

CS 305 Computer Networks

Chapter 2 Application Layer (2)

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Chapter 2: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks

2.7 socket programming with UDP and TCP

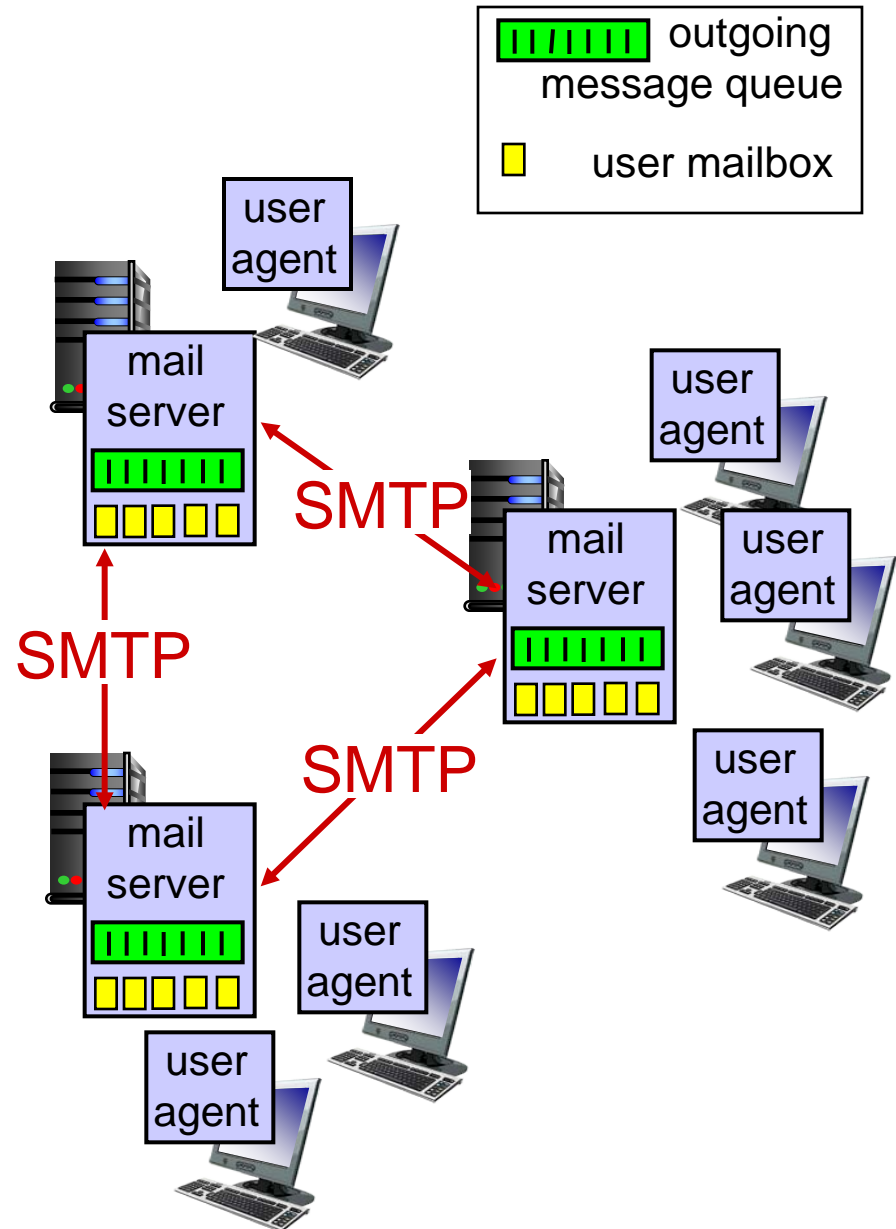
Electronic mail

Three major components:

- user agents
- mail servers
- simple mail transfer protocol: SMTP

User Agent

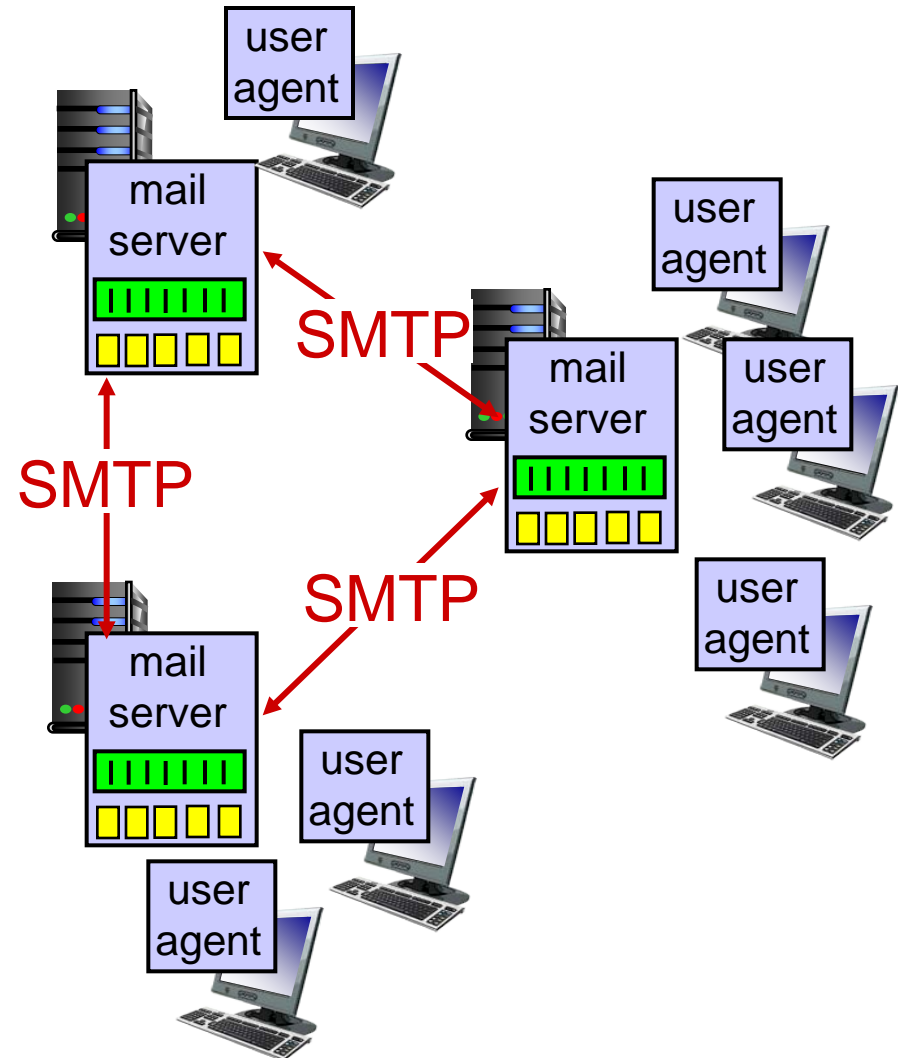
- a.k.a. “mail reader”
- composing, editing, reading mail messages
- e.g., Outlook, Thunderbird, iPhone mail client
- outgoing, incoming messages stored on server



Electronic mail: mail servers

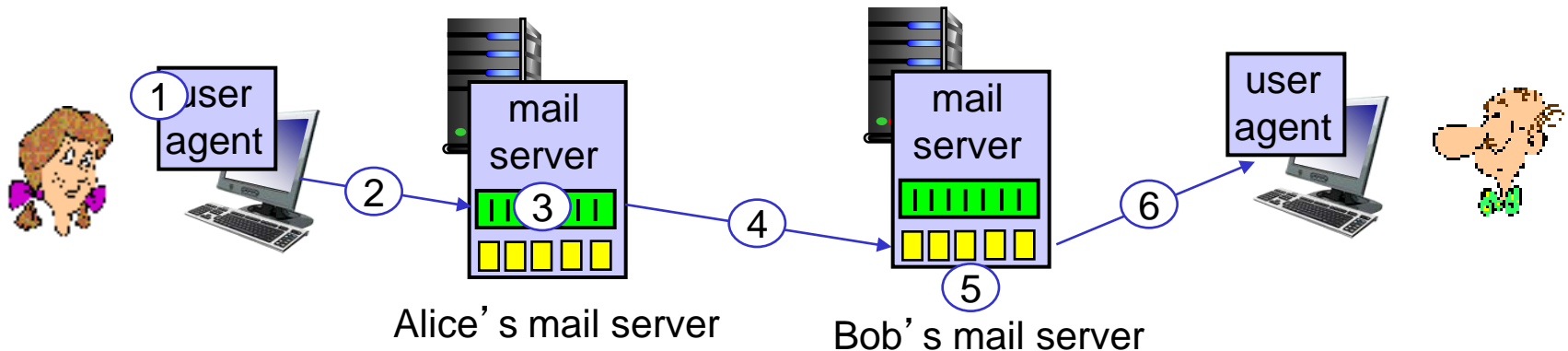
mail servers:

- *mailbox* contains incoming messages for user
- *message queue* of outgoing (to be sent) mail messages
- *SMTP protocol* between mail servers to send email messages
 - client: sending mail server
 - “server”: receiving mail server



Scenario: Alice sends message to Bob

- 1) Alice uses UA to compose message “to” bob@someschool.edu
- 2) Alice’s UA sends message to her mail server; message placed in message queue
- 3) client side of SMTP opens TCP connection with Bob’s mail server
- 4) SMTP client sends Alice’s message over the TCP connection
- 5) Bob’s mail server places the message in Bob’s mailbox
- 6) Bob invokes his user agent to read message



Electronic Mail: SMTP [RFC 2821]

- uses TCP to reliably transfer email message from client to server, port 25
- direct transfer: sending server to receiving server
- three phases of transfer
 - handshaking (greeting)
 - transfer of messages
 - closure
- command/response interaction (like HTTP)
 - **commands:** ASCII text
 - **response:** status code and phrase
- messages must be in 7-bit ASCII

Sample SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250 Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

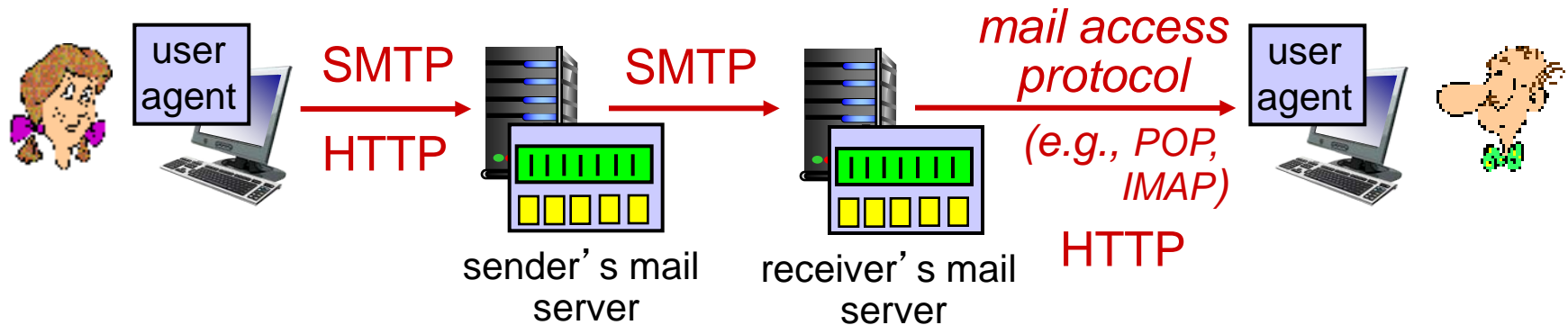
SMTP: final words

- SMTP uses persistent connections
- SMTP requires message (header & body) to be in 7-bit ASCII
- SMTP server uses CRLF . CRLF to determine end of message

comparison with HTTP:

- HTTP: pull
- SMTP: push
- both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response message
- SMTP: multiple objects sent in multipart message

Mail access protocols



- **SMTP:** delivery/storage to receiver's server
- mail access protocol: retrieval from server
 - **POP:** Post Office Protocol [RFC 1939]: authorization, download
 - **IMAP:** Internet Mail Access Protocol [RFC 1730]: more features, including manipulation of stored messages on server
 - **HTTP:** gmail, Hotmail, Yahoo! Mail, etc.

POP3 protocol

authorization phase

- client commands:
 - **user**: declare username
 - **pass**: password
- server responses
 - **+OK**
 - **-ERR**

```
S: +OK POP3 server ready
C: user bob
S: +OK
C: pass hungry
S: +OK user successfully logged on
```

transaction phase, client:

- **list**: list message numbers
- **retr**: retrieve message by number
- **dele**: delete
- **quit**

```
C: list
S: 1 498
S: 2 912
S: .
C: retr 1
S: <message 1 contents>
S: .
C: dele 1
C: retr 2
S: <message 1 contents>
S: .
C: dele 2
C: quit
S: +OK POP3 server signing off
```

POP3 (more) and IMAP

more about POP3

- previous example uses POP3 “download and delete” mode
 - Bob cannot re-read e-mail if he changes client
- POP3 “download-and-keep”: copies of messages on different clients
- POP3 is stateless across sessions

IMAP

- keeps all messages in one place: at server
- allows user to organize messages in folders
- keeps user state across sessions:
 - names of folders and mappings between message IDs and folder name

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DNS: domain name system

people: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

- IP address (32 bit) - used for addressing datagrams
- “name”, e.g., `www.yahoo.com` - used by humans

Q: how to map between IP address and name, and vice versa ?

Domain Name System:

- *distributed database*
implemented in hierarchy of many *name servers*
- *application-layer protocol*: hosts, name servers communicate to *resolve* names (address/name translation)
 - note: core Internet function, implemented as application-layer protocol
 - complexity at network's “edge”

DNS: services, structure

DNS services

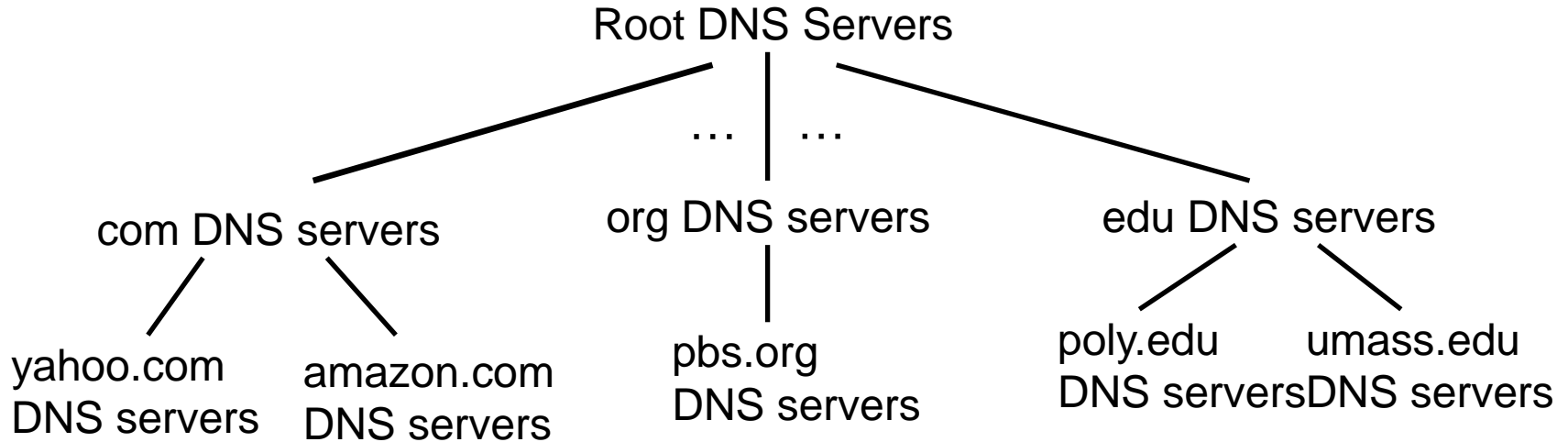
- hostname to IP address translation
- host aliasing
 - canonical, alias names
- mail server aliasing
- load distribution
 - replicated Web servers: many IP addresses correspond to one name

why not centralize DNS?

- single point of failure
- traffic volume
- distant centralized database
- maintenance

A: doesn't scale!

DNS: a distributed, hierarchical database

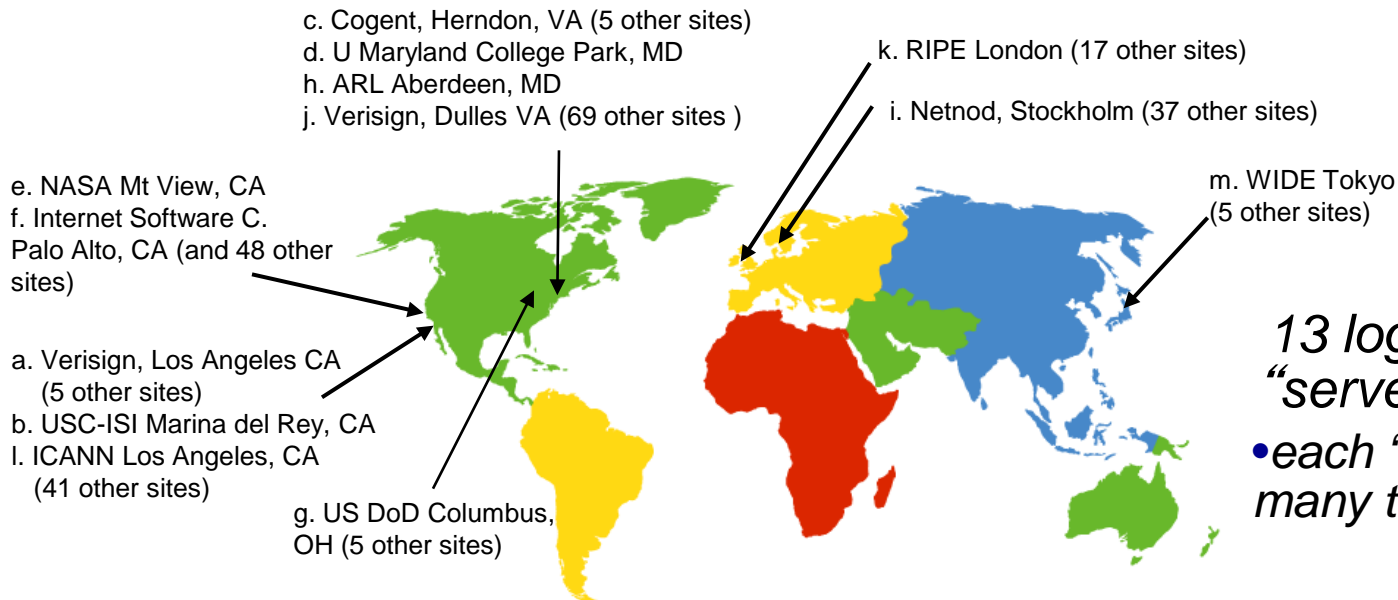


client wants IP for www.amazon.com; 1st approximation:

- client queries root server to find com DNS server
- client queries .com DNS server to get amazon.com DNS server
- client queries amazon.com DNS server to get IP address for www.amazon.com

DNS: root name servers

- contacted by local name server that can not resolve name
- root name server:
 - contacts authoritative name server if name mapping not known
 - gets mapping
 - returns mapping to local name server



*13 logical root name
“servers” worldwide*

- *each “server” replicated many times*

TLD, authoritative servers

top-level domain (TLD) servers:

- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Educause for .edu TLD

authoritative DNS servers:

- organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
- can be maintained by organization or service provider

Local DNS name server

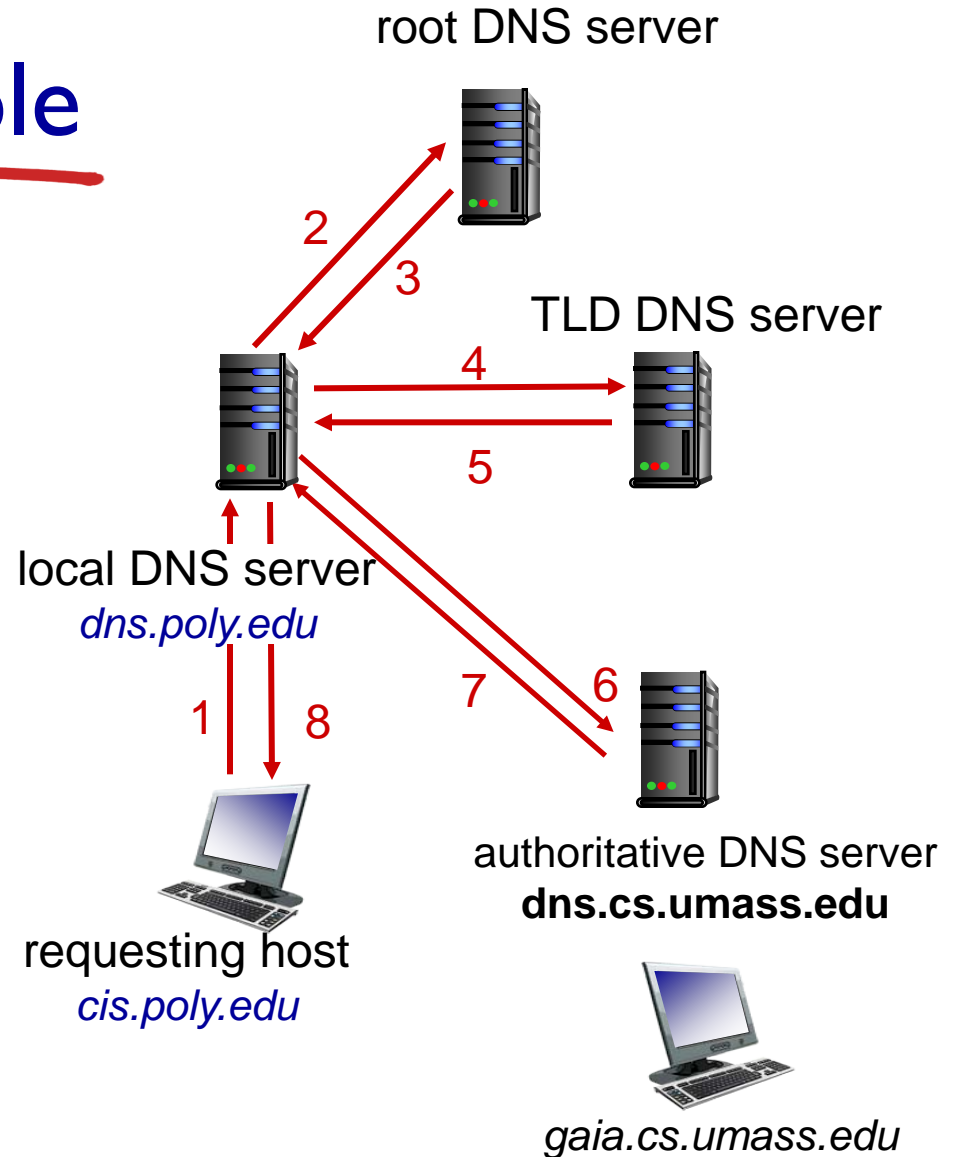
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
 - also called “default name server”
- when host makes DNS query, query is sent to its local DNS server
 - has local cache of recent name-to-address translation pairs (but may be out of date!)
 - acts as proxy, forwards query into hierarchy

DNS name resolution example

- host at cis.poly.edu wants IP address for gaia.cs.umass.edu

iterated query:

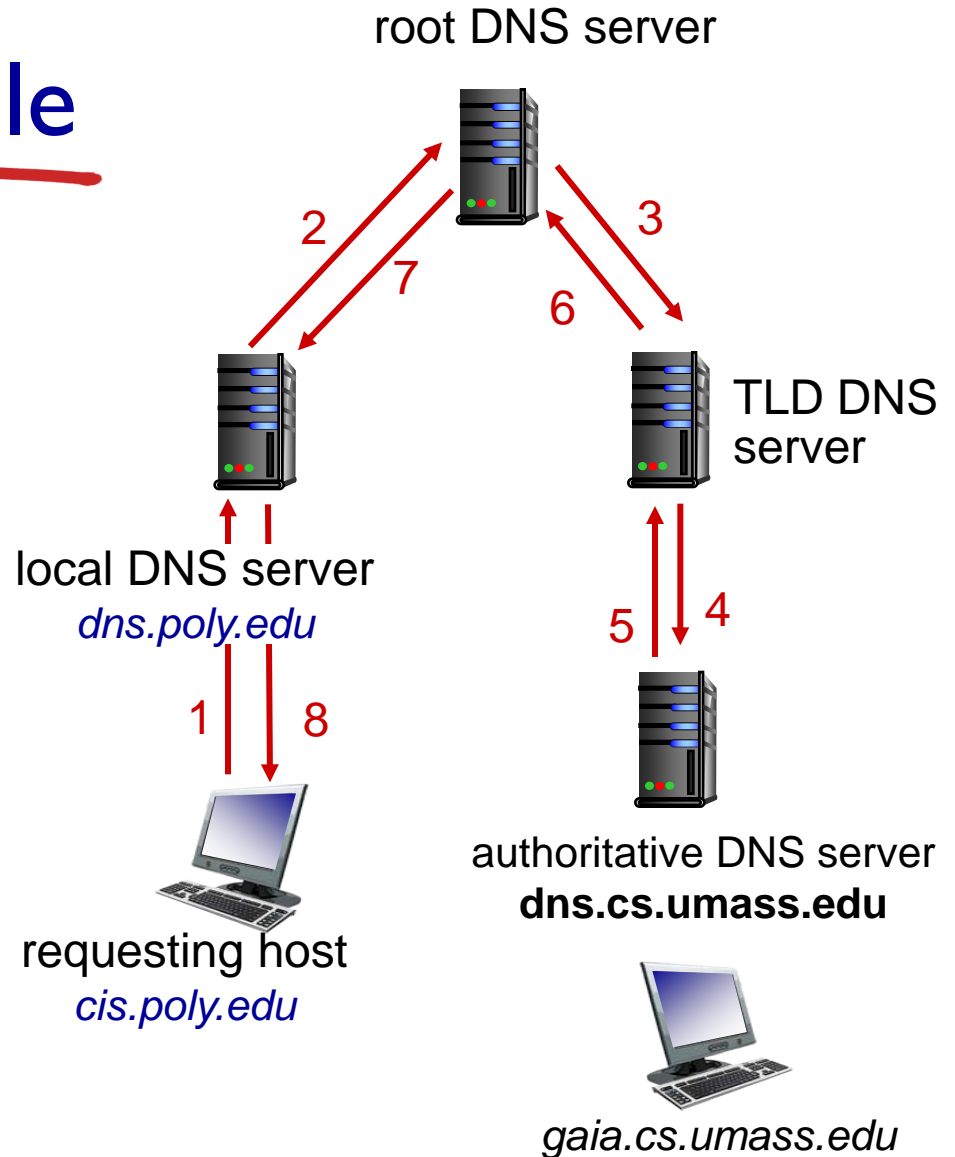
- contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”



DNS name resolution example

recursive query:

- puts burden of name resolution on contacted name server
- heavy load at upper levels of hierarchy?



DNS: caching, updating records

- once (any) name server learns mapping, it *caches* mapping
 - cache entries timeout (disappear) after some time (TTL)
 - TLD servers typically cached in local name servers
 - thus root name servers not often visited
- cached entries may be *out-of-date* (best effort name-to-address translation!)
 - if name host changes IP address, may not be known Internet-wide until all TTLs expire
- update/notify mechanisms proposed IETF standard
 - RFC 2136

DNS records

DNS: distributed database storing resource records (RR)

RR format: (name, value, type, ttl)

type=A

- **name** is hostname
- **value** is IP address

type=NS

- **name** is domain (e.g., foo.com)
- **value** is hostname of authoritative name server for this domain

type=CNAME

- **name** is alias name for some “canonical” (the real) name
- **www.ibm.com** is really **servereast.backup2.ibm.com**
- **value** is canonical name

type=MX

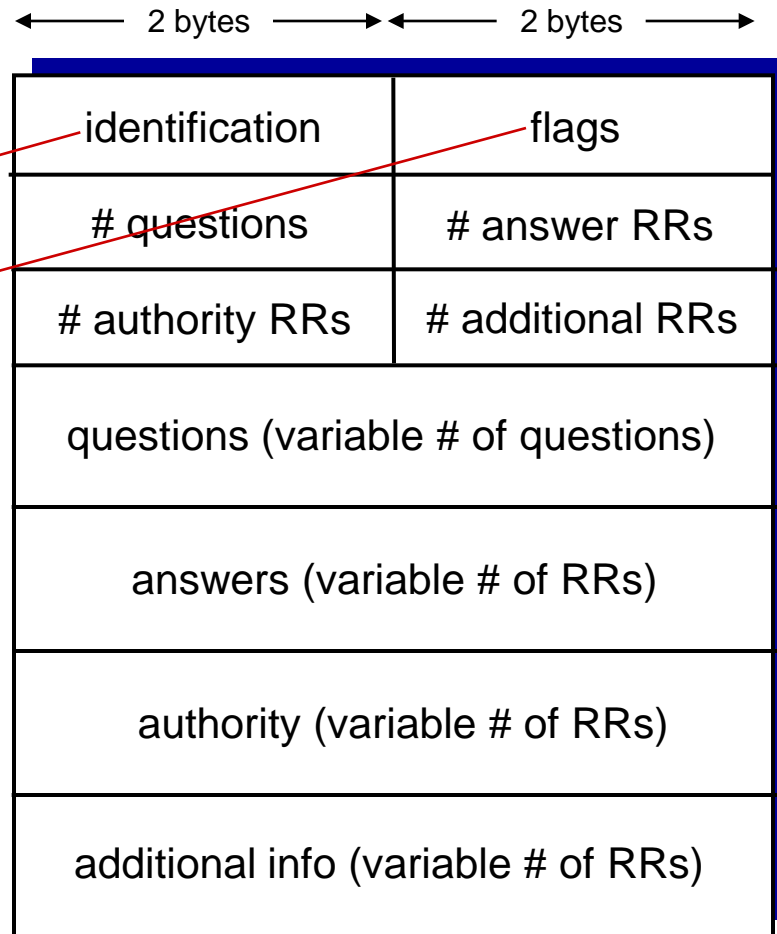
- **value** is name of mailserver associated with **name**

DNS protocol, messages

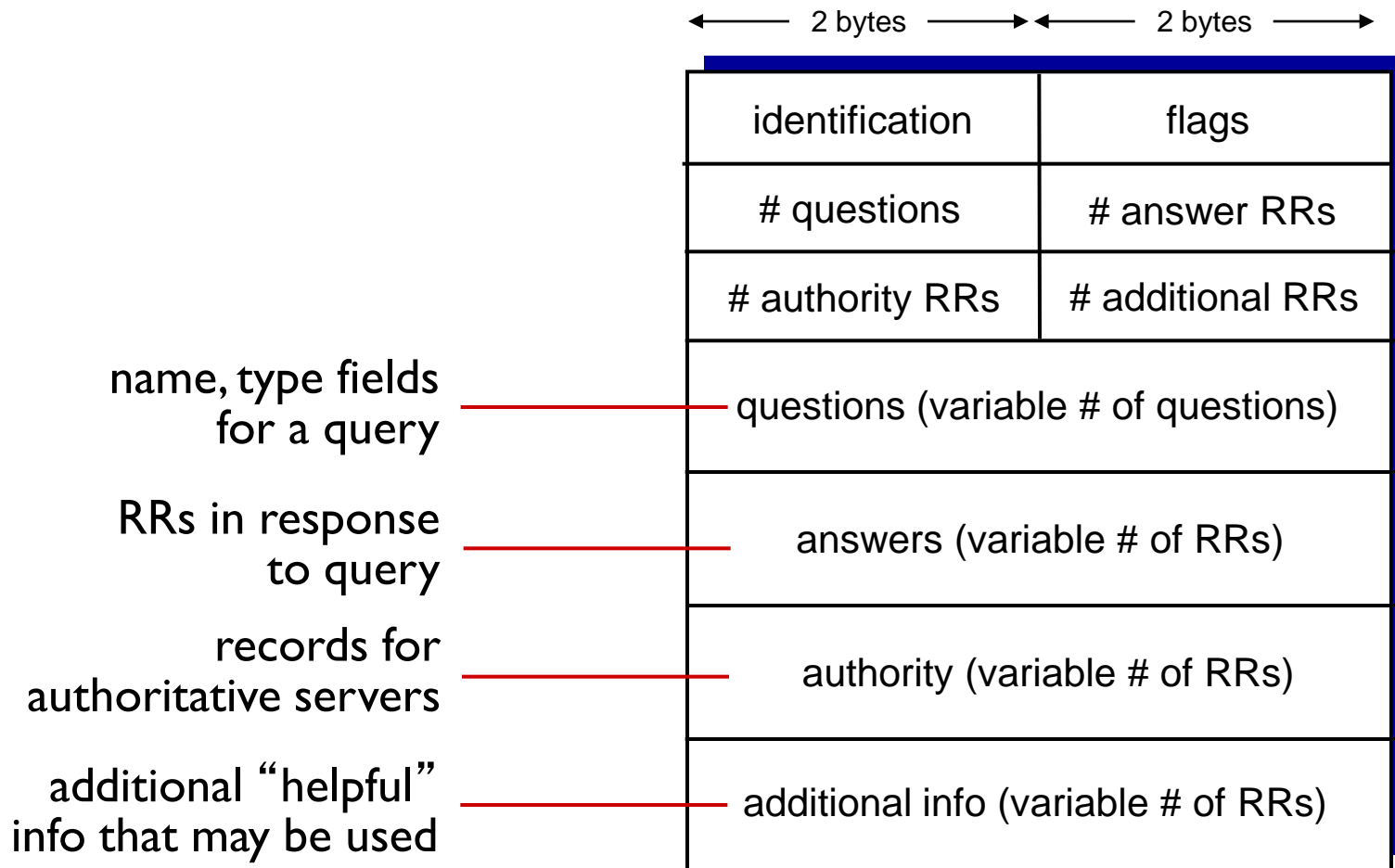
- *query* and *reply* messages, both with same *message format*

message header

- **identification:** 16 bit # for query, reply to query uses same #
- **flags:**
 - query or reply
 - recursion desired
 - recursion available
 - reply is authoritative



DNS protocol, messages



Inserting records into DNS

- example: new startup “Network Utopia”
- register name networkutopia.com at *DNS registrar* (e.g., Network Solutions)
 - provide names, IP addresses of authoritative name server (primary and secondary)
 - registrar inserts two RRs into .com TLD server:
(networkutopia.com, dns1.networkutopia.com, NS)
(dns1.networkutopia.com, 212.212.212.1, A)
- create authoritative server type A record for www.networkutopia.com; type MX record for networkutopia.com

Attacking DNS

DDoS attacks

- bombard root servers with traffic
 - not successful to date
 - traffic filtering
 - local DNS servers cache IPs of TLD servers, allowing root server bypass
- bombard TLD servers
 - potentially more dangerous

redirect attacks

- man-in-middle
 - Intercept queries
- DNS poisoning
 - Send bogus replies to DNS server, which caches

exploit DNS for DDoS

- send queries with spoofed source address: target IP
- requires amplification

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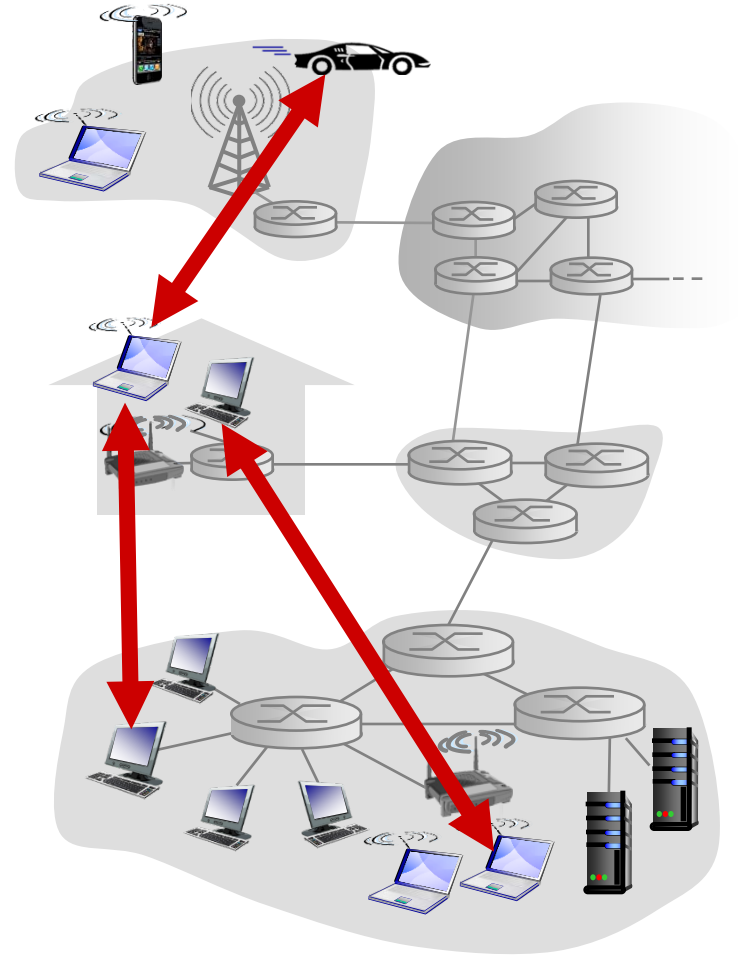
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Pure P2P architecture

- no always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses

examples:

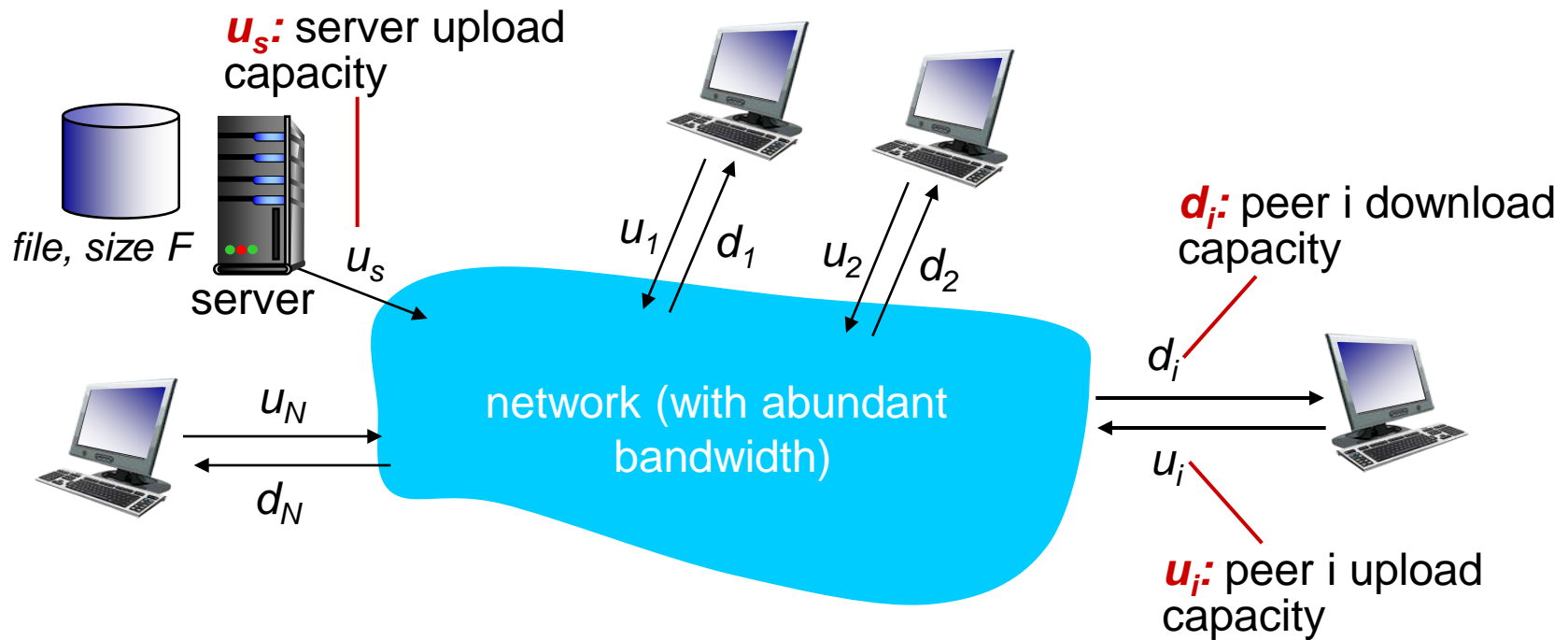
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

Question: how much time to distribute file (size F) from one server to N peers?

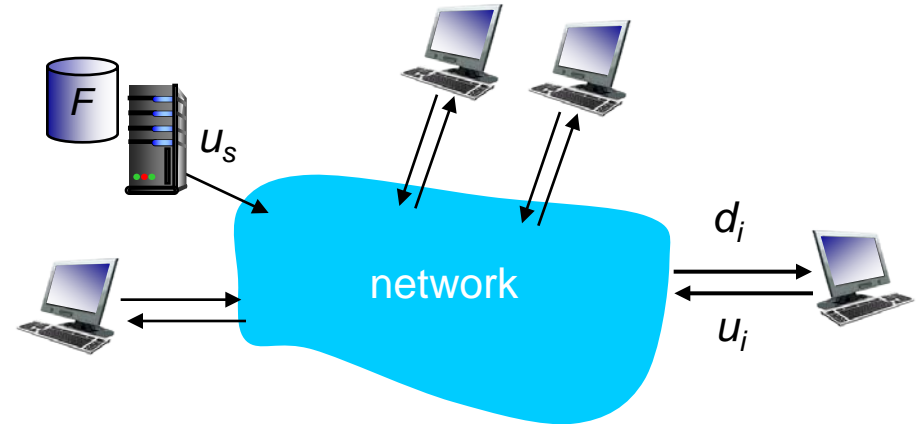
- peer upload/download capacity is limited resource



File distribution time: client-server

- **server transmission:** must sequentially send (upload) N file copies:

- time to send one copy: F/u_s
- time to send N copies: NF/u_s



- **client:** each client must download file copy

- d_{min} = min client download rate
- min client download time: F/d_{min}

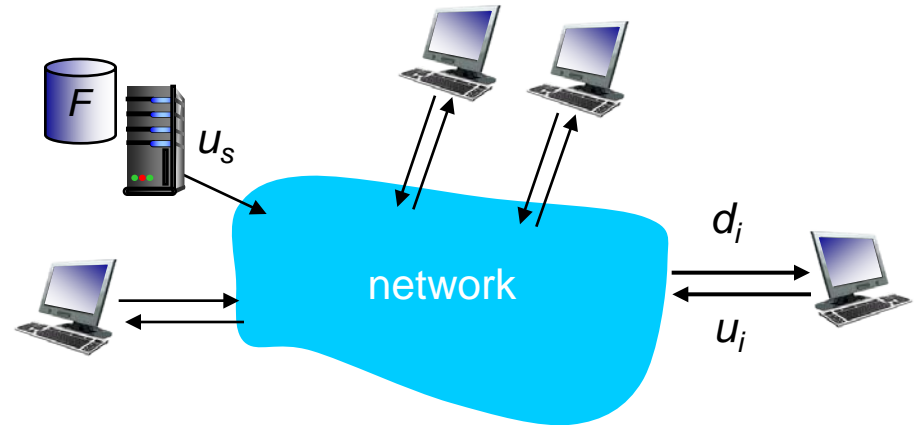
*time to distribute F
to N clients using
client-server approach*

$$D_{c-s} \geq \max\{NF/u_s, F/d_{min}\}$$

increases linearly in N

File distribution time: P2P

- **server transmission:** must upload at least one copy
 - time to send one copy: F/u_s
- **client:** each client must download file copy
 - min client download time: F/d_{\min}
- **clients:** as aggregate must download NF bits
 - max upload rate (limiting max download rate) is $u_s + \sum u_i$



*time to distribute F
to N clients using
P2P approach*

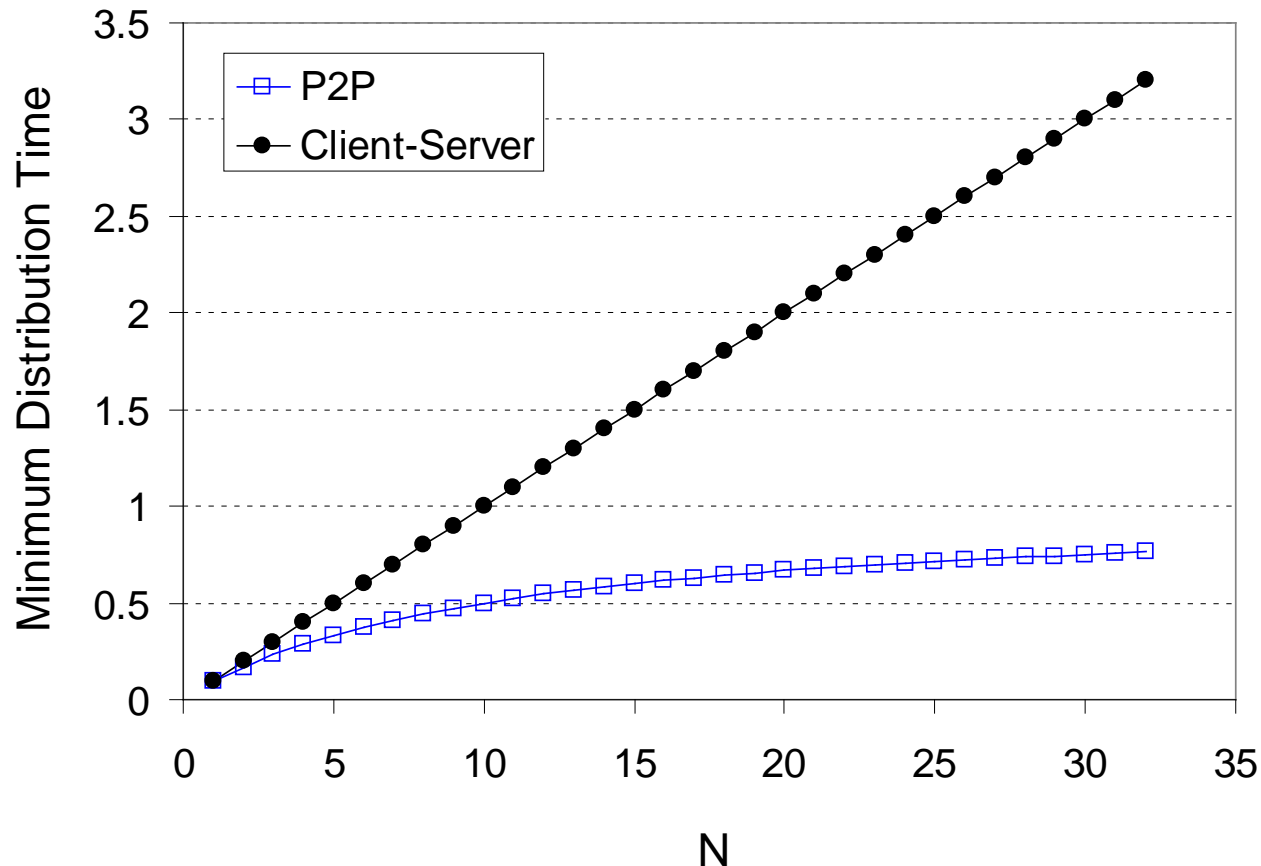
$$D_{P2P} \geq \max\{F/u_s, F/d_{\min}, NF/(u_s + \sum u_i)\}$$

increases linearly in N ...

... but so does this, as each peer brings service capacity

Client-server vs. P2P: example

client upload rate = u , $F/u = 1$ hour, $u_s = 10u$, $d_{min} \geq u_s$

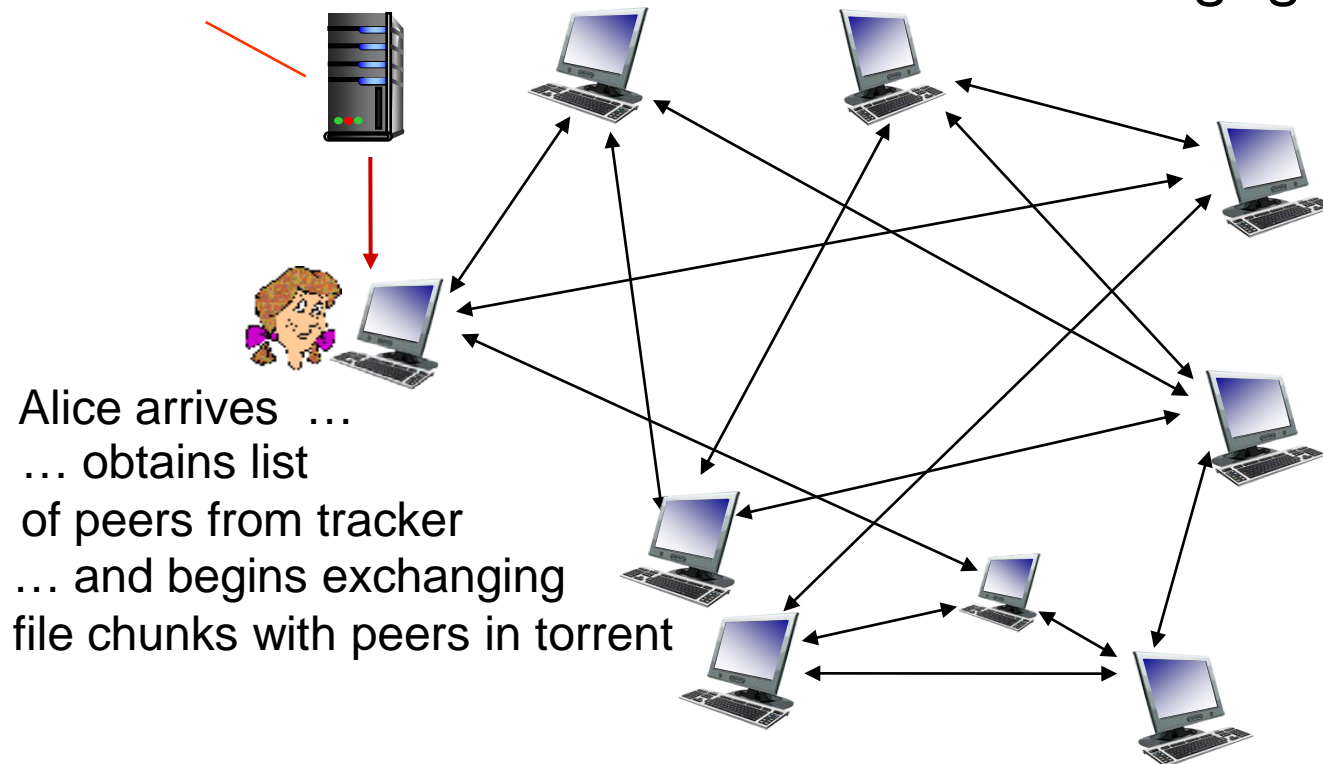


P2P file distribution: BitTorrent

- file divided into 256Kb chunks
- peers in torrent send/receive file chunks

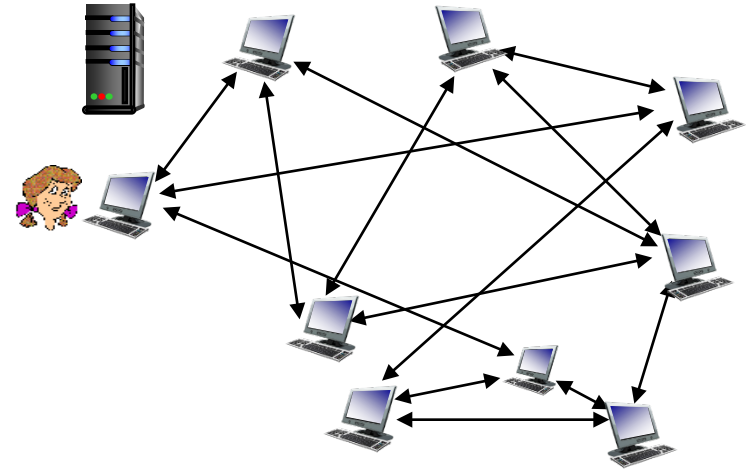
tracker: tracks peers participating in torrent

torrent: group of peers exchanging chunks of a file



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



BitTorrent: requesting, sending file chunks

requesting chunks:

- at any given time, different peers have different subsets of file chunks
- periodically, Alice asks each peer for list of chunks that they have
- Alice requests missing chunks from peers, rarest first

sending chunks: tit-for-tat

- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
 - other peers are choked by Alice (do not receive chunks from her)
 - re-evaluate top 4 every 10 secs
- every 30 secs: randomly select another peer, starts sending chunks
 - “optimistically unchoke” this peer
 - newly chosen peer may join top 4

BitTorrent: tit-for-tat

- (1) Alice “optimistically unchokes” Bob
- (2) Alice becomes one of Bob’s top-four providers; Bob reciprocates
- (3) Bob becomes one of Alice’s top-four providers

