Summary of the BitTorrent Protocol

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Discussion on modelling and BitTorrent

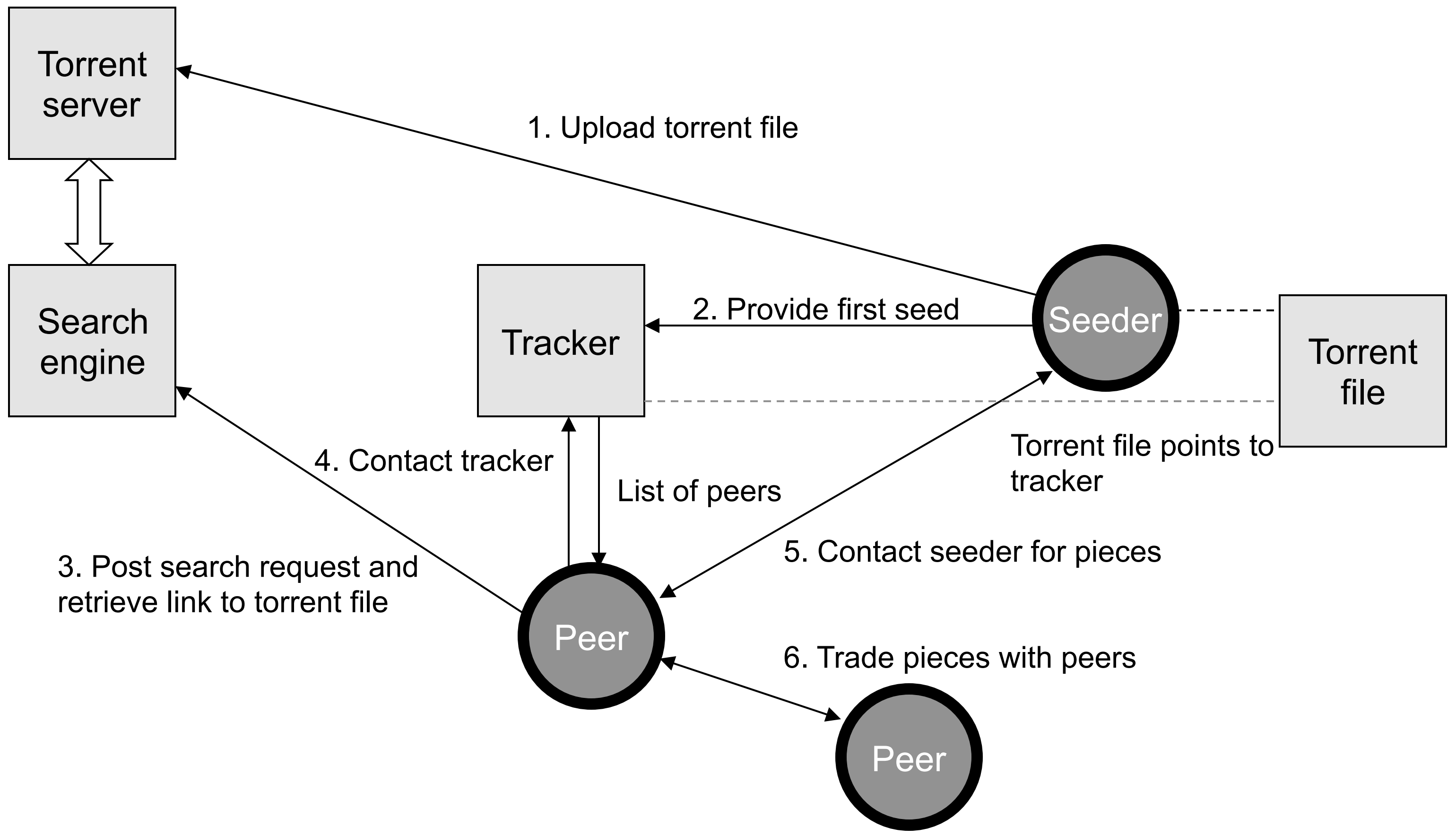
BitTorrent

BitTorrent is based on the notion of a **torrent**, which is a smallish file that contains **metadata** about a host, the tracker, that coordinates the file distribution and files that are shared

A peer that wishes to make data available must first find a tracker for the data, create a torrent, and then distribute the torrent file. Other peers can then using information contained in the torrent file assist each other in downloading the file

The download is coordinated by the tracker. In BitTorrent terminology, peers that provide a complete file with all of its pieces are called **seeders**

BitTorrent: Downloading Files


Torrent server
1. Upload torrent file
Search engine
Tracker
2. Provide first seed
Seeder
Torrent file
Torrent file points to tracker
4. Contact tracker
List of peers
5. Contact seeder for pieces
3. Post search request and retrieve link to torrent file
Peer
6. Trade pieces with peers
Peer

Difference to HTTP

A BitTorrent file download differs from an HTTP request in the following ways:

- BitTorrent uses multiple parallel connections to improve download rates, whereas Web browsers typically use a single TCP Socket to transfer HTTP requests and responses
- BitTorrent is peer-assisted whereas HTTP request is strictly client-server
- BitTorrent uses the random or rarest-first mechanisms to ensure data availability, whereas HTTP is incremental

Characteristics of the BitTorrent protocol I/II

- **Peer selection** is about selecting peers who are willing to share files back to the current peer
  - **Tit for tat** in peer selection based on download-speed.
  - The mechanism uses a **choking/unchoking** mechanism to control peer selection. The goal is to get good TCP performance and mitigate free riders
- **Optimistic unchoking**
  - The client uses a part of its available bandwidth for sending data to random peers
  - The motivation for this mechanism is to avoid bootstrapping problem with the tit for tat selection process and ensure that new peers can join the swarm

Characteristics of the BitTorrent protocol II

- **Piece selection** is about supporting high piece diversity
  - Local Rarest First for piece selection (start with random, then finally use end game mode)
  - BITFIELD message after handshake with a peer, then HAVE messages for downloaded pieces
- **End game mode**
  - To avoid delays in obtaining the last blocks the protocol requests the last blocks from all peers
  - Sends cancel messages for downloaded blocks to avoid unnecessary transmissions
  - When to start the end game mode is not detailed in the specification

Tit-for-tat in Bittorrent

- Tit-for-tat is a an effective strategy in game theory
  - Idea: cooperate first, and then respond in kind
- Peer has limited number of upload slots
- Upload bandwidth is exchanged for download bandwidth
- If peer is not uploading (only downloading) --> choke
- Upload slot to a random peer (optimistic unchoke)
- Searches for cooperative peers

TFT in more detail

1. Sort peers by incoming data rate
2. Reciprocate with top k, k is proportional to the square root of the upload capacity
3. Optimistically unchoke one other peer
4. Send each peer selected an equal split of capacity

Data transport in BitTorrent

Typically, BitTorrent uses **TCP** as its transport protocol for exchanging pieces, and it uses HTTP for tracker comms.

Possible to use HTTP port and real/fake HTTP headers for transport to avoid throttling (not in the specification)

The well known TCP port for BitTorrent traffic is 6881-6889 (and 6969 for the tracker port).

The DHT extension (peer-to-peer tracker) uses various UDP ports negotiated by the peers.

Web seeding (extension)
Use HTTP to download pieces from Web sites

Security extensions (similar to TLS: message stream encryption)

Micro Transport Protocol (µTP)

TCP creates buffer bloat, has latency and overhead due to
- congestion control

µTP is an open UDP based protocol for P2P file sharing
- Is supported by many BitTorrent clients (µTorrrent, KTorrent, ..)
- Suitable for background transfers

Low Extra Delay Background Transport (LEDBAT)
- congestion control

µTP supports NAT traversal using UDP hole punching
- between two port-restricted peers where a third unrestricted peer acts as a STUN server (*remember Skype NAT discussion*)

“libutp" library and published under the MIT license

NAT traversal

- Open ports in firewall/NAT device
- µTP NAT traversal support
- UPnP configuration
- SSH tunnelling
- HTTP tunnelling/proxying
  - Any traffic through NATs
  - Not necessarily efficient (with relay)

Distributed Tracker

BitTorrent Mainline DHT

Based on Kademlia DHT

Find peers through the DHT network

We will examine Kademlia later on this course

Altruism in BitTorrent

Seeders keep file available

A peer can choose to stay in the network and become a seeder, or leave

Upload activity is also example of altruistic behaviour

Biased neighbor selection

A technique called **biased neighbor selection** has been proposed for reducing cross-ISP traffic

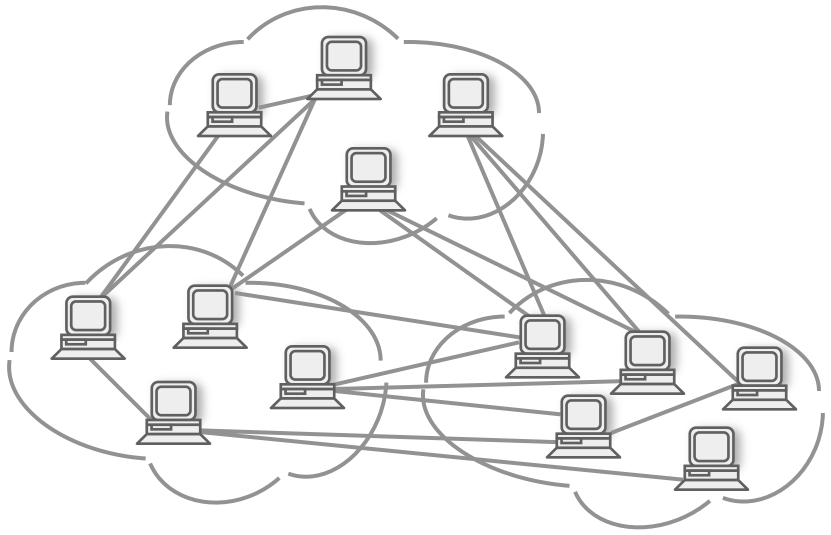
A BitTorrent peer chooses most of its neighbors from the local ISP, and only a few peers from other ISPs.

Essentially, the peer selection is biased towards local peers. A parameter *k* represents the number of external peers from other ISPs. The tracker is modified to select 35 − *k* internal peers and *k* external peers that are returned to the client requesting a peer list for a torrent.

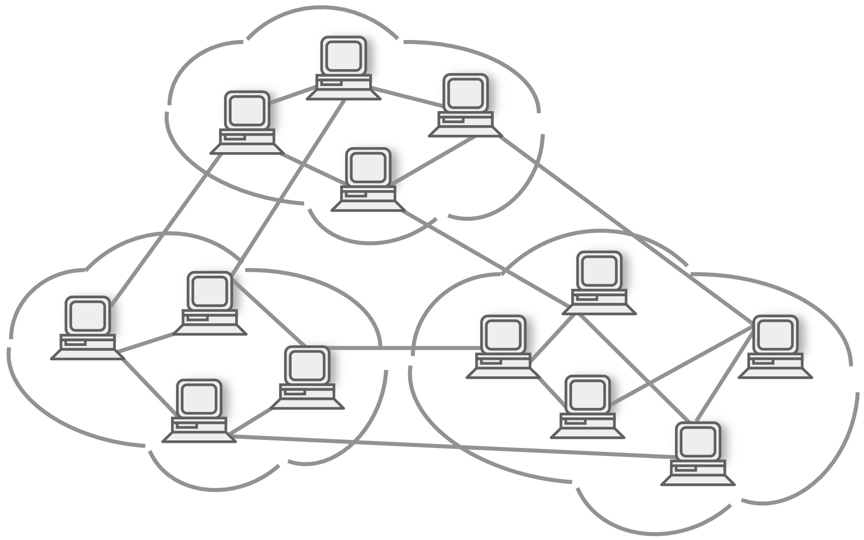
If there are less than 35 − *k* internal peers, the client is notified by the tracker to try again later.

The biased neighbour selection technique works well with the rarest first replication algorithm of BitTorrent; however, other piece selection algorithms, such as random selection, may not lead to optimal performance

BitTorrent: Effects of Network Topology

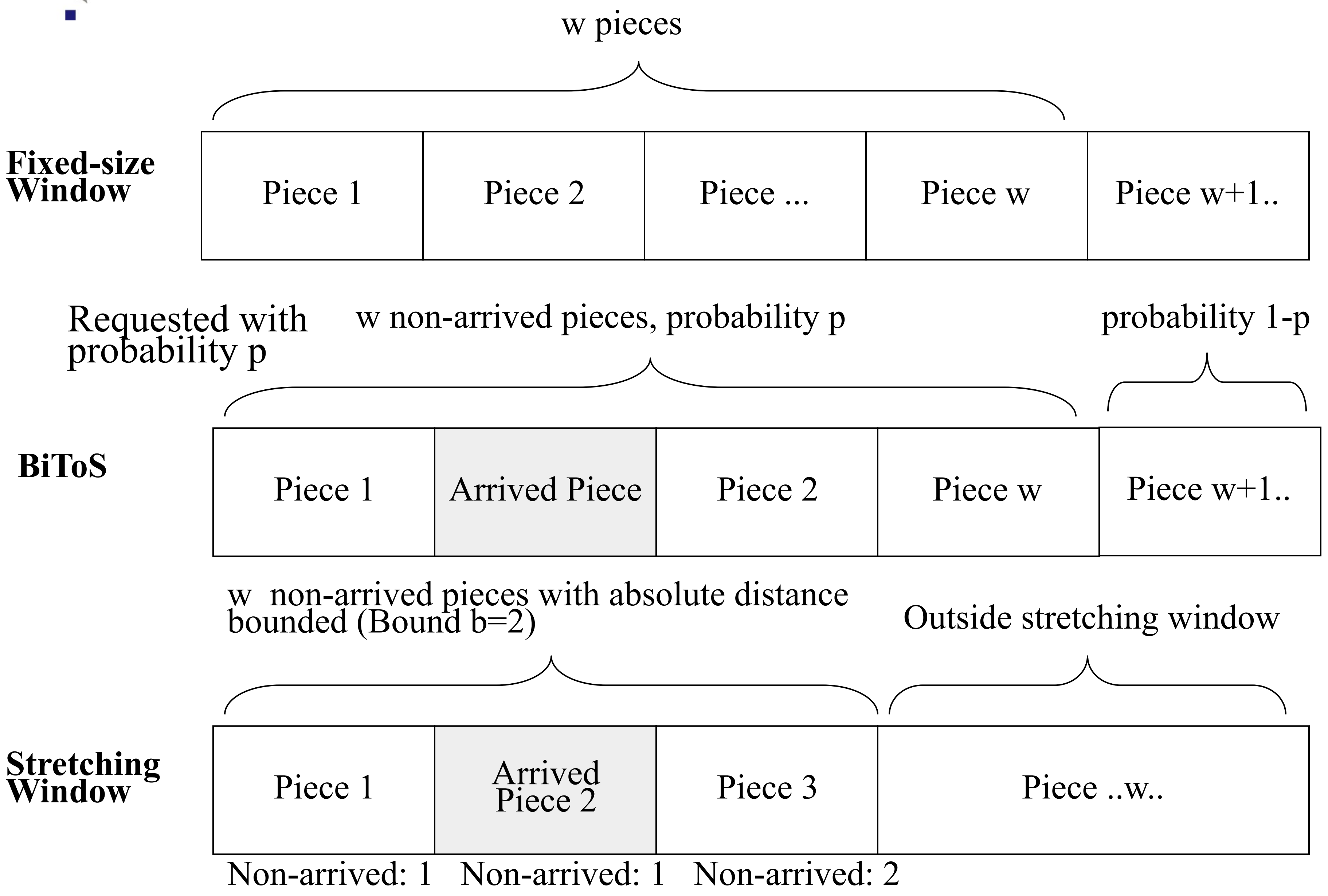


Uniform random neighbor selection

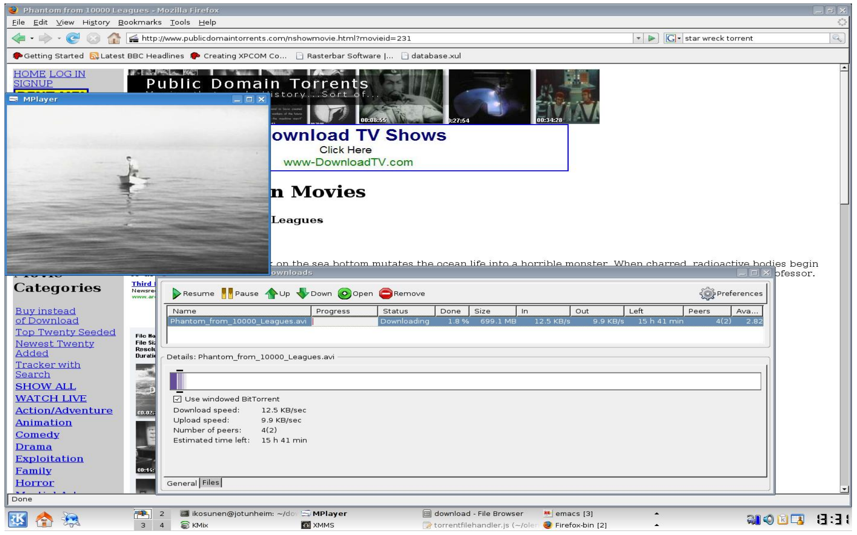


Biased neighbor selection

Video-on-Demand



VoD Examples



Phantom from 10000 Leagues - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.publicdomaintorrents.com/nshowmovie.html?movieid=231

star wreck torrent

Public Domain Torrents

ownload TV Shows
Click Here
www-DownloadTV.com

n Movies

Leagues

on the sea bottom mutates the ocean life into a horrible monster. When charred, radioactive bodies begin

ofessor.

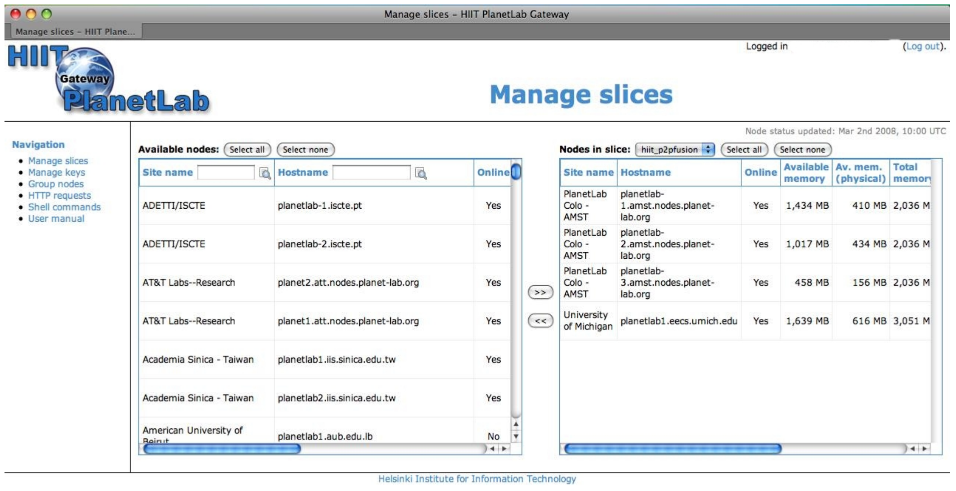
Categories

Buy instead of Download
Top Twenty Seeded
Newest Twenty Added
Tracker with Search
SHOW ALL
WATCH LIVE
Action/Adventure
Animation
Comedy
Drama
Exploitation
Family
Horror

```
Name                          Progress  Status       Done   Size      In         Out       Left          Peers  Ava...
Phantom_from_10000_Leagues.avi          Downloading  1.8 %  699.1 MB  12.5 KB/s  9.9 KB/s  15 h 41 min   4(2)   2.82
```

Details: Phantom_from_10000_Leagues.avi

```
Use windowed BitTorrent
Download speed:        12.5 KB/sec
Upload speed:          9.9 KB/sec
Number of peers:       4(2)
Estimated time left:   15 h 41 min
```



Manage slices – HIIT PlanetLab Gateway

HIIT Gateway PlanetLab

Logged in (Log out).

Manage slices

Node status updated: Mar 2nd 2008, 10:00 UTC

Navigation
- Manage slices
- Manage keys
- Group nodes
- HTTP requests
- Shell commands
- User manual

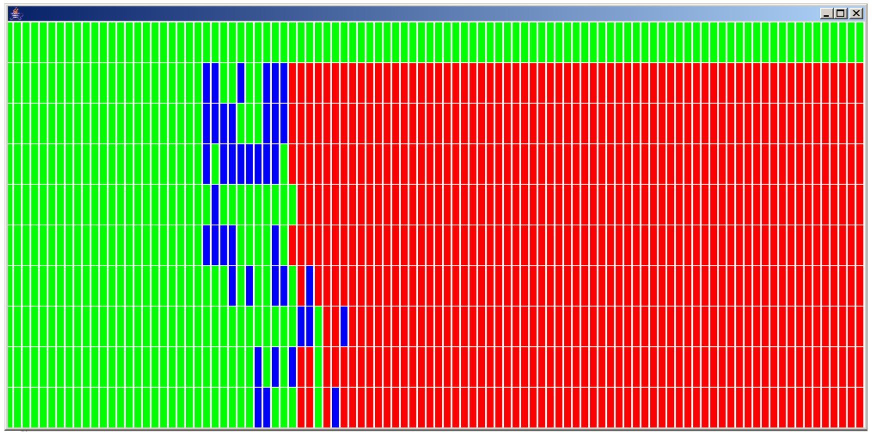
Available nodes:

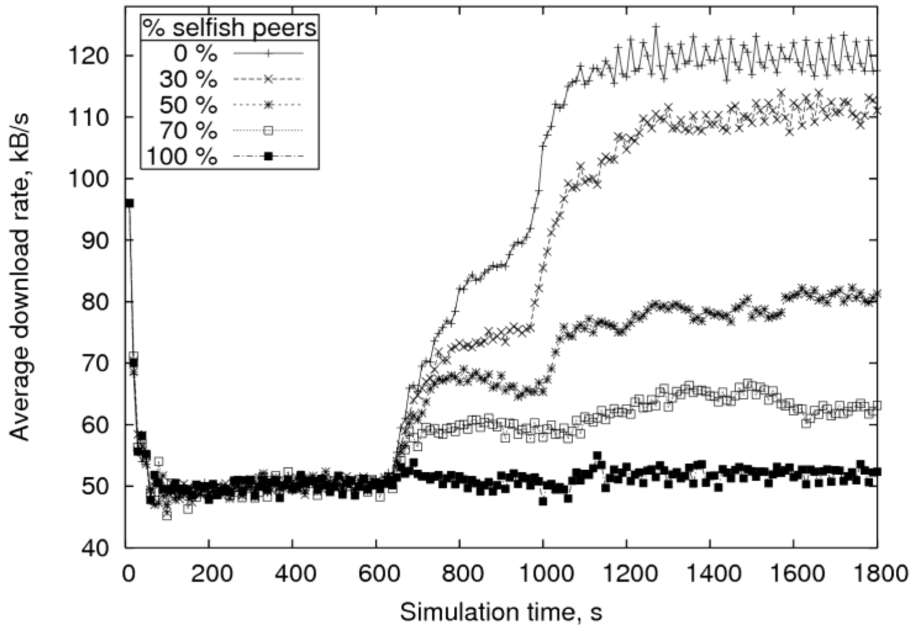
Site name	Hostname	Online
ADETTI/ISCTE	planetlab-1.iscte.pt	Yes
ADETTI/ISCTE	planetlab-2.iscte.pt	Yes
AT&T Labs--Research	planet2.att.nodes.planet-lab.org	Yes
AT&T Labs--Research	planet1.att.nodes.planet-lab.org	Yes
Academia Sinica - Taiwan	planetlab1.iis.sinica.edu.tw	Yes
Academia Sinica - Taiwan	planetlab2.iis.sinica.edu.tw	Yes
American University of Beirut	planetlab1.aub.edu.lb	No

Nodes in slice: hiit_p2pfusion

Site name	Hostname	Online	Available memory	Av. mem. (physical)	Total memory
PlanetLab Colo - AMST	planetlab-1.amst.nodes.planet-lab.org	Yes	1,434 MB	410 MB	2,036 M
PlanetLab Colo - AMST	planetlab-2.amst.nodes.planet-lab.org	Yes	1,017 MB	434 MB	2,036 M
PlanetLab Colo - AMST	planetlab-3.amst.nodes.planet-lab.org	Yes	458 MB	156 MB	2,036 M
University of Michigan	planetlab1.eecs.umich.edu	Yes	1,639 MB	616 MB	3,051 M

Helsinki Institute for Information Technology





Free-riding and tragedy of the commons

Users of P2P file sharing networks, such as Gnutella, face the question of whether or not to share resources to other peers in the community

They face essentially a social dilemma of balancing between common good and selfish goals

The selfish behaviour often encountered in P2P networks in which peers only download files and do not make resources available on the network is called *free-riding*

Free-riding occurs because the peers have no incentives for uploading files. Free-riding becomes a major problem when significant numbers of peers consume network resources while not contributing to the network. In the context of P2P this is often referred to as *tragedy of the digital commons*

Preventing free-riding

BitTorrent has several mechanisms

- Peer selection: tit-for-tat
- Optimistic unchoking
  - Two uses: find good peers and allow new peers to bootstrap

Other solutions have been proposed as well

BitTyrant (NSDI 2007)

Observation: BitTorrent peers are altruistic

Incentives do not build robustness

A selfish BitTorrent client

Optimize return-on-investment (upload)

- Dynamically set the upload rate to maximize download rate

Can boost download speed by 70%

Building BitTyrant

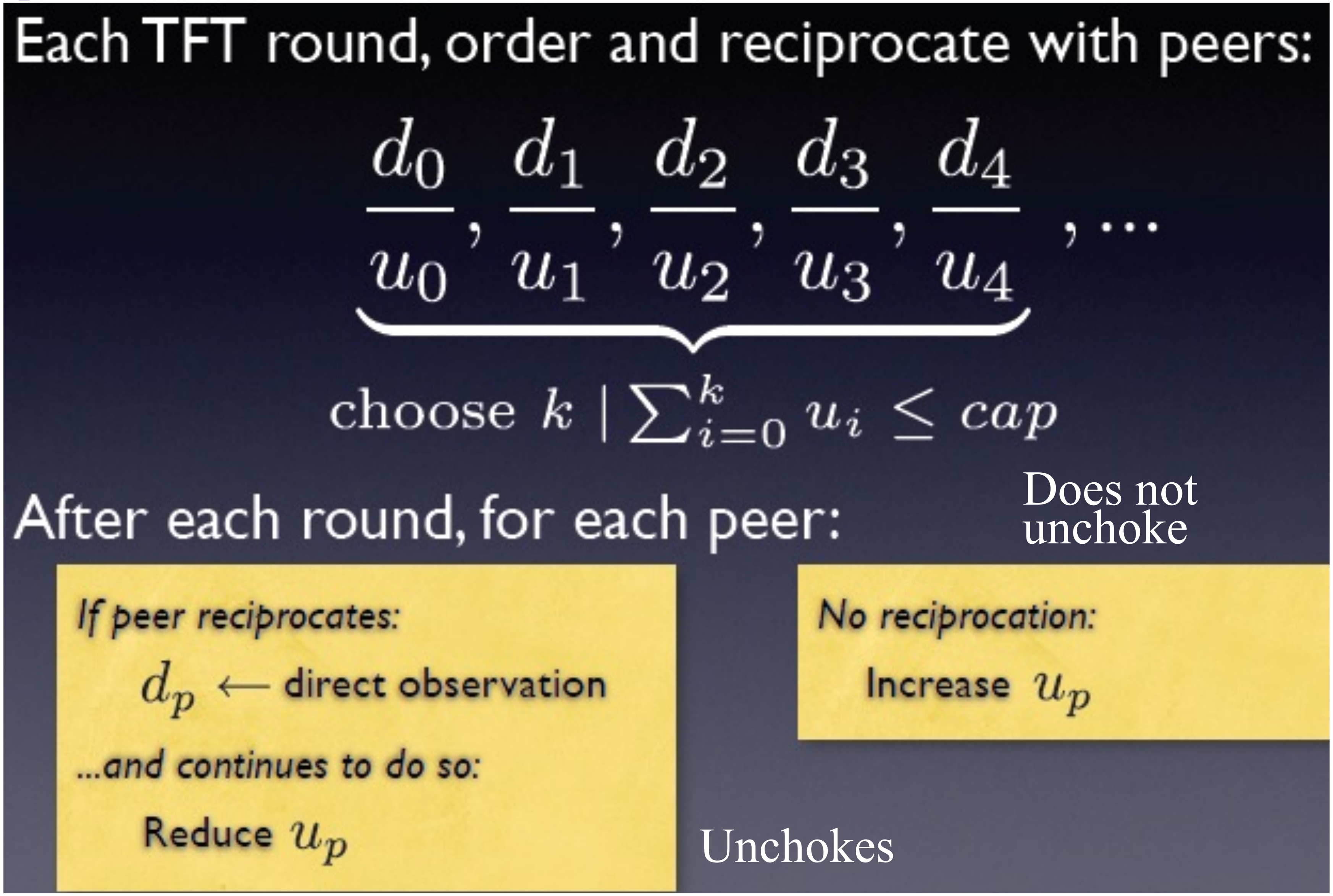
Key idea: maximize return on investment (RoI)
 strategic peer selection
 strategic upload rate allocation

Cost: upload rate to peer p, u_p
 Benefit: download rate from peer p, d_p

BitTyrant dynamically estimates these rates each tit-for-tat round

www.cs.utexas.edu/~yzhang/Teaching/cs386m-f10/Slides/3-2.**ppt**

Source: www.cs.utexas.edu/~yzhang/Teaching/cs386m-f10/Slides/3-2.**ppt**



Each TFT round, order and reciprocate with peers:

$$\underbrace{\frac{d_0}{u_0}, \frac{d_1}{u_1}, \frac{d_2}{u_2}, \frac{d_3}{u_3}, \frac{d_4}{u_4}}_{\text{choose } k \mid \sum_{i=0}^{k} u_i \leq cap}, \cdots$$

After each round, for each peer:

Does not unchoke

If peer reciprocates:

$d_p \leftarrow$ direct observation

...and continues to do so:

Reduce u_p

No reciprocation:

Increase u_p

Unchokes

Modelling and analysis

A solution to the broadcasting problem

BitTorrent attempts to solve the broadcasting problem, which has the goal of disseminating M messages in a population of N nodes in the shortest time

In an environment in which the nodes have bidirectional communications and the same bandwidth, the lower bound on download time (rounds) is given by $M + \log_2 N$, the unit is the time it takes for two nodes to exchange a message

This problem can be solved optimally with a centralized scheduler; however, BitTorrent lacks this centralized component and furthermore it does not have a completely connected graph as well

BitTorrent therefore has a heuristic approach to solving this problem that works very well in practice

Lower Bound

Assume bidirectional communications and the same bandwidth (can send to a different node than the one sending)

The lower bound on download time (rounds) is given by $M + \log_2 N$, the unit is the time it takes for two nodes to exchange a message

Proof: stat.haifa.ac.il/~gweiss/publications/p2pjos.pdf

Idea: in the first phase one client has the messages, and in the next phase $\log_2 N$ rounds are needed to inform the N-1 clients. The log comes from the P2P behaviour in which the clients utilize parallel data transfers to propagate the messages

Modelling BitTorrent

- BitTorrent performance has been analyzed in the literature using analytical models, including stochastic and fluid models, extensive simulation experiments, experiments on distributed testbeds (PlanetLab), and by obtaining traces from real clients
- Both analytical and empirical evaluation and estimation are needed to dimension deployments to meet the service capacity demands
  - Variance analysis
- Fluid models can be used to analytically estimate the protocol performance and understand the time evolution of the system by using differential equations
  - Do not give variance

Modelling aspects

- Dynamic population model
  - describing the evolution of the peer population in the P2P system
- Peer arrival process
  - steady arrival rate, smoothly attenuating arrival rate, or flash crowd?
- Efficiency of resource sharing
  - utilization of a peer's upload capacity
  - effect of the piece/peer selection policy
  - number of parallel connections
- Selfishness / altruism
  - part of peers are free-riders that do not want to share upload capacity
- Download and upload rates
  - homogeneous or heterogeneous peer population?
- Number of permanent seeds
  - correspond to servers in the client-server architecture

Key performance questions

Scalability

- Is the system really scalable?

Stability

- Is the system stable?
- If not, where is the stability limit for the load?

Performance

- When stable, is the performance sufficient?

Arrival processes

Various different arrival processes for new peers have been considered in the literature. The three key scenarios are as follows:

- The steady flow scenario used above assumes that new peers appear with a constant rate
- The flash crowd scenario, considers the case where a (large) number of peers appear at the same time after which no new peers arrive
- In a third scenario, the arrival rate is high in the beginning but smoothly attenuates as time passes

Stochastic vs deterministic modelling

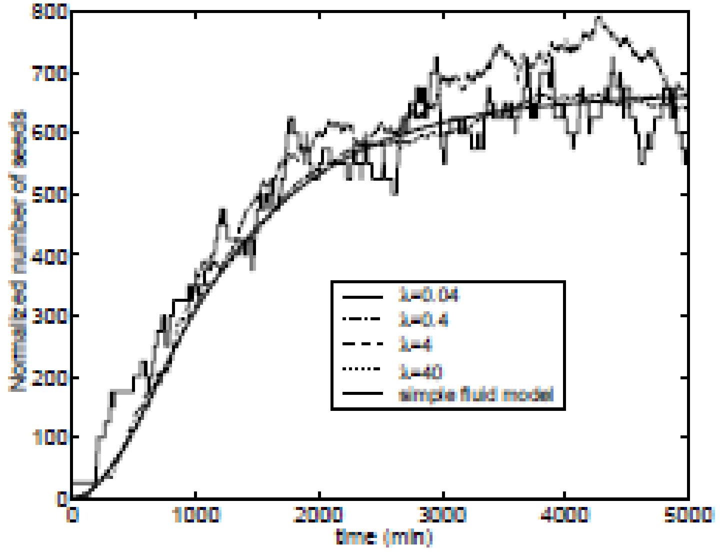


Figure 1: Experiment 1 : The evolution of the number of seeds as a function of time

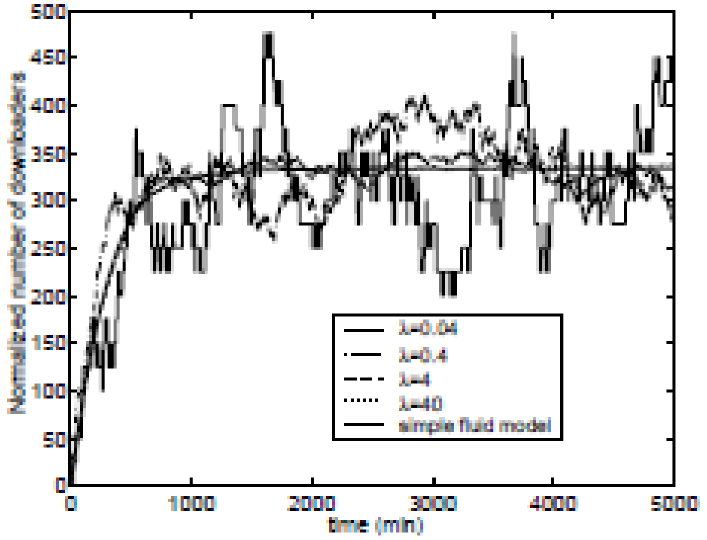


Figure 2: Experiment 1 : The evolution of the number of downloaders as a function of time

D. Qiu and R. Srikant. Modelling and performance analysis of BitTorrent like peer-to-peer networks. In ACM SIgcomm, pp. 367-378, 2004.

Model by Qiu and Srikant (2004):

Deterministic fluid model (= system of differential equations)
Describing the system dynamics related to sharing of a single file

$x(t)$ = (average) number of leechers at time t

$y(t)$ = (average) number of non-permanent seeds at time t

$$\begin{tikzcd} {} \arrow[r, "\lambda"] & x \arrow[r, "\phi(x,y)"] & y \arrow[r, "\gamma \cdot y"] & {} \end{tikzcd}$$

Sources:
D. Qiu and R. Srikant. Modelling and performance analysis of BitTorrent like peer-to-peer networks. In ACM SIgcomm, pp. 367-378, 2004.
http://www.netlab.tkk.fi/~samuli/Presentations/Workshops/P2PVoD.pdf

Assumptions

Steady arrival process described by

– arrival rate λ to transfer phase (arrivals per time unit)

- Efficiency described by

  – upload utilization ratio η (belonging to (0,1])

- Selfishness described by

  – departure rate γ from service phase (departures per time unit)

- Homogeneous peer population with

– download rate *c* (file transfers per time unit) and

– upload rate μ (file transfers per time unit)

- No permanent seeds

$$\begin{tikzcd} {} \arrow[r, "\lambda"] & x \arrow[r, "\phi(x,y)"] & y \arrow[r, "\gamma\cdot y"] & {} \end{tikzcd}$$

Fluid Model

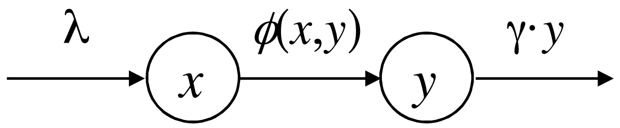
- Switched nonlinear system:

$$\begin{cases} x'(t) = \lambda - \phi(t), \\ y'(t) = \phi(t) - \gamma y(t), \end{cases} \tag{1}$$

- Aggregate service rate:

$$\phi(t) = \min\{cx(t), \mu(\eta x(t) + y(t))\}. \tag{2}$$

Solve the equilibrium of the system by setting $x'(t) = y'(t) = 0$ in (1)



Analysis of Fluid Model

Analysis of two cases

- Upload constrained
- Download constrained

System scalable in the whole parameter space (η>0)

System is stable for any λ > 0

Performance

- Little's law gives the mean transfer time for a file

$$T = \frac{\bar{x}}{\lambda} = \max\{\frac{1}{c}, \frac{1}{\eta}\left(\frac{1}{\mu} - \frac{1}{\gamma}\right)\} \leq \max\{\frac{1}{c}, \frac{1}{\eta\mu}\} \approx \max\{\frac{1}{c}, \frac{1}{\mu}\}.$$

No problems if reasonable download/upload rates compared to file size

Comparison of simulators

- Overview presentation
  - http://www.ietf.org/proceedings/65/slides/P2PRG-1.pdf
- Fine-grained or coarse-grained
  - Packet level vs overlay network
- Important features
  - Wide-area support
  - Level of detail
  - Distributed simulation
  - Network topology

Simulation Tools

- Ns2 and ns3
  - Network simulation, established system
  - Not many P2P systems (Gnutella)
- Omnet++ (http://www.omnetpp.org)
  - Network simulation, distributed simulation
- P2PSim (http://pdos.csail.mit.edu/p2psim)
  - Event Simulator, multi-threaded
  - Many algorithms Chord, Tapestry, Kademlia,…
- PlanetSim (http://ants.etse.urv.es/planetsim)
  - Partitions simulations into overlay networks
  - Chord and Symphony simulations exists
  - Scalability to 100 000 nodes
- PeerSim (http://peersim.sourceforge.net)
  - Various topologies and algorithms
  - Pastry, Chord, Kademlia, Skipnet, BitTorrent
  - Up to one million nodes without transport level details

	BitTorrent
Decentralization	Centralized model
Foundation	Tracker
Routing function	Tracker
Routing performance	Guarantee to locate data, good performance for popular data
Routing state	Constant, choking may occur
Reliability	Tracker keeps track of the peers and pieces