CS 43: Computer Networks
BitTorrent, DHTs, and CDNs

Kevin Webb

Swarthmore College

February 15, 2022

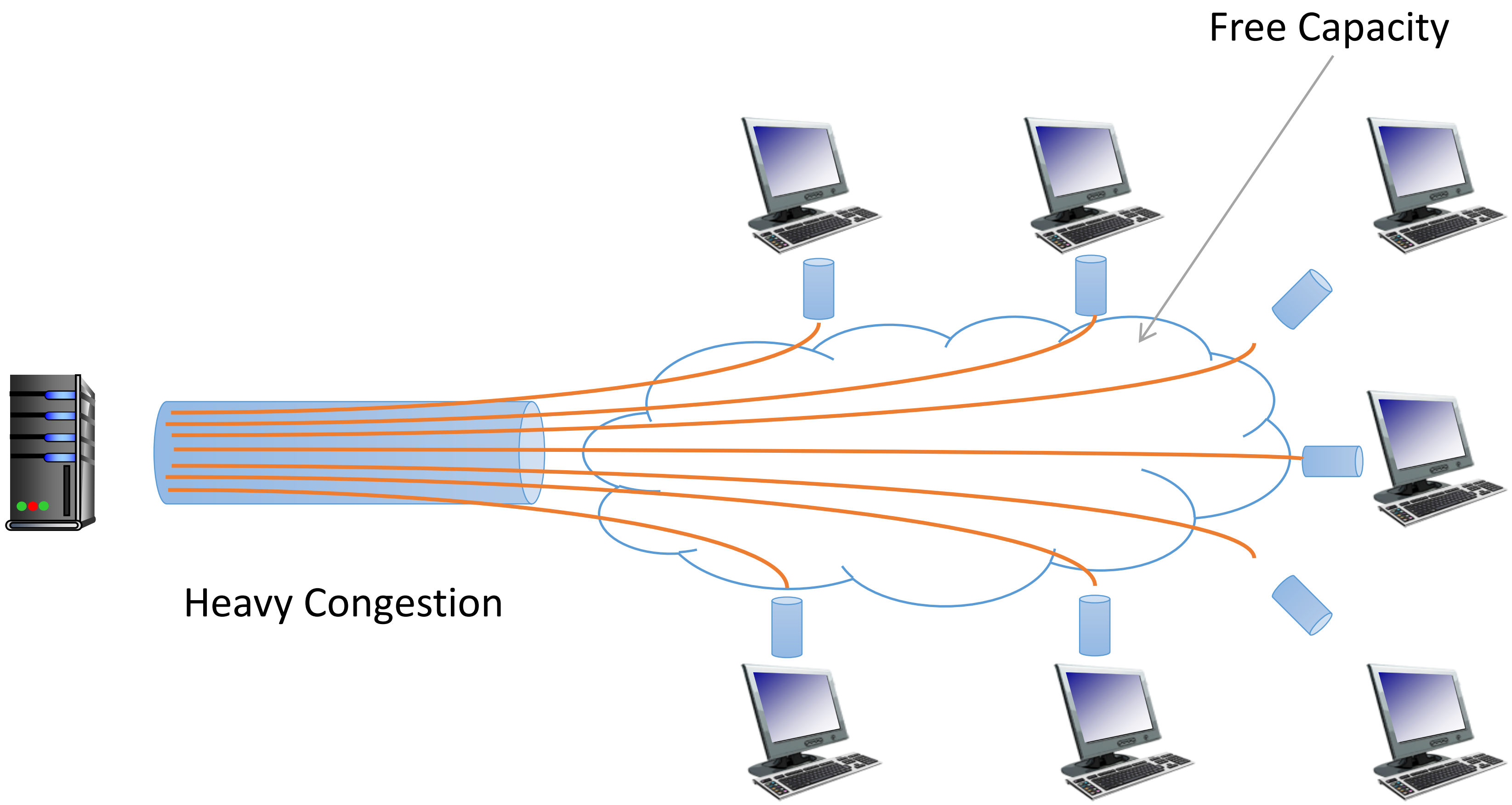
Agenda

- BitTorrent
  - Cooperative file transfers
- Briefly: Distributed Hash Tables
  - Finding things without central authority
- Content distribution networks (CDNs)
  - Add hosts to network to exploit locality
- Video streaming (DASH)

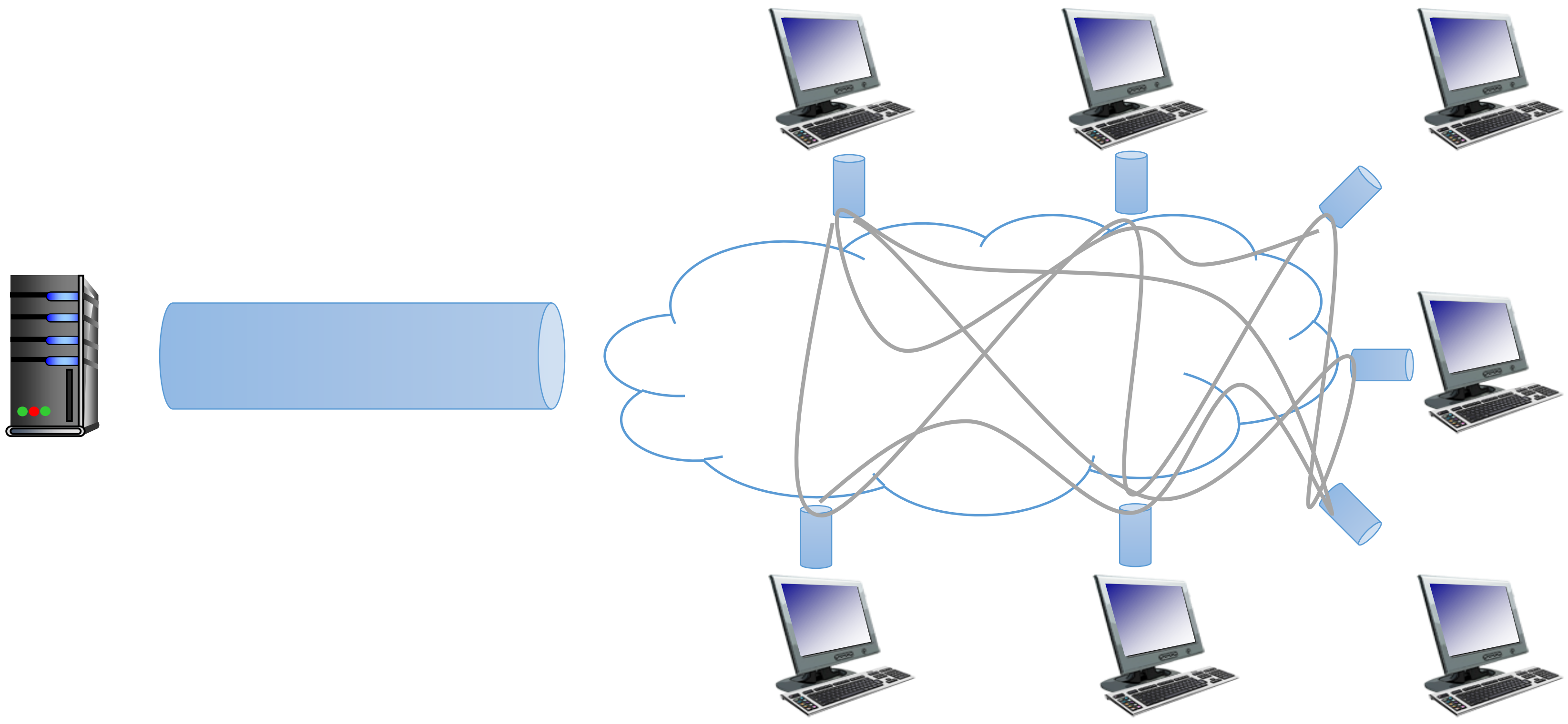
File Transfer Problem

- You want to distribute a file to a large number of people as quickly as possible.

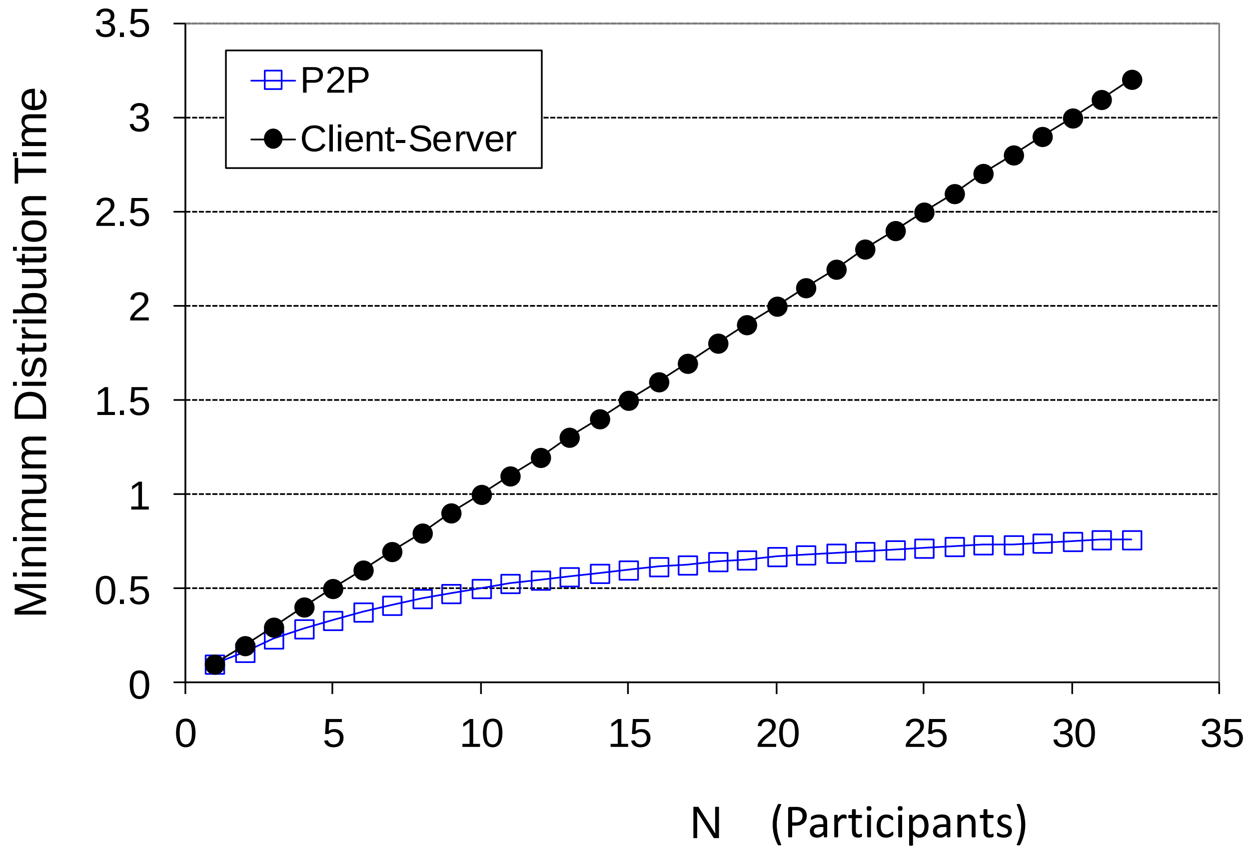
Traditional Client/Server



P2P Solution



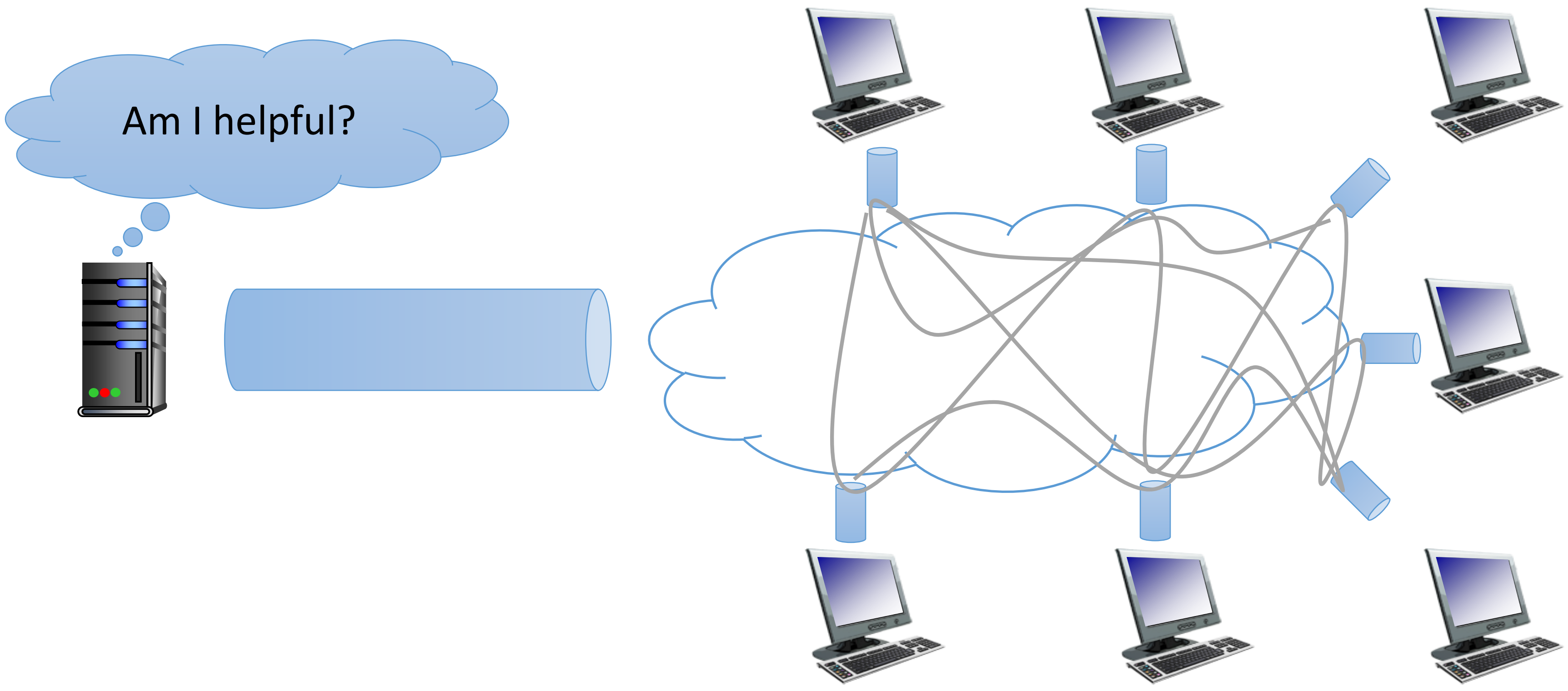
Client-server vs. P2P: example



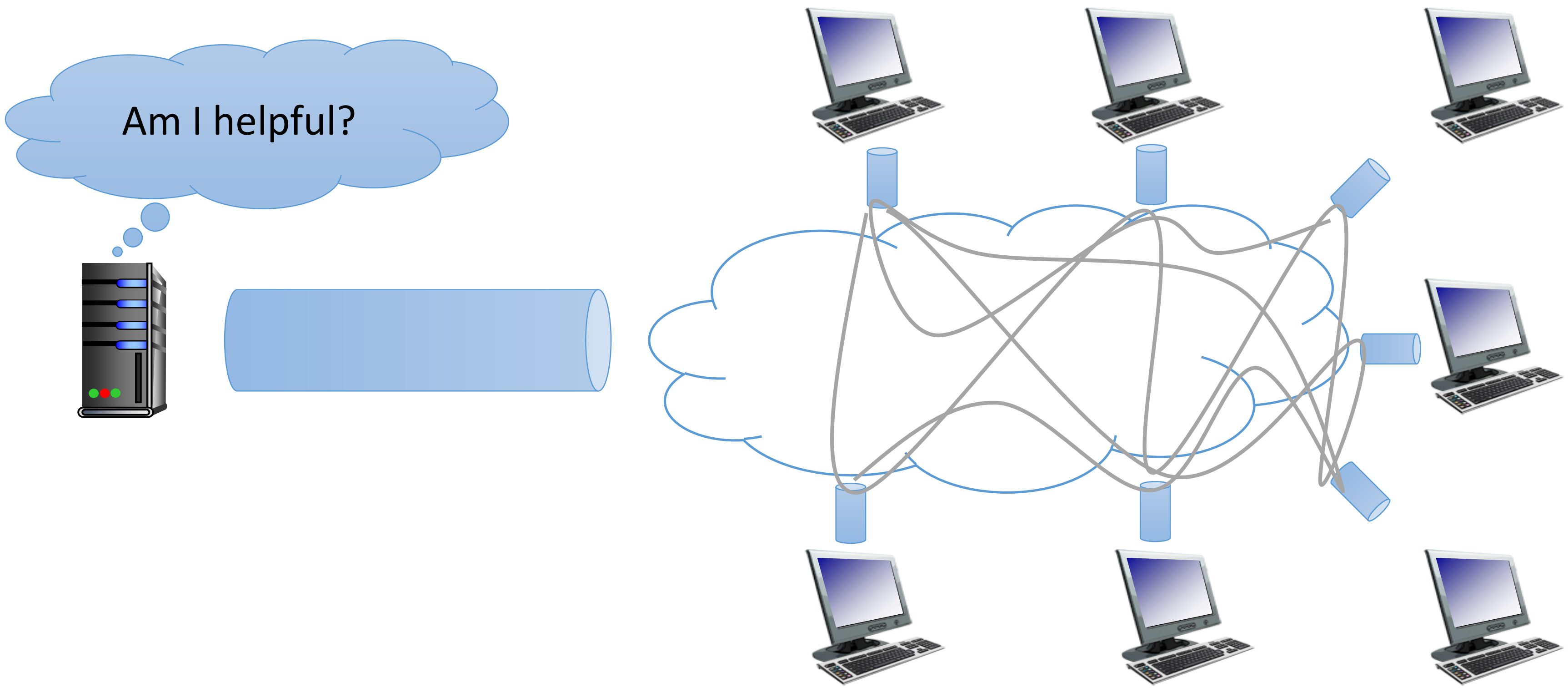
Let F = file size, client UL rate = u, server rate = u_s, d = client DL rate

Assumptions: F/u = 1 hour, $u_s = 10u$, $d_{min} \geq u_s$

P2P Solution



Do we need a centralized server at all? Would you use one for something?

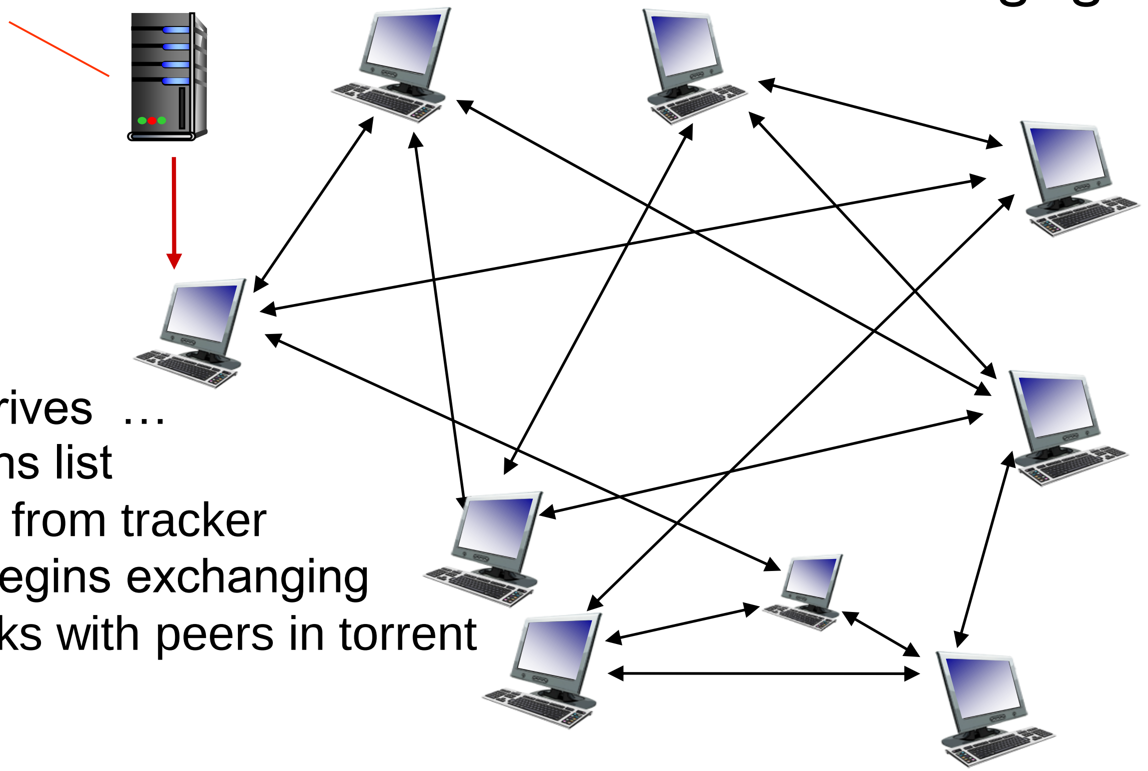


P2P file distribution: BitTorrent

- File divided into chunks (commonly 256 KB)
- Peers in torrent send/receive file chunks

tracker: tracks peers participating in torrent

torrent: group of peers exchanging chunks of a file



Node arrives …
… obtains list
of peers from tracker
… and begins exchanging
file chunks with peers in torrent

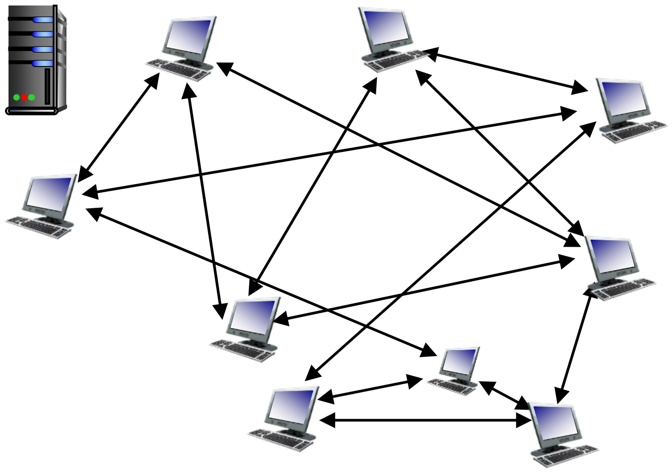
.torrent files

- Contains address of tracker for the file
  - Where can I find other peers?

- Contain a list of file chunks and their cryptographic hashes
  - This ensures pieces are not modified

P2P file distribution: BitTorrent

- Peer joining torrent:
  - has no chunks, but will accumulate them over time from other peers
  - registers with tracker to get list of peers, connects to subset of peers ("neighbors")



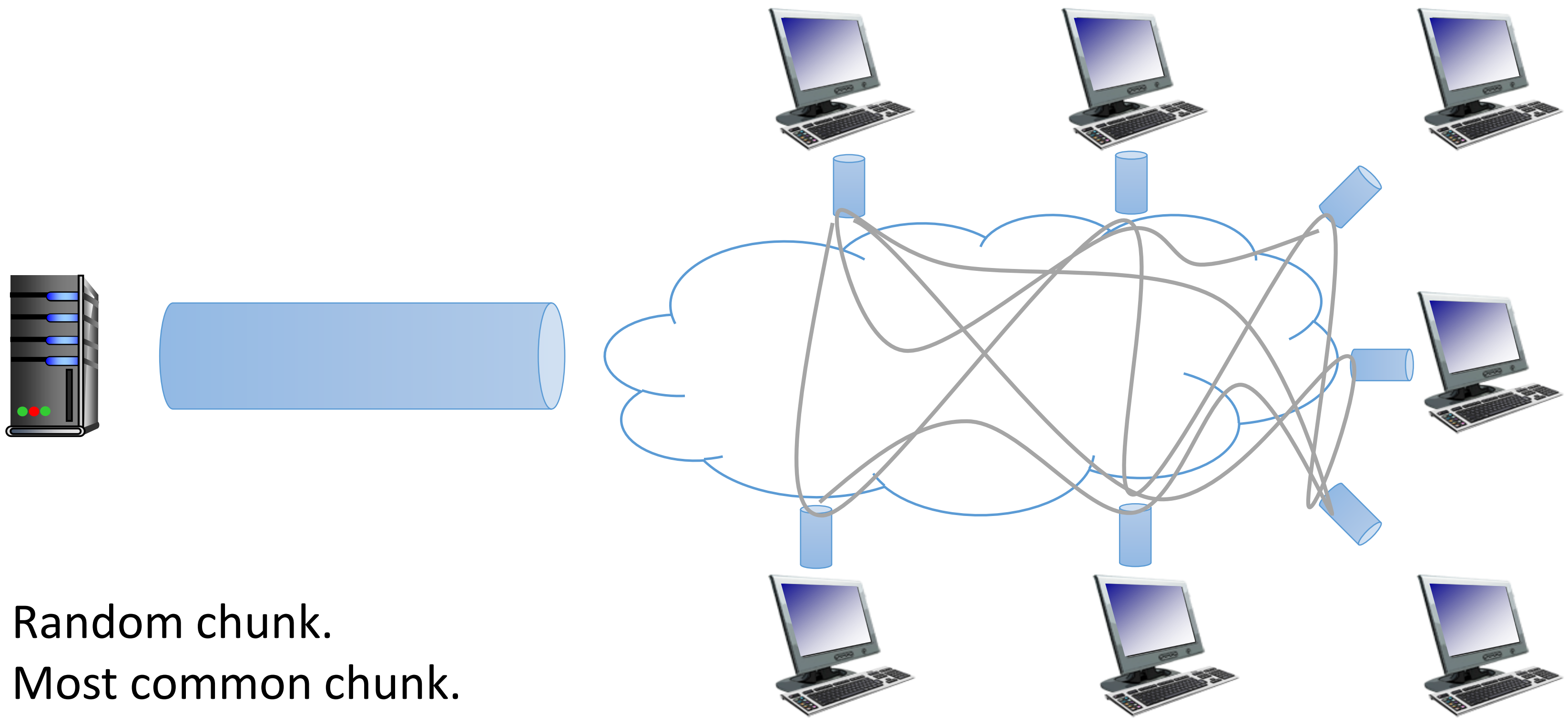
- While downloading, peer uploads chunks to other peers
- Peer may change peers with whom it exchanges chunks
- *Churn:* peers may come and go
- Once peer has entire file, it may (selfishly) leave or (altruistically) remain in torrent

Requesting Chunks

- At any given time, peers have different subsets of file chunks.

- Periodically, each asks peers for list of chunks that they have.

If you’re trying to receive a file, which chunk should you request next?



A. Random chunk.
B. Most common chunk.
C. Least common chunk.
D. Some other chunk.
E. It doesn’t matter.

Requesting Chunks

- At any given time, peers have different subsets of file chunks.
- Periodically, each asks peers for list of chunks that they have.
- In BitTorrent: Peers request rarest chunks first.

Sending Chunks

- A node sends chunks to those four peers currently sending it chunks *at highest rate*
  - other peers are choked (do not receive chunks)
  - re-evaluate top 4 every ~10 secs
- Every 30 seconds: randomly select another peer, start sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

Academic Interest in BitTorrent

- BitTorrent was enormously successful
  - Large user base
  - Lots of aggregate traffic
  - Invented relatively recently

- Academic Projects
  - Modifications to improve performance
  - Modeling peer communications (auctions)
  - Gaming the system (BitTyrant)

Getting rid of that server…

- Distribute the tracker information using a Distributed Hash Table (DHT)

- A DHT is a lookup structure.
  - Maps keys to an arbitrary value.
  - Works a lot like, well…a hash table.

Recall: Hash Function

- Mapping of any data to an integer
  - E.g., md5sum, sha1, etc.
  - md5: 04c3416cadd85971a129dd1de86cee49

- With a good (cryptographic) hash function:
  - Hash values *very* likely to be unique
  - Near-impossible to find collisions (hashes spread out)

Recall: Hash table

- N buckets

- Key-value pair is assigned bucket i
  - i = HASH(key)%N

- Easy to look up value based on key

- Multiple key-value pairs assigned to each bucket

Distributed Hash Table (DHT)

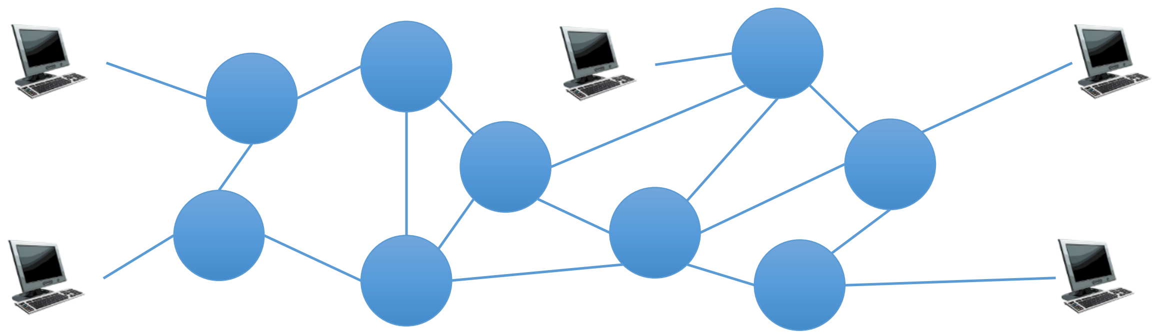
- DHT: a *distributed P2P database*

- Distribute the (k, v) pairs across the peers
  - key: ss number; value: human name
  - key: file name; value: BT tracker peer(s)

- Same interface as standard HT: (key, value) pairs
  - get(key) – send key to DHT, get back value
  - put(key, value) – modify stored value at the given key

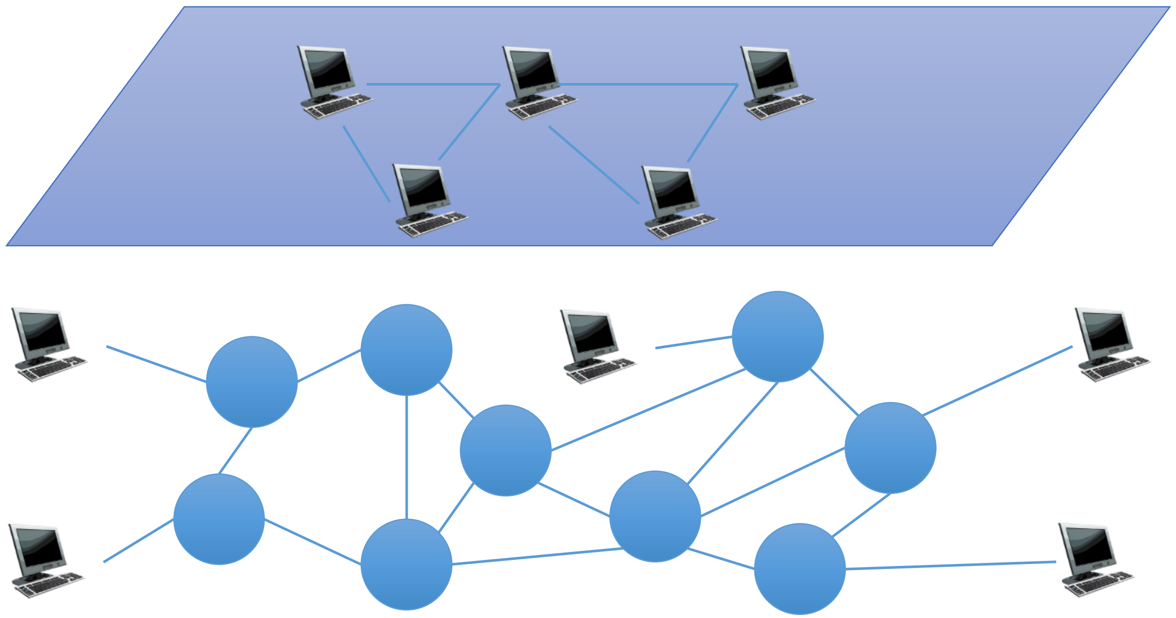
Overlay Network (P2P)

- A network made up of “virtual” or logical links
- Virtual links map to one or more physical links



Overlay Network (P2P)

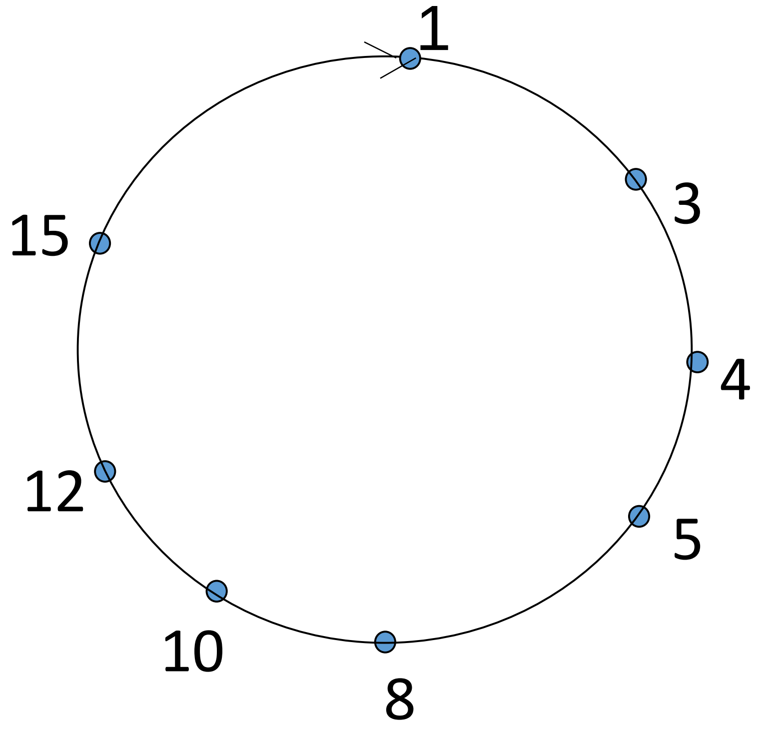
- A network made up of “virtual” or logical links
- Virtual links map to one or more physical links



Challenges

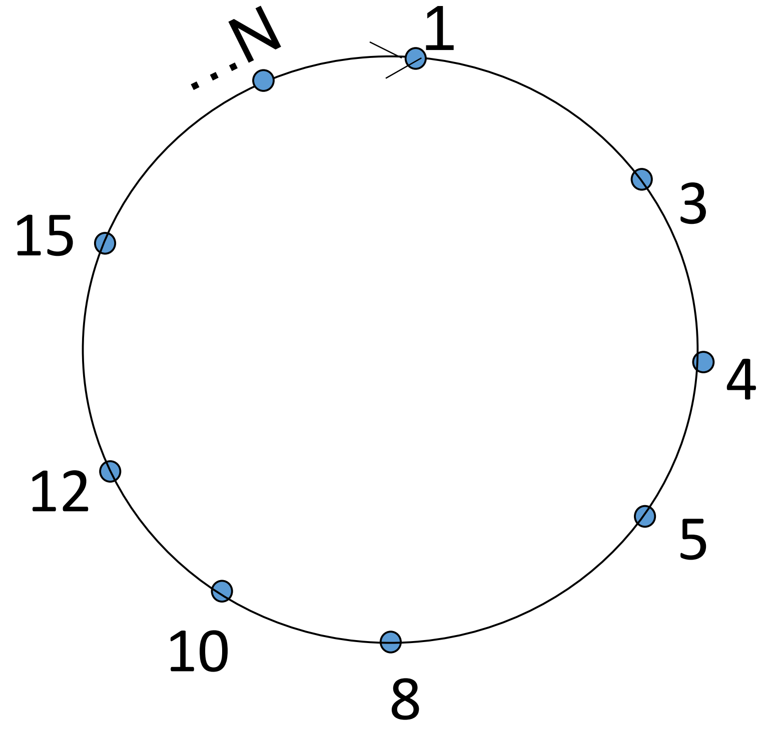
- How do we assign (key, value) pairs to nodes?
- How do we find them again quickly?
- What happens if nodes join/leave?
- Basic idea:
  - Convert each key to an integer via hash
  - Assign integer to each peer via hash
  - Store (key, value) pair at the peer closest to the key

Circular DHT Overlay



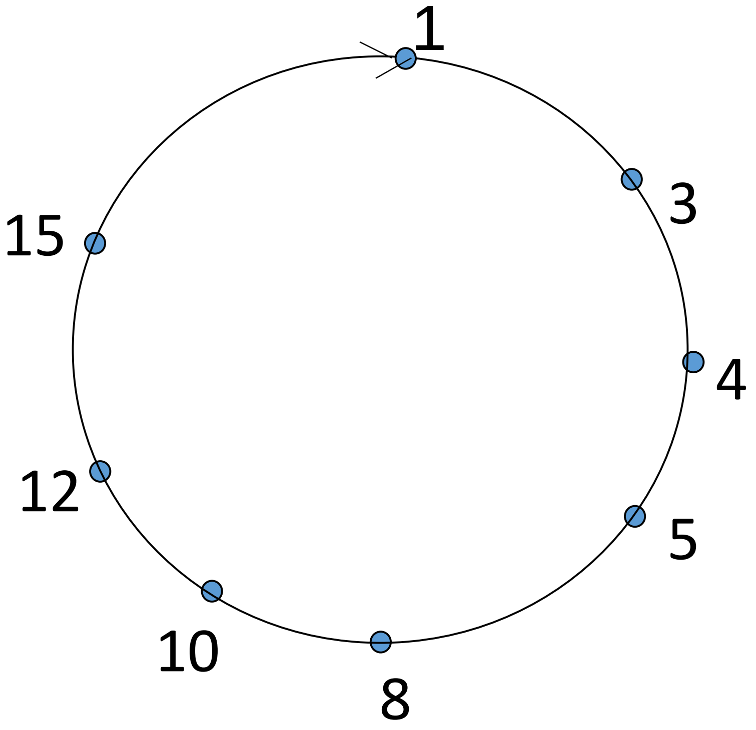
- Simplest form: each peer *only* aware of immediate successor and predecessor.

Circular DHT Overlay



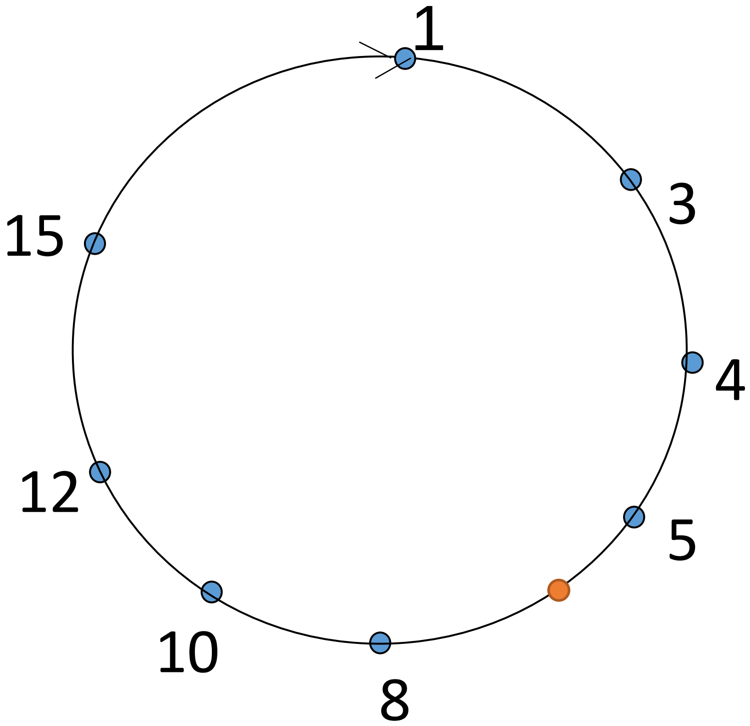
- Simplest form: each peer *only* aware of immediate successor and predecessor.

Circular DHT Overlay



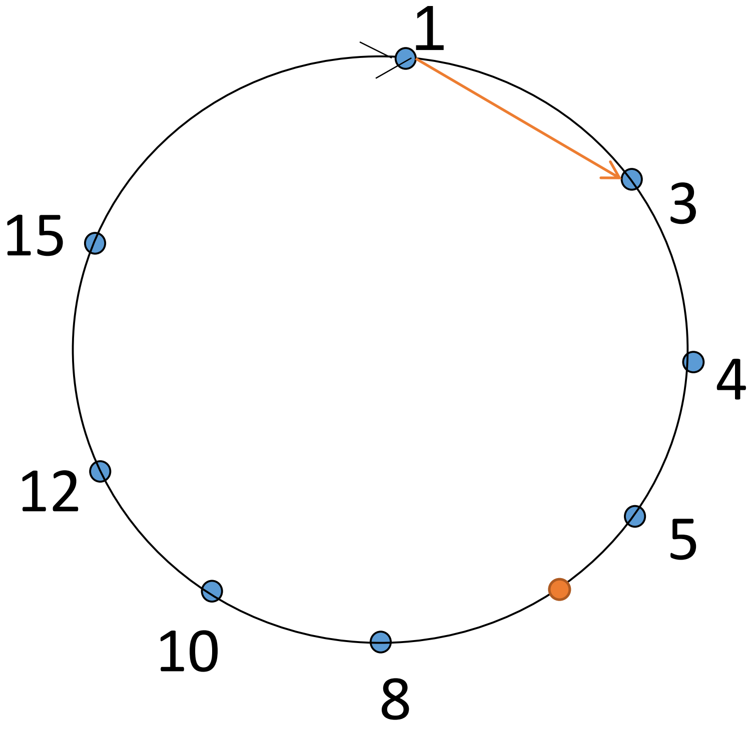
- Example: Node 1 wants key “Led Zeppelin IV”
  - Hash the key

Circular DHT Overlay



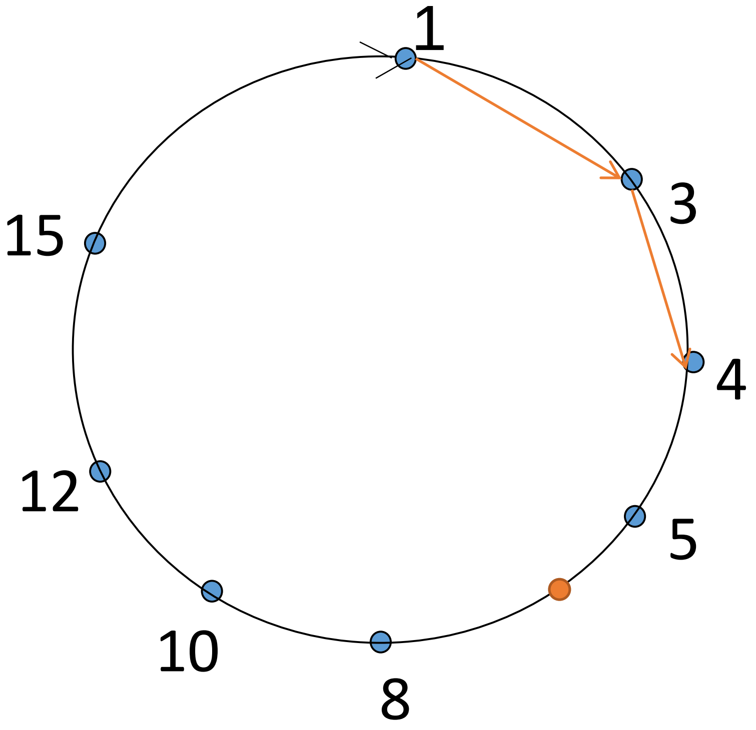
- Example: Node 1 wants key "Led Zeppelin IV"
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



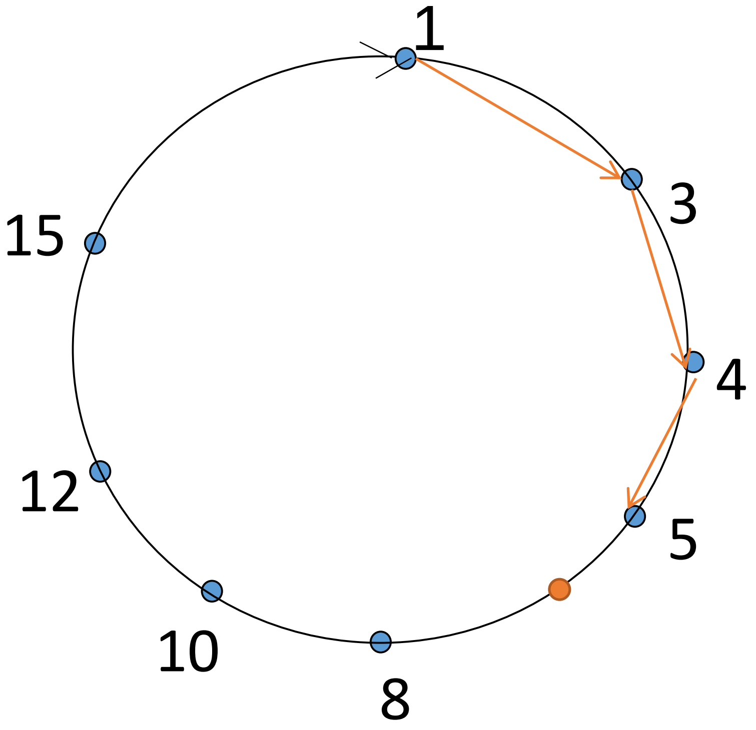
- Example: Node 1 wants key “Led Zeppelin IV”
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



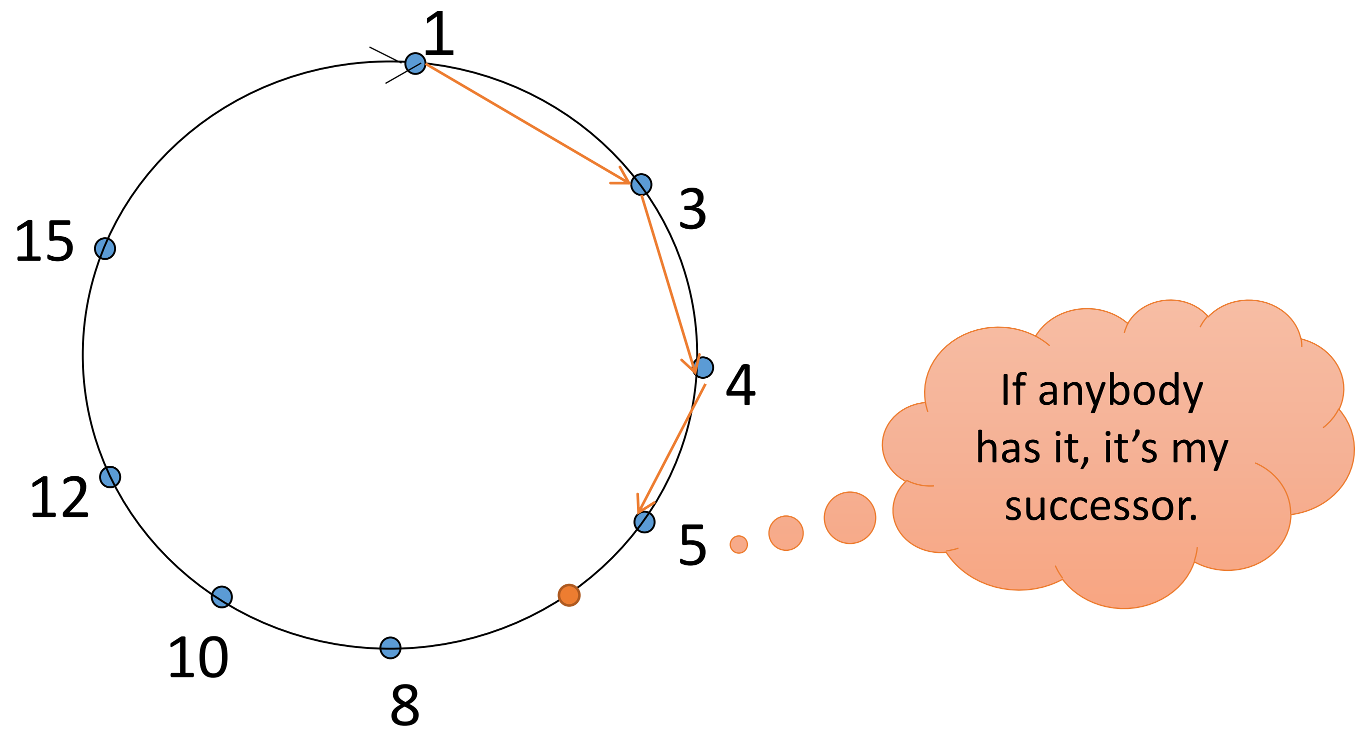
- Example: Node 1 wants key “Led Zeppelin IV”
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



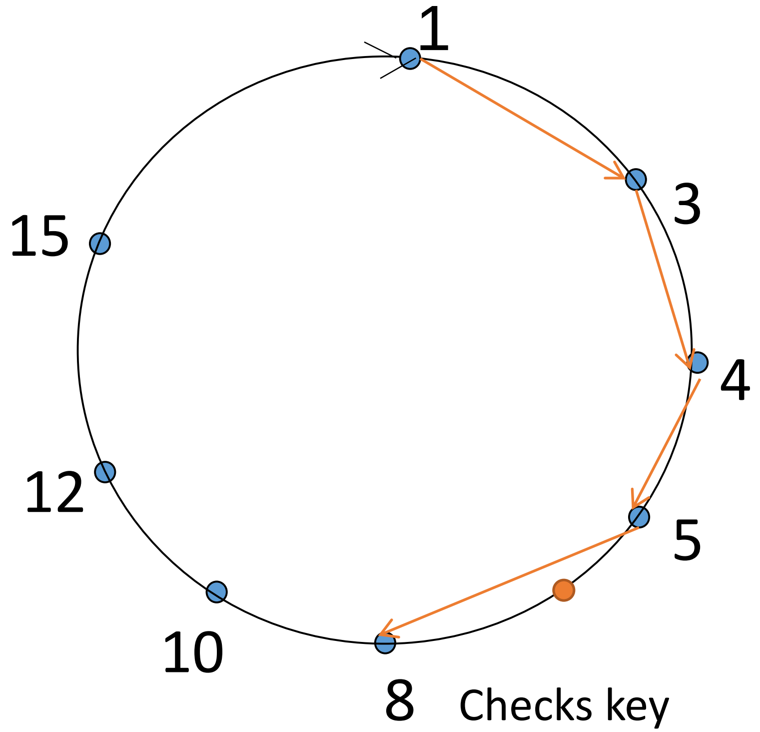
- Example: Node 1 wants key “Led Zeppelin IV”
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



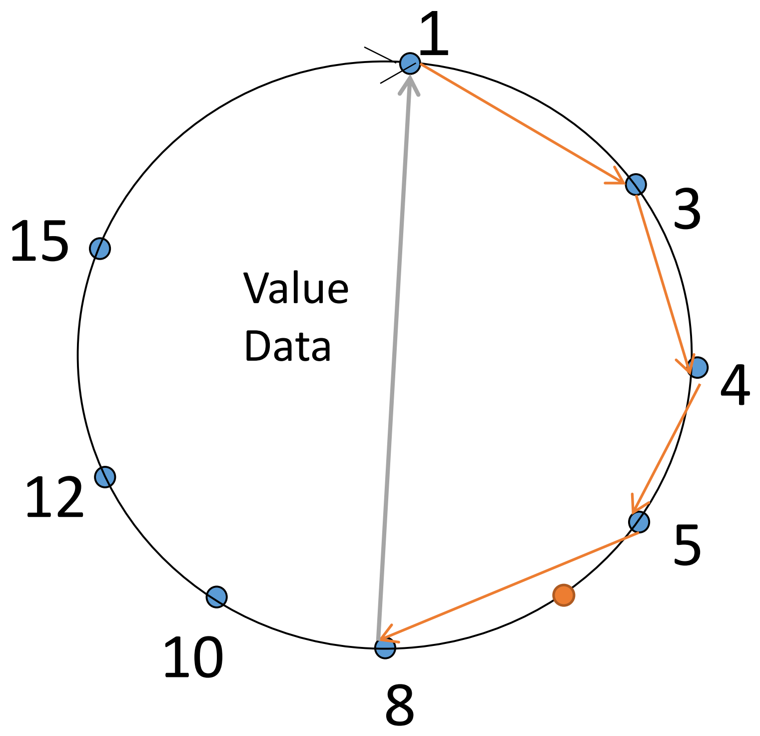
- Example: Node 1 wants key "Led Zeppelin IV"
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



- Example: Node 1 wants key "Led Zeppelin IV"
  - Hash the key (suppose it gives us 6)

Circular DHT Overlay



- Example: Node 1 wants key "Led Zeppelin IV"
  - Hash the key (suppose it gives us 6)

Given N nodes, what is the complexity (number of messages) of finding a value when each peer knows its successor?

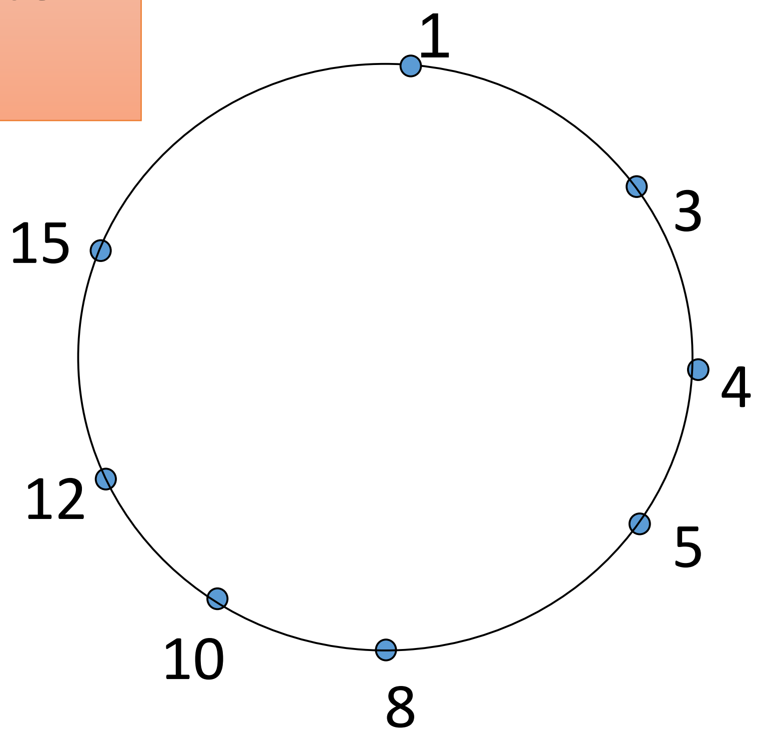
Can we do better?
How?

A. O(log n)

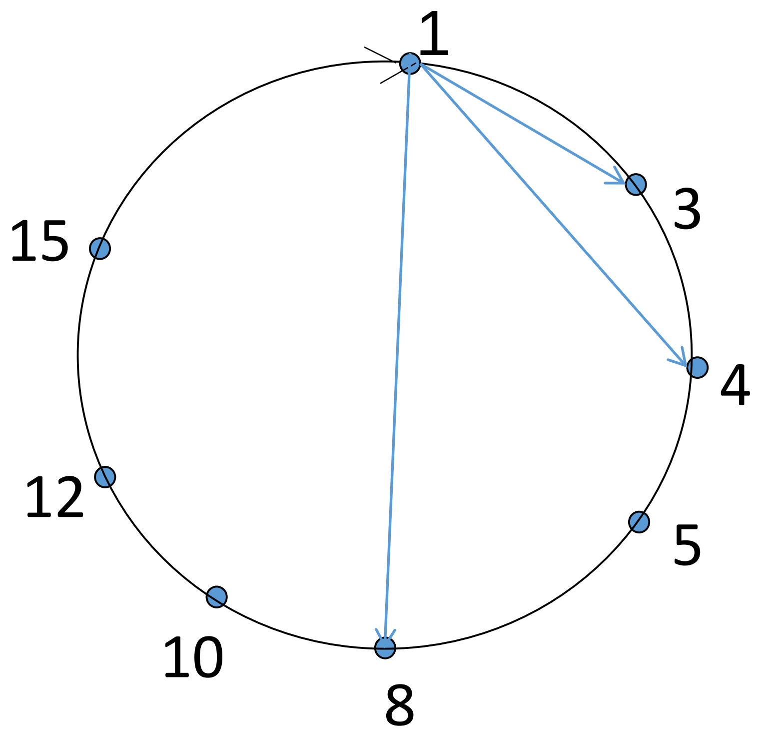
B. O(n)

C. $O(n^2)$

D. $O(2^n)$

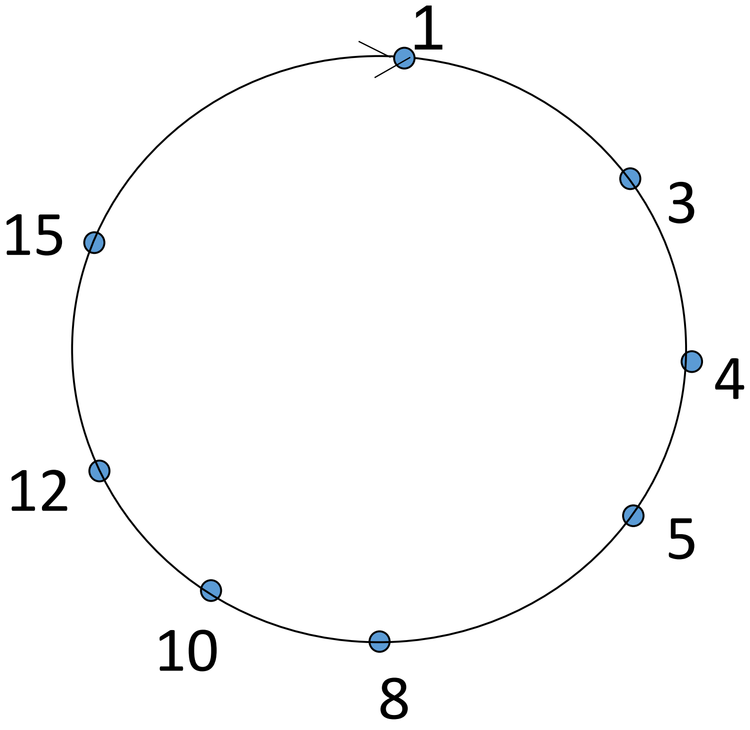


Reducing Message Count



- Store successors that are 1, 2, 4, 8, …, N/2 away.
- Can jump up to half way across the ring at once.
- Cut the search space in half - lookups take O(log N) messages.

Peer churn



Handling peer churn:

- peers may come and go (churn)
- each peer knows address of its two successors
- each peer periodically pings its two successors to check aliveness
- if immediate successor leaves, choose next successor as new immediate successor

More DHT Info

- How do nodes join/leave?
- How does cryptographic hashing work?
- How much state does each node store?

More DHT Info

- How do nodes join/leave?
- How does cryptographic hashing work?
- How much state does each node store?

- Chord: A Scalable Peer-to-Peer Lookup Service for Internet Applications
- Dynamo: Amazon’s Highly Available Key-value Store

High-Performance Content Distribution

- Problem:
  You have a service that supplies lots of data. You want good performance for all users!

(often "lots of data" means media files)

High-Performance Content Distribution

- CDNs applied to all sorts of traffic.
  - You pay for service (e.g., Akamai), they'll host your content very "close" to many users.

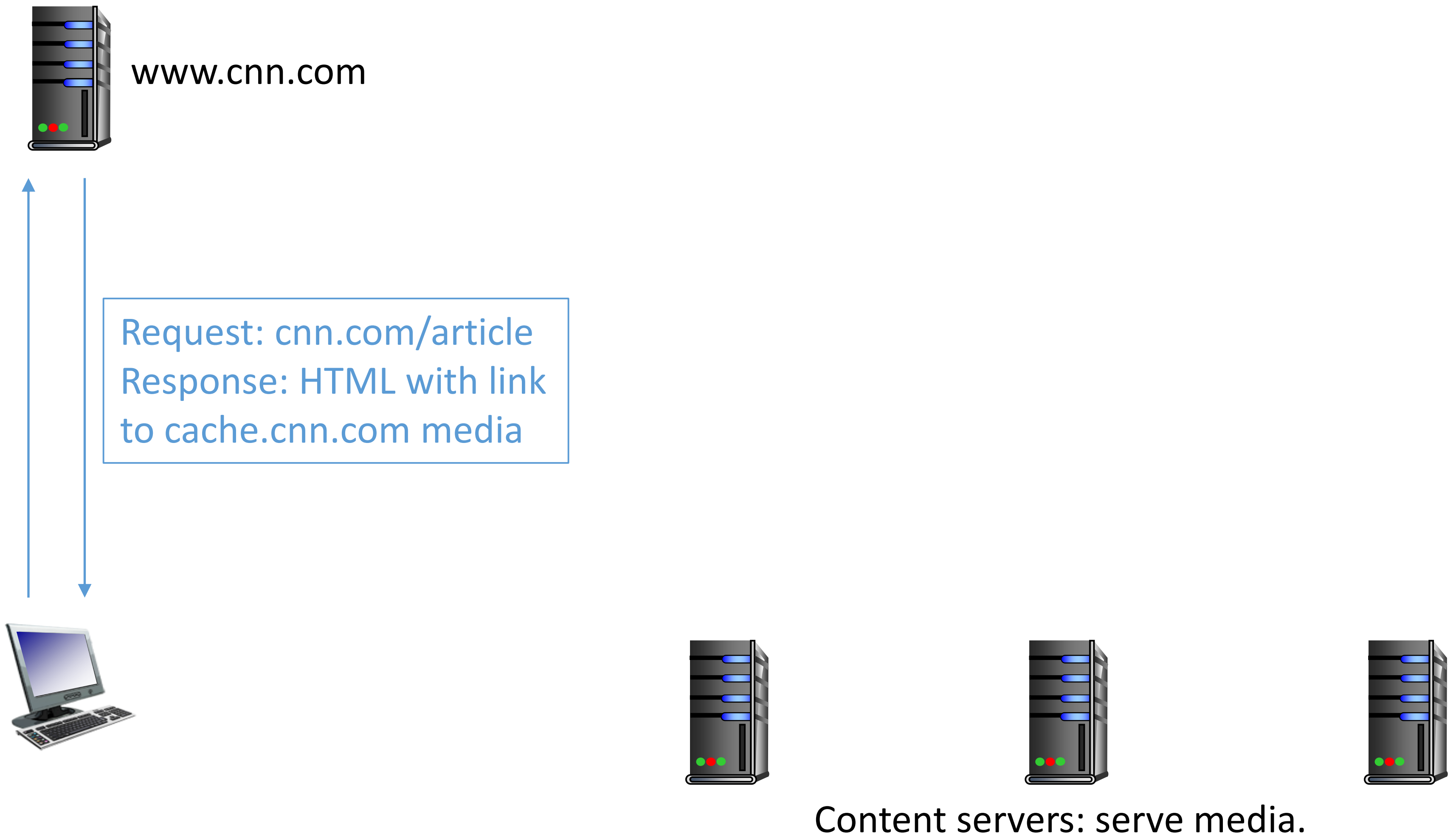
- Major challenges:
  - How do we direct the user to a nearby replica instead of the centralized source?
  - How do we determine which replica is the best to send them to?

Finding the CDN

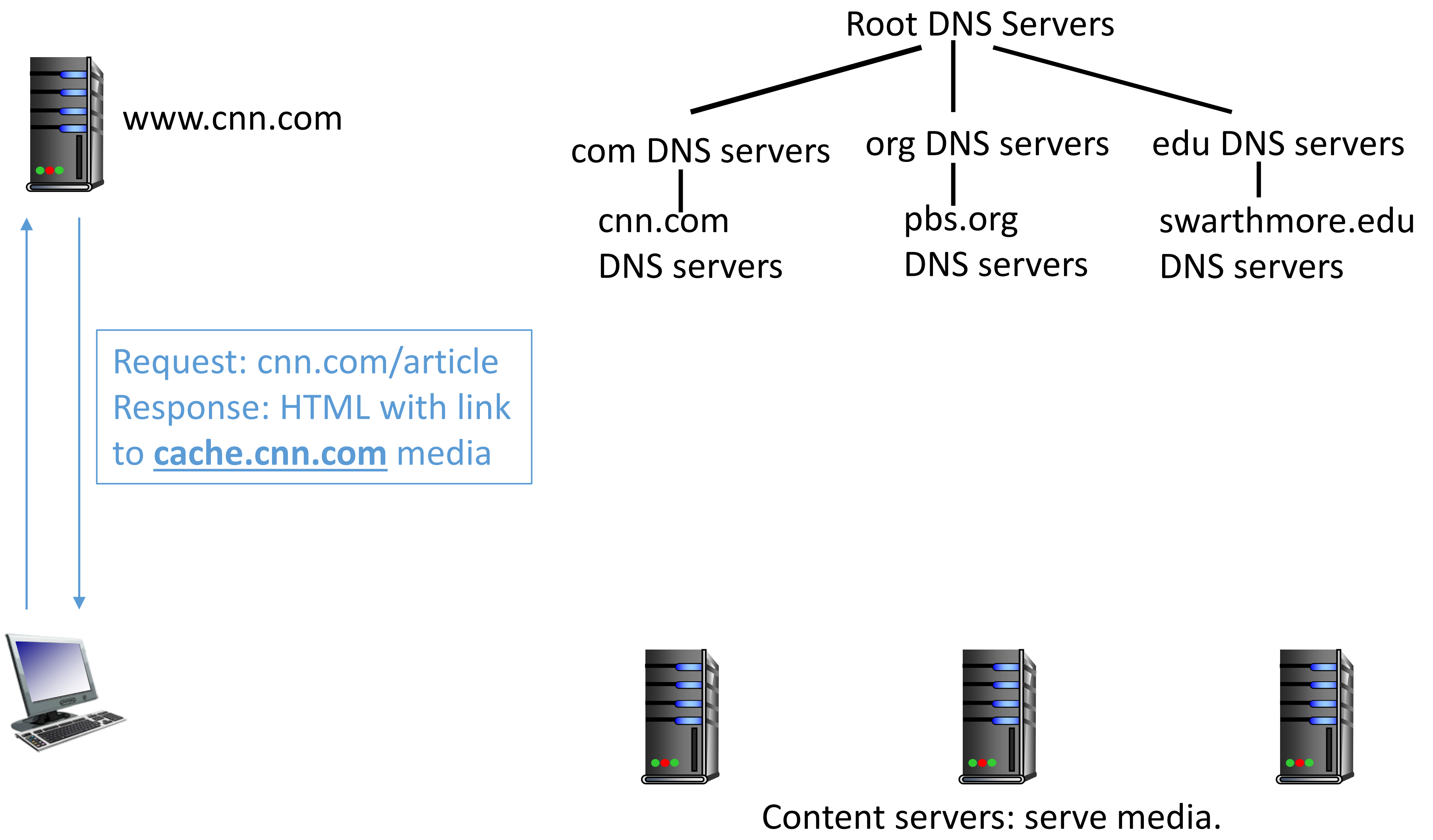
- Three main options:
  - Application redirect (e.g., HTTP)
  - “Anycast” routing
  - DNS resolution (most popular in practice)

- Example: CNN + Akamai

CNN + Akamai

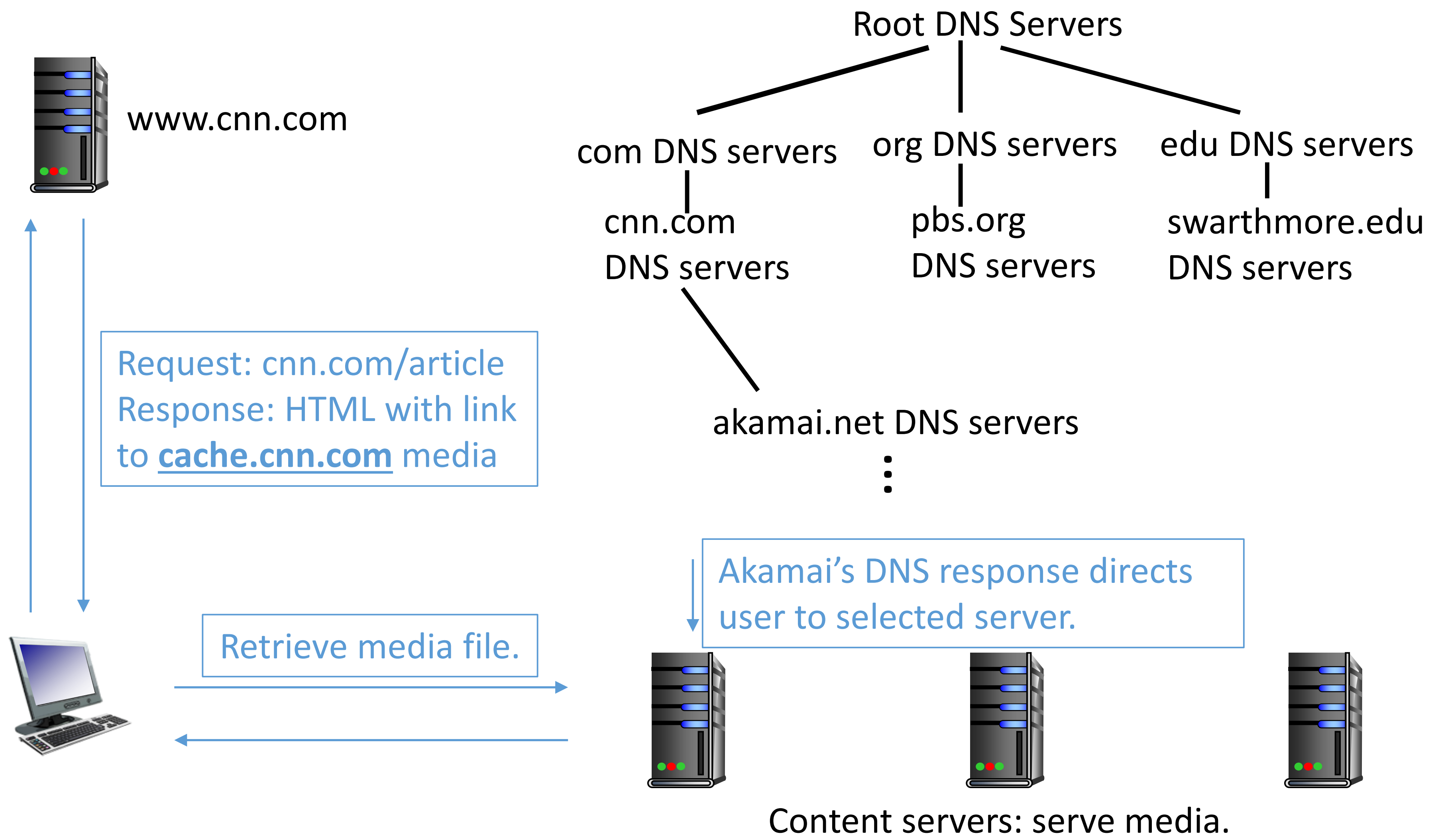

www.cnn.com
Request: cnn.com/article
Response: HTML with link
to cache.cnn.com media
Content servers: serve media.

CNN + Akamai



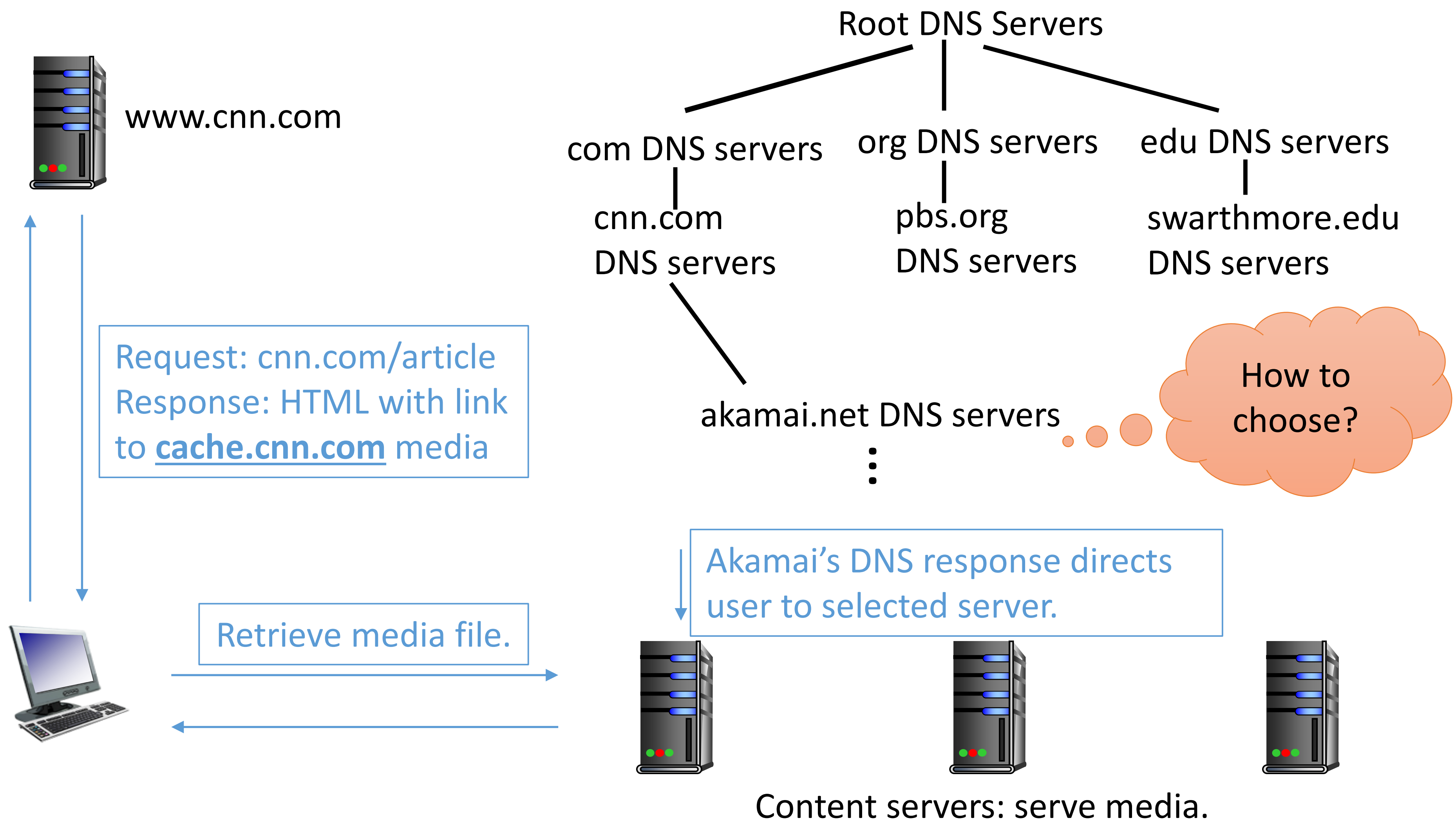
Root DNS Servers
com DNS servers
org DNS servers
edu DNS servers
cnn.com DNS servers
pbs.org DNS servers
swarthmore.edu DNS servers
www.cnn.com
Request: cnn.com/article
Response: HTML with link to cache.cnn.com media
Content servers: serve media.

CNN + Akamai



www.cnn.com
Request: cnn.com/article
Response: HTML with link
to **cache.cnn.com** media
Retrieve media file.
Root DNS Servers
com DNS servers
org DNS servers
edu DNS servers
cnn.com
DNS servers
pbs.org
DNS servers
swarthmore.edu
DNS servers
akamai.net DNS servers
⋮
Akamai's DNS response directs
user to selected server.
Content servers: serve media.

CNN + Akamai


Root DNS Servers
com DNS servers
org DNS servers
edu DNS servers
cnn.com DNS servers
pbs.org DNS servers
swarthmore.edu DNS servers
akamai.net DNS servers
How to choose?
www.cnn.com
Request: cnn.com/article
Response: HTML with link to cache.cnn.com media
Retrieve media file.
Akamai's DNS response directs user to selected server.
Content servers: serve media.

Which measure is most important when choosing a server? (CDN or otherwise)

A. RTT latency

B. Data transfer rate / throughput

C. Hardware ownership

D. Geographic location

E. Some other measure(s) (such as?)

This is the CDN operator's secret sauce!

Streaming Media

- Straightforward approach: simple GET

- Challenges:
  - Dynamic network characteristics
  - Varying user device capabilities
  - User mobility

Dynamic Adaptive Streaming over HTTP (DASH)

- Encode several versions of the same media file
  - low / medium / high / ultra quality

- Break each file into chunks

- Create a “manifest” to map file versions to chunks / video time offset

Dynamic Adaptive Streaming over HTTP (DASH)

- Client requests manifest file, chooses version
- Requests new chunks as it plays existing ones
- Can switch between versions at any time!

Summary

- Peer-to-peer architectures for:
  - High performance: BitTorrent
  - Decentralized lookup: DHTs

- CDNs: locating "good" replica for media server

- DASH: streaming despite dynamic conditions