CS 640 Introduction to Computer Networks

Lecture30

Today's lecture

- Peer to peer applications
  - Napster
  - Gnutella
  - KaZaA
  - Chord

What is P2P?

- Significant autonomy from central servers
- Exploits resources at the edges of Internet
  - Bandwidth
  - Storage
  - Processing
- Resources at edge have intermittent connectivity
- Dynamic joins and leaves

Applications

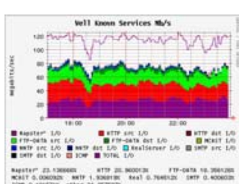
- P2P file sharing
  - Napster, Gnutella, KaZaA, etc.
- Storage and lookup
  - Chord, CAN, etc.
- P2P communication
  - Instant messaging
- P2P computation
  - seti@home

P2P file sharing software

- Allows Alice to open up a directory in her file system
  - Anyone can retrieve a file from directory
  - Like a Web server
- Allows Alice to copy files from other users' open directories:
  - Like a Web client
- Allows users to search the peers for content based on keyword matches:
  - Like Google

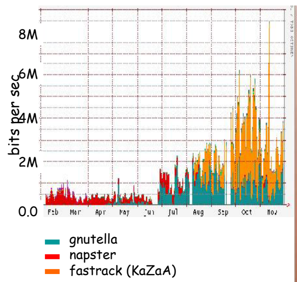
Napster

- The most (in)famous file sharing program
  - 5/99: Shawn Fanning (freshman, Northeasten U.) founds Napster Online music service
  - 12/99: First lawsuit
  - 3/00: 25% UW traffic Napster
  - 2/01: US Circuit Court of Appeals: Napster knew users violating copyright laws
  - 7/01: Simultaneous online: Napster 160K, Gnutella: 40K, Morpheus (KaZaA): 300K



Napster

- Judge orders Napster to pull plug in July ‘01
- Other file sharing apps take over!



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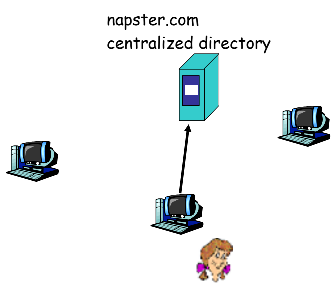
How Napster works

1. File list and IP address is uploaded



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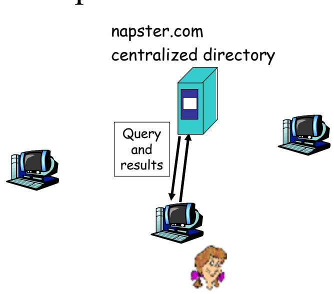
How Napster works

2. User requests search at server.



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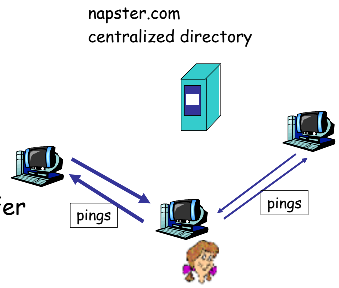
How Napster works

3. User pings hosts that apparently have data.

   Looks for ***best*** transfer rate.



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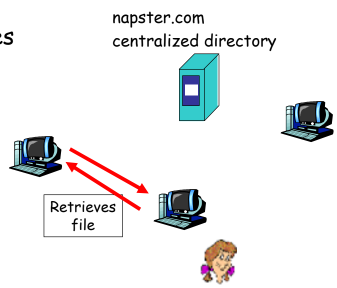
How Napster works

4. User chooses server

Napster's centralized server farm had difficult time keeping up with traffic



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2. Unstructured P2P File Sharing

- Napster
- Gnutella
- KaZaA
- Chord

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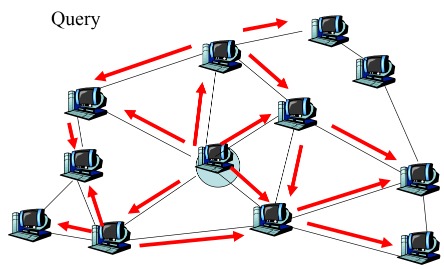
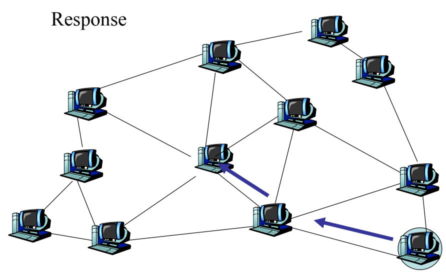
Distributed Search/Flooding



Distributed Search/Flooding



Gnutella

- Focus: decentralize search for files
  - Central directory server no longer the bottleneck
  - More difficult to "pull plug"
- Each application instance serves to:
  - Store selected files
  - Route queries from and to its neighboring peers
  - Respond to queries if file stored locally
  - Serve files

Gnutella

- Gnutella history:
  - 3/14/00: release by AOL, almost immediately withdrawn
  - Became open source
  - Many iterations to fix poor initial design (poor design turned many people off)
- Issues:
  - How much traffic does one query generate?
  - How many hosts can it support at once?
  - What is the latency associated with querying?
  - Is there a bottleneck?

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Gnutella: limited scope query

Searching by flooding:

- If you don’t have the file you want, query 7 of your neighbors.
- If they don’t have it, they contact 7 of their neighbors, for a maximum hop count of 10.
- Reverse path forwarding for responses (not files)

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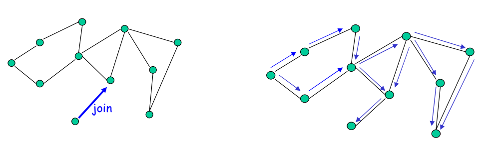
Gnutella overlay management

- New node uses bootstrap node to get IP addresses of existing Gnutella nodes
- New node establishes neighboring relations by sending join messages



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Gnutella in practice

- Gnutella traffic << KaZaA traffic
- KaZaA:
  - hierarchy, queue management, parallel download,…

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Gnutella Discussion:

- researchers like it because it's open source
  - but is it truly representative?
- architectural lessons learned?
- good source for technical info/open questions:
  http://www.limewire.com/index.jsp/tech_papers

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2. Unstructured P2P File Sharing

- Napster
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KaZaA: The service

- More than 3 million up peers sharing over 3,000 terabytes of content
- More popular than Napster ever was
- More than 50% of Internet traffic?
- MP3s & entire albums, videos, games
- Optional parallel downloading of files
- Automatically switch to new download server when current server becomes unavailable
- Provides estimated download times

KaZaA: The service (2)

- User can configure max number of simultaneous uploads and max number of simultaneous downloads
- Queue management at server and client
  - Frequent uploaders can get priority in server queue
- Keyword search
  - User can configure “up to x” responses to keywords
- Responses to keyword queries come in waves; stops when x responses are found
- To user, service resembles Google, but provides links to MP3s and videos, not Web pages

KaZaA: Technology

Software

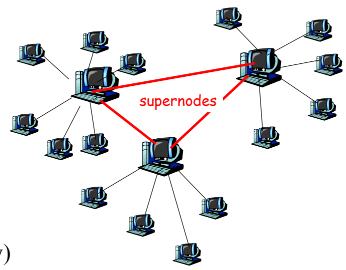
- Proprietary, files and control data encrypted
- Hints:
  - KaZaA Web site gives a few
  - Reverse engineering attempts described on Web
- Everything is HTTP requests and responses

Architecture

- Hierarchical
- Cross between Napster and Gnutella

KaZaA: Architecture

- Each peer is either a supernode or is assigned to a supernode
- Each supernode knows about many other supernodes (almost mesh overlay)



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KaZaA: Architecture (2)

- Nodes with more bandwidth and more available are designated as supernodes
- Each supernode acts as a mini-Napster hub, tracking the content and IP addresses of its descendants
- Guess: supernode has (on average) 200-500 descendants; roughly 10,000 supernodes
- There is also dedicated user authentication server and supernode list server

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KaZaA: Overlay maintenance

- List of potential supernodes included within software download
- New peer goes through list until it finds operational supernode
  - Connects, obtains more up to date list
  - Node then pings 5 nodes on list and connects with the one with smallest RTT
- If supernode goes down, node obtains updated list and chooses new supernode

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KaZaA Queries

- Node first sends query to supernode
  - Supernode responds with matches
  - If x matches found, done.
- Otherwise, supernode forwards query to subset of supernodes
  - If total of x matches found, done.
- Otherwise, query further forwarded
  - Probably by original supernode

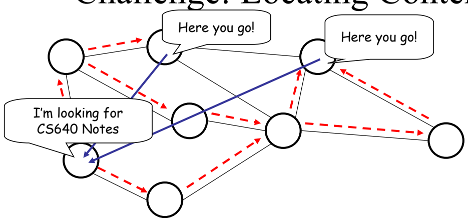
Parallel Downloading; Recovery

- If file is found in multiple nodes, user can select parallel downloading
- Most likely HTTP byte-range header used to request different portions of the file from different nodes
- Automatic recovery when server peer stops sending file

3. Structured P2P: DHT Approaches

- Want a storage and lookup service with better service guarantees and more efficient
- A Distributed Hash Table (DHT)
  - Chord
  - CAN
  - Pastry
  - Tapestry

Challenge: Locating Content



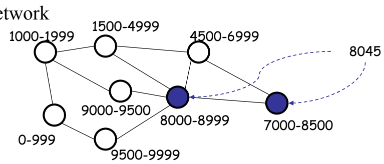
- Simplest strategy: expanding ring search
  - If K of N nodes have copy, expected search cost *at least* N/K, i.e., O(N)
  - Need many cached copies to keep search overhead small

Directed Searches

- Idea:
  - Assign particular nodes to hold particular content (or pointers to it, like an information booth)
  - When a node wants that content, go to the node that is supposed to have or know about it
- Challenges:
  - Distributed: want to distribute responsibilities among existing nodes in the overlay
  - Adaptive: nodes join and leave the P2P overlay
    - distribute knowledge responsibility to joining nodes
    - redistribute knowledge responsibility from those leaving

DHT Step 1: The Hash

- Introduce a hash function to map the object being searched for to a unique identifier:
  - e.g., h("CS640 Class notes") → 8045
- Distribute the range of the hash function among all nodes in the network



- Each node must "know about" at least one copy of each object that hashes within its range (when one exists)

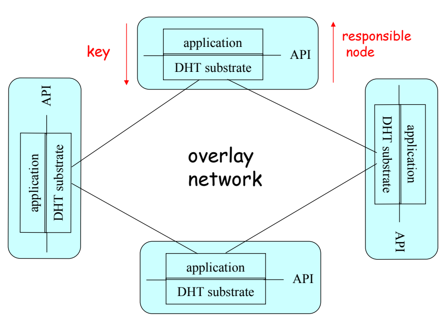
DHT Step 2: Routing

- For each object, node(s) whose range(s) cover that object must be reachable via a "short" path by any querying node
- Different approaches for routing requests
  - (CAN,Chord,Pastry,Tapestry) differ fundamentally only in the routing approach
  - They all rely on hash functions to map objects

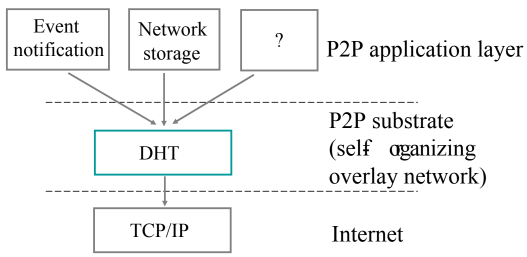
DHT API

- each data item (e.g., file or metadata with pointers) has a key in some ID space
- In each node, DHT software provides API:
  - Application gives API key k
  - API returns IP address of node responsible for k
- API is implemented with an underlying DHT overlay and distributed algorithms

DHT API



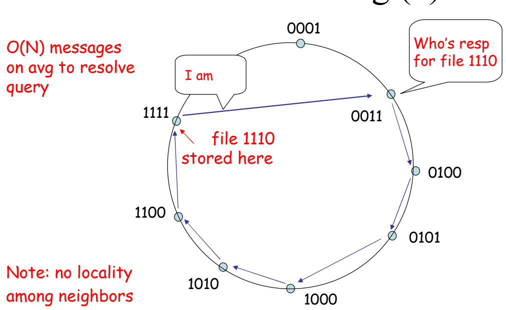
DHT Layered Architecture



Consistent hashing (1)

- Overlay network is a circle
- Each node has randomly chosen id
  - Keys in same id space
- Node's successor in circle is node with next largest id
  - Each node knows IP address of its successor
- Key is stored in closest successor

Consistent hashing (2)



Consistent hashing (3)

Node departures

- Each node must track s ≥ 2 successors
- If your successor leaves, take next one
- Ask your new successor for list of its successors; update your s successors

Node joins

- You're new, node id k
- Ask any node n to find the node n' that is the successor for id k
- Get successor list from n'
- Tell your predecessors to update their successor lists
- Thus, each node must track its predecessor

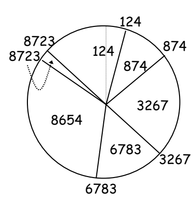
Consistent hashing (4)

- Overlay is actually a circle with small chords for tracking predecessor and k successors
- # of neighbors = s+1: O(1)
  - The ids of your neighbors along with their IP addresses is your "routing table"
- Average # of messages to find key is O(N)

Can we do better?

Chord

- Nodes assigned 1-dimensional IDs in hash space at random (e.g., hash on IP address)
- Consistent hashing: Range covered by node is from previous ID up to its own ID (modulo the ID space)

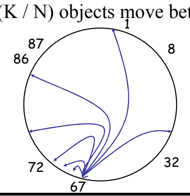


Chord Routing

- 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 $\#\log_2(t\text{-}s)$
- 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)

- A node s is node t's neighbor if s is the closest node to $t+2^i$ mod 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
- 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



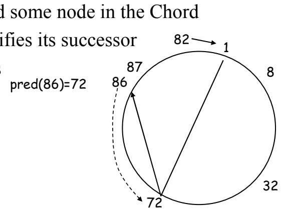
i	Finger table for node 67
0	72
1	72
2	72
3	86
4	86
5	1
6	32

Closest node clockwise to $67+2^i$ mod 100

Chord Node Insertion

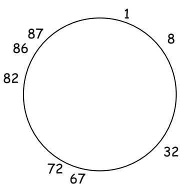
- One protocol addition: each node knows its closest counter-clockwise neighbor
- A node selects its unique (pseudo-random) ID and uses a bootstrapping process to find some node in the Chord
- Using Chord, the node identifies its successor
- A new node's predecessor is its successor's former predecessor

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

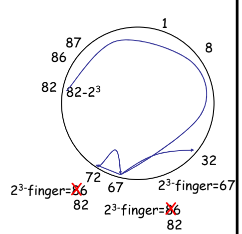


Lookups from node 72
Lookup(83) = 86
Lookup(84) = 86
Lookup(86) = 86
Lookup(90) = 1
Lookup(98) = 1
Lookup(14) = 32
Lookup(46) = 67

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)

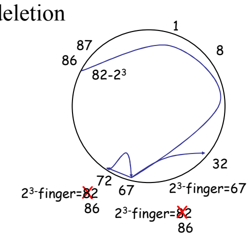
- Next, update other nodes' fingers about the entrance of s (when relevant). For each i:
  - Locate the closest node to s (counter-clockwise) whose 2^i-finger can point to s: largest possible is s - 2^i
  - Use Chord to go (clockwise) to largest node t before or at s - 2^i
    - route to s - 2^i, if 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)



e.g., for i=3

Chord Node Deletion

- Similar process can perform deletion



e.g., for i=3