Peer-to-Peer Systems

Agenda

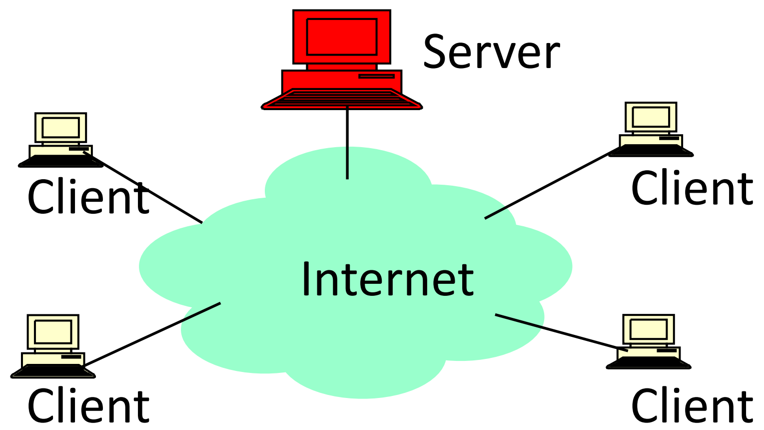
- Peer-to-peer networking
  - Definition
  - Use cases
- Peer-to-peer overlays
  - Unstructured systems
  - Distributed hash table abstraction
  - Structured systems realizing DHTs

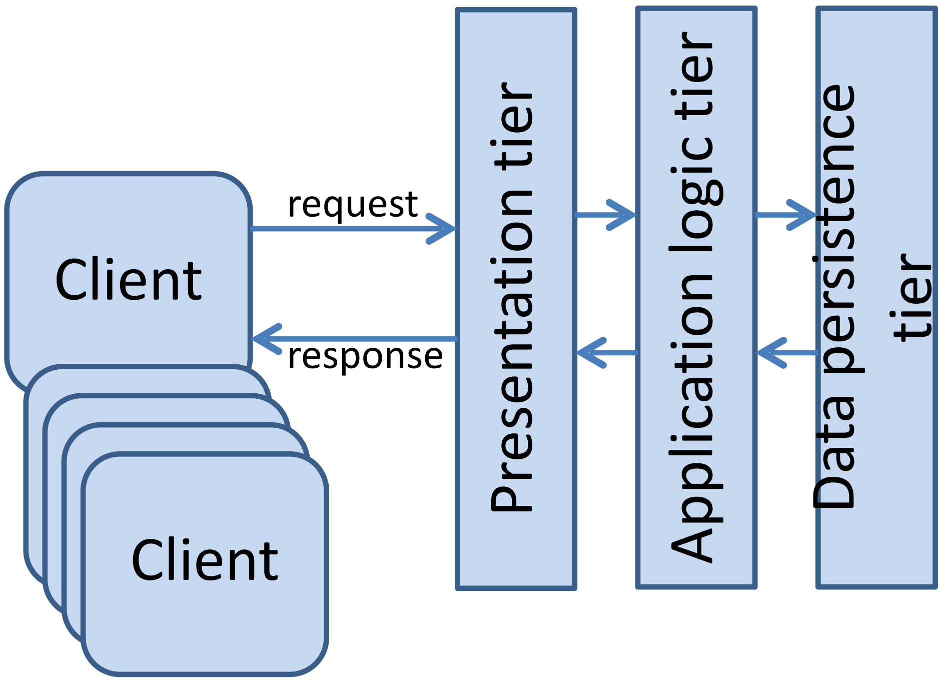
Peer-to-Peer Systems

Introduction

Client-Server Architecture

- Well known, powerful, reliable server as data source
- Clients request data from server
- Very successful model
  - WWW (HTTP), FTP, Web services, etc.
- N-tier architecture





Client-Server Limitations

- Scalability is expensive (vertical vs. horizontal)
- Presents a single point of failure
- Requires administration
- Unused resources at network edge

- P2P systems try to address these limitations and leverage (otherwise) unused resources

Peer-to-Peer

Compute, storage, network

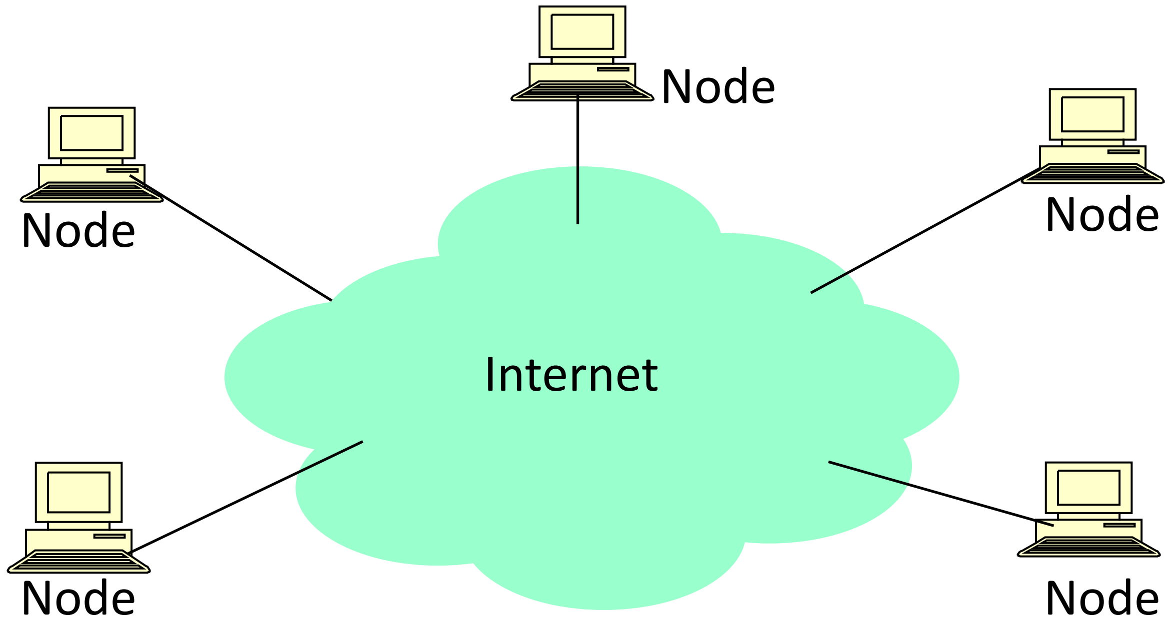
- P2P computing is the sharing of **compute resources** and **services** by **direct** exchange between peers (a.k.a. nodes)

- These resources and services include the **exchange of data, processing cycles, cache storage**, **disk storage,** and **bandwidth**

- P2P computing takes advantage of existing computing power, computer storage and networking connectivity, allowing users to leverage their **collective power to the ' benefit' of all**

* From (accessed June, 2004) http://www-sop.inria.fr/mistral/personnel/Robin.Groenevelt/ Publications/Peer-to-Peer_Introduction_Feb.ppt

What is a P2P system?

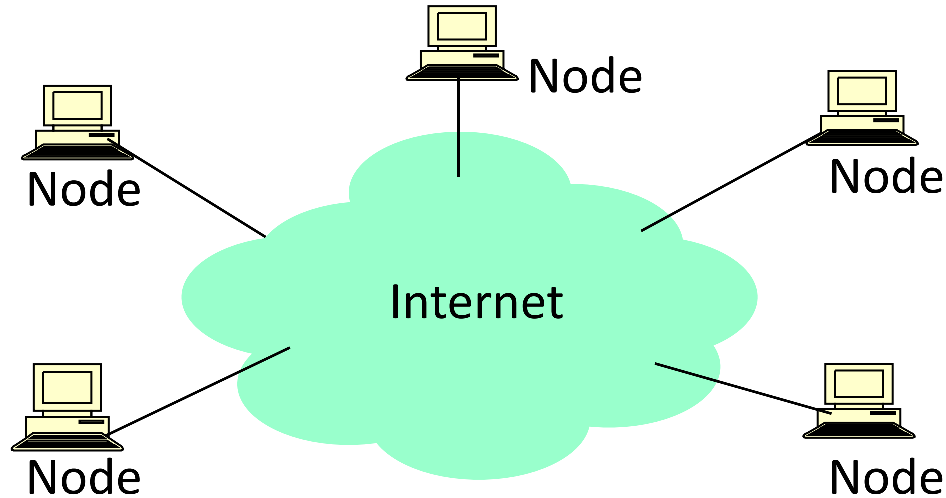


- A distributed system architecture
  - No centralized control
  - Nodes are symmetric in function
- Larger number of unreliable nodes
- Enabled by technology improvements

* Content from http://project-iris.net/dht-toronto-03.ppt

P2P Architecture

- All nodes are both *clients* and *servers*
  - Provide and consume
  - Any node can initiate a connection



- No centralized data source
  - *"The ultimate form of democracy on the Internet"*
  - *"The ultimate threat to copyright protection on the Internet"*

- In practice, hybrid models are popular
  - Combination of client-server & peer-to-peer
  - Skype (early days, now unknown)
  - Spotify (peer-assisted)
  - BitTorrent (trackers)

* Content from http://project-iris.net/dht-toronto-03.ppt

P2P Benefits I

- Efficient use of resources
  - Unused bandwidth, storage, processing power at the edge of network
- Scalability
  - Consumers of resources also donate resources
  - Aggregate resources grow naturally with utilization
    - Organic scaling (more users, more resources)
    - “Infrastructure-less” scaling
- **Caveat**: It is not a one size fits all
  - Large companies are not switching in droves to P2P

P2P Benefits II

- Reliability (in aggregate)
  - Many replicas, redundancy
  - Geographic distribution
  - No single point of failure and control
- Ease of administration
  - Nodes self-organize
  - No need to deploy servers to satisfy demand
  - Built-in fault-tolerance, replication, and load balancing

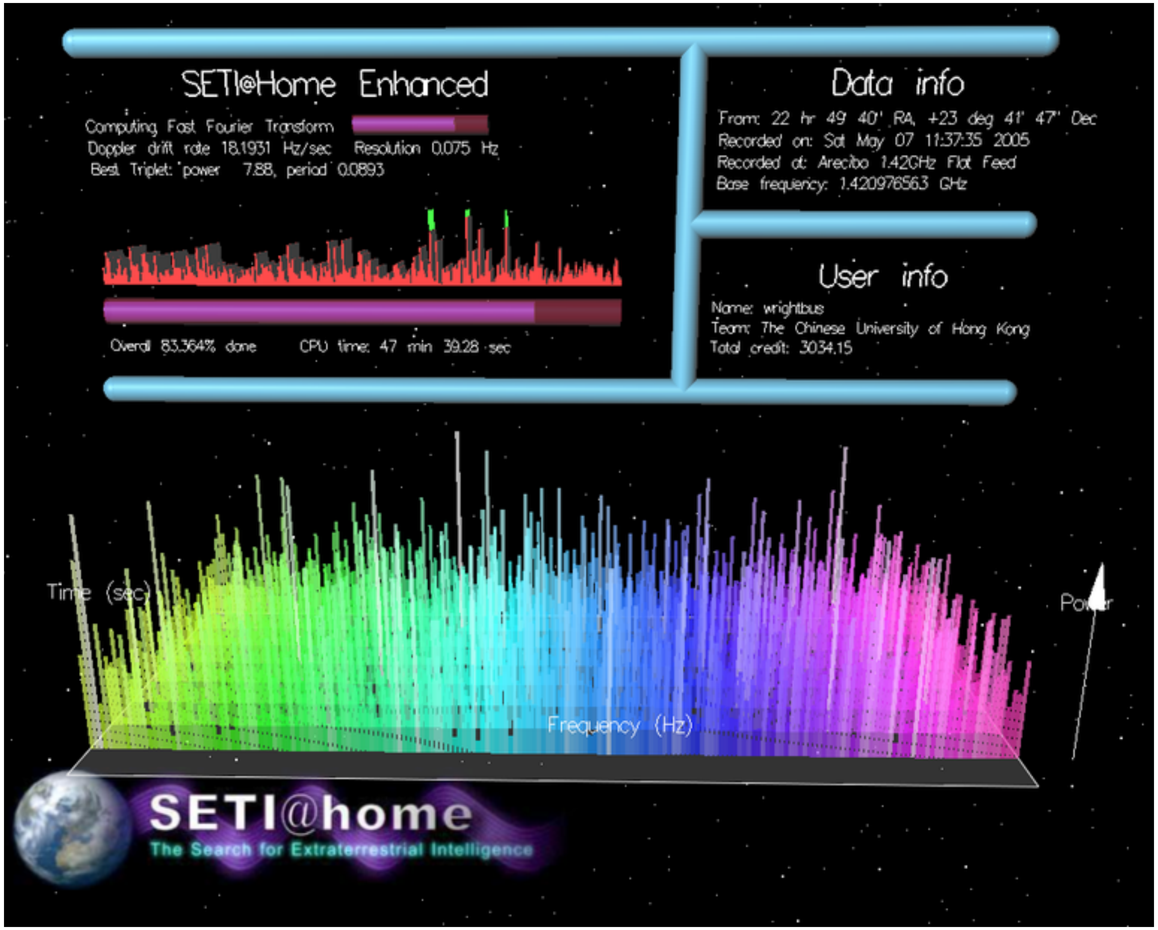
Use Cases: Large-Scale Systems

- Some applications require immense resources
  – CPU: Scientific data analysis (*@home)
  – Bandwidth: Streaming, file sharing
  – Storage: Decentralized data, file sharing

- Thousands or even millions of nodes
  – How to efficiently manage such a large network?

SETI@home – started in 1999

- 5.2 million participants worldwide
- On September 26, 2001, had performed a total of 10^{21} flops
- 35 GB/data per day, 140K work units
- 30 hours/WU
- 4.2M hours of computation/day
- Centralized database



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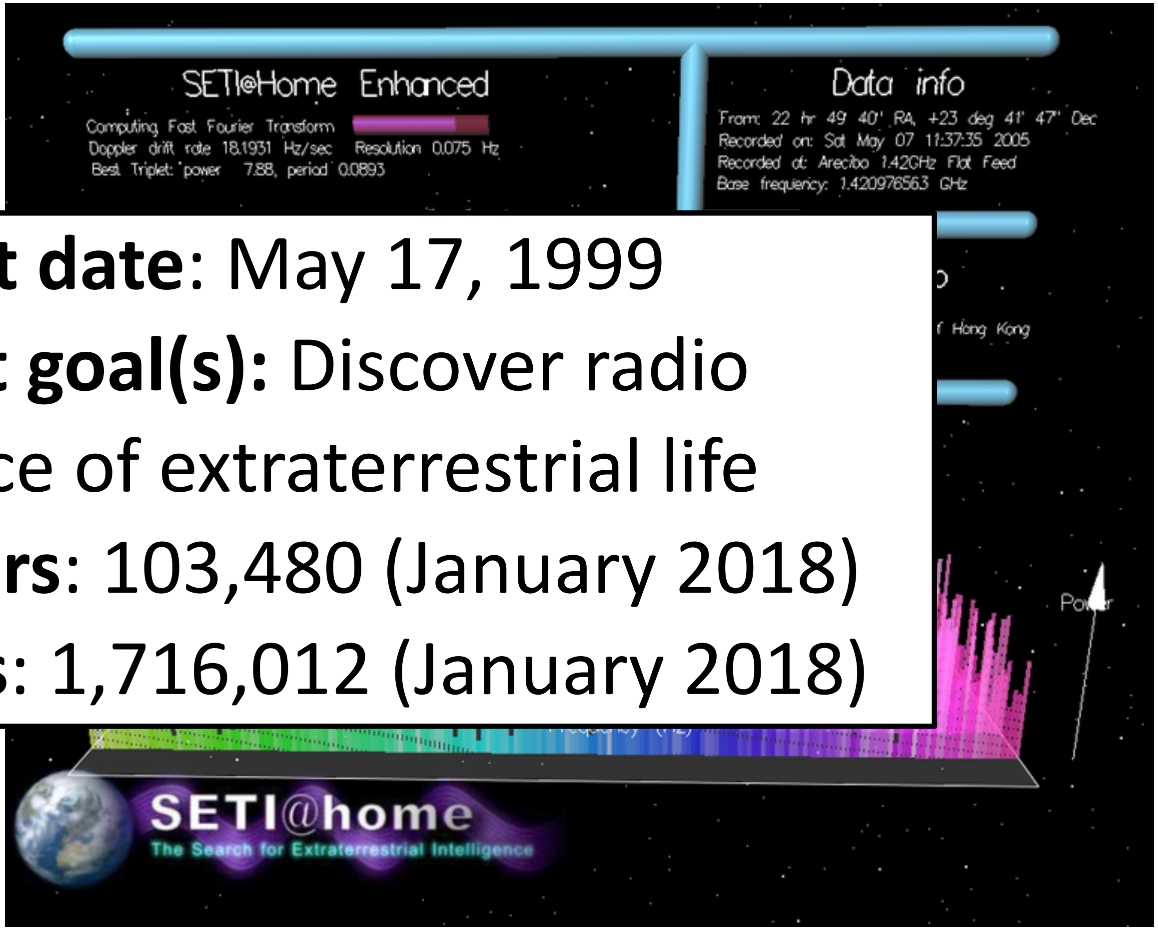

Start date: May 17, 1999

Project goal(s): Discover radio evidence of extraterrestrial life

Active users: 103,480 (January 2018)

Total users: 1,716,012 (January 2018)

2015 NA Traffic

Traffic share in North America during peak hours

	Upstream		Downstream		Aggregate	
Rank	Application	Share	Application	Share	Application	Share
1	BitTorrent	28.56%	Netflix	37.05%	Netflix	34.70%
2	Netflix	6.78%	YouTube	17.85%	YouTube	16.88%
3	HTTP	5.93%	HTTP	6.06%	HTTP	6.05%
4	Google Cloud	5.30%	Amazon Video	3.11%	BitTorrent	4.35%
5	YouTube	5.21%	iTunes	2.79%	Amazon Video	2.94%
6	SSL - OTHER	5.10%	BitTorrent	2.67%	iTunes	2.62%
7	iCloud	3.08%	Hulu	2.58%	Facebook	2.51%
8	FaceTime	2.55%	Facebook	2.53%	Hulu	2.48%
9	Facebook	2.25%	MPEG - OTHER	2.30%	MPEG	2.16%
10	Dropbox	1.18%	SSL - OTHER	1.73%	SSL - OTHER	1.99%
		65.95%		78.69%		76.68%

sandvine

https://www.sandvine.com

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6	SSL - OTHER	5.10%	BitTorrent	2.67%	iTunes	2.62%
7	iCloud	3.08%	Hulu	2.58%	Facebook	2.51%
8	FaceTime	2.55%	Facebook	2.53%	Hulu	2.48%
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But streaming is larger overall…

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8	FaceTime	2.55%	Facebook	2.53%	Hulu	2.48%
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P2P File Sharing Systems

- Large-scale sharing of files
  - User *A* makes files (music, video, etc.) on their computer available to others
  - User *B* connects to “network,” searches for files and downloads files *directly* from User *A*

- P2P networks
  - Peers are connected to each other to form an **overlay network**
  - Peers communicate using links established in overlay

- Fallen out of favor (*RIP 1999-2015*)
  - Issues of copyright infringement
  - Cloud infrastructures has taken over (controlled resources)
  - Harder to exploit mobile and connected devices
  - Streaming makes file sharing obsolete (cf. P2P Streaming)

Types of P2P Systems

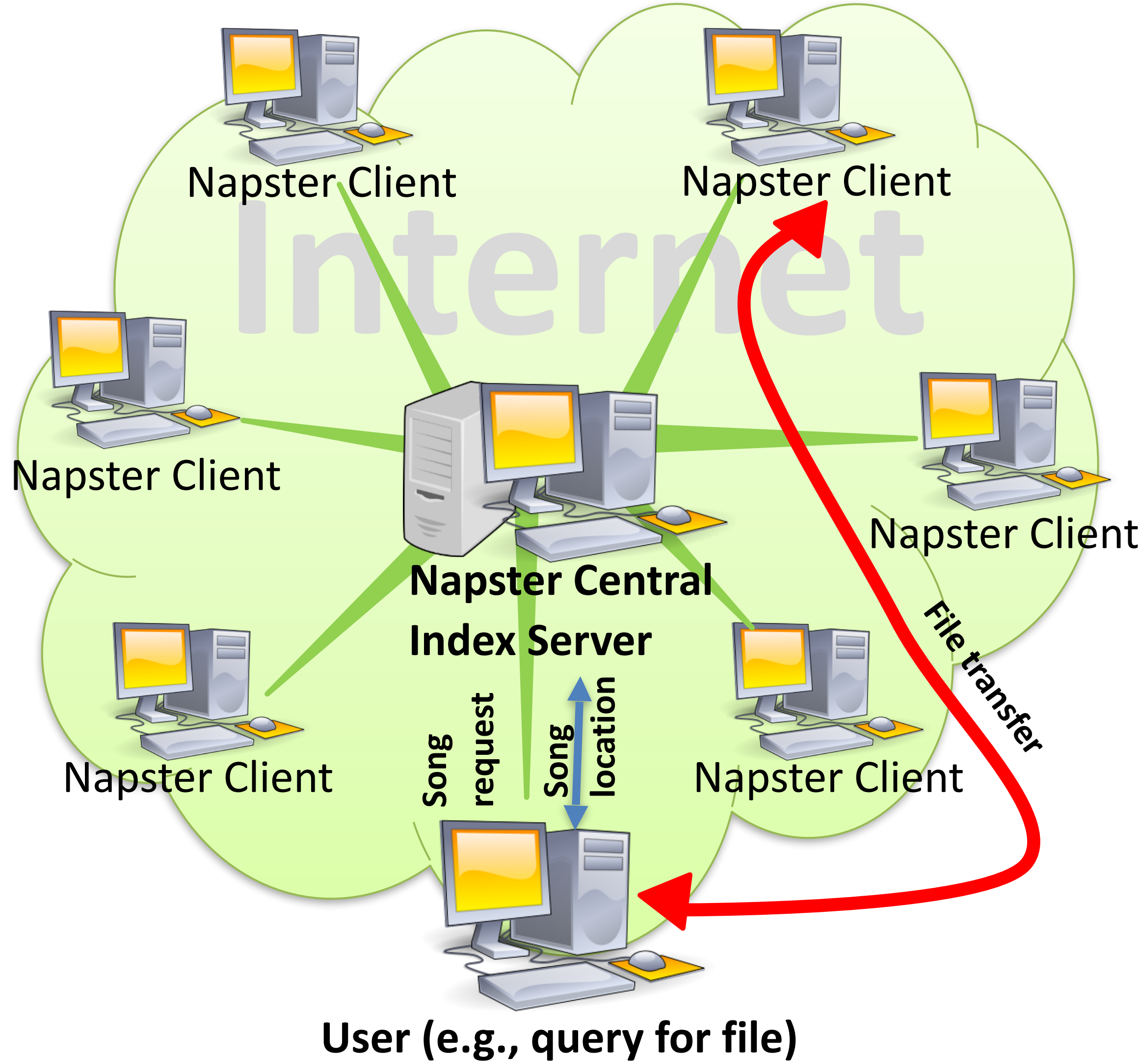
- Unstructured networks
  - No obvious structure in overlay topology
  - Peers simply connect to anyone in existing network
- First generation:
  - Centralized: **Napster**
  - Pure: **Gnutella**, Freenet
- Second generation:
  - Dynamic “supernodes”
  - Hybrid: **Skype**, **Spotify**, FastTrack, eDonkey, **BitTorrent**
- Structured networks
  - Topology of overlay is controlled: peers’ connections are fixed
  - Based on the distributed hash table abstraction (**DHT**)

Peer-to-Peer Systems

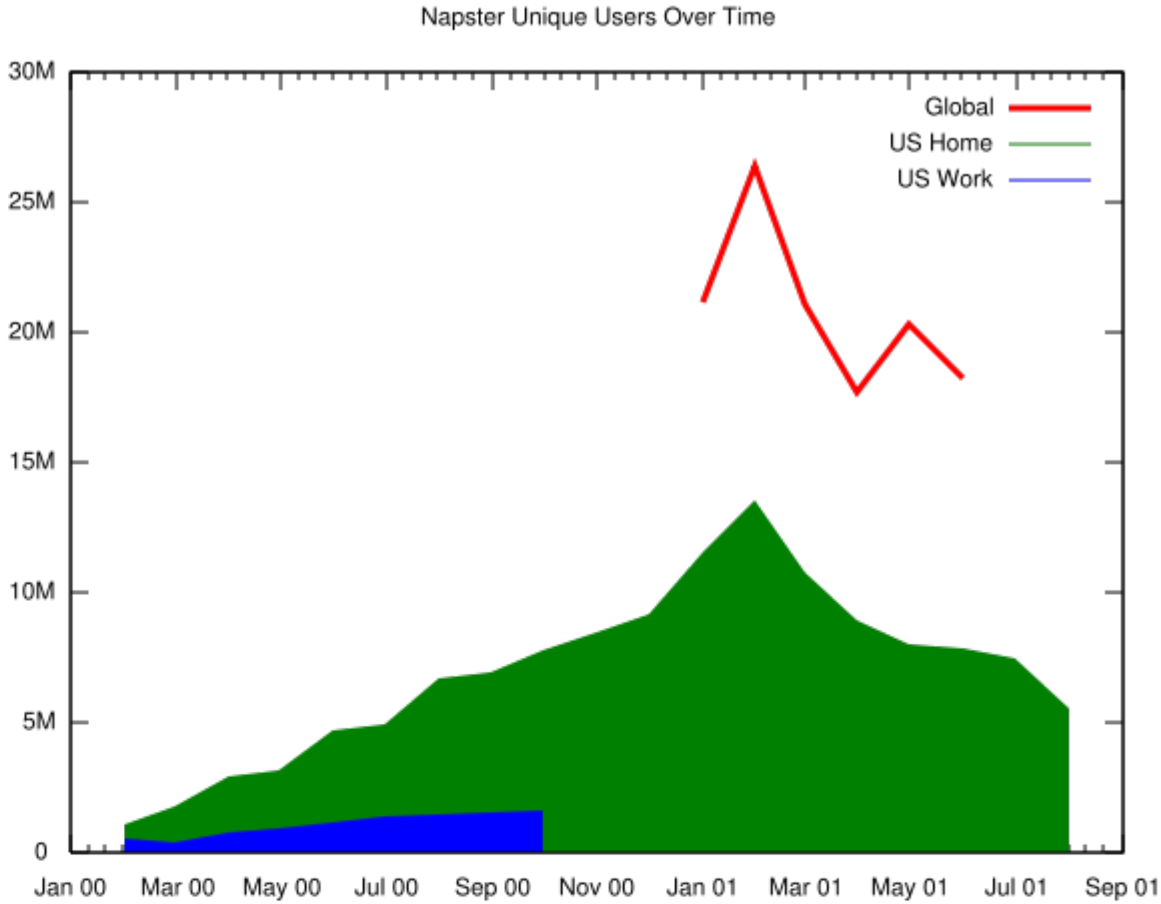
Unstructured peer-to-peer systems

Centralized: Napster “June 1999 – July 2001”

- Centralized search indexes music files
  - Perfect knowledge
  - Bottleneck
- Users query server
  - Keyword search (artist, song, album, bit rate, etc.)
- Napster server replies with IP address of users with matching files
- Querying users connect **directly** to remote node for file to download



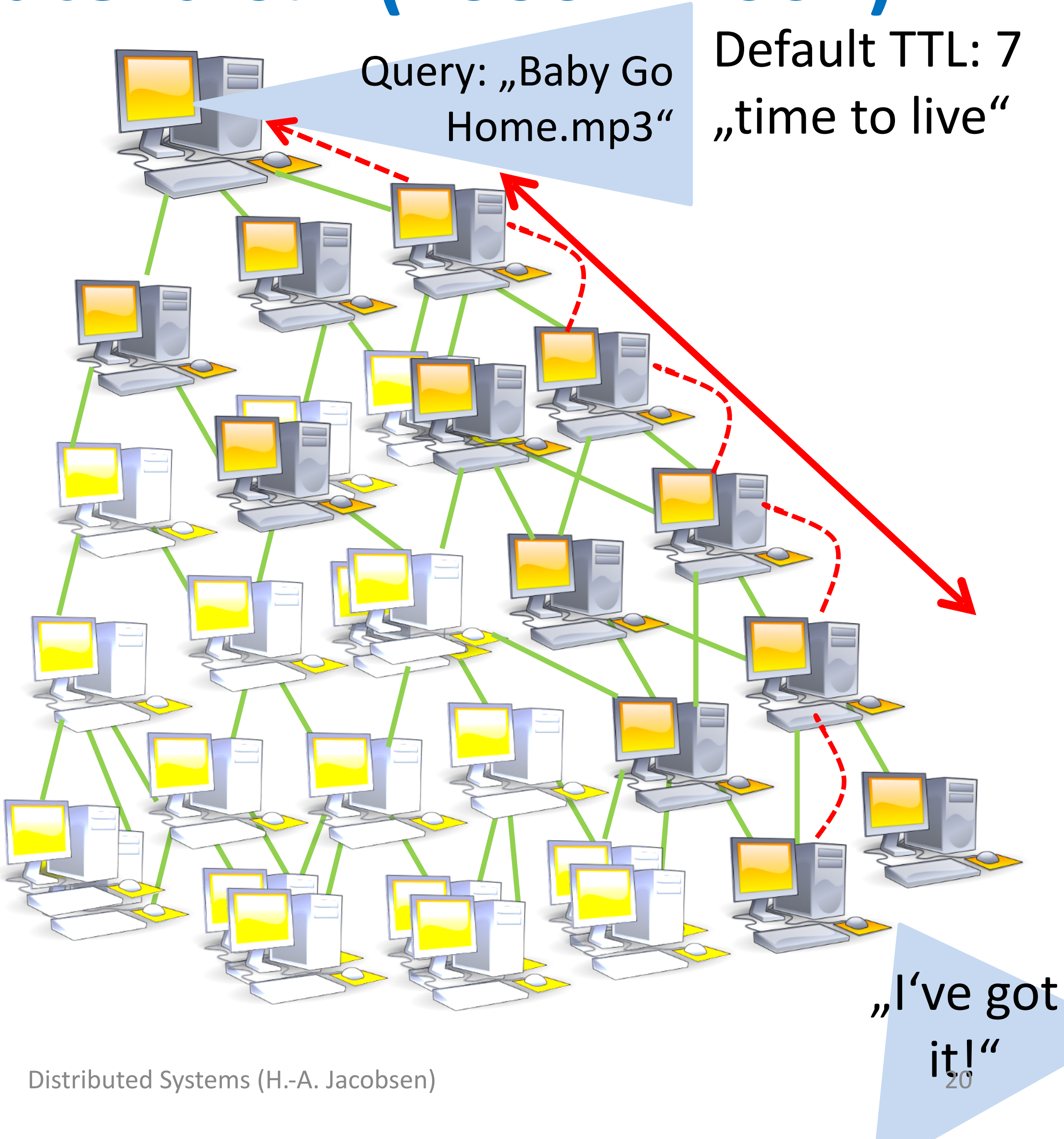
The Rise and Fall of Napster



RIAA shut down Napster easily because it used a central server!

Pure P2P: Gnutella 0.4 (2000 – 2001)

- Share any type of files
- Decentralized search
  - **Imperfect** content availability
- Client connect to (on average) 3 peers
- **Flood a QUERY** to connected peers
- Flooding propagates in network up to TTL
- Users with matching files **reply with QUERYHIT**
- Flooding wastes **bandwidth**: Later versions used more sophisticated search



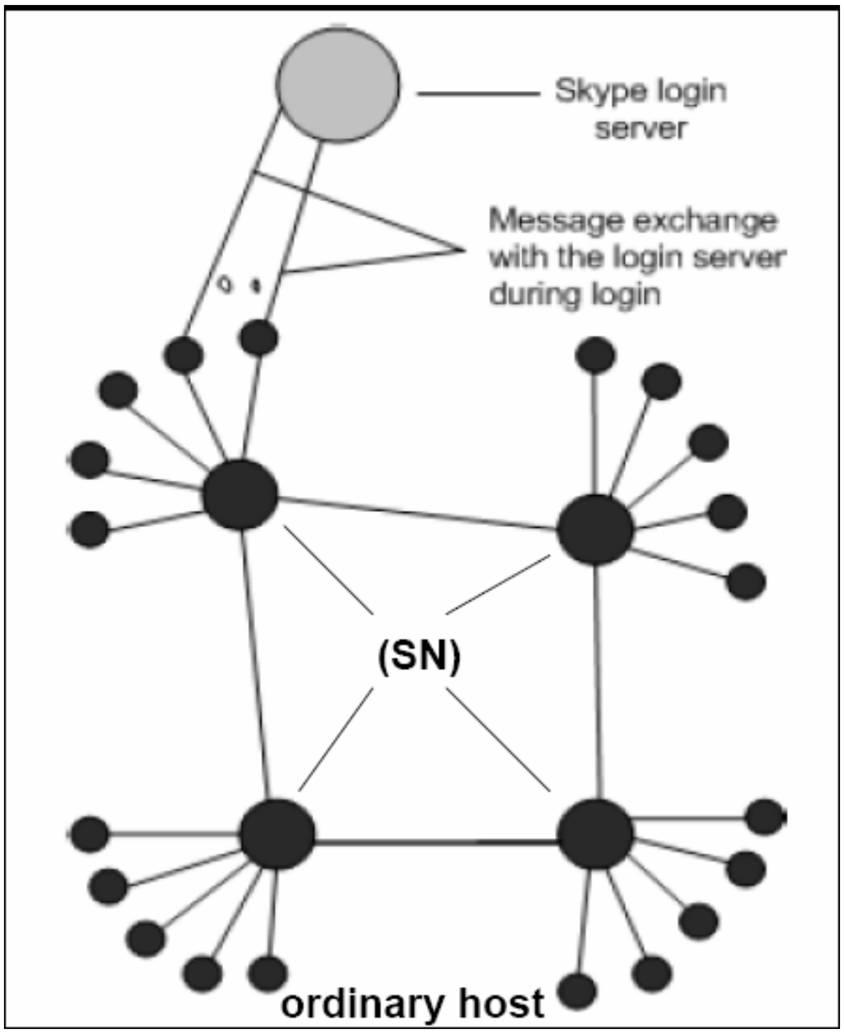
Hybrid P2P

- Both previous approaches have advantages and disadvantages
  - Centralized: single point of failure, easy to control, but perfect content availability
  - Pure: decentralized (resistant), costly and unreliable search
- Hybrid P2P combines both approaches
  - Hierarchy of peers
  - Superpeers with more capacity, discovered **dynamically**
  - Normal peers (leaf nodes) are users
- Superpeer responsibilities
  - Participates in search protocol, indexes and caches data
  - Improves content availability
  - Reduces message load

Skype Network

Around 2004

- **Super Nodes**: Any node with a public IP address having sufficient CPU, memory and network bandwidth is candidate to become a superpeer
- **Ordinary Host**: Host needs to connect to superpeer and must register itself with the Skype login server
- Login server and PSTN gateway (not shown) **are centralized components**



Responsibilities of Superpeers

In Skype Around 2004

- Indexes user directory
  - Distributed among superpeers
  - Communication among superpeers for lookup

- Communication relay
  - NAT traversal

- Phased out by Microsoft in 2011 (speculation)
  - Replaced with private servers
  - “[T]hat is in part why Skype has switched to server-based "dedicated supernodes"... nodes that **we control**, can handle orders of magnitudes **more clients per host**, are in **protected data centers** and up all the time, and **running code that is less complex** than the entire client code base. ”

Skype Impact

- Skype has shown, at least has suggested,:
  - Signaling, unique property of traditional phone system, is accomplished effortlessly with self-organizing P2P networks
  - P2P overlay networks can scale up to handle large-scale connection-oriented real-time services such as video and voice
- AT&T: *"The end of landlines …"*

Peer-to-Peer Systems

DHT - Distributed Hash Table

Structured Peer-to-Peer Systems

- Third generation P2P overlay networks
- Self-organizing, load balanced, fault-tolerant
- "Fast" and efficient **lookup guarantees**, e.g.,
  - O(log(n)) lookups
  - O(1): centralized, O(n): pure, O(#S): hybrid
- Based on a hash table interface (cf. KV-Store)
  - Put(Key, Data) and Get(Key)
  - Coined term **distributed hash table** (DHT)
- Systems: Chord, CAN, Pastry, etc.

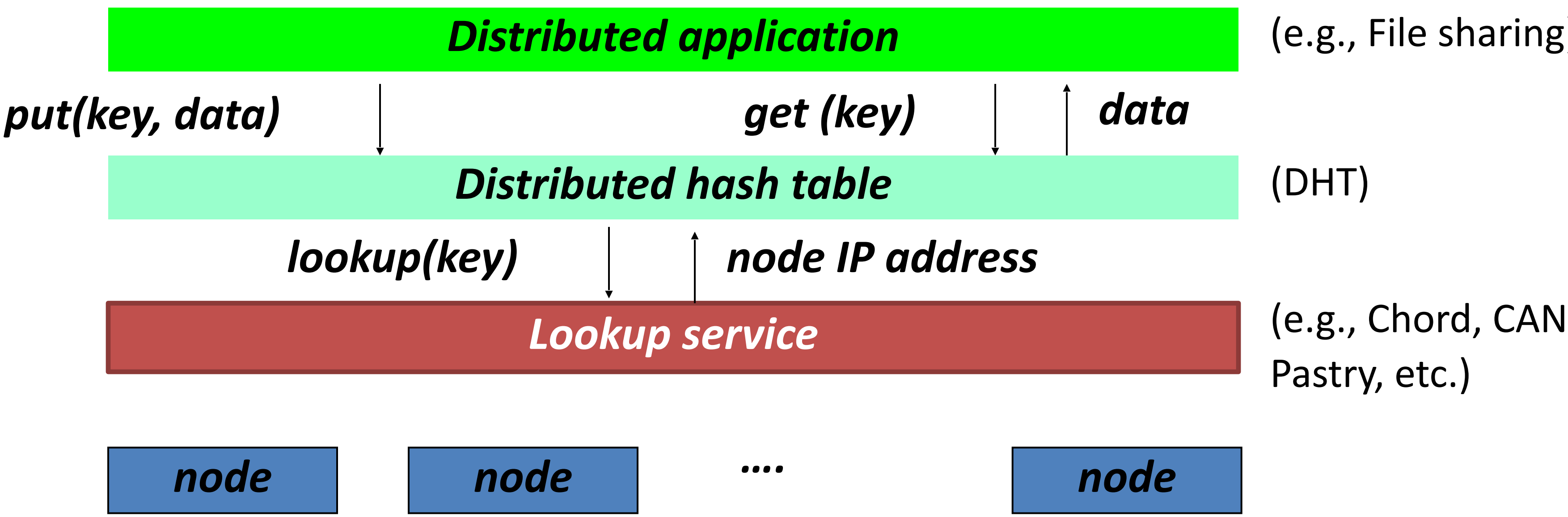
Distributed Hash Tables (DHT)

- Distributed version of a hash table data structure

- Store and retrieve (key, value)-pairs
  - **Key** is like a filename, hash of name, hash of content (since name could change)
  - **Value** is file content
    - Often just a reference to a node with the content

- Keys are hashed and mapped to a set of distributed nodes
  - Realization via consistent hashing *et al*.
  - System change should impact few nodes

DHT Abstraction



- Application distributed over many nodes
- DHT distributes data storage over many nodes

DHT Interface

- Put(key, value) and get(key) $\rightarrow$ value
  - Simple interface!
- API supports a wide range of applications
  - DHT imposes neither structure nor meaning on keys/values
- Key-value pairs are persisted and globally available
  - Good availability, content stored at edge
  - Store keys in other DHT values
  - Thus, build complex data structures

DHT as Infrastructure or Service

- Many applications can share single DHT service
- Eases deployment of new applications
- Pools resources from many participants (P2P…)
- Essentially, a middleware service, a piece of distributed systems infrastructure

DHT-based Projects

- File sharing [CFS, OceanStore, PAST, Ivy, …]
- Web cache [Squirrel, ..]
- Archival/Backup store [HiveNet, Mojo, Pastiche]
- Censor-resistant stores [Eternity,..]
- DB query and indexing [PIER, …]
- Event notification (Publish/Subscribe) [Scribe, ToPSS]
- Naming systems [ChordDNS, Twine, ..]
- Communication primitives [I3, …]
- Key-value stores [Cassandra*, Dynamo*, …]

Common denominator:

- **Data is location-independent**
- **All leverage DHT abstraction**

* In as far as they use consistent hashing among nodes

Peer-to-Peer Systems

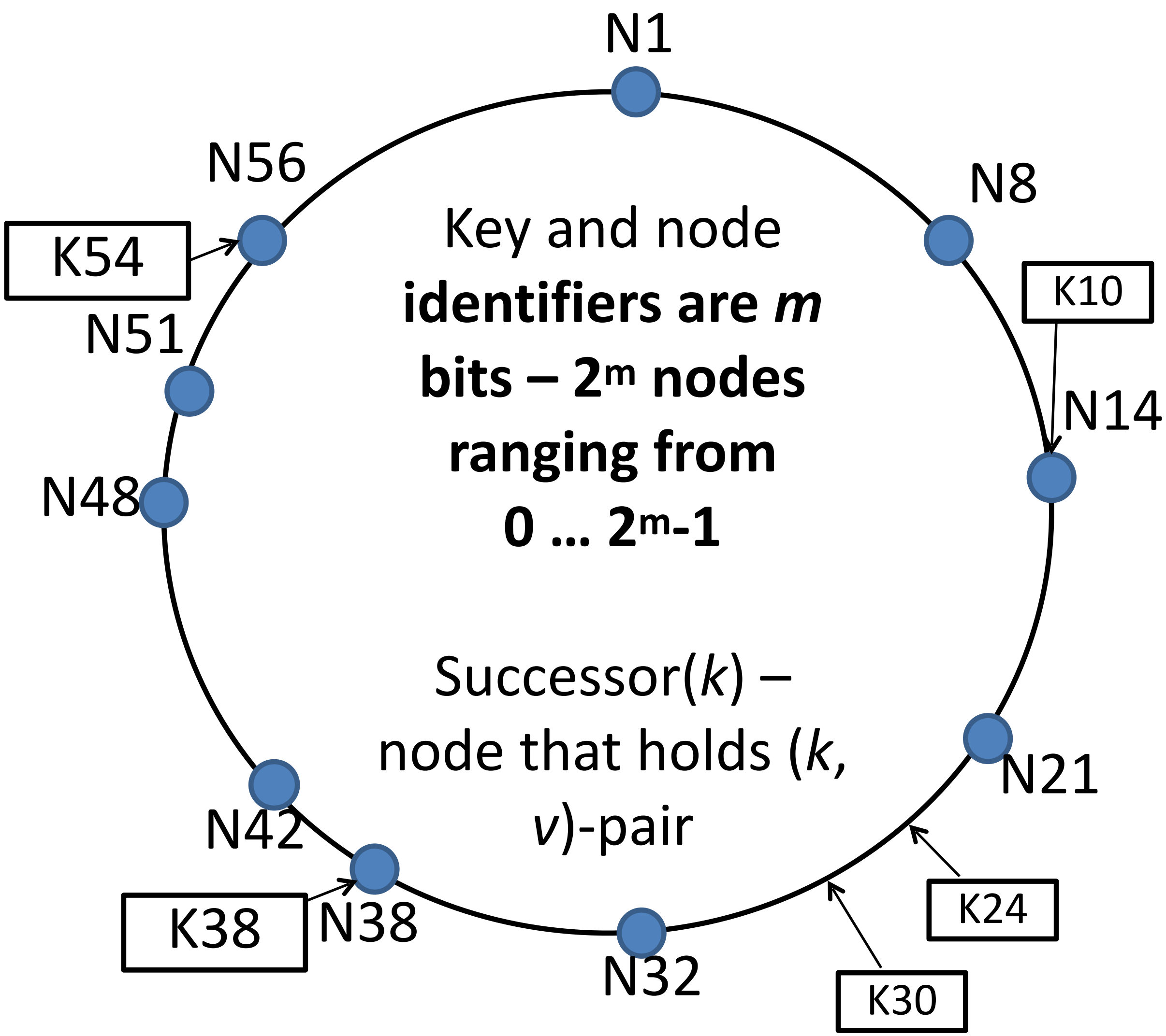
Chord DHT

DHT Requirements

- Keys mapped evenly to all nodes in the network (**load balancing**)
- Node arrivals & departures only affect a few nodes (**low maintenance**)
- Each node maintains information about only a few other nodes (**low maintenance**)
- Messages can be routed to a node efficiently (**fast lookup**)

Chord Identifier Circle

- **Nodes** organized in an identifier circle based on **node identifiers**
- **Keys** assigned to their successor node in the identifier circle
- **Hash function** ensures even distribution of nodes and keys on the identifier circle
- Cf. **consistent hashing**
- With *N* nodes and *K* keys each **node is responsible for** roughly *K/N* keys



* All Chord figures from "Chord: A Scalable Peer-to-peer Lookup Protocol for Internet Applications", Ion Stoica et al., IEEE/ ACM Transactions on Networking, Feb. 2003.

Node Joins & Leaves

- Nodes may disappear from the network (e.g., failure, departure)
- Each node records a whole **segment of the circle** adjacent to it, i.e., ***r*** **nodes preceding** and **following** it
- With high probability a node is able to correctly locate its successor or predecessor (even under high node churn)

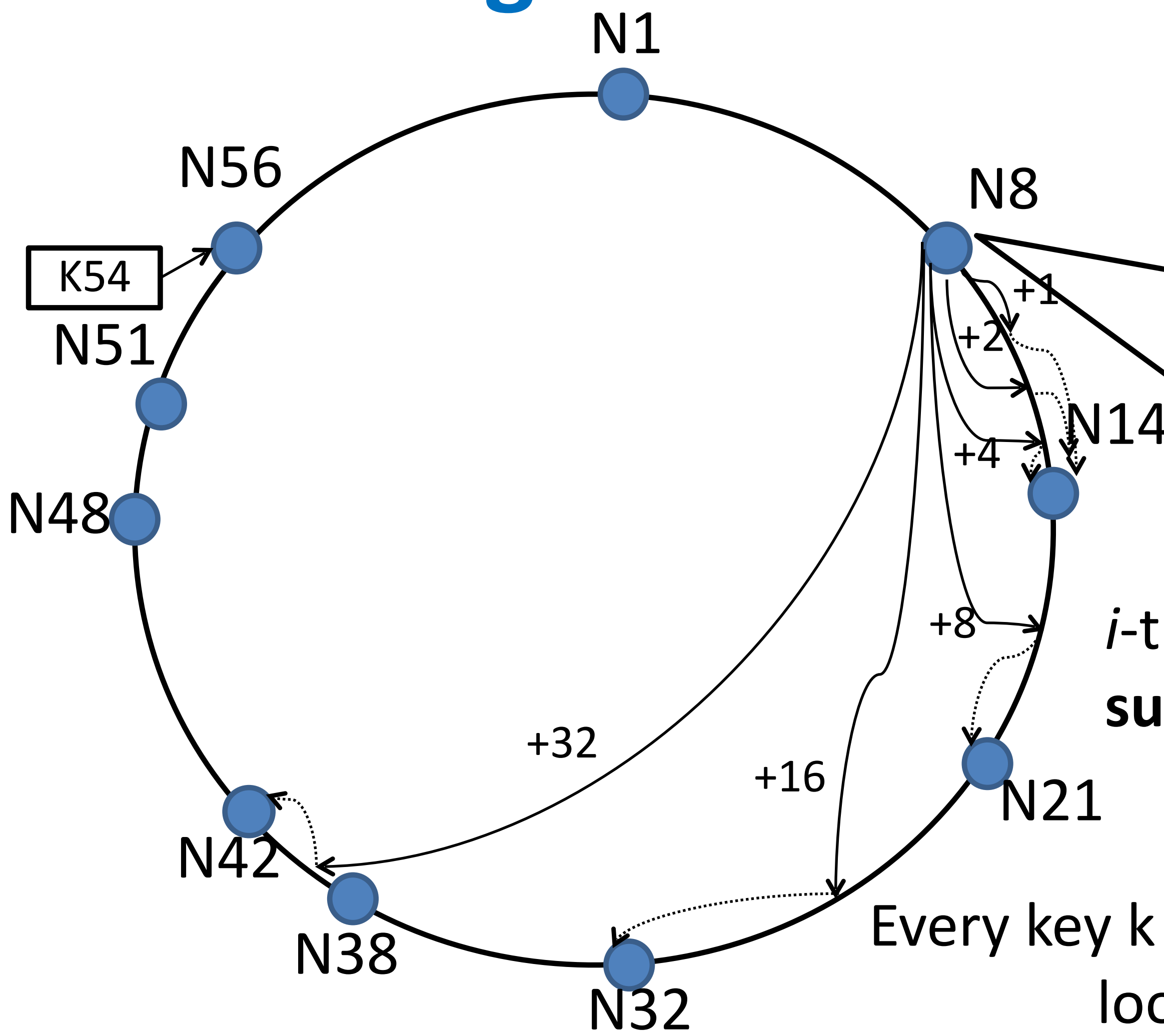
- When a new node joins or leaves the network, responsibility for O(*K*/*N*) keys changes hands

Searching in Chord

- With knowledge of a single successor, a linear search through network could locate key (naïve search)
- Any given message may potentially have to be relayed through most of the network, i.e., cost is O(*n*)

- Faster search method requires each node to keep a "***finger table***“ (FT) containing up to ***m*** entries
  - ***i***-th entry in FT of node ***n*** contains the address of **successor((n + 2^{i-1}) mod 2^m)**
  - number of nodes that must be contacted to find a successor in an ***n***-node network is **O(log n)**

Chord Finger Table



Finger table

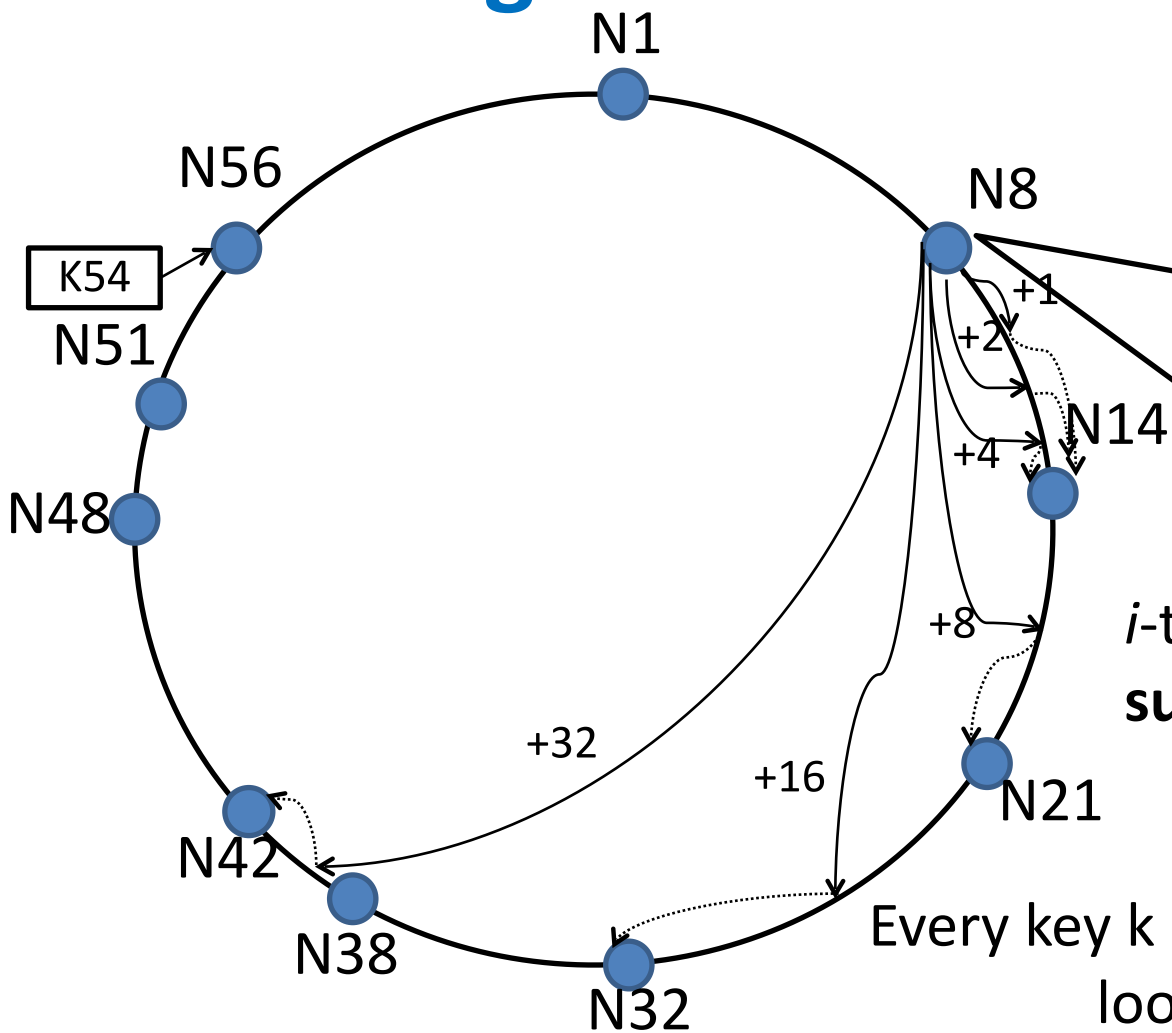
N8 + 1	N14
N8 + 2	N14
N8 + 4	N14
N8 + 8	N21
N8 + 16	N32
N8 + 32	N42

i-th entry is address of **successor((n + 2^{i-1}) mod 2^m)**

Every key k is stored at its successor – lookup a key via successor(*k*)

successor(…) is the node on the circle associated with the input argument – whether it is a *key* or a *node identifier*

Chord Finger Table



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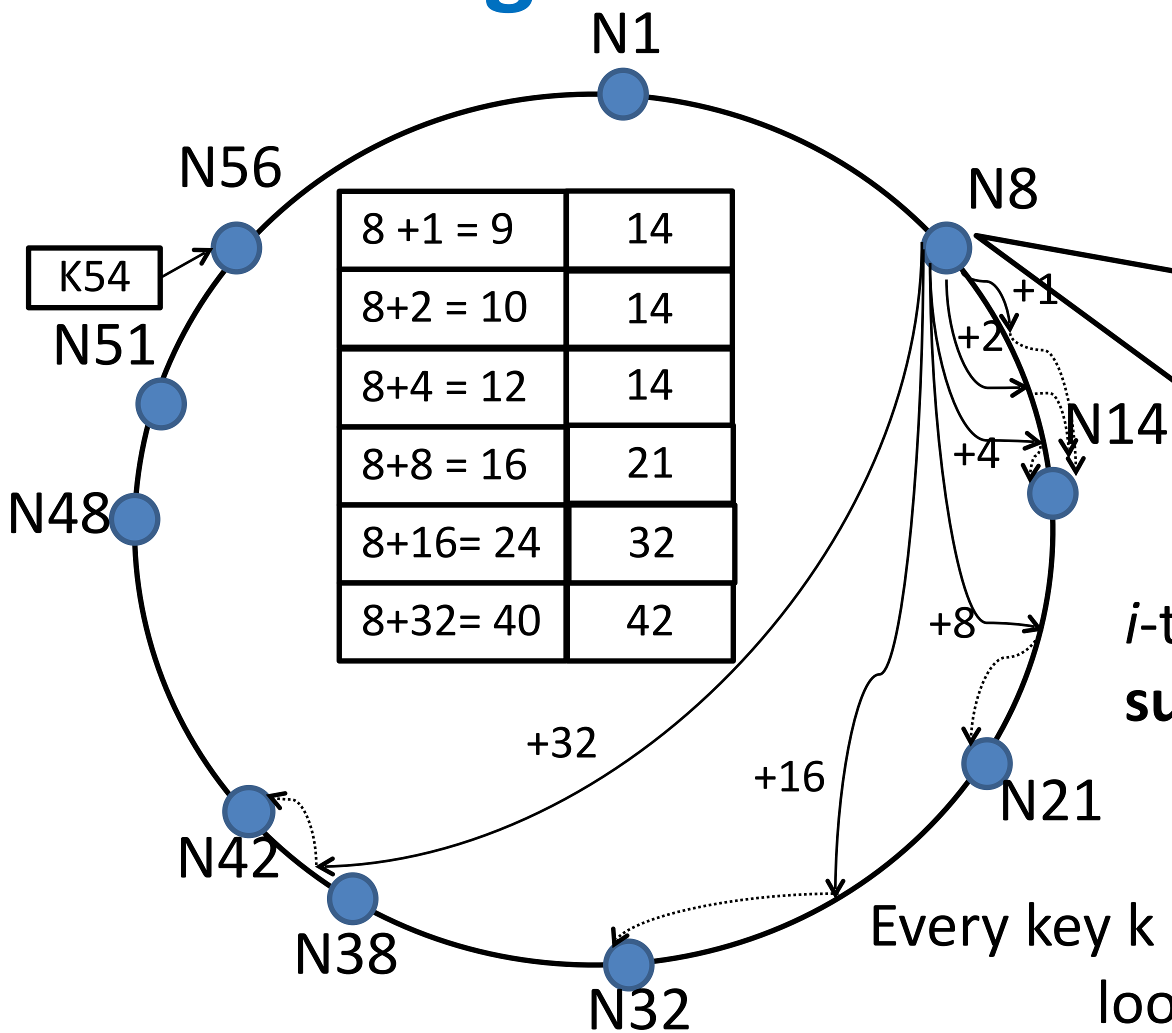

8 +1 = 9	14
8+2 = 10	14
8+4 = 12	14
8+8 = 16	21
8+16= 24	32
8+32= 40	42

Finger table

N8 + 1	N14
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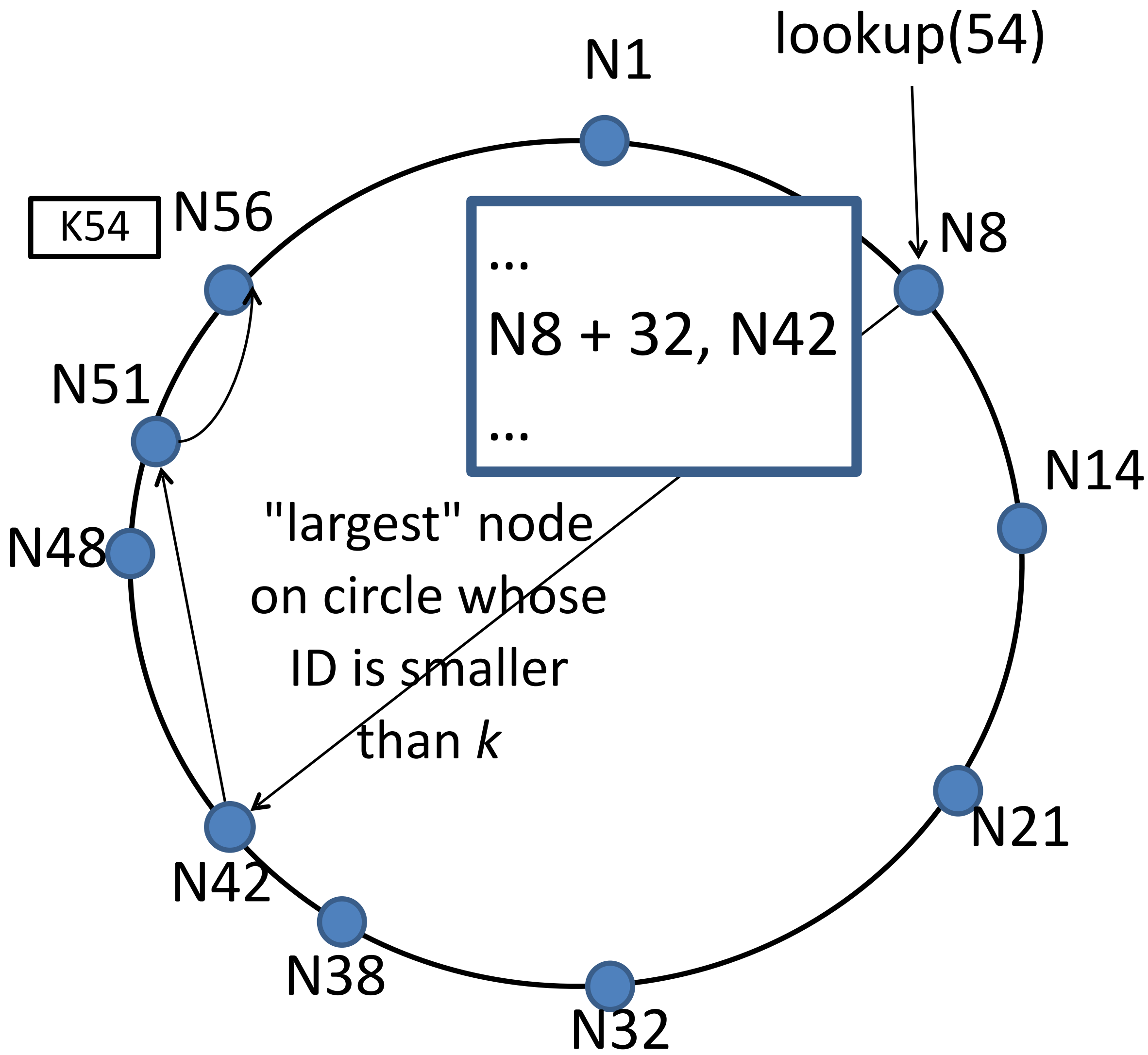
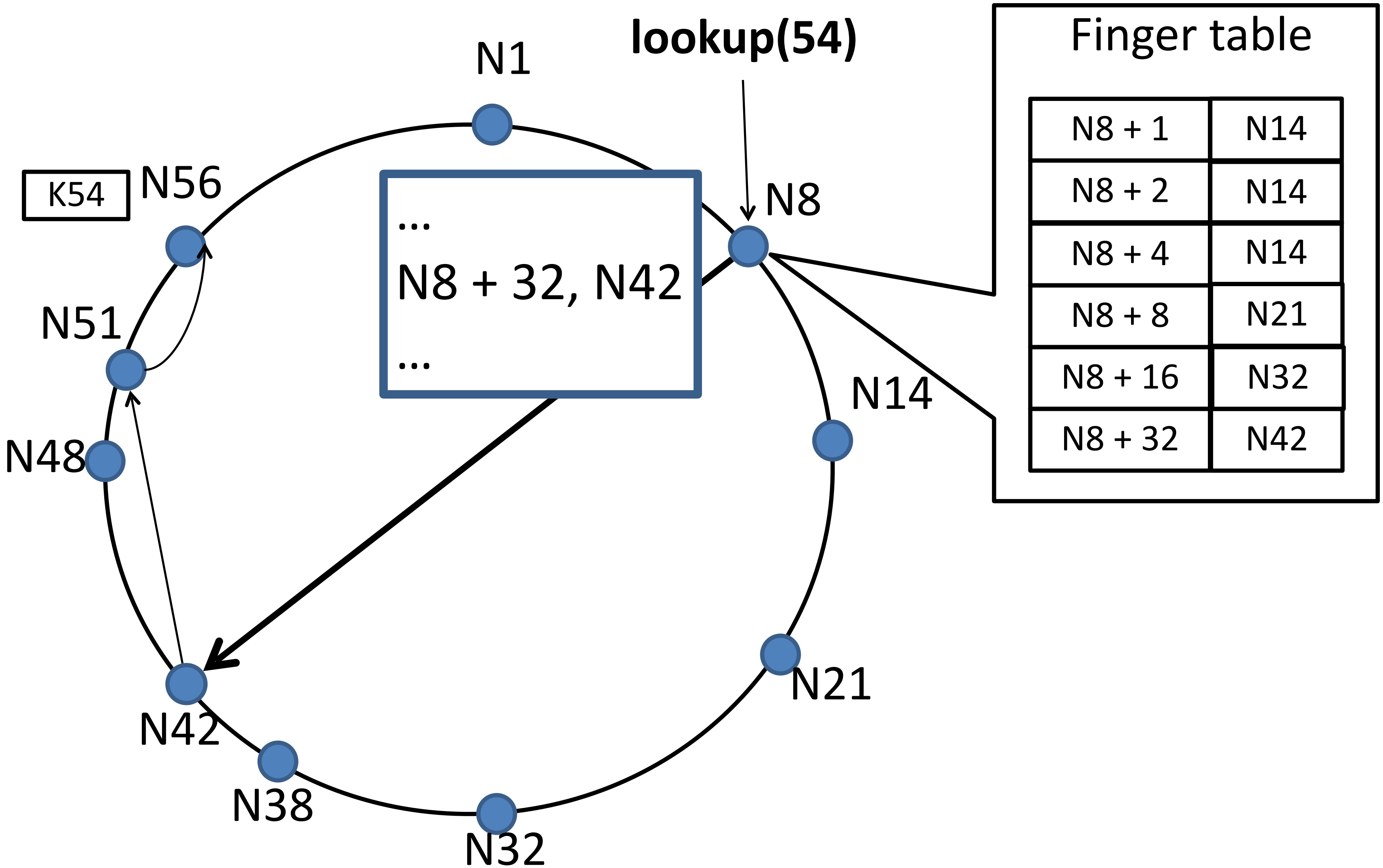
Chord Key Location

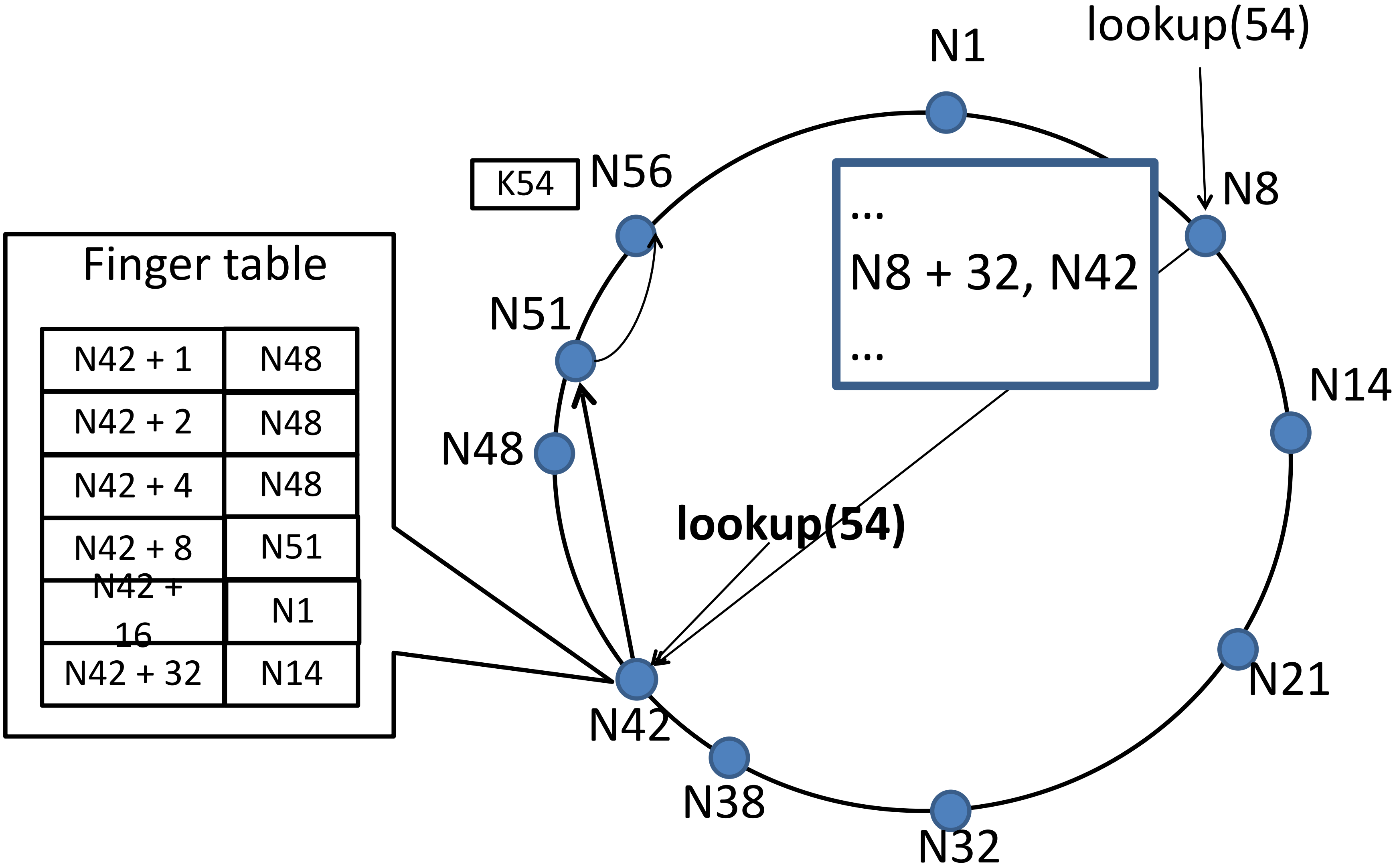
- Lookup in finger table the farthest node that precedes key – closest successor of key in FT
- Query homes in on target in O(log *n*) hops
- Each hop at least halves distance to destination



Lookup Example



Lookup Example (cont.)



Lookup Latencies

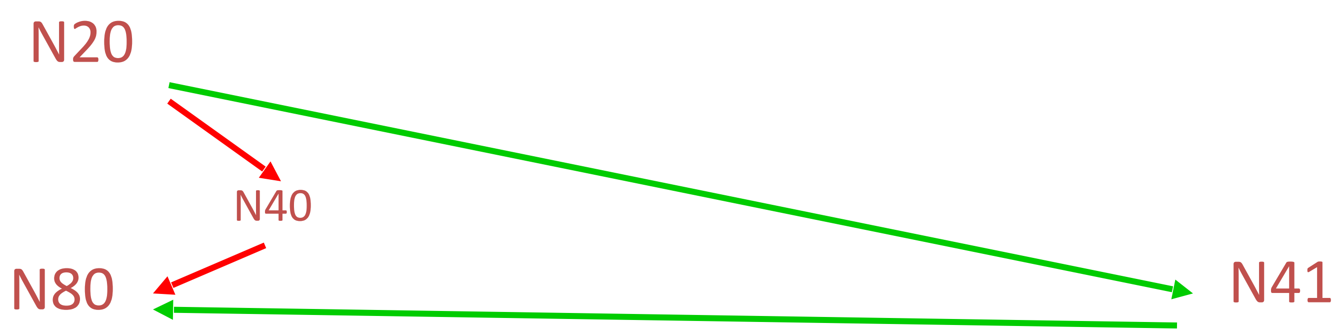
- While O(*log n*) is better than O(*n*), it can still take considerable amount of time to find the target

- For example, log (*1,000,000*) hops which may be distributed anywhere

- Results in potentially high response latencies

Network locality

- Nodes close on ring can be far away in network



* Figure from http://project-iris.net/dht-toronto-03.ppt

Peer-to-Peer Systems

CAN Pastry DHT

CAN: Content Addressable Network

- Design is based on virtual multi-dimensional Cartesian coordinate space to organize overlay
- Nodes are mapped into space (co-ordinates at edges wrap around)
- Address space is independent of physical location and physical connectivity of nodes
- Points in the space are identified with coordinates
- General model is an *n*-dimensional torus that uses dimensions for routing

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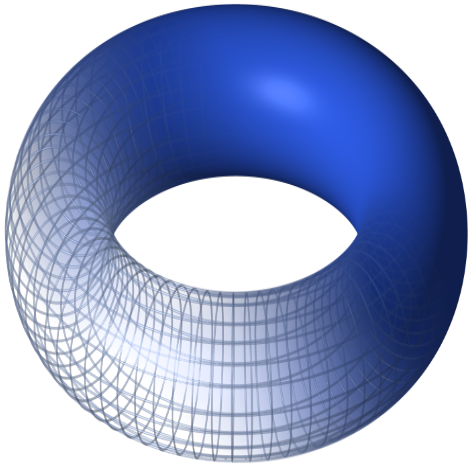
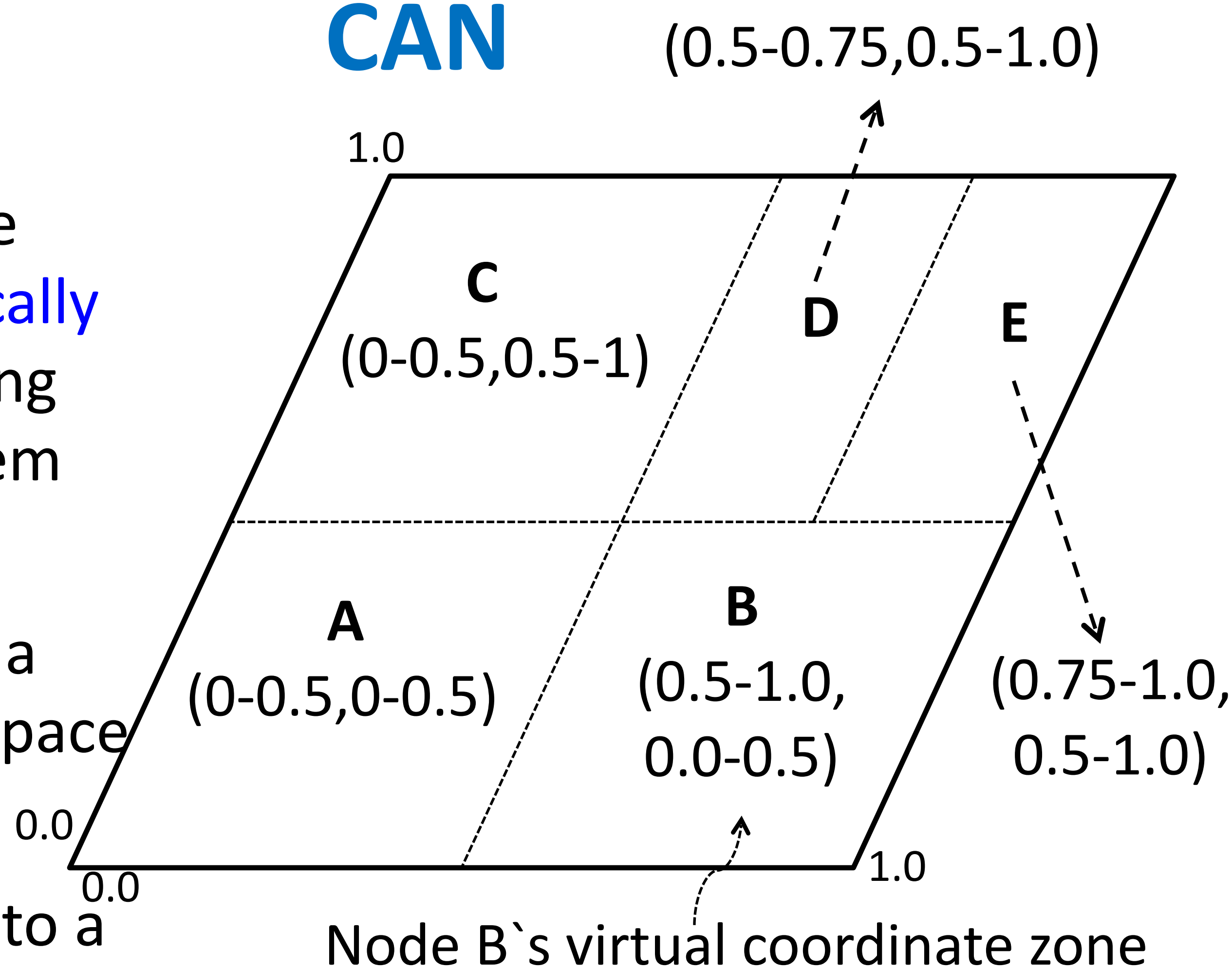


Example 2-d space
with 5 nodes

CAN

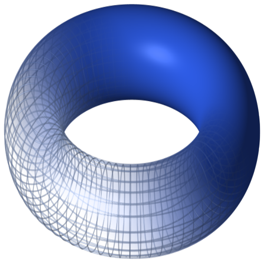
- Entire coordinate space is dynamically partitioned among all nodes in system
- Each node owns a distinct zone in space
- Each key hashes to a point in space

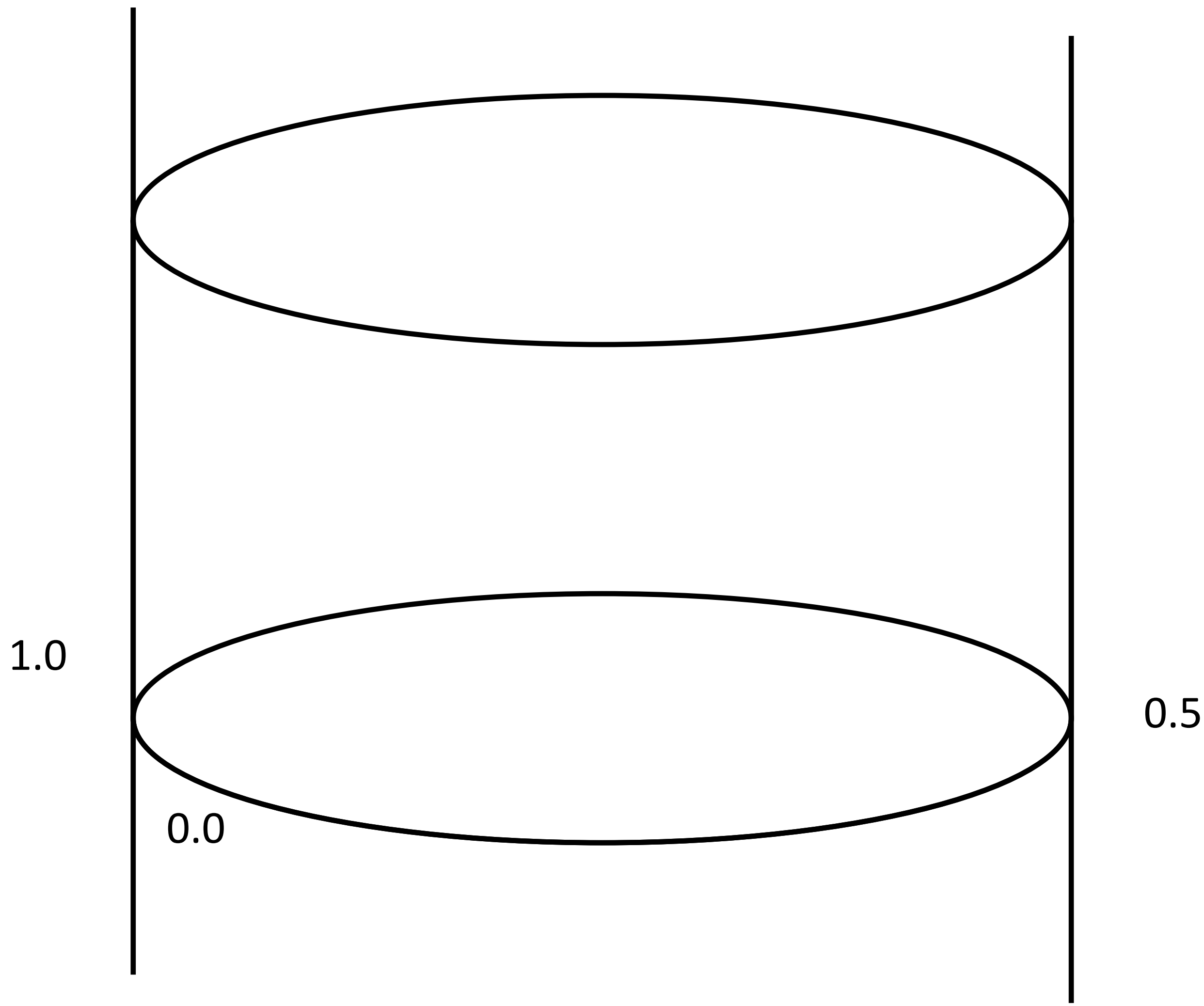


* All CAN figures from "A Scalable Content-Addressable Network", S. Ratnasamy et al., In Proceedings of ACM SIGCOMM 2001.

Coordinates Wrap Around

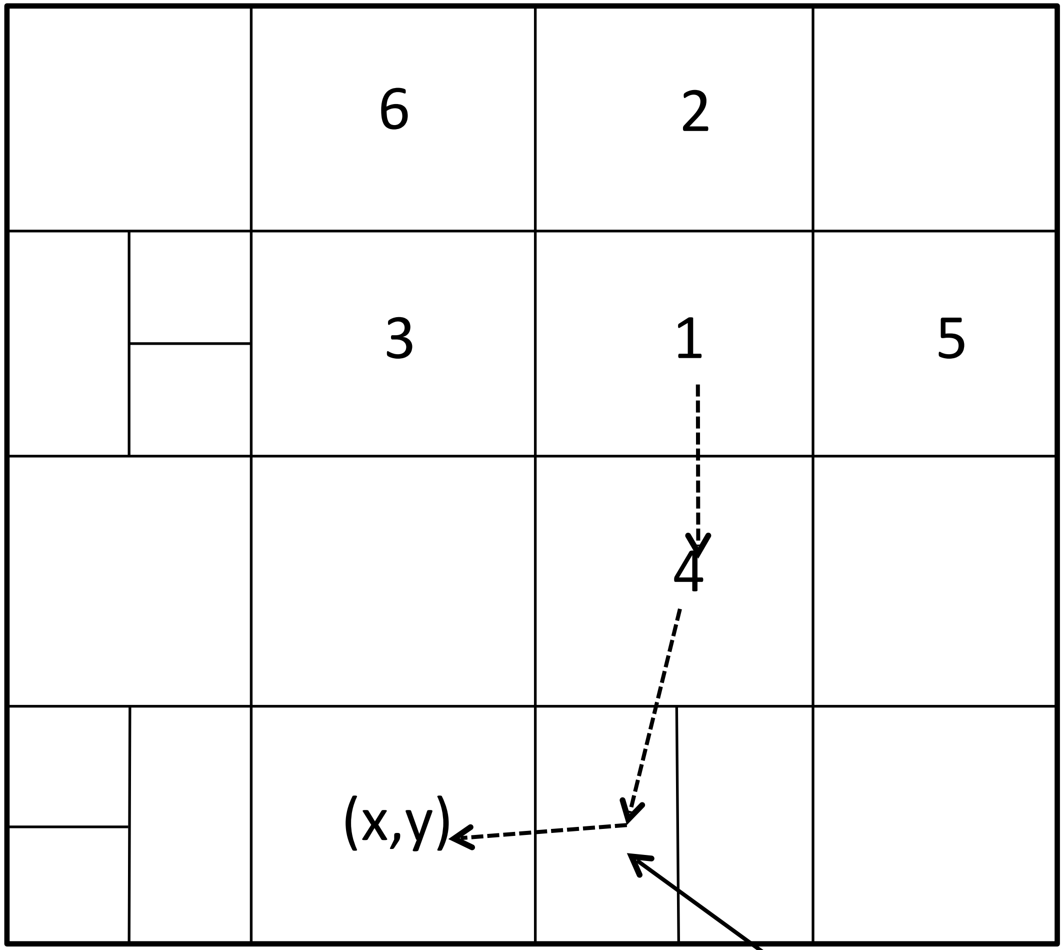
In all dimensions (only x-axis shown)





CAN Routing

- Put(key, data), get(key)
- Greedily forward message to neighbor closest to destination in Cartesian coordinate space
- Nodes maintain a routing table that holds IP address and zone of its neighbours



Sample routing path from node 1 to point (x,y)

1`s coordinate neighbor set = {2,3,4,5}

CAN Routing

- Many possible routing paths exist between two points in space
- If a neighbour on a path crashes, simply pick the next best available (node) path

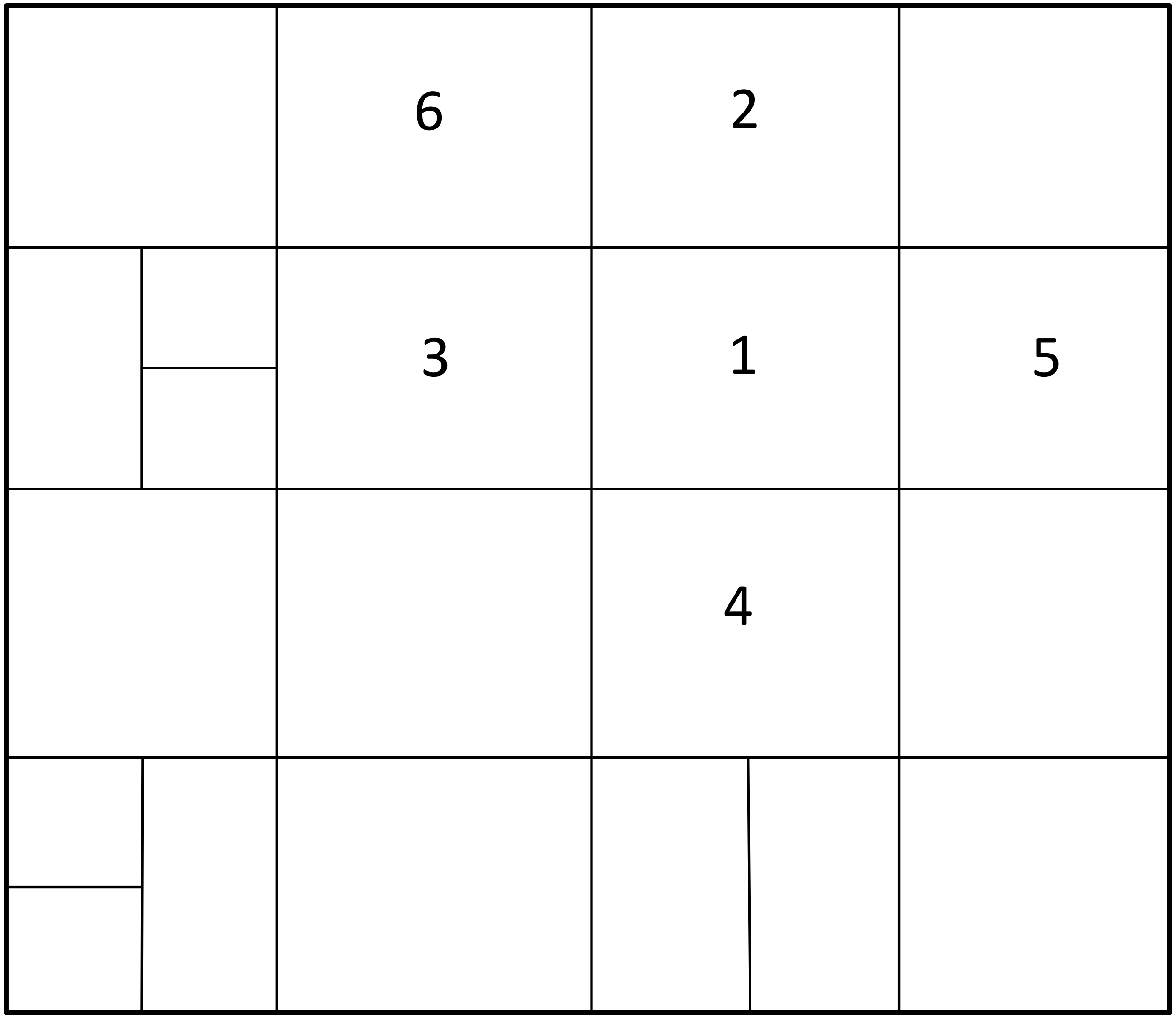
Average Path Length

- ***d*-dimensional space**, partitioned into ***n* equal-sized zones**, **average routing path length** is: $d/4 * n^{1/d}$
- Each node maintains $2d$ neighbours
- Grow number of nodes, without affecting per node state
- Grow number of nodes, increases path length by $O(n^{1/d})$
- 2-dimensional space: $1/2 * n^{1/2}$ (average routing path)
- 3-dimensional space: $3/4 * n^{1/3}$ (average routing path)

Node Joining a CAN

- Find a node already in overlay network
- Identify a zone that can be split
  - Pick random point
  - Route join request to node managing the point's zone
  - Initiate split of zone at that node
- Update routing tables of nodes neighbouring newly split zone
- If refused, try with a new random point

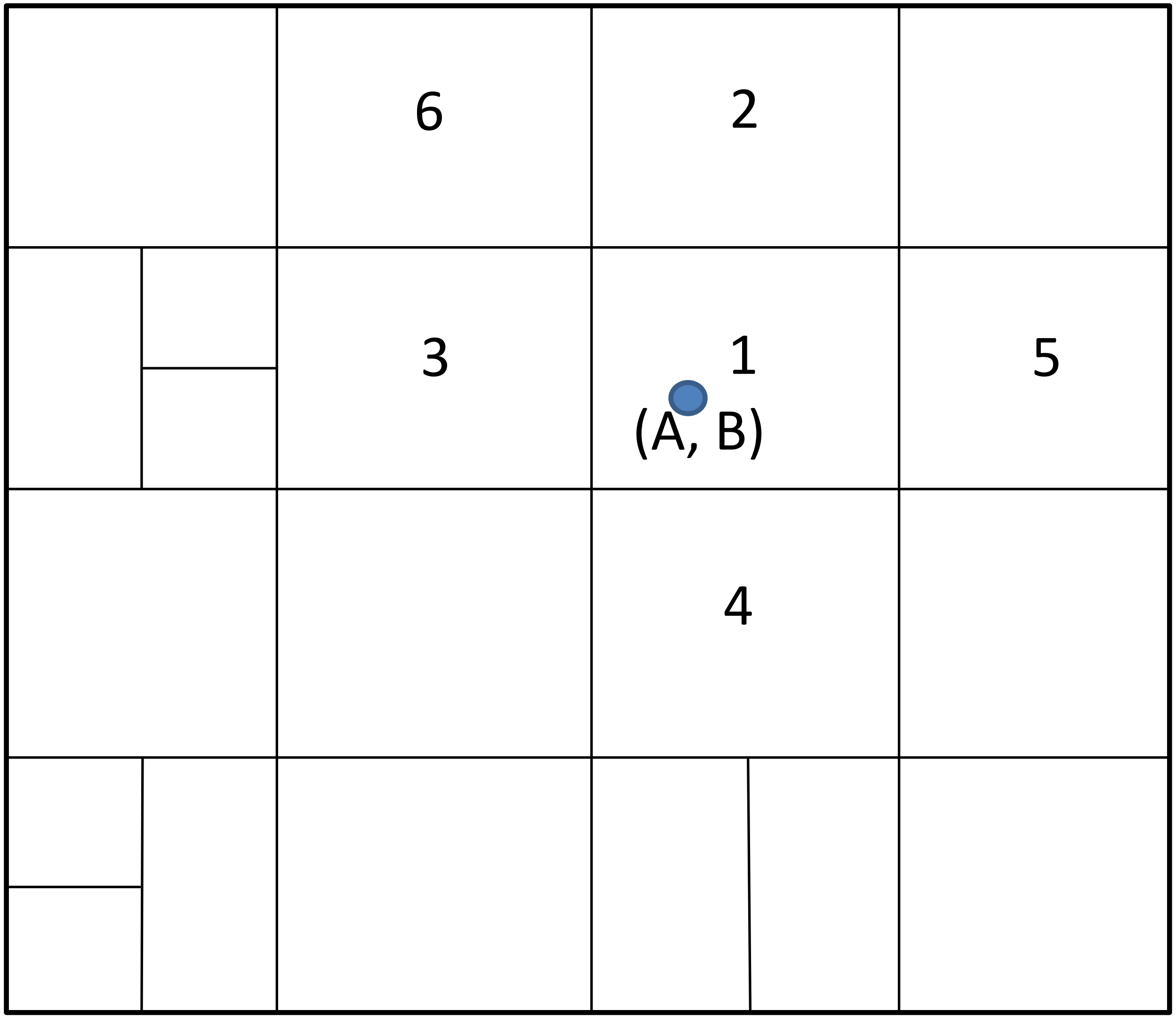
Zone Splitting Upon Node Joining



1`s coordinate neighbor set = {2,3,4,5}

Join request Node 7

Zone Splitting Upon Node Joining



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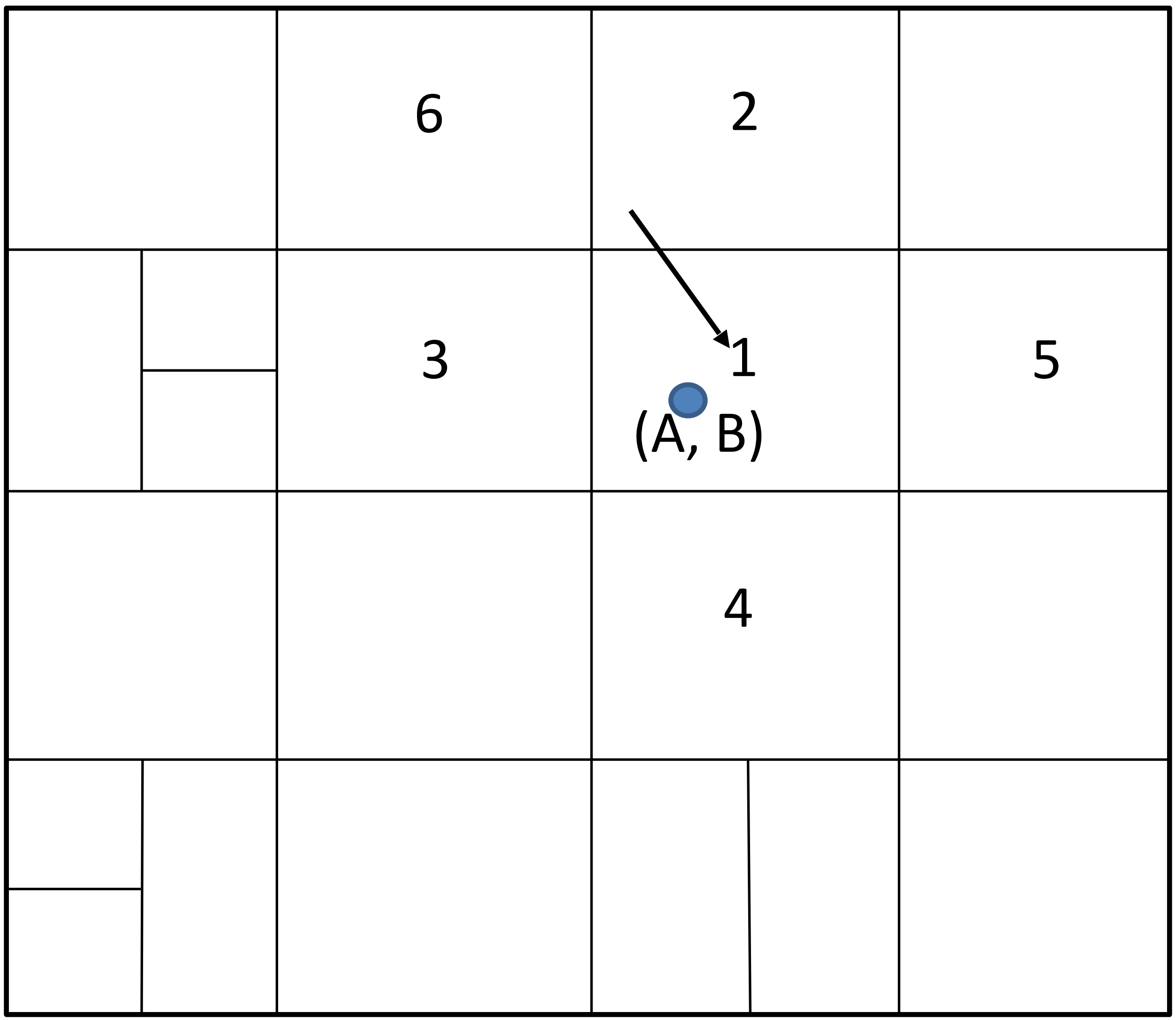
- Pick random point (A, B)

Zone Splitting Upon Node Joining



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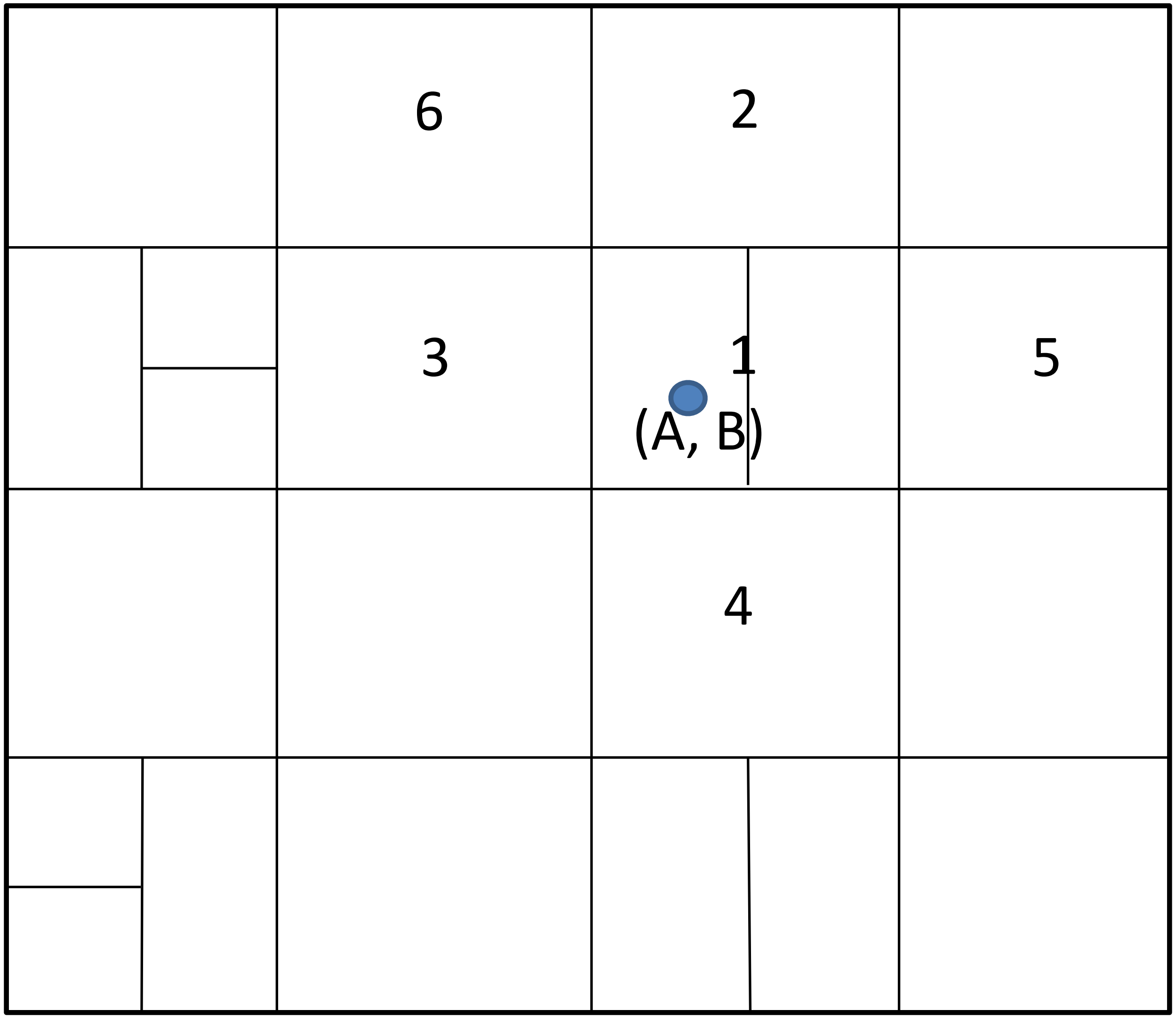
Join request Node 7

- Pick random point (A, B)
- Route join request of 7 to 1

Zone Splitting Upon Node Joining



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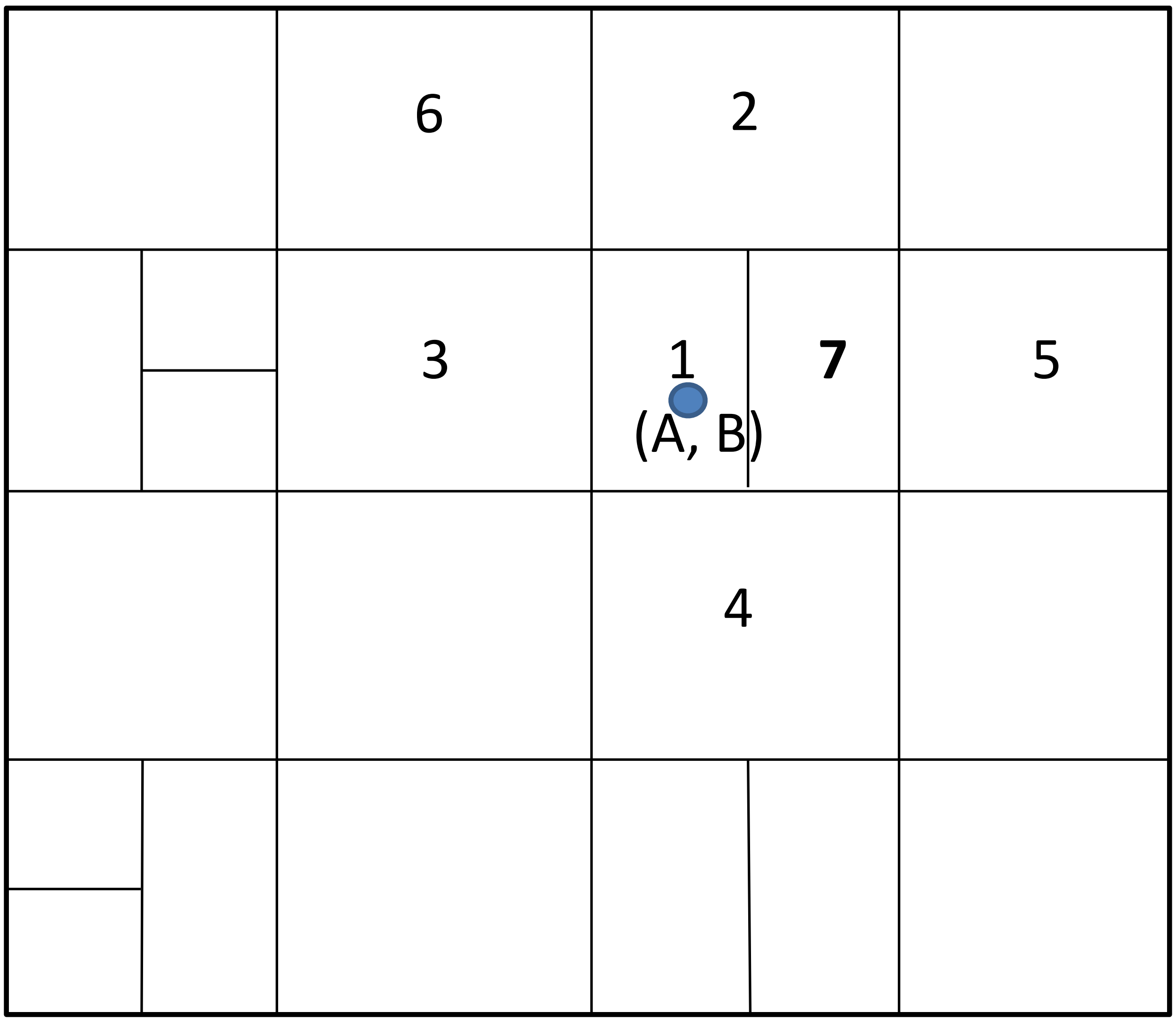
Join request Node 7

- Pick random point (A, B)
- Route join request of 7 to 1
- Initiate zone split

Zone Splitting Upon Node Joining



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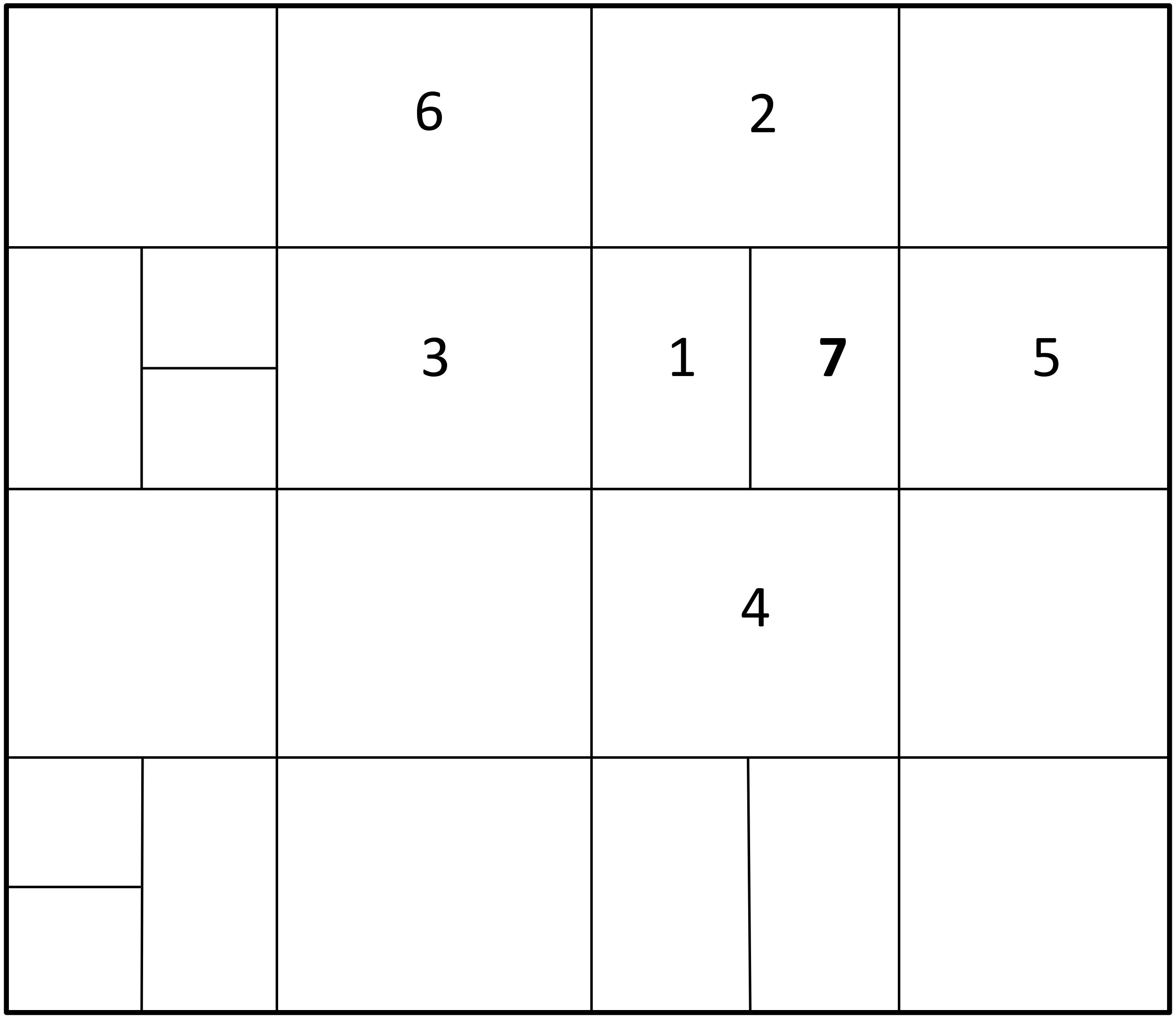


1`s coordinate neighbor set = {2,3,4,7}

7`s coordinate neighbor set = {1,2,4,5}

Update routing tables of nodes, transfer state, i.e., (k, v)-pairs (not shown)

Node Join Properties

- Only O(*d*) nodes are effected when a node joins/leaves CAN (a node has 2d neighbours)
- Independent of *n*, number of nodes in CAN

Pastry (2001)

- Ring-based partitioning like Chord
- Each peer discovers and exchanges state information: List of leaf nodes, neighborhood list, routing table
- **Leaf node list** are *L/2* closest peers by Node ID in each direction around the circle
  - Lookups first search the leaf node list
- **Neighborhood list** are *M* closest peers in terms of routing metric (e.g. ping delay)
  - Good candidates for routing table

Routing Table

- 6 digits, base 4: table of 6x4 entries
- Row *i* contains nodes which share *i-1-th* long prefix
- Populate cells with neighbors if possible
- Column indicates *i-th* digit
- Lookup in RT finds a node with a longer prefix

Node 103220	0	1	2	3
1	031120	**1**03220	201303	312201
2	**10**3220	110003	120132	132012
3	100221	101203	102303	**103**220
4		103112	**1032**20	103302
5		103210	**10322**0	
6	**103220**			

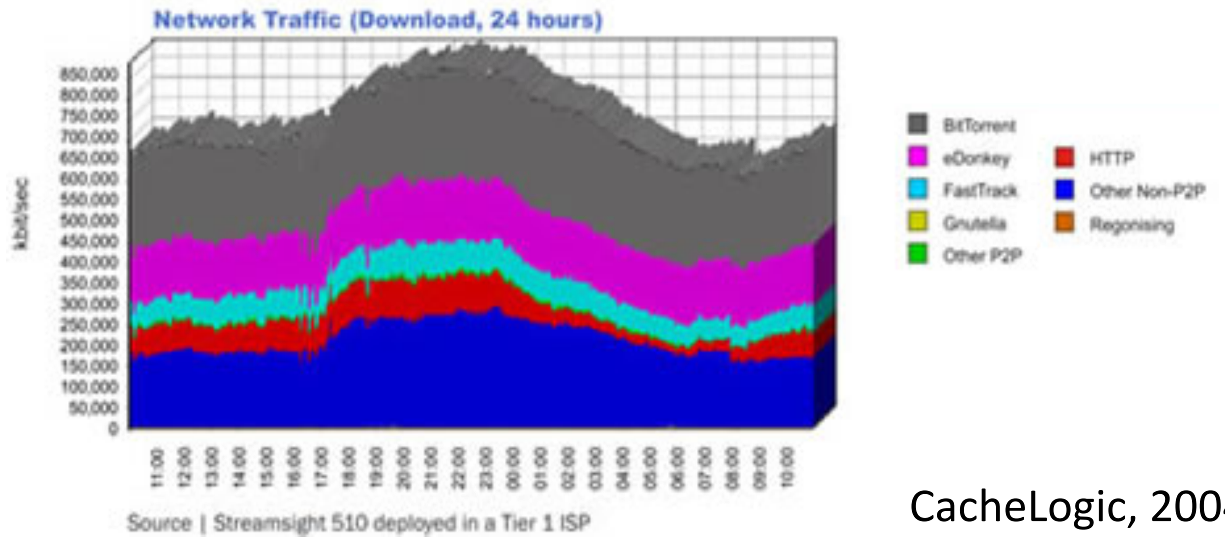
Example: lookup(102332) -> 102303

DHT Routing Summary

- Chord
  - Finger table routing
    - Each hop at least halves distance (in identifier circle) to destination
- Pastry
  - Proximity-based Routing
- CAN
  - Neighbour routing
    - Forward to neighbor closest (in Cartesian coordinate space) to destination

Conclusions on P2P

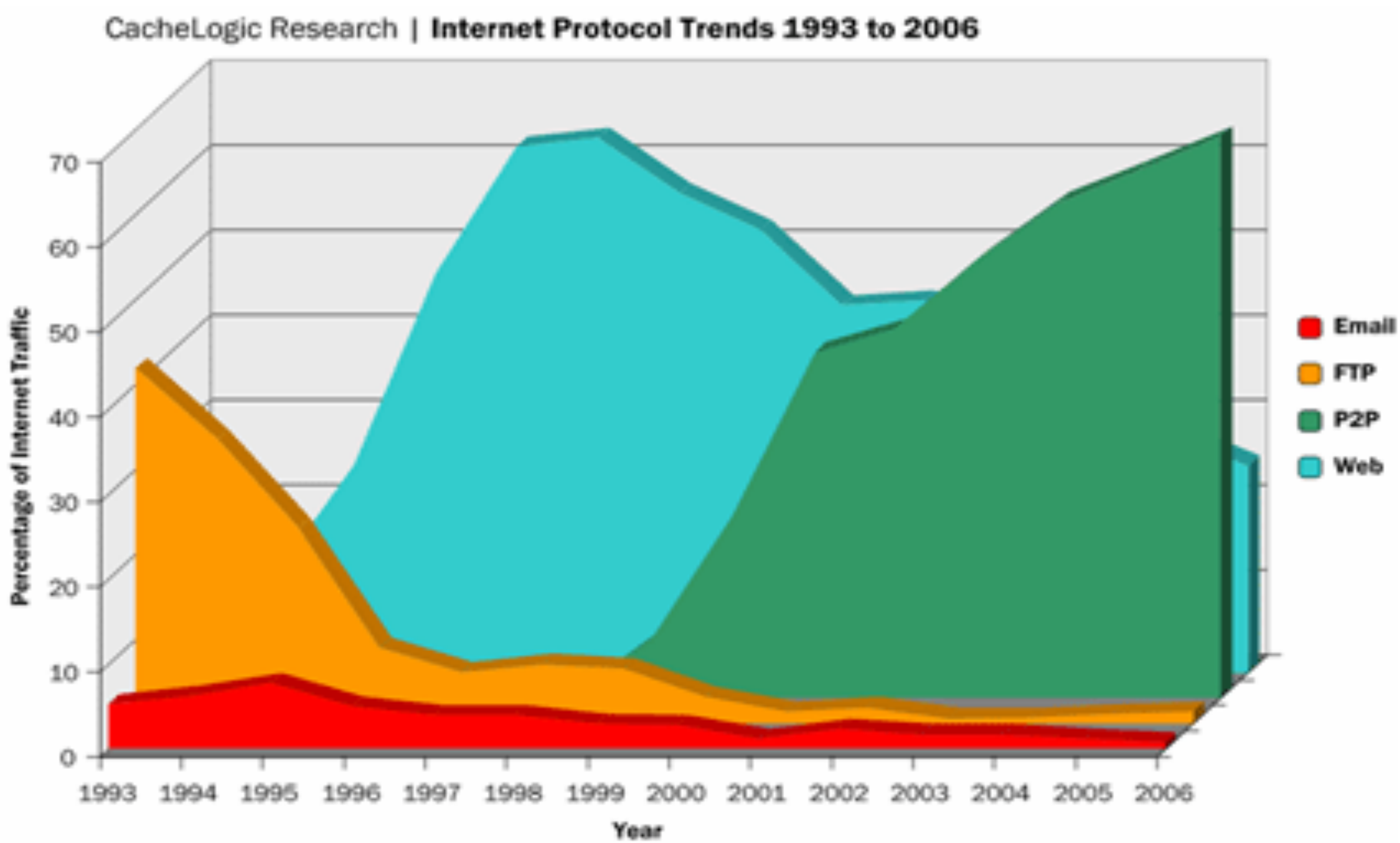
- Hugely popular area of research 2000-2010
- Large-scale companies (Amazon & Google et al.) prefer self-managed cloud infrastructures
- P2P principles, techniques and abstractions are used by large-scale systems (e.g., **DHTs**)
- Active applications: **BitTorrent, Bitcoin** *et al.*
- Peer-assisted, hybrid systems were popular: **Skype**, **Spotify**, etc.



CacheLogic, 2004

PEER-TO-PEER APPLICATIONS

More data
(Source: CacheLogic)



Spotify - Large Scale, Low Latency, P2P Music-on-Demand Streaming
Gunnar Kreitz, Fredrik Niemelä
IEEE P2P'10

Following slides are adapted from authors' slides at P2P in 2010 & 2011.

SPOTIFY

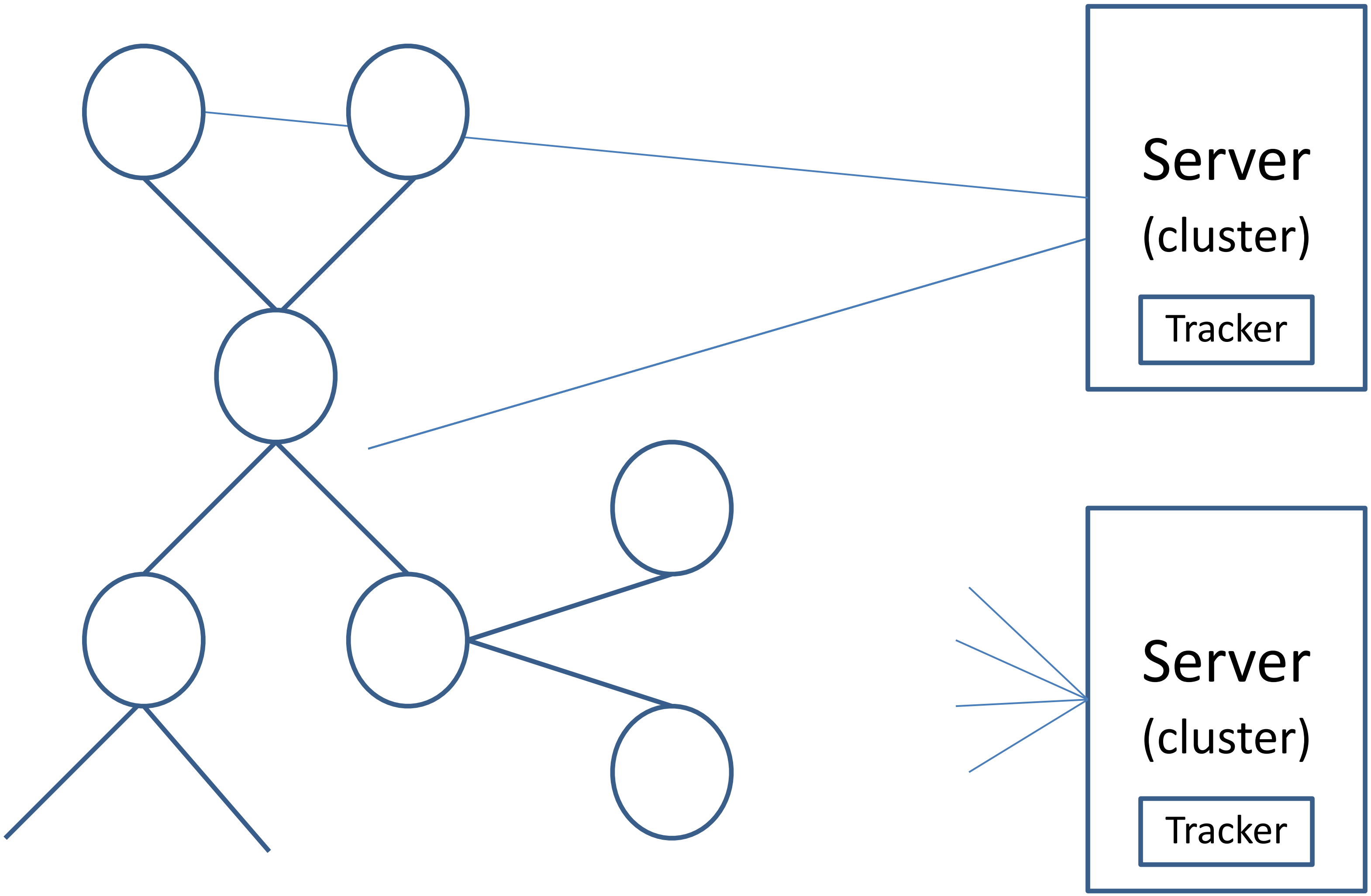
Spotify.com, 2004

- Commercially deployed system, KTH start-up (Sweden)
- Peer-assisted on-demand music streaming
- Legal and licensed content, only
- Large catalogue of music (over 15 million tracks)
- Available in U.S. & 7 European countries, over 10 million users, 1.6 million subscribers (in 2004)
- Fast (median playback latency of 265 ms)
- Proprietary client software for desktop & phone (not p2p)
- Business model: Ad-funded and free & monthly subscription, no ads, premium content, higher quality streaming

Overview of Spotify Protocol

- Proprietary protocol
- Designed for on-demand music streaming
- Only Spotify can add tracks
- 96–320 kbps audio streams (most are Ogg Vorbis q5, 160 kbps)
- Relatively simple and straightforward design
- Phased out in 2014: "*We're now at a stage where we can power music delivery through **our** growing number of **servers** and ensure our users continue to receive **a best-in-class service**.*"
- Conclusion: *Commercially*, P2P technology is good for **startups** who demand more resources than their servers offer. Avoid "***death by success***".

Spotify architecture: Peer-assisted



Why a Peer-to-peer Protocol?

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- **Improve scalability** of service

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- **Improve scalability** of service
- **Decrease load** on servers and network resources

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- Explicit design goal

Why a Peer-to-peer Protocol?

- **Improve scalability** of service
- **Decrease load** on servers and network resources

- Explicit design goal
  – Use of peer-to-peer should not decrease overall performance (i.e., playback latency & stutter)

Peer-to-peer Overlay Structure

- Unstructured overlay
- Does not use a DHT
  - **Fast lookup required (Hybrid p2p)**
  - Let us do some rough estimates (ping times)
    - Latency UK – Netherlands ~ 10 ms and up
    - Latency across EU more like ~ 80 ms and up
    - Latency US – Europe ~ 100 ms and up
    - Playback latency ~265 ms
    - <1% Playbacks have stuttering
  - **Simplicity of protocol design & implementation**

Peer-to-peer Overlay Structure

- Nodes have fixed maximum degree (60)
- Neighbour eviction by heuristic evaluation of utility
- Looks for and connects to new peers when streaming new track
- Overlay becomes (weakly) clustered by interest
- Client only downloads data user needs

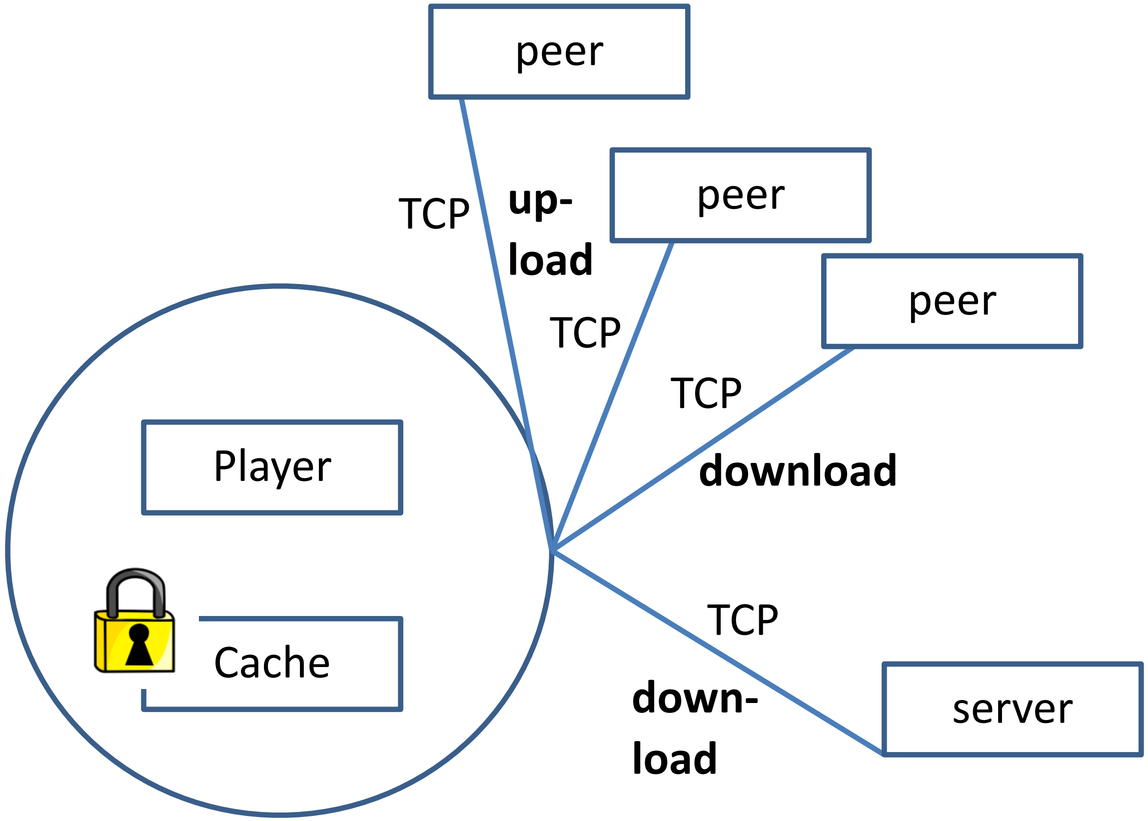
Finding Peers

- Server-side tracker (cf. BitTorrent)
  - Only remembers 20 peers per track
  - Returns 10 (online) peers to client on query

- Clients broadcast query in small (2 hops) neighbourhood in overlay (cf. Gnutella)

- Client uses both mechanisms for every track

Peers


peer
peer
peer
TCP
up-
load
TCP
TCP
download
Player
Cache
TCP
down-
load
server

Protocol

- (Almost) everything encrypted
- (Almost) everything over TCP
- Persistent connection to server while logged in
- Multiplex messages over a single TCP connection

Caches

- Client (player) caches tracks it has played
- Default policy is to use 10% of free space (capped at 10 GB)
- Caches are often larger (56% are over 5 GB)
- Least Recently Used policy for cache eviction
- Over 50% of data comes from local cache
- Cached files are served in peer-to-peer overlay (if track completely downloaded)

Streaming a Track

- Tracks are decomposed into 16 kB chunks
- Request first chunk of track from Spotify servers
- Meanwhile, search for peers that cache track
- Download data in-order (chunk by chunk via TCP)
- Towards end of a track, start prefetching next track

Streaming a Track

- If a remote peer is slow, re-request data from new peers
- If local buffer is sufficiently **filled**, only download from peer-to-peer overlay
- If **buffer** is getting **low**, download from central server as well
  - Estimate at what point p2p download could resume
- If **buffer** is **very low**, stop uploading

Security Through Obscurity, ☹

- Music data lies encrypted in caches
- Client must be able to access music data
- Reverse engineers should not be able to access music data
- Details are secret and client code is obfuscated

- **Do not do this "at home"**
  – ***Security through obscurity*** is a bad idea
  – It is a matter of time until someone hacks the Spotify client (cf. the various Skype reverse engineering efforts)

Data sources: 8.8% from servers, 35.8% from p2p network, 55.4 % from caches

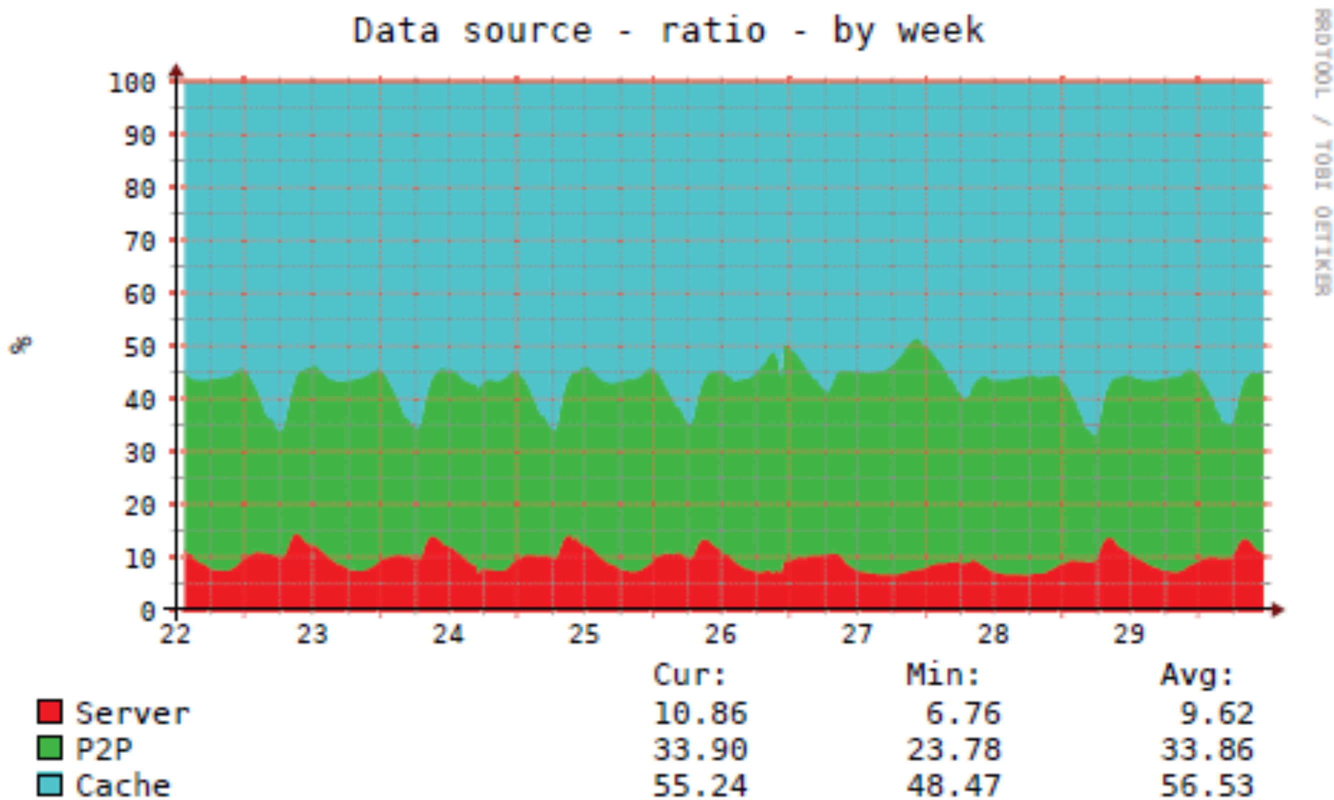
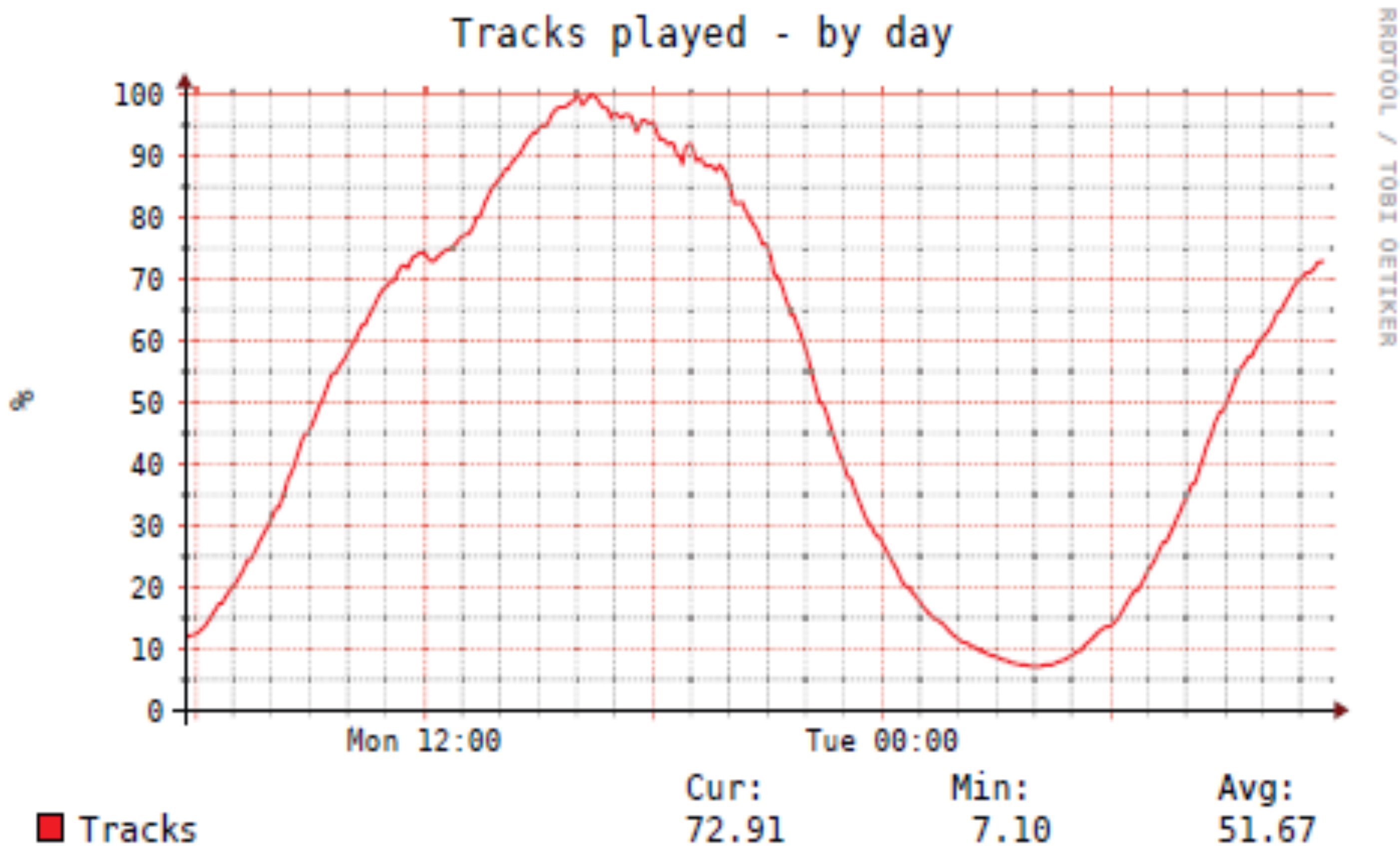


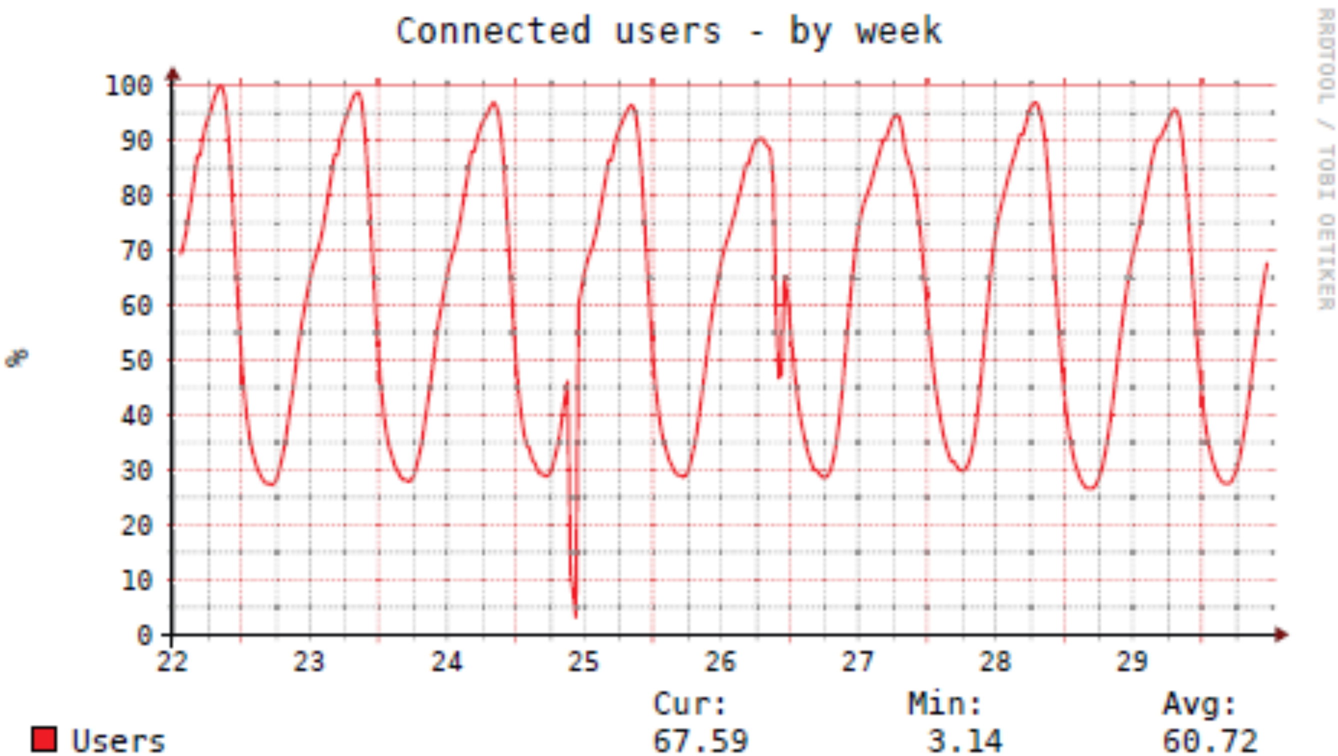
Figure 2. Sources of data used by clients

Tracks played



(a) Tracks played

Users connected



(b) Users connected

Key Points

- Simplicity of architecture, protocol, design
- Peer-assisted, i.e., rely on centralized server
- Use of peer-to-peer techniques for scalability and avoid heavy, over-provisioned infrastructure
- Use of centralized tracker

Incentives build robustness in BitTorrent
by Bram Cohen

BitTorrent Protocol Specification
http://www.bittorrent.org/protocol.html

BIT TORRENT

BitTorrent

- Written by Bram Cohen (in Python) in 2001
- Pull-based, swarming approach (segmented)
  - Each file is split into smaller pieces (& sub-pieces)
  - Peers request desired pieces from neighboring peers
  - Pieces are not downloaded in sequential order
- Encourages contribution by all peers
  - Based on a **tit-for-tat model**

BitTorrent Use cases

- File-sharing
- *What uses does BitTorrent support?*
  - Downloading (licensed only ☺) movies, music, etc.
  - *And …?*

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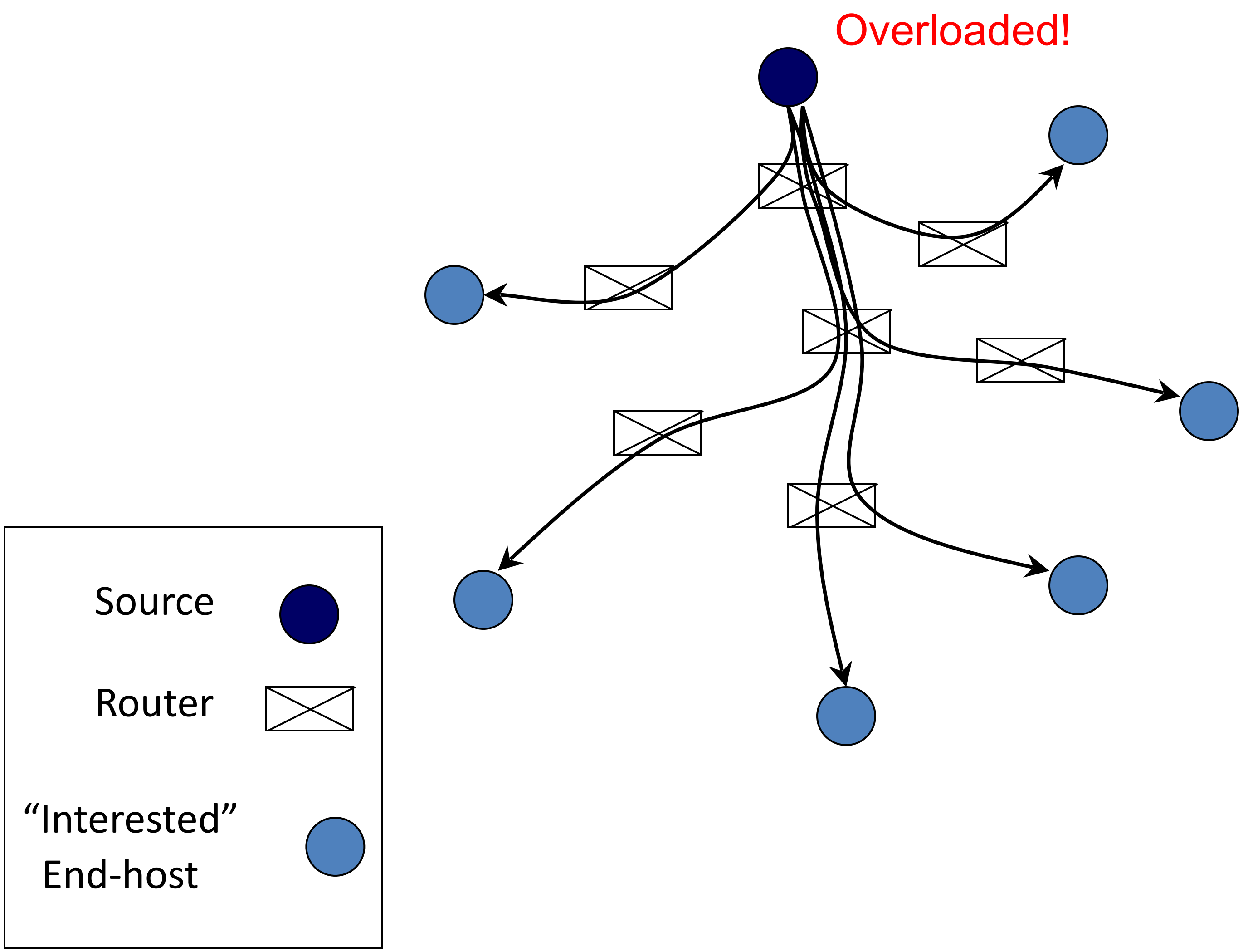
  - *And …?*
    - Update distribution among servers at Facebook et al.
    - Distribution of updates and releases (e.g., World of Warcraft -> Blizzard Downloader)
    - …

Client-server



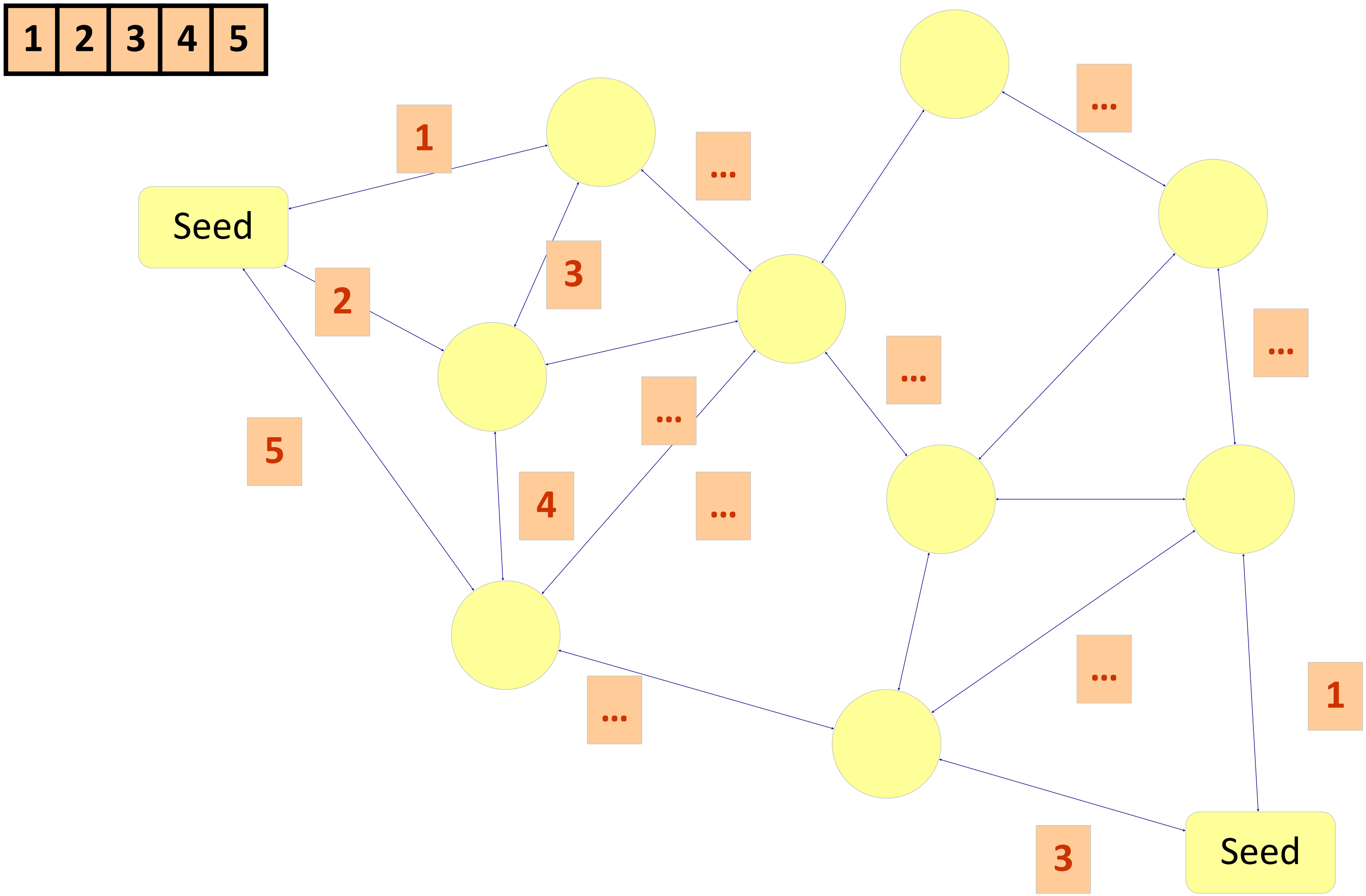
BitTorrent Swarm

- **Swarm**
  - Set of peers downloading the same file
  - Organized as a randomly connected mesh of peers
- Each peer knows list of pieces downloaded by neighboring peers
- Peer requests pieces it does not own from neighbors

BitTorrent Terminology

- **Seed**: Peer with the entire file
  - **Original Seed**: First seed for a file
- **Leech**: Peer downloading the file
  - Leech becomes a seed, once file downloaded, if the peer stays online & continues by protocol
- **Sub-piece**: Further subdivision of a piece
  - “Unit for requests” is a sub-piece (16 kB)
  - Peer uploads piece only after assembling it completely

BitTorrent Swarm



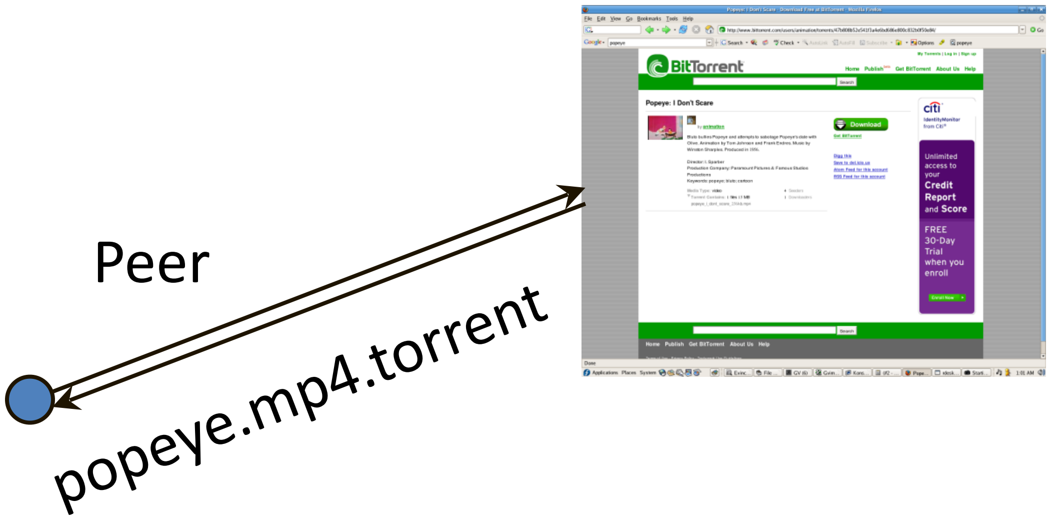
* From Analyzing and Improving BitTorrent by Ashwin R. Bharambe, Cormac Herley and Venkat Padmanabhan

Entering a Swarm
for file "popeye.mp4"

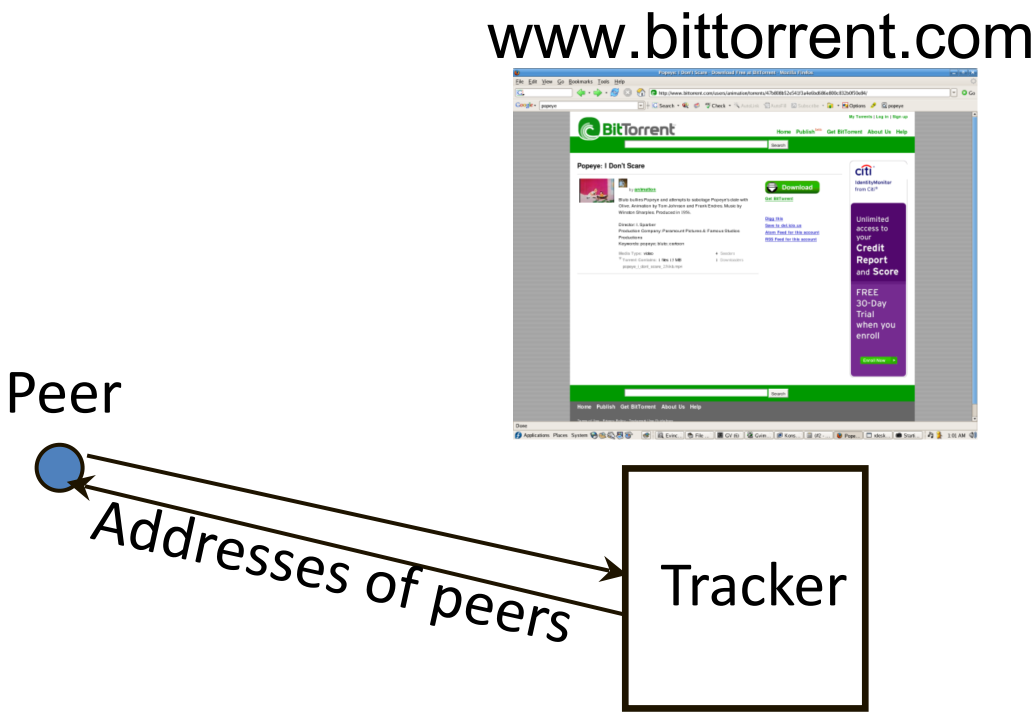
- File **popeye.mp4.torrent** hosted at a (well-known) web server
- The **.torrent** has address of **tracker** for file
- The tracker, which runs on a web server as well, keeps track of all peers downloading file

Find the Torrent for Desired Content

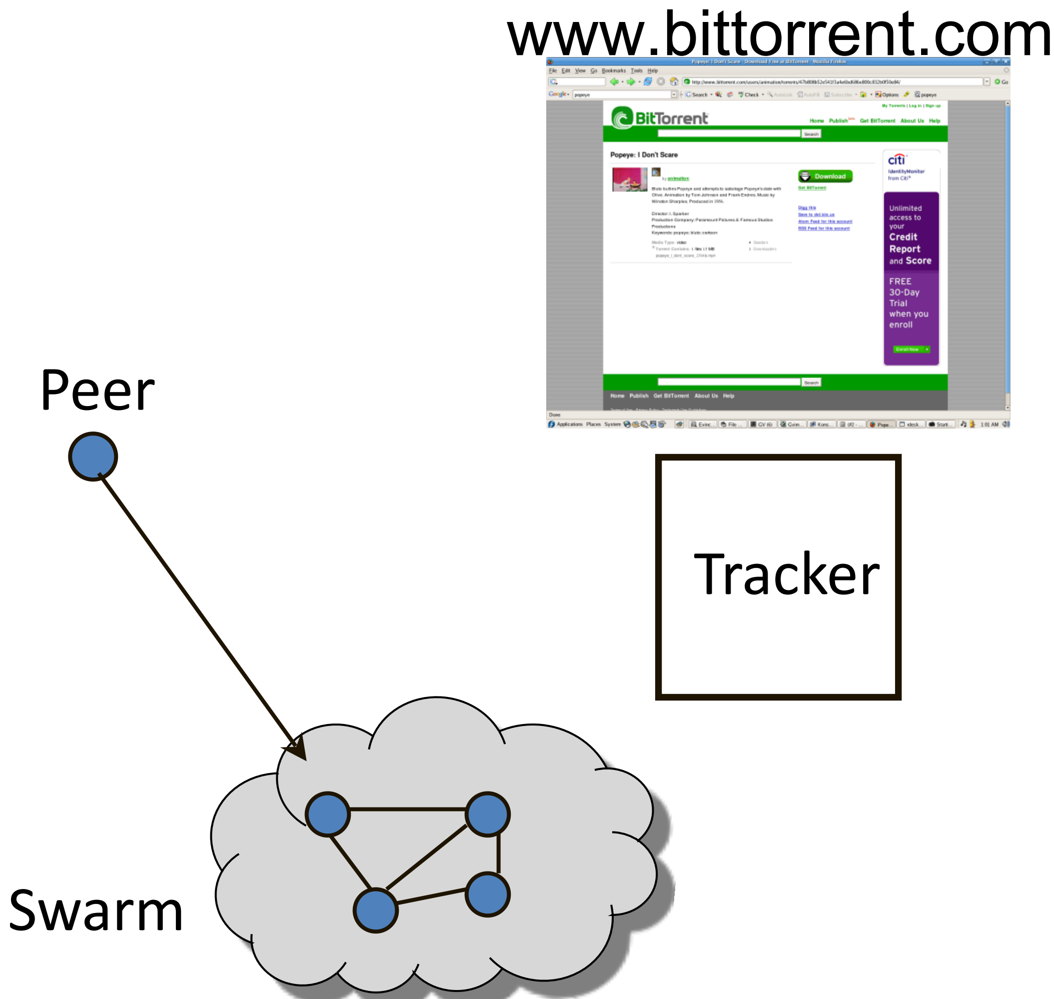
www.bittorrent.com or anywhere



Contact the Tracker of Retrieved Torrent



Connect to Available Peers

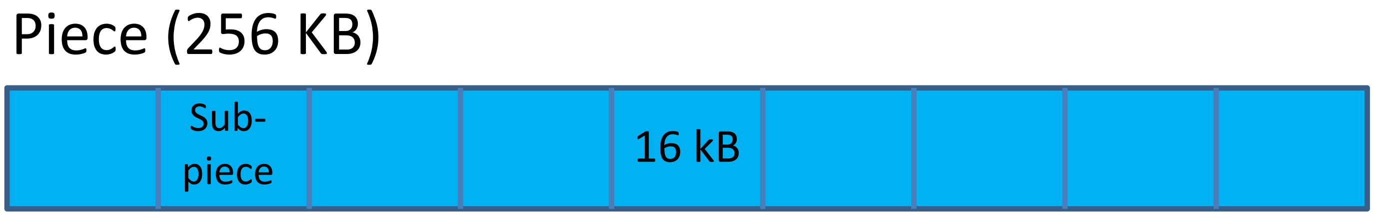


Contents of .torrent File

- URL of tracker
- Piece length – usually 256 KB
- SHA-1 hashes of each piece in file - ***Why?***

Download Phases

- **Beginning**: First piece
- **Middle**: Piece 2 to n-x
- **End-game**: Pieces n-x to n



Middle: Choosing Pieces to Request

- *What is a good strategy?*
  - Most frequent first vs. rarest first?

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- **Rarest-first**: Look at all pieces at all neighboring peers and request a piece that's owned by the fewest peers – ***Why?***

Middle: Choosing Pieces to Request

- *What is a good strategy?*
  - Most frequent first vs. rarest first?
- **Rarest-first**: Look at all pieces at all neighboring peers and request a piece that's owned by the fewest peers – ***Why?***
  - **Increases diversity** in pieces downloaded
    - Avoids case where a node and each of its peers have exactly the same pieces
    - Increases system-wide throughput
  - Increases **likelihood all pieces still available** even if original seed leaves before any one node has downloaded entire file

Choosing Pieces to Request: Initial Piece

- First, pick a random piece (**random first policy**)
  - When peer starts to download, request random piece from a peer
  - When first complete piece assembled, **switch to rarest-first**

Choosing Pieces to Request: Initial Piece

- First, pick a random piece (**random first policy**)
  - When peer starts to download, request random piece from a peer
  - When first complete piece assembled, **switch to rarest-first**
  - Get first piece to quickly participate in swarm with upload
  - Rare pieces are only available at few peers (slows download down)
- **Strict priority policy**
  - Always **complete download of piece** (sub-pieces) before starting a new piece
  - Getting a complete piece as quickly as possible

Choosing Pieces to Request: Final Pieces

End-game mode

- Coupon's collector problem
- Send requests for the final piece to **all peers**
- Upon download of entire piece, cancel request for downloading that piece from other peers
- Speeds up completion of download, otherwise last piece could delay completion of download

- ***Why isn't this done all along?***

Why BitTorrent took off

- Working implementation (Bram Cohen) with simple well-defined interfaces for publishing content
- Open specification
- Many competitors got sued & shut down (Napster, KaZaA)
- Simple approach
  - Doesn't do "search" per se
  - Users use well-known, trusted sources to locate content

Pros & Cons of BitTorrent

- Proficient in utilizing partially downloaded files
- Discourages “freeloading”
  - By rewarding fastest uploaders
- Encourages diversity through “rarest-first”
  - Extends lifetime of swarm
- Works well for “hot content”

Pros & **Cons** of BitTorrent

- Assumes all interested peers active at same time

- Performance deteriorates if swarm “cools off”

- Too much overhead to disseminate small files

Pros & Cons of BitTorrent

- Dependence on centralized trackers
  - Single point of failure
    - New nodes can’t enter swarm if tracker goes down
    - Simple to design, implement, deploy
  - Today, BitTorrent supports trackerless downloads

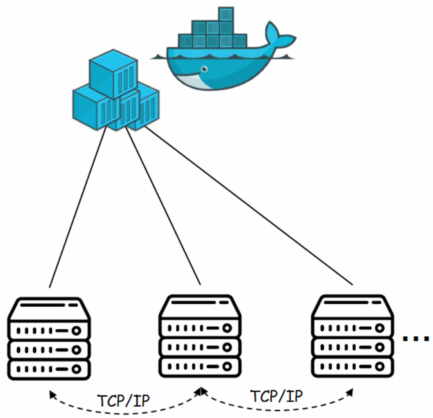
- Lack of a search feature
  - Users need to resort to out-of-band search: Well known torrent-hosting sites, plain old web-search

Docker Image Distribution via BitTorrent

- Docker images are containers that encapsulate applications and systems with full run-time stacks
- Image comprised of minimal file system composed of layers
- When launching a system based on containers, its images must be present on every node.
- Layers are downloaded from **central registry**
- Layers can be downloaded **in parallel**

Traditional Approach

- Every node downloads image layers from registry



Fact:
- 76% of the time spent on container deployment is spent on downloading layers

- Problem
  - High contention at registry
  - Images are pulled entirely from registry to every node
  - Massive network bandwidth overhead and performance bottleneck at the central registry!

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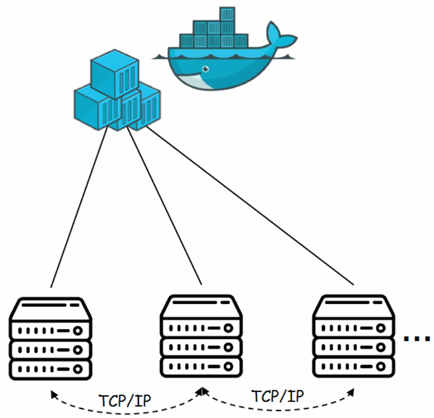

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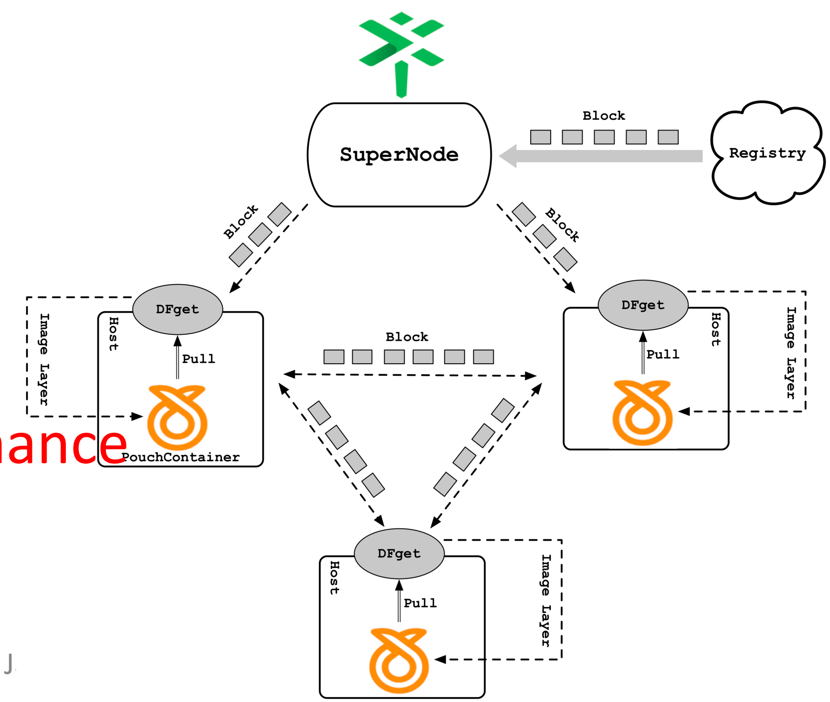
New Approach

P2P via BitTorrent (organization-internal)

- Nodes exchange available layers instead of inundating registry
- **Idea**: Chunk layers into small-sized blocks and distribute via BitTorrent (layer*XYZ*.torrent)
- Widely adopted in industry:
  - E.g., Alibaba Dragenfly, Uber Kraken, etc.

https://github.com/dragonflyoss/Dragonfly

https://github.com/uber/kraken



- Drastically improves performance (almost 100x speedup!)

Spotify vs. BitTorrent

- Live listening of streamed track
- One peer-to-peer overlay for all tracks
- Does not inform peers about downloaded blocks
- Downloads blocks in order
- Does not enforce fairness
- Informs peers about urgency of request
- Supports search

- Batch download of large files
- Essentially, a swarm (overlay) per torrent
- Exchange of downloaded blocks with peers
- Random download order
- Tit-for-tat (game theoretic roots)
- No notion of urgency
- No search feature