From Napster to PlayStation 3:

Tour d'Horizon of Peer-to-Peer Technology

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Wroclaw Information Technology Initiative (2008)

In This Lecture...

What are the dead sea scrolls of peer-to-peer?

What has my Playstation 3 to do with this lecture?

Why did Gnutella crash after the inrush of former Napster users?

How does BitTorrent foster cooperation among peers?

How can I use BitTorrent without going to jail?

How does a BitTorrent download differ from a HTTP download?

What is an end-game?

How to remove Simpsons from *Kad*?

What does Skype do when I am *not* on the phone?

Peer-to-peer botnets?

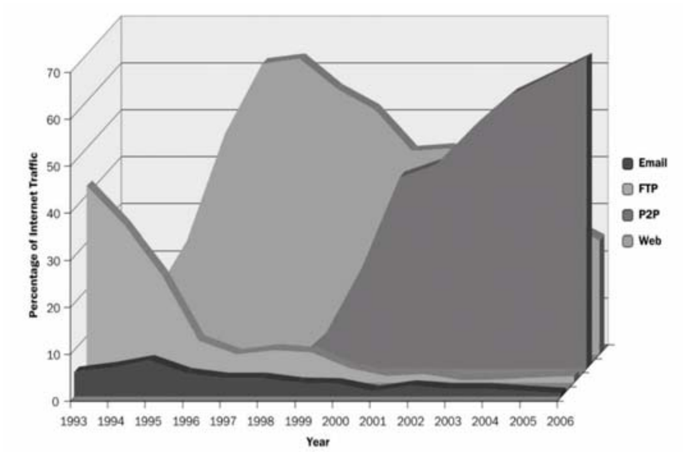
Before We Go Backstage...

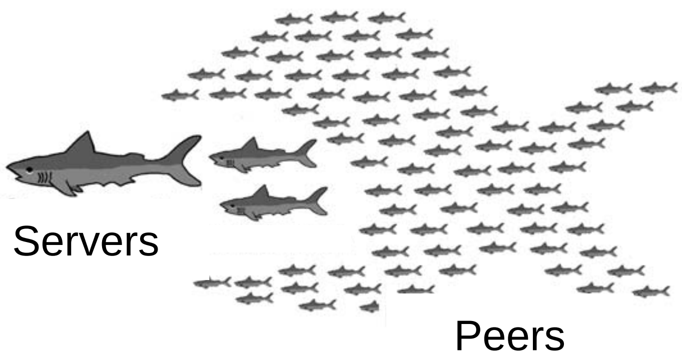
- This talk = „all“ I know about today‘s peer-to-peer systems...
- ... and a bit more! ☺
- Systems evolve over time, and hardly any client applies the same algorithms
- Thus:
  - focus on what I find interesting
  - some simplifications to focus on main concepts
  - selection of topics is biased
- Most importantly: when you know better, let us know.

The Paradigm

- Key idea: Participating machines are both consumers and contributors

- Popularity: Peer-to-peer accounts for a large fraction of Internet traffic
  (source: CacheLogic.com)



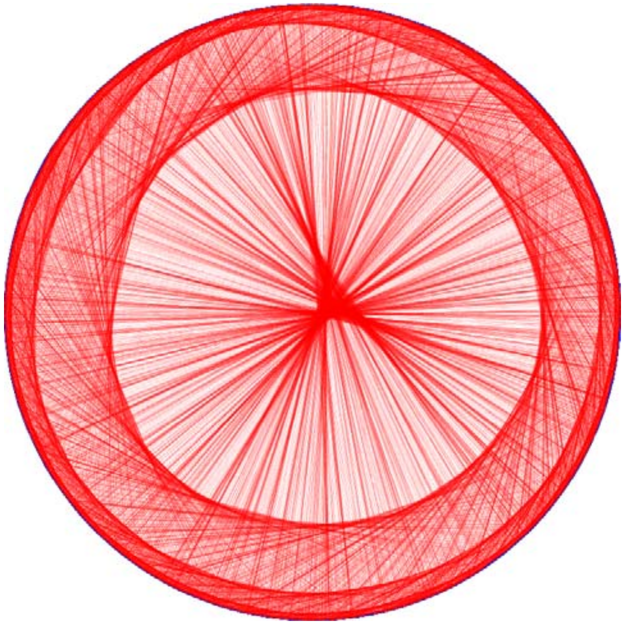


- Promises of the paradigm
  - Efficiency and scalability
  - Robustness, no single point of failure
  - Cheap: no expensive infrastructure at content distributor
  - „Democratic“ aspect: anyone can publish its contents / speeches / etc.

From Theory to Practice… (1)

- Much scientific literature on peer-to-peer computing
  - Topics: scalability, dynamics / churn, heterogeneity, incentives, etc.

- Sample peer-to-peer systems (mostly DHTs in literature): who has heard of
  - Chord? Pastry? Tapestry? Kademlia?
  - Viceroy? Koorde?
  - SplitStream?
  - Pagoda?
  - etc.



From Theory to Practice… (2)

- The four evangelists...

- If you read your average P2P paper, there are (almost) always four papers cited that “invented” efficient P2P in 2001:

Chord	CAN	Pastry	Tapestry

- These papers are somewhat similar, with the exception of CAN

- So what’s the „Dead Sea Scrolls of P2P”?

From Theory to Practice… (3)

„Accessing Nearby Copies of Replicated Objects in a Distributed Environment“, by Greg Plaxton, Rajmohan Rajaraman, and Andrea Richa, at SPAA 1997.

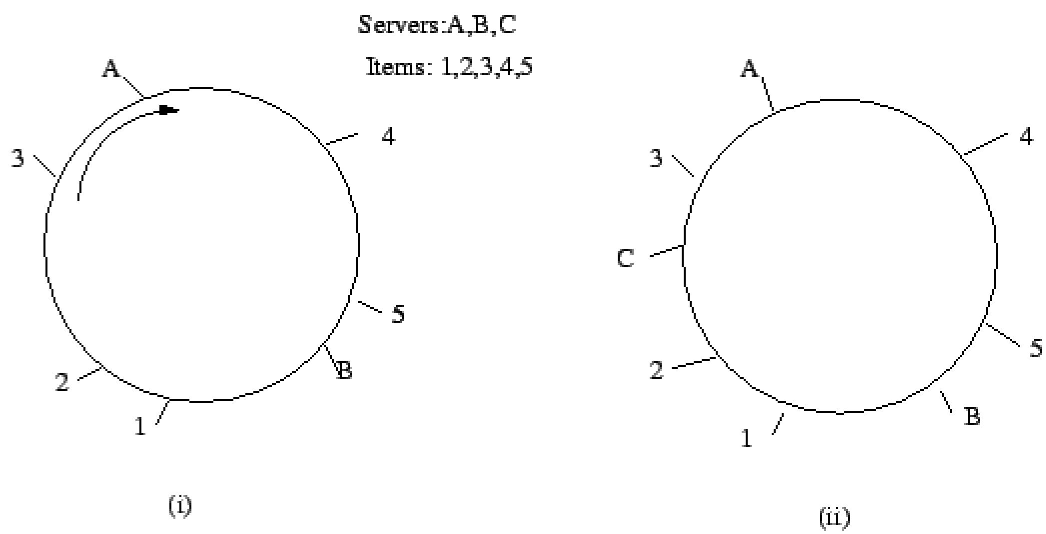
- Basically, the paper proposes an efficient search routine (similar to the evangelist papers). In particular search, insert, delete, storage costs are all logarithmic, the base of the logarithm is a parameter.

- However, it‘s a theory paper, so that alone would be too simple...

- So the paper takes into account latency; in particular it is assumed that nodes are living in a metric, and that the graph is of „bounded growth“ (meaning that peer densities do not change abruptly).

From Theory to Practice… (4)

"Consistent hashing and random trees: Distributed caching protocols for relieving hot spots on the World Wide Web." David Karger, Eric Lehman, Tom Leighton, Matthew Levine, Daniel Lewin and Rina Panigrahy, at STOC 1997.



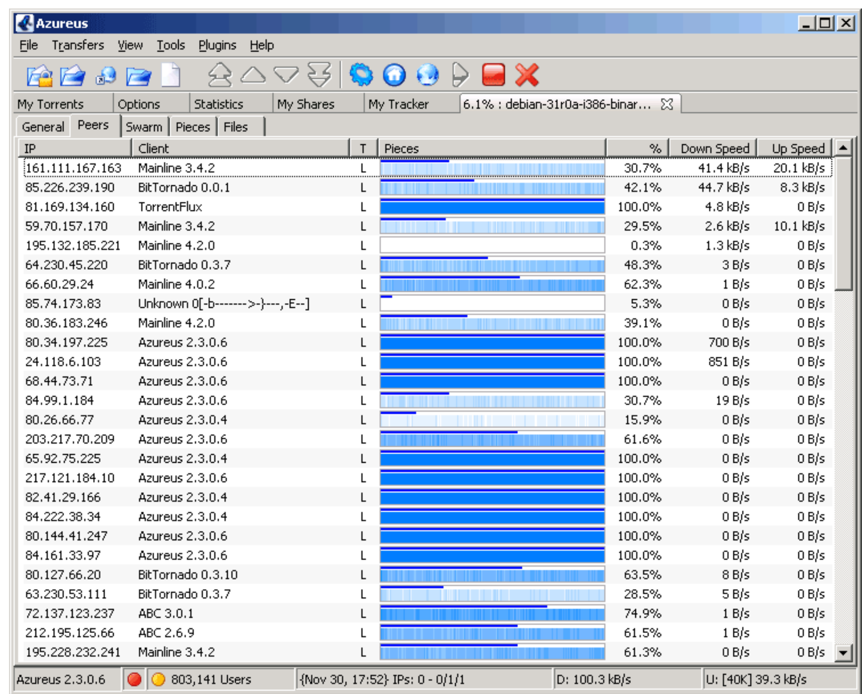
- Big difference: still a client/server paradigm.

slide © Roger Wattenhofer

From Theory to Practice… (5)

- Popular networks in practice: who has heard of
  - Skype?
  - Napster? Kazaa? eMule?
  - BitTorrent?
  - Kad network?
  - Zattoo?

- Applications
  - Internet telephony
  - File sharing
  - TV streaming
  - Distribution of sw updates
  - etc.



IP	Client	T	Pieces	%	Down Speed	Up Speed
161.111.167.163	Mainline 3.4.2	L		30.7%	41.4 kB/s	20.1 kB/s
85.226.239.190	BitTornado 0.0.1	L		42.1%	44.7 kB/s	8.3 kB/s
81.169.134.160	TorrentFlux	L		100.0%	4.8 kB/s	0 B/s
59.70.157.170	Mainline 3.4.2	L		29.5%	2.6 kB/s	10.1 kB/s
195.132.185.221	Mainline 4.2.0	L		0.3%	1.3 kB/s	0 B/s
64.230.45.220	BitTornado 0.3.7	L		48.3%	3 B/s	0 B/s
66.60.29.24	Mainline 4.0.2	L		62.3%	1 B/s	0 B/s
85.74.173.83	Unknown 0[-b------->-}---,-E--]	L		5.3%	0 B/s	0 B/s
80.36.183.246	Mainline 4.2.0	L		39.1%	0 B/s	0 B/s
80.34.197.225	Azureus 2.3.0.6	L		100.0%	700 B/s	0 B/s
24.118.6.103	Azureus 2.3.0.6	L		100.0%	851 B/s	0 B/s
68.44.73.71	Azureus 2.3.0.6	L		100.0%	0 B/s	0 B/s
84.99.1.184	Azureus 2.3.0.6	L		30.7%	19 B/s	0 B/s
80.26.66.77	Azureus 2.3.0.4	L		15.9%	0 B/s	0 B/s
203.217.70.209	Azureus 2.3.0.6	L		61.6%	0 B/s	0 B/s
65.92.75.225	Azureus 2.3.0.4	L		100.0%	0 B/s	0 B/s
217.121.184.10	Azureus 2.3.0.6	L		100.0%	0 B/s	0 B/s
82.41.29.166	Azureus 2.3.0.4	L		100.0%	0 B/s	0 B/s
84.222.38.34	Azureus 2.3.0.4	L		100.0%	0 B/s	0 B/s
80.144.41.247	Azureus 2.3.0.6	L		100.0%	0 B/s	0 B/s
84.161.33.97	Azureus 2.3.0.6	L		100.0%	0 B/s	0 B/s
80.127.66.20	BitTornado 0.3.10	L		63.5%	8 B/s	0 B/s
63.230.53.111	BitTornado 0.3.7	L		28.5%	5 B/s	0 B/s
72.137.123.237	ABC 3.0.1	L		74.9%	1 B/s	0 B/s
212.195.125.66	ABC 2.6.9	L		61.5%	1 B/s	0 B/s
195.228.232.241	Mainline 3.4.2	L		61.3%	0 B/s	0 B/s

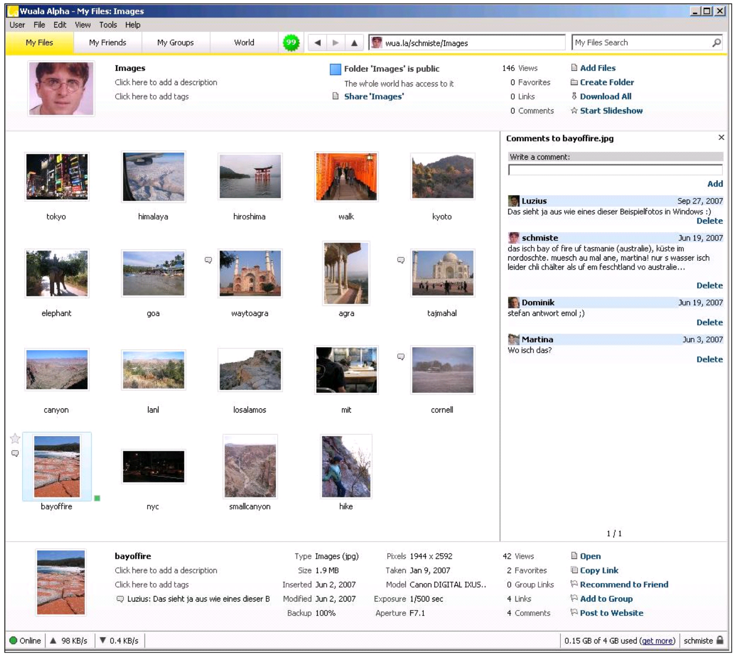
From Theory to Practice… (6)

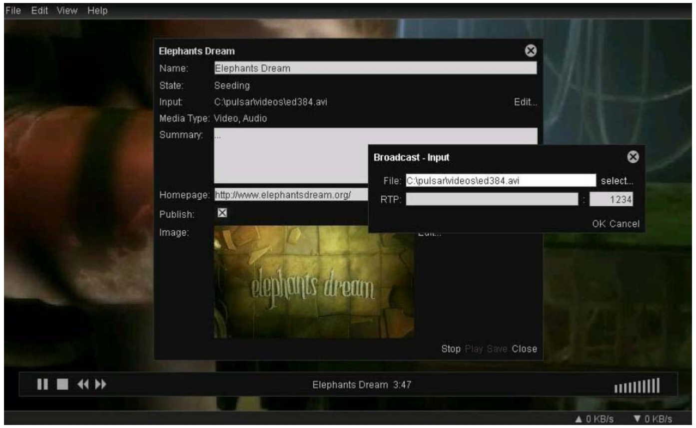
- Olympic games 2008 opening ceremony
  - estimated 5.5 mio peer-to-peer viewers
  - e.g., PPLive

From Theory to Practice… (7)

Own projects...

- Pulsar streaming system (e.g., *tilllate* clips?)
- Wuala online storage system





see www.wua.la

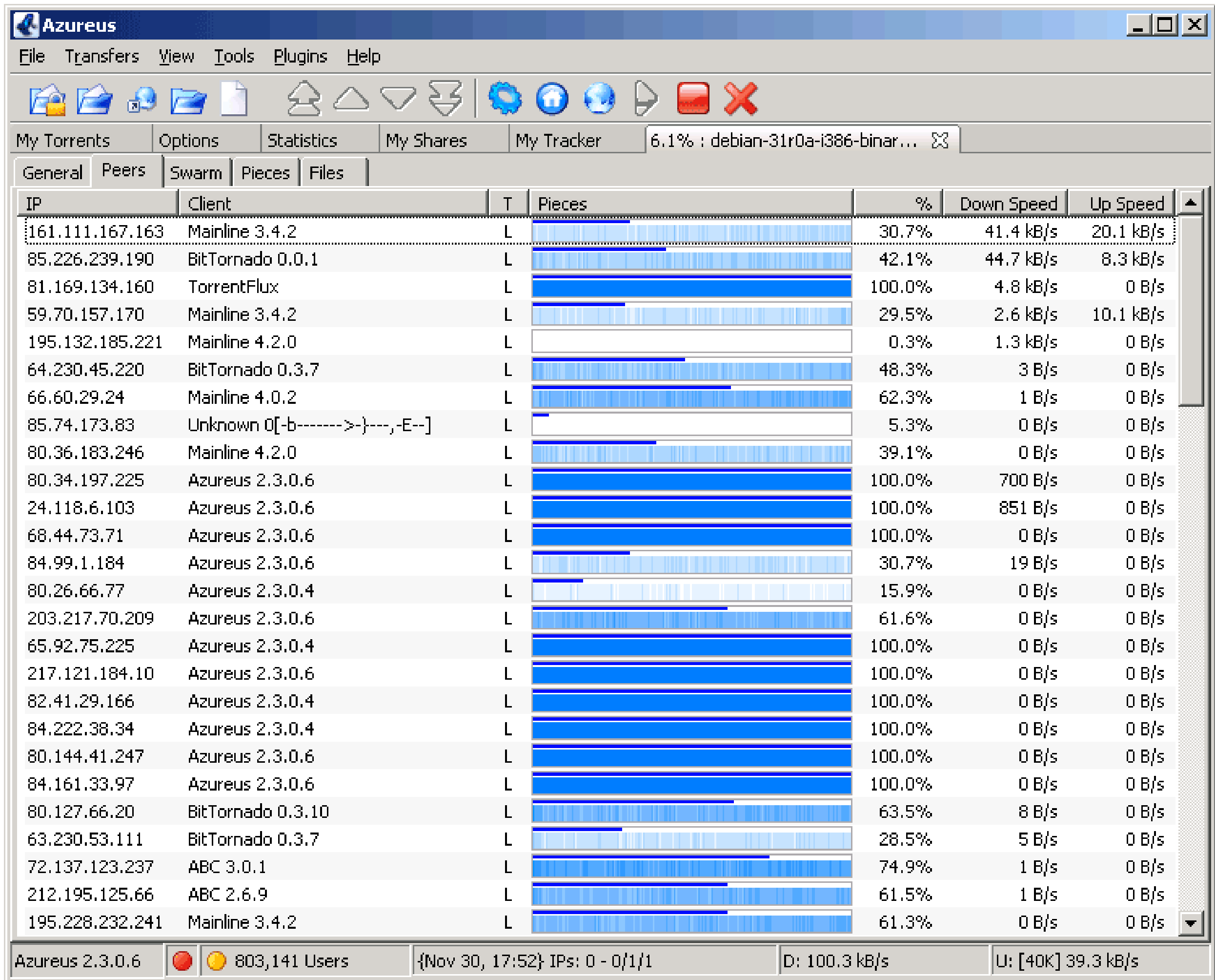
see www.getpulsar.com

The Genealogy of Peer-to-Peer

		WWW, POTS, etc.
PRR	1997	
	1998	
	1999	Napster
	2000	Gnutella
Chord, CAN, Pastry, Tapestry	2001	eDonkey, Kazaa
Viceroy, P-Grid, Kademlia	2002	Gnutella-2, BitTorrent
Koorde, SkipGraph, SkipNet	2003	Skype, Steam, PS3

slide © Roger Wattenhofer

What happens behind the scenes of my peer-to-peer client?



It depends on the system.

vs vs vs ...

Some (simplified) examples!

Napster:

One of the first and best-known

„peer-to-peer“ systems

Napster (1)

- One of the first „peer-to-peer“ file sharing systems (mainly MP3s)
  – Release year: 1999 (in the same year also first RIAA law-suit)
  – Shut down in year 2001 (today: pay service)

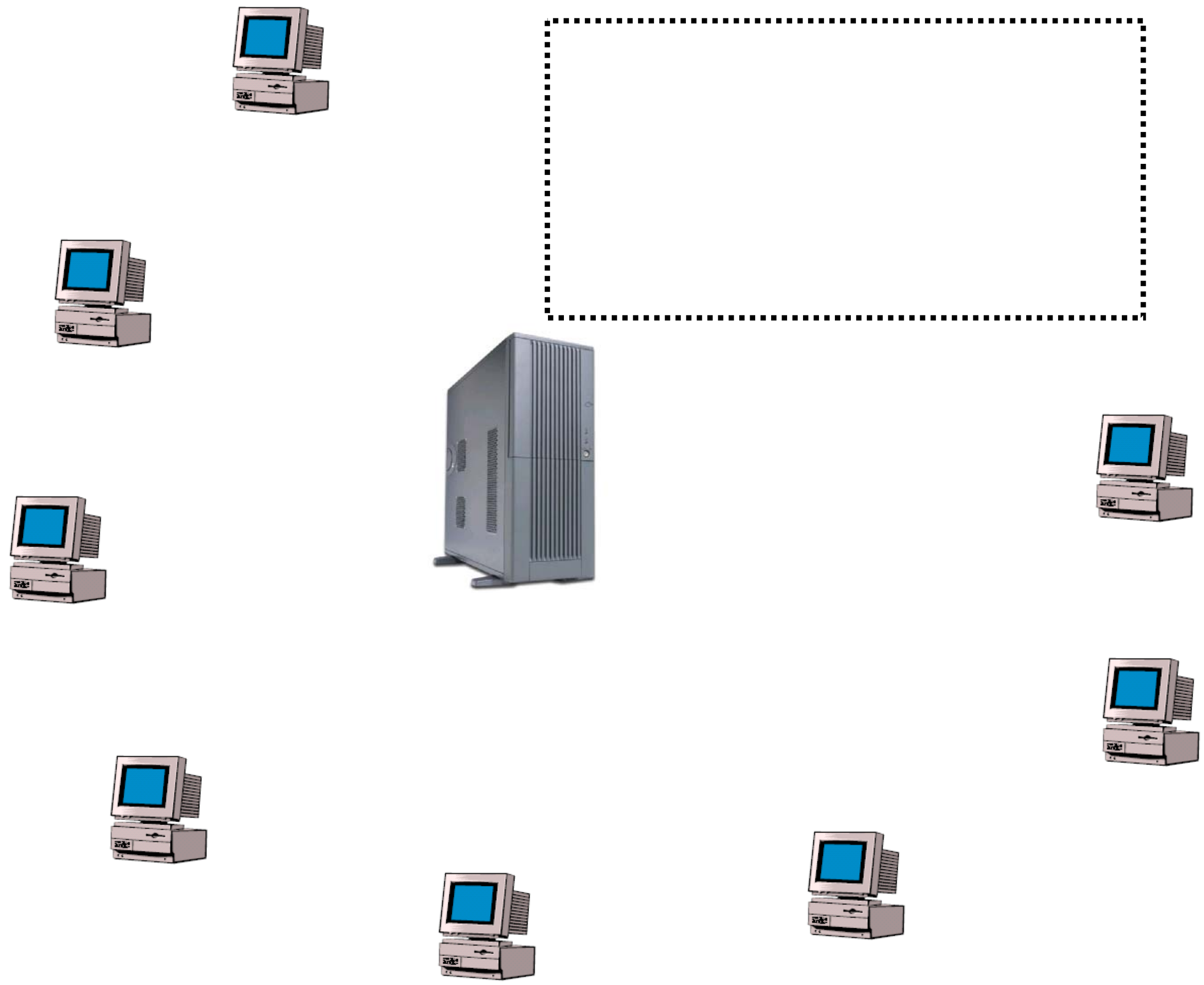
- Napster is not a pure peer-to-peer system

  - Relies on servers which store directory (but not files)

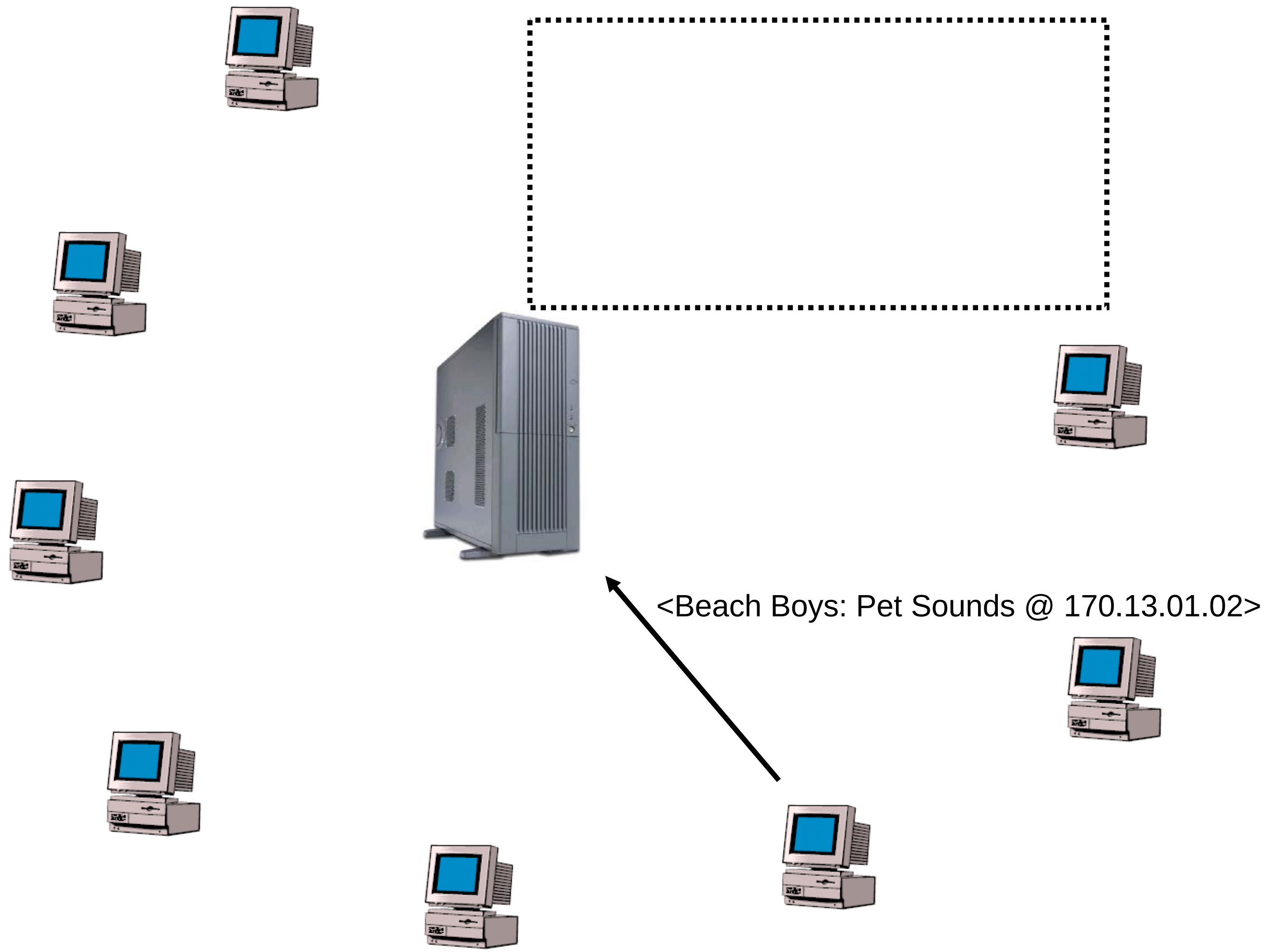
  - Resource discovery problem trivial: ask index server

  - Download then happens „peer-to-peer“ (not via server)

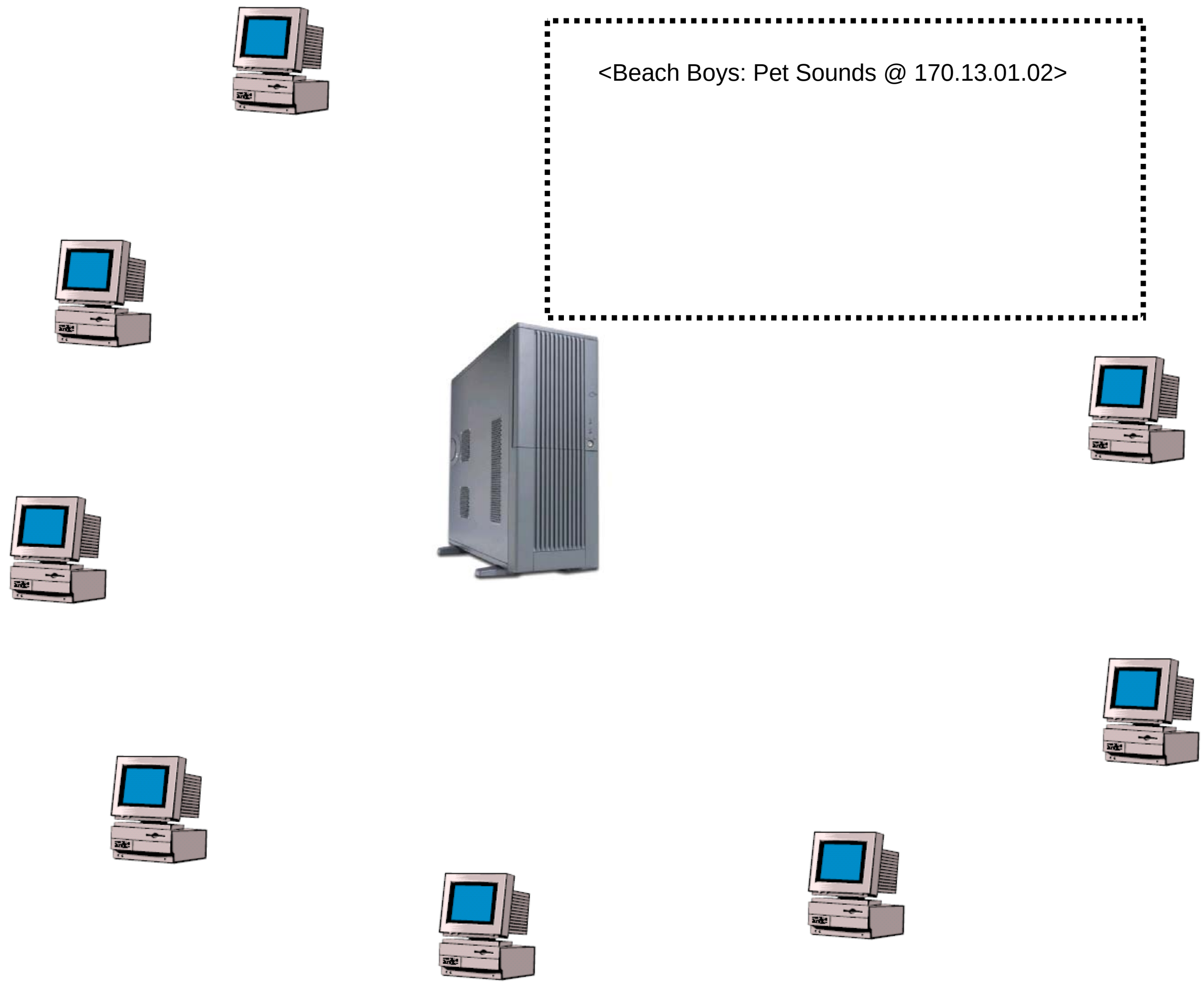
Napster (2)



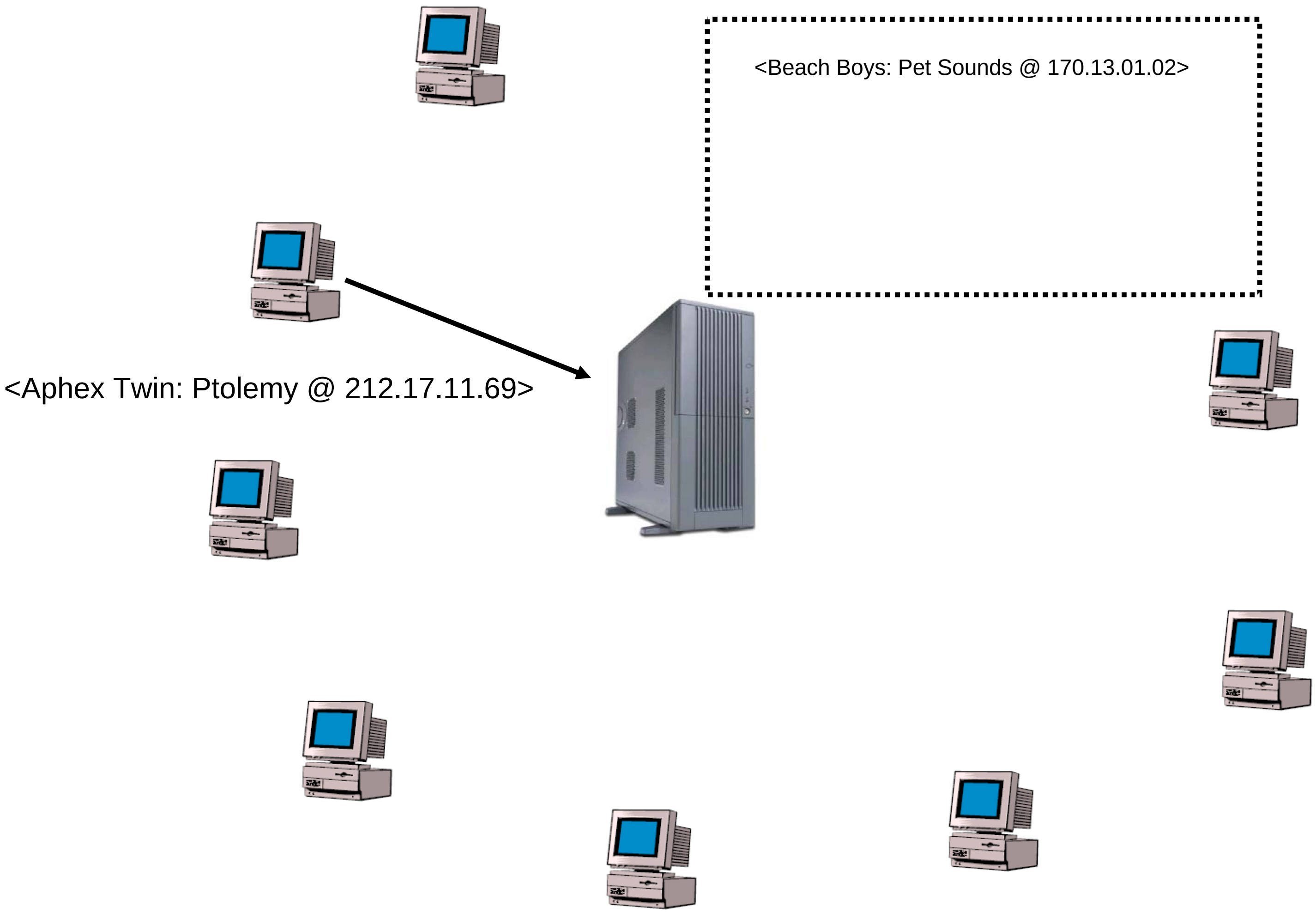
Napster (2)



Napster (2)



Napster (2)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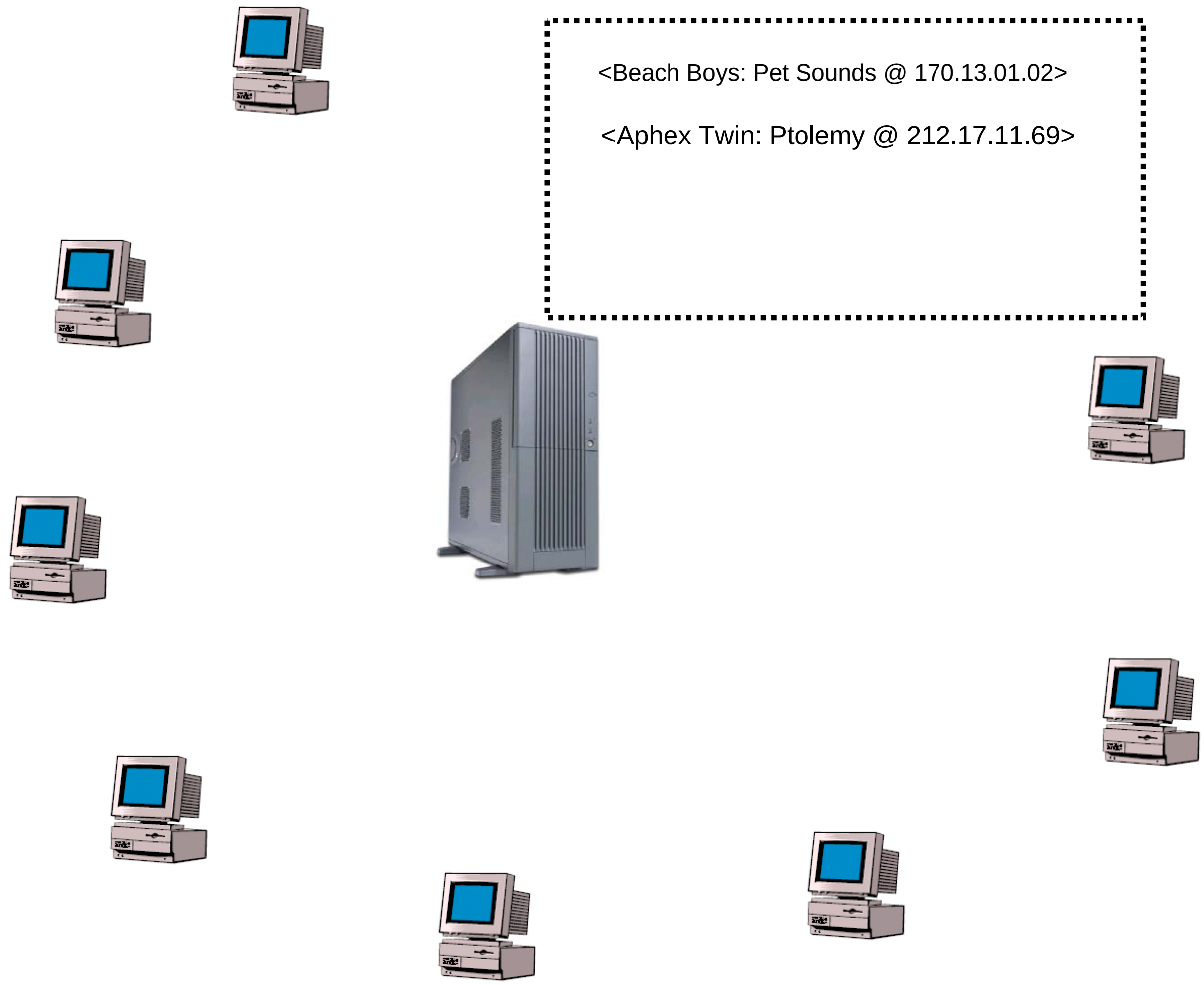
<Aphex Twin: Ptolemy @ 212.17.11.69>

Napster (2)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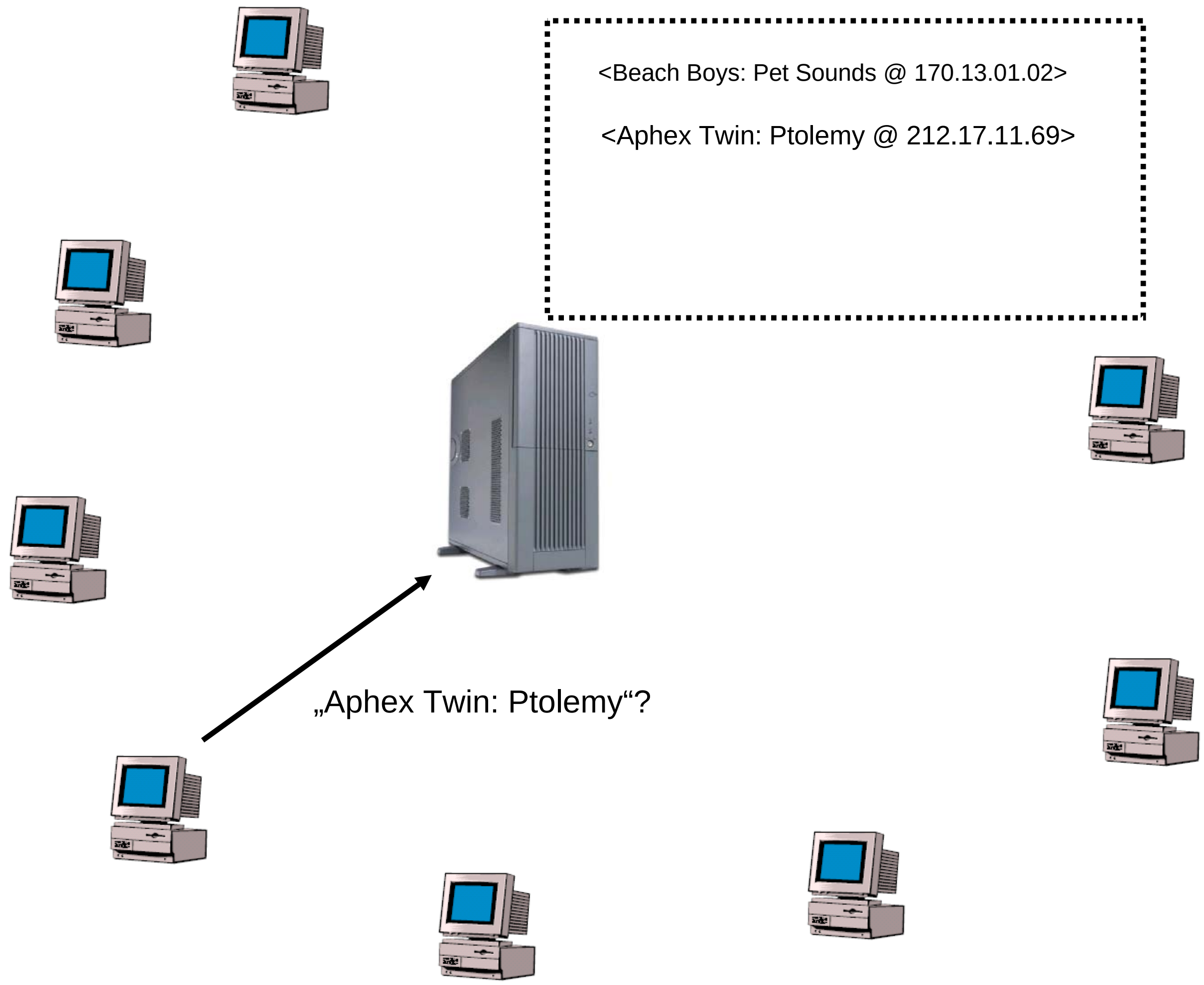
Napster (2)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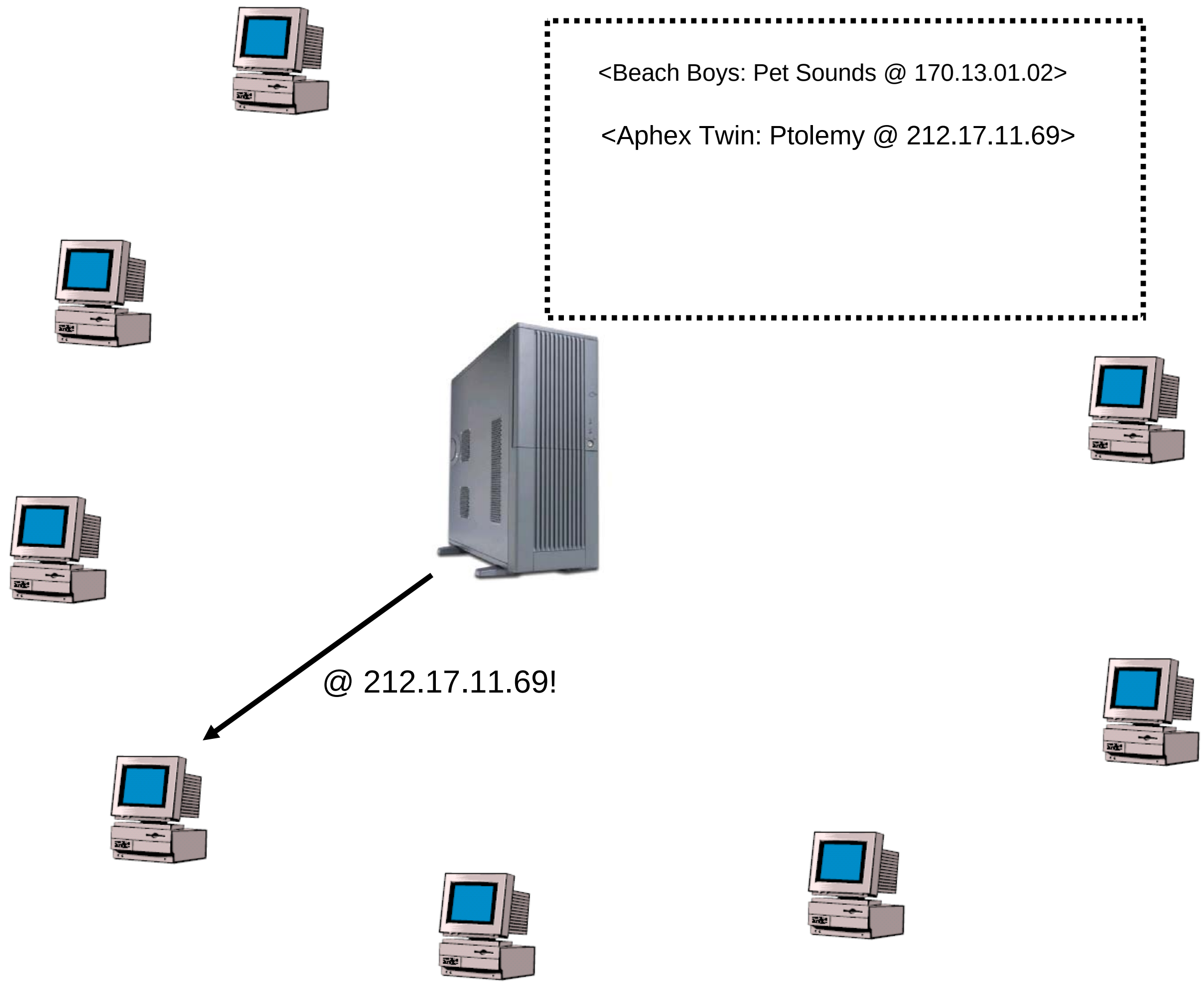
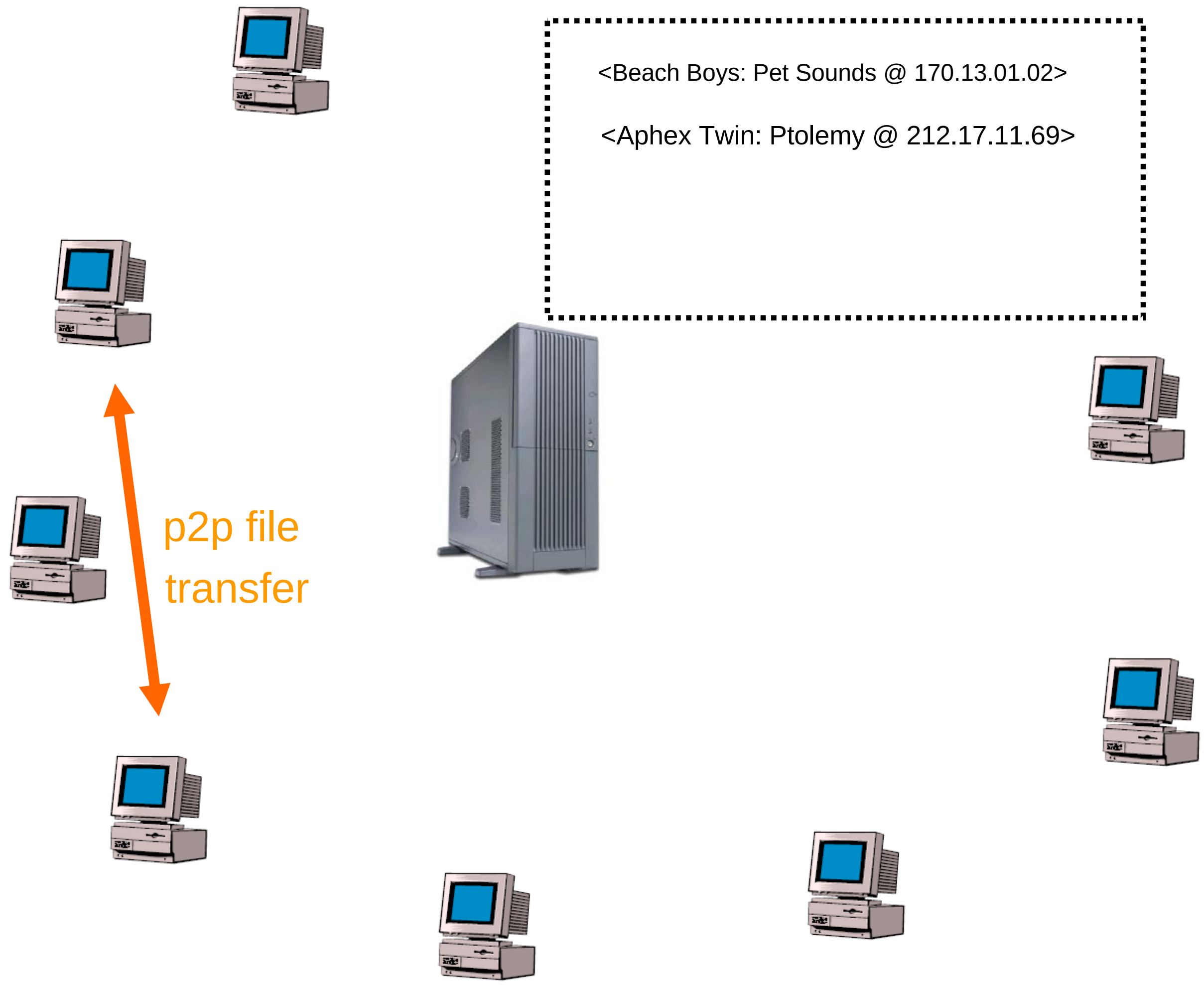
„Aphex Twin: Ptolemy“?

Napster (2)


<Beach Boys: Pet Sounds @ 170.13.01.02>
<Aphex Twin: Ptolemy @ 212.17.11.69>
@ 212.17.11.69!

Napster (2)


<Beach Boys: Pet Sounds @ 170.13.01.02>
<Aphex Twin: Ptolemy @ 212.17.11.69>
p2p file
transfer

Napster (3)

- Evaluation
  - Does the job: facilitates file sharing!
  - Highly popular
  - Not really peer-to-peer
  - Server = Single point of failure (legal action!)
  - Does not scale

Gnutella:

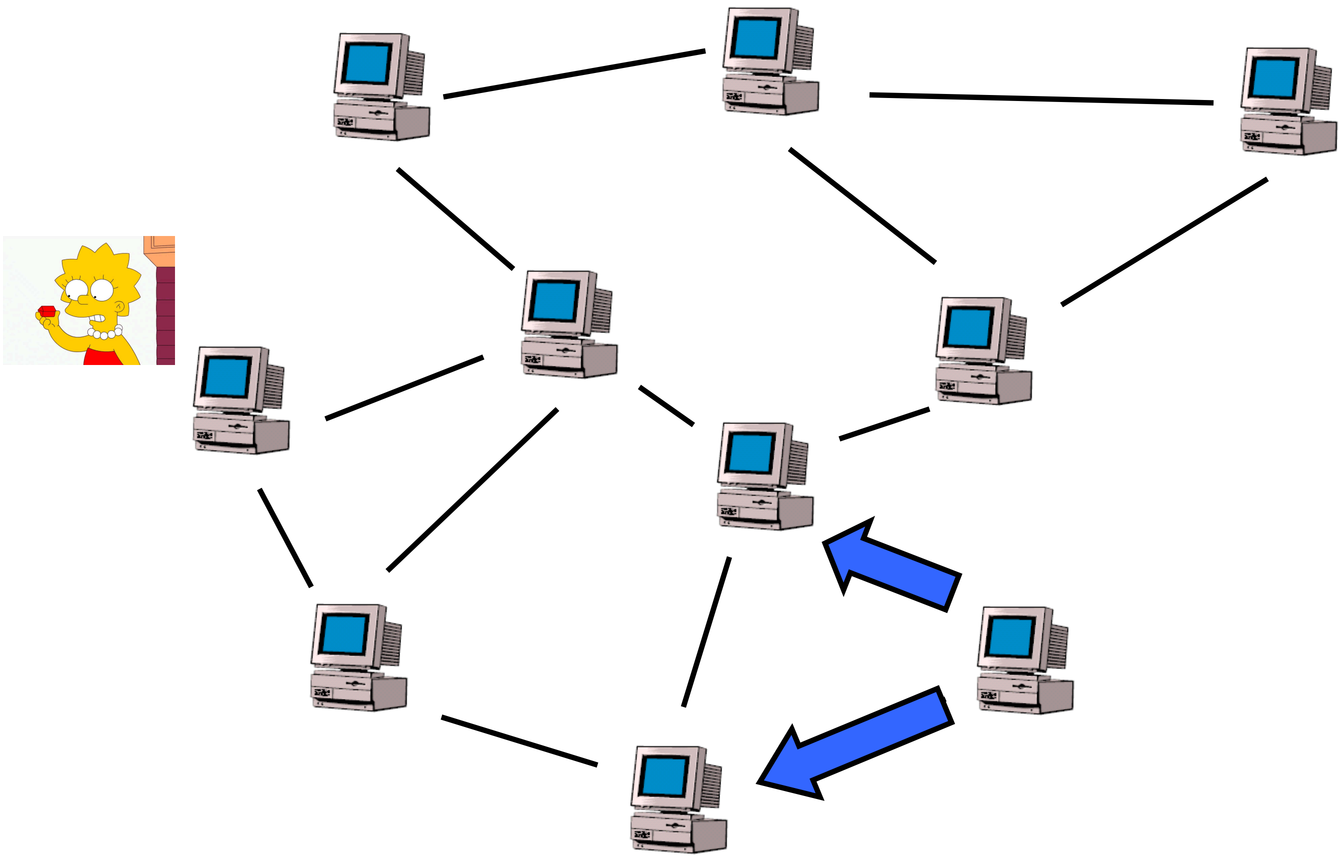
An early, completely decentralized approach

Gnutella (1)

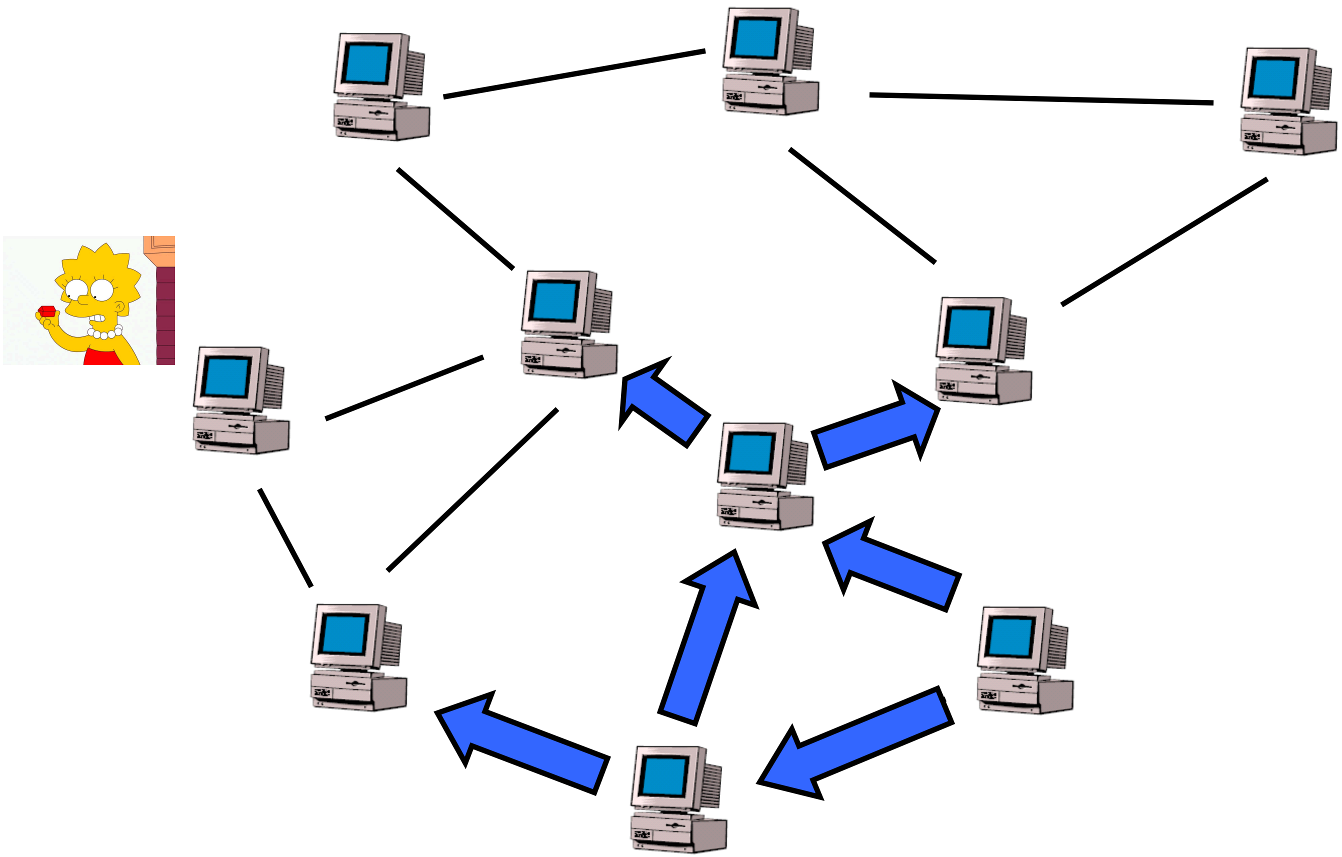
- Completely decentralized architecture
  - Beta release in March 2000
  - No index server!
  - Cannot be „shut down“
- Also very popular
  - Estimated 2+ million users
- Clients
  - LimeWire, BearShare, Acqlite, Mutella, ...
- Many Gnutella versions
  - Many different clients
  - Protocol evolves over time

We will only present the main concepts of Gnutella!

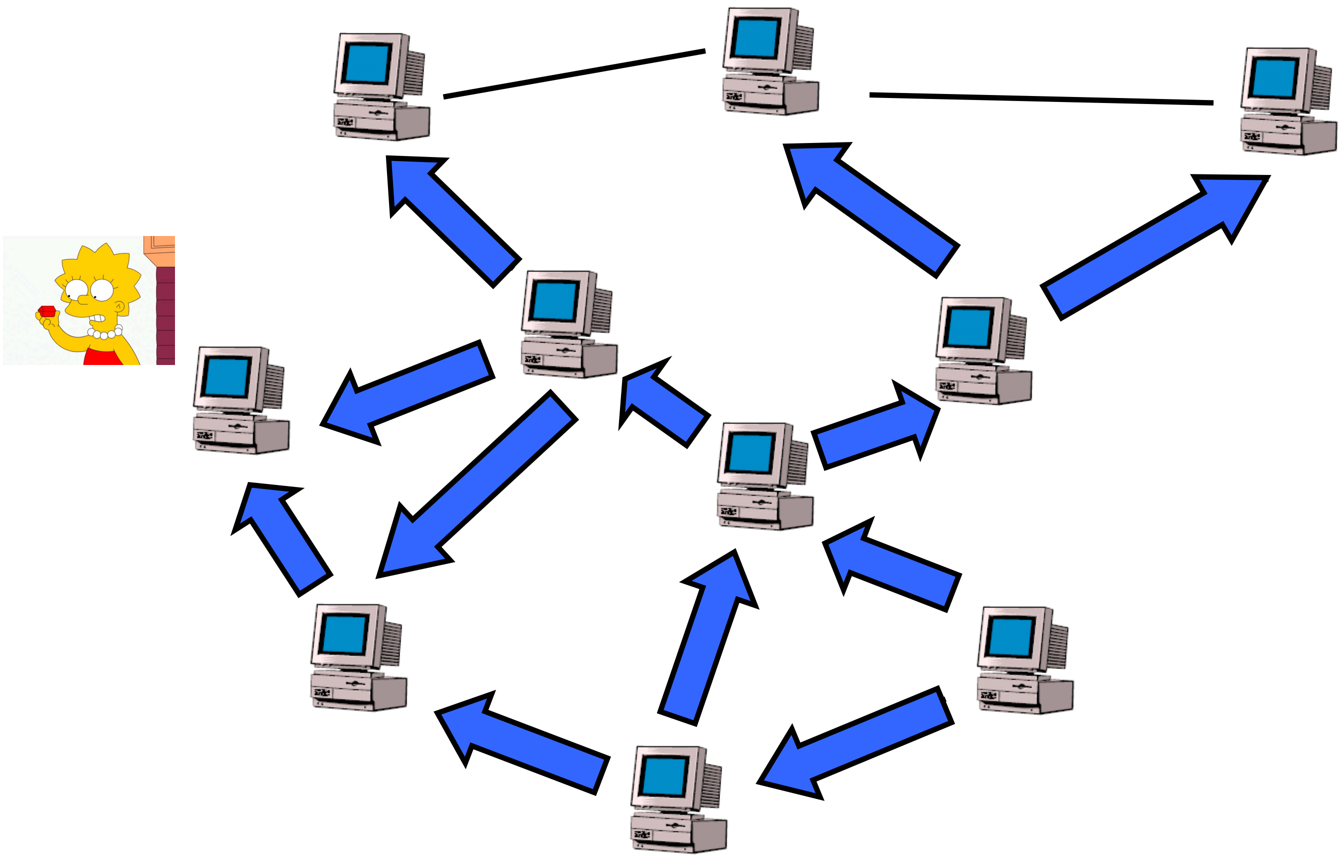
Gnutella (2)



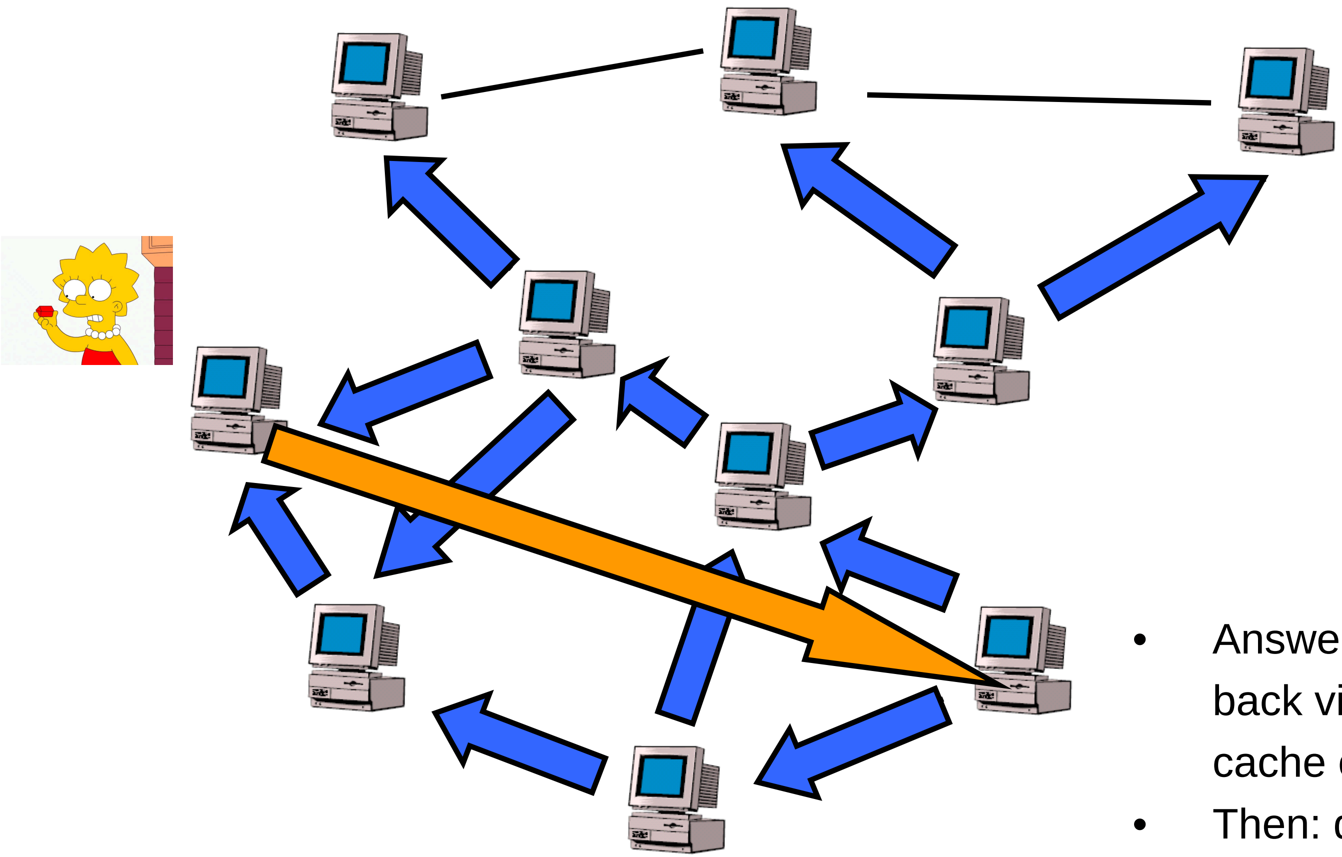
Gnutella (2)



Gnutella (2)



Gnutella (2)

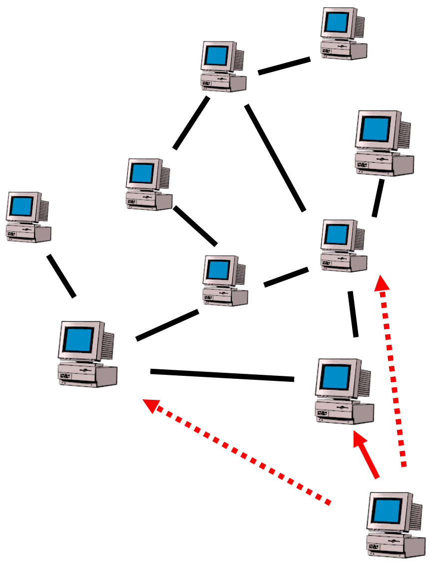


- Answers come back via multihop (why? cache or anonymity?!)
- Then: direct download from one source

Gnutella (3)

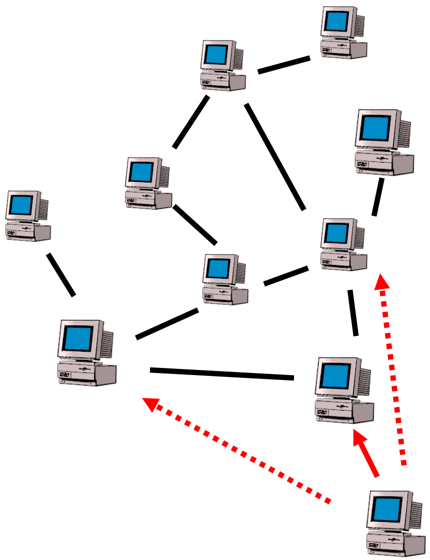
Bootstrap

- e.g., pre-existing address list of peers, shipped with the software
- e.g., web caches
- e.g., IRC chat
- ...



Gnutella (4)

- Topology
  - join: depends on client, no specific requirements
  - typically: starting with bootstrap peer, recursively explore neighbors until degree (depends on client) is reached
  - this can result in inefficient (reduandant transmissions, „linear topology“) or even disconnected topologies (unlike Napster)
  - countermeasure high peer degree?

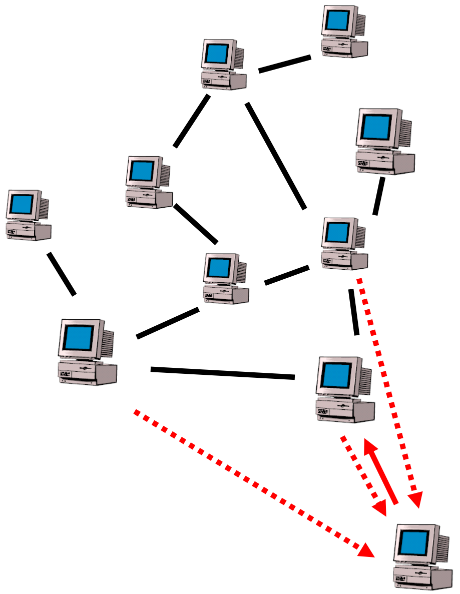


- Some measurement studied found small-world / power law properties in modern graphs

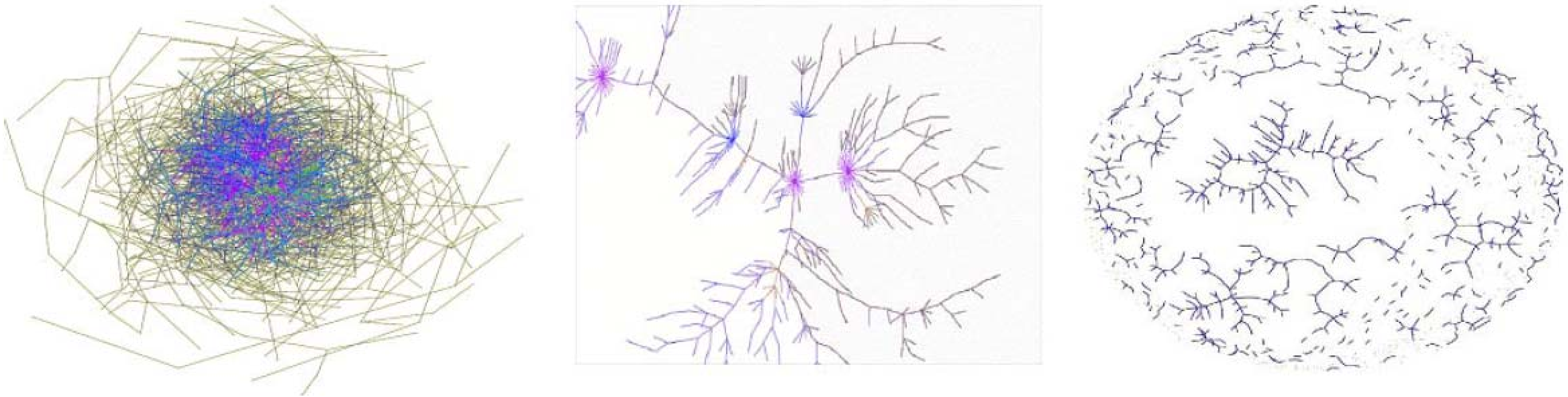
- After join, no rule how and when to find alternative peers for crashed neighbors
  - graph / out-degree distribution mainly a social phenomenon

Gnutella (5)

- The ping/pong join protocol
  - join similar to query
  - joining peer sends a ping message to neighbor
  - neighbor returns pong message, and forwards ping to its neighbors
  - iteratively: whenever a peer receives a ping, it sends pong to originator (multi-hop on same path)
  - up to some time-to-live
  - originator randomly selects subset of these peers as neighbors (neighborhood size: >= 5)



Gnutella (6)



- Measurement study 2001 with 1771 peers
  - „A Measurement Study of Peer-to-Peer File Sharing Systems“, 2002
    (Saroiu, Gummadi, Gribble)
  - Left: Gnutella topology Februar 16, 2001
  - Middle: 30% peers removed at random (still large connected component)
  - Right: 4% highest degree peers removed
  - quite robust to random faults, but not worst-case faults (attacks)

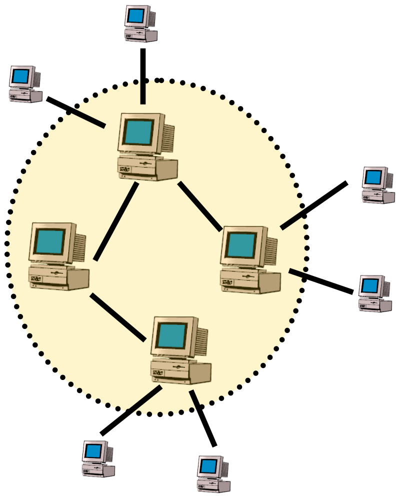
Gnutella (7)

- Evaluation
  - Fully decentralized and „simple“
  - Hardly any restrictions on topology...
  - ... but hardly any guarantees (e.g., diameter or connectivity) either
  - Still not very scalable: flooding results in many redundant transmissions
  - In fact, when Napster was unplugged, Gnutella broke down due to the inrush of former Napster users

- Files may not be found although they exist (if TTL < ∞)
  - Problematic for „rare files“
  - But approach directly supports queries like range queries, Boolean queries, etc.

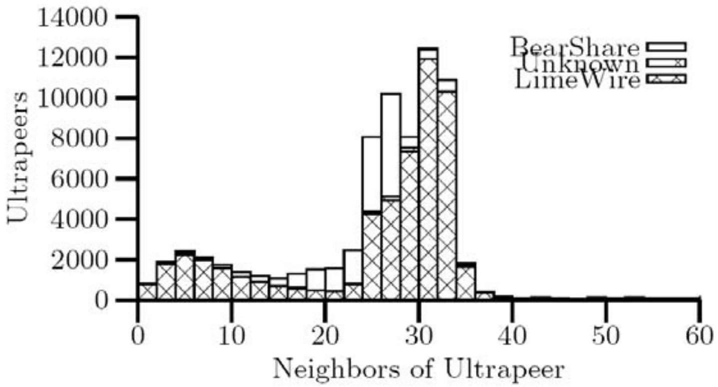
Gnutella (8)

- Many extensions (e.g., Gnutella-2), e.g., hybrid two-tier architecture
  - Ultrapeers: have higher bandwidth, do most of the routing
  - Ultrapeers form the „core network“, are connected to (many) other ultrapeers; store indices of their leaves
  - Ideally, an ultrapeer has a high bandwidth, long session times, and other peers can connect to it via TCP
  - Ultrapeer degree: around 30 (LimeWire)
  - Leaves: only connect to a small number of ultrapeers
  - Renders system more efficient in heterogeneous environment



- Search by dynamic flooding on core network
  - increasing TTL, until around 100 results are found

- Peers decide themselves which role they assume (no control)



BitTorrent:
Cooperation in swarms

BitTorrent

Peer-to-peer computing relies on the contributions of the peers

However, peers may be selfish!

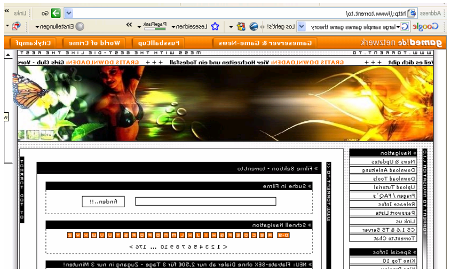
How to provide incentives for cooperation?

Tit-for-Tat

- Simple solution: tit-for-tat
  - Barter system: peer p offers resources to peer p‘ while p‘ offers resources to p
  - But: What if p‘ is not interested in the resources (e.g. files) of p? (cf “real economy“)
  - BitTorrent heralded paradigm shift: it showed that cooperation can be achieved on a single file

- Main ideas
  - Peers interested in a certain file form a swarm
  - Swarms can be found via trackers
  - Instead of sharing the entire file, file is divided into smaller pieces
  - Pieces of a file are exchanged in a tit-for-tat like manner (details later)
  - Pipelining: peer downloads different parts of the file from different sources concurrently

BitTorrent Architecture

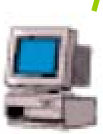


website with .torrent file

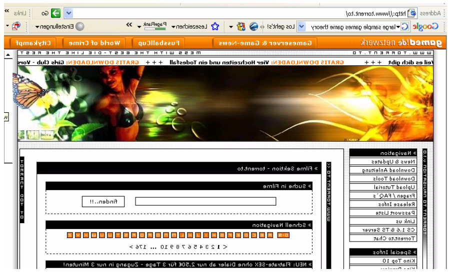
Bootstrap: .torrent meta files are offered by various websites and can be found, e.g., via web search engines

tracker address,
verification data,
file and piece size, ...

visit website

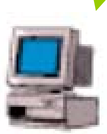


BitTorrent Architecture

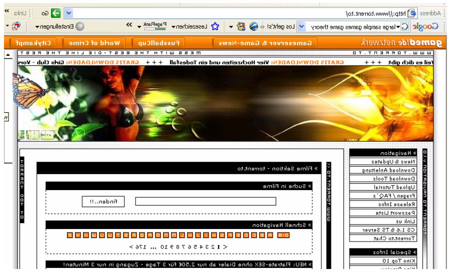


website with .torrent file

download .torrent file

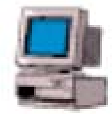


BitTorrent Architecture

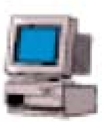


website with .torrent file

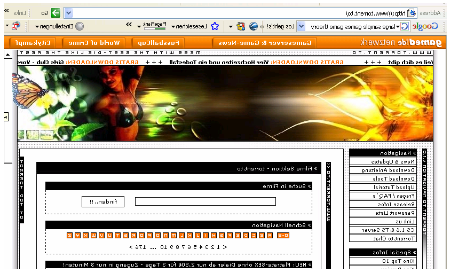
Tracker



contact tracker

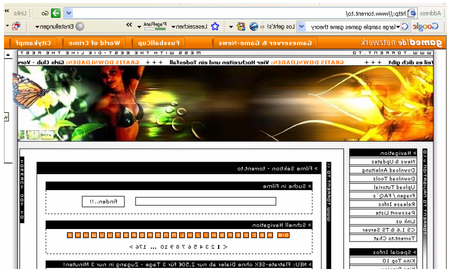


BitTorrent Architecture

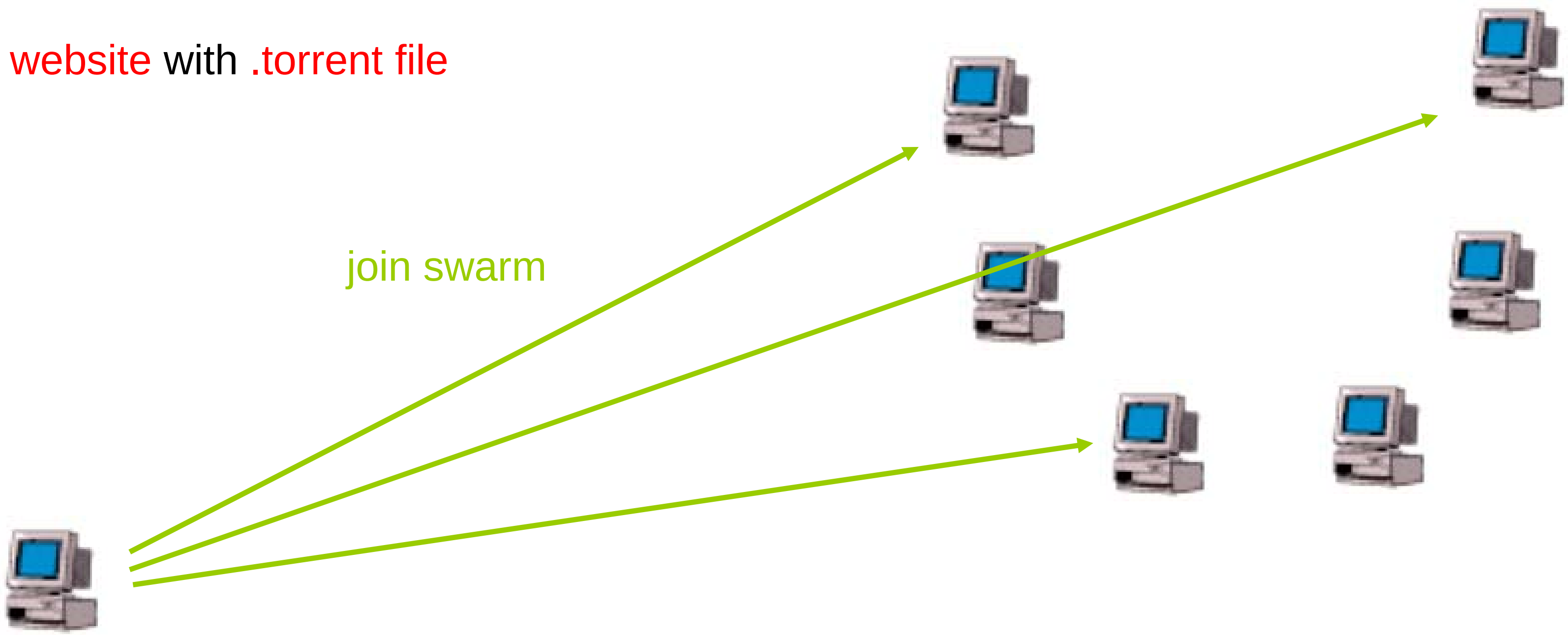


website with .torrent file

BitTorrent Architecture



website with .torrent file



Cache / FIFO: connect to most recent set,
not structured / hypercubic etc.

BitTorrent Architecture

- Tracker: maintains information on peers in swarm
  - „problematic“: tracker knows many IP addresses
  - easy to check whether they are really downloading...

- Peers send periodical updates to the tracker about their status
  - e.g., all 30 minutes
  - peers also contact the server when they join and leave

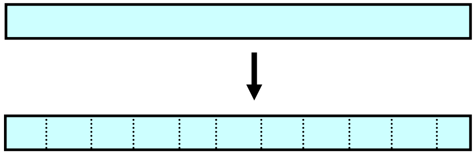
- When joining, peers establish roughly 40 connections to other peers in swarm

- If number of responsive neighbors < 20, tracker is contacted again
  - peer retrieves additional contacts

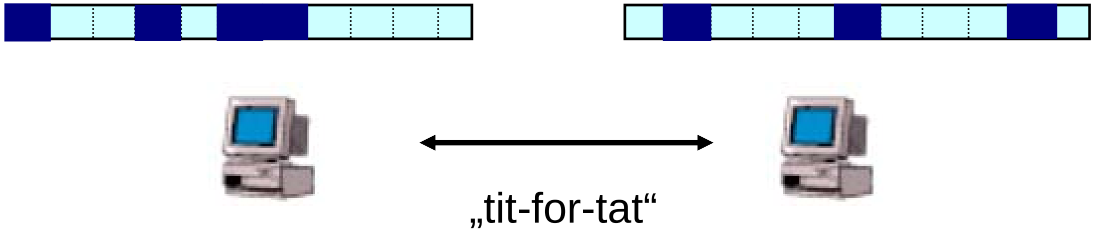
BitTorrent Swarm

- Swarm consists of peers interested in same file (or collection of files)

- File is divided into several pieces (usually a couple of thousand pieces)



- Peers trade these pieces („swarming“)
  - In a tit-for-tat like manner



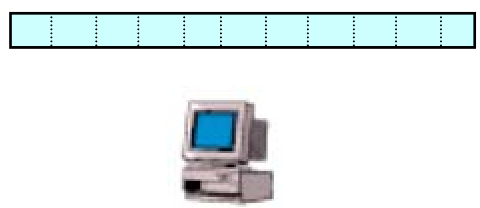
BitTorrent: Peer Types

- Peers in the swarm which have all pieces are called seeders

- Peers which only have a subset of all pieces are called leechers

BitTorrent: Bootstrap Problem

- But what about newly joined peers?
  - Do not have anything (any pieces) to offer...
  - Will not be able to trade!
  - That‘s known as the bootstrap problem



- That‘s the reason that BitTorrent does not employ a pure tit-for-tat policy: concept of optimistic unchoking

BitTorrent: Incentive Mechanism (1)

- BitTorrent uses the following mechanism:

- Seeders upload their pieces to leechers in a round robin fashion
  - round robin = „one after another“

- Leechers perform a modified version of tit-for-tat,
  use optimistic unchoking slots

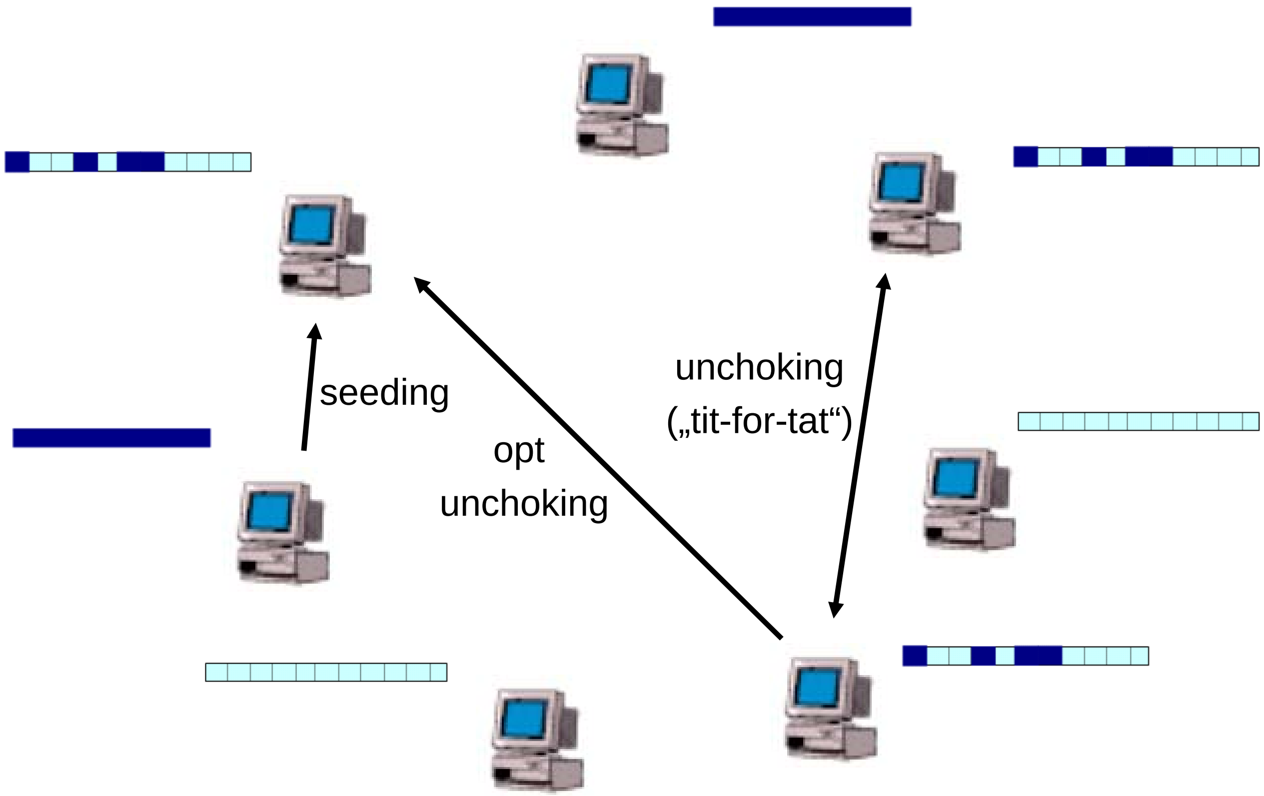
BitTorrent: Incentive Mechanism (2)

Leechers do the following:

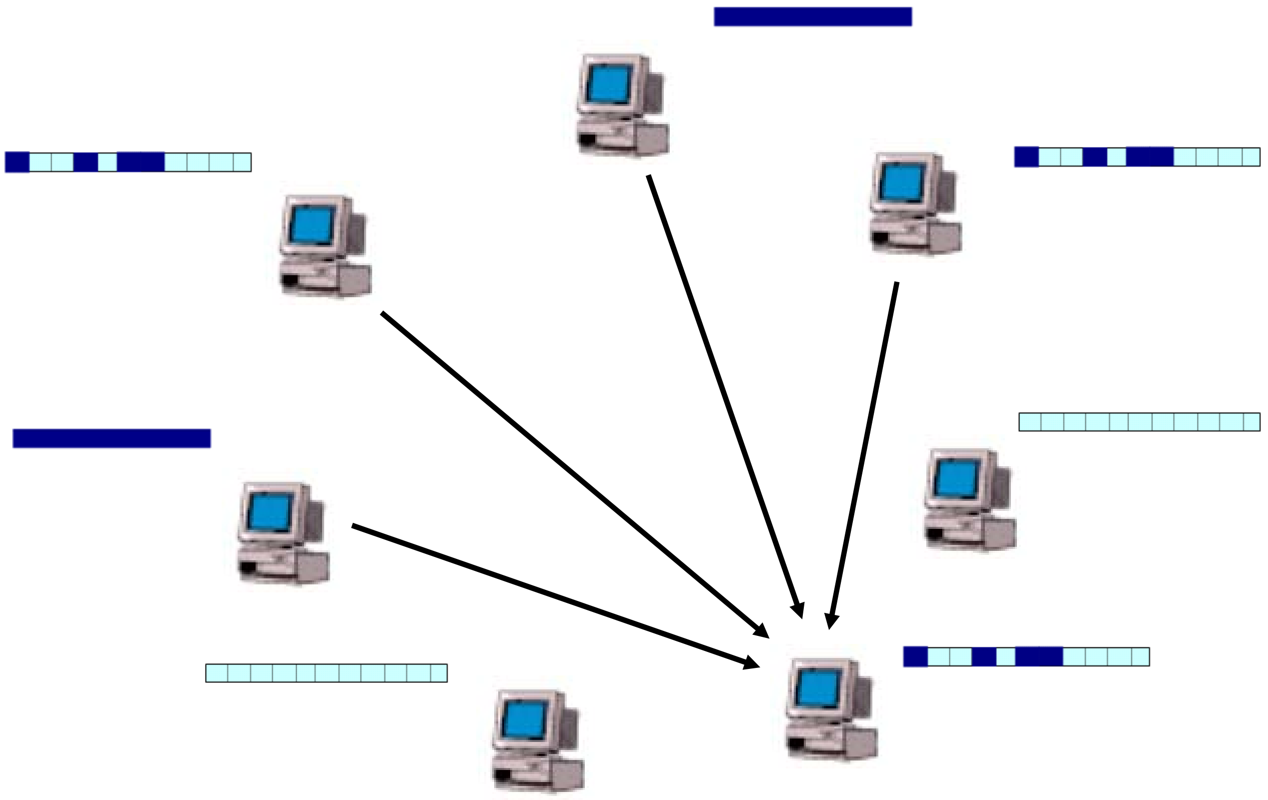
- Peers upload concurrently to the „best neighbors“ (active set)
- Active set typically consists of 5 peers only
- We say that active set is „unchoked“
- Peer uploads (as much as possible) to peers in active set (not purely tit-for-tat)
- Download rate received from neighbors is evaluated every 10 secs

- In addition, a peer optimistically unchokes a random neighbor: it uploads pieces for free to this neighbor for roughly 30 secs, independently of the download received; gives that peer a chance to bootstrap or to become an active set peer!

Swarm Overview



Concurrent Downloads



Local Rarest First Policy (1)

- A peer is informed about the new pieces available at its neighbors
  - „have-message"
- Which piece should a peer download?
- Typical policy: LRF
  - Local rarest first
  - Try to download piece which is least replicated among neighbors
  - Minimizes chance that rare piece gets lost when seeder leaves
- Exception: Pieces are selected at random until first piece is completely downloaded, enables a fast start (rare pieces can typically only be obtained from one, potentially slow, peer)

Local Rarest First Policy (2)

Thus, since pieces are retrieved in random order (non-contiguous download), BitTorrent is not directly made for, e.g., on-demand streaming where pieces at the beginning of the file should be downloaded earlier

BitTorrent Download Characteristics (1)

BitTorrent downloads differ from, e.g., HTTP downloads

- HTTP more or less constant speed from the beginning
- BitTorrent uses many TCP sockets
- Characteristics: slow beginning and endgame, fast midgame

BitTorrent Download Characteristics (2)

- Download performance slow in the beginning (takes time to collect neighbors and sufficient data to become effective uploader)

- Full speed during „midgame“

- Endgame slower again: only a small number of pieces left to download, restricted choice of neighbors offering this content

  - BitTorrent uses special endgame mode where the same subpieces are requested in parallel and redundantly from several neighbors in order to remain efficient towards the end (if a subpiece is obtained from one peer, cancel is sent to others)

Data Verification and Subpieces

- In practice, pieces (size ~100 KB) are further divided into subpieces
  - Pipelining: More pending requests, improves TCP throughput
  - Schedule new request whenever subpiece arrives
  - Parallelism (subpieces from different peers)
  - Subpieces of a piece can be obtained from different peers
    (some clients restrict to one peer after some time)

- The .torrent metafile contains checksum for each piece (but not subpiece)
  - SHA1 hashing algorithm
  - Most BitTorrent clients ban IP address if verification fails

Evaluation of Fairness Mechanism (1)

- Cooperation is important in p2p computing

  - incentives needed if peers are selfish

  - measurement studies: large fraction of peers are free-riders

- BitTorrent is one of the first systems to tackle this problem algorithmically

- Other approaches

  - e.g., Kazaa client: monitors its contributions

  - can be bypassed by implementing different client (Kazaa Lite) which hardwires contribution level to maximum

  - many other solutions (e.g., virtual money systems)

  - some proposals resemble real economies and have to deal with inflation, deflation etc. => complex!

Evaluation of Fairness Mechanism (2)

- BitTorrent works very well in practice and is a big success

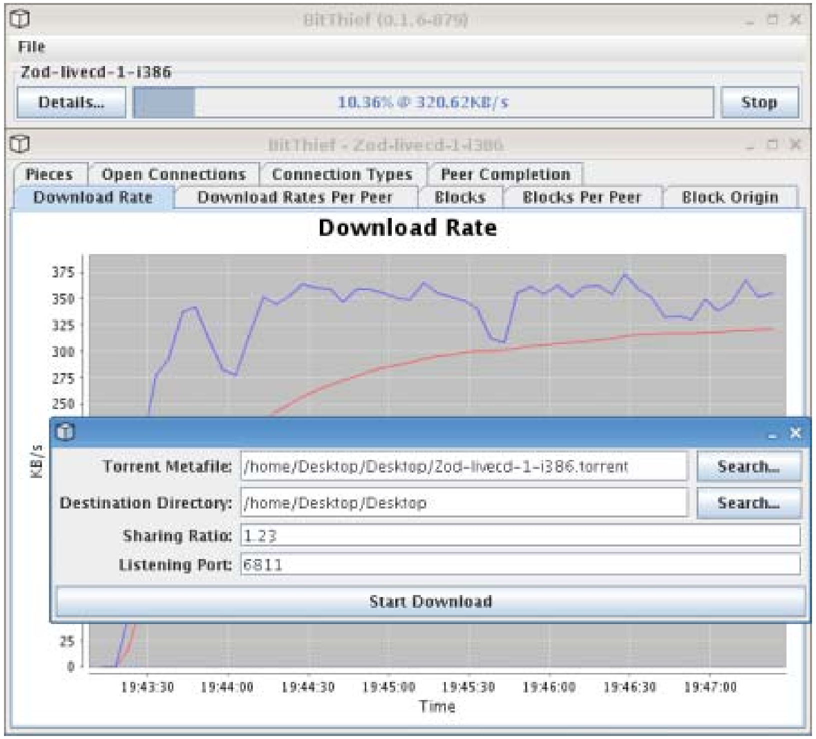
- Cheating is still possible though
  - e.g., clients such as BitThief or BitTyrant
  - poses interesting algorithmic questions (see also game theory)

Evaluation of Fairness Mechanism (3)

- How to cheat?
- Peers can re-contact tracker more frequently (=> more neighbors)
- More neighbors => benefit more frequently from optimistic unchoking slots (free-ride!)
- Sharing communities: BitTorrent networks which require user registration, monitor contribution of users; peers can announce wrong upload rates to tracker and benefit from more seeders
- Active set: peers can behave strategically and upload just enough to become member of active set (and not more)
- etc.

Example: BitThief Client (1)

- BitThief is a Java client (implemented from scratch) which achieves fast downloads without uploading at all



Example: BitThief Client (2)

BitThief's three tricks:

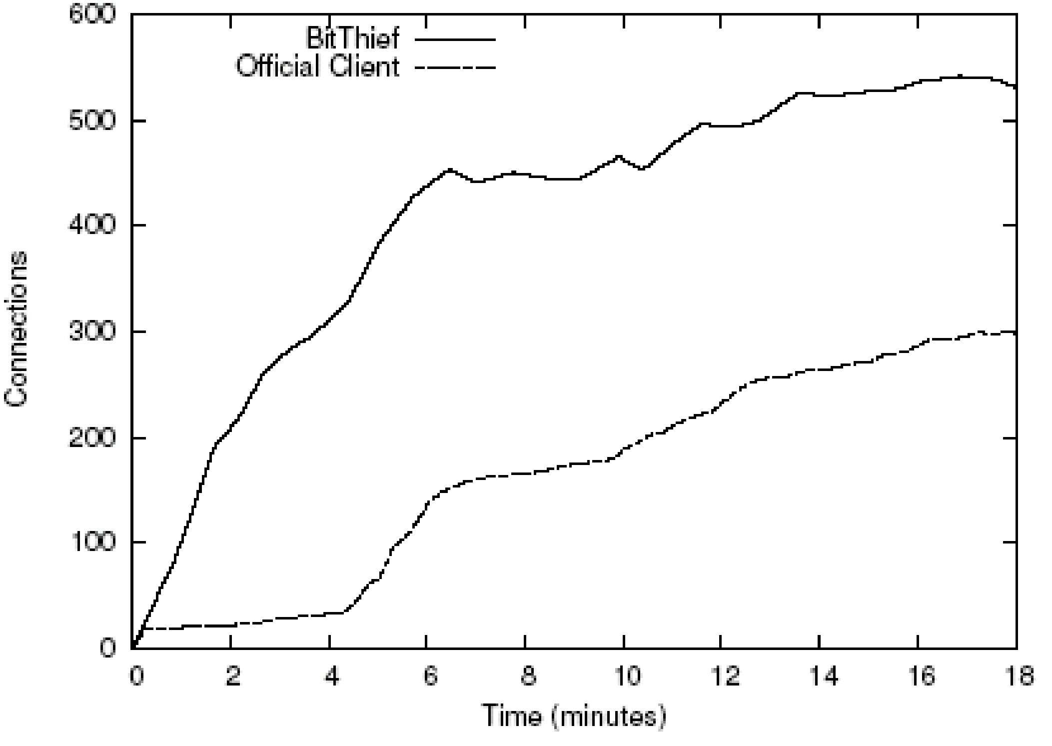
- Open as many TCP connections as possible (no performance problem!)
- Contacting tracker again and again, asking for more peers (never banned during our tests!)
- Pretend being a great uploader in sharing communities (tracker believed all our tracker announcements)

=> Exploit optimistic unchoking

=> Exploit seeders

=> Exploit sharing communities

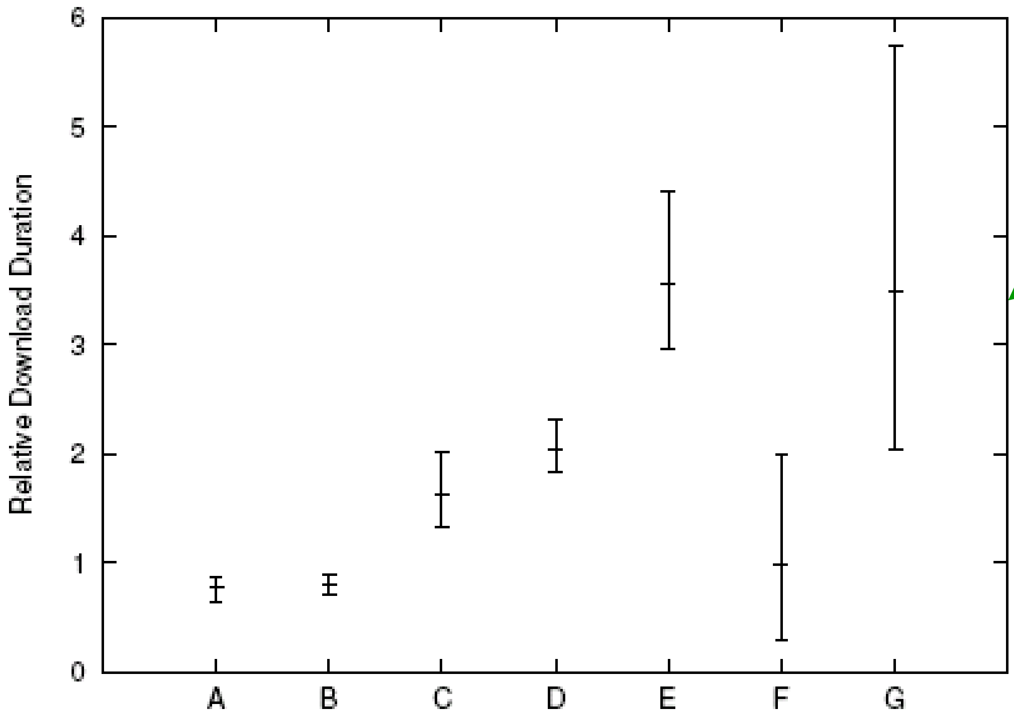
Example: BitThief Client (3)



Example: BitThief Client (4)

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

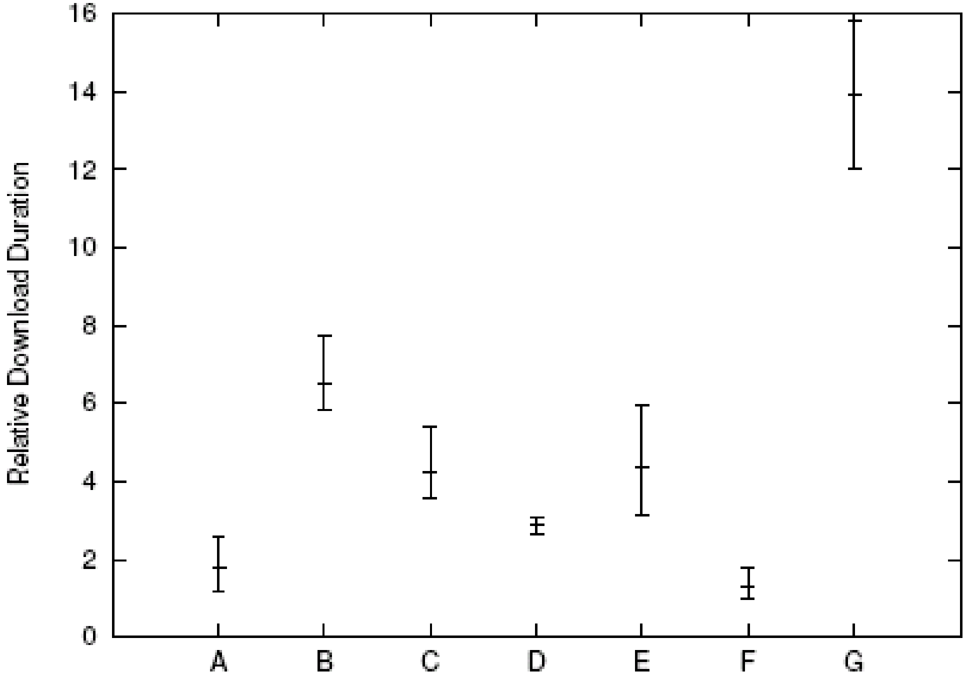
1

	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

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

Example: BitThief Client (5)



- 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)
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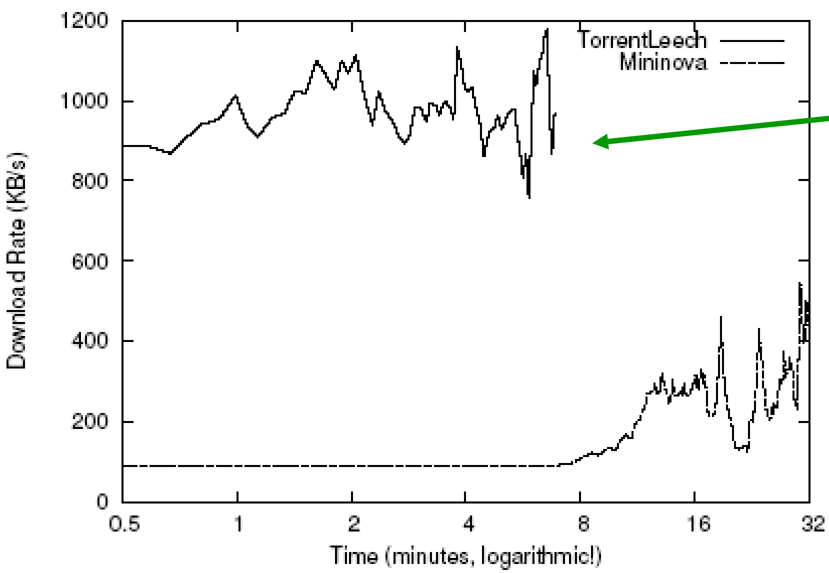
Example: BitThief Client (6)

- Sharing communities ban peers with low sharing ratios
- Uploading is encouraged; user registration required
- Client can report uploaded data itself (tracker announcements)
  - as tracker does not verify, it‘s easy to cheat



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

Example: BitThief Client (7)

All information available to the tracker comes from the periodic announce messages peers send to it:

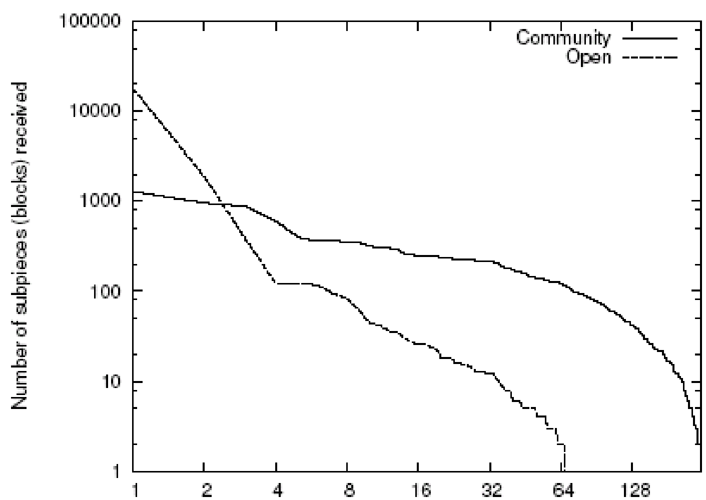
Tracker HTTP Request

GET /announce?...&uploaded=**86016**&downloaded=22528&left=81920&...

- In communities, contribution is more balanced

- Reason?

  - Peers want to boost ratio? Users more tech-savvy? (less firewalled peers? faster network connections?)



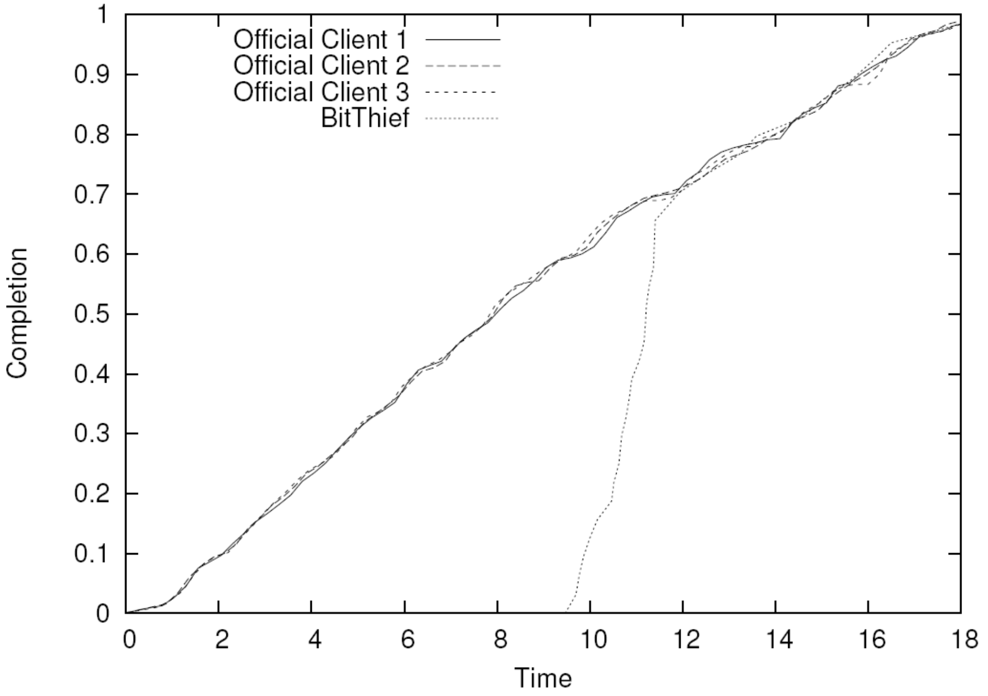
Example: BitThief Client (8)

Some tricks did not work for BitThief:

- Announce many available pieces
  (0%-99% all the same, 100% very bad, considered a seeder)
- Upload garbage
  (easier with mainline client than with Azureus; Azureus remembers from which it has got most subpieces/blocks and tries to get all from him; otherwise you are banned)
- Sybil attacks with same IP address
  (goal: more often in „round robin unchoke slots“ of seeder)
- …

Example: BitThief Client (9)

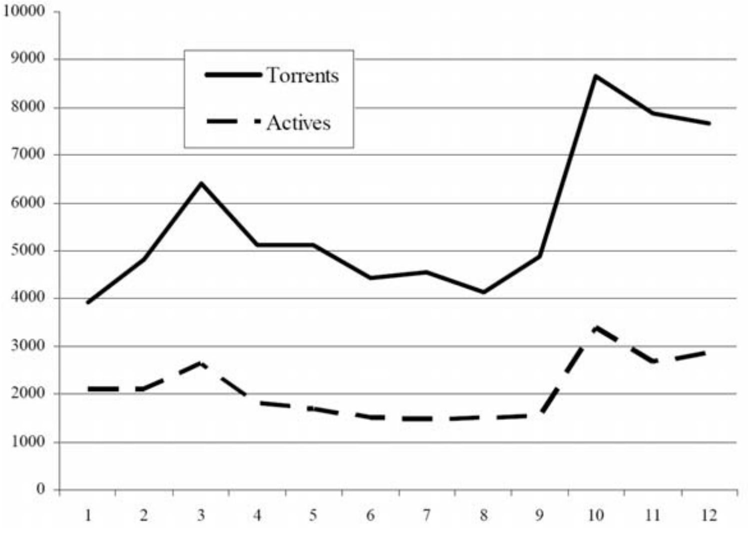
- Particularly fast if
  - Many seeders
  - Sharing communities (many and fast seeders!)
  - Small files: Aggressive startup behavior of BitThief
  - Few and slow seeders: Other leechers are starving, plenty of redundant „optimistic unchoking slots“, BitThief relatively good



- Relatively slow if
  - Few fast seeders
  - Seeders are occupied, other leechers also busy with tit-for-tat

Example: BitThief Client (10)

- Are people selfish?
  - no advertisement of client
  - poor GUI (will change now...)
  - collects data...



Example: BitTyrant

- BitTyrant (Piatek et al., NSDI'07)
  - Another strategic BitTorrent client
  - Goal: more efficient downloads, uploading allowed

- Means: smart neighbor selection
  - e.g., client seeks to be among top 5 neighbors (active set) at minimal cost
  - BitTyrant has larger active set
  - find peers with good reciprocation ratio ...
  - ... i.e., peers which upload much but need little
  - etc.

Future Fairness Mechanisms?

- How to improve BitTorrents robustness to selfish attacks?
- Problem: Strict tit-for-tat impossible due to bootstrap problem
- Recent proposal: fast extension
  - newly joined peers also obtain „venture capital“ for free
  - i.e., pieces which can be downloaded from other peers without reciprocating
  - however, peer p only obtains random subset of pieces
  - this subset depends on p‘s IP address (constant subset, e.g., by hash func)
  - in absence of seeders, free-riding is no longer possible!

Final Remarks

- BitTorrent is still a centralized peer-to-peer system
  - introduces vulnerability
  - e.g., websites hosting trackers can be shut down (e.g., suprnova.org etc.)

- In 2005, a distributed tracker protocol has been released
  - e.g., for torrents which do not have a working BitTorrent tracker
  - Azureus is Kademlia DHT (see later), not compatible with official DHT
  - unfortunately, not much information available...
  - e.g., find new peers even without tracker
  - e.g., efficiently find rare missing pieces during end game?

The eMule Client and Kad:
Towards distributed hash tables

Towards Distributed Hash Tables

- Seen so far:
  - Napster = server-based p2p architecture
  - Gnutella = unstructured p2p architecture
  - BitTorrent = swarms of peers interested in same file, tracker-based

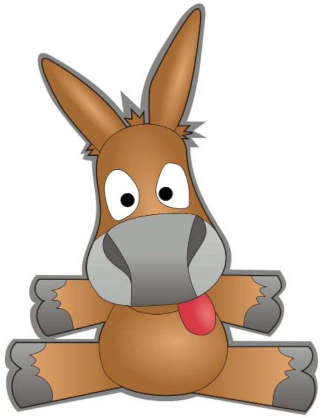
- Recently, distributed hash tables and structured p2p systems also emerge in practice

- A case study of eMule...

eMule & eDonkey (1)

The eMule client allows to connect to two different networks:

- the server-based eDonkey2000 (eD2K) network
- the decentralized Kad network
- open-source, and many mods exist...



eMule & eDonkey (2)

- eDonkey2000 network

  - popularity: several million users

  - technically uninteresting: server-based

  - eMule is connected to a eD2K server

  - at login time, client informs server about available files

  - client maintains a file with a list of servers (in order of acquaintance)

  - most servers are based on lugdunum software (not open-source)

  - client iterates from one server in the list to the next until roughly 300 results have been collected

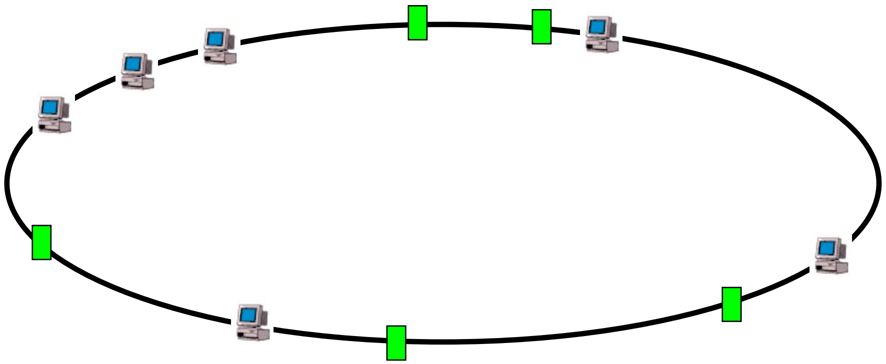
  - concentration on „popular“ servers, problematic when taken down (e.g. Razorback 2.0)?

- Kad network based on DHT

  - in more detail now...

DHT Refresher (1)

- „Distributed hash table“
  - Peers and data have overlay IDs (or keys)
  - E.g., peer ID is hash of peer‘s IP address
  - E.g., file ID is hash of file name or file content

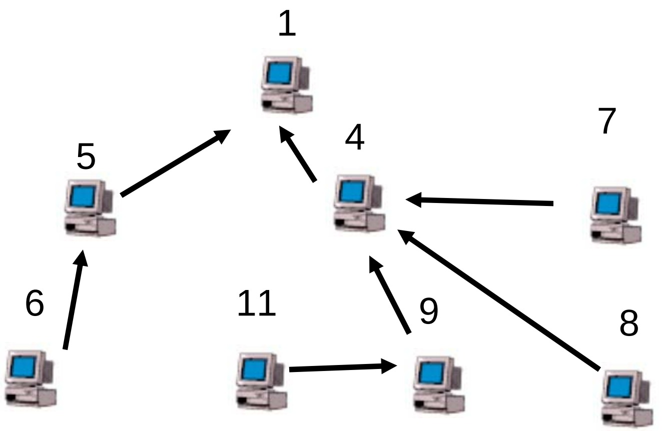


- Typically, both IDs are chosen from same space
  - e.g., 1-dimensional [0,1) space, data is stored on „closest peer“ (consistent hashing approach)
  - Peers are connected to each other with respect to their IDs (structured peer-to-peer topology)

DHT Refresher (2)

- Data can be found efficiently (also rare data)
  - Routing algorithms beyond „flooding“ and random walks

- Overlay topology gives guarantees
  - simple rules ensure connectivity and low diameter
  - networks often hypercubic
  - e.g.: peers have unique numbers as identifiers
  - rule „connect to a peer of lower ID“ already ensures connectivity



DHT Refresher (3)

- Some common mechanisms and principles...

- Mechanism 1: Do not store entire files at the corresponding position, but only the pointer
  - \+ Can be copied much more quickly
  - \+ Beneficial under dynamics
  - \+ Nobody has to store other people's files

- Directed search and routing:

  \- for a DHT lookup, you need to know the file hash / file key

DHT Refresher (4)

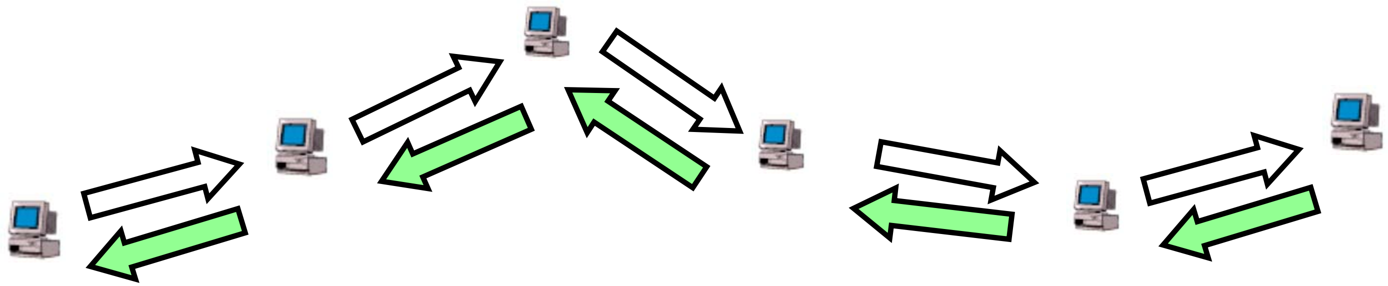
- In order to find a file, a peer needs the file hash
- Mechanism 2: introduce another indirection
- First lookup step: enter keywords and find peers responsible for these keywords => obtain file hash
- Second lookup step: contact peer responsible for the file hash => obtain addresses of peers storing a copy of the file
- Generally, DHTs are well-suited to find specific (and rare) data efficiently

  - However, more inexact and approximate lookups are challenging

DHT Refresher (5)

- Mechanism 3: Direct downloads
  - Although data is found in a multi-hop manner, download takes place directly between two peers

- In systems with emphasis on anonymity (e.g., Freenet), this may be implemented differently: return path is also multi-hop
  - Peer does not know whether its neighbor requested the file or whether it is simply a forwarder
  - less efficient



Kad Network (1)

- The Kad network is the most popular DHT today
  - DHTs have been a successful concept in literature, but most systems in practice are server-based
  - Kad network consists of around 4 million peers
  - about half of these peers can be contacted directly (no firewall or NAT)
  - it is based on the Kademlia paper by Maymounkov and Mazières

- Kademlia is also used in the Overnet p2p system
  - properietary protocol, „shut down“ 2006

Many interesting measurement study results of the Kad network as well as implementation details can be found in the recent papers by Steiner and Biersack.

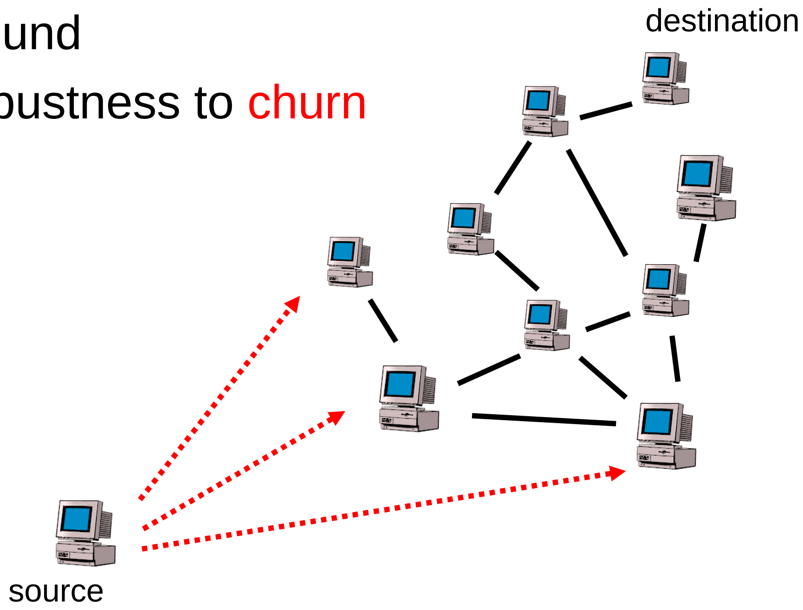
Kad Network (2)

- Main conepts
  - each peer has 128-bit ID (usually created by random generator)
  - ID defines position in cyclic ID space
  - stored at peer and reused when peer joins the network again
  - „hypercubic“ routing via XOR metric
  - for each $i \in [0,127]$, a peer stores some contacts with distance between 2^i and 2^{i+1} to its own location
  - yields logarithmic network diameter
  - for each contact, peer stores: <Kad ID, IP address, port>
  - replication policy (typically 10 replicas in zone of peers which share first 8 bits)
  - 8-bit zone called „tolerance zone“, beneficial under churn
  - periodically republished

- In zone of 8-bit, in one day, measurement studies observed 1.4 million publications of files by 1.5 million distinct users and with 42,000 different keywords

Kad Network (3)

- Iterative routing
  - in contrast to recursive routing
  - requester runs 3 parallel lookups which return new peers
  - from them, requester selects 3 peers closer to destination
  - and so on!
  - termination: no closer peer found
  - higher delay but improved robustness to churn



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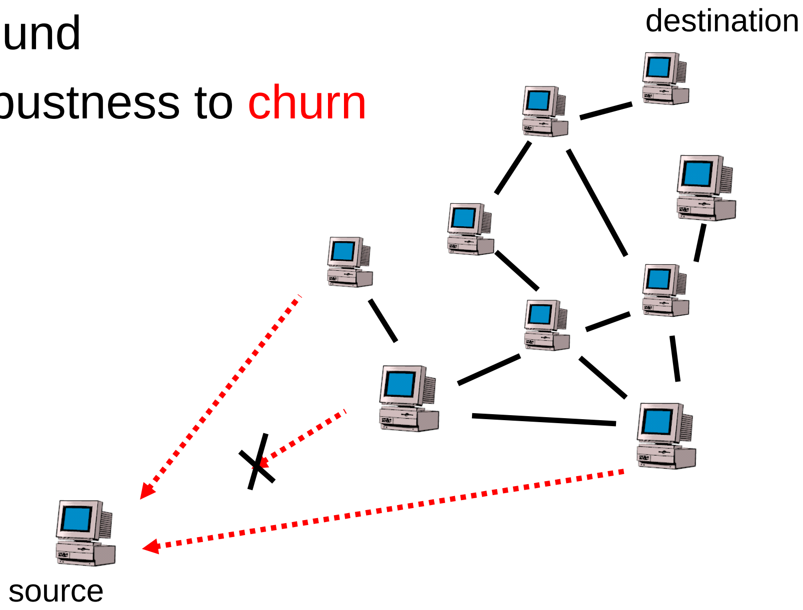

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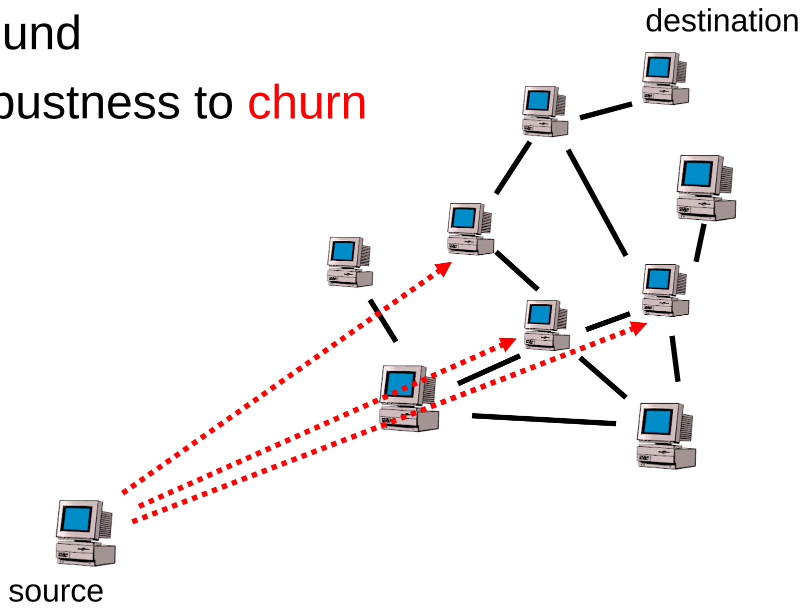
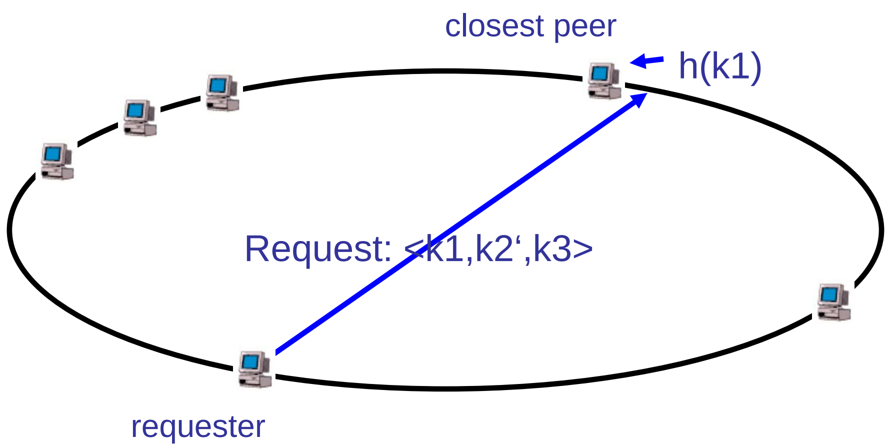
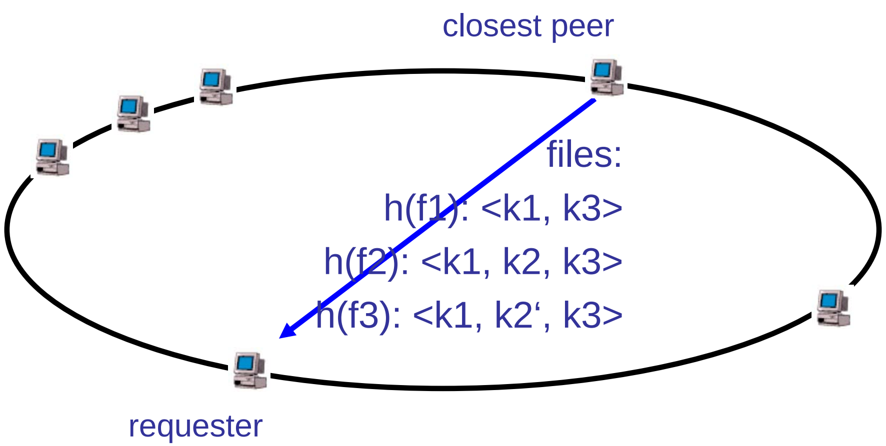


Kad Keyword Request



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.

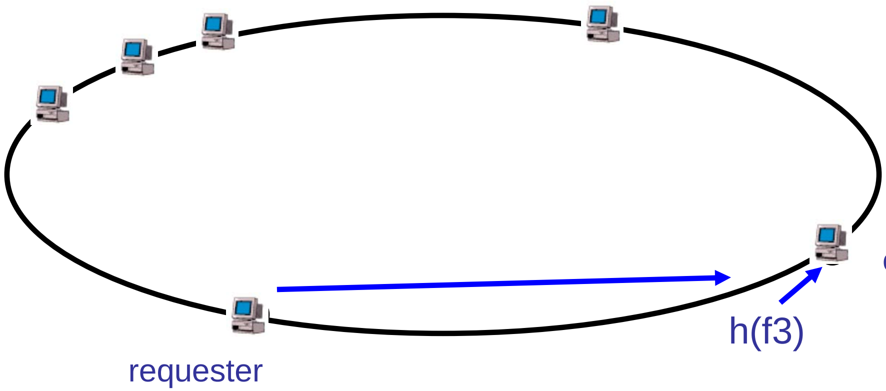
Kad Keyword Request



Peer responsible for this keyword returns different sources together with keywords.

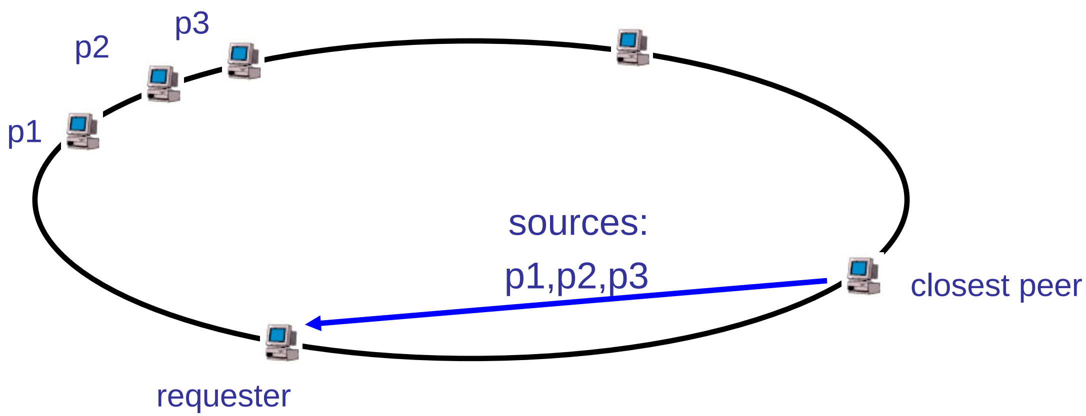
(remark: only those files with entries that include remaining keywords of request are returned, see later)

Kad Source Request



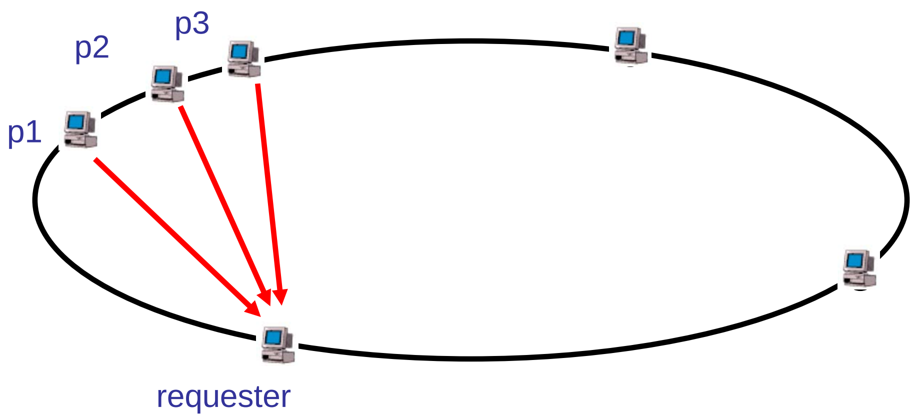
Peer can use this hash to find peer responsible for the file (possibly many with same content / same hash)

Kad Source Request



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

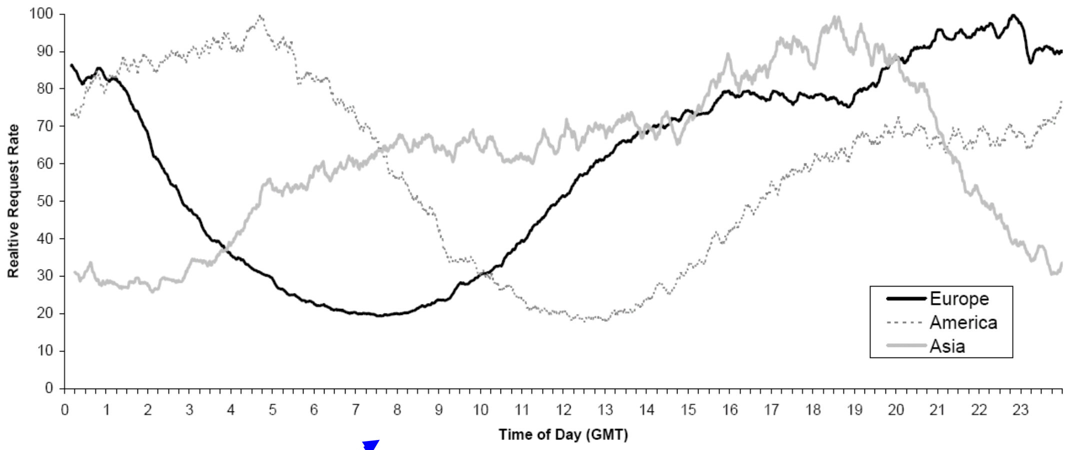
Kad Download



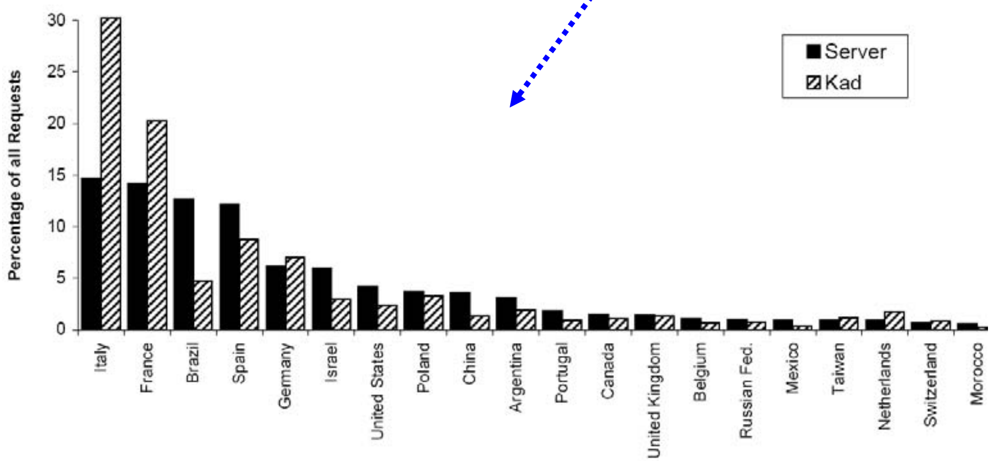
Eventually, the requester can download the data from these peers.

Some Data

- In 2007, we received roughly 8 requests per minute in Kad for the keyword „Simpsons“ (which also includes queries for „Simpsons Movie“, „Simpsons Sountrack“, etc.)



Most Kad activity during evening / night (same for eDonkey)



Quite popular in Europe (why this difference between eDonkey and Kad?)

Some Challenges

- Peer-to-peer principles also play a role in certain discussions about the design of a future Internet

  - e.g., to disburden hotspots

- Therefore, interesting to study today's state-of-the-art systems

- Some challenges that Kad currently faces...

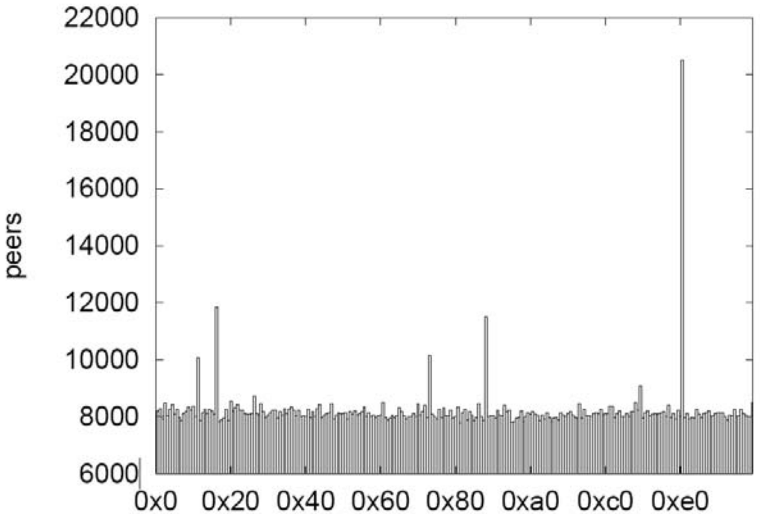
  - case study: ID assignment

Kad ID Assignment (1)

- Recall: each peer in Kad chooses a random ID
  - e.g., created with a local random generator

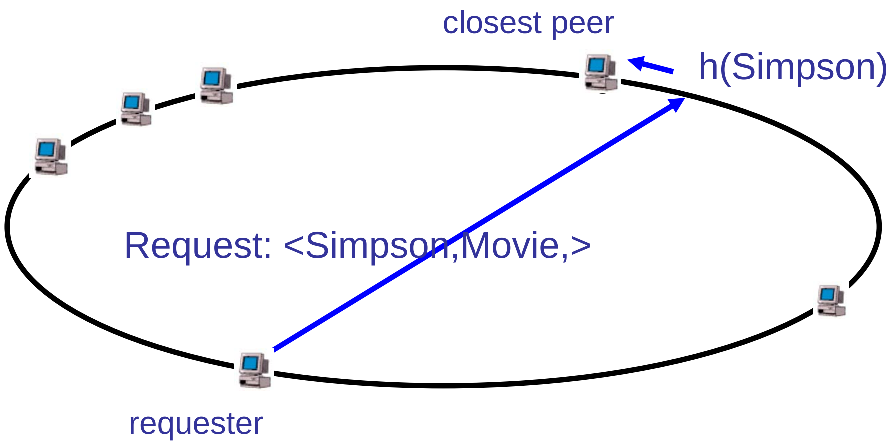
- Kad does not include any mechanisms to verify whether this ID has been produced „properly"

- Consequence: choosing IDs can be used for attacks or for spying
  - indeed, many irregularities observed in today's Kad network
  - e.g., peers in China often change ID, non-uniform ID space, etc.
  - exploit, for censorship



Kad ID Assignment (2)

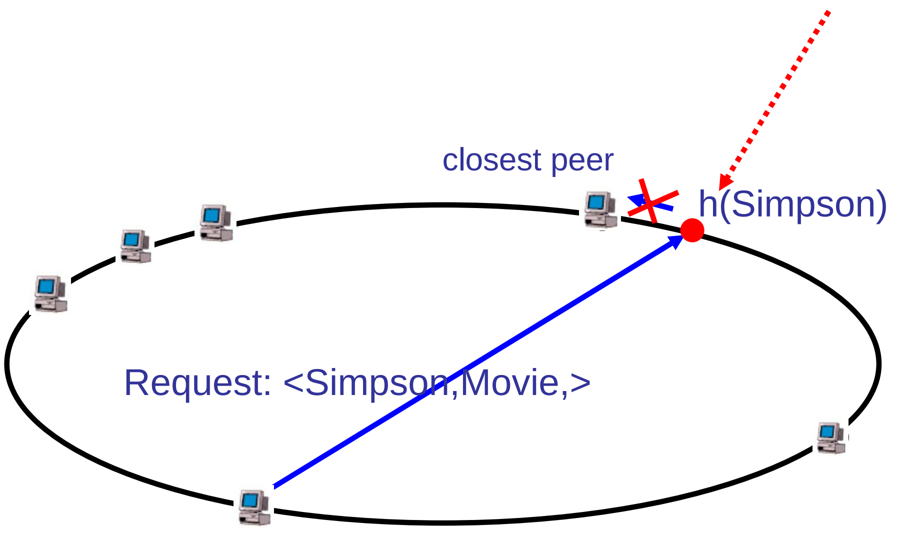
- E.g., censoring contents in Kad



Kad ID Assignment (2)

- E.g., censoring contents in Kad

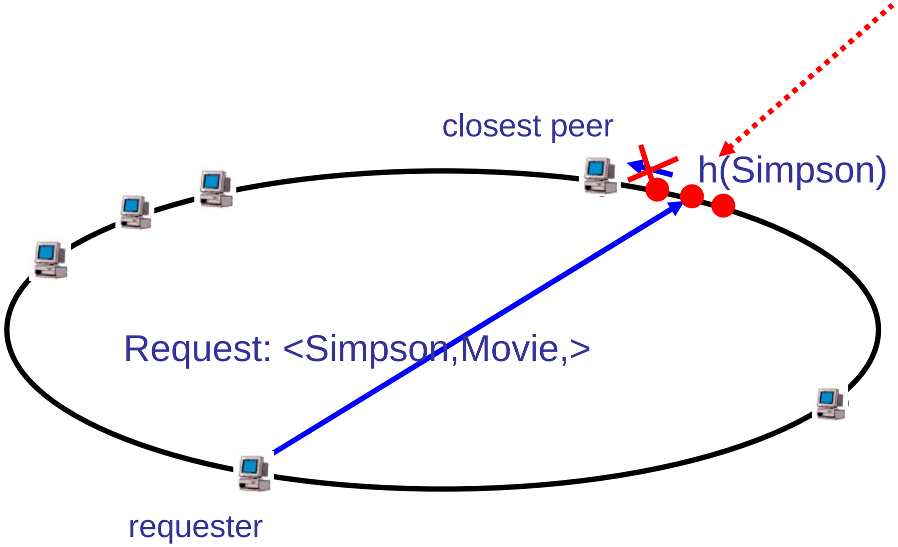
If peer is inserted here, it can block (or spy on) keyword requests for „Simpsons“, „Simpsons Movie“, etc.



Kad ID Assignment (2)

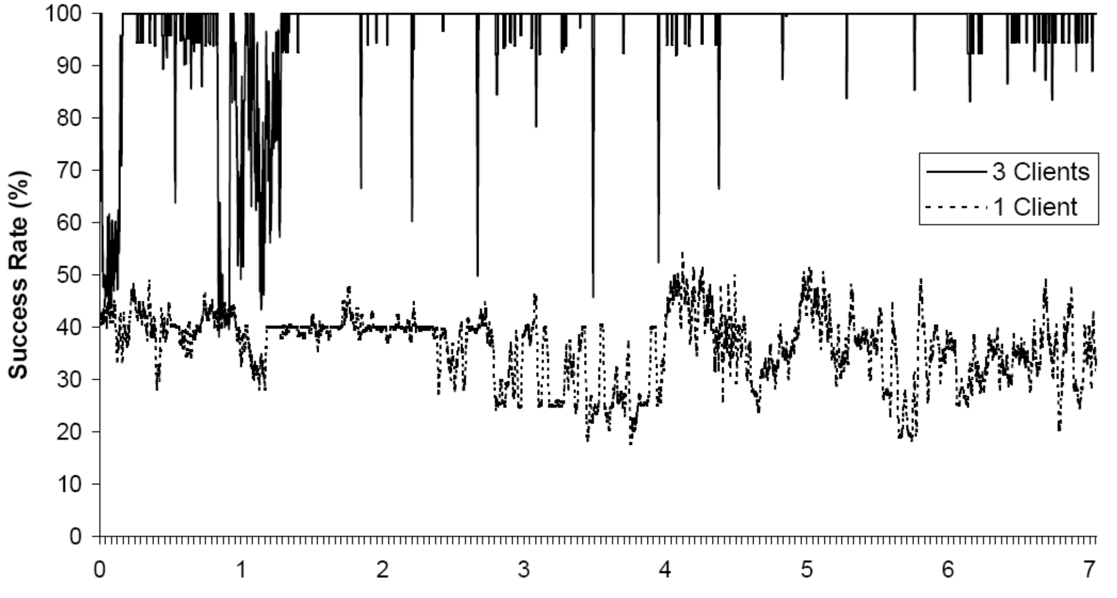
- E.g., censoring contents in Kad

Sybil attack works even better...
(Steiner and Biersack introduced up to 2^{16} Sybils!)



Kad ID Assignment (3)

- Some data

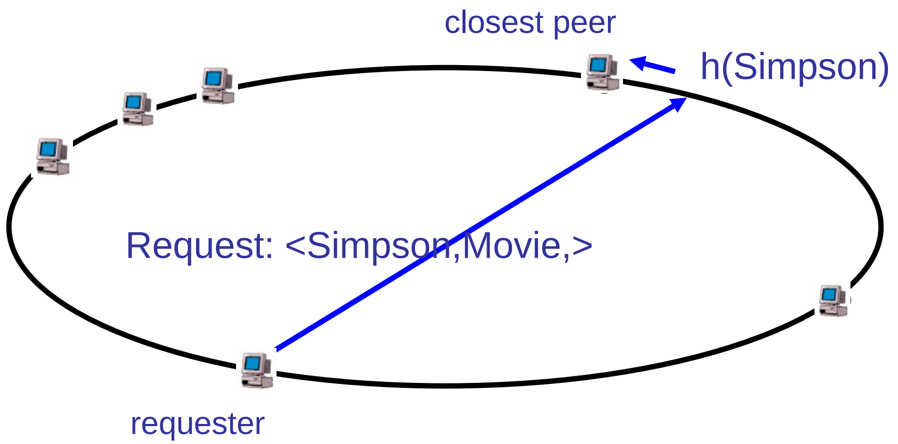


More Censorship: Publish Attack (1)

- Besides this „peer insertion attack“, additional censorship attacks exist

- For instance, a „publish attack“
  - We can also attack the originally publishing peers...
  - ... by creating fake entries
  - For each entry: unique hash
    (but from same IP ok)

<keywords, filename>
<keywords, filename>
...



Publish Attack (2)

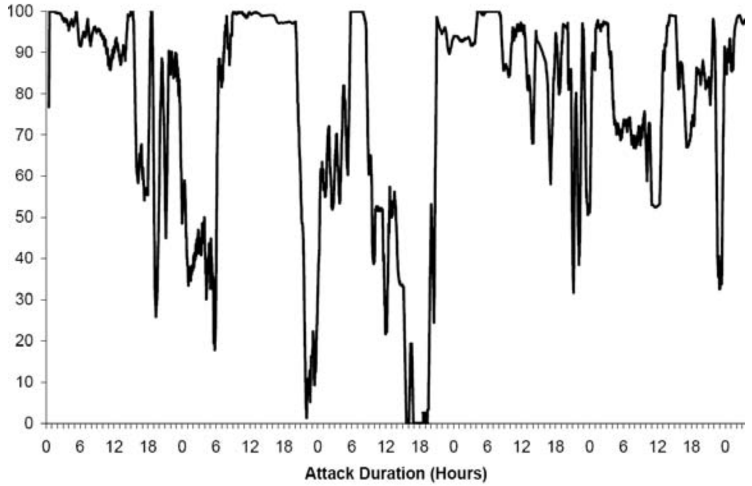
- Publishing peers return at most 300 result tuples per request
- Give priority to latest additions to index table
- Every entry expires after a couple of hours
- More difficult: attacked entry must include superset of keywords from the request

  - not known in advance: include interpreter name, label, etc.

Publish Attack (3)

- Problem: Publishing peers accept many tuples from same peer / IP address!

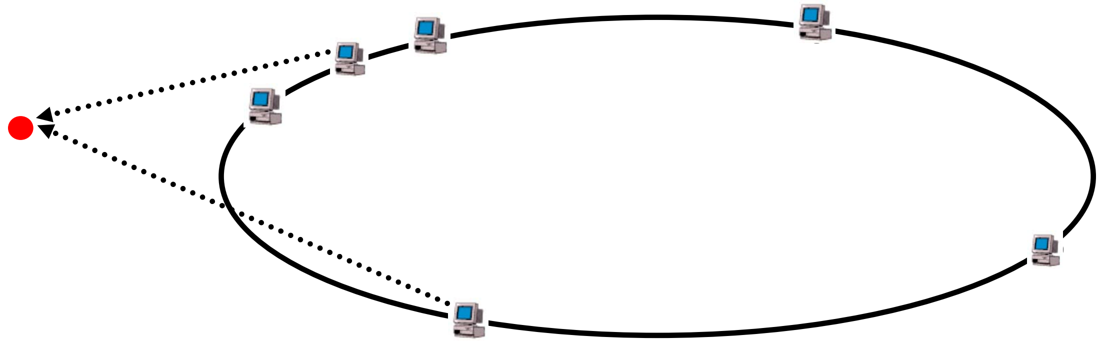
- Less successful: some peers are immune



Other Attacks

- It‘s possible to fill neighbor tables of peers
  - „eclipses“ this peer (eclipse attack)

- DDoS attack: publish attack can also be used to overwhelm peers outside the network with reuqests



Countermeasures? (1)

It seems that these attacks can easily be prevented

- important insight: do not accept too much information from same peer!
- do not allow peers to choose their ID!

Countermeasures? (2)

A solution? Choose overlay ID depending on IP address

- e.g., a hash function on the IP address can be verified! (e.g., Azureus)
- but what if IP address changes over time (dynamic IP addresses / DHCP)?
- e.g., peers should not lose their credits when their IP changes
- many peers have same IP address if behind a NAT!
- other idea: compute a hash of user-generated data (e.g., a password) rather than of the IP address; thus, many different strings need to be tried to produce a specific ID
- however, as there are much less than 2^{128} peers in a network, an approximate ID will do the job for a peer insertion attack, and this can be computed efficiently
- finally, an attacker may indeed have access to many IP addresses etc.

Countermeasures? (3)

- What about Sybil attacks?
  - Same peer joins many times (with same or different IP address)
  - Difficult in decentralized environment?
  - Centralized solutions? Send SMS to obtain unique ID (hash from mobile phone number)? Solve CAPTCHA?
  - etc.

Many of these problems are not trivial
in purely decentralized environments,
and further research is needed!

A Glimpse at Two Other „Popular“ Applications:
Peer-to-Peer Telephony with Skype
and Botnets

Skype (1)

Some facts...

- VoIP network with more than 200 million users
- efforts to offer Skype on mobile phones, PSP, etc.
- proprietary protocol, reverse-engineering difficult
  (many papers report on it... => ask me for literature)
- encrypted (AES, and RSA for key establishment)
- not interoperable with other VoIP networks
- bought by eBay (for approx. 3.3 billion USD, October 2005)
- according to Wikipedia: first quarter 2008 total of 14.2 billion minutes skype-to-skype, 1.7 billion minutes skype-out, net revenue 126 million USD

Skype (2)

- What is p2p? E.g., yellow pages...
- Predecessor file sharing system: KaZaa (FastTrack protocol)

  - two types of peers: ordinary peers and super peers (algorithms unpublished)

  - communication via port 80

  - super peer: public IP, sufficient CPU / bandwidth / memory / ...

  - UUHash algorithm used to allow downloading from multiple sources (checksum efficiently over parts of file)

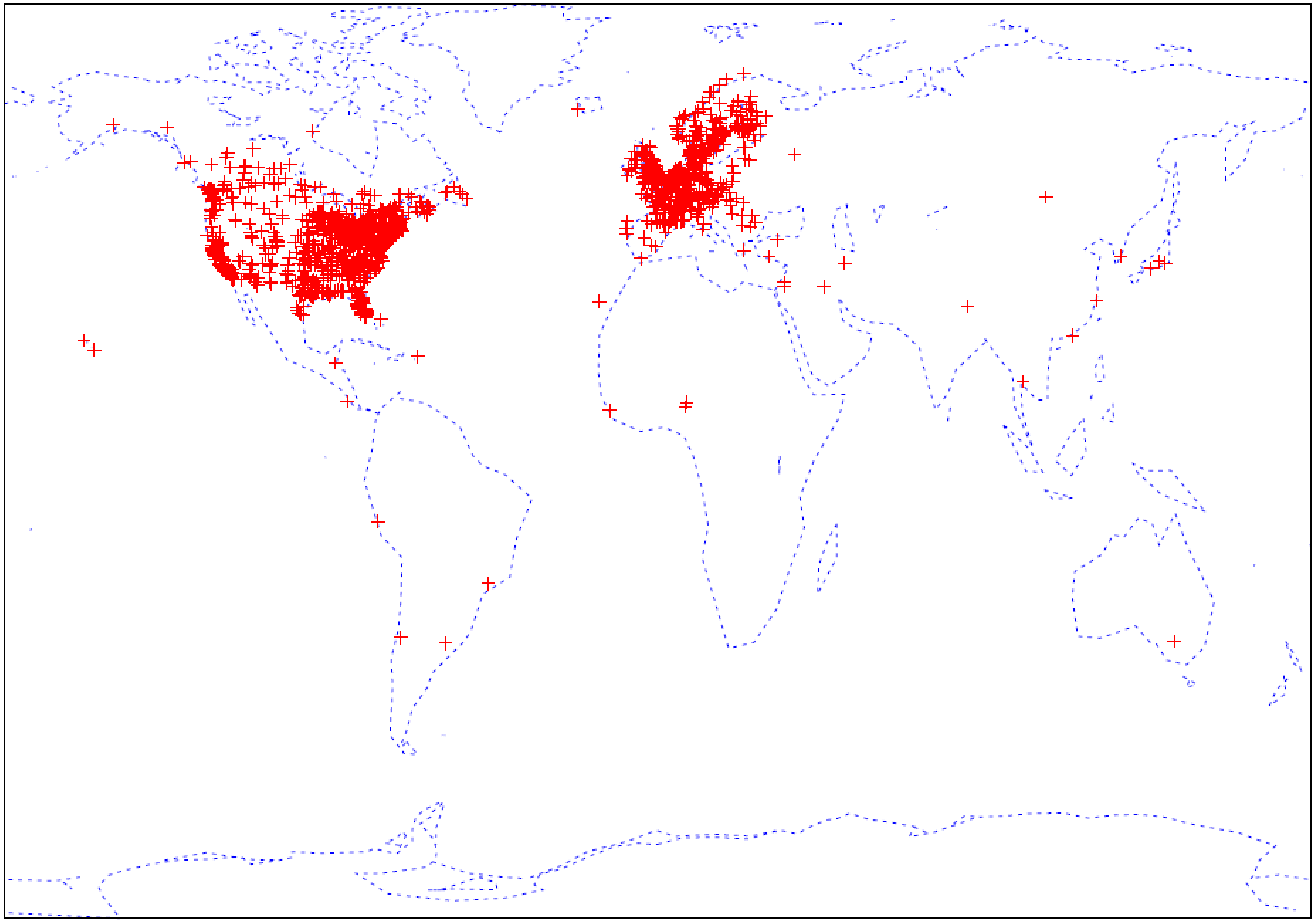
  - but uploading only possible when entire file has been downloaded

  - UUHash algorithm problematic: RIAA used it to distribute fake files

  - no real incentive mechanism (KaZaa lite...)

Skype (2)

- Map of Skype supernodes (Xie&Yang, IPTPS 2007)



Skype (3)

- Traffic

  - phone call: approx. 30 MB per hour

  - however, background traffic up to 1 GB per month (without any call)

  - traffic pattern can be problematic for ISPs (e.g., violating no-valley routing policy where customer relays traffic for its provider), claimed to increase costs

- Congestion control policy?

  - „youth hostel experience“

Botnets (1)

- Botnets are one of the most significant threats in the Internet today
  - bot = program that performs tasks without user interaction
  - botnet = network of malicious bots that illegally control computing resources
  - some attackers are able to gain control of large portions of the Internet

- Used to disperse spam, conduct DoS attacks, etc.

- Keynote by Tom Leighton (Akamai) at PODC 2007:
  - 100s of servers under DDoS attack all the time
  - anti-virus company under constant attack since 2 years
  - some banks today pay extortion money
  - 4 large zombie armies today, one tried to steal other three

Botnets (2)

- Traditionally, botnets were coordinated centrally, e.g., via IRC chat

  - once identified, central IRC server can be taken down

- Now, first peer-to-peer architectures are emerging

  - e.g., Peacomm, aka Nuwar aka Zhelatin (= storm worm)

- E.g., paper by Grizzard et al. HotBots 2007

The Peacomm Bot (1)

- Trojan.Peacomm botnet uses Overnet peer-to-peer protocol
  - i.e., Kademlia DHT
  - DHT provides communication primitive
  - allows peers to download secondary injections and to upgrade

- Protocol
  1. spread, e.g., via email
  2. connection to Overnet: initial list of peers hard-coded (bootstrap)
  3. download secondary injection (hard-coded keys to search and download an encrypted URL)
  4. hard-coded keys to decrypt URL
  5. download secondary injection from this URL
  6. execute

The Peacomm Bot (2)

- Peer-to-peer protocol mainly used as a name resolution server for upgrading the bot

  - Peer-to-peer DNS with encrypted data

  - Data / URLs can change over time, nodes on which information is stored cannot be taken down (DHT...)

  - But keys indicate where data is (at least in ID space)

  - And bootstrap is also a weakness

- Secondary injections

  - e.g., to download additional components

  - e.g., SMTP emailing / spamming component

  - e.g., email propagation component

  - e.g., DDoS tool

  - etc.

Conclusion

Peer-to-Peer „Backstage“...

- Existing p2p systems are heterogeneous and dynamic

  - different goals (e.g., file sharing vs live streaming, anonymity, etc.)

- Some fundamental concepts

  - trend to structured p2p systems

- Interesting research challenges

  - incentive-compatibility
  - robustness to attacks
  - churn tolerance
  - in some sense, much research in distributed computing can be considered „peer-to-peer research“

Dziekuje!

Slides and papers at

http://www14.informatik.tu-muenchen.de/personen/schmiste/