Computer Networks

Instructor: Niklas Carlsson

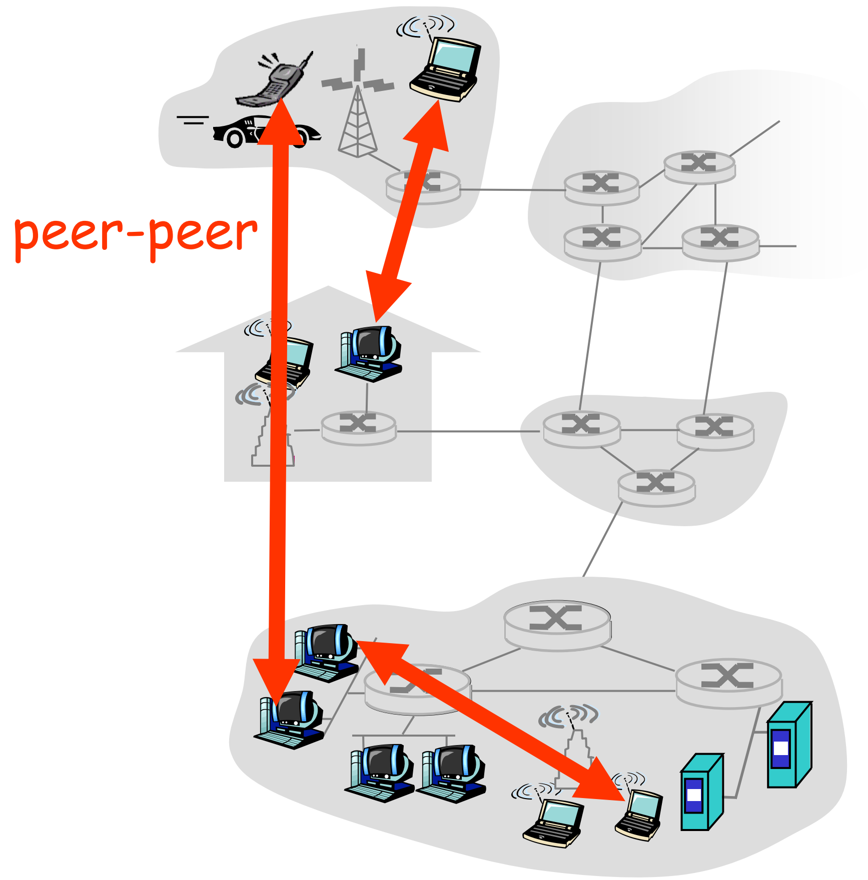
Email: niklas.carlsson@liu.se

Notes derived from "*Computer Networking: A Top Down Approach*", by Jim Kurose and Keith Ross, Addison-Wesley.

The slides are adapted and modified based on slides from the book's companion Web site, as well as modified slides by Anirban Mahanti and Carey Williamson.

Pure P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses



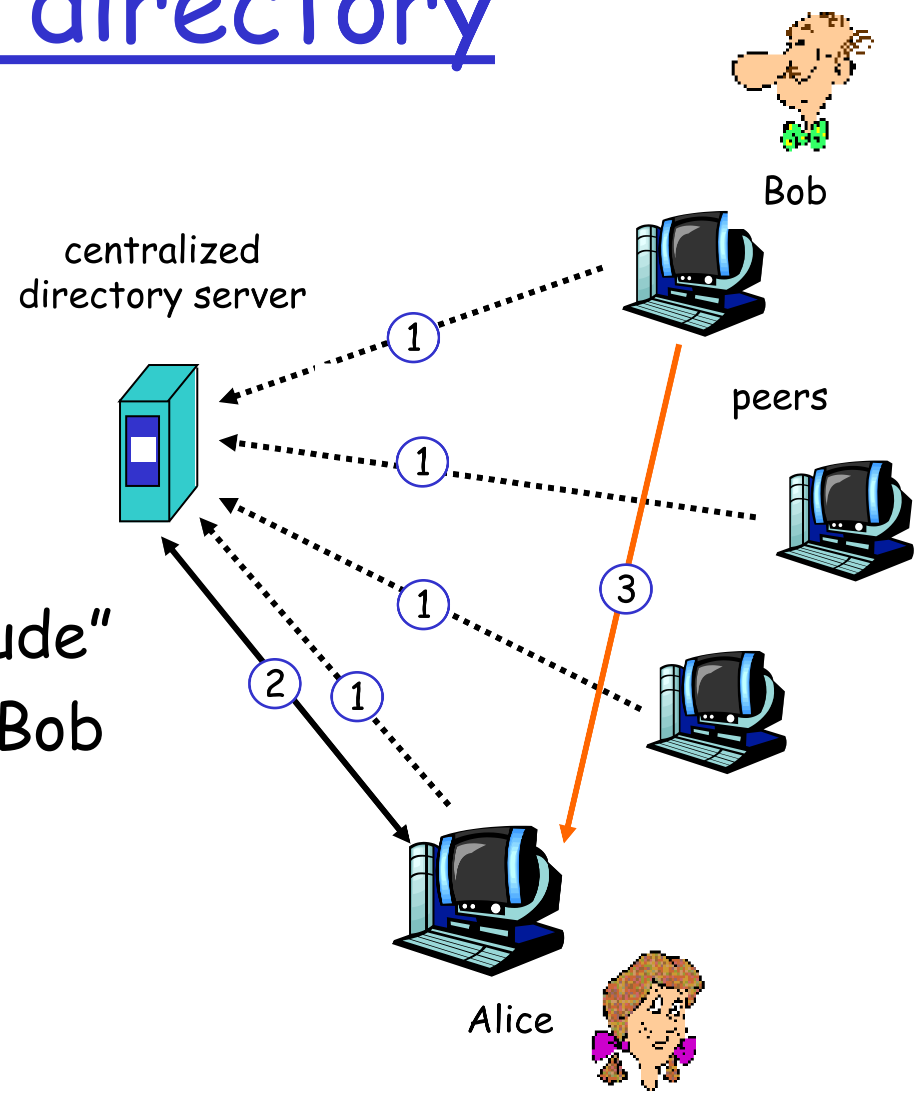
P2P: centralized directory

original "Napster" design

1) when peer connects, it informs central server:
   - IP address
   - content

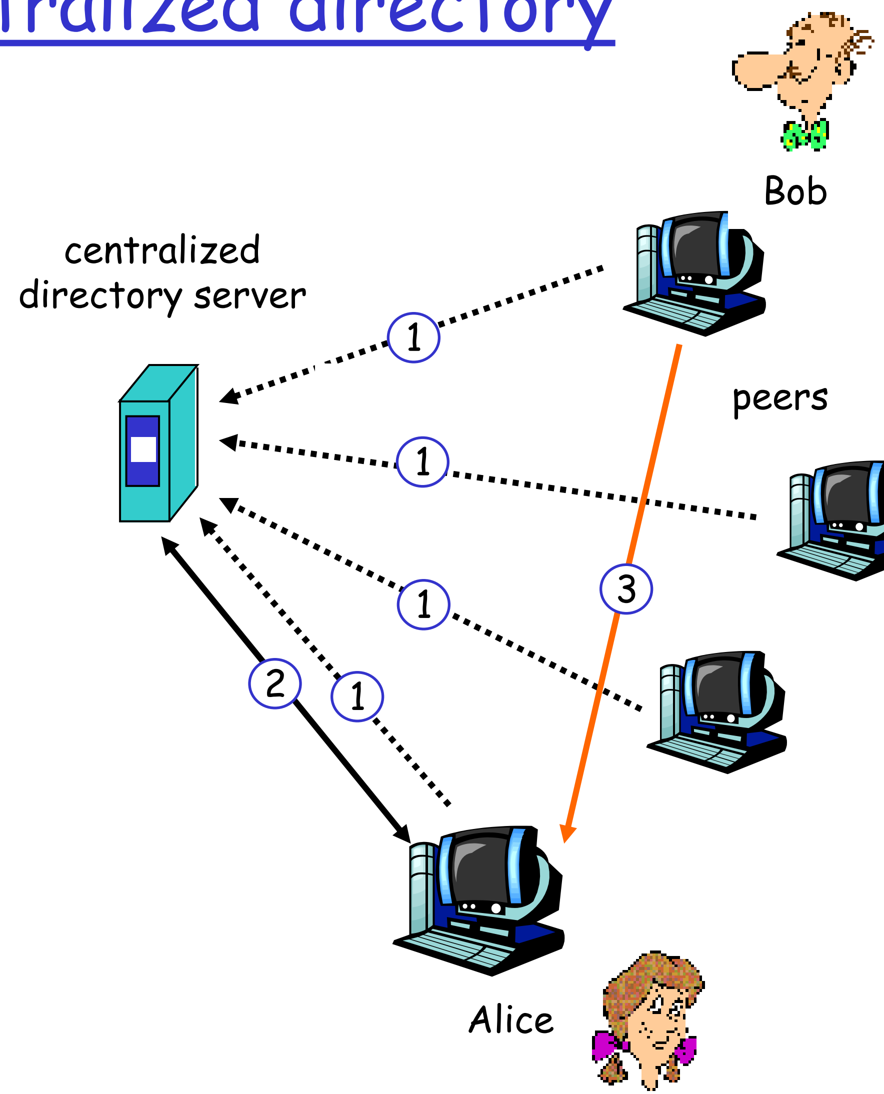
2) Alice queries for "Hey Jude"

3) Alice requests file from Bob



P2P: problems with centralized directory

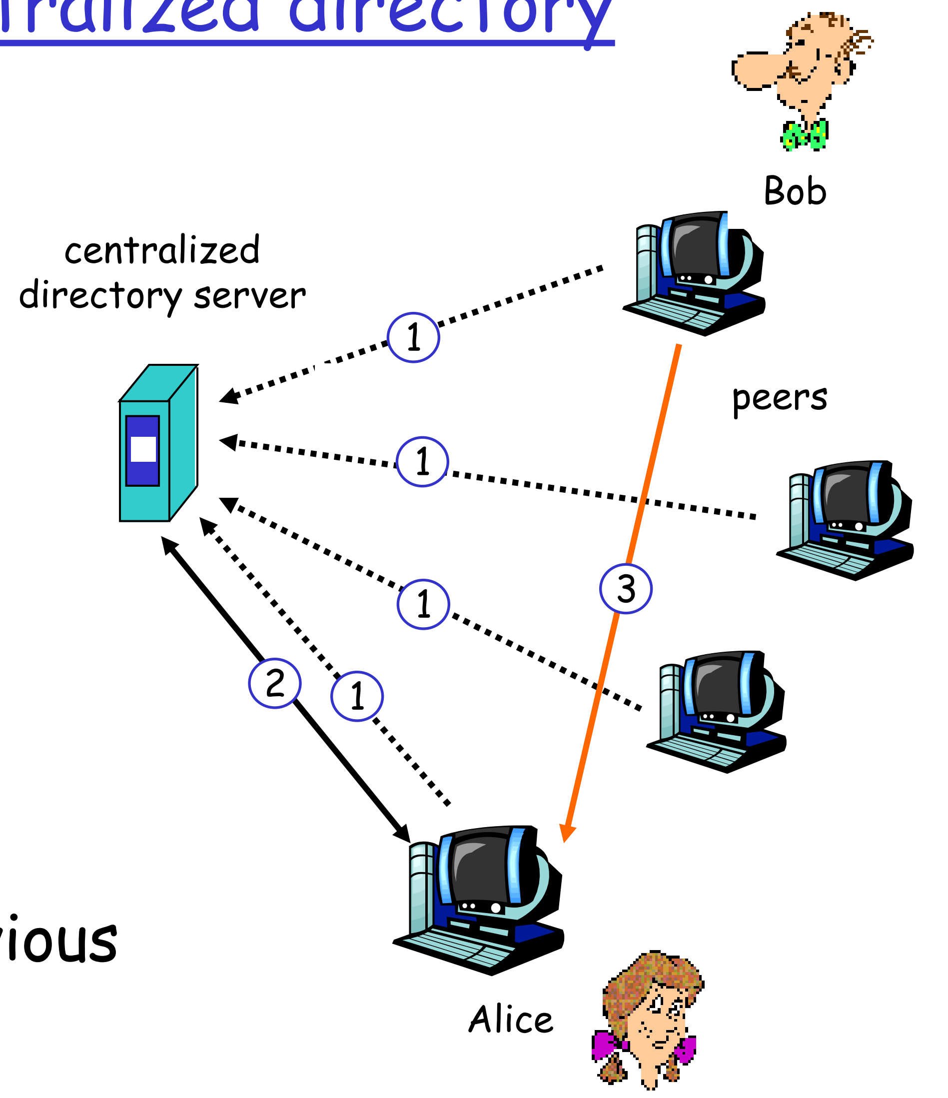
file transfer is decentralized, but locating content is highly centralized



P2P: problems with centralized directory

file transfer is decentralized, but locating content is highly centralized

- single point of failure
- performance bottleneck
- copyright infringement: "target" of lawsuit is obvious

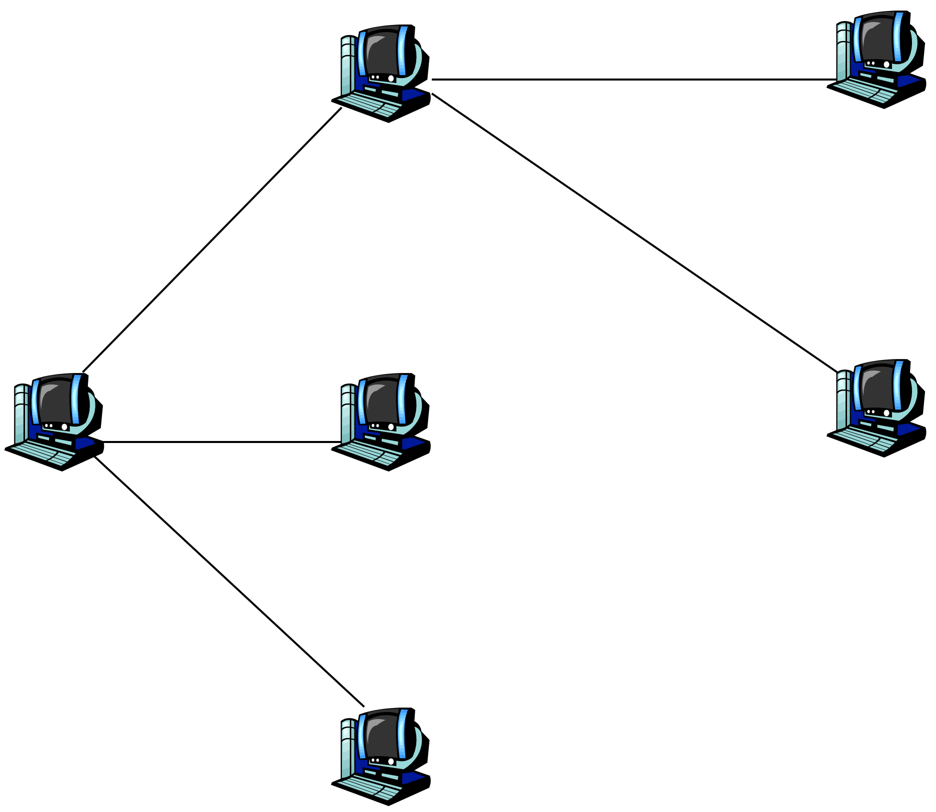


Query flooding: Gnutella

- fully distributed
  - no central server
- public domain protocol
- many Gnutella clients implementing protocol

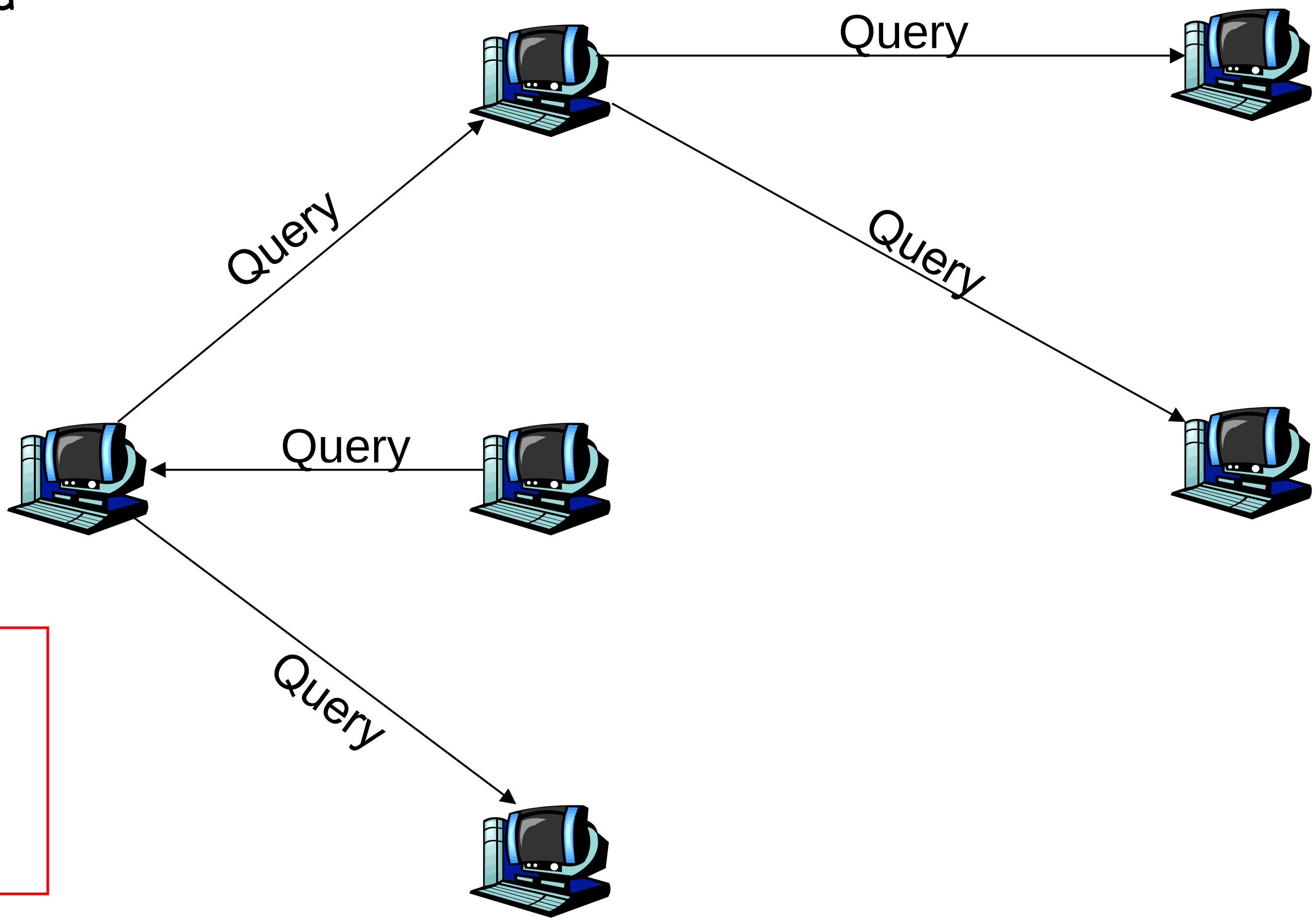
overlay network: graph

- edge between peer X and Y if there's a TCP connection
- all active peers and edges form overlay net
- edge: virtual (*not* physical) link
- given peer typically connected with < 10 overlay neighbors



Gnutella: protocol

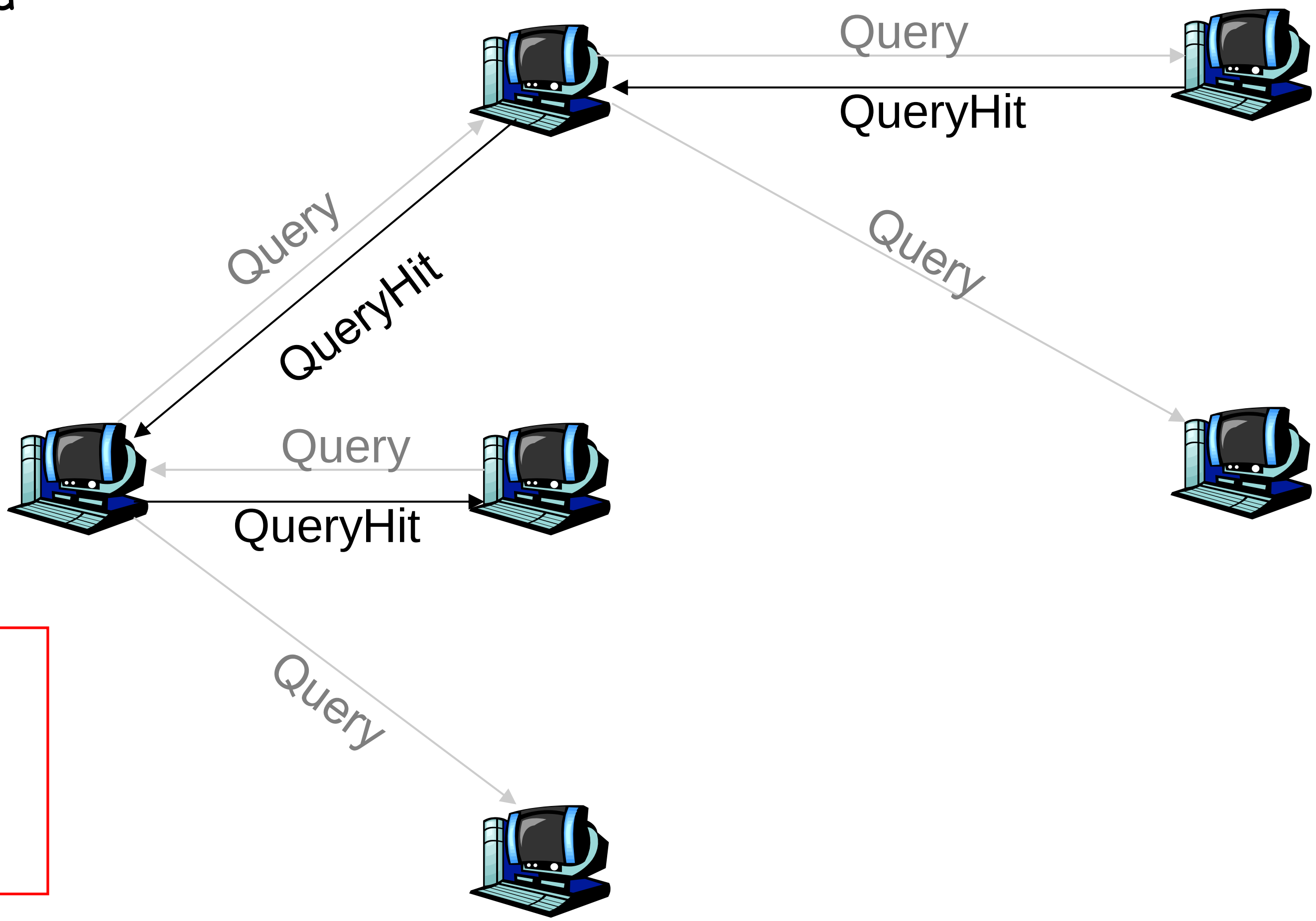
- Query message sent over existing TCP connections
- peers forward Query message
-



Scalability:
limited scope flooding

Gnutella: protocol

- Query message sent over existing TCP connections
- peers forward Query message
- QueryHit sent over reverse path



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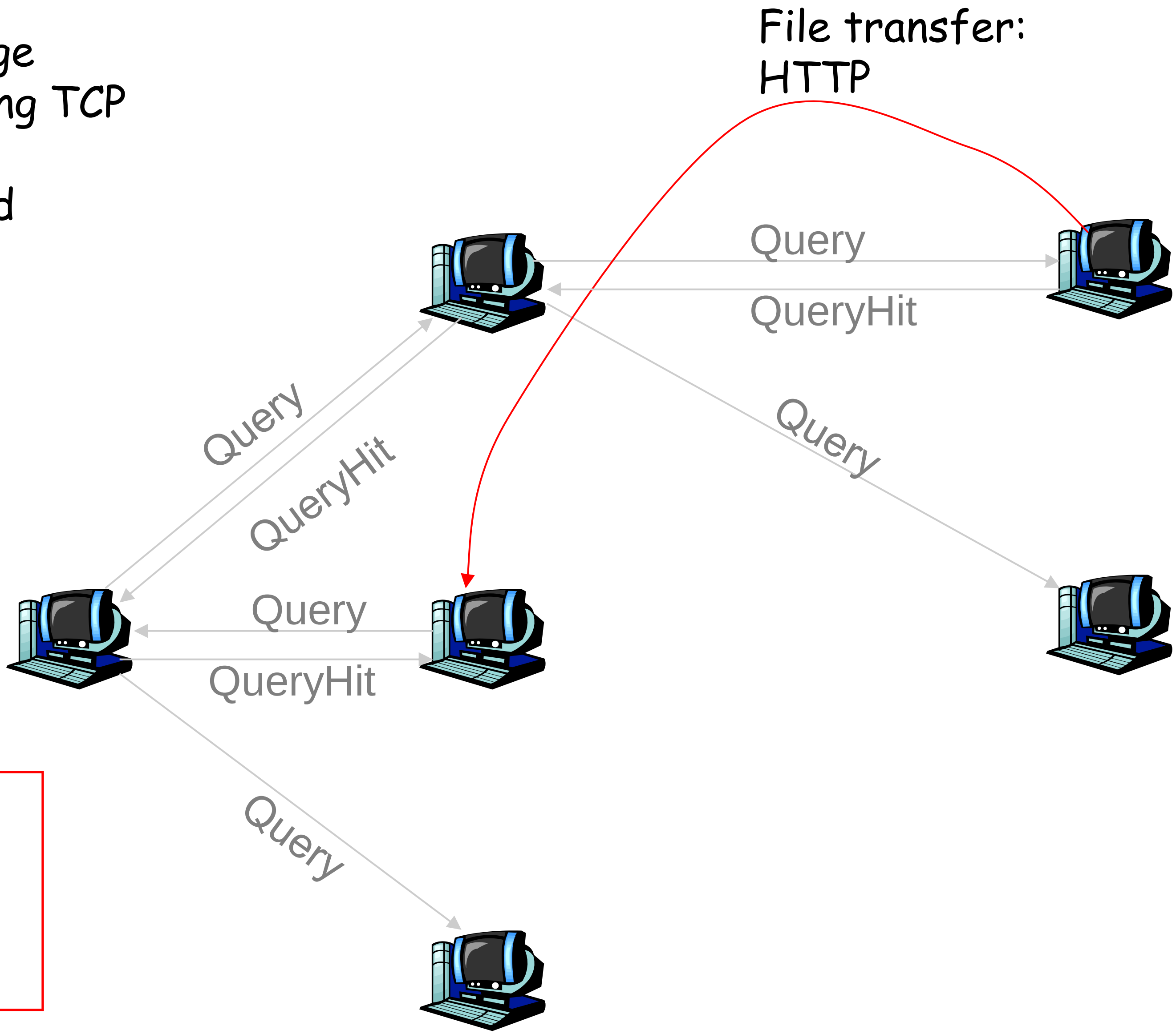
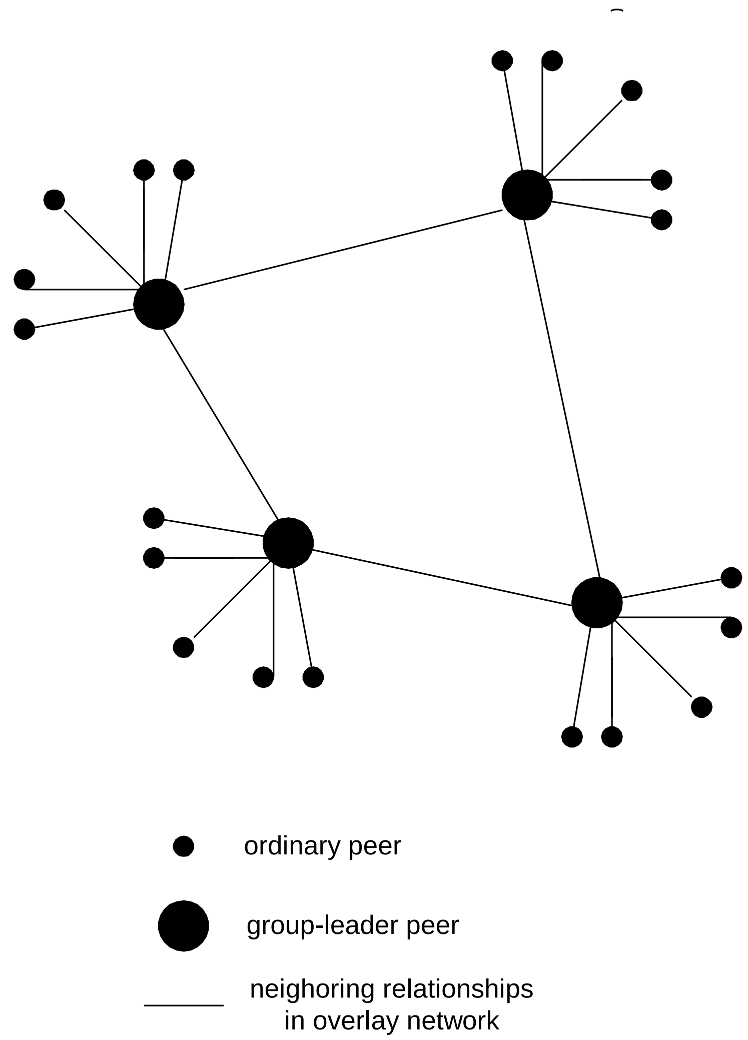


Scalability: limited scope flooding

Hierarchical Overlay

- between centralized index, query flooding approaches
- each peer is either a *group leader* or assigned to a group leader.
- group leader tracks content in its children



Structured p2p systems

Distributed Hash Table (DHT)

- DHT = distributed P2P database
- Database has (key, value) pairs;
  - key: ss number; value: human name
  - key: content type; value: IP address
- Peers query DB with key
  - DB returns values that match the key
- Peers can also insert (key, value) peers

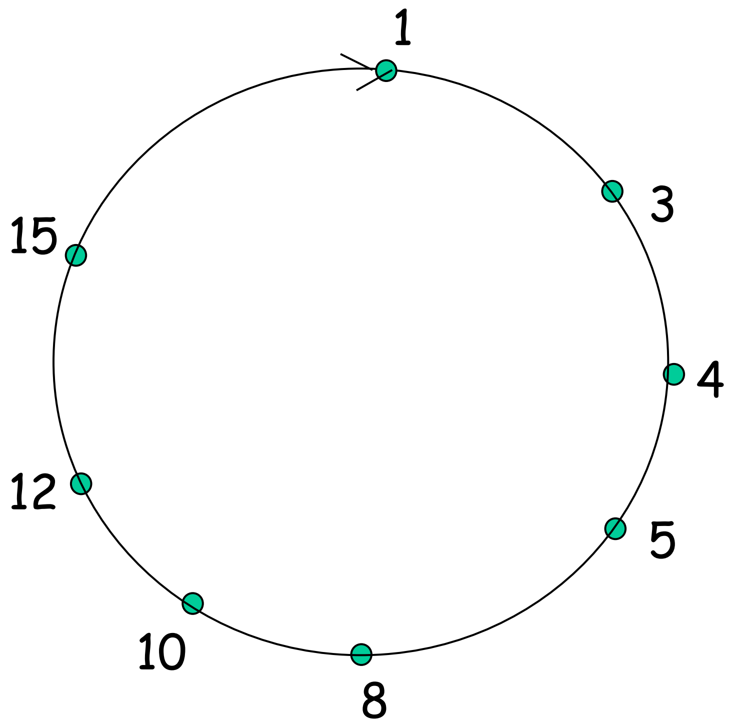
DHT Identifiers

- Assign integer identifier to each peer in range $[0,2^n-1]$.
  - Each identifier can be represented by n bits.
- Require each key to be an integer in same range.
- To get integer keys, hash original key.
  - eg, key = h("Led Zeppelin IV")
  - This is why they call it a distributed "hash" table

How to assign keys to peers?

- Central issue:
  - Assigning (key, value) pairs to peers.
- Rule: assign key to the peer that has the closest ID.
- Convention in lecture: closest is the closest successor of the key.
- Ex: n=4; peers: 1,3,4,5,8,10,12,14;
  - key = 13, then successor peer = 14
  - key = 15, then successor peer = 1

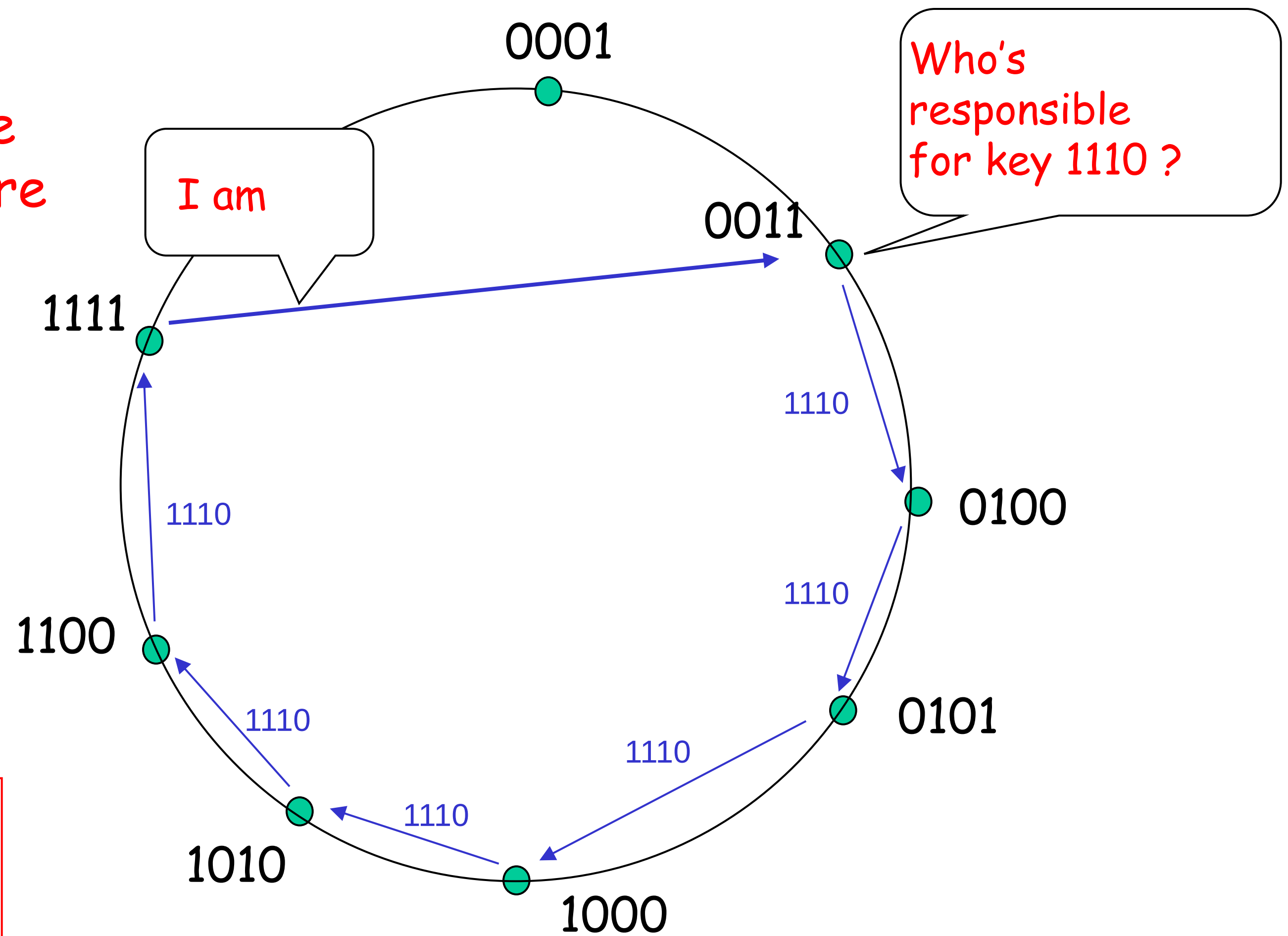
Circular DHT (1)



- Each peer *only* aware of immediate successor and predecessor.
- "Overlay network"

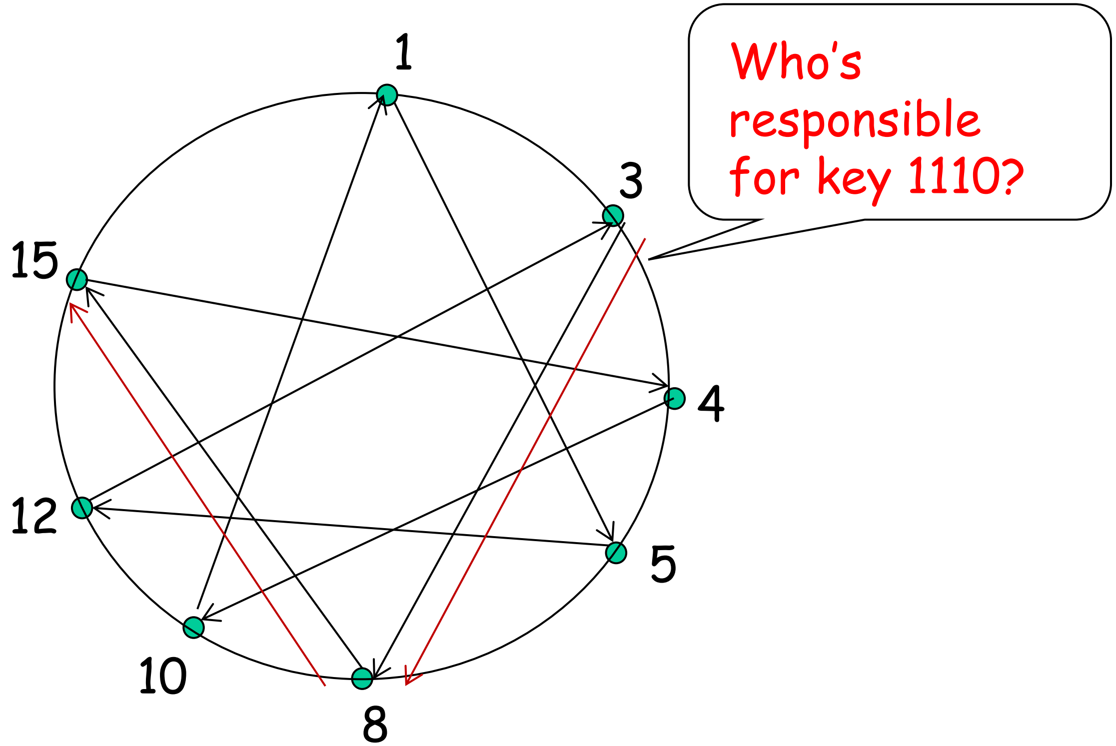
Circle DHT (2)

O(N) messages on avg to resolve query, when there are N peers



Define closest as closest successor

Circular DHT with Shortcuts

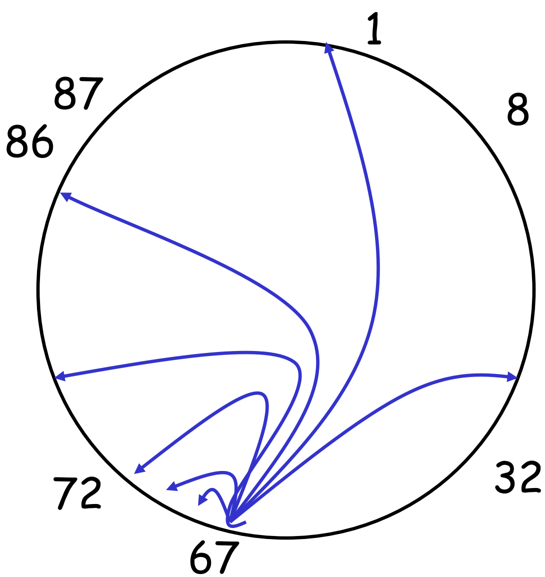


- Each peer keeps track of IP addresses of predecessor, successor, short cuts.
- Reduced from 6 to 2 messages.
- Possible to design shortcuts so O(log N) neighbors, O(log N) messages in query

Example: Chord Routing [see paper for details instead]

- A node s's i^{th} neighbor has the ID that is equal to $s+2^i$ or is the next largest ID (mod ID space), $i \geq 0$
- To reach the node handling ID t, send the message to neighbor $\#\log_2(t-s)$
- Requirement: each node s must know about the next node that exists clockwise on the Chord (0^{th} neighbor)
- Set of known neighbors called a finger table

Chord Routing (cont'd)



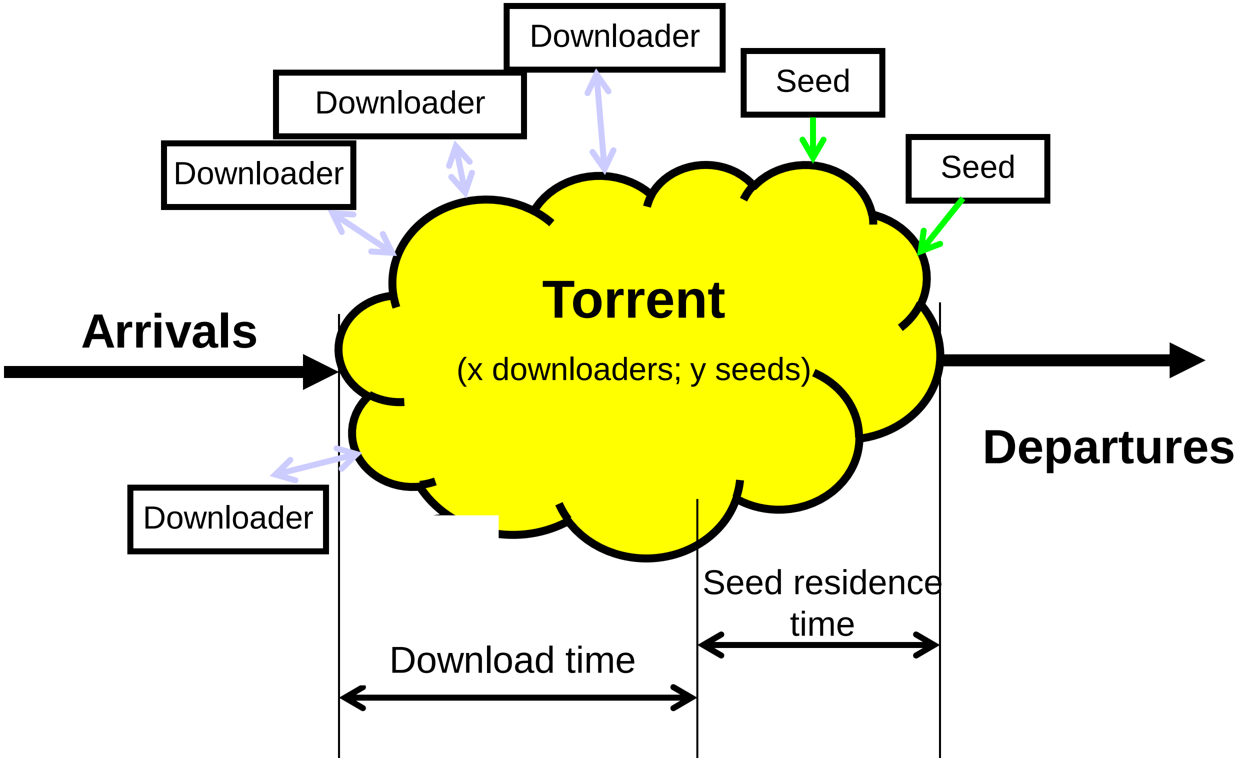
i	Finger table for node 67
0	72
1	72
2	72
3	86
4	86
5	1
6	32

Closest node clockwise to

$67+2^i$ mod 100

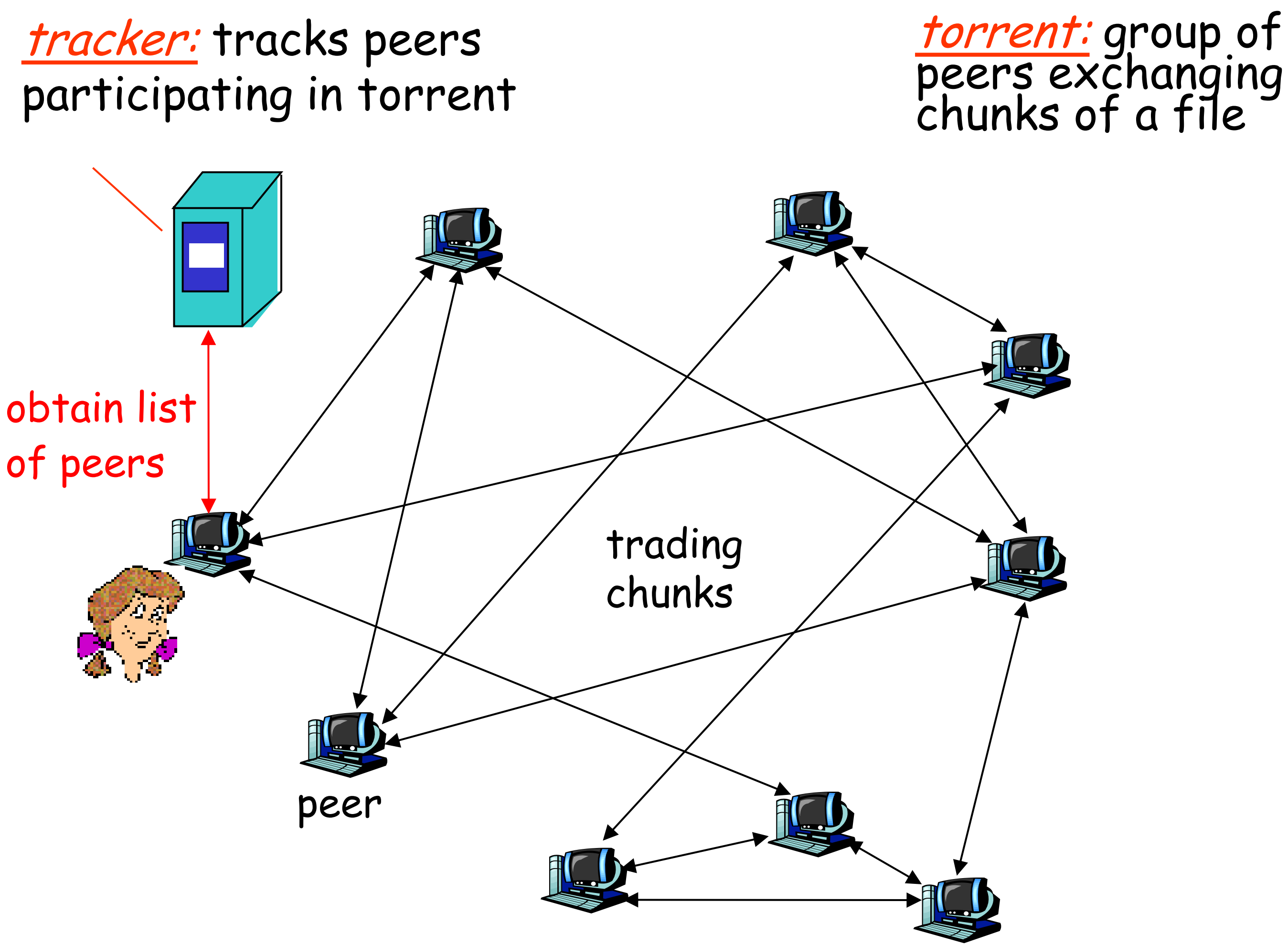
BitTorrent-like systems

- File split into many smaller pieces
- Pieces are downloaded from both seeds and downloaders
- Distribution paths are dynamically determined
  - Based on data availability



File distribution: BitTorrent

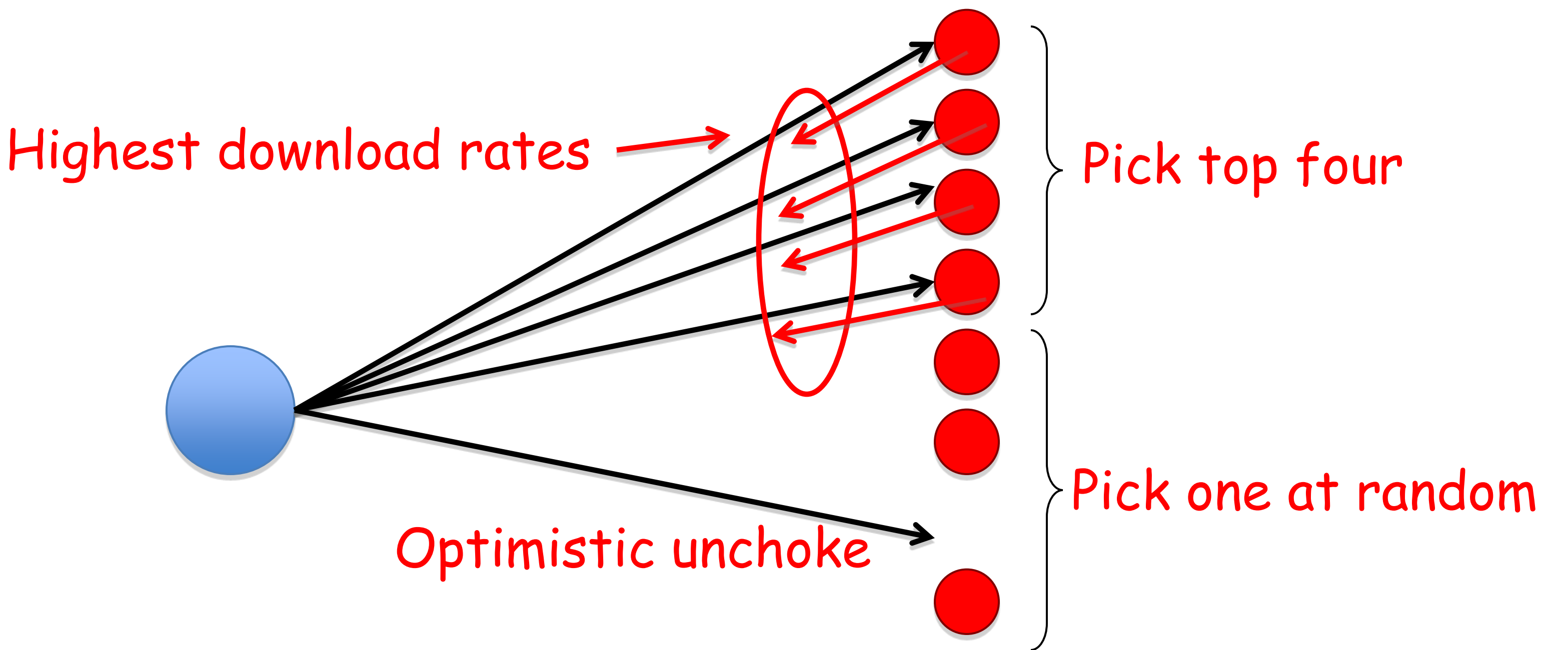
- P2P file distribution



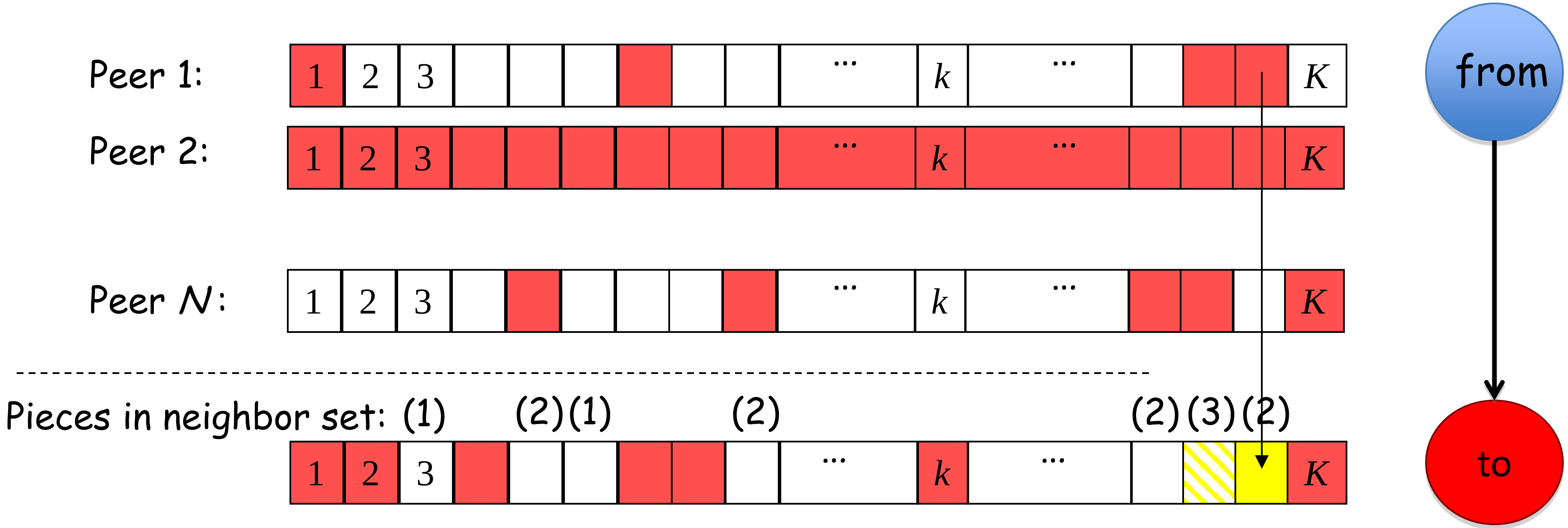
Download using BitTorrent

Background: Incentive mechanism

- Establish connections to large set of peers
  - At each time, only upload to a small (changing) set of peers
- Rate-based tit-for-tat policy
  - Downloaders give upload preference to the downloaders that provide the highest download rates



Download using BitTorrent
Background: Piece selection

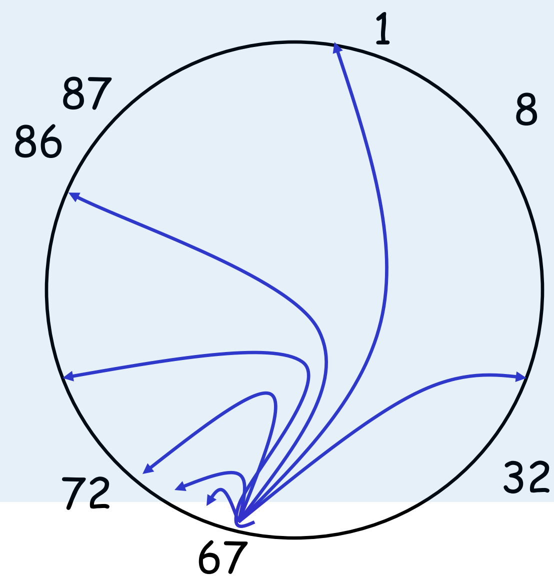


- Rarest first piece selection policy
  - Achieves high piece diversity
- Request pieces that
  - the uploader has;
  - the downloader is interested (wants); and
  - is the rarest among this set of pieces

More slides …

Chord Routing (cont'd)

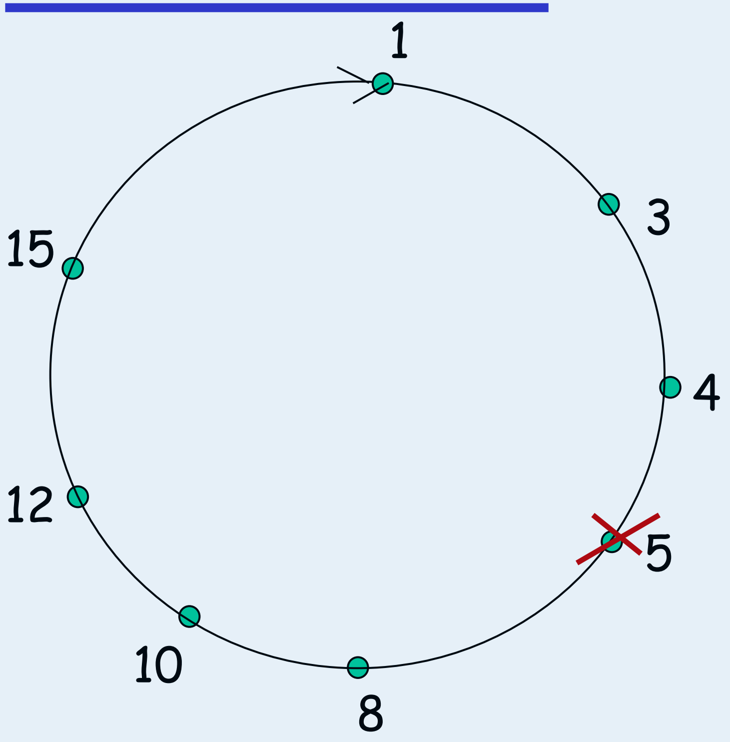
- A node s is node t's neighbor if s is the closest node to $t+2^i \bmod H$ for some i. Thus,
  - each node has at most $\log_2 N$ neighbors
  - for any object, the node whose range contains the object is reachable from any node in no more than $\log_2 N$ overlay hops
    (each step can always traverse at least half the distance to the ID)
- Given K objects, with high probability each node has at most $(1 + \log_2 N)\, K / N$ in its range
- When a new node joins or leaves the overlay, $O(K / N)$ objects move between nodes



i	Finger table for node 67
0	72
1	72
2	72
3	86
4	86
5	1
6	32

Closest node clockwise to $67+2^i \bmod 100$

Peer Churn

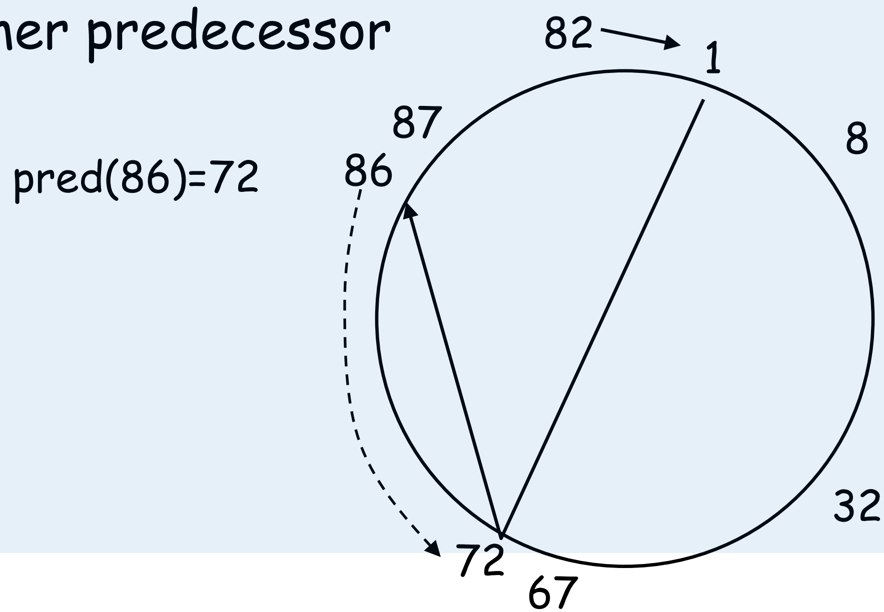


• To handle peer churn, require each peer to know the IP address of its two successors.
• Each peer periodically pings its two successors to see if they are still alive.

- Peer 5 abruptly leaves
- Peer 4 detects; makes 8 its immediate successor; asks 8 who its immediate successor is; makes 8's immediate successor its second successor.
- What if peer 13 wants to join?

Chord Node Insertion

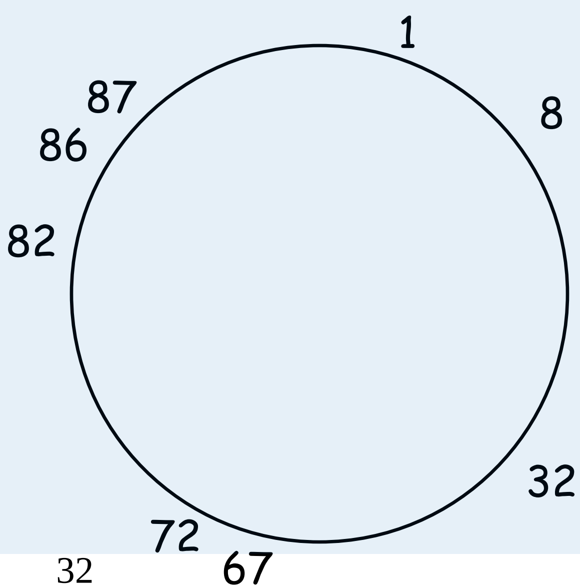
- One protocol addition: each node knows its closest counter-clockwise neighbor
- A node selects its unique (pseudo-random) ID and uses a bootstrapping process to find some node in the Chord
- Using Chord, the node identifies its successor in the clockwise direction
- An newly inserted node's predecessor is its successor's former predecessor



Example: Insert 82

Chord Node Insertion (cont'd)

- First: set added node s's fingers correctly
  - s's predecessor t does the lookup for each distance of 2^i from s



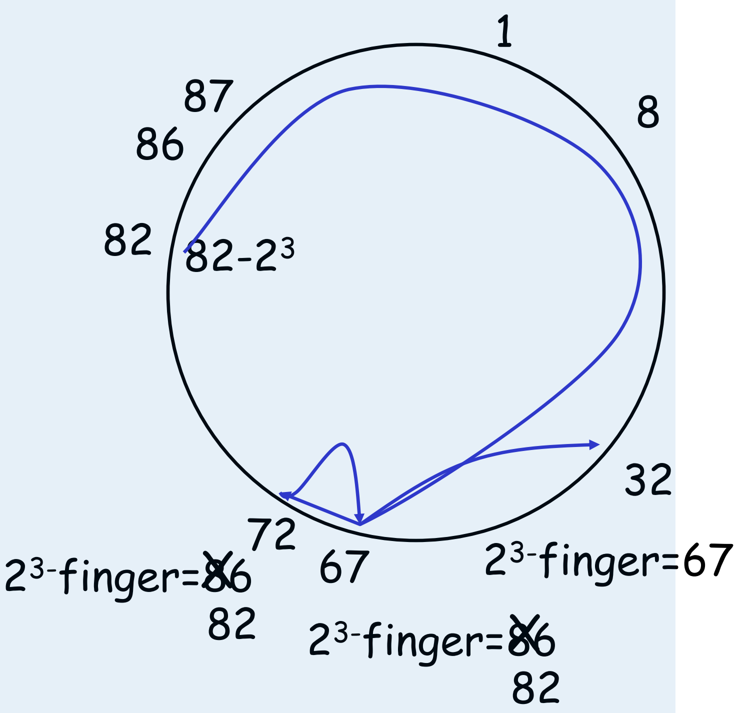
Lookups from node 72

Lookup(83) = 86
Lookup(84) = 86
Lookup(86) = 86
Lookup(90) = 1
Lookup(98) = 1
Lookup(14) = 32
Lookup(46) = 67

i	Finger table for node 82
0	86
1	86
2	86
3	1
4	1
5	32
6	67

Chord Node Insertion (cont'd)

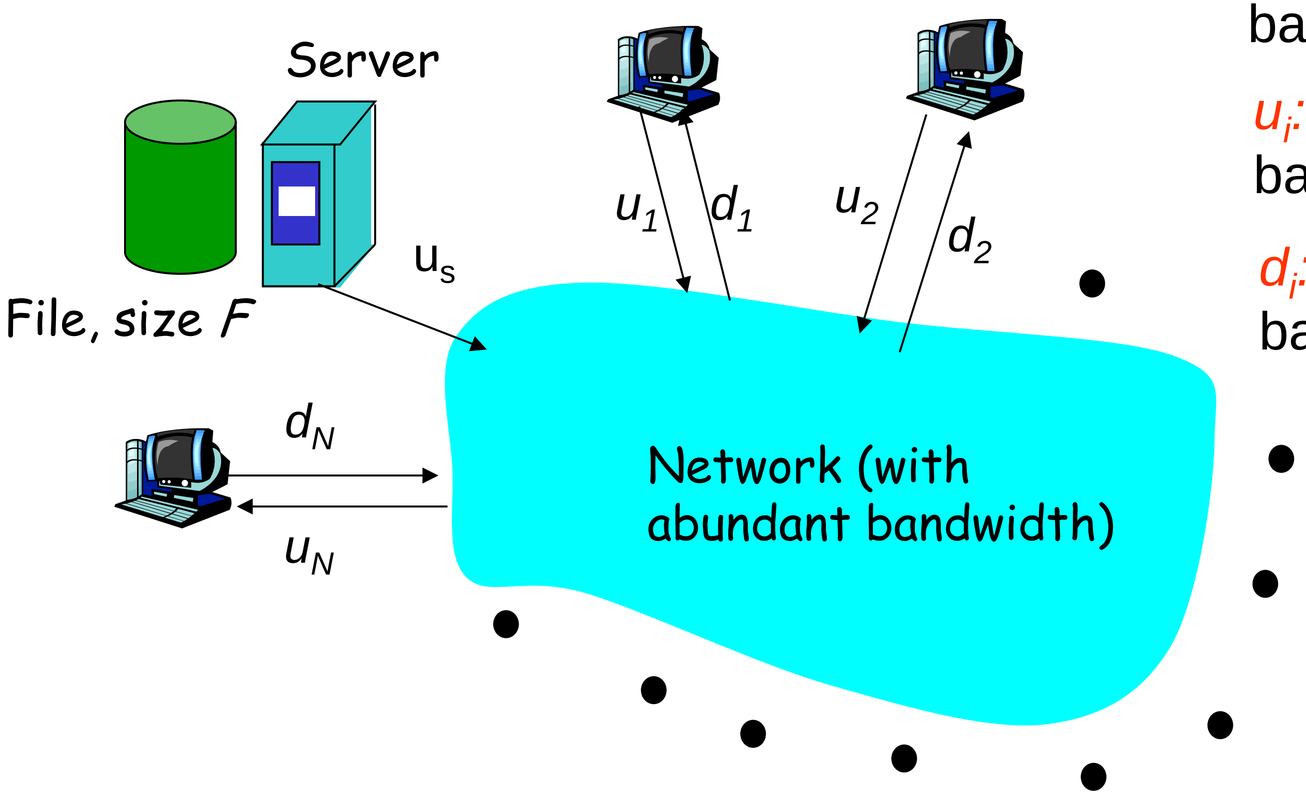
- Next, update other nodes' fingers about the entrance of s (when relevant). For each i:
  - Locate the closest node to s (counter-clockwise) whose 2^i-finger can point to s: largest possible is s - 2^i
  - Use Chord to go (clockwise) to largest node t before or at s - 2^i
    - route to s - 2^i, if arrived at a larger node, select its predecessor as t
  - If t's 2^i-finger routes to a node larger than s
    - change t's 2^i-finger to s
    - set t = predecessor of t and repeat
  - Else i++, repeat from top
- O($\log^2$ N) time to find and update nodes



e.g., for i=3

File Distribution: Server-Client vs P2P

Question : How much time to distribute file from one server to N *peers*?



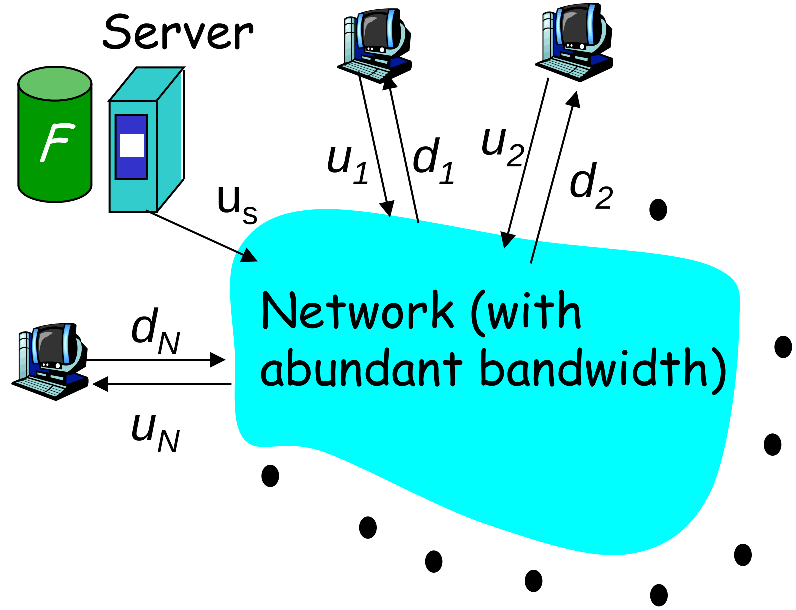
u_s: server upload bandwidth

u_i: peer i upload bandwidth

d_i: peer i download bandwidth

File distribution time: server-client

- server must upload N copies:
  - NF/u_s time
- client i takes F/d_i time to download

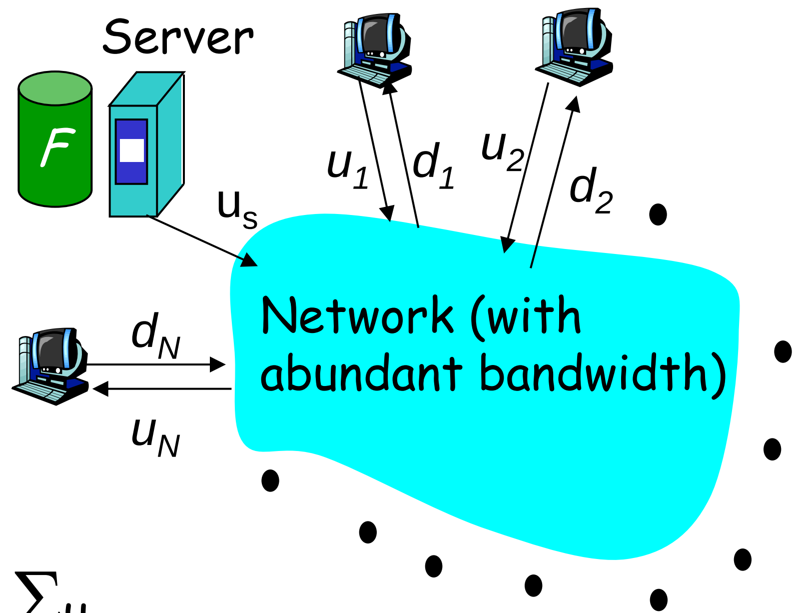


Time to distribute F to N clients using client/server approach $= d_{cs} = \max_i \left\{ NF/u_s, F/\min_i(d_i) \right\}$

increases linearly in N (for large N)

File distribution time: P2P

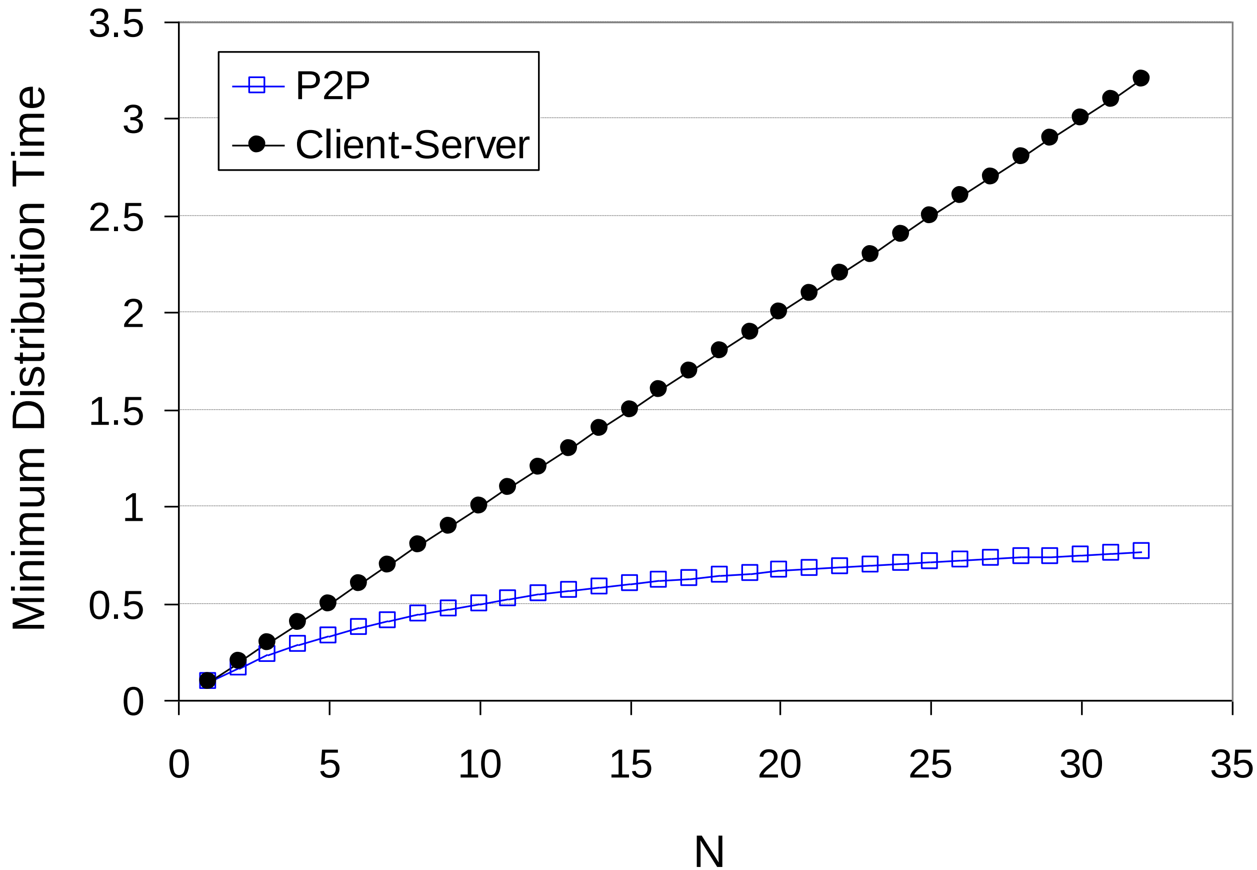
- server must send one copy: F/u_s time
- client i takes F/d_i time to download
- NF bits must be downloaded (aggregate)
  - fastest possible upload rate: $u_s + \sum u_i$



$$d_{P2P} = \max\left\{ F/u_s,\ F/\min(d_i),\ NF/(u_s + \sum_i u_i) \right\}$$

Server-client vs. P2P: example

Client upload rate = u, F/u = 1 hour, u_s = 10u, $d_{min} \geq u_s$

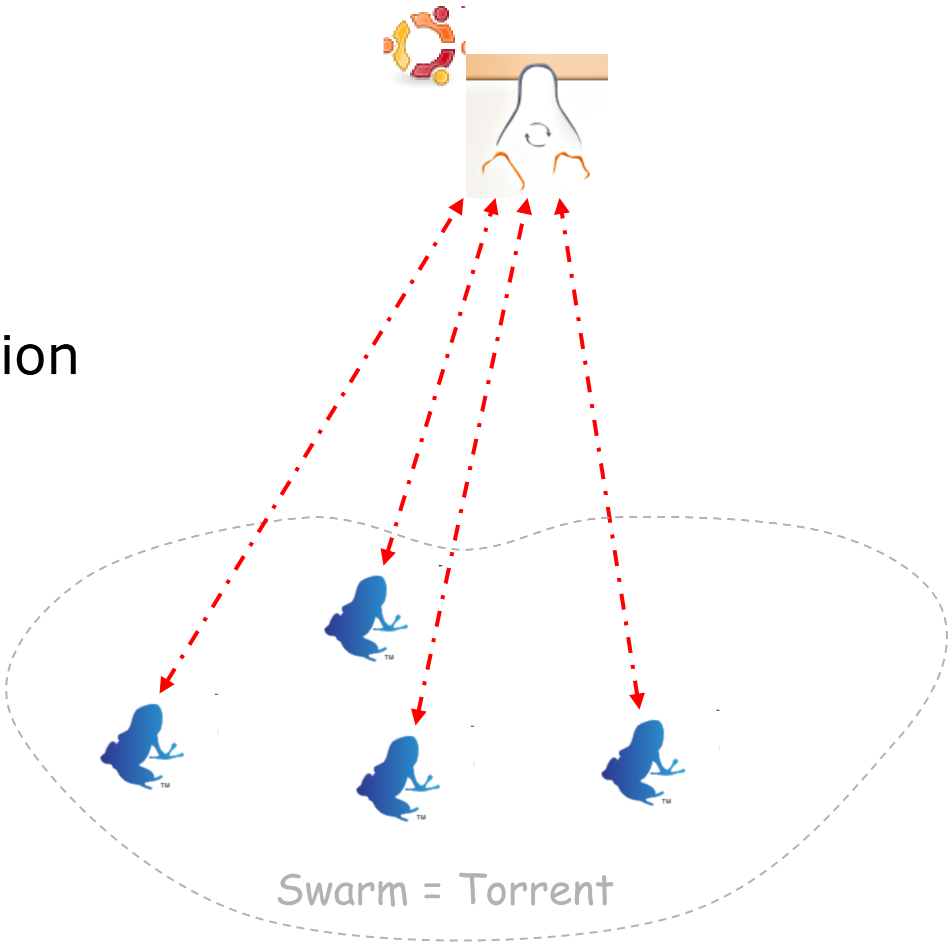


More slides …

Background

Peer discovery in BitTorrent

- Torrent file
  - “announce” URL
- Tracker
  - Register torrent file
  - Maintain state information
- Peers
  - Obtain torrent file
  - Announce
  - Report status
  - Peer exchange (PEX)
- Issues
  - Central point of failure
  - Tracker load



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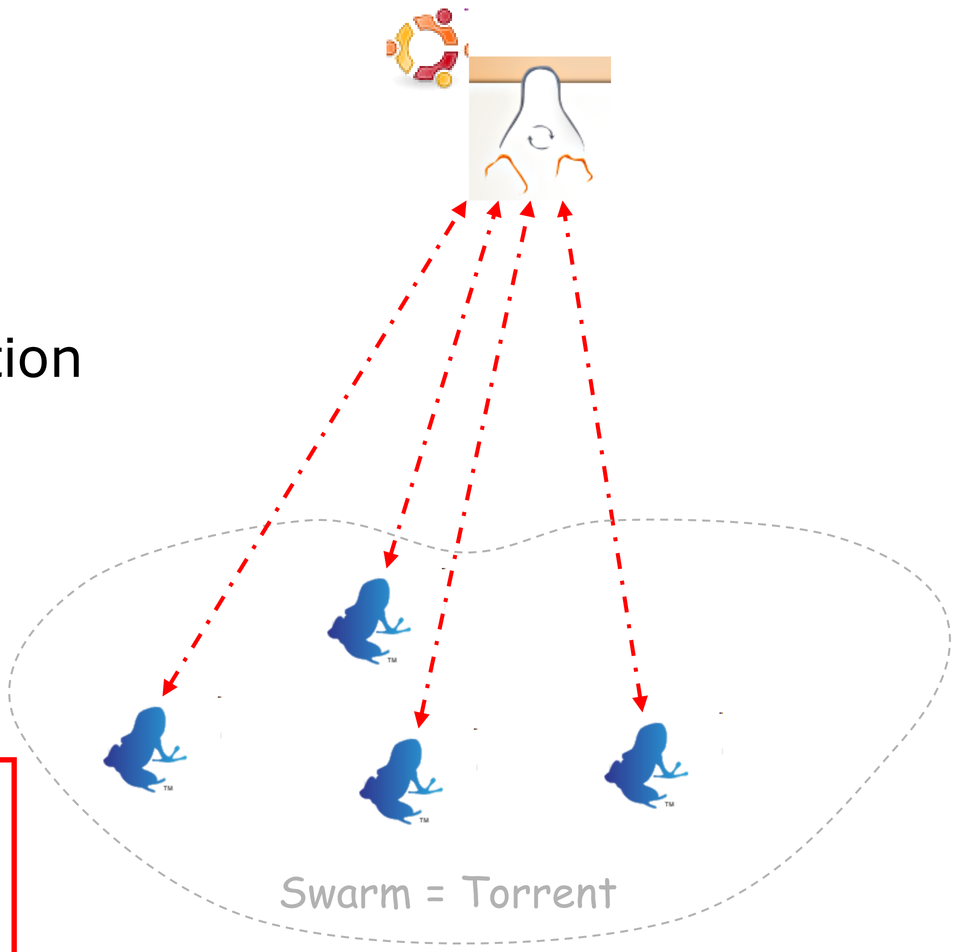
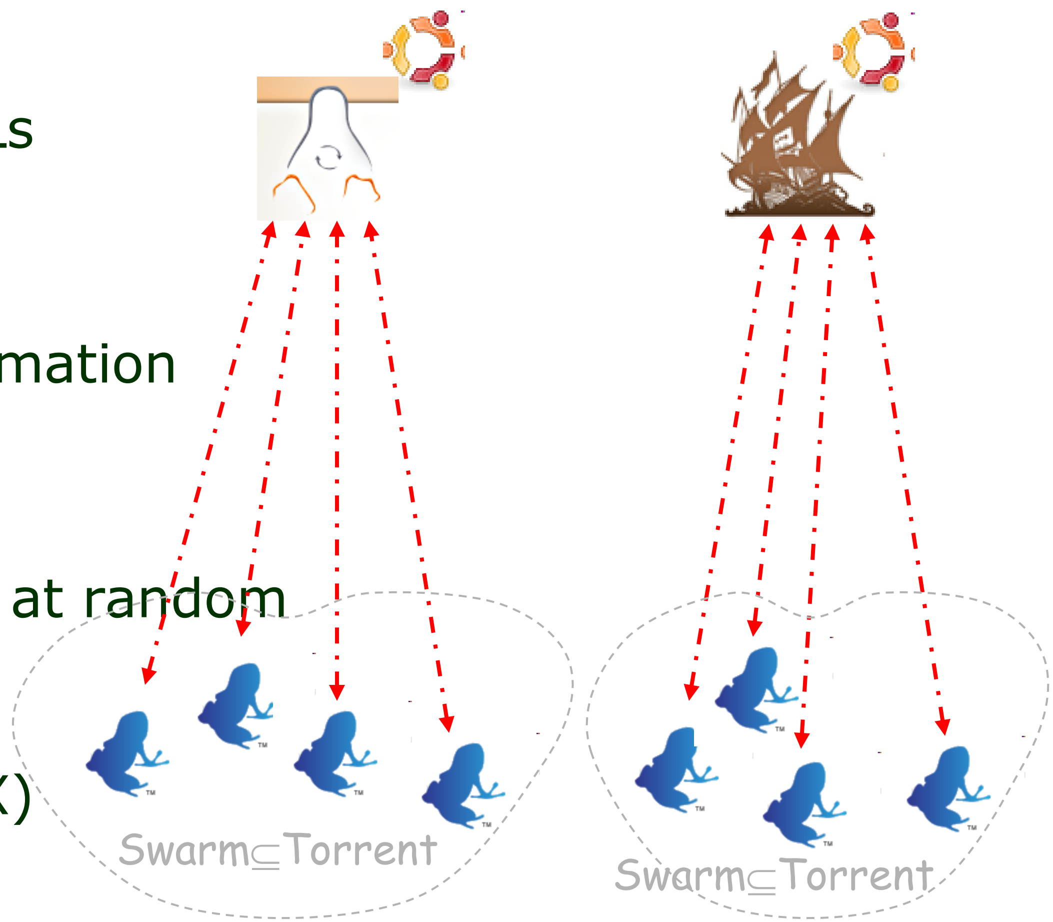


Background

Multi-tracked torrents

- Torrent file
  - "announce-list" URLs
- Trackers
  - Register torrent file
  - Maintain state information
- Peers
  - Obtain torrent file
  - Choose one tracker at random
  - Announce
  - Report status
  - Peer exchange (PEX)
- Issue
  - Multiple smaller swarms



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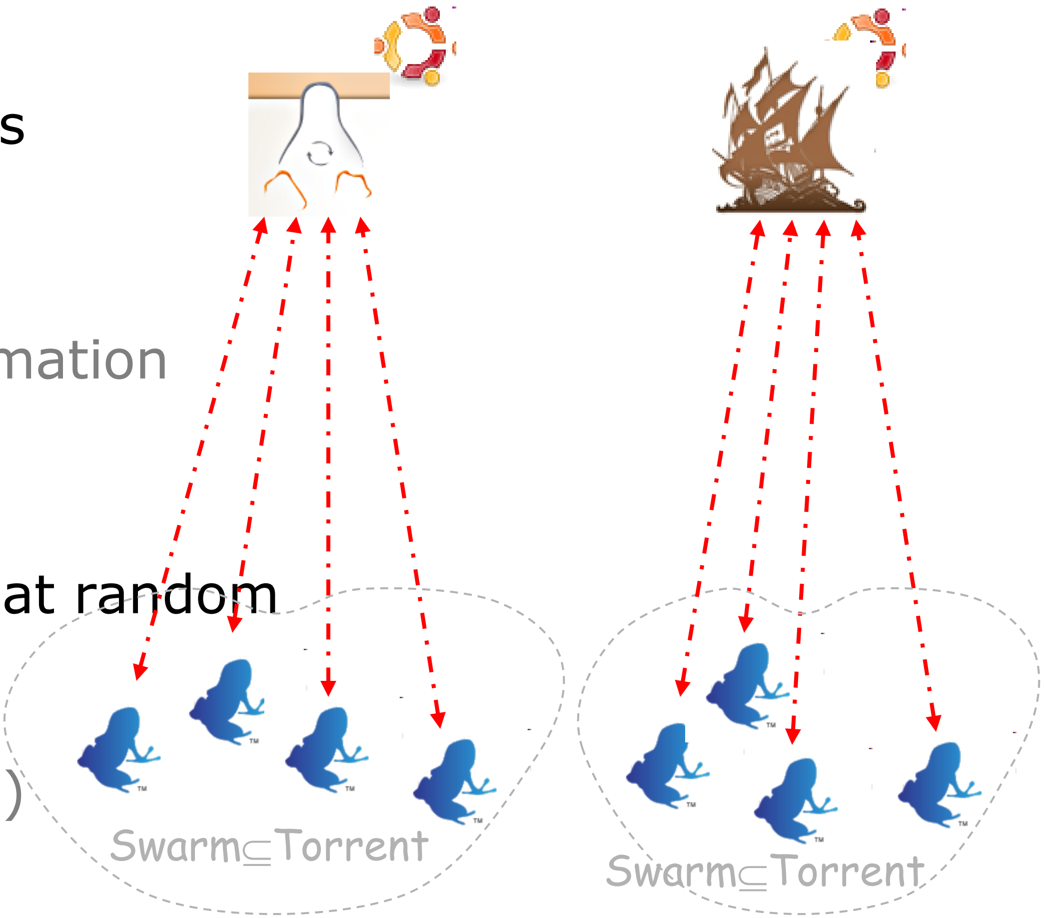

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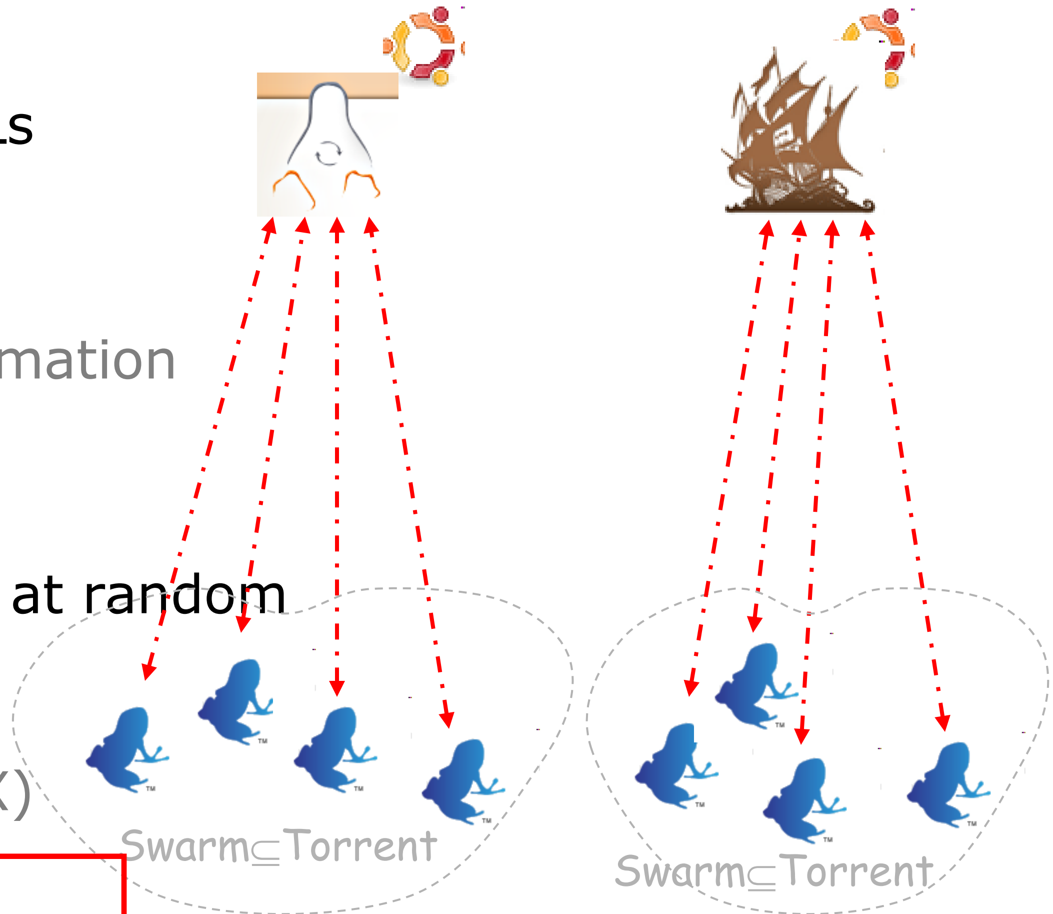
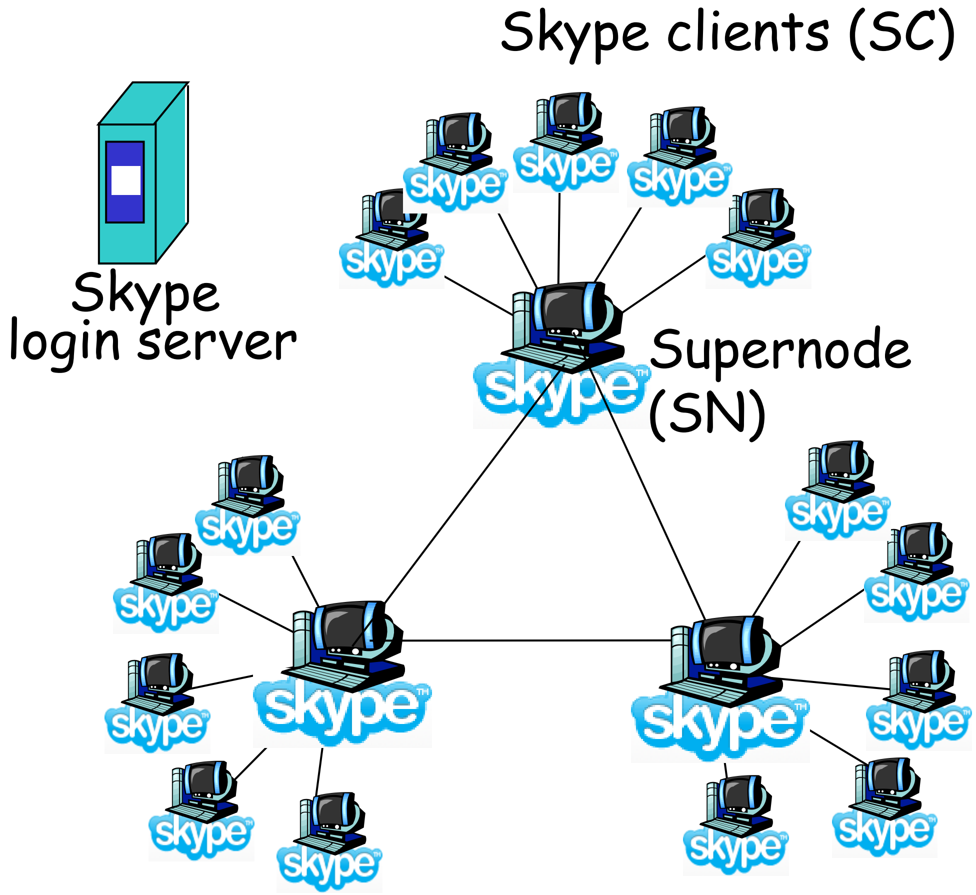


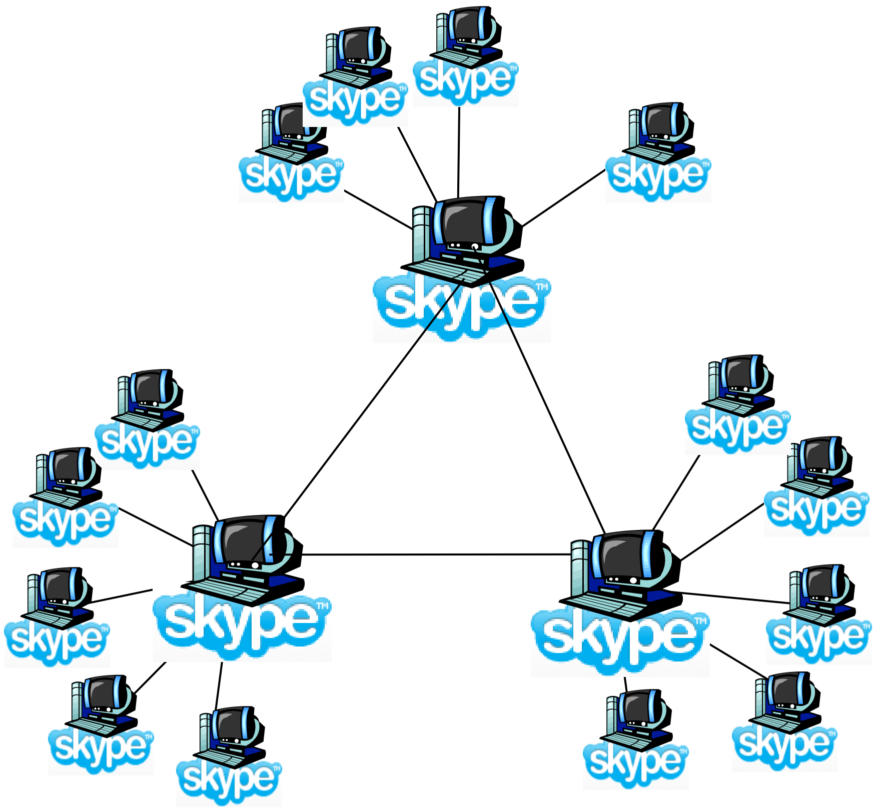
P2P Case study: Skype

- inherently P2P: pairs of users communicate.
- proprietary application-layer protocol (inferred via reverse engineering)
- hierarchical overlay with Supernodes (SNs)
- Index maps usernames to IP addresses; distributed over SNs



NAT/firewall problems …

- Problem when both Alice and Bob are behind "NATs".
  - NAT prevents an outside peer from initiating a call to insider peer
- Solution:



Peers as relays

- Problem when both Alice and Bob are behind "NATs".
  - NAT prevents an outside peer from initiating a call to insider peer
- Solution:
  - Using Alice's and Bob's SNs, Relay is chosen
  - Each peer initiates session with relay.
  - Peers can now communicate through NATs via relay