

Chapter 2 (review)

Application Layer

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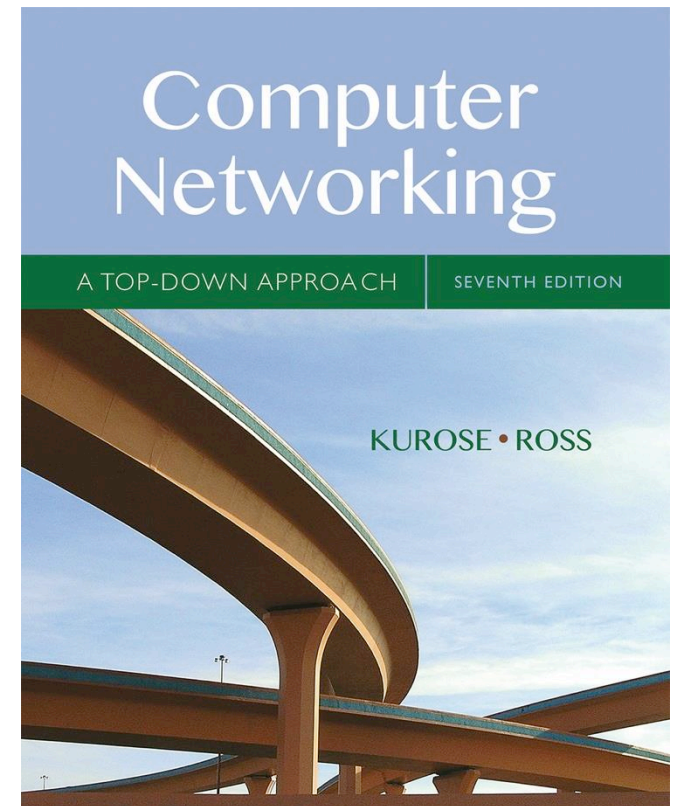
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Computer Networking: A Top Down Approach

7th edition

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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

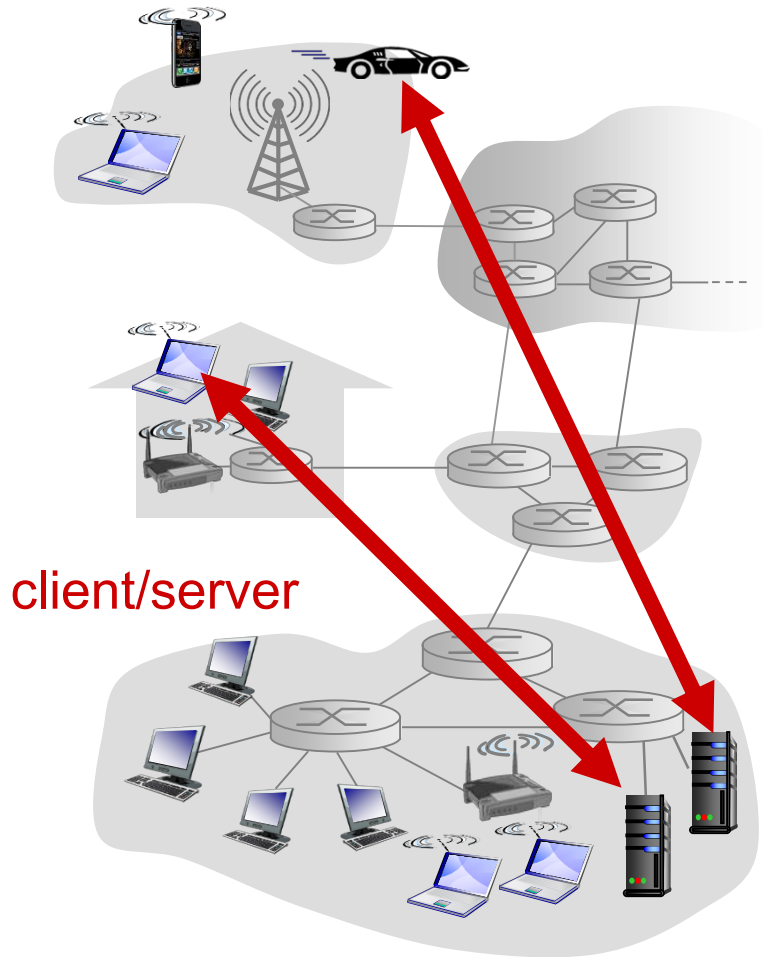
2.6 video streaming and content distribution networks

Application architectures

possible structure of applications:

- client-server
- peer-to-peer (P2P)

Client Server (C-S) architecture



server:

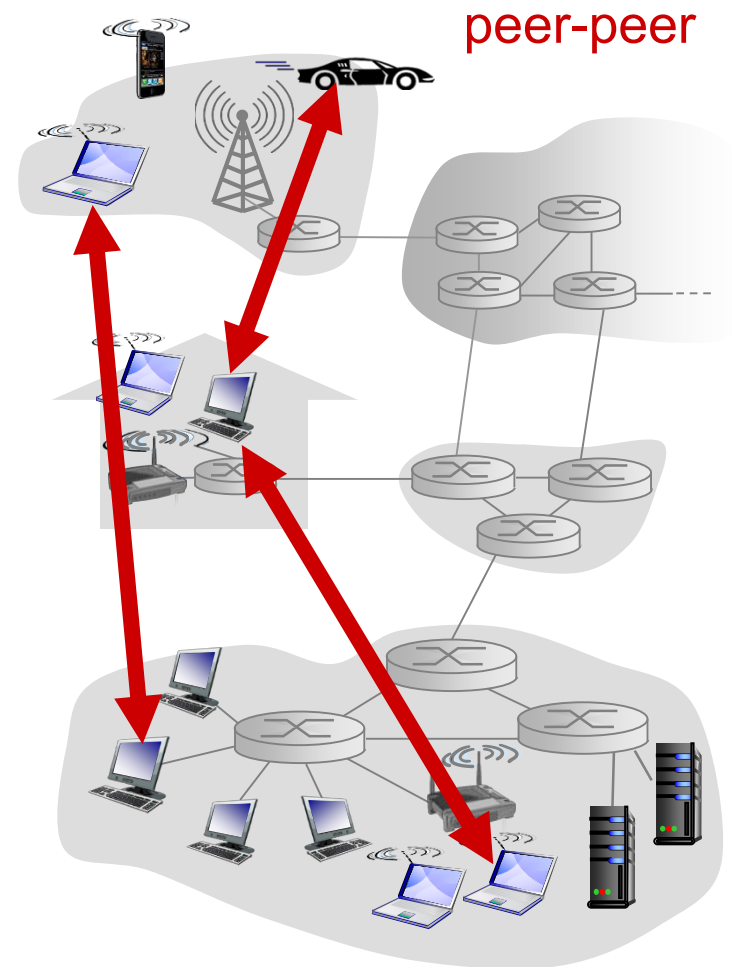
- always-on host
- permanent IP address
- data centers for scaling

clients:

- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other

P2P architecture

- no always-on server
- arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
 - *self scalability* – new peers bring new service capacity, as well as new service demands
- peers are intermittently connected and change IP addresses
 - complex management



Processes communicating

process: program running within a host

- within same host, two processes communicate using **inter-process communication** (defined by OS)
- processes in different hosts communicate by exchanging **messages**

clients, servers

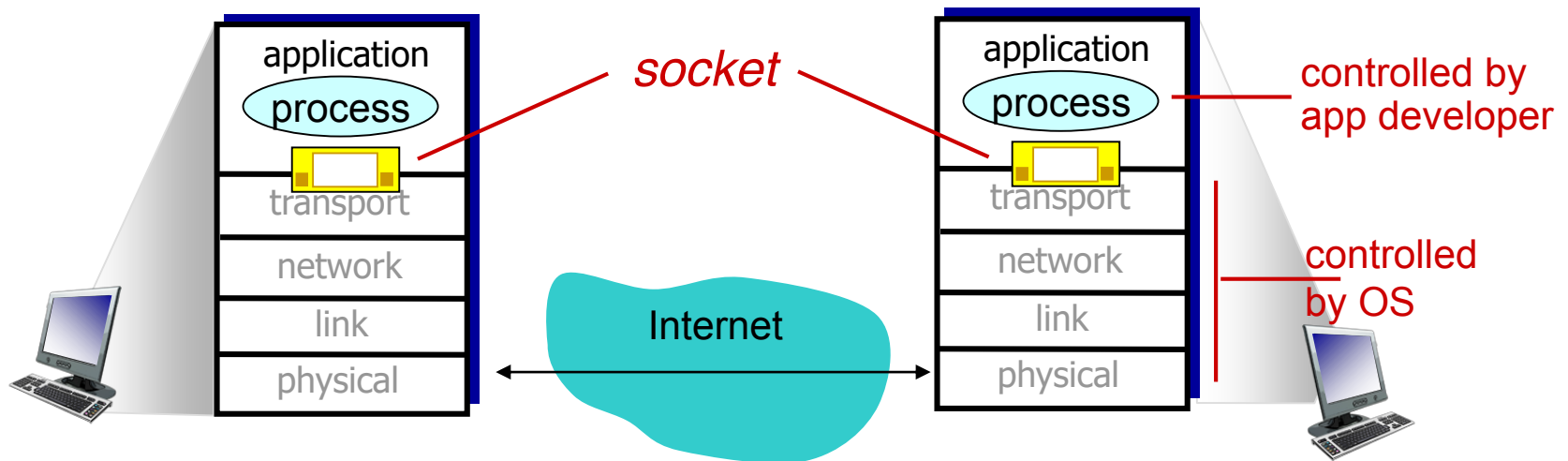
client process: process that initiates communication

server process: process that waits to be contacted

- aside: applications with P2P architectures have client processes & server processes

Sockets (套接字)

- process sends/receives messages to/from its **socket**
- socket analogous to door
 - sending process shoves message out door
 - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process



Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- Q: does IP address of host on which process runs suffice for identifying the process?
 - A: **No**, many processes can be running on same host
- *identifier* includes both **IP address** and **port numbers** associated with process on host.
- example port numbers:
 - HTTP server: **80**
 - mail server: **25**
- to send HTTP message to gaia.cs.umass.edu web server:
 - **IP address**: 128.119.245.12
 - **port number**: 80
- more shortly...

What transport service does an app need?

data integrity

- some apps (e.g., file transfer, web transactions) require 100% reliable data transfer
- other apps (e.g., audio) can tolerate some loss

timing

- some apps (e.g., Internet telephony, interactive games) require low delay to be “effective”

throughput

- some apps (e.g., multimedia) require minimum amount of throughput to be “effective”
- other apps (“elastic apps”) make use of whatever throughput they get

security

- encryption, data integrity, ...

Transport service requirements: common apps

application	data loss	throughput	time sensitive
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
Web documents	no loss	elastic	no
real-time audio/video	loss-tolerant	audio: 5kbps-1Mbps video: 10kbps-5Mbps	yes, 100' s msec
stored audio/video	loss-tolerant	same as above	
interactive games	loss-tolerant	few kbps up	yes, few secs
text messaging	no loss	elastic	yes, 100' s msec yes and no

Internet transport protocols services

TCP service:

- *reliable transport* between sending and receiving process
- *flow control*: sender won't overwhelm receiver
- *congestion control*: throttle sender when network overloaded
- *connection-oriented*: setup required between client and server processes
- *does not provide*: timing, minimum throughput guarantee, security

UDP service:

- *unreliable data transfer* between sending and receiving process
- *does not provide*: reliability, flow control, congestion control, timing, throughput guarantee, security, or connection setup,

Q: why bother? Why is there a UDP?

Internet apps: application, transport protocols

application	application layer protocol	underlying transport protocol
e-mail	SMTP [RFC 2821]	TCP
remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
file transfer	FTP [RFC 959]	TCP
streaming multimedia	HTTP (e.g., YouTube), RTP [RFC 1889]	TCP or UDP
Internet telephony	SIP, RTP, proprietary (e.g., Skype)	TCP or UDP

Securing TCP

TCP & UDP

- **No encryption (无加密)**
- cleartext passwds sent into socket traverse Internet in cleartext

SSL (Secure Sockets Layer 安全套接层)

- provides encrypted TCP connection
- data integrity
- end-point authentication

SSL is at app layer

- apps use SSL libraries, that “talk” to TCP

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2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

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2.5 P2P applications

2.6 video streaming and content distribution networks

2.7 socket programming with UDP and TCP

Web and HTTP

First, a review...

- *web page* consists of *objects*
- object can be HTML file, JPEG image, Java applet, audio file,...
- web page consists of *base HTML-file* which includes *several referenced objects*
- each object is addressable by a *URL*, e.g.,

`www.someschool.edu/someDept/pic.gif`

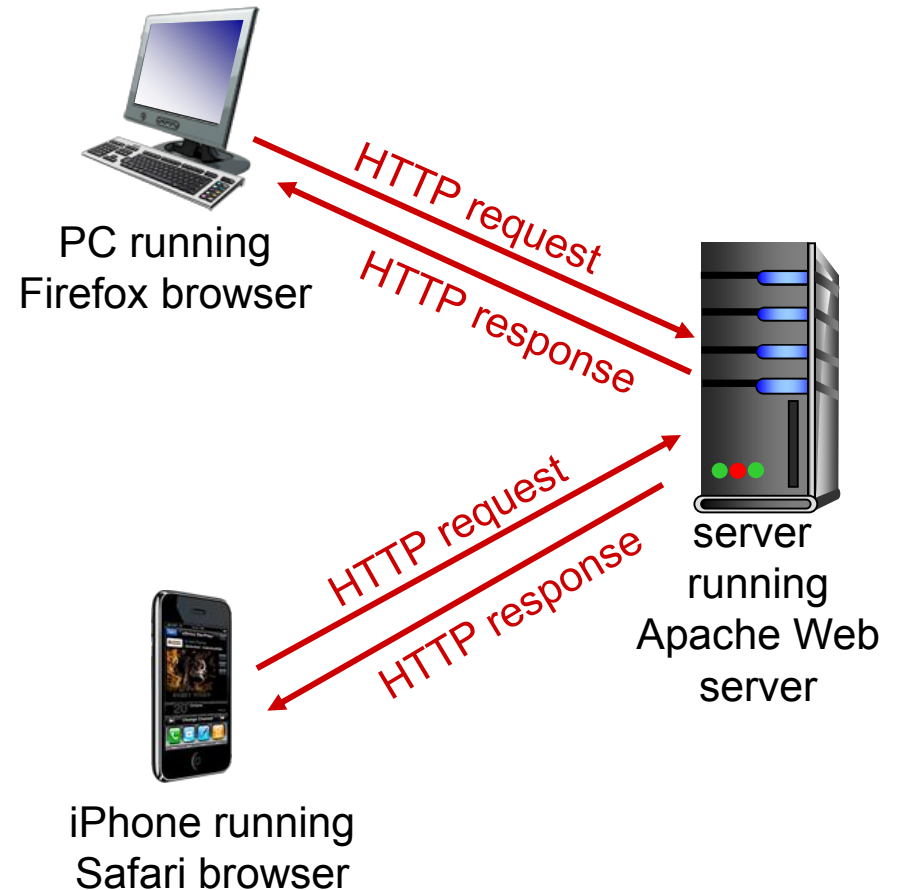
host name

path name

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
 - **client**: browser that requests, receives, (using HTTP protocol) and "displays" Web objects
 - **server**: Web server sends (using HTTP protocol) objects in response to requests



HTTP overview (continued)

uses TCP:

- client initiates TCP connection (creates socket) to server, **port 80**
- server accepts TCP connection from client
- HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- TCP connection closed

HTTP is “stateless” (无状态)

- server maintains no information about past client requests

HTTP connections

non-persistent HTTP (非持续)

- at most one object sent over TCP connection
 - connection then closed
- downloading multiple objects required multiple connections

persistent HTTP (持续)

- multiple objects can be sent over single TCP connection between client, server

User-server state: cookies

many Web sites use cookies

four components:

- 1) cookie header line of HTTP *response* message
- 2) cookie header line in next HTTP *request* message
- 3) cookie file kept on user's host, managed by user's browser
- 4) back-end database at Web site

example:

- Susan always access Internet from PC
- visits specific e-commerce site for first time
- when initial HTTP requests arrives at site, site creates:
 - unique ID
 - entry in backend database for ID

Cookies: keeping “state” (cont.)

client



server



cookie file



ebay 8734
amazon 1678

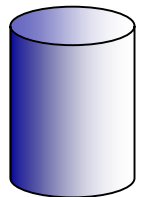
usual http request msg

Amazon server
creates ID
1678 for user

usual http response
set-cookie: 1678

create
entry

backend
database



usual http request msg
cookie: 1678

cookie-
specific
action

access

usual http response msg

access

cookie-
specific
action

one week later:



ebay 8734
amazon 1678

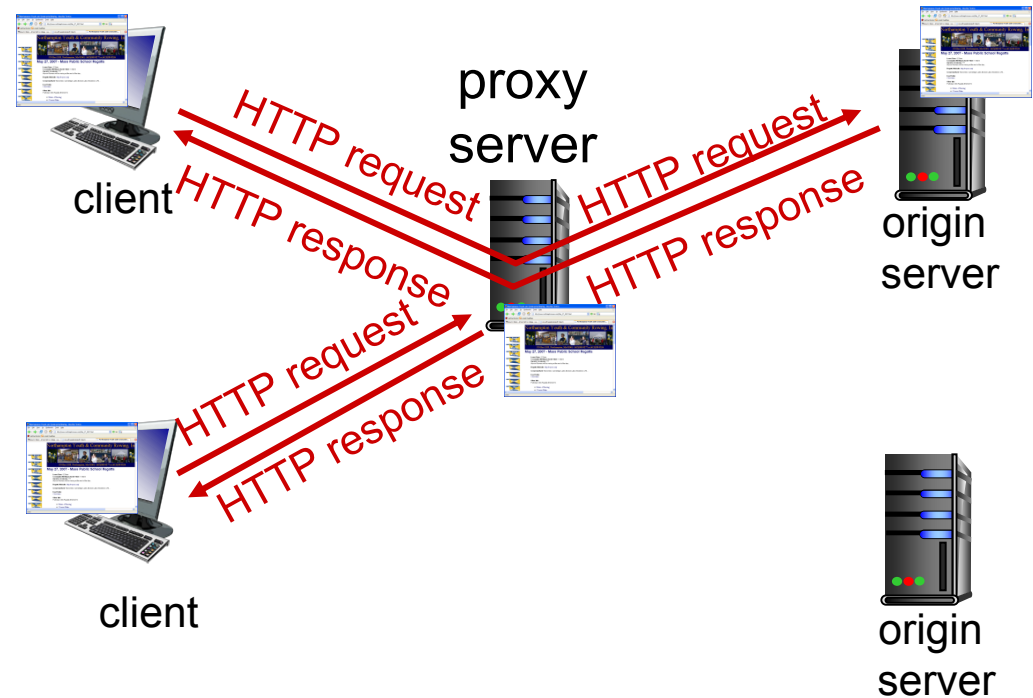
usual http request msg
cookie: 1678

usual http response msg

Web caches (proxy server) 代理服务器

goal: satisfy client request without involving origin server

- user sets browser: Web accesses via cache
- browser sends all HTTP requests to cache
 - object in cache: cache returns object
 - else cache requests object from origin server, then returns object to client



More about Web caching

- cache acts as both client and server
 - server for original requesting client
 - client to origin server
- typically cache is installed by ISP (university, company, residential ISP)

why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link
- Internet dense with caches: enables “poor” content providers to effectively deliver content (so too does P2P file sharing)

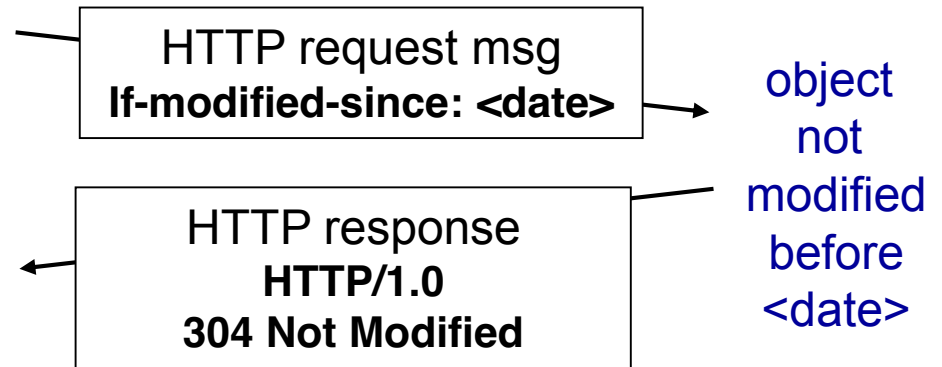
Conditional GET

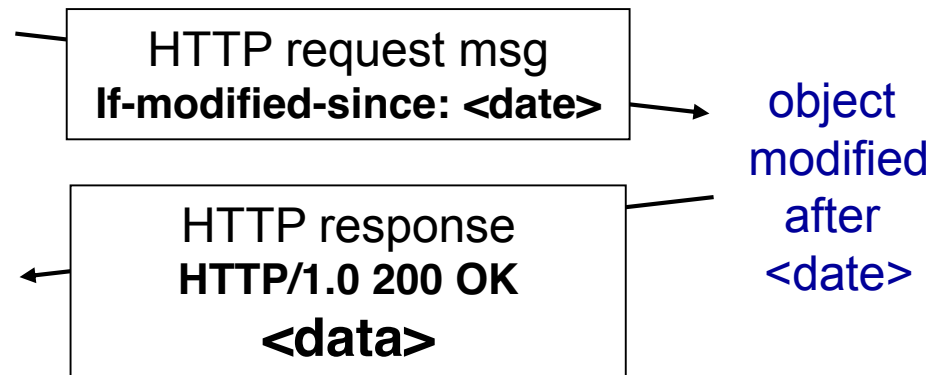
- **Goal:** don't send object if cache has up-to-date cached version
 - no object transmission delay
 - lower link utilization
- **cache:** specify date of cached copy in HTTP request
If-modified-since: <date>
- **server:** response contains no object if cached copy is up-to-date:
HTTP/1.0 304 Not Modified

client



server





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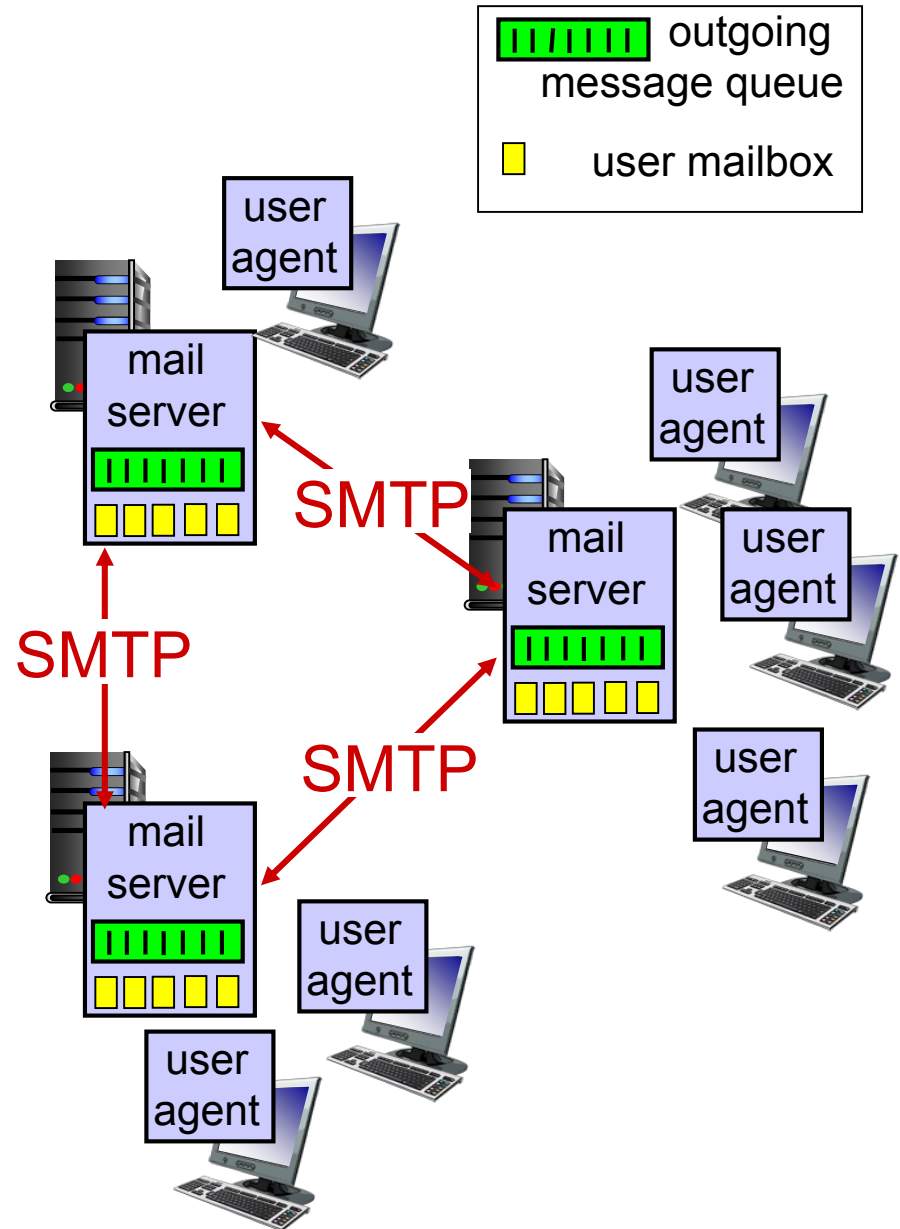
Electronic mail

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

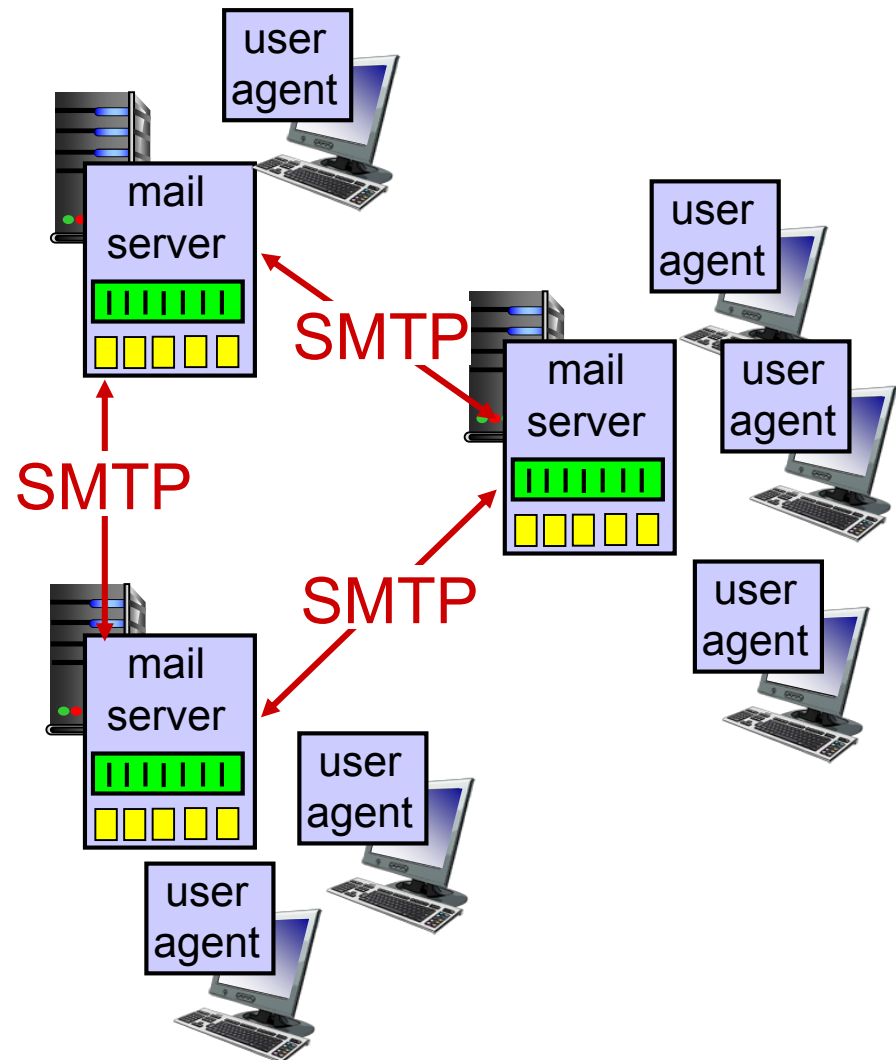
mail servers:

- *mailbox* contains incoming messages for user
- *message queue* of outgoing (to be sent) mail messages

SMTP protocol :

between mail servers to send email messages

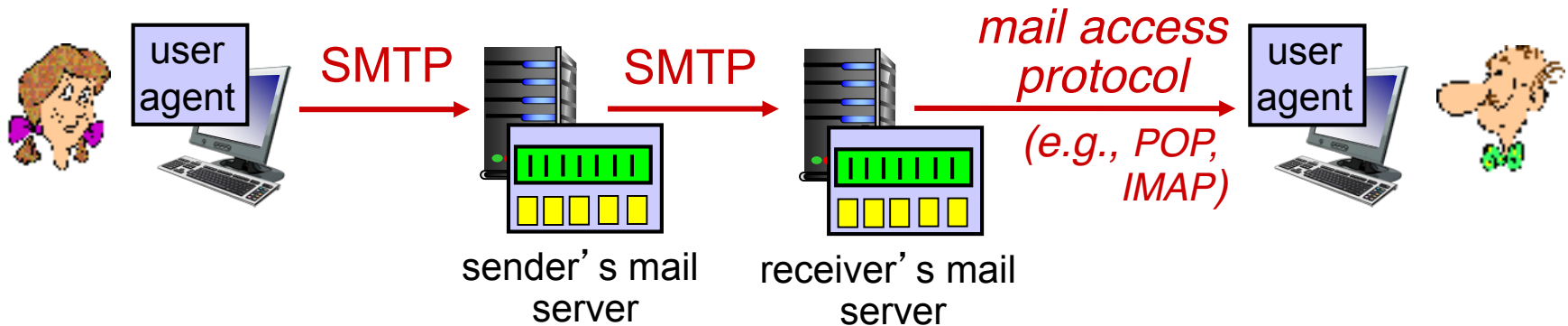
- client: sending mail server
- “server”: receiving mail server



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

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.

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DNS: domain name system 域名系统

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

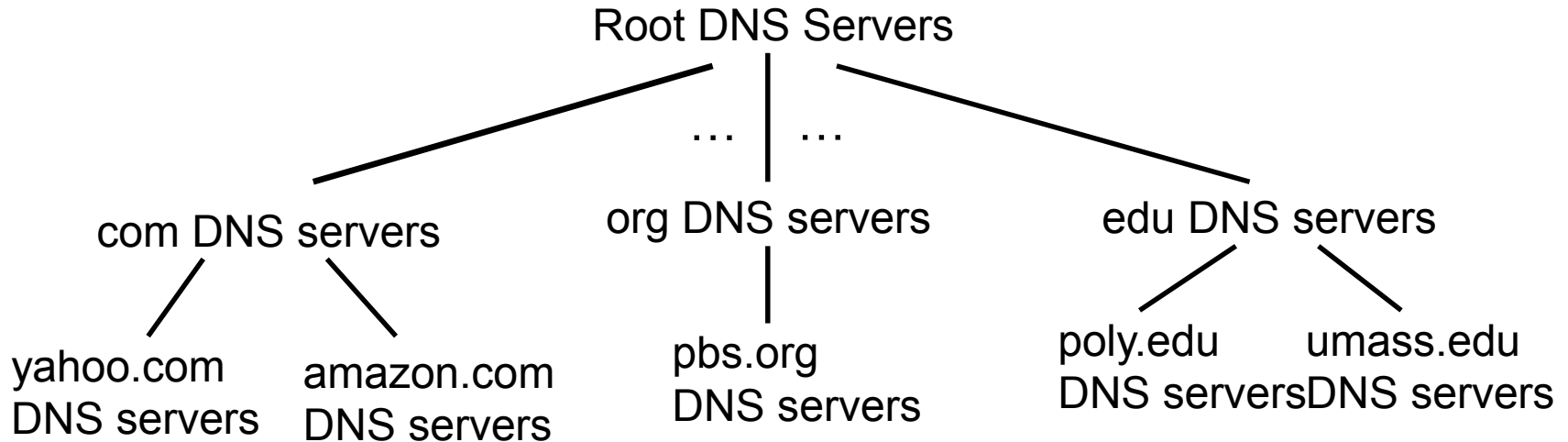
- hostname to IP address translation
- host aliasing
 - canonical, alias names
- mail server aliasing
- load distribution
 - replicated Web servers: many IP addresses correspond to one name

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

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

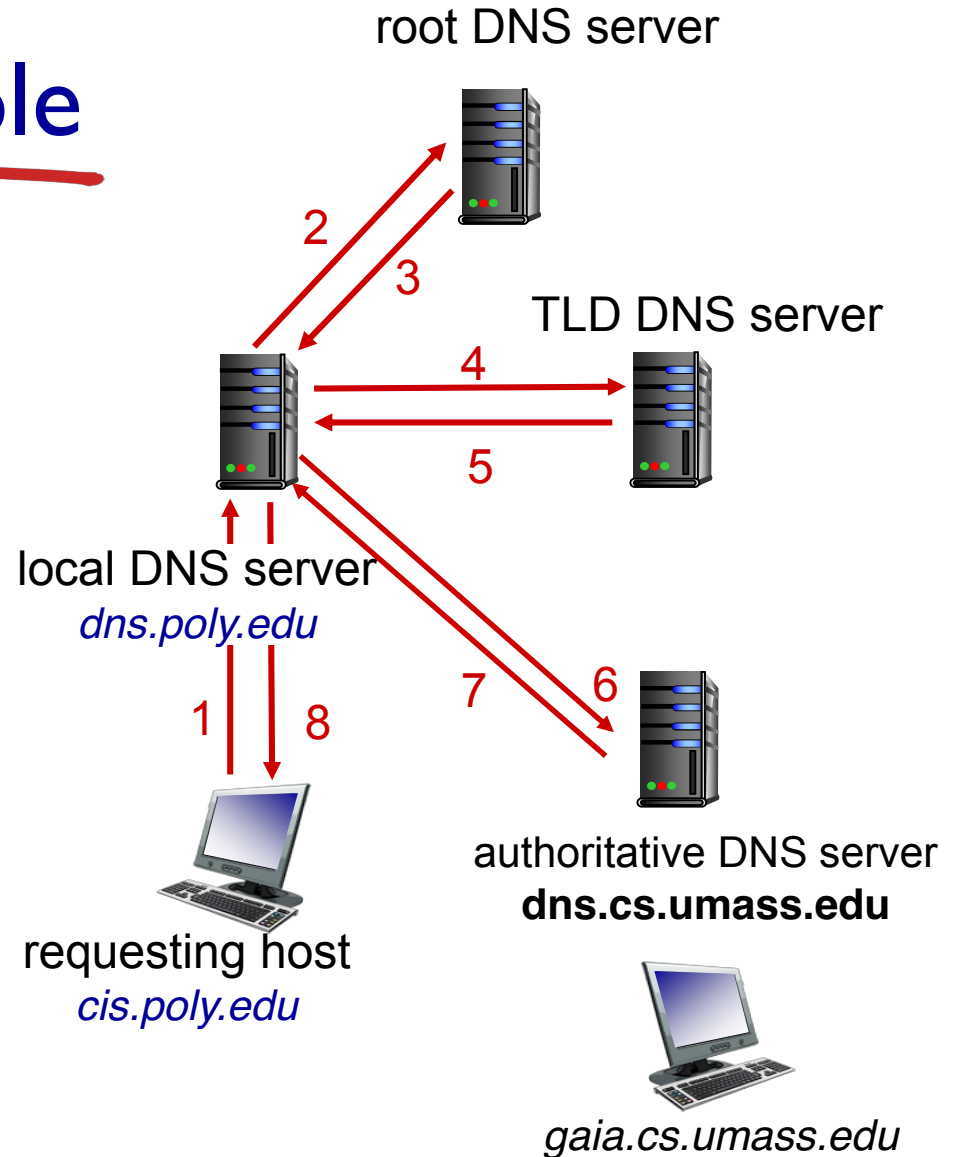
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
 - also called “default name server”
- when host makes DNS query, query is sent to its local DNS server
 - has local cache of recent name-to-address translation pairs (but may be out of date!)
 - acts as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

DNS name resolution example

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

iterated query:(迭代查询)

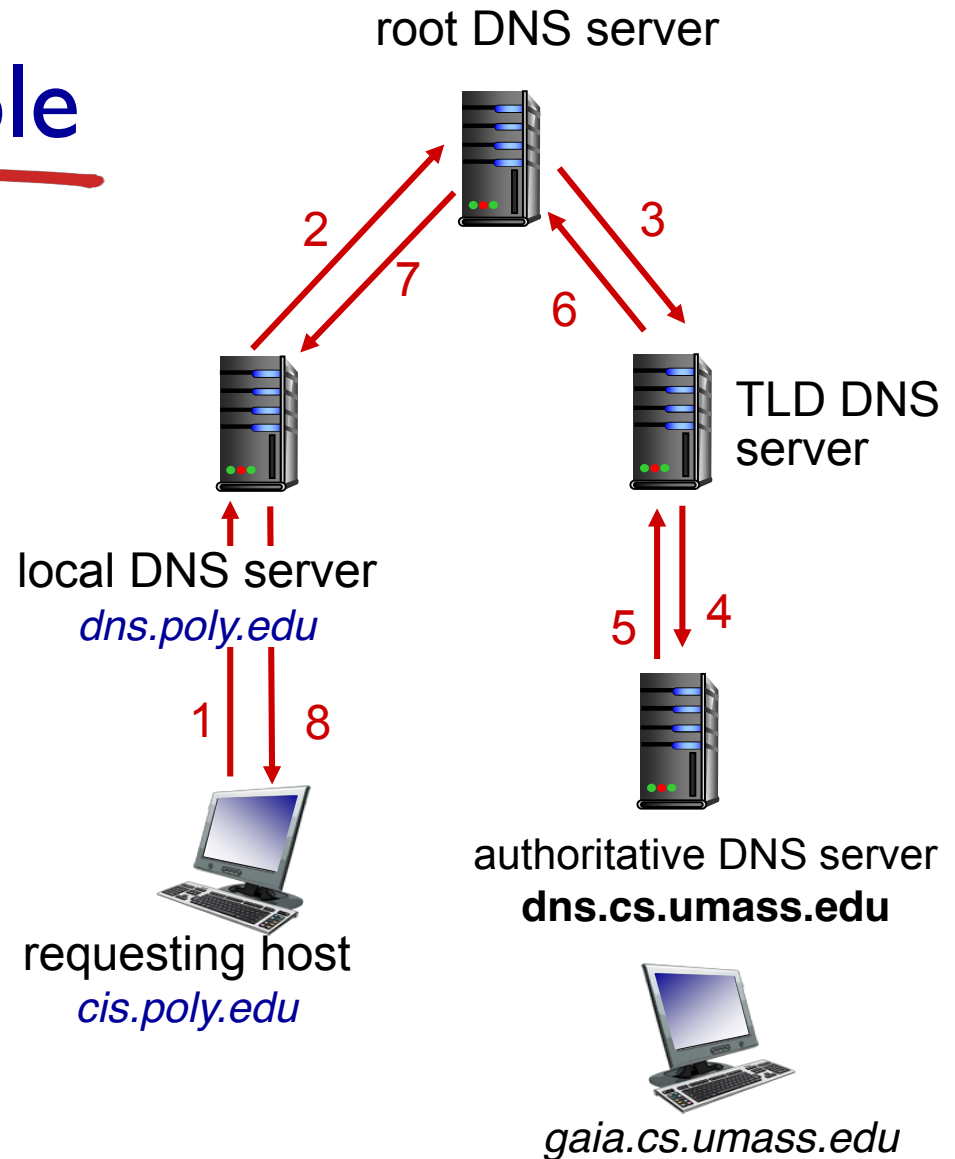
- contacted server replies with name of server to contact
- “I don't know this name, but ask this server”



DNS name resolution example

recursive query (递归查询)

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



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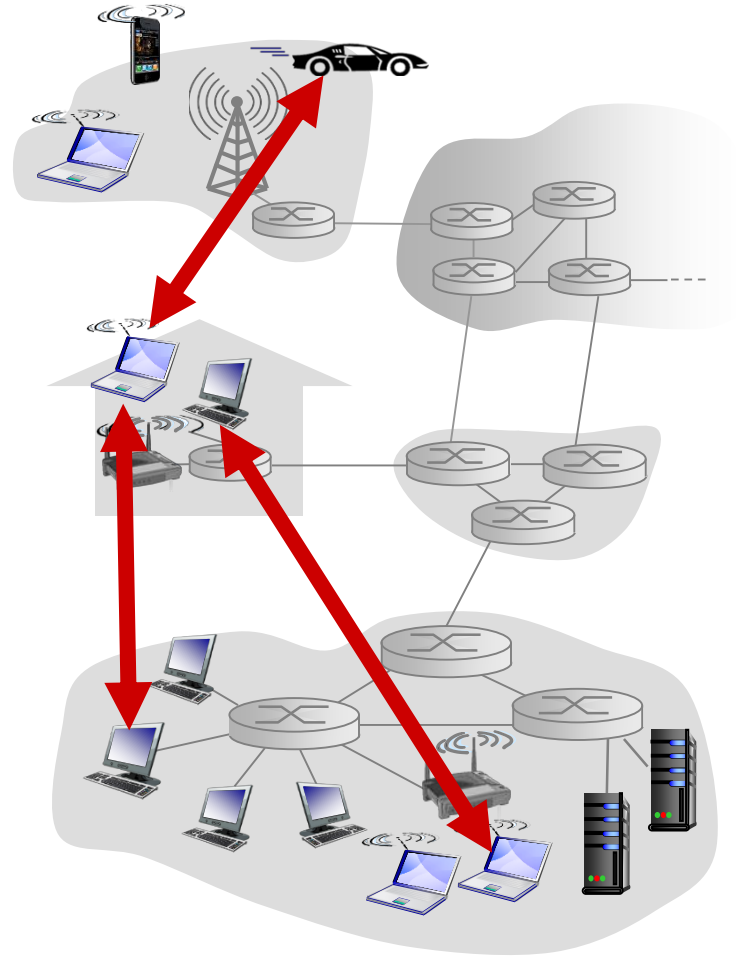
2.6 video streaming and content distribution networks

Pure P2P architecture

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

examples:

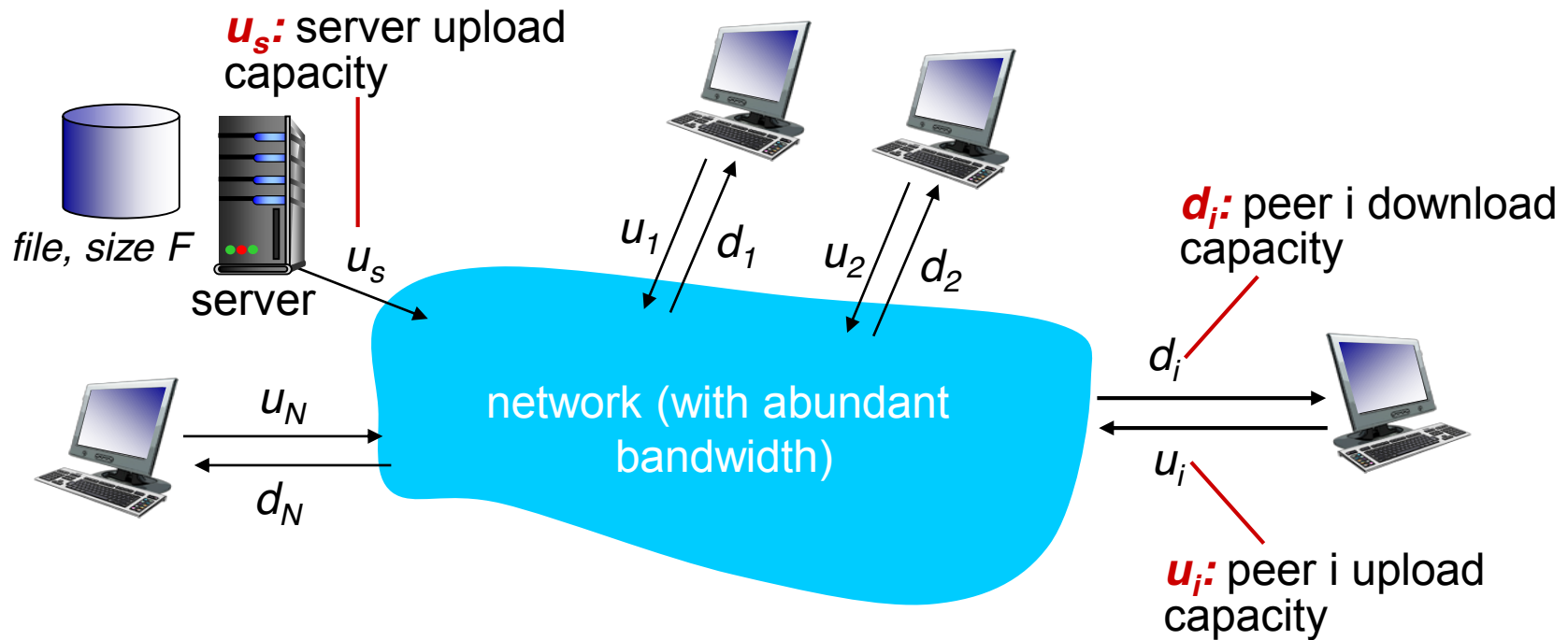
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

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

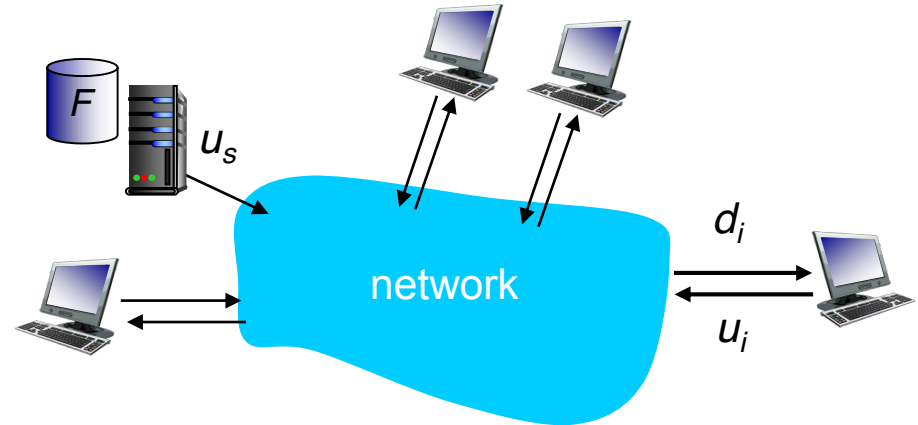
- peer upload/download capacity is limited resource



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}

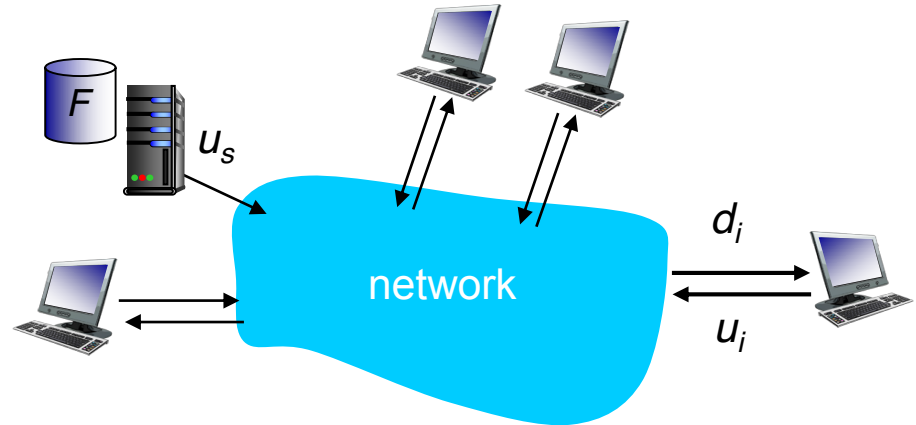
*time to distribute F
to N clients using
client-server approach*

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

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*

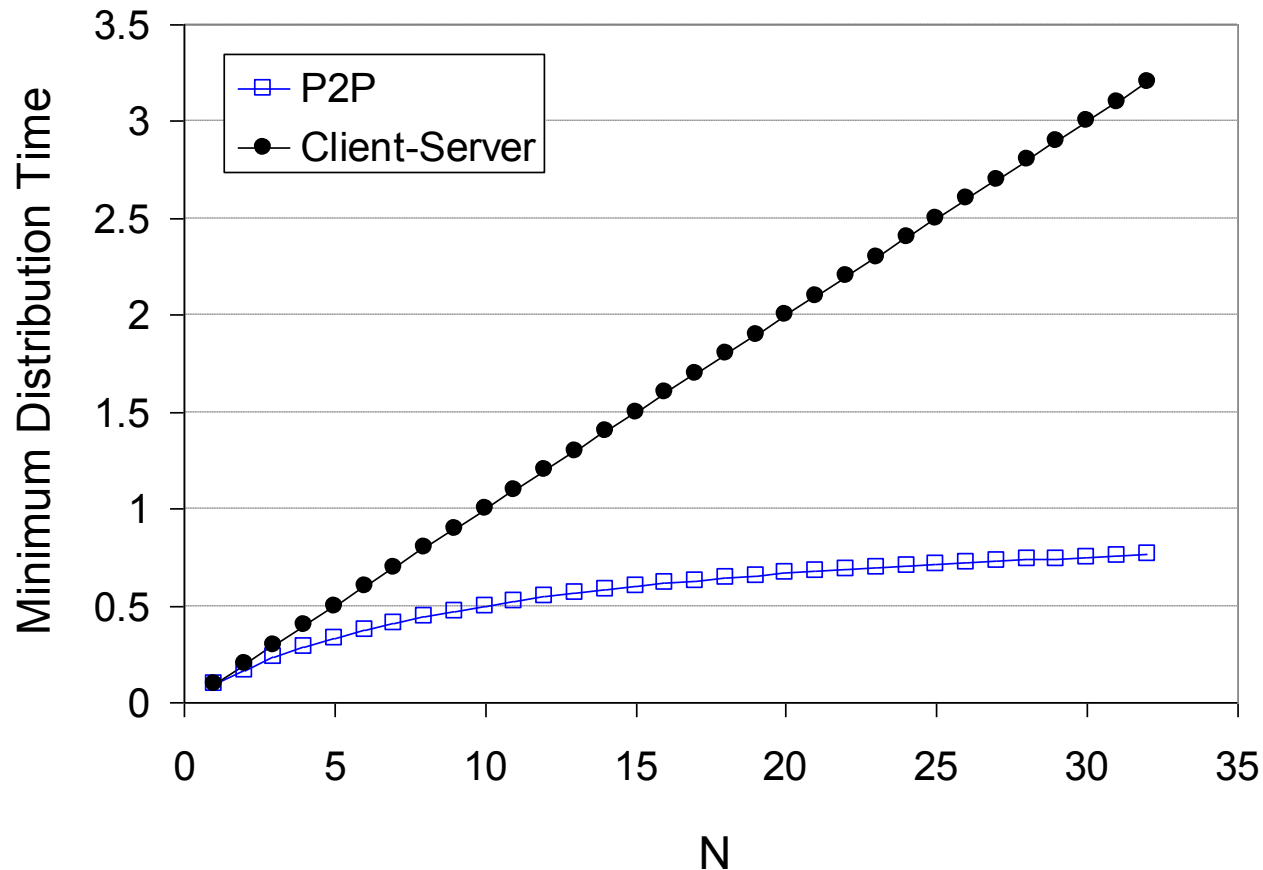
$$D_{P2P} \geq \max\{F/u_s, F/d_{\min}, NF/(u_s + \sum u_i)\}$$

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, $u_s = 10u$, $d_{min} \geq u_s$



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Video Streaming and CDNs: context

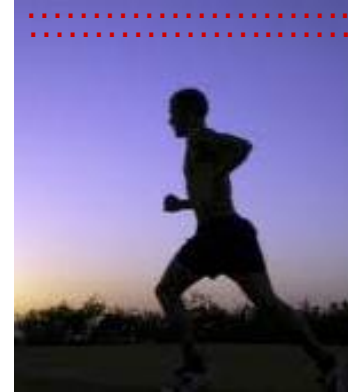
- video traffic: major consumer of Internet bandwidth
 - Netflix, YouTube: 37%, 16% of downstream residential ISP traffic
 - ~1B YouTube users, ~75M Netflix users
- challenge: scale - how to reach ~1B users?
 - single mega-video server won't work (why?)
- challenge: heterogeneity
 - different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus bandwidth poor)
- **solution:** distributed, application-level infrastructure



Multimedia: video

- video: sequence of images displayed at constant rate
 - e.g., 24 images/sec
- digital image: array of pixels
 - each pixel represented by bits
- coding: use redundancy *within* and *between* images to decrease # bits used to encode image
 - **spatial** (within image)
 - **temporal** (from one image to next)

spatial coding example: instead of sending N values of same color (all purple), send only two values: color value (*purple*) and number of repeated values (N)



frame i

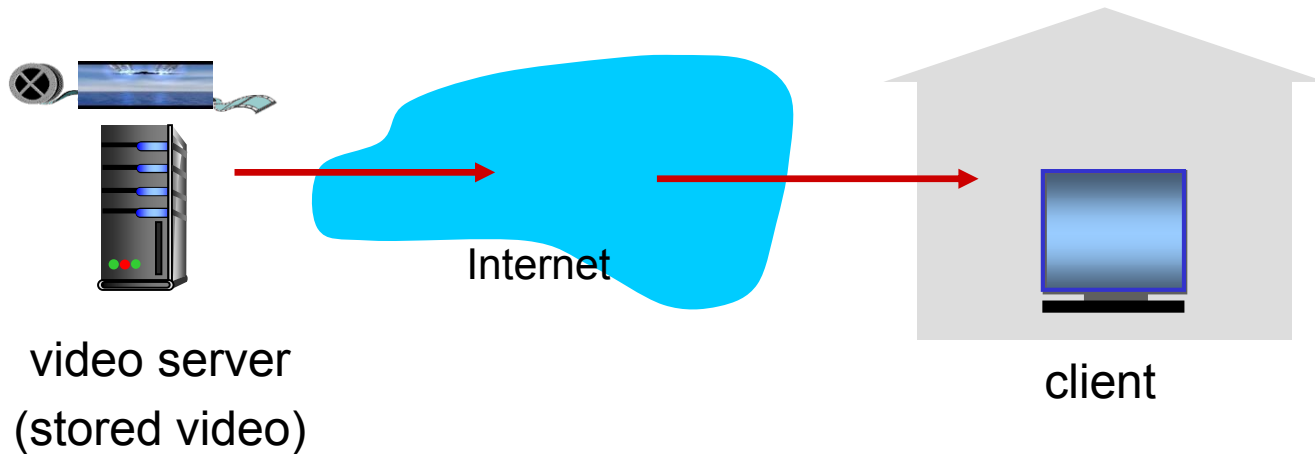
temporal coding example: instead of sending complete frame at $i+1$, send only differences from frame i



frame $i+1$

Streaming stored video:

simple scenario:



Streaming multimedia: DASH

- *DASH*: *D*ynamic, *A*daptive *S*treaming over *H*TTP
- *server*:
 - divides video file into multiple chunks
 - each chunk stored, encoded at different rates
 - *manifest file*: provides URLs for different chunks
- *client*:
 - periodically measures server-to-client bandwidth
 - consulting manifest, requests one chunk at a time
 - chooses maximum coding rate sustainable given current bandwidth
 - can choose different coding rates at different points in time (depending on available bandwidth at time)

Streaming multimedia: DASH

- *DASH: Dynamic, Adaptive Streaming over HTTP*
- “intelligence” at client: client determines
 - *when* to request chunk (so that buffer starvation, or overflow does not occur)
 - *what encoding rate* to request (higher quality when more bandwidth available)
 - *where* to request chunk (can request from URL server that is “close” to client or has high available bandwidth)

Content distribution networks

- *challenge*: how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?
- *option 1*: single, large “mega-server”
 - single point of failure
 - point of network congestion
 - long path to distant clients
 - multiple copies of video sent over outgoing link

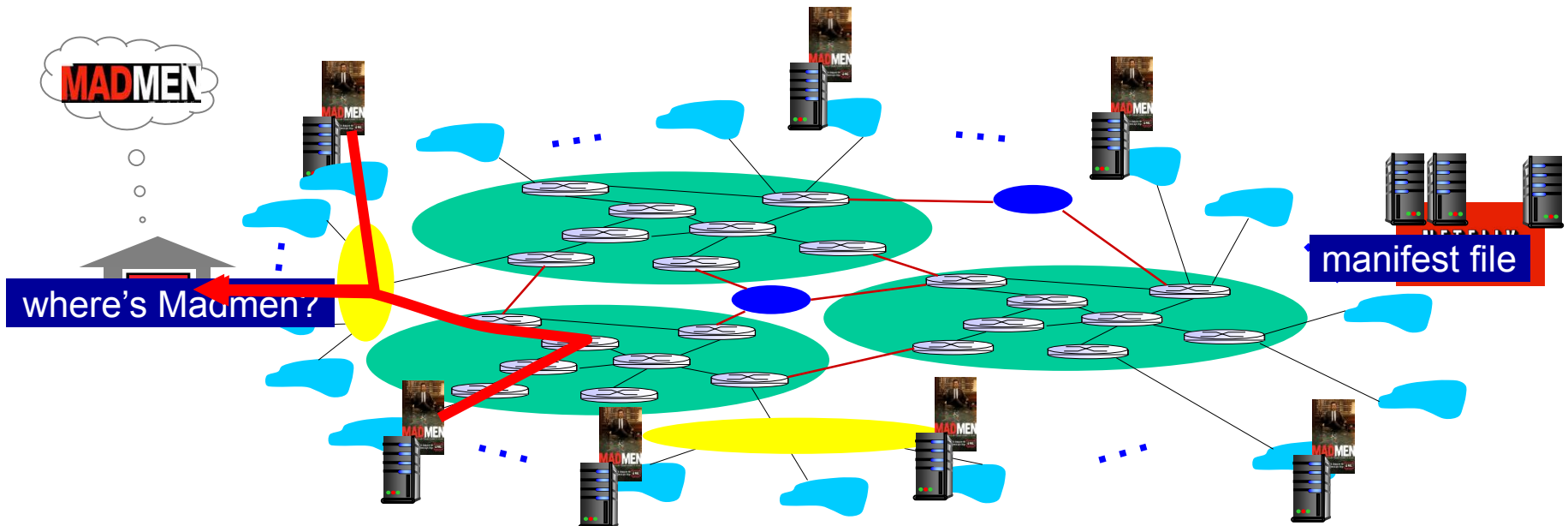
....quite simply: this solution *doesn't scale*

Content distribution networks

- *challenge*: how to stream content (selected from millions of videos) to hundreds of thousands of simultaneous users?
- *option 2*: store/serve multiple copies of videos at multiple geographically distributed sites (*CDN*)
 - *enter deep*: push CDN servers deep into many access networks
 - close to users
 - used by Akamai, 1700 locations
 - *bring home*: smaller number (10's) of larger clusters in POPs near (but not within) access networks
 - used by Limelight

Content Distribution Networks (CDNs)

- CDN: stores copies of content at CDN nodes
 - e.g. Netflix stores copies of MadMen
- subscriber requests content from CDN
 - directed to nearby copy, retrieves content
 - may choose different copy if network path congested



Chapter 2

End