BitTorrent

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Overview

- **BitTorrent terms**
- The BitTorrent protocol
- The life of a torrent
- Attacking BitTorrent

BitTorrent terms

- **The BitTorrent protocol operates with these important terms:**
  - Tracker: a centralised component used for peer discovery.
  - Seeds: peers that have fully downloaded the file being shared.
  - Leechers: peers that are actively downloading the file.
  - Swarm: the collection of peers participating in sharing the torrent data.
  - .torrent file: a meta data file containing information about the torrent.

Tracker

- **The tracker is the only centralised component in BitTorrent.**
- **It is used to bootstrap the system by providing peer discovery.**
  - The tracker thus does no heavy lifting at all. It is never involved in transferring any of the data that is shared in the torrents it provides access to.
    - . . . which is probably also why varying tracker sites have claimed to be innocent when faced with infringement suits ;-)
  - Peer selection is done completely at random—there is no weighing of peers or peer capabilities.

Seeders

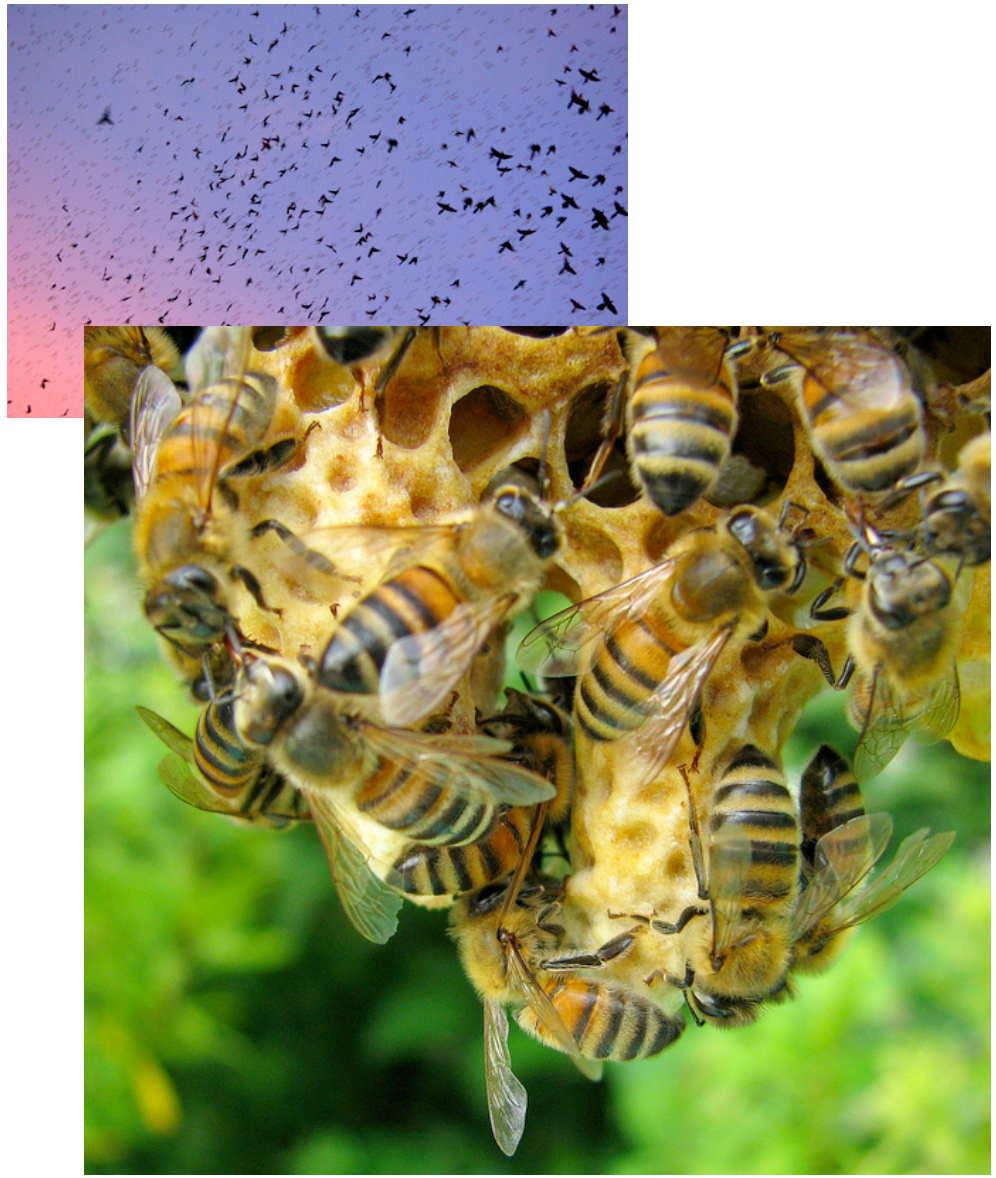
- **A seeder is a peer that has the entire file being served.**
- **Initially, when a torrent is initiated, a single seeder connects to the tracker to make its content available.**
- **While the torrent swarm is active, peers will change from leechers to seeders when they finish downloading the torrent.**
  - Which also means that it is good practice to leave the BitTorrent client on for a while after downloading finishes, so that you get to contribute to the swarm.

Leechers

- **A leecher is a peer that is actively downloading the torrent.**
- **Being a leecher does not mean that the peer contributes nothing to the swarm.**
  - All leechers must serve the pieces that they have already finished to the swarm.

Swarm

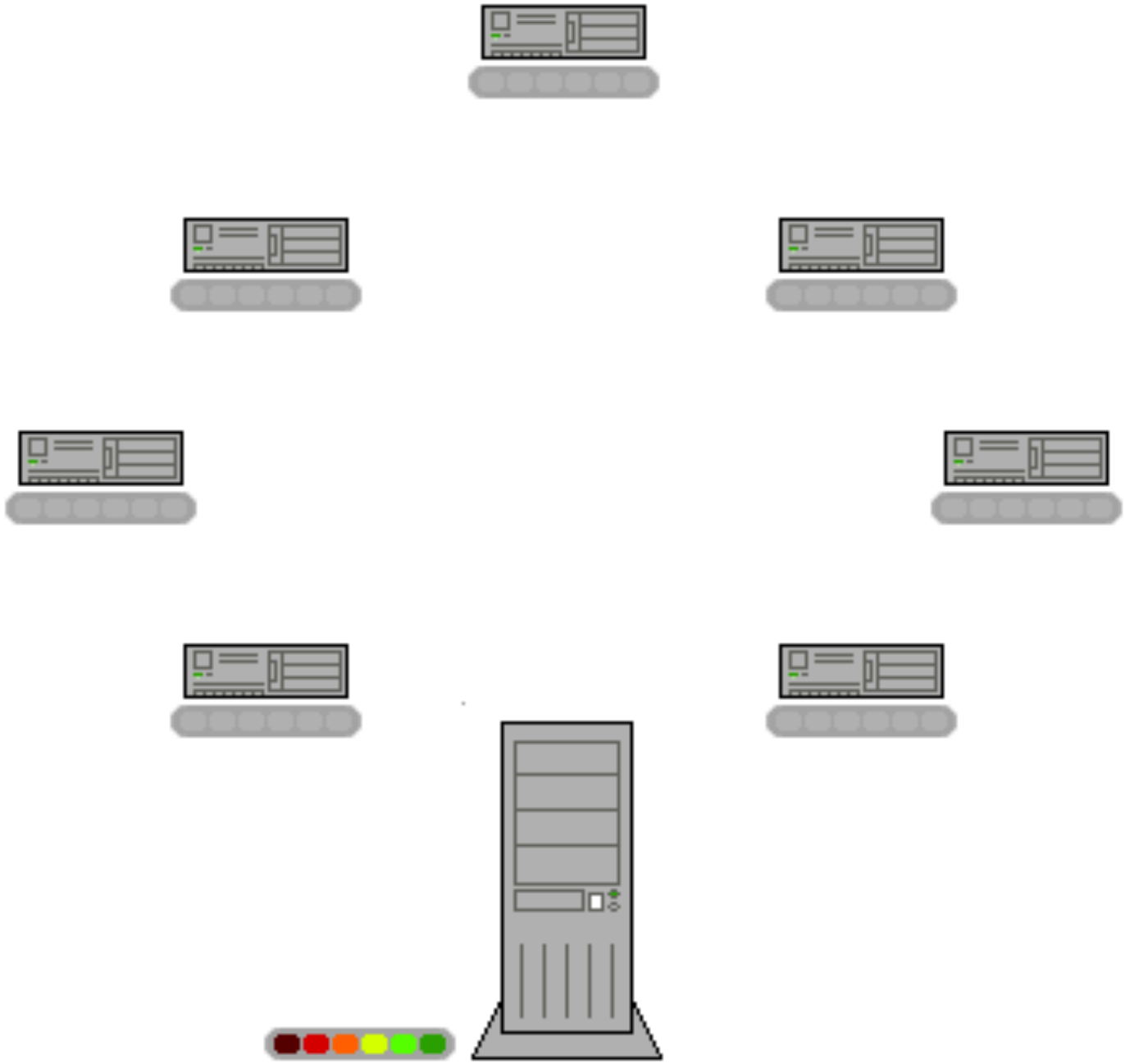
- **The swarm is all of the peers currently participating in the torrent**
  - The swarm may be huge, so most peers only deal with a small subset of the swarm—their personal *peer set*.



.torrent files

- **The .torrent file describes a given torrent.**
- **It contains information about the tracker(s) coordinating the torrent, as well as some meta information about the file being shared.**
- **The .torrent file is distributed "offline" (i.e., outside of the BitTorrent system).**
  - Typically it is hosted on a webpage (or send around to peers in an email).

A BitTorrent animation



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The BitTorrent protocol

- **In the following I will explain the basics of the BitTorrent protocol.**
  - For a more in-depth introduction to the nitty gritty details see
    - http://bittorrent.org/beps/bep_0003.html
    - http://wiki.theory.org/BitTorrentSpecification

The contents of a .torrent file

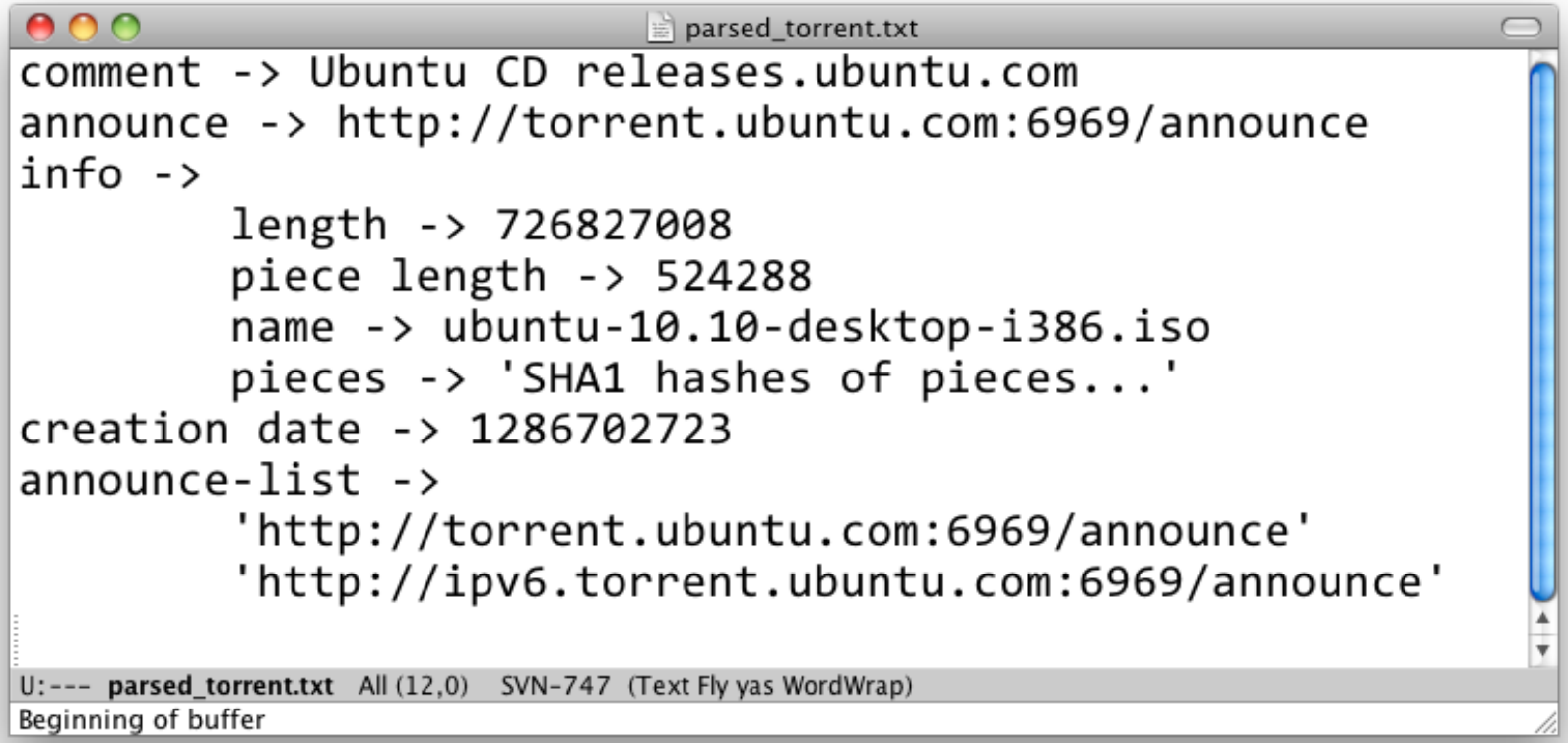
- **When a peer wishes to download a file, it retrieves the .torrent file.**
- **A .torrent file is a *bencoded* Python dictionary containing (at least) the keys `announce` and `info`.**
  - **`announce`** is the URL of the tracker.
  - Where `info` is another dict containing the following keys:
    - **`name`**: the suggested file (or directory) name of the shared file.
    - **`piece length`**: the length in bytes of the individual pieces.
    - **`pieces`**: one big string containing the SHA1 hashes of all pieces.
    - **`length`**: the total length of the file being shared.

Sharing directories

- It is also possible to share an entire directory using BitTorrent.
- In this case the `length` field is exchanged for a files field containing a list of files with information about the length and path of each file.
- For the purposes of the other keys, the multi-file case is treated as only having a single file by concatenating the files in the order they appear in the files list.

An example .torrent file

- **This .torrent was retrieved from Ubuntu's homepage. It has been parsed—the native format is** bencoded**.**



Working with the tracker

- **After retrieving the .torrent file, the peer contacts the tracker listed in that file.**
- **The tracker responds by returning a list of (~50) randomly chosen peers in the swarm.**
- **After that point in time the tracker is only rarely contacted:**
  - Once every 30 minutes to show that the peer is active,
  - if running low on peers in the peer set,
  - and when leaving the swarm.

The peer protocol

- After receiving a list of ~50 peers, the new peer proceeds to establish a TCP connection to ~30 of these peers.
- The peer thus enters into a neighbourhood of peers and starts adhering to the *peer protocol*.

Spreading information about available pieces

- **Initially, when a peer enters a new neighbourhood of the swarm (i.e., when it gets new neighbours) it sends a bitfield message to the new neighbours.**
  - The bitfield message contains a space efficient representation of the pieces that the peer holds (a bitmap)
    - If the peer has the piece at index x the x'th bit is set to one
    - … and if it hasn't got it the bit is set to zero
- **When a peer finished downloading a piece (and the SHA1 sum matches) it sends a have message to all its neighbours, telling them that the new piece has been fetched.**

Downloading

- **Peers may then start downloading pieces from each other.**
  - They know which peers have got pieces that they are interested in…
- **But peers are not allowed to download pieces willy nilly. BitTorrent is a tit-for-tat protocol, meaning that you have to give in order to receive.**
- **Once a peer is allowed to fetch a given piece is does so by sending the `piece` message with the index of the piece as an argument.**

Downloading

- **Each peer in a peer's neighbour list has two state bits:**
  - **interested/uninterested:** this bit tells us whether the neighbour is interested in the pieces we have got.
  - **choked/unchoked:** this bit states whether we are currently choking the neighbour.
- **Choking a peer means disallowing it to download pieces at this point in time.**
- **Peers send `choke`, `unchoke`, `interested`, and `not interested` messages to each other in the peer protocol.**

Choking

- **Choking works on a tit-for-tat basis:**
  - If we are currently downloading from a peer, we will unchoke that peer so that it may also download from us.
    - This means, that when selecting a peer to download from, we should prefer peers that are interested in us.
  - If a peer does not contribute (i.e., we are not able to download from it) we can choke it again.
- **Optimistic unchoke:**
  - One or more peers will be optimistically unchoked at all time. This role rotates every 30 seconds.
  - If an optimistically unchoked peer start contributing, it may stay unchoked.

Choking

- **Choked/unchoked state of neighbours is reconsidered every 10 seconds.**
- **At any point in time a peer should have a number of unchoked neighbours.**
  - This is of course implementation specific. . .
    - Some implementations have a static value of 4, whereas others use the square root of the upload capacity in KB/s
- **Replacing contributing peers**
  - If an optimistic unchoke results in a peer that is performing better (yielding faster download rates), one of the currently unchoked peers will be replaced.

Choking and seeders

- **When seeding tit-for-tat stops making sense**
- **A seeder works for the general good of the swarm**
  - It wants to upload as much as possible to the swarm.
  - It thus prefers to unchoke peers to which it has a **high upload rate**.

Piece distribution

- **Piece selection strategies are in use in BitTorrent to ensure that the swarm stays alive.**
- **A client may choose to simply select pieces at *random***
  - This means, that the different peers will (with high probability) possess different pieces of the file, meaning that they have something to contribute to the swarm
- **Another selection strategy is the *rarest first* strategy**
  - In this strategy peers request the pieces that are least distributed within their peer set.
  - This decreases the likelihood of the the torrent "breaking" when a peer leaves.
    - . . . no peers will be holding "the only copy" of a piece for very long.

Rarest first

- **Initially, a peer will request a randomly chosen piece.**
  - This is done in order to get started—the rarest pieces will be slightly harder to get at, since many peers are interested in them.
- **Then it will start adhering to the *rarest first* strategy:**
  - By looking at its bitfields it will calculate a set of the *n* rarest pieces and at random choose some pieces to download from that set.
    - This randomisation is done to balance the load so that all peers do not jump on the same least common piece.
- **In the end, when the peer only misses a few pieces, it may start downloading all of them in parallel.**
  - It is even allowed to download the same piece from two sources, but it is good form to notify the slowest of the two when download has succeeded from another source.

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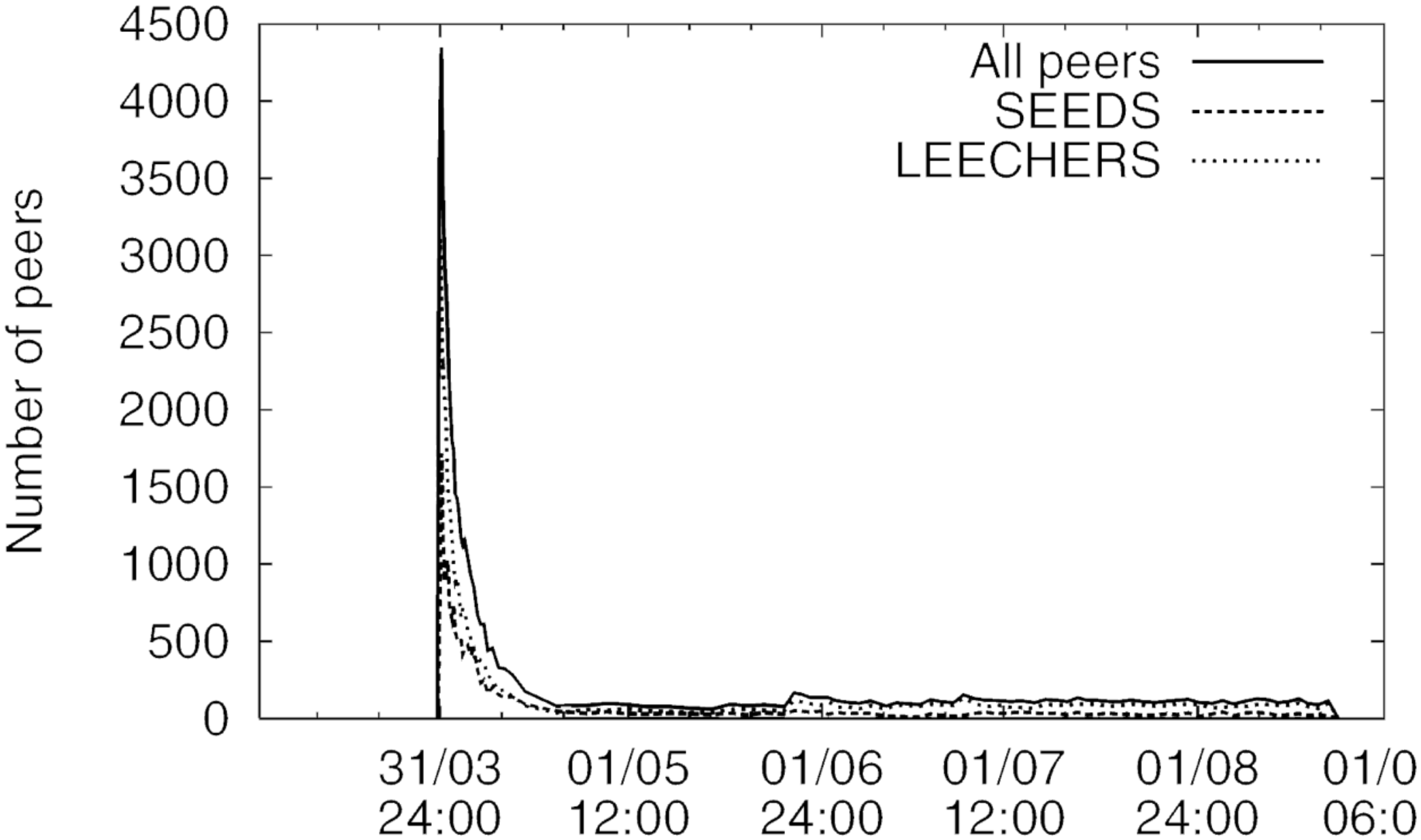
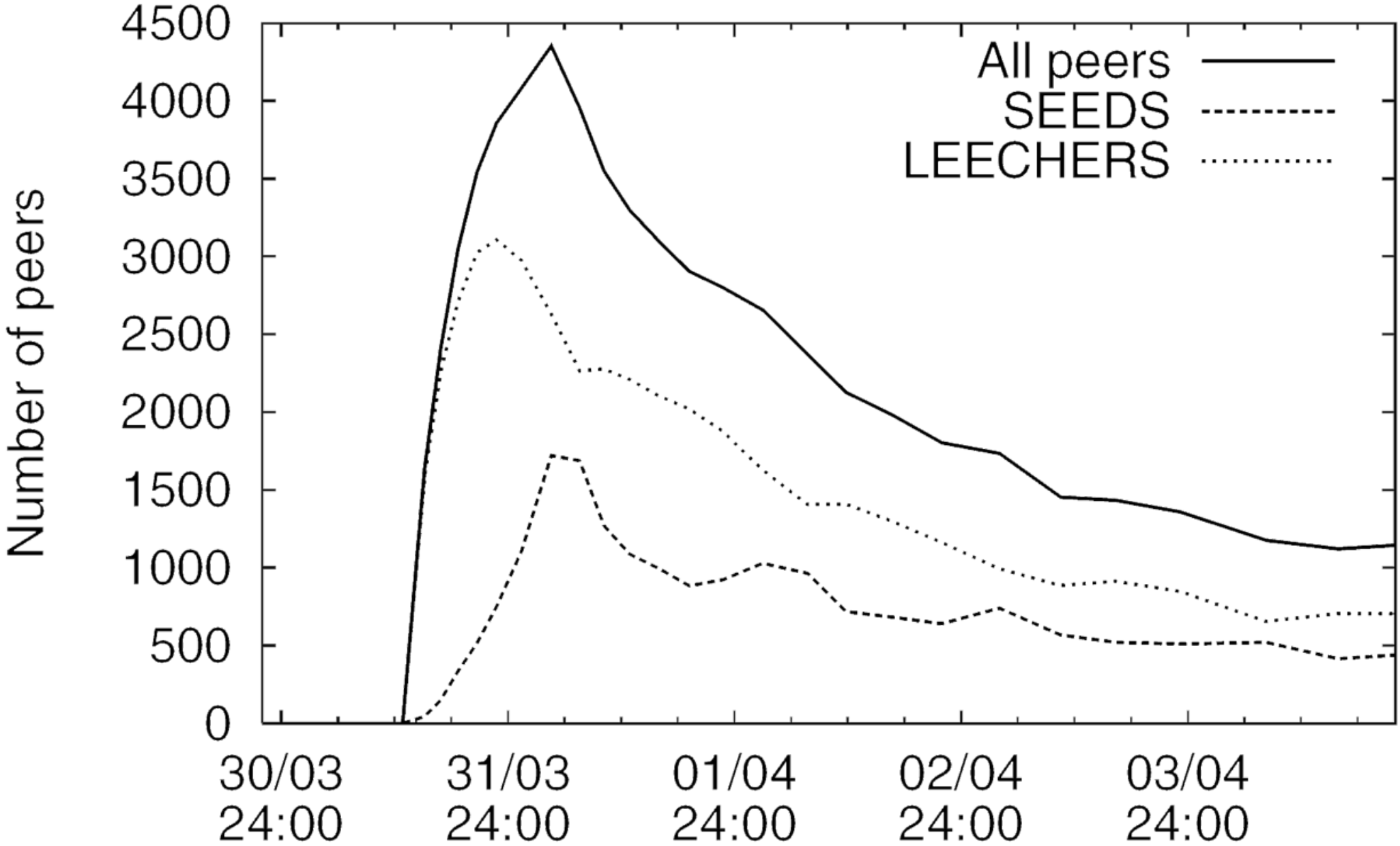
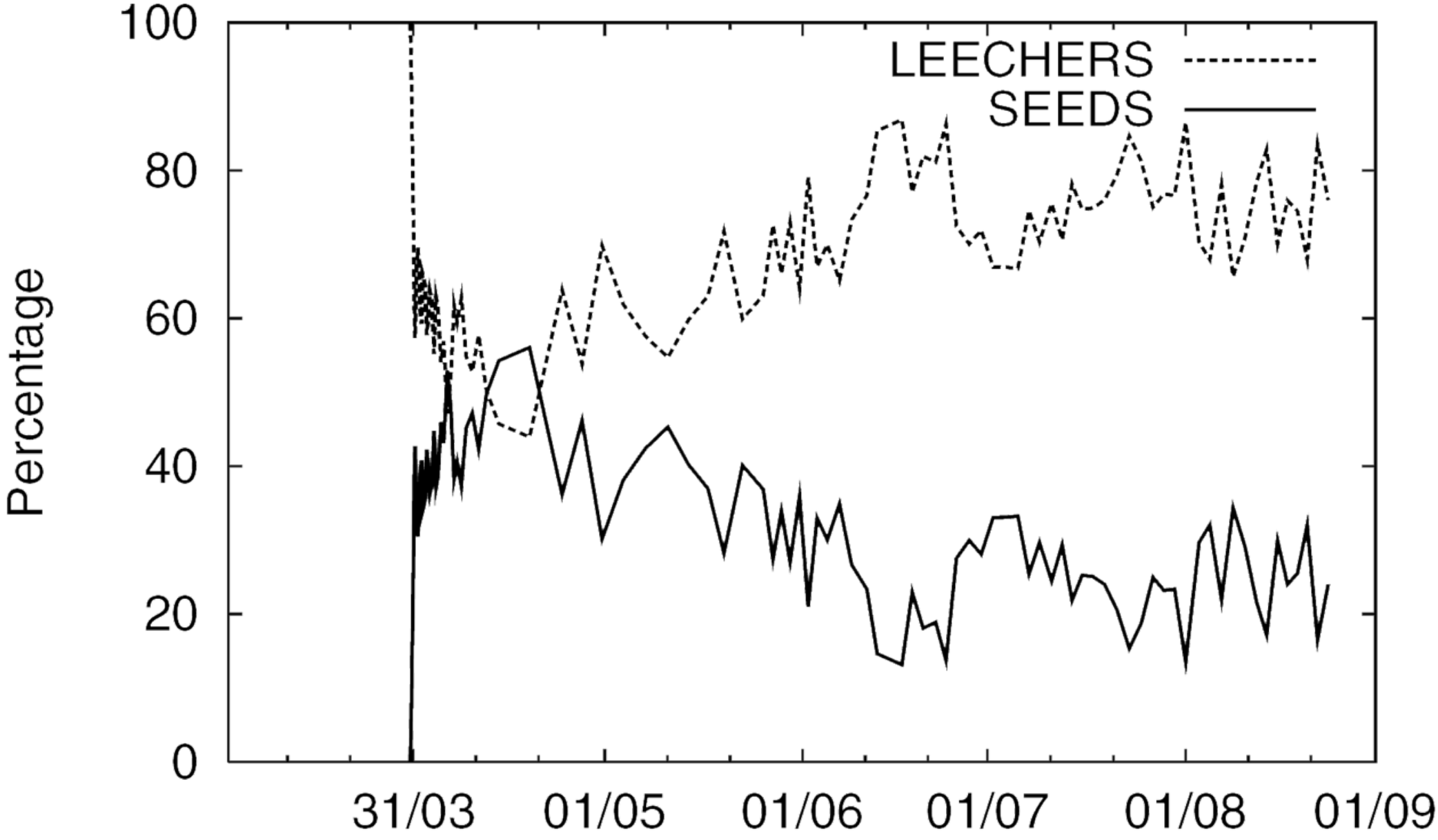
The life of a (legal) torrent



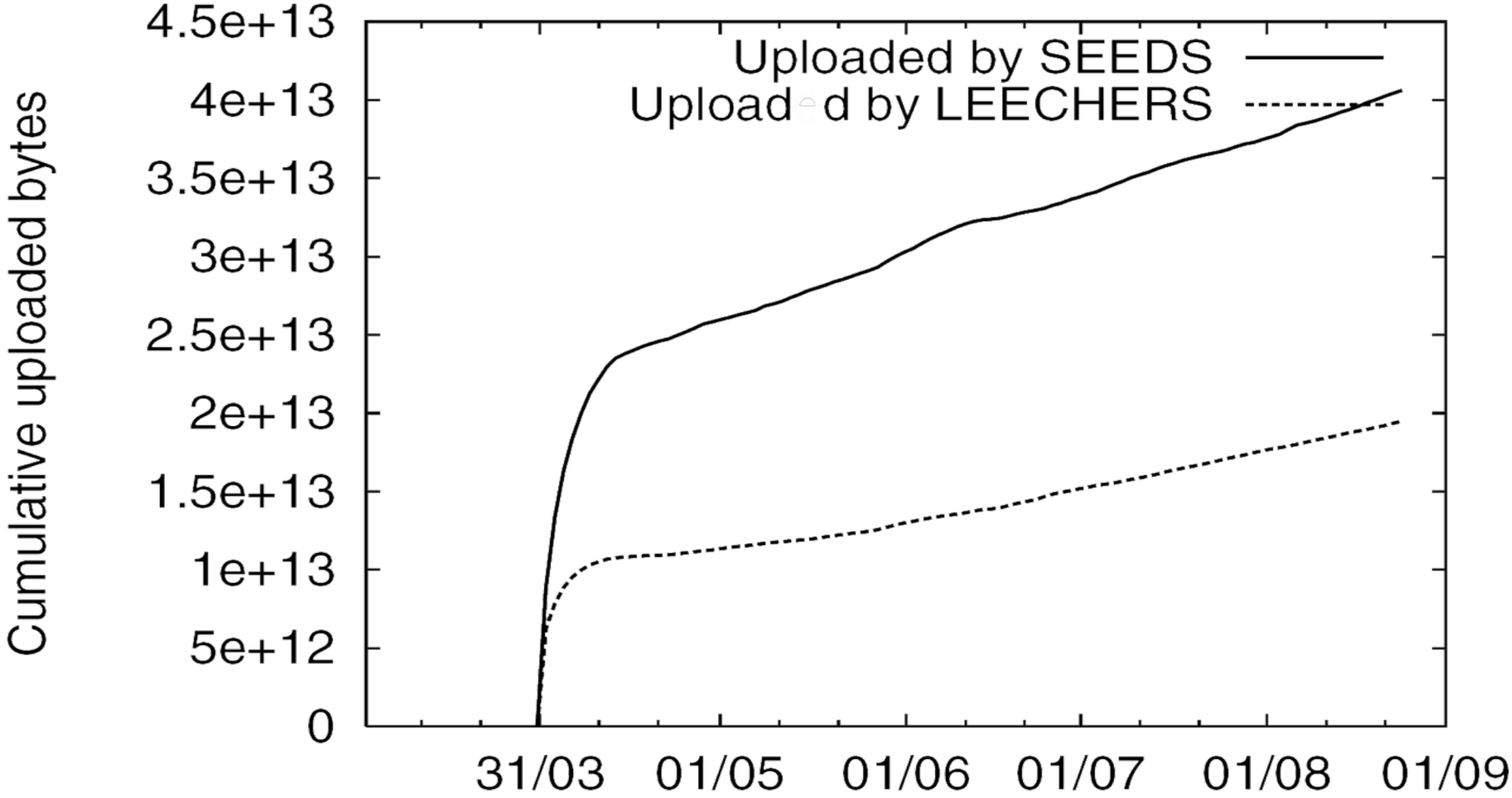
The first few days



Seeders vs. leechers



Contributions by seeders and leechers



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Collaboration?

- **BitTorrent is great for collaborating peers.**
  - But can the protocol be subverted by malicious peers?
- **An "attack" on a BitTorrent may take on two forms:**
  - Harming the swarm; i.e., making it difficult for other peers to download the file.
  - Taking advantage of the swarm; i.e., (mis)using the protocol to ones own advantage.

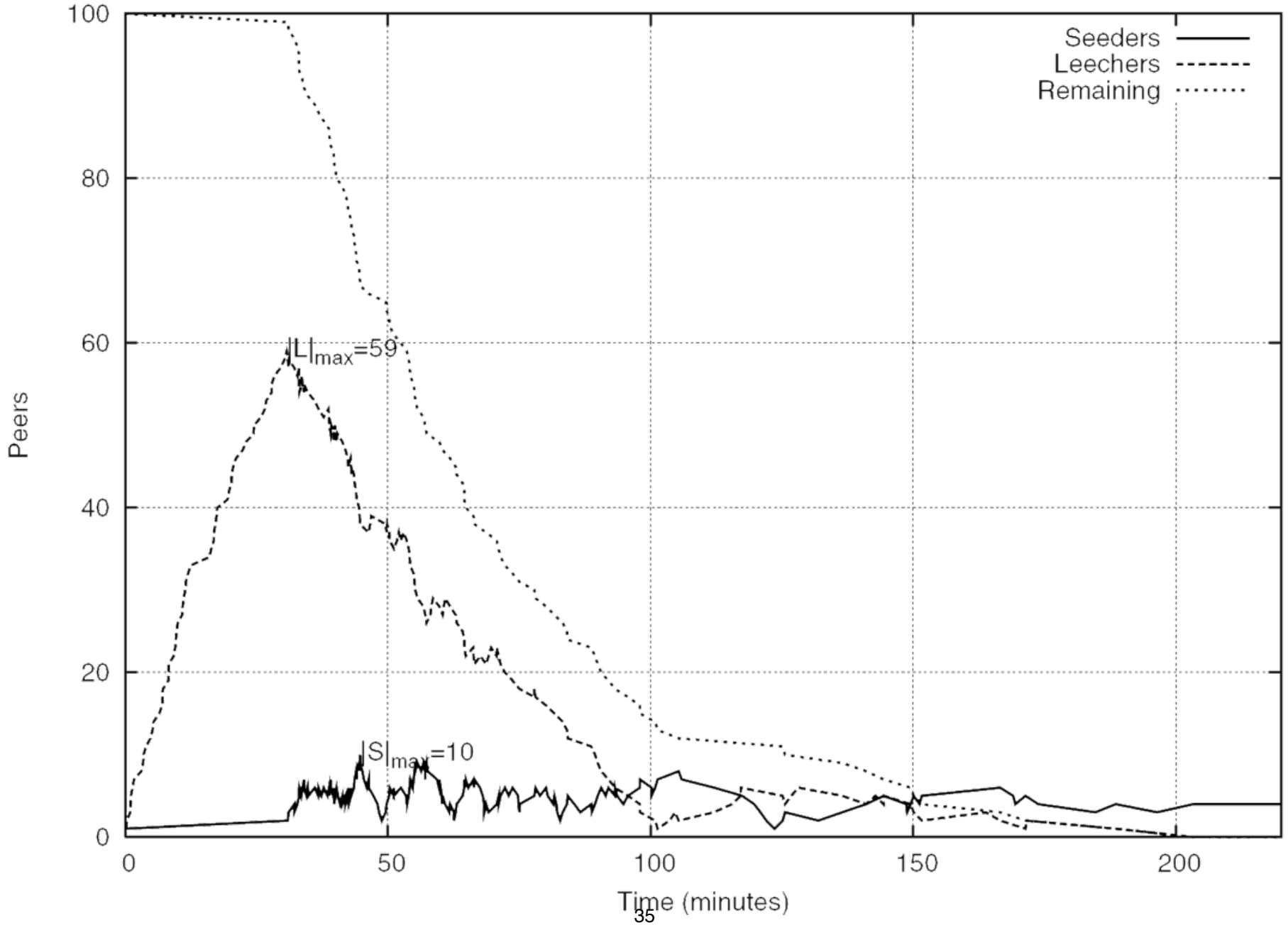
Harming the swarm

- **"Attacking a Swarm with a Band of Liars: evaluating the impact of attacks on BitTorrent" explores methods to poison a swarm.**
  - . . . and provide an excellent overview and analysis of BitTorrent.
- **They mention two Sybil attacks on BitTorrent:**
  - Piece lying
  - Eclipse attacks

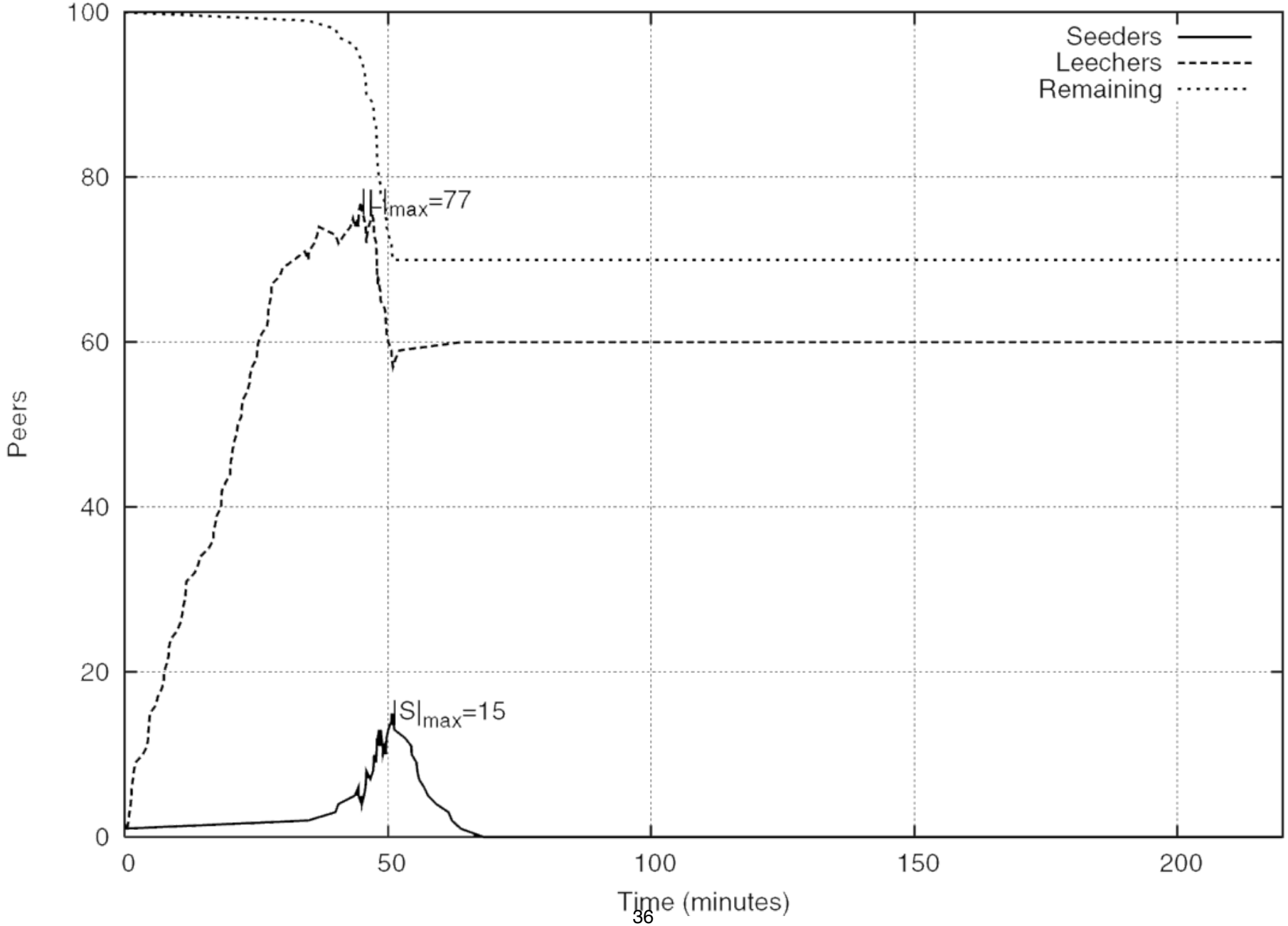
Piece lying

- **A Sybil attack on a P2P network is an attack using multiple, pseudonymous peers (Sybils)**
  - This could be multiple peers spawned on the same physical machine.
- **In the piece lying attack the attacker(s) take advantage of the *rarest first* piece selection scheme.**
  - The attackers work in collusion lying about a set of pieces.
  - By having a large number of peers that claim to hold that set of pieces, the rare pieces *appear* common, and thus nobody specifically requests them
    - If a peer should request nonetheless randomly request one of the pieces, the lying peers will simply **choke** the requesting peer.
- **Once the last true seed has left, the swarm has *failed***

A honest swarm



A swarm with piece lying (25 liars)



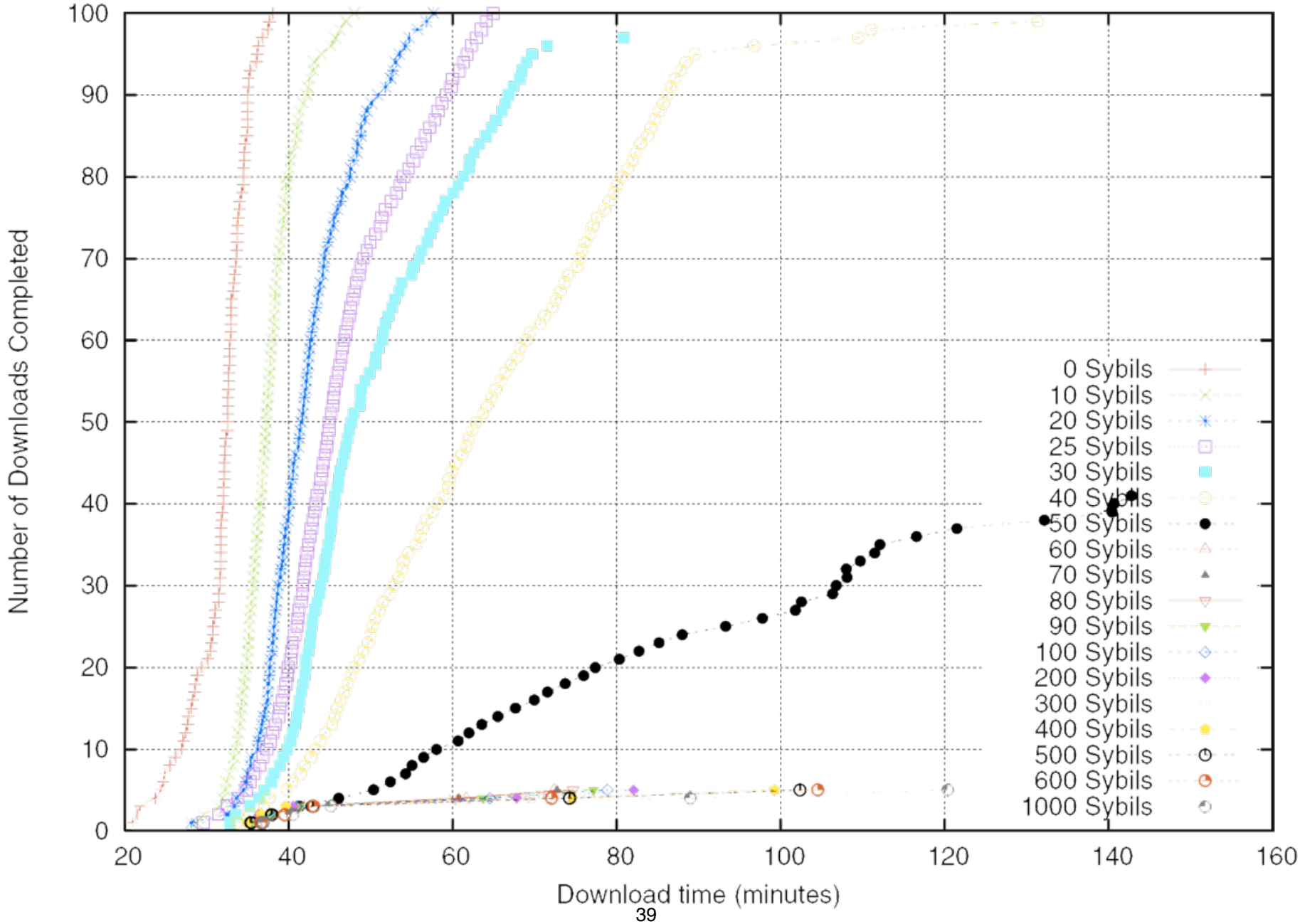
Effectiveness of piece lying

- **As the evaluation (the previous two graphs) show, piece lying can be detrimental to swarm health.**
- **The effectiveness is tied to**
  - 1) the number of sybils in the attack
  - 2) the size of the swarm
  - 3) peer behaviour—if e.g., all peers keep seeding for a long time, the attack will be less effective.

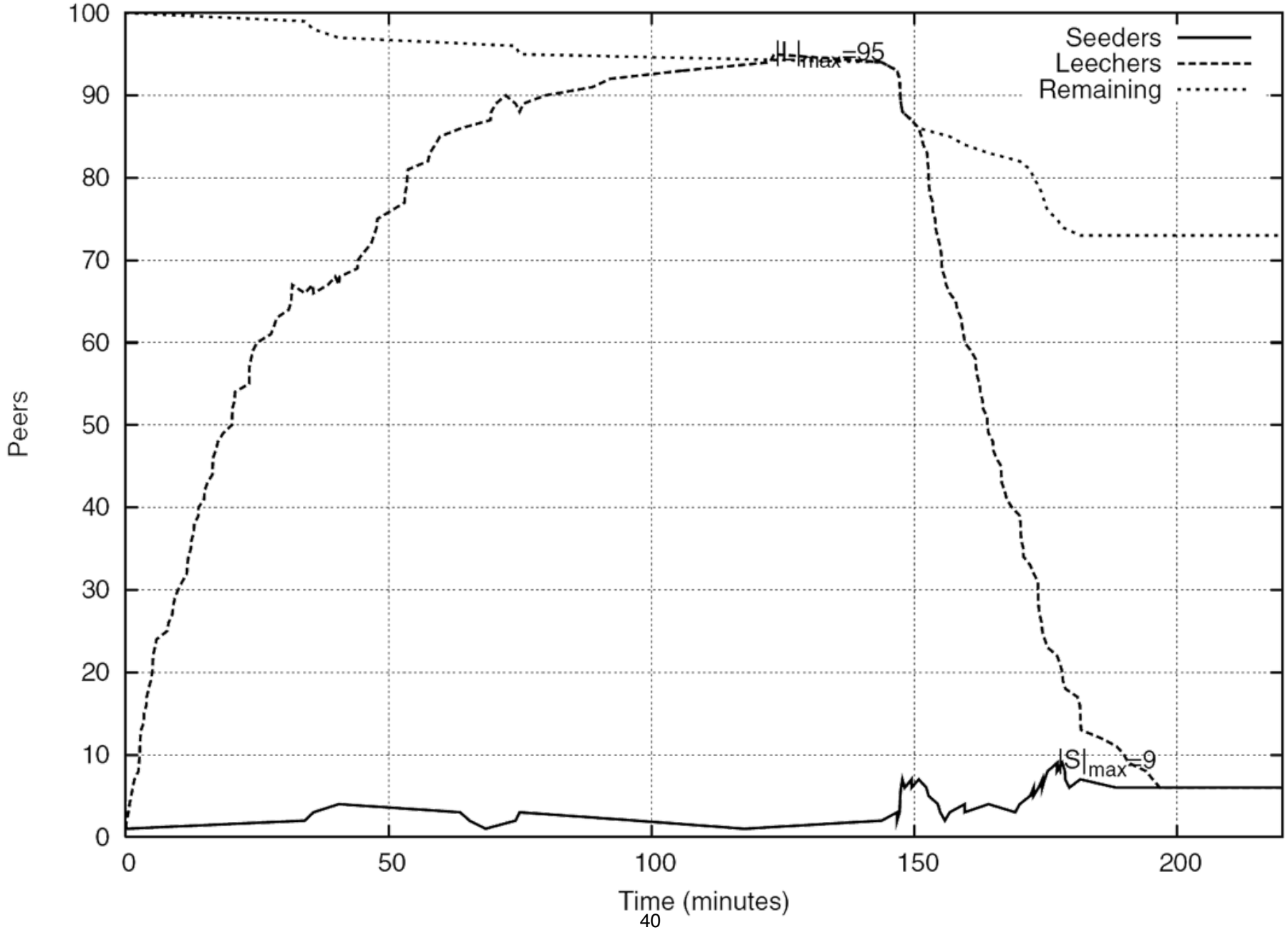
Eclipsing correct peers

- **The idea behind an eclipse attack is to eclipse the regular peers by making sure that they only (or at least to a very high degree) connect to malicious peers.**
- **In BitTorrent, this is done by adding a large number of malicious peers to the swarm.**
  - These peers will try to connect to as many peers as possible to spread their influence in the network.
  - When a correct peer connects to a malicious peer the malicious peer will notify other malicious peers of this.
    - … these will then try to connect to the correct peer also.

How many peers do you need to poison the swarm?



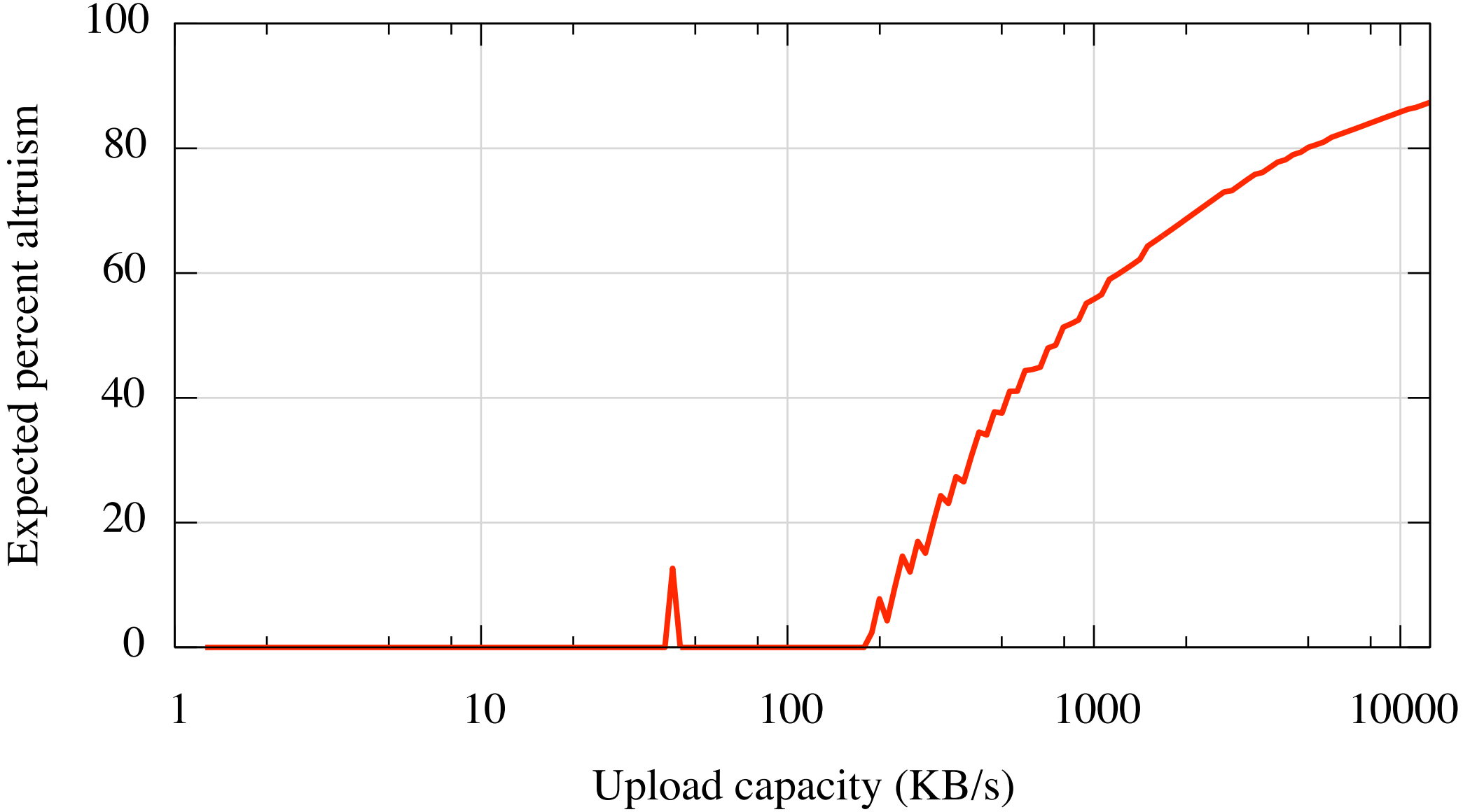
Peer eclipsing (50 sybils)



Taking advantage of the swarm

- **What if an attacker's intension is selfishness?**
  - The aim of such attacks is increasing one's own benefits,
  - and not as such to harm the swarm—but of course the swarm is hurt in the process, when some peers start to "free ride" the system.
- **BitTorrent has an incentive mechanism (tit-for-tat) that *should* provide incentive to contribute, but this can be circumvented.**
- **The BitTyrant system is an example of a *strategic* client that takes advantage of the BitTorrent protocol**
  - insight: you want to do the **minimal needed to stay unchoked**

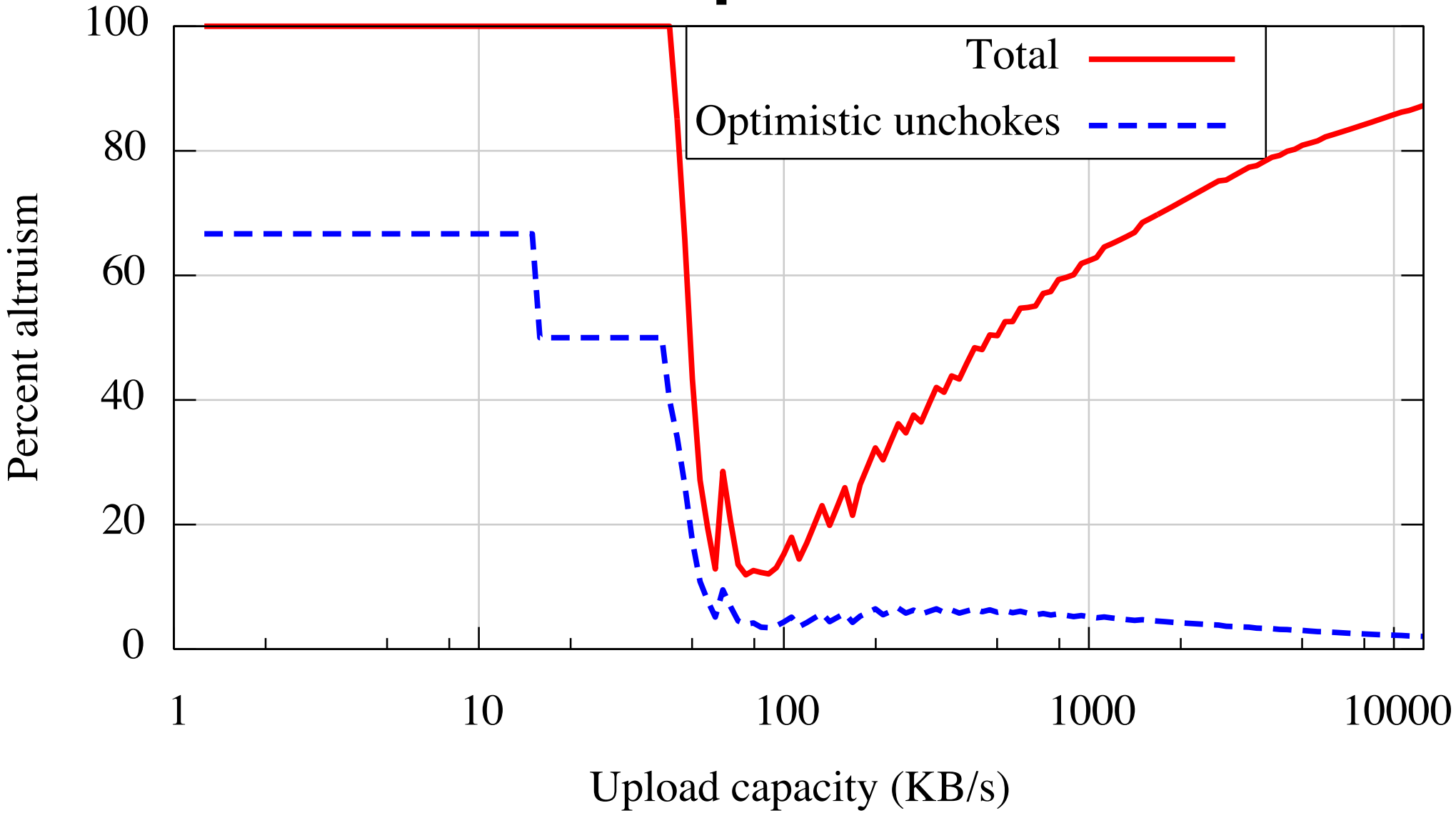
Some observations about upload/download bandwidth



Altruistic upload as a function of rate

The powerful peers donate a large part of their bandwidth

Some observations about upload/download bandwidth



Altruism when defined as upload capacity not resulting in direct reciprocation. The strong peers contribute more than they get.

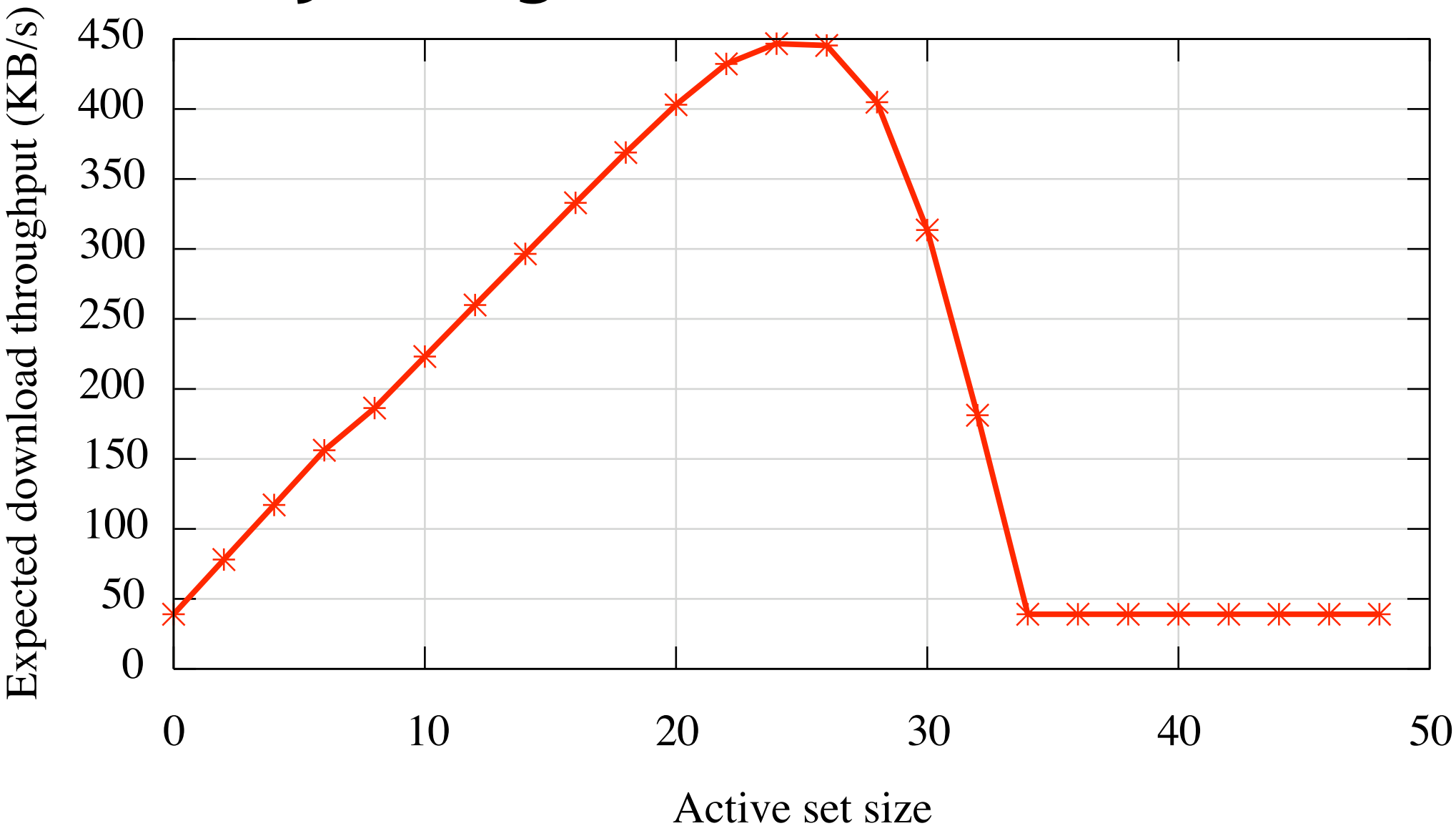
A Sybil attack

- **Looking at the data it seems that low capacity peers have disproportionally high performance.**
- **An obvious attack is then disguising a high capacity peer as multiple low capacity peers.**
  - flooding the local neighbourhood of high capacity peers these Sybils increase the likelihood of tit-for-tat reciprocation
  - and of receiving optimistic unchokes
- **Such attacks may be mitigated by disallowing multiple connections from one IP address.**

Adaptively resizing the active set

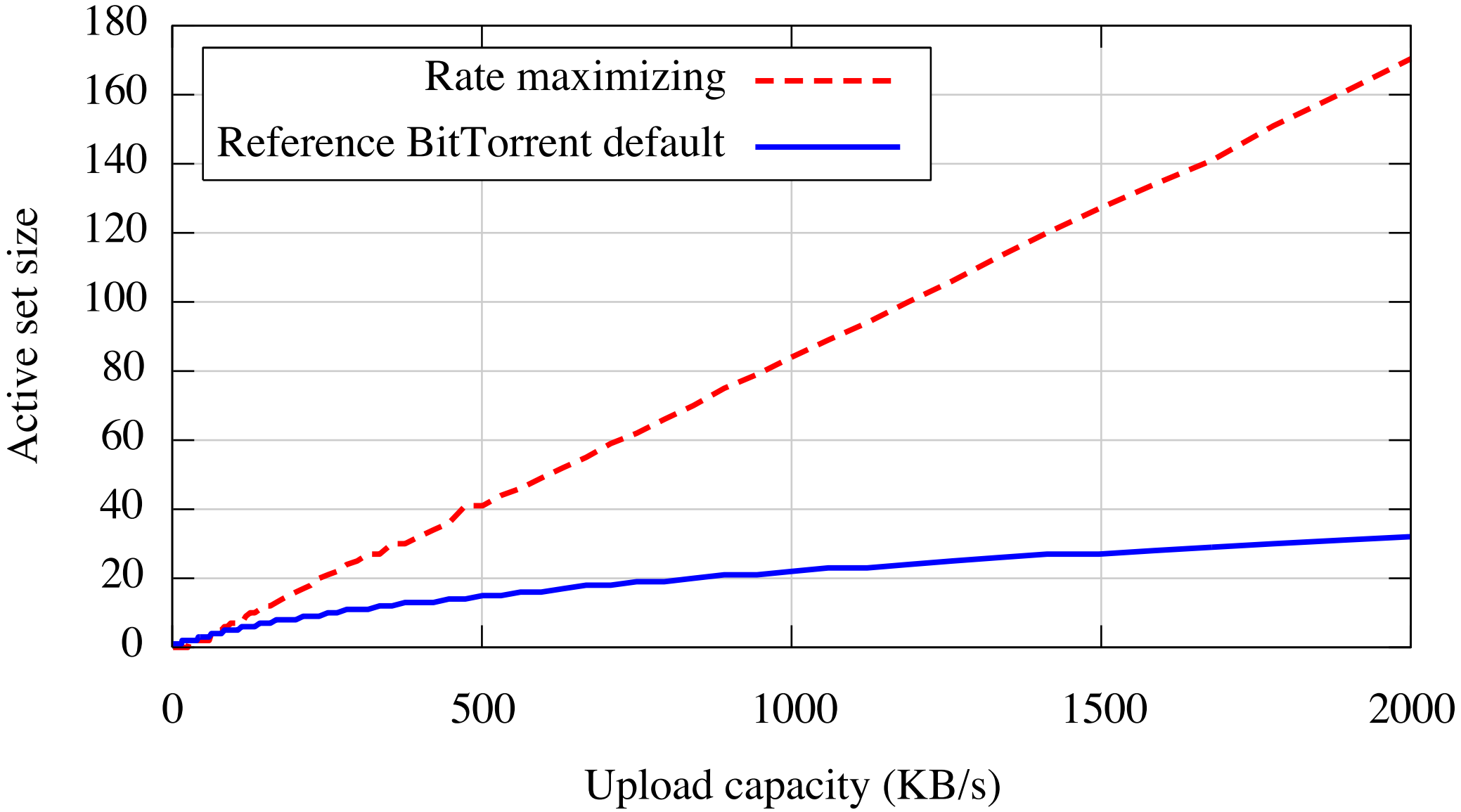
- **From the data it seems that high capacity peers upload "too much" to their neighbours.**
  - that would imply that having more neighbours in the active set would be beneficial.
- **If the equal split capacity distribution of the swarm is known, we can derive the active set size that maximises the expected download rate.**

Adjusting the active set size



Expected download throughput for a peer with 300 KB/s upload

Adjusting the active set size



Optimal active set size as a function of upload capacity

BitTyrant's unchoke algorithm

- **For each neighbouring peer *p* BitTyrant maintains estimates of the upload rate required for reciprocation u_p,**
  - as well as measured download throughput d_p.
- **Peers are then ordered by d_p/u_p and unchoked in order until the sum of u_p terms exceeds the upload capacity.**

BitTyrant's unchoke algorithm

For each peer p, maintain estimates of expected download performance d_p and upload required for reciprocation u_p.

Initialize u_p and d_p assuming the bandwidth distribution in Figure 2.

d_p is initially the expected equal split capacity of p.

u_p is initially the rate just above the step in the reciprocation probability.

Each round, rank order peers by the ratio d_p/u_p and unchoke those of top rank until the upload capacity is reached.

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

At the end of each round for each unchoked peer:

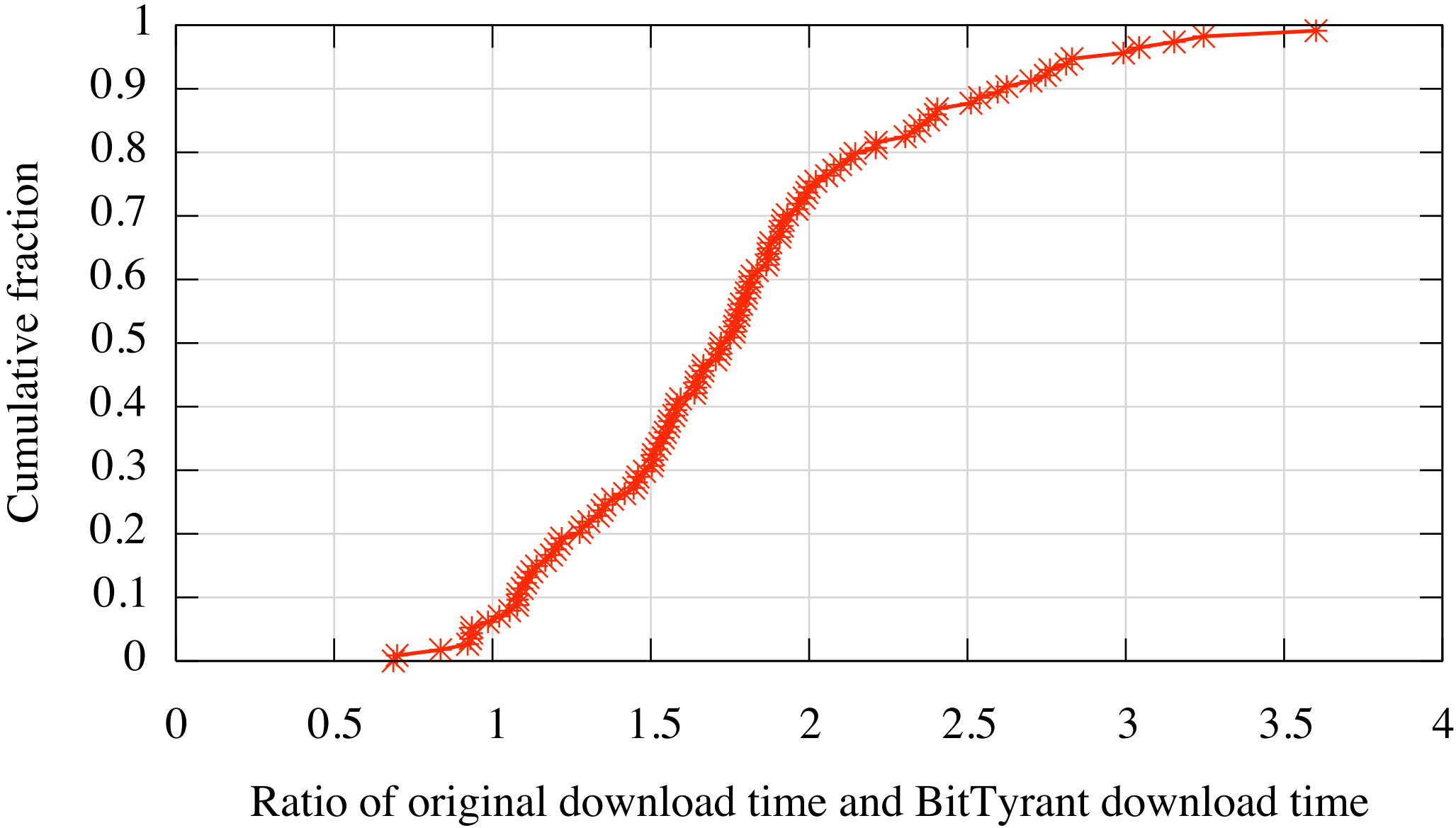
If peer p does not unchoke us: $u_p \leftarrow (1+\delta)u_p$

If peer p unchokes us: $d_p \leftarrow$ observed rate.

If peer p has unchoked us for the last r rounds: $u_p \leftarrow (1-\gamma)u_p$

- $\gamma = 10\%$
- $\delta = 20\%$
- $r = 3$

BitTyrant in a regular swarm



Summary

- BitTyrant performs well in a regular swarm—where it lives off the altruism of the other peers.
- High bandwidth peers really benefit from BitTyrant.
- It also lives well in a swarm of only BitTyrant peers—as long as these are altruistic, i.e., they still contribute excess capacity.
- But when the entire BitTyrant swarm is acting selfishly the performance takes a serious hit. Selfish meaning that the peer will never use excess capacity.

Summary

- **We have seen a number of ways to attack BitTorrent:**
  - Sybil attacks, piece lying, peer eclipsing
- **The BitTyrant system, a strategic BitTorrent client, was presented. BitTyrant increases download speed by:**
  - varying the active set size based on the reciprocation and,
  - making sure that you only give what is necessary to other peers.

Summary

- **Scalability**
  - Highly scalable and widely used
- **Fairness**
  - You are only involved if you are interested in a particular file, give and ye shall receive…
- **Integrity and security**
  - Files are integrity checked – peers may be malicious
- **Anonymity, deniability, censorship resistance**
  - Not a part of the protocol – transactions can be (and are) followed, and trackers can certainly be shutdown

Milestone 4

- With both Chord and Photon in place, it is time to ensure robust persistence of collected data. Your current design has one Chord peer responsible for the Photon's state, but what if that peer is lost? Or, a better matching peer joins the Chord network?
- You must extend your Chord peers so that they save the data generated by the Photon they are responsible for. You are welcome to use a third-party library for persistence, e.g., SQLite or CouchDB. Extend your peers, so that all saved data can be displayed at the responsible peer
- Persistence at one peer is not safe enough—extend your peers to replicate data to *k* successors, so that the failure of one peer does not lead to data loss. You should also consider that data collection and replication must continue even if the originally responsible peer has been lost, or a new node is a better match for the Photon