LAU
الجامعة اللبنانية الأميركية
Lebanese American University

CSC 634: Networks Programming

Lecture 08: Peer to Peer Computing

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Traditional Internet Services Model

- Client-server
  - Many clients, 1 (or more) server(s)
  - Web servers, DNS, file downloads, video streaming
- Problems
  - Scalability: how many users can a server support?
    - What happens when user traffic overload servers?
    - Limited resources (bandwidth, CPU, storage)
  - Reliability: if # of servers is small, what happens when they break, fail, get disconnected, are mismanaged by humans?
  - Efficiency: if your users are spread across the entire globe, how do you make sure you answer their requests quickly?

The Alternative: Peer-to-Peer

- A simple idea
  - Users bring their own resources to the table
  - A cooperative model: clients = peers = servers
- The benefits
  - Scalability: # of "servers" grows with users
    - BYOR: bring your own resources (storage, CPU, B/W)
  - Reliability: load spread across many peers
    - Probability of them all failing is very low…
  - Efficiency: peers are distributed
    - Peers can try and get service from nearby peers

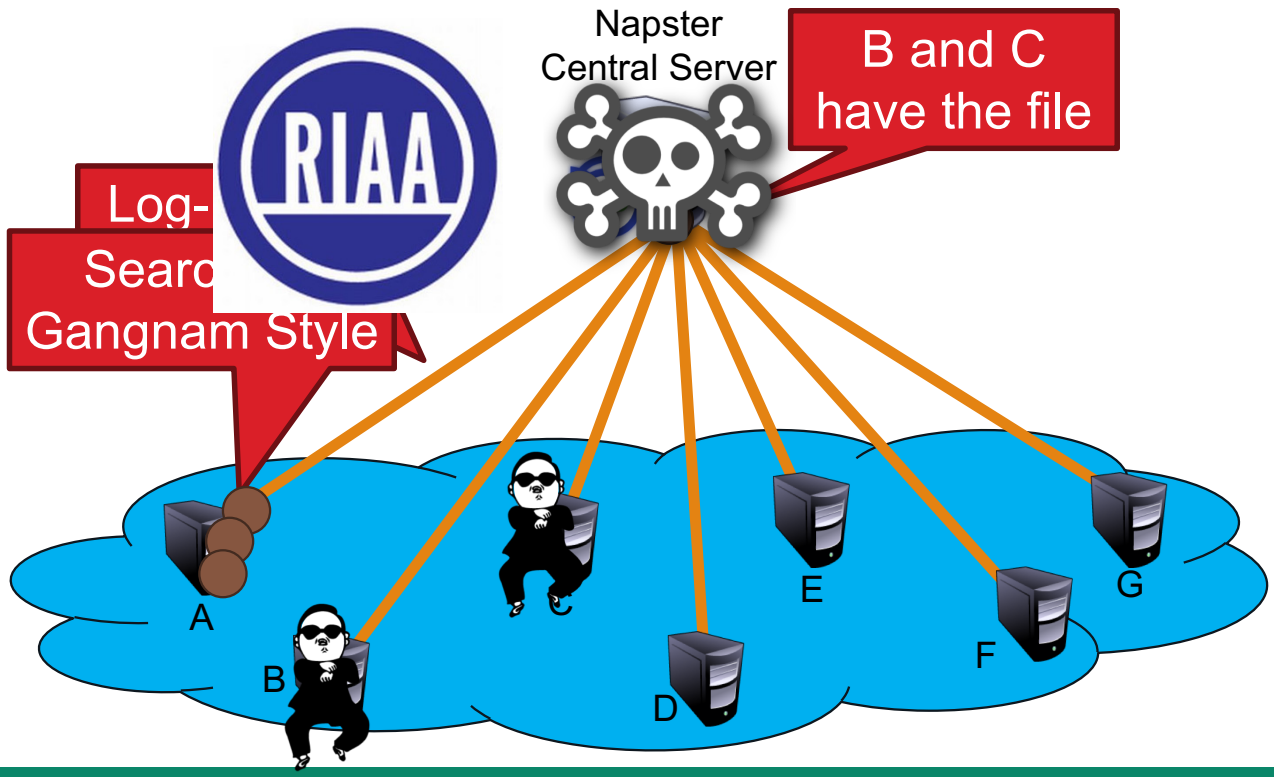
The Peer-to-Peer Challenge

- What are the key components for leveraging P2P?
  - Communication: how do peers talk to each other
  - Service/data location: how do peers know who to talk to
- New reliability challenges
  - Network reachability, i.e. dealing with NATs
  - Dealing with churn, i.e. short peer uptimes
- What about security?
  - Malicious peers and cheating
  - The Sybil attack

Centralized Approach

- The original: Napster
  - 1999-2001
  - Shawn Fanning, Sean Parker
  - Invented at NEU
  - Specialized in MP3s (but not for long)
- Centralized index server(s)
  - Supported all queries
- What caused its downfall?
  - Not scalable
  - Centralization of liability

Napster Architecture

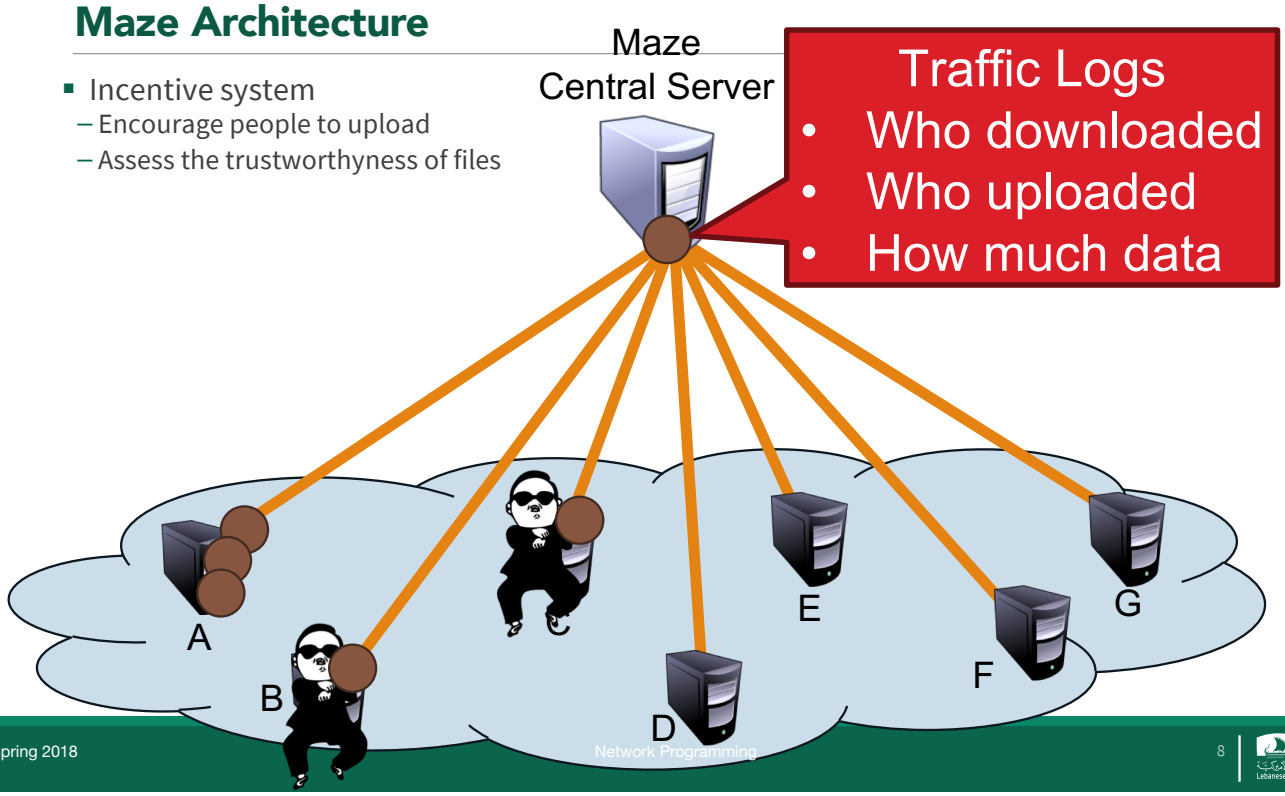


Centralized != Scalable?

- Another centralized protocol: Maze
  - Highly active network in China / Asia
  - Over 2 million users, more than 13 TB transferred/day
  - Central index servers run out of PKU
  - Survives because RIAA/MPAA doesn't exist in China
- Why is this interesting?
  - Shows centralized systems can work
    - Of course have to be smart about it…
  - Central servers "see" everything
    - Quite useful for research / measurement studies

Maze Architecture

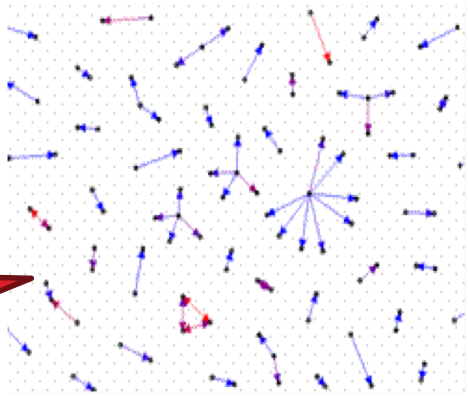
- Incentive system
  - Encourage people to upload
  - Assess the trustworthyness of files



Colluding Users

The Sybil Attack

- Why and How of collusion
  - Collusion gets you points in Maze (incentive system)
  - Spawn fake users/identities for free
- Collusion detectors (ICDCS 2007)
  - Duplicate traffic across links
  - Pair-wise mutual upload behavior
  - Peer-to-IP ratio of clients
  - Traffic concentration



Duplicate transfer graph: 100 links w/ highest duplicate transfer rates

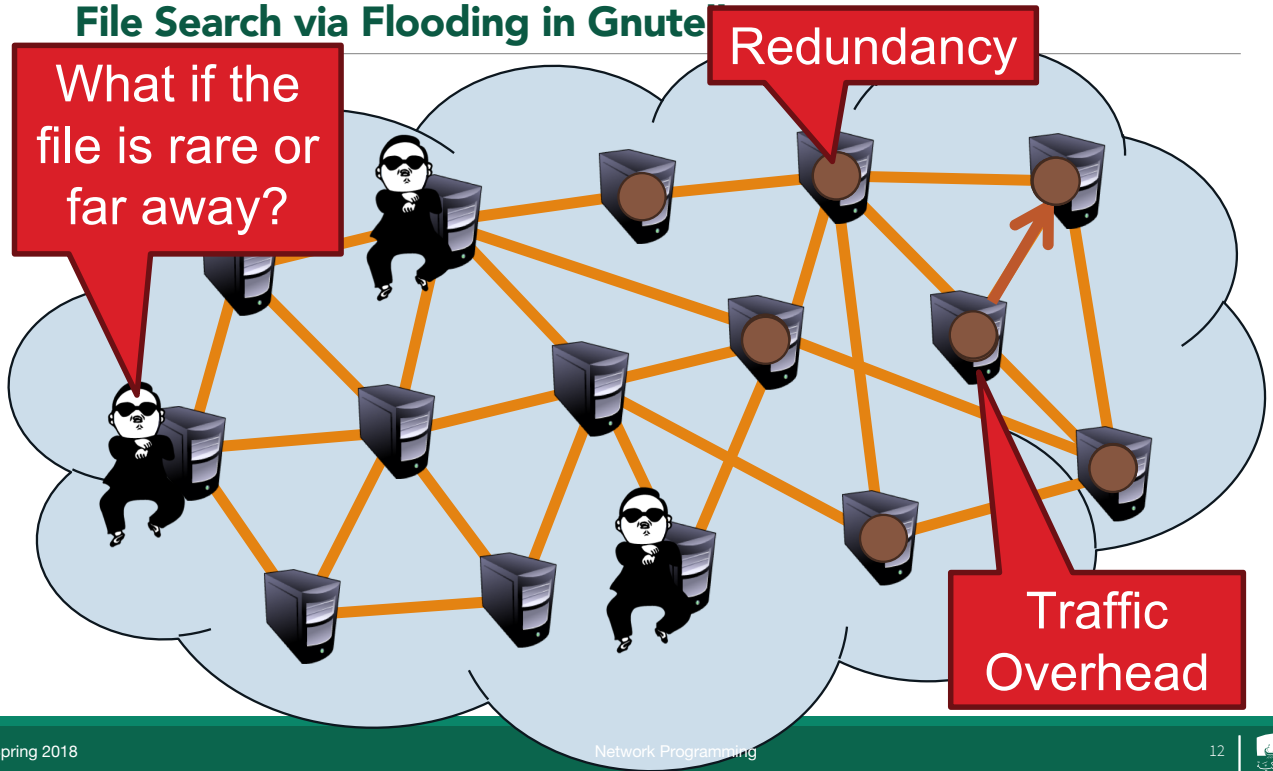
Unstructured P2P Applications

- Centralized systems have single points of failure
- Response: fully unstructured P2P
  - No central server, peers only connect to each other
  - Queries sent as controlled flood
  - Later systems are hierarchical for performance reasons
- Limitations
  - Bootstrapping: how to join without central knowledge?
  - Floods of traffic = high network overhead
  - Probabilistic: can only search a small portion of the system
  - Uncommon files are easily lost

Gnutella

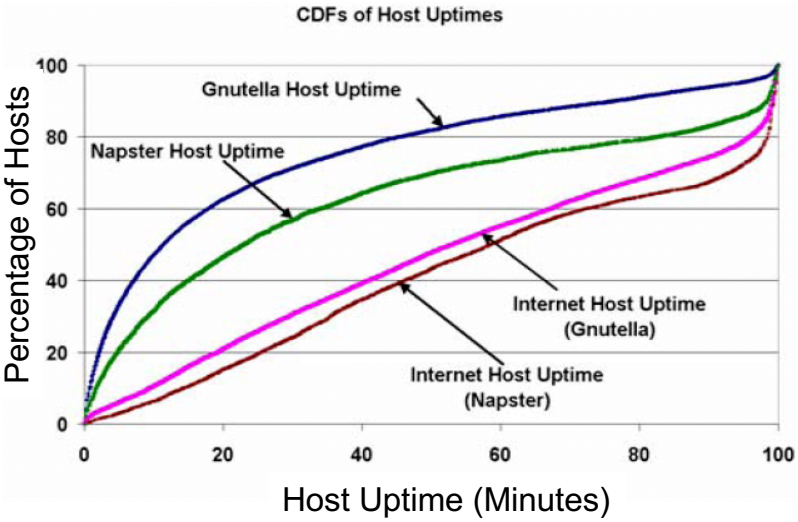
- First massively popular unstructured P2P application
  - Justin Frankel, Nullsoft, 2000
  - AOL was not happy at all [AOL acquired Nullsoft]
- Original design: flat network
  - Join via bootstrap node
  - Connect to random set of existing hosts
  - Resolve queries by localized flooding
    - Time to live fields limit hops
- Recent incarnations use hierarchical structure
- Problems
  - High bandwidth costs in control messages
  - Flood of queries took up all avail b/w for dialup users

File Search via Flooding in Gnute



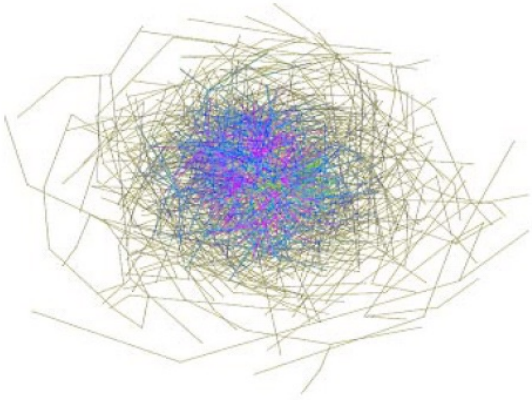
Peer Lifetimes

- Study of host uptime and application uptime (MMCN 2002)
  - 17,000+ Gnutella peers for 60 hours
  - 7,000 Napster peers for 25 hours

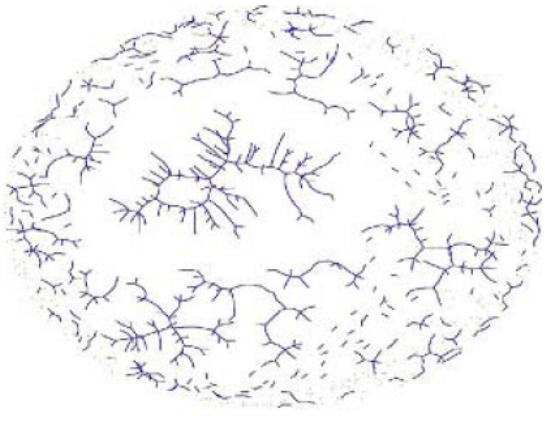


Resilience to Failures and Attacks

- Previous studies (Barabasi) show interesting dichotomy of resilience for "scale-free networks"
  - Resilient to random failures, but not attacks
- Here's what it looks like for Gnutella



1771 Peers in Feb, 2001

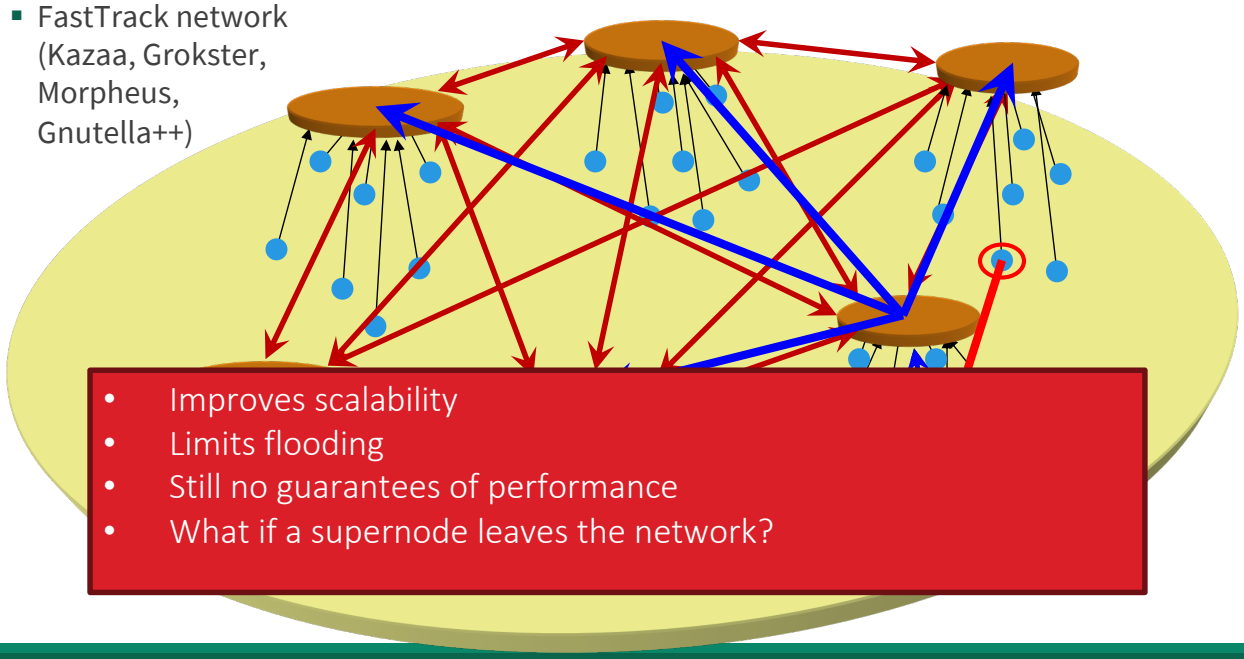


After removing 30% of peers

After removing 4% of peers

Hierarchical P2P Networks

- FastTrack network (Kazaa, Grokster, Morpheus, Gnutella++)



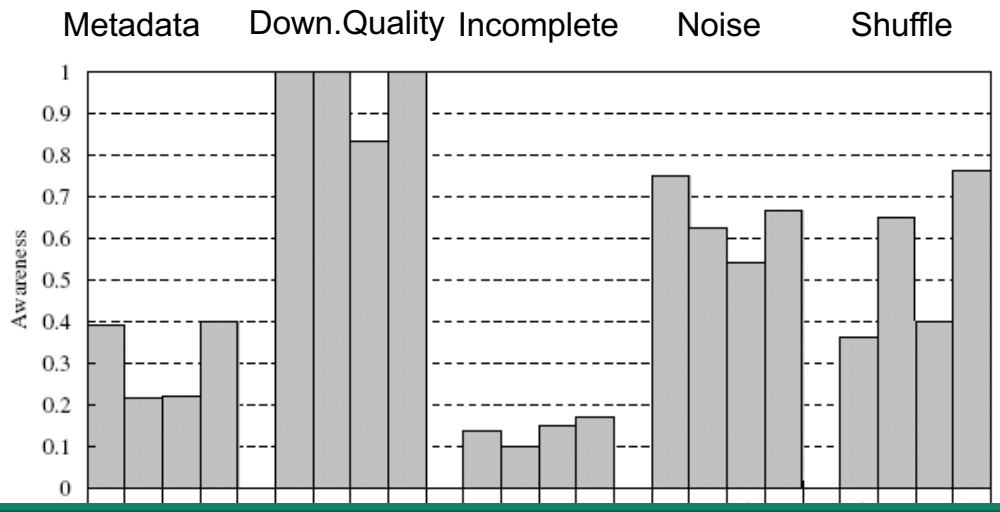
- Improves scalability
- Limits flooding
- Still no guarantees of performance
- What if a supernode leaves the network?

Kazaa

- Very popular from its inception
  - Hierarchical flooding helps improve scale
  - Large shift to broadband helped quite a bit as well
  - Based in Europe, more relaxed copyright laws
- New problem: poison attacks
  - Mainly used by RIAA-like organizations
  - Create many Sybils that distribute “popular content”
    - Files are corrupted, truncated, scrambled
    - In some cases, audio/video about copyright infringement
  - Quite effective in dissuading downloaders

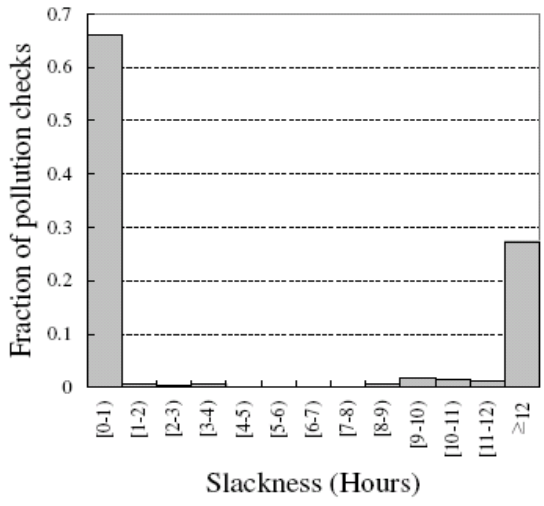
Data Poisoning on Kazaa

- Why is poisoning effective? (IPTPS 2006)
  - People don't check their songs!
  - Apparently not easy to detect file pollution!



Distribution of Poisoned Files

- Why are poisoned files so widely distributed?
  - "Slackness", even when users are "asked" to check files



Skype: P2P VoIP

- P2P client supporting VoIP, video, and text based conversation, buddy lists, etc.
  - Based on Kazaa network (FastTrack)
  - Overlay P2P network consisting of ordinary and Super Nodes (SN)
  - Ordinary node connects to network through a Super Node
- Each user registers with a central server
  - User information propagated in a decentralized fashion
- Uses a variant of STUN to identify the type of NAT and firewall
  - Session Traversal Utilities for NAT

What's New About Skype

- MSN, Yahoo, GoogleTalk all provide similar functionality
  - But generally rely on centralized servers
- So why peer-to-peer for Skype?
  - One reason: cost
    - If redirect VoIP through peers, can leverage geographic distribution
    - i.e. traffic to a phone in Berlin goes to peer in Berlin, thus becomes a local call
  - Another reason: NAT traversal
    - Choose peers to do P2P rendezvous of NAT'ed clients

What does it mean that Skype is moving from peer-to-peer to the cloud

We're making sure that Skype continuously evolves to offer our users the latest technology. Therefore, Skype has been transitioning from a peer-to-peer architecture to a cloud infrastructure. Moving to the cloud ensures that Skype features such as group video calling, audio, and chat are available when you want them.

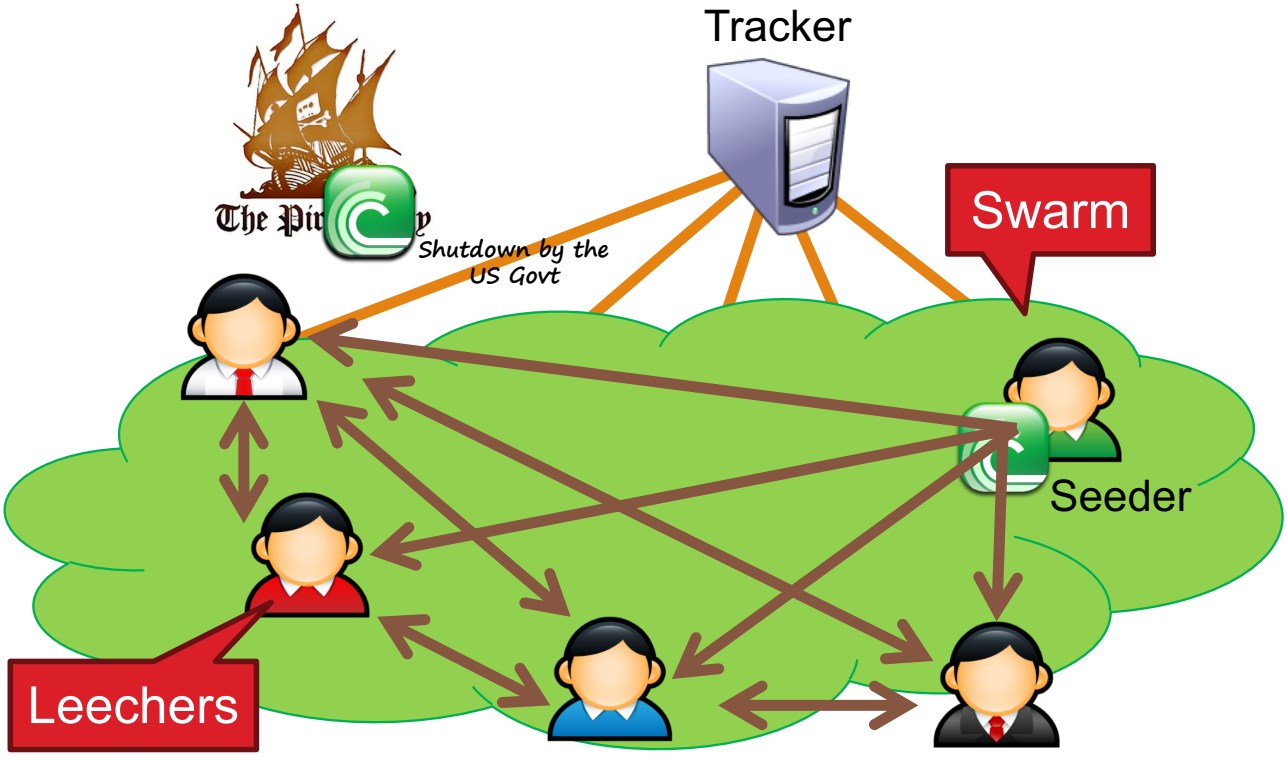
Beginning July 1, 2017, Skype users on some platforms will no longer be able to sign in to Skype. If you're running Skype on any of these platforms, you'll need to access Skype on a supported platform, or use Skype for Web via your internet browser.

If you're on a supported platform and unable to sign in to Skype, you'll need to download the latest update. Still having problems signing in after updating, try our sign in assistant.

What is BitTorrent

- Designed for fast, efficient content distribution
  - Ideal for large files, e.g. movies, DVDs, ISOs, etc.
  - Uses P2P file swarming
- Not a full fledged P2P system
  - Does not support searching for files
  - File swarms must be located out-of-band
  - Trackers acts a centralized swarm coordinators
    - Fully P2P, tracker-less torrents are now possible
- Insanely popular
  - 35-70% of all Internet traffic

BitTorrent Overview



.torrent File

- Contains all meta-data related to a torrent
  - File name(s), sizes
  - Torrent hash: hash of the whole file
  - URL of tracker(s)
- BitTorrent breaks files into pieces
  - 64 KB – 1 MB per piece
  - .torrent contains the size and SHA-1 hash of each piece
- Basically, a .torrent tells you
  - Everything about a given file
  - Where to go to start downloading

Torrent Sites

- Just standard web servers
  - Allow users to upload .torrent files
  - Search, ratings, comments, etc.
- Some also host trackers
- Many famous ones
  - Mostly because they host illegal content
- Legitimate .torrents
  - Linux distros
  - World of Warcraft patches
- Both sites were shutdown by the US Govt but mirrors persist

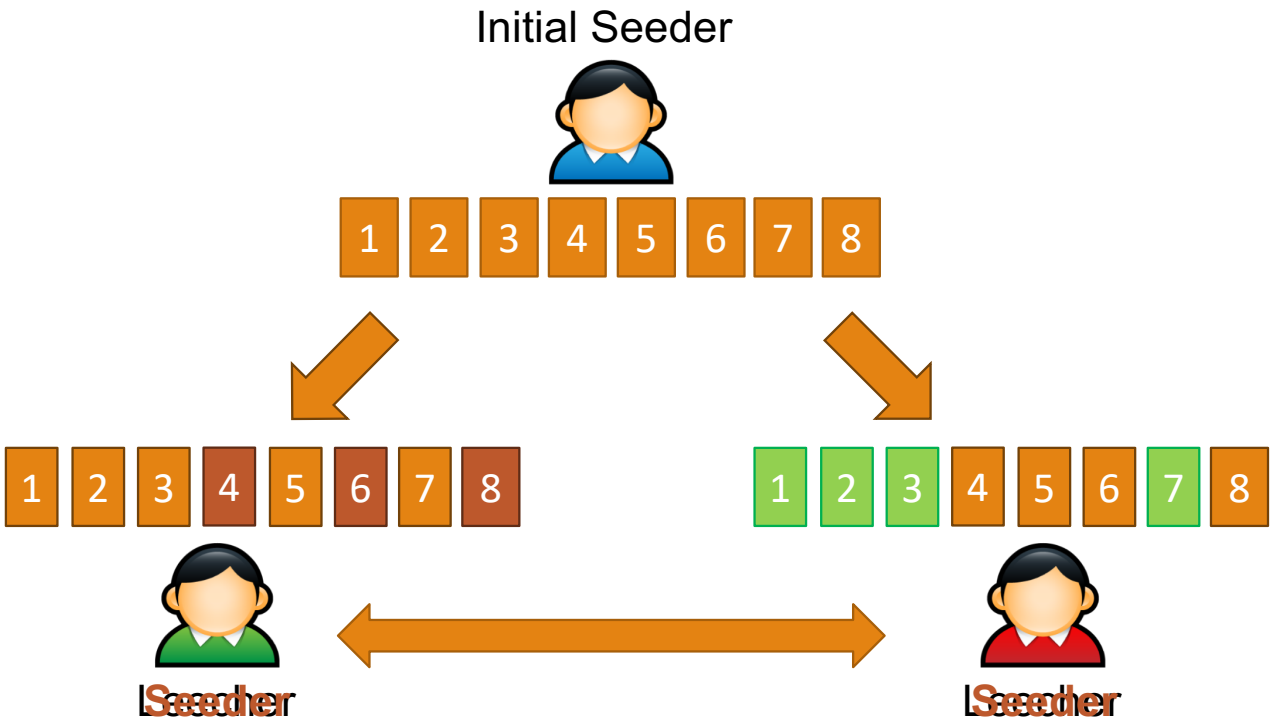
Torrent Trackers

- Really, just a highly specialized webserver
  - BitTorrent protocol is built on top of HTTP
- Keeps a database of swarms
  - Swarms identified by torrent hash
  - State of each peer in each swarm
    - IP address, port, peer ID, TTL
    - Status: leeching or seeding
    - Optional: upload/download stats (to track fairness)
  - Returns a random list of peers to new leechers

Peer Selection

- Tracker provides each client with a list of peers
  - Which peers are best?
    - Truthful (not cheating)
    - Fastest bandwidth
- Option 1: learn dynamically
  - Try downloading from many peers
  - Keep only the best peers
  - Strategy used by BitTorrent
- Option 2: use external information
  - E.g. Some torrent clients prefer peers in the same ISP

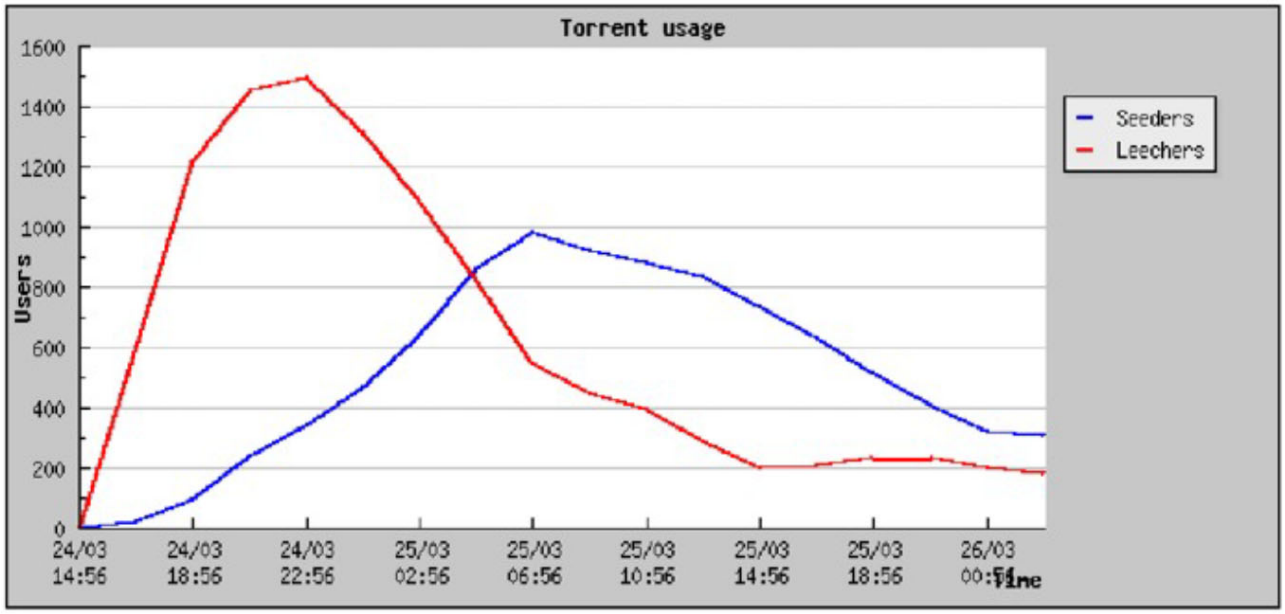
Sharing Pieces



The Beauty of BitTorrent

- More leechers = more replicas of pieces
- More replicas = faster downloads
  - Multiple, redundant sources for each piece
- Even while downloading, leechers take load off the seed(s)
  - Great for content distribution
  - Cost is shared among the swarm

Typical Swarm Behavior



Sub-Pieces and Pipelining

- Each piece is broken into sub-pieces
  - ~16 KB in size
- TCP Pipelining
  - For performance, you want long lived TCP connections (to get out of slow start)
  - Peers generally request 5 sub-pieces at a time
  - When one finished, immediately request another
  - Don't start a new piece until previous is complete
    - Prioritizes complete pieces
    - Only complete pieces can be shared with other peers

Piece Selection

- Piece download order is critical
  - Worst-case scenario: all leeches have identical pieces
    - Nobody can share anything :(
  - Worst-case scenario: the initial seed disappears
    - If a piece is missing from the swarm, the torrent is broken
- What is the best strategy for selecting pieces?
  - Trick question
  - It depends on how many pieces you already have

Download Phases

- Bootstrap: random selection
  - Initially, you have no pieces to trade
  - Essentially, beg for free pieces at random
- Steady-state: rarest piece first
  - Ensures that common pieces are saved for last
- Endgame
  - Simultaneously request final pieces from multiple peers
  - Cancel connections to slow peers
  - Ensures that final pieces arrive quickly

Upload and Download Control

- How does each peer decide who to trade with?
- Incentive mechanism
  - Based on tit-for-tat, game theory
  - "If you give a piece to me, I'll give a piece to you"
  - "If you screw me over, you get nothing"
  - Two mechanisms: choking and optimistic unchoke
- Tit-for-tat strategy is based on game-theoretic concepts.

A Bit of Game Theory

- Iterated prisoner's dilemma
- Very simple game, two players, multiple rounds
  - Both players agree: +2 points each
  - One player defects: +5 for defector, +0 to other
  - Both players defect: +0 for each
- Maps well to trading pieces in BitTorrent
  - Both peers trade, they both get useful data
  - If both peers do nothing, they both get nothing
  - If one peer defects, he gets a free piece, other peer gets nothing
- What is the best strategy for this game?

Tit-for-Tat

- Best general strategy for iterated prisoner's dilemma
- Meaning: "Equivalent Retaliation"

Rules

1. Initially: cooperate
2. If opponent cooperates, cooperate next round
3. If opponent defects, defect next round

Round			Points
1	Cooperate	Cooperate	+2 / +2

Choking

- Choke is a temporary refusal to upload
  - One of BT's most powerful idea to deal with free riders
  - Tit-for-tat: choke free riders
  - Cap the number of simultaneous uploads
    - Too many connections congests your network
  - Periodically unchoke to test the network connection
    - Choked peer might have better bandwidth

Optimistic Unchoke

- Each peer has one optimistic unchoke slot
  - Uploads to one random peer regardless of the current download rate from it
  - Peer rotates every 30 seconds
- Reasons for optimistic unchoke
  - Help to bootstrap peers without pieces
  - Discover new peers with fast connections

BitTorrent Protocol Fundamentals

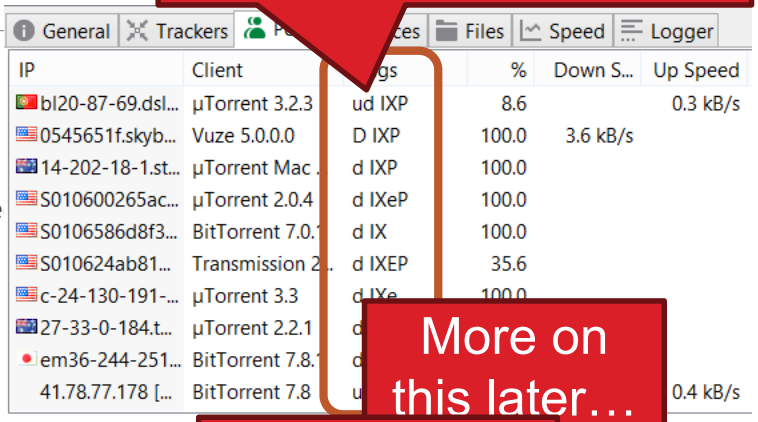
- BitTorrent divides time into rounds
  - Each round, decide who to upload to/download from
  - Rounds are typically 30 seconds
- Each connection to a peer is controlled by four states
  - Interested / uninterested – do I want a piece from you?
  - Choked / unchoked – am I currently downloading from you?
- Connections are bidirectional
  - You decide interest/choking on each peer
  - Each peer decides interest/chocking on you

Error states. Connection should be closed.

Most peers are d or D. No need to connect with uninteresting peers.

- D – interested and unchoked
- K – uninterested and unchoked
- S – snubbed (no data received in 60 s
- F – piece(s) failed to hash

- Upload control
  - u – interested and choked
  - U – interested and unchoked
  - O – optimistic unchoke
  - ? – uninterested and unchoked
- Connection information
  - I – incoming connection
  - E/e – Using protocol encryption



More on this later…

More on this next week

- h –
- P –
- How was this r located?
  - H – DHT (distributed hash table)
  - L – local peer discovery (multicast)
  - X – peer exchange

Upload-Only Mode

- Once a peer completes a torrent, it becomes a seed
  - No downloads, no tit-for-tat
  - No download rates to use for comparison nor has any need to use them
  - Who to upload to first?
- BitTorrent policy
  - Upload to the fastest known peer
  - Why?
    - Faster uploads = more available pieces
    - More available pieces helps the swarm

Trackerless Torrents

- New versions of BitTorrent have the ability to locate swarms without a tracker
  - Based on a P2P overlay
  - Distributed hash table (DHT)
- Recall: peers located via DHT are given “H” state
- More on this next week

BitTorrent and TCP

- BitTorrent accounts for 35-70% of all Internet traffic
- Thus, BitTorrent’s behavior impacts everyone
- BitTorrent’s use of TCP causes problems
  - Long lived, BitTorrent TCP flows are “elephants”
    - Ramp up past slow start, dominate router queues
  - Many applications are “mice,” get trampled by elephants
    - Short lived flows (e.g. HTTP traffic)
    - Delay sensitive apps (i.e. VoIP, SSH, online games)
- Have you ever tried using SSH while using BitTorrent?

Making BitTorrent Play Nice

- Key issue: long-lived TCP flows are aggressive
  - TCP is constantly probing for more bandwidth
  - TCP induces queuing delay in the network
- Does BitTorrent really need to be so aggressive?
  - BitTorrent is not delay sensitive
    - Do you care if your download takes a few minutes longer?
  - BitTorrent is low-priority background traffic
    - You probably want to do other things on the Internet while BitTorrent is downloading
- Solution: use less a less aggressive transport protocol for BitTorrent

Micro Transport Protocol (µTP)

- Designed by BitTorrent, Inc.
- UDP-based transport protocol
- Uses LEDBAT principals
  - Low Extra Delay Background Transport
- Duplicates many TCP features
  - Window based sending, advertised windows
  - Sequence numbers (packet based, not byte based)
  - Reliable, in-order packet delivery
- Today: widely adopted by BitTorrent clients and open-sourced

µTP and LEDBAT

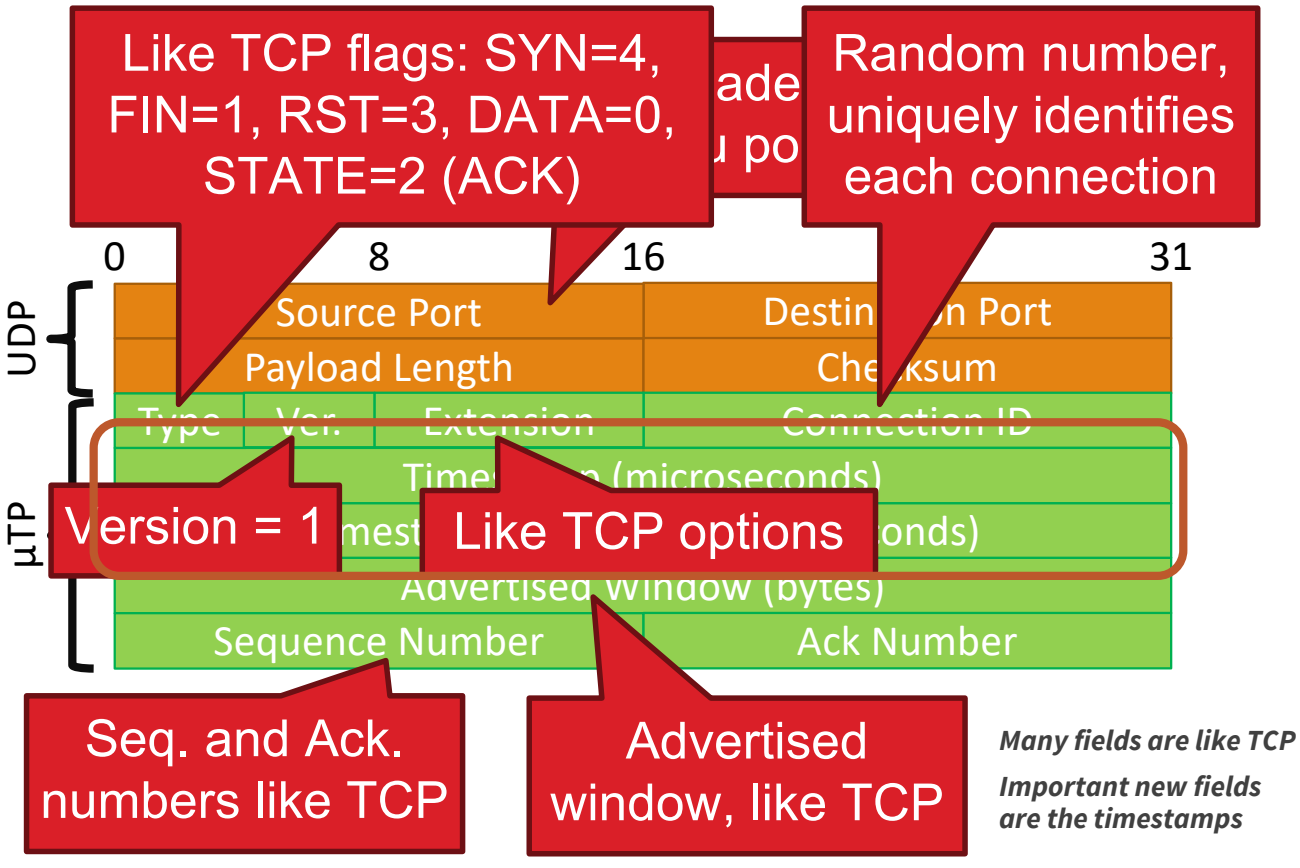
- µTP is based on IETF LEDBAT standard (RFC 6817)
- Low Extra Delay Background Transport
  - Low delay congestion control algorithm
  - Seeks to use all available bandwidth…
  - … without increasing queuing delay on the path
- Goal: fast transfer of bulk data in the background
  - Use all available bandwidth (fast transfer speed)
  - … but, do not starve other applications
    - Background data transfer is not delay sensitive
    - Backoff gracefully and give bandwidth to delay sensitive applications

LEDBAT Details

- Delay-based congestion control protocol
  - Similar algorithm to TCP Vegas
  - Measure one-way delay, reduce rate when delay increases
- Constraint: be less aggressive than TCP
  - React early to congestion and slow down
  - Do not induce queuing delay in the network
- LEDBAT is a “scavenger” cc protocol
  - Scavenge unused bandwidth for file transfer
  - … but don’t take bandwidth from other flows

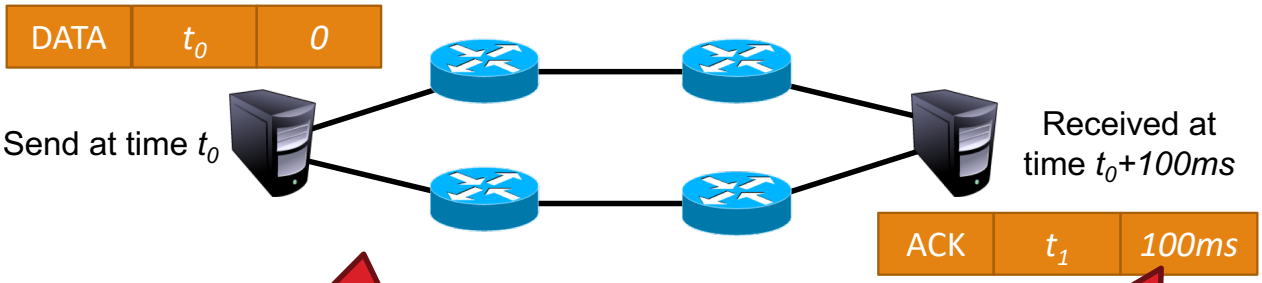
LEDBAT Details

- Many fields are like TCP
- Important new fields are the timestamps



Timestamps and Delay

- Timestamps used to measure one-way delay
  - Timestamp: time at which packet was sent
  - Timestamp Difference: sent time – received time



Sender knows one-way delay = 100ms

Time difference inserted into ACK

- ne-way delay
- paths are not sy
- path doesn't i

µTP tries to keep one-way delay ~100ms

Estimate the baseline delay on the path

- 2 minutes])
-

Is delay below our target (positive value), or above our target (negative value)

Current delay on the path above the b

Time difference fr most recent AC

Convert units from "time" to "packets"

Finally, adjust the window size (may be + or – adjustment)

- scaled * window_factor
- max_window = max_window + scaled_gain

More µTP Details

- Delay-based mechanism replaces slow start and additive increase
- What if a packet drops?
  - max_window = max_window * 0.5 (just like TCP)
- What if off_target is a large negative number?
  - max_window = 1 packet (don't starve the connection)
- Error handling in µTP :
  - Uses RTO like Tahoe to retransmit lost packets
  - Uses fast retransmit like TCP Reno

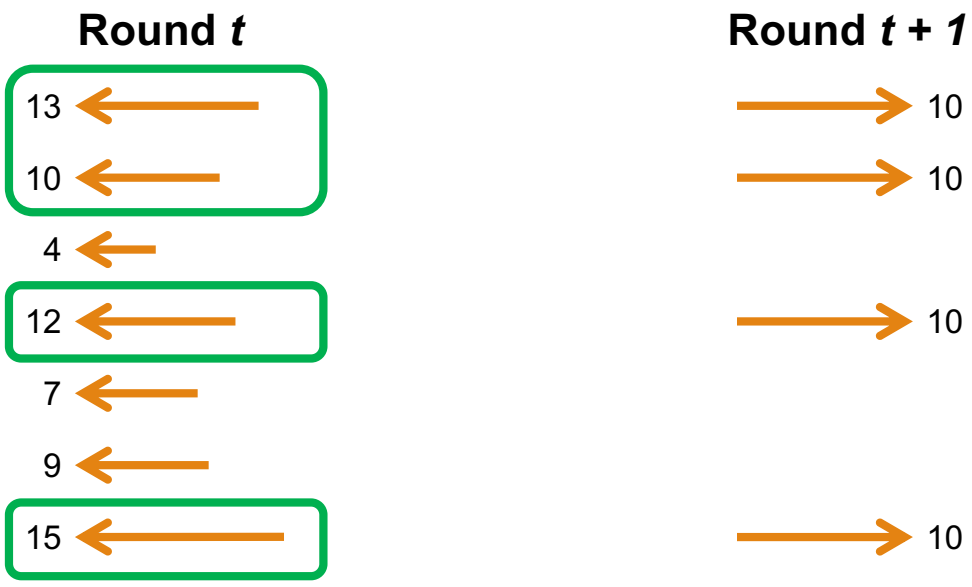
Discussion

- In this case, developing a new transport protocol was (arguably) the right decision
  - BitTorrent generates huge amounts of traffic
  - Whole Internet benefits if BitTorrent is more friendly
- However, inventing new protocols is hard
  - µTP reimplements most of TCP
    - RTO estimation, Nagle's algorithm, etc.
  - Early version of µTP performed much worse than TCP
    - Lots of bugs related to packet pacing and sizing
- Takeaway: develop new transport protocols only if absolutely necessary

Incentives to Upload

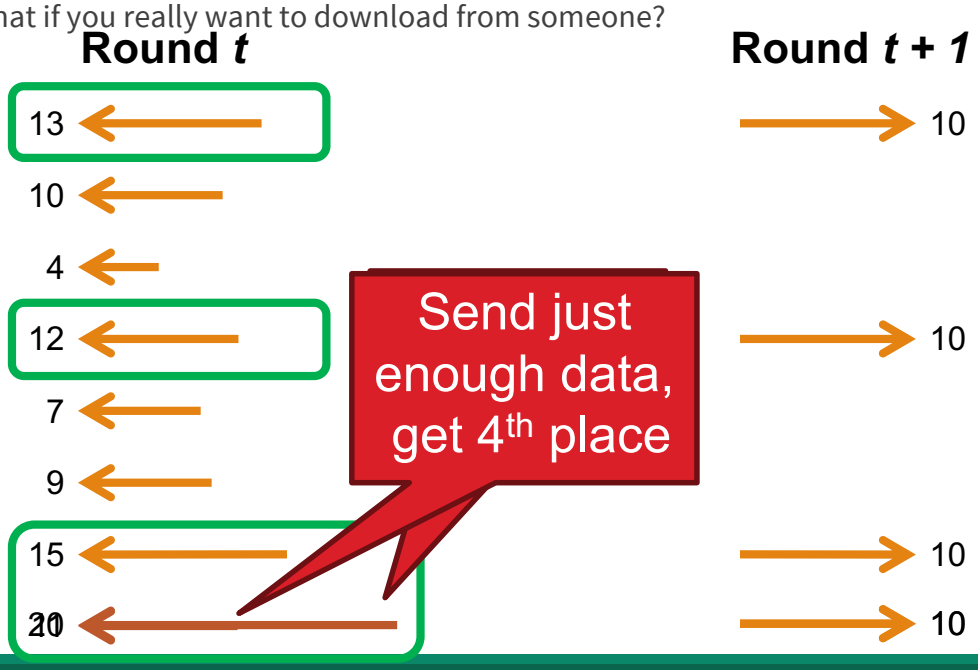
- Every round, a BitTorrent client calculates the number of pieces received from each peer
  - The peers who gave the most will receive pieces in the next round
  - These decisions are made by the unchoker
- Assumption
  - Peers will give as many pieces as possible each round
  - Based on bandwidth constraints, etc.
- Can an attacker abuse this assumption?

Unchoker Example

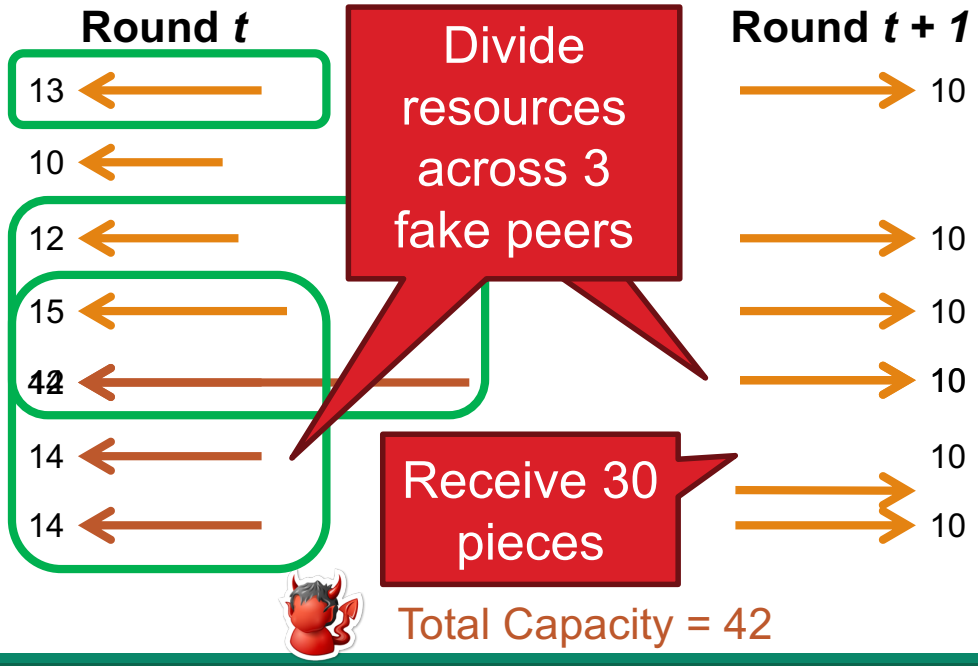


Abusing the Unchocker

- What if you really want to download from someone?



Sybil Attack



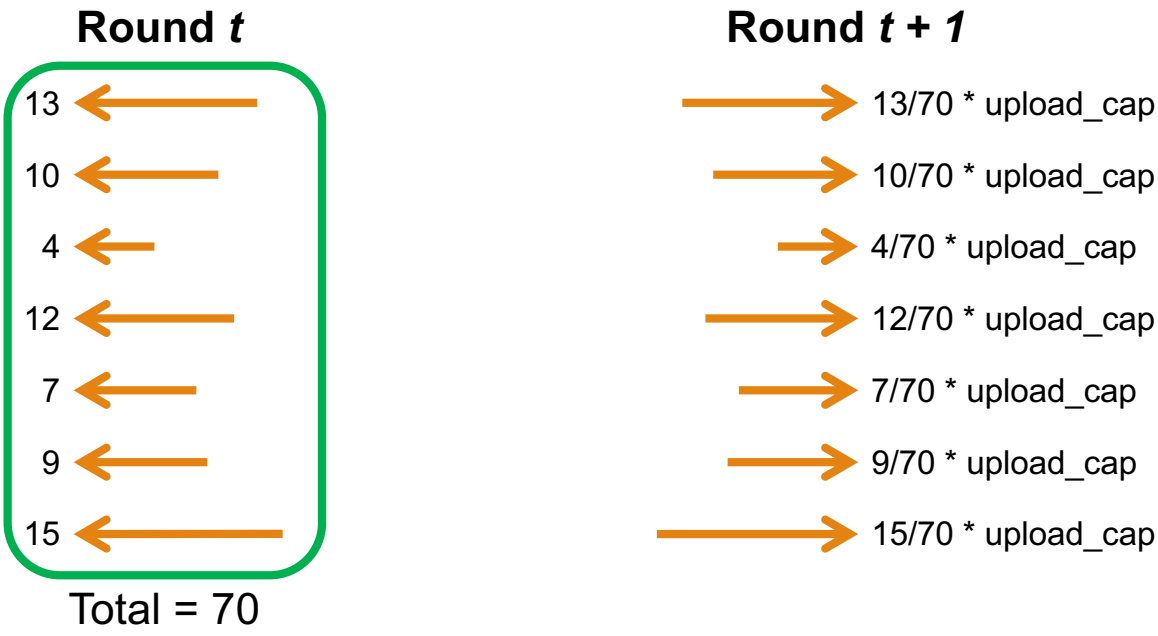
BitTyrant

- Piatek et al. 2007
  - Implements the “come in last strategy”
  - Essentially, an unfair unchoker
  - Faster than stock BitTorrent
    - For the Tyrant user
- Problem with BitTyrant
  - Tragedy of the commons
  - BitTyrant performs well if most peers are honest
  - As more peers use BitTyrant, performace suffers
  - If all users used BitTyrant, torrents wouldn’t work at all

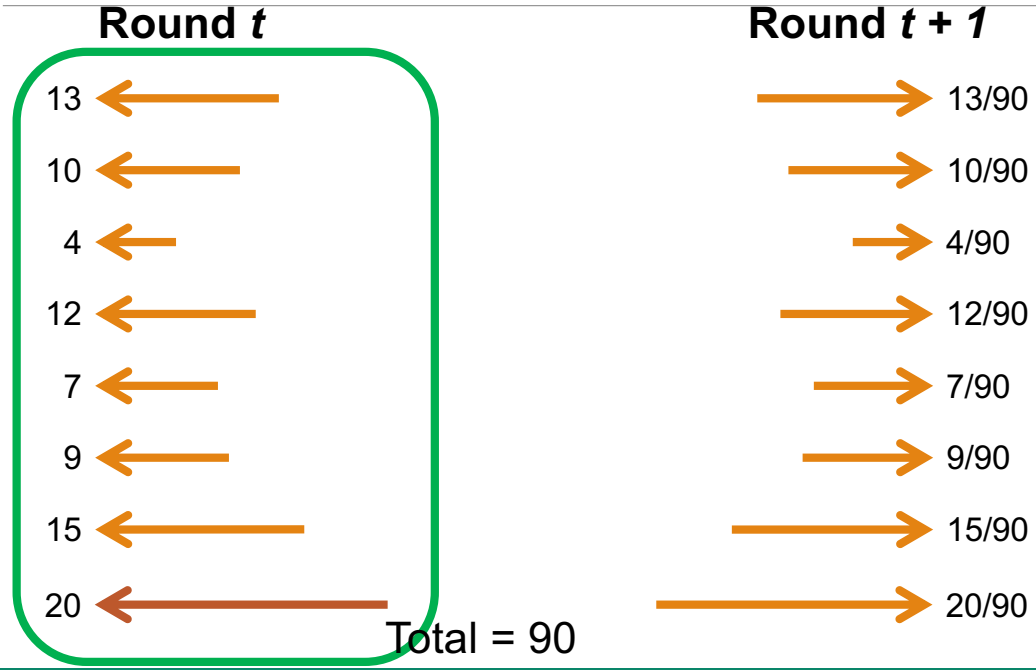
PropShare Unchoker

- Goal: modify BitTorrents incentive mechanisms to mitigate “come in last” and Sybil attacks
- Levin et al. 2008
  - Propose PropShare unchoker
  - PropShare clients allocate upload bandwidth proportionally across all peers
  - There is no longer a “top four”
- Can you cheat vs. PropShare?

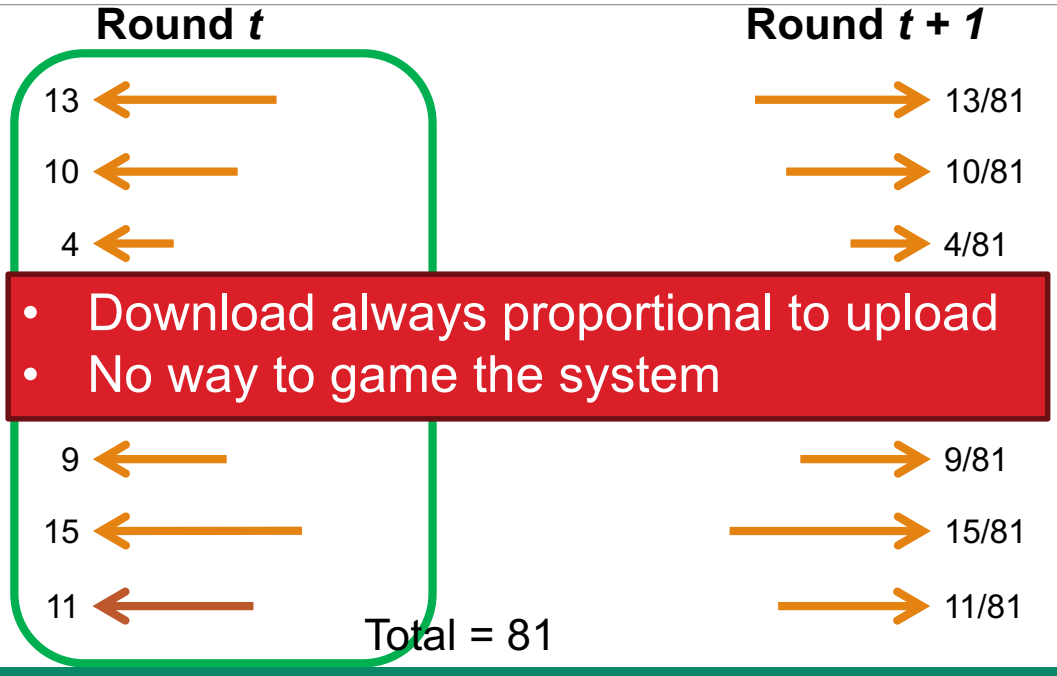
PropShare Unchoker



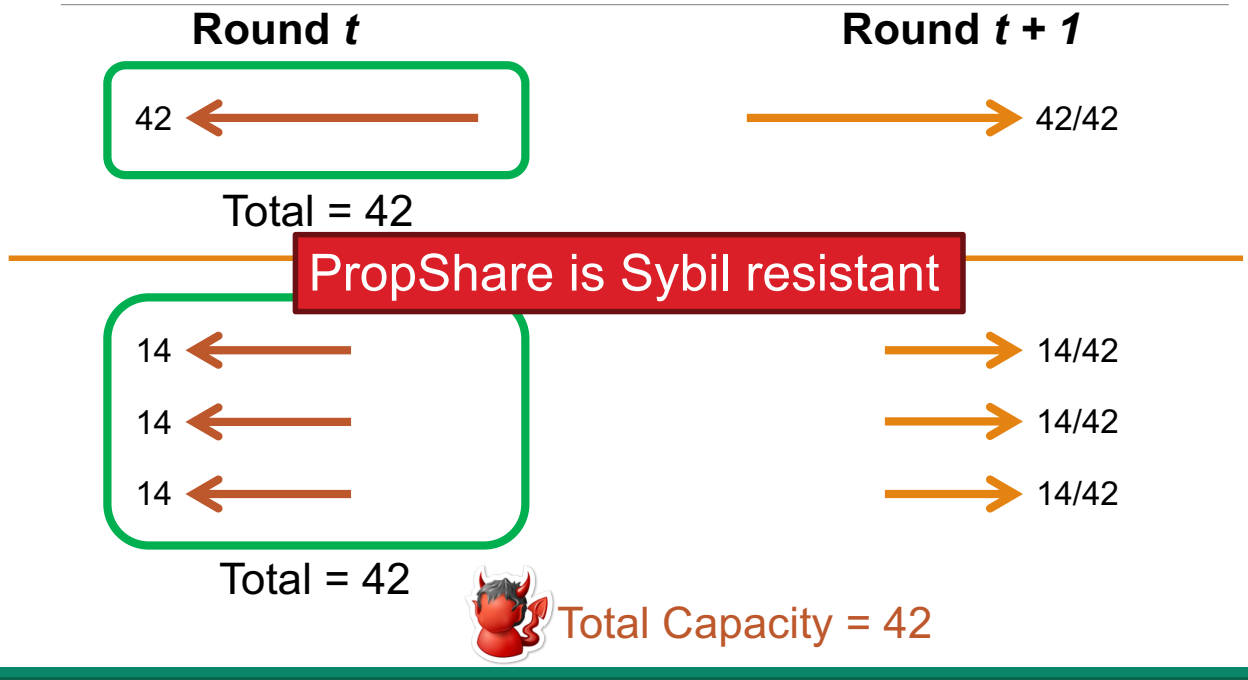
PropShare Resiliency to BitTyrant



PropShare Resiliency to BitTyrant



PropShare Resiliency to Sybils



Unchoker Summary

- BitTyrant and PropShare are both faster than stock BitTorrent
  - But for different reasons
- PropShare performs comparably to BitTyrant
- PropShare does not suffer from a tragedy of the commons
  - i.e. it's safe for all peers to use PropShare
  - Not true for BitTyrant

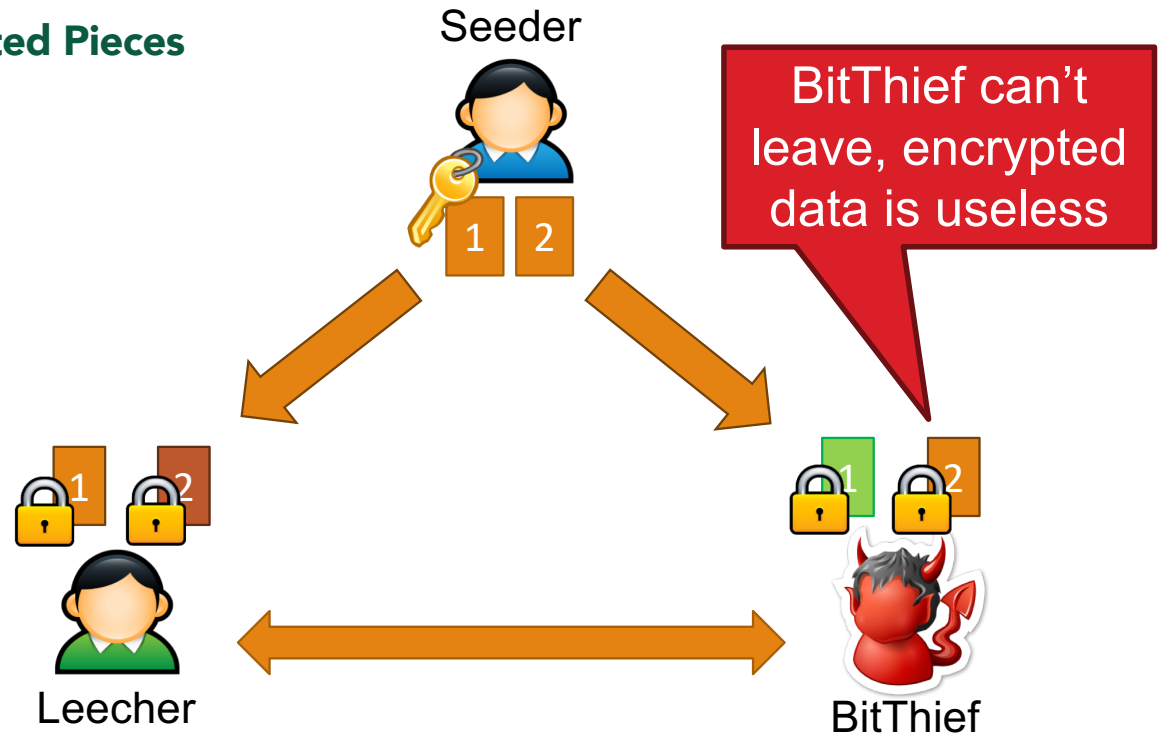
Abusing Optimistic Unchoking

- So far, assumed peers all have pieces to trade
  - Thus, all peers are interesting
- What about peers that have nothing?
  - The bootstrap mechanism is supposed to help them
  - Optimistic unchoke: reserve some bandwidth to give free pieces away (presumably to new peers)
- BitThief (Locher et al. 2006)
  - Abuses optimistic unchoke, uploads nothing
  - Swarm collapses if all peers use BitThief

BitThief Details

- Large-view exploit
  - The swarm is (potentially) huge
  - BitThief client tries to get optimistic unchoke from many, many peers
  - Will only receive one free piece from each
    - Since there is no reciprocal upload
  - But in aggregate, this is enough to finish download
- How to deal with this?
  - Enlist the help of peers
  - Have them verify that a given client uploads

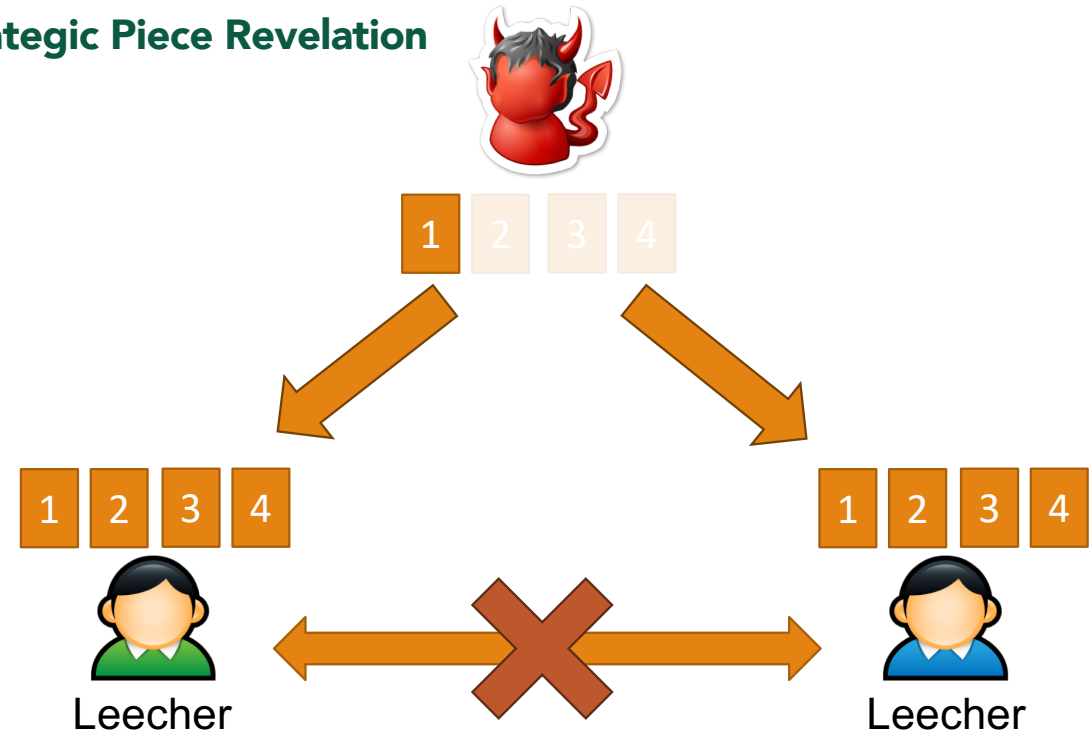
Encrypted Pieces



Abusing the Endgame

- Rare pieces are valuable
  - Make you popular, many people want to trade with you
  - More trading partners = faster downloads
- Selective piece revelation
  - You can't advertise pieces you don't have
    - Peers could detect this
  - But you can hide information about the pieces you have
- Why is this useful?
  - Pieces sent at time t impact your popularity at time t+1
  - Sending common pieces first, monopolize rare pieces

Strategic Piece Revelation



Conclusions

- BitTorrent is an extremely efficient tool for content distribution
  - Strong incentive system based on game theory
  - Most popular file sharing client since 2001
  - More active users than YouTube and Facebook combined
- However, BitTorrent is a large system with many different mechanisms
  - Ample room to modify the client, alter behavior
  - Cheating can happen, not all strategies are fair