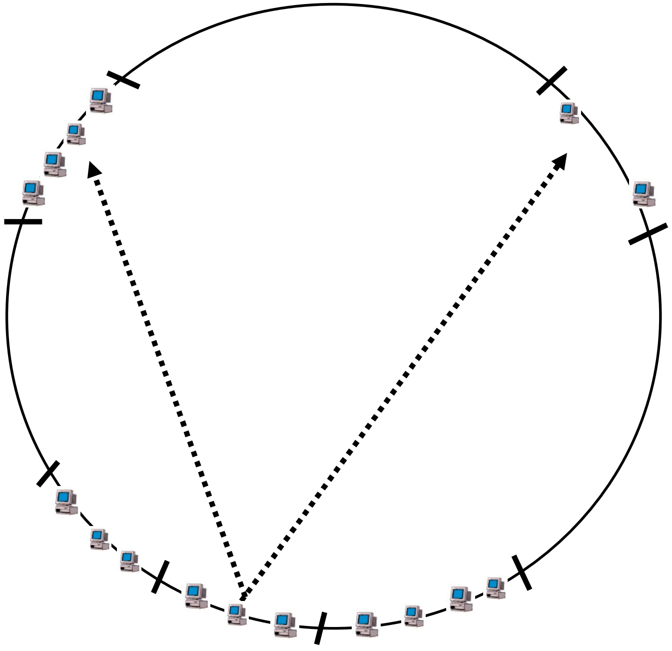
- Problem: de Bruijn neighbor may have larger rank



- Solution
  - peer at position x connects to all lower-ranked peers in an interval around x/2 and (x+1)/2
  - i.e., space divided into intervals
  - size of interval depends on number of low-rank peers there
  - larger degree, but still logarithmic diameter etc.

The SHELL Topology (2)

- Peer connects to all peers of lower order in
  - Level-i home interval (interval which includes position x of peer)
  - Adjacent level-i intervals to home
  - de Bruijn intervals: intervals which include position x/2 and (x+1)/2
- What is level i?
  - Level i chosen s.t. there are at least $c \log n_v$ lower order peers in interval
  - n_v = total number of peers in system with lower order
  - n_v can be estimated, in the following we assume it is given



Routing

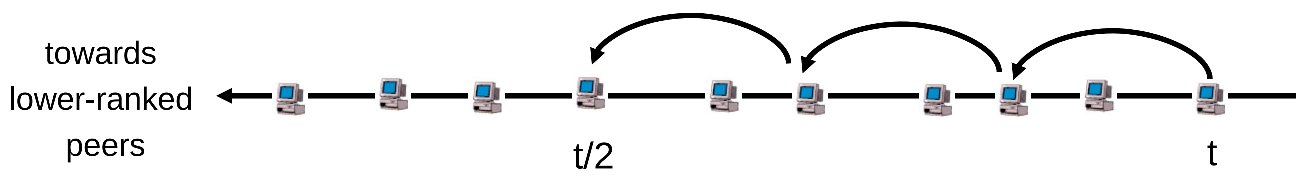
- Routing paths: if peer p is weaker than peer p‘, a request sent from p to p‘ only traverses peers which are stronger than p

  - „augmenting paths“

- E.g., live streaming: quality of transmission depends on weaker of the two peers, but not on peers in-between

- General routing policy: route according to de Bruijn rules, and choose highest-ranked peer to forward message in interval

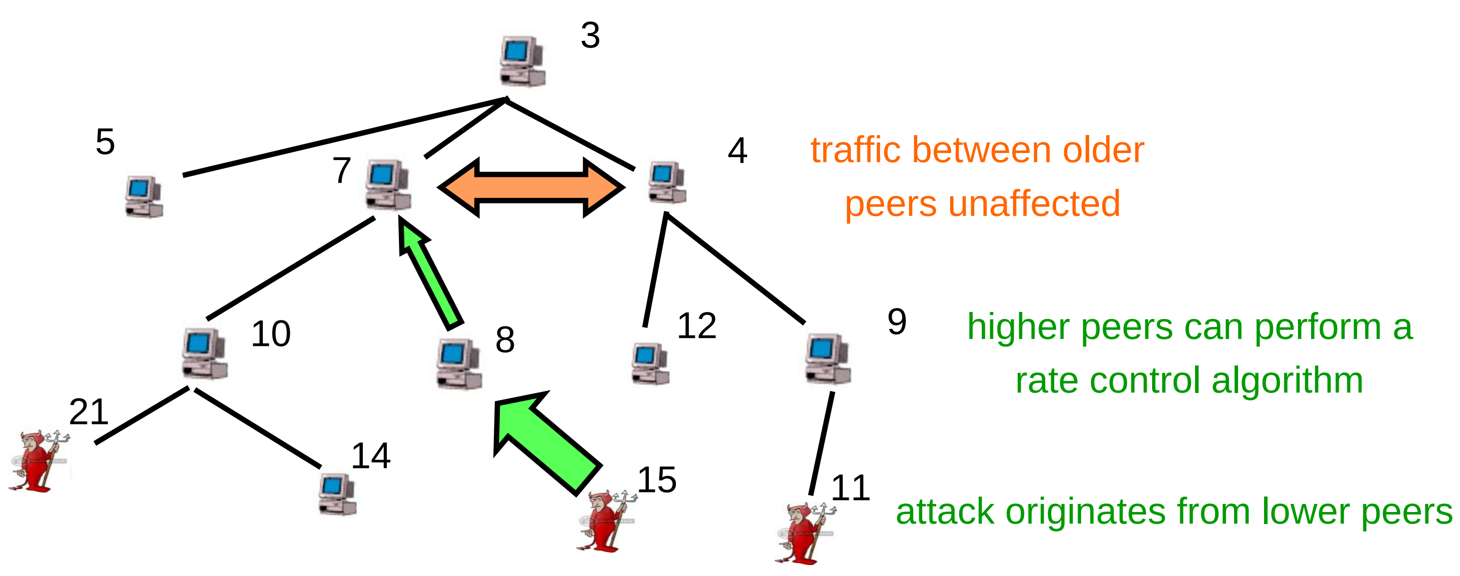
  - yields low congestion: first phase ends at peer rank at least t/2 w.h.p.



Other Application: Robust Information System

- Approach also useful as robust distributed information system

- Idea: build same de Bruijn heap, but use different peer ranks
  - Instead of rank ~ peer capacity, we use rank ~ join time
  - Thus: peers only connect to older peers
  - i.e., we want to maintain join time order in our distributed system

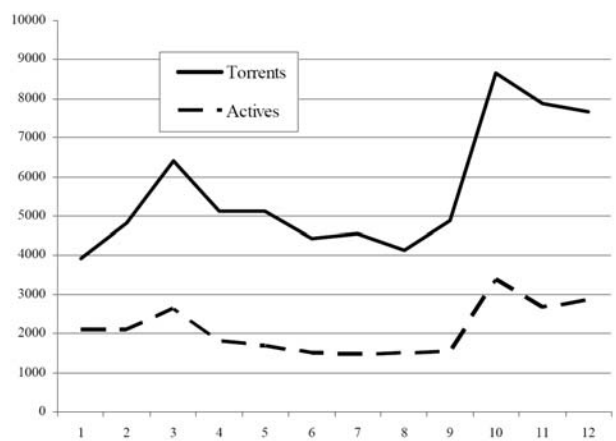


Conclusion

Conclusion

- Presence of unequal participants is interesting and important challenge in peer-to-peer computing
  - Unequal peers = peers which voluntarily or involuntarily do not contribute the same amount of resources as/to other peers
  - How to distinguish the two cases in a distributed environment?

- Reality check: are people selfish?

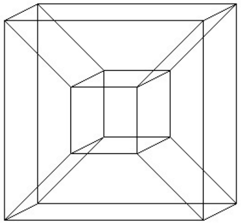


“Some Peers Are More Equal than Others!”

Ongoing and Future Research

Dynamic Peers / Robustness: Self-Stabilization

[Joint work with TU München (Prof. Christian Scheideler, Dr. Riko Jacob, Dr. Hanjo Täubig) and University of Arizona (Prof. Andrea Richa)]



Robustness: DoS Attack Resistent Distributed Information System

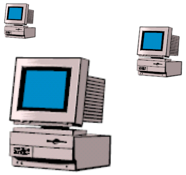
[Joint work with Prof. Christian Scheideler and Matthias Baumgart]

Heterogeneity / Selfishness: Distributed Streaming

Incentives for on demand streaming?

Coping with churn and heterogeneity? (Measurements to assess characteristics?)

Robustness to attacks, censorship, manipulation / integrity, ...?



Efficiency / Robustness: Distributed Information Systems

How to deal with huge amounts of data? (E.g., distributed aggregation)

DoS resistant redundancy in multi-hop networks?

ID assignment problem?

Thank you for your attention!