CS514: Intermediate Course in Operating Systems

Professor Ken Birman
Vivek Vishnumurthy: TA

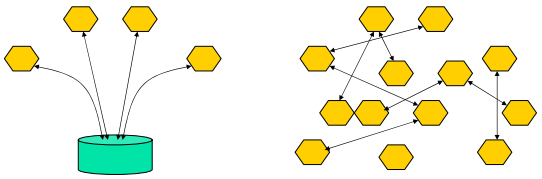
Peer-to-Peer (p2p) Systems

- The term refers to a kind of distributed computing system in which the "main" service is provided by having the client systems talk directly to one-another
- In contrast, traditional systems are structured with servers at the core and clients around the edges

p2p systems

Standard systems: Client/Server structured

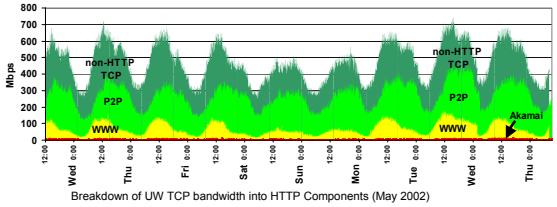
P2P systems: Clients help one-another out



An "important" topic

- … or at least, it gets a lot of press
  - Recording industry claims that p2p downloads are killing profits!
    - Used to be mostly file sharing, but now online radio feeds (RSS feeds) are a big deal too
  - U. Wash. study showed that 80% of their network bandwidth was spent on music/video downloads!
    - DVDs are largest, and accounted for the lion's share
    - A great many objects were downloaded *many* times
    - Strangely, many downloads took months to complete…
    - Most went to a tiny handful of machines in dorm rooms

Where has all the bandwidth gone?

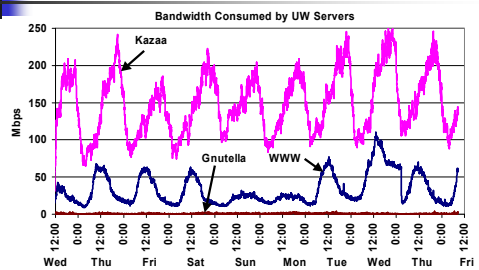


Breakdown of UW TCP bandwidth into HTTP Components (May 2002)

- WWW = 14% of TCP traffic; P2P = 43% of TCP traffic
- **P2P dominates WWW in bandwidth consumed!!**

Source: Hank Levy. See http://www.cs.washington.edu/research/networking/websys/pubs/osdi_2002/osdi.pdf

Bandwidth consumed by UW servers (outbound traffic)



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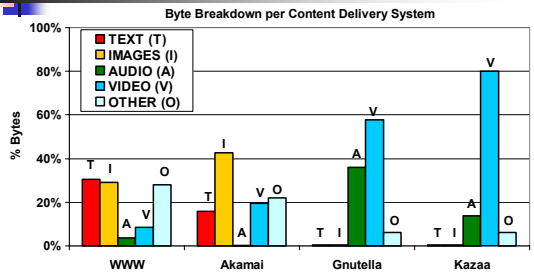
Object type for different systems



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Today: An Overview

- Today we'll look at the area as a whole
  - Origins: Illegal fire sharing
  - Early academic work: "Distributed hash tables"
  - Subsequent spread of field into many other areas: steganographic storage, erasure codes, gossip protocols and epidemic data dissemination, etc
- In upcoming lectures we'll look at details of some research systems

An old idea…

- If you think about it, most of the protocols we've discussed are "peer to peer" in a broad sense
  - Pretty much everything Lamport was interested in uses direct client-to-client communication
  - Group communication systems often do have servers, but not all need them…
- But the term really has a stronger meaning
  - Denotes systems where the "data that matters" is passed among cooperating client systems
  - And there may be huge numbers of clients
  - Evokes image of resistance fighters working to overthrow an evil IP empire

Attributes of p2p systems

- They can be enormous
  - We often talk about hundreds of thousands or millions of client nodes, coming and going rapidly
  - If there are servers, they are small in number and have limited roles
- These clients are everywhere
  - Even in Kenya or Nepal… places with lousy network connectivity
  - Often behind firewalls or NAT boxes
  - Some are supercomputers. But many are slow

The issue with NAT boxes

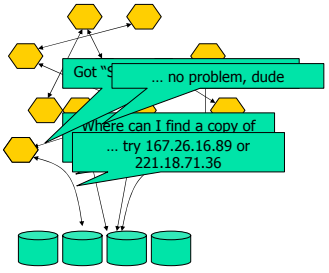
- When a system uses firewalls or NAT boxes
  - Client systems *inside* the network can usually talk to servers outside it
    - The NAT knows about the TCP 3-way handshake and "creates a tunnel" on the fly
    - It remaps the (IP address, port) pair as packets pass by, so it looks as if the NAT (not the client) is making the connection and receiving the replies…
  - But connectivity from outside to inside is blocked
    - In fact, because client IP address is mapped, the client simply can't be addressed other than through the NAT!

The first peer-to-peer system

- The term, and the intuition, emerged from the Napster file sharing service
  - In fact Napster *has* a set of servers
  - But these just keep a directory on behalf of clients and orchestrate publicity inserts
  - Servers build the web pages users see
  - Actual music and DVD downloads are done from client to client

Napster

Having obtained a top-level page listing peers with copies of music or other content desired, a client can download the files directly from the peer



Data center builds the pages users see when they access Napster

Quick aside

- Should "intellectual property" be free?
  - Topic of much debate right now
  - Lessig: "East Code vs West Code"
    - East Code is a term for "laws on the books"
    - West Code is a term for software
  - His point?
    - We need to evolve a balance between what we demand (law), what we can implement (code), and what will promote the general wellfare
    - What regime gives the most benefit for the most people?

Why did Napster go this route?

- When service launched, developers hoped to work around legal limits on sharing media
  - They reasoned: let client systems advertise "stuff"
  - If some of that stuff happens to be music, that's the responsibility of the person who does it
  - The directory system "helps clients advertise wares" but doesn't "endorse" the sharing of protected intellectual property. Client who chooses to do so is violating the law
  - They make their money on advertising they insert
- Judges saw it differently…
  - "Napster's clear purpose is to facilitate theft of IP…"

Characteristics of big populations

- With huge numbers of users
  - Surprisingly many "come and go" on short time scales
  - One study: mean residence time in Freenet was just a few seconds… and many clients were never heard of again!
  - British telcom reassigns IP addresses for all its networked users every few hours!

List of (technical) issues with Napster

- Many clients just aren't accessible
  - Firewalls can limit incoming connections to clients
  - Many client systems come and go (churn)
  - Round trip times to Nepal are slow…
  - Slow "upload" speeds are common connections
- Clients might withdraw a file unexpectedly
  - E.g. if low on disk space, or if they download something on top of a song they aren't listening to anymore

More (technical) issues with Napster

- Industry has been attacking the service… and not just in court of law
  - Denial of service assaults on core servers
  - Some clients lie about content (e.g. serve Frank Sinatra in response to download for Eminem)
  - Hacking Napster "clients" to run the protocol in various broken (disruptive) ways
  - And trying to figure out who is serving which files, in order to sue those people

What problems are "fundamental"?

- If we assume clients serve up the same stuff people download, the number of sources for a *less popular item* will be very small
- Under assumption that churn is a constant, these less popular items will generally not be accessible.
- But experiments show that clients fall into two categories:
  - Well-connected clients that hang around
  - Poorly-connected clients that also churn
  - … this confuses the question

What problems are fundamental?

- One can have, some claim, as many electronic personas as one has the time and energy to create. – *Judith S. Donath.*
- So-called "Sybil attack…."
  - Attacker buys a high performance computer cluster
  - It registers *many times* with Napster using a variety of IP addresses (maybe 10's of thousands of times)
  - Thinking these are real, Napster lists them in download pages. Real clients get poor service or even get snared
  - Studies show that no p2p system can easily defend against Sybil attacks!

Refined Napster structure

- Early Napster just listed anything. Later:
  - Enhanced directory servers to probe clients, track their health. Uses an automated reporting of download problems to trim "bad sources" from list
  - Ranks data sources to preferentially list clients who…
    - Have been up for a long time, and
    - Seem to have fast connections, and
    - Appear to be "close" to the client doing the download (uses notion of "Internet distance")
  - Implement parallel downloads and even an experimental method for doing "striped" downloads (first block from source A, second from source B, third from C, etc)
    - Leverages asymmetric download/uplink speeds

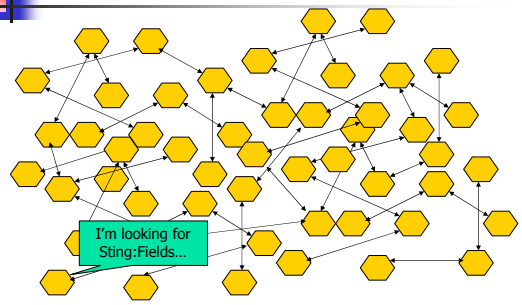
Meanwhile, p2p took off

- By the time Napster was ruled illegal, it had 15 million users. 5 million of them joined in just a few months!
- With Napster out of business, a vacuum arose
  - Some users teamed up to define an open standard called "Gnutella" and to develop many protocol implementations
  - Gnutella eliminates the server
    - Judge singled it out in deciding that Napster was illegal
    - Also, a true peer-to-peer network seems harder to defeat than one that is only partly peer-to-peer
    - Credo: "All information should be free"

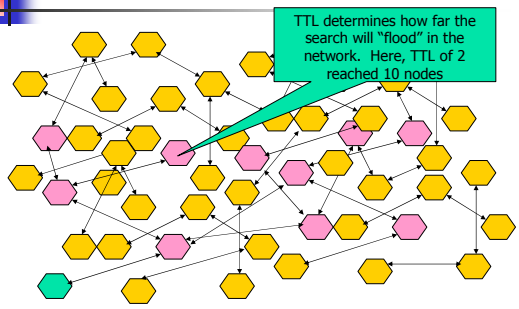
How Gnutella works

- Rough outline
  - User joins the network using a broadcast with increasing TTL values
    - "Is anyone out there?"
    - Links itself to the first Gnutella node to respond
  - To find content, protocol searches in a similar way
    - Broadcasts "I'm looking for Eminem:WhackHer"
    - Keeps increasing TTL value… eventually gives up if no system respond
    - Hopefully, popular content will turn up nearby

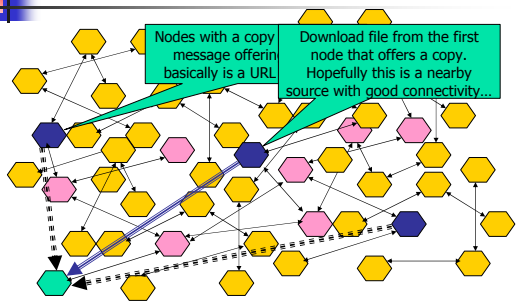
Self-organized "overlay" network



Self-organized "overlay" network



Self-organized "overlay" network



Gnutella has "issues"

- In experimental studies of the system
  - Very high rates of join requests and queries are sometimes observed
  - Departures (churn) found to disrupt the Gnutella communication graph
  - Requests for rare *or misspelled* content turn into world-wide broadcasts
    - Rare is… um… rare. Misspellings are common.

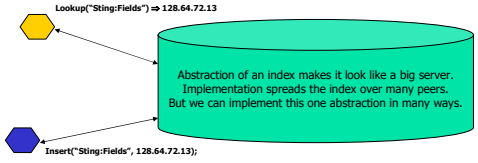
Berkeley, MIT research in p2p

- Universities were first to view p2p as an interesting research area
  - CAN: "Content addressable network" proposed by Berkeley
  - Chord: MIT "distributed hash table"
- Both systems separate the "indexing" problem from actual storage

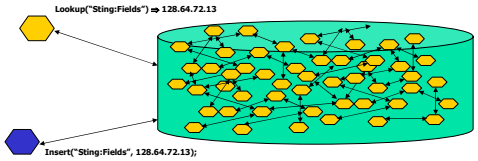
Distributed hash tables (DHTs)

- Idea is to support a simple index with API:
  - Insert(key, value) – saves (key,value) tuple
  - Lookup(key) – looks up key and returns value
- Implement it in a p2p network, not a server…
  - Exactly *how* we implement it varies
  - Normally, each p2p client has just part of the tuples, hence must route query to the right place

Distributed indexing



Distributed indexing



Some details

- Keep in mind
  - There are lots of protocols that can solve this problem: *the protocol used is not part of the problem statement*
  - Some DHTs allow updates (e.g. if data moves, or nodes crash). Others are write once.
  - Most DHTs allow many tuples with the same key and can return the whole list, or a random subset of size k, etc

So what can we insert?

- Normally, we want to keep the values small… like an IP address
  - So the (key,value) pairs might tell us *where to look for something* but probably not *the actual thing*
  - Value could be (and often is) a URL
- Once we have the DHT running we can use it to build a p2p file system

DHTs: Area quickly took off

- Can, Chord: DHTs, already mentioned
- Pastry: From Rice and MSR, uses "Plaxton trees" (a kind of lookup tree)
- Tapestry: Berkeley (similar to Pastry)
- Kelips, Beehive: Cornell (use replication to get much faster responses)

… and too many more to list!

Representative research topics

- Can we make a DHT…
  - … "resilient" to churn?
  - … hide content and guarantee anonymity?
  - … secure and robust against attack?
  - … support high quality parallel striped downloads?
- Can we use a DHT…
  - To support scalable content distribution (IP multicast isn't popular with ISPs)?
  - To implement a new style of Internet addressing (i.e. replace IP routing or multicast)?

Are there legitimate uses of p2p file systems?

- One thought: corporations might want to index "everything in their file store" or to archive stuff
- Digital libraries might use p2p to avoid keeping extra copies of special or extremely big objects
- Risk of "bit rot" is a big concern
  - Suppose some huge set of PCs collaborates to preserve important documents
    - Might also encrypt them – various options exist…
  - How many replicas needed to avoid risk that "rare events" will destroy all copies simultaneously?
  - A topic of study in Oceanstore and at UCSD

Are there legitimate uses of p2p file systems?

- p2p could be a great way to legally share information within a team of collaborators at work, or some other "interest group"
  - Think of these as little groups superimposed on a massive p2p network using the same technology
  - Idea would be: "We help each other out"
- Some argue that p2p systems could be valuable in resisting repressive political regimes
  - Like "coffee house" meetings in pre-revolutionary Russia
  - Can repressive regimes survive if they can't control the flow of information?

Spyware: The real thing

- Imagine a *popular* p2p system that
  - Encrypts content: need key to make sense of it
  - Achieves a high degree of anonymity
    - Pretty much everyone helps to serve each request, but nobody actually has a copy of the whole file on their drive – e.g. I have a few bits, you have a few bits
    - Real sources and nodes accessing content concealed from intruders
    - Robust against disruptive attack
- Needs to be popular: Spies hide in crowds

Philosophical debate

- Is technology "political"?
  - Here we have a technology invented to
    - Rip off IP from owners
    - Conceal crime from law enforcement
    - Pretty much unstoppable without incredibly intrusive oversight mechanisms
  - What's the story here? Are we all anarchists?
- Some people believe technology is negative, some positive, some neutral
  - What about p2p technology?
  - Are we allowed to answer "all of the above"?

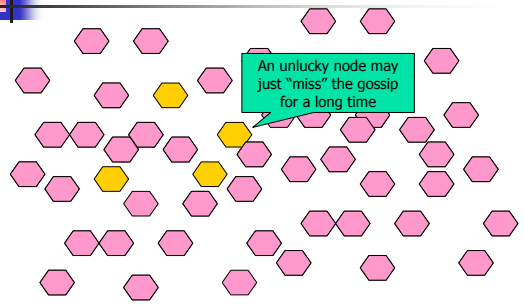
p2p outside of file sharing

- Key idea was that p2p systems could "gossip" about replicated data
  - Now and then, each node picks some "peer" (at random, more or less)
  - Sends it a snapshot of its own data
    - Called "push gossip"
  - Or asks for a snapshot of the peer's data
    - "Pull" gossip
  - Or both: a push-pull interaction

Gossip "epidemics"

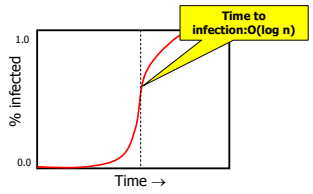
- [t=0] Suppose that I know something
- [t=1] I pick you… Now two of us know it.
- [t=2] We each pick … now 4 know it…
- Information spread: exponential rate.
  - Due to re-infection (gossip to an infected node) spreads as 1.8^k after k rounds
  - But in O(log(N)) time, N nodes are infected

Gossip epidemics



Gossip scales very nicely

- Participants' loads independent of size
- Network load linear in system size
- Data spreads in log(system size) time



Facts about gossip epidemics

- Extremely robust
  - Data travels on exponentially many paths!
  - Hard to even slow it down…
    - Suppose 50% of our packets are simply lost…
    - … we'll need 1 additional round: a trivial delay!
  - Push-pull works best. For push-only/pull-only a few nodes can remain uninfected for a *long time*
- Later we'll see that many optimizations are needed in practice… but the approach works!

Uses of gossip epidemics

- To robustly multicast data
  - Slow, but very sure of getting through
- To repair inconsistency in replicas
- To support "all to all" monitoring and distributed management
- For distributed data mining and discovery

A contemporary perspective

- p2p computing has many pros and many cons, and for most purposes the cons outweigh the pros
  - A "hard to control" technology
  - Firewalls cause many annoyances
  - Rather slow to propagate updates
- But at the same time
  - Incredibly robust against disruption

Contemporary response?

- So… use p2p techniques, but mostly
  - In data centers or LANs where there are no firewalls
  - In uses where slow update times aren't an issue
- Often means that we need to marry p2p mechanism to a more "urgent" protocol like our multicast protocols

Peek ahead

- We'll look at several p2p technologies
  - Chord, Pastry, Kelips: three DHTs
  - Bimodal Multicast: Uses gossip in a multicast protocol to get superior scalability
  - Astrolabe: Uses gossip to implement a scalable monitoring, management and control infrastructure (also great for data mining)