Internet Technology

04. Peer-to-Peer Applications

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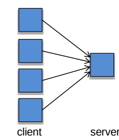
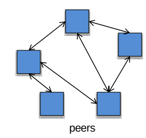
Peer-to-Peer (P2P) Application Architectures

- No reliance on a central server
- Machines (peers) communicate with each other
- Pools of machines (peers) provide the service
- Goals
  - Robustness
    - Expect that some systems may be down
  - Self-scalability
    - The system can handle greater workloads as more peers are added





Peer-to-Peer networking

> "If a million people use a web site simultaneously, doesn't that mean that we must have a heavy-duty remote server to keep them all happy?
>
> No; we could move the site onto a million desktops and use the Internet for coordination.
>
> Could amazon.com be an itinerant horde instead of a fixed central command post? Yes."

– David Gelernter
The Second Coming – A Manifesto

See http://edge.org/conversation/the-second-coming-a-manifesto

Peer to Peer applications

- P2P targets diverse solutions
  - Cooperative computation
  - Communications (e.g., Skype)
  - Exchanges, digital currency (bitcoin)
  - DNS (including multicast DNS)
  - Content distribution (e.g., BitTorrent)
  - Storage distribution
- P2P can be a distributed server
  - Lots of machines spread across multiple datacenters

Today, we'll focus on file distribution

Four key primitives

- Join/Leave
  - How do you join a P2P system?
  - How do you leave it?
  - Who can join?
- Publish
  - How do you advertise content?
- Search
  - How do you find a file?
- Fetch
  - How do you download the file?

Strategies:
- Central server
- Flood the query
- Route the query

Example: Napster

- Background
  - Started in 1999 by 19-year-old college dropout Shawn Fanning
  - Built only for sharing MP3 files
  - Stirred up legal battles with $15B recording industry
  - Before it was shut down in 2001:
    - 2.2M users/day, 28 TB data, 122 servers
    - Access to contents could be slow or unreliable
- Big idea: Central directory, distributed contents
  - Users register files in a directory for sharing
  - Search in the directory to find files to copy

Napster: Overview

Napster is based on a **central directory**

- Join
  - On startup, a client contacts the central server
- Publish
  - Upload a list of files to the central server
  - These are the files you are sharing and are on your system
- Search
  - Query the sever
  - Get back one or more peers that have the file
- Fetch
  - Connect to the peer and download the file

Napster: Discussion

- Pros
  - Super simple
  - Search is handled by a single server
  - The directory server is a single point of control
    - Provides definitive answers to a query
- Cons
  - Server has to maintain state of all peers
  - Server gets all the queries
  - The directory server is a single point of control
    - No directory server, no Napster!

Example: Gnutella

- Background
  - Created by Justin Frankel and Tom Pepper (authors of Winamp)
  - AOL acquired their company, Nullsoft in 1999
  - In 2000, accidentally released gnutella
  - AOL shut down the project but the code was released
- Big idea: create fully distributed file sharing
  - Unlike Napster, you cannot shut down gnutella

Gnutella: Overview

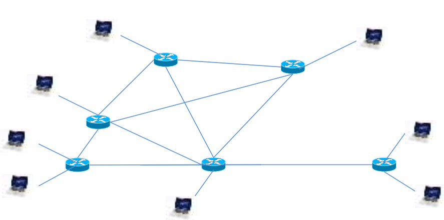
Gnutella is based on **query flooding**

- Join
  - On startup, a node (peer) contacts at least one node
    - Asks who its friends are
  - These become its “connected nodes”
- Publish
  - No need to publish
- Search
  - Ask connected nodes. If they don’t know, they will ask their connected nodes, and so on…
  - Once/if the reply is found, it is returned to the sender
- Fetch
  - The reply identifies the peer; connect to the peer via HTTP & download

Overlay network

An overlay network is a virtual network formed by peer connections

- Any node might know about a small set of machines
- “Neighbors” might not be physically close to you – they’re just who you know



Underlying IP Network

Overlay network

An overlay network is a virtual network formed by peer connections

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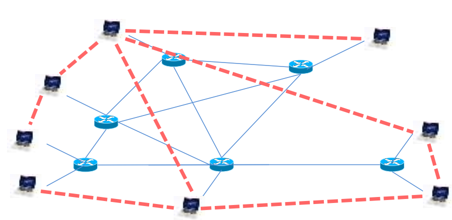
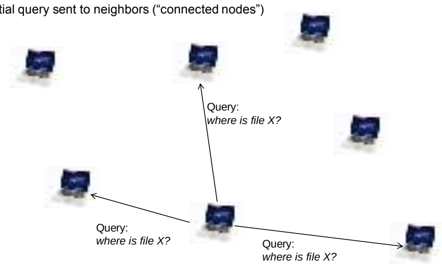


Overlay Network

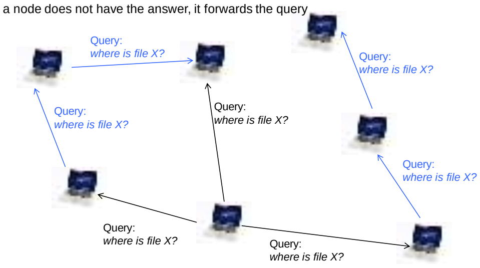
Gnutella: Search

Initial query sent to neighbors ("connected nodes")



Gnutella: Search

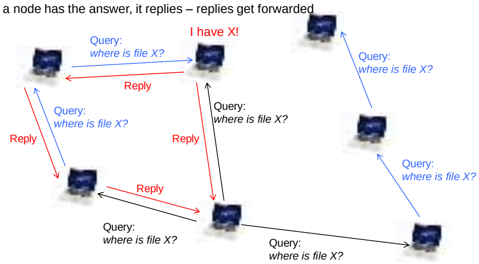
If a node does not have the answer, it forwards the query



Queries have a hop count (time to live) – so we avoid **forwarding loops**

Gnutella: Search

If a node has the answer, it replies – replies get forwarded



Gnutella: Search

- Original protocol
  - Anonymous: you didn't know if the request you're getting is from the originator or the forwarder
  - Replies went through the same query path
- Downloads
  - Node connects to the server identified in the reply
  - If a connection is not possible due to firewalls, the requesting node can send a *push request* for the remote client to send it the file

Peers do not have equal capabilities

- Network upstream and downstream bandwidth
- Connectivity costs (willingness to participate)
- Availability
- Compute capabilities

Gnutella: Enhancements

- Optimizations
  - Requester's IP address sent in query to optimize reply
  - Every node is no longer equal
    - Leaf nodes & Ultrapeers
    - Leaf nodes connect to a small number of ultrapeers
    - Ultrapeers are connected to ≥ 32 other ultrapeers
    - Route search requests through ultrapeers
- Downloads
  - Node connects to the server identified in the reply
  - If a connection is not possible due to firewalls, the requesting node can send a *push request* for the remote client to send it the file

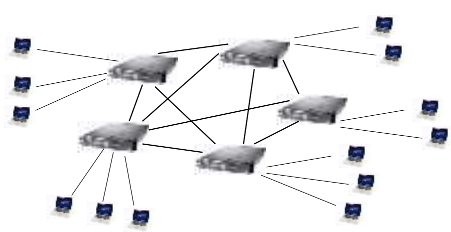
Gnutella: Summary

- Pros
  - Fully decentralized design
  - Searching is distributed
  - No control node – cannot be shut down
  - Open protocol
- Cons
  - Flooding is inefficient:
    - Searching may require contacting a lot of systems; limit hop count
  - Well-known nodes can become highly congested
  - In the classic design, if nodes leave the service, the system is crippled

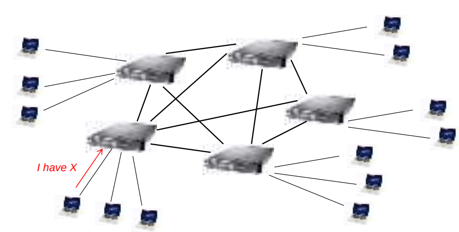
Example: FastTrack/Kazaa

- Background
  - Kazaa & FastTrack protocol created in 2001
  - Team of Estonian programmers – same team that will later create Skype
  - Post-Napster and a year after Gnutella was released
  - FastTrack: used by others (Grokster, iMesh, Morpheus)
    - Proprietary protocol; Several incompatible versions
- Big idea: Some nodes are better than others
  - A subset of client nodes have fast connectivity, lots of storage, and fast processors
  - These will be used as supernodes (similar to gnutella's ultrapeers)
  - Supernodes:
    - Serve as indexing servers for slower clients
    - Know other supernodes

Kazaa: Supernodes

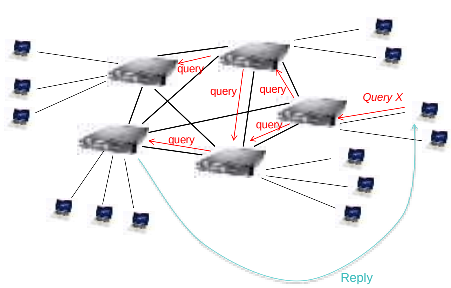


Kazaa: publish a file



Kazaa: search

Supernodes answer for all their peers (ordinary nodes)



Kazaa: Discussion

Selective flooding of queries

- Join
  - A peer contacts a supernode
- Publish
  - Peer sends a list of files to a supernode
- Search
  - Send a query to the supernode
  - Supernodes flood the query to other supernodes
- Fetch
  - Download the file from the peer with the content

Kazaa: Summary

- Pros
  - Similar to improved Gnutella
  - Efficient searching via supernodes
  - Flooding restricted to supernodes
- Cons
  - Can still miss files
  - Well-known supernodes provide opportunity to stop service

BitTorrent

- Background
  - Introduced in 2002 by Bram Cohen
  - Motivation
    - Popular content exhibits temporal locality: *flash crowds*
      - E.g., slashdot effect, CNN on 9/11, new movies, new OS releases
- Big idea: allow others to download from you while you are downloading
  - Efficient fetching, not searching
  - Single publisher, many downloaders

BitTorrent: Overview

Enable downloads from peers

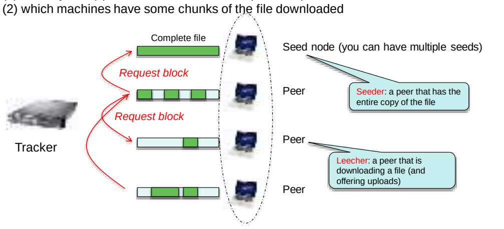
- Join
  - No need to join
    (seed registers with tracker server; peers register when they download)
- Publish
  - Create a torrent file; give it to a *tracker server*
- Search
  - Outside the BitTorrent protocol
  - Find the tracker for the file you want, contact it to get a list of peers with files
- Fetch
  - Download chunks of the file from our peers
  - At the same time, other peers may request chunks from you

BitTorrent: Publishing & Fetching

- To distribute a file
  - Create a .torrent file
  - Contains
    name, size, hash of each chunk, address of a tracker server.
  - Start a seed node: initial copy of the full file
  - Start the *tracker* for the file
    - Tracker manages uploading & downloading of the content
- To get a file
  - Get a .torrent file
  - Contact *tracker* named in the file
    - Get the list of seeders and other nodes with portions of the file
    - Tracker will also announce you to othersâ
  - Contact a random node for a list of file chunk numbers
  - Request a random block of the file

BitTorrent: Downloading a file in chunks

Tracker identifies:
(1) initial system(s) that has 100% of the file (the seed)
(2) which machines have some chunks of the file downloaded



When a peer finished downloading a file, it may become a seed and remain online without downloading any content.

BitTorrent Summary

- Pros
  - Scales well; performs well when many participants
  - Gives peers an incentive to share
    - It is sometimes not possible to download without offering to upload
- Cons
  - Search is not a part of the protocol; relies on torrent index servers
  - Files need to be large for this to work well
  - Rare files do not offer distribution
  - A tracker needs to be running to bootstrap the downloads

Distributed Hash Tables

Locating content

- Our discussion on peer-to-peer applications focused on content distribution
  - Content was fully distributed
- How do we find the content?

Napster	Central server (hybrid architecture)
Gnutella & Kazaa	Network flooding Optimized to flood supernodes … but it's still flooding
BitTorrent	Nothing! It's somebody else's problem

- Can we do better?

What's wrong with flooding?

- Some nodes are not always up and some are slower than others
  - Gnutella & Kazaa dealt with this by classifying some nodes as "supernodes" (called "ultrapeers" in Gnutella)
- Poor use of network (and system) resources
- Potentially high latency
  - Requests get forwarded from one machine to another
  - Back propagation (e.g., Gnutella design), where the replies go through the same chain of machines used in the query, increases latency even more

Hash tables

- Remember hash functions & hash tables?
  - Linear search: O(*N*)
  - Tree: O(log*N*)
  - Hash table: O(1)

What's a hash function? (refresher)

- Hash function
  - A function that takes a variable length input (e.g., a string) and generates a (usually smaller) fixed length result (e.g., an integer)
  - Example: hash strings to a range 0-6:
    - *hash("Newark") → 1*
    - *hash("Jersey City") → 6*
    - *hash("Paterson") → 2*
- Hash table
  - Table of *(key, value)* tuples
  - Look up a key:
    - Hash function maps *keys* to a range *0 … N-1*
      table of *N* elements
      `i = hash(key)`
      `table[i]` contains the item
  - No need to search through the table!

Considerations with hash tables (refresher)

- Picking a good hash function
  - We want uniform distribution of all values of *key* over the space *0 … N-1*
- Collisions
  - Multiple keys may hash to the same value
    - hash("Paterson") → 2
    - hash("Edison") → 2
  - `table[i]` is a bucket (slot) for all such *(key, value)* sets
  - Within `table[i]`, use a linked list or another layer of hashing
- Think about a hash table that grows or shrinks
  - If we add or remove buckets → need to rehash keys and move items

Distributed Hash Tables (DHT)

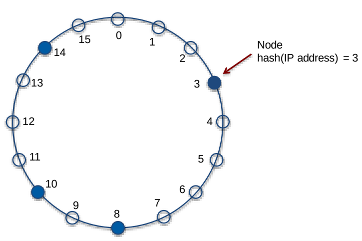
- Create a peer-to-peer version of a (*key, value*) database
- How we want it to work
  1. A peer queries the database with a key
  2. The database finds the peer that has the value
  3. That peer returns the (key, value) pair to the querying peer
- Make it efficient!
  - A query should not generate a flood!
- We'll look at one DHT implementation called **Chord**

The basic idea

- Each node (peer) is identified by an integer in the range $[0, 2^n-1]$
  - *n* is a big number, like 160 bits
- Each key is hashed into the range $[0, 2^n-1]$
  - E.g., SHA-1 hash
- Each peer will be responsible for a range of keys
  - A key is stored at the closest successor node
  - Successor node = first node whose ID ≥ hash(key)
- If we arrange the peers in a logical ring (incrementing IDs) then a peer needs to know only of its successor and predecessor
  - This limited knowledge of peers makes it an **overlay network**

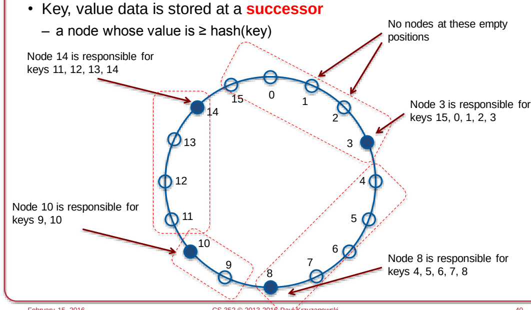
Chord & consistent hashing

- A key is hashed to an *m*-bit value: $0 \ldots 2^m-1$
- A logical ring is constructed for the values $0 \ldots 2^m-1$
- Nodes are placed on the ring at *hash(IP address)*



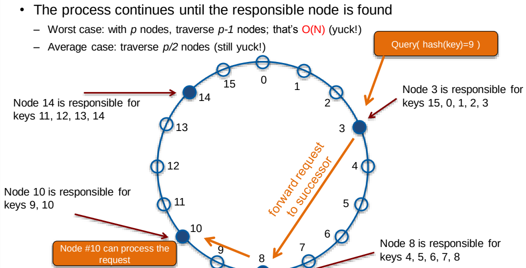
Key assignment

- Example: *n=16;* system with 4 nodes (so far)
- Key, value data is stored at a **successor**
  - a node whose value is ≥ hash(key)



Handling query requests

- Any peer can get a request (*insert* or *query*). If the hash(key) is not for its ranges of keys, it forwards the request to a successor.
- The process continues until the responsible node is found
  - Worst case: with *p* nodes, traverse *p-1* nodes; that's O(N) (yuck!)
  - Average case: traverse *p/2* nodes (still yuck!)

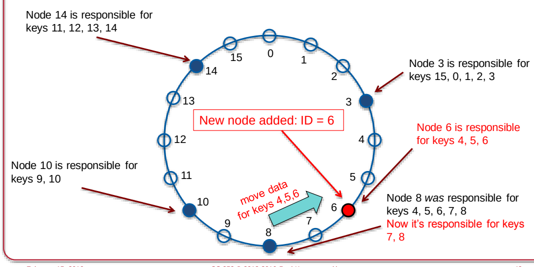


Let's figure out three more things

1. Adding/removing nodes
2. Improving lookup time
3. Fault tolerance

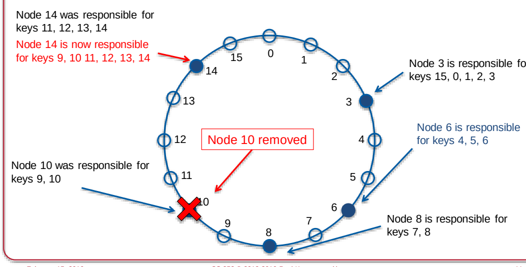
Adding a node

- Some keys that were assigned to a node's successor now get assigned to the new node
- Data for those *(key, value)* pairs must be moved to the new node



Removing a node

- Keys are reassigned to the node's successor
- Data for those *(key, value)* pairs must be moved to the successor



Performance

- We're not thrilled about *O(N)* lookup
- Simple approach for great performance
  - Have all nodes know about each other
  - When a peer gets a node, it searches its table of nodes for the node that owns those values
  - Gives us *O(1)* performance
  - Add/remove node operations must inform everyone
  - Not a good solution if we have millions of peers (huge tables)

Finger tables

- Compromise to avoid huge per-node tables
  - Use finger tables to place an upper bound on the table size
- Finger table = partial list of nodes
- At each node, i^{th} entry in finger table identifies node that succeeds it by at least 2^{i-1} in the circle
  - finger_table[0]: immediate (1^{st}) successor
  - finger_table[1]: successor after that (2^{nd})
  - finger_table[2]: 4^{th} successor
  - finger_table[3]: 8^{th} successor
  - …
- *O(log N)* nodes need to be contacted to find the node that owns a key
  … not as great as *O(1)* but way better than *O(N)*

Fault tolerance

- Nodes might die
  - (key, value) data would need to be replicated
  - Create *R* replicas, storing each one at *R-1* successor nodes in the ring
- It gets a bit complex
  - A node needs to know how to find its successor's successor (or more)
    - Easy if it knows all nodes!
  - When a node is back up, it needs to check with successors for updates
  - Any changes need to be propagated to all replicas

The end