

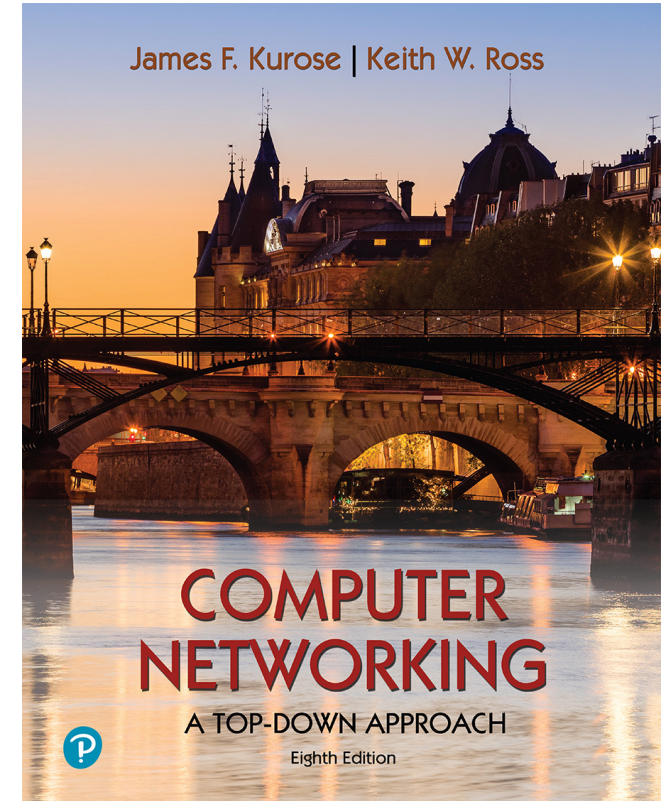
Chapter 2

Application Layer

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Adapted from the slides of the book's authors



*Computer Networking: A
Top-Down Approach*

8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Application layer: overview

- Principles of network applications
- socket programming with UDP and TCP
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS
- P2P applications
- video streaming and content distribution networks



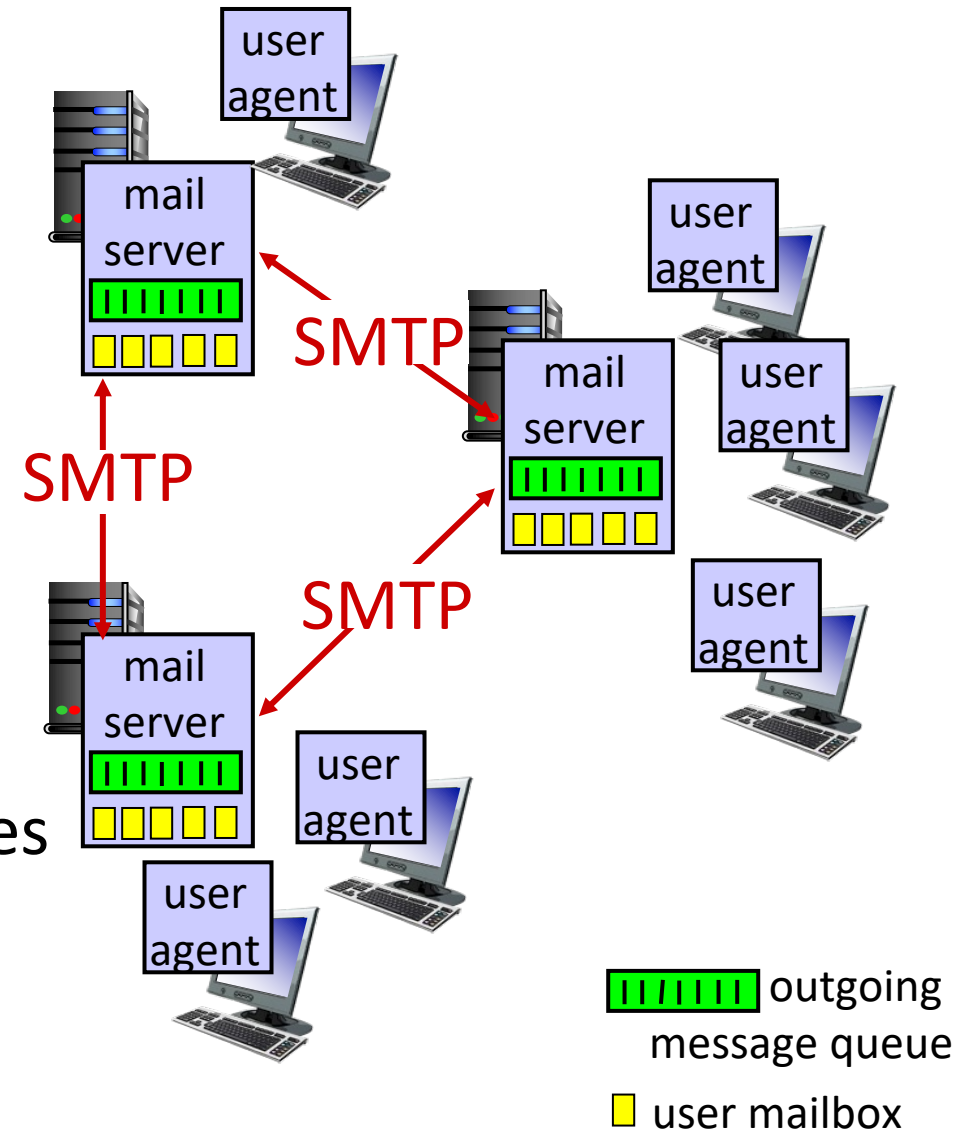
E-mail

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, iPhone mail client
- outgoing, incoming messages stored on server



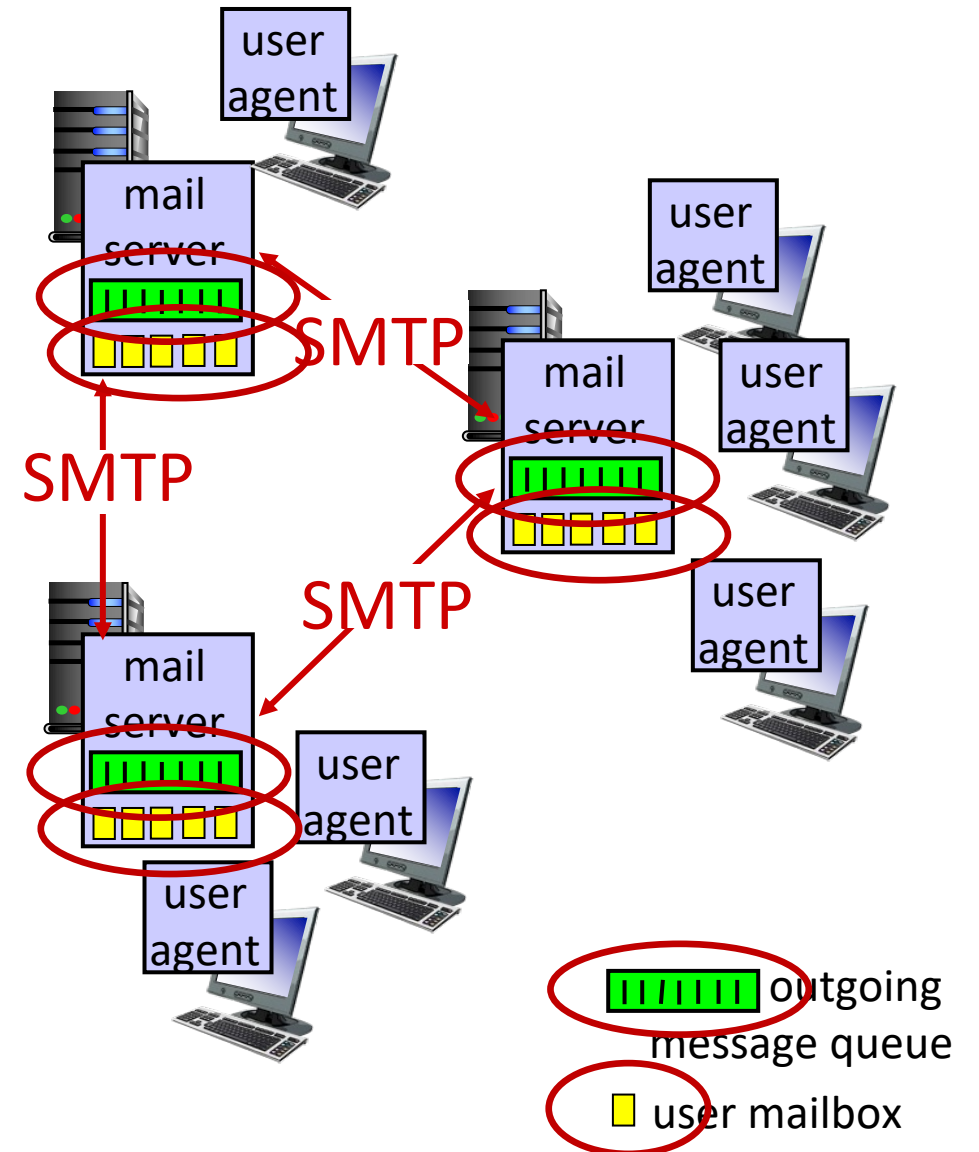
E-mail: mail servers

mail servers:

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

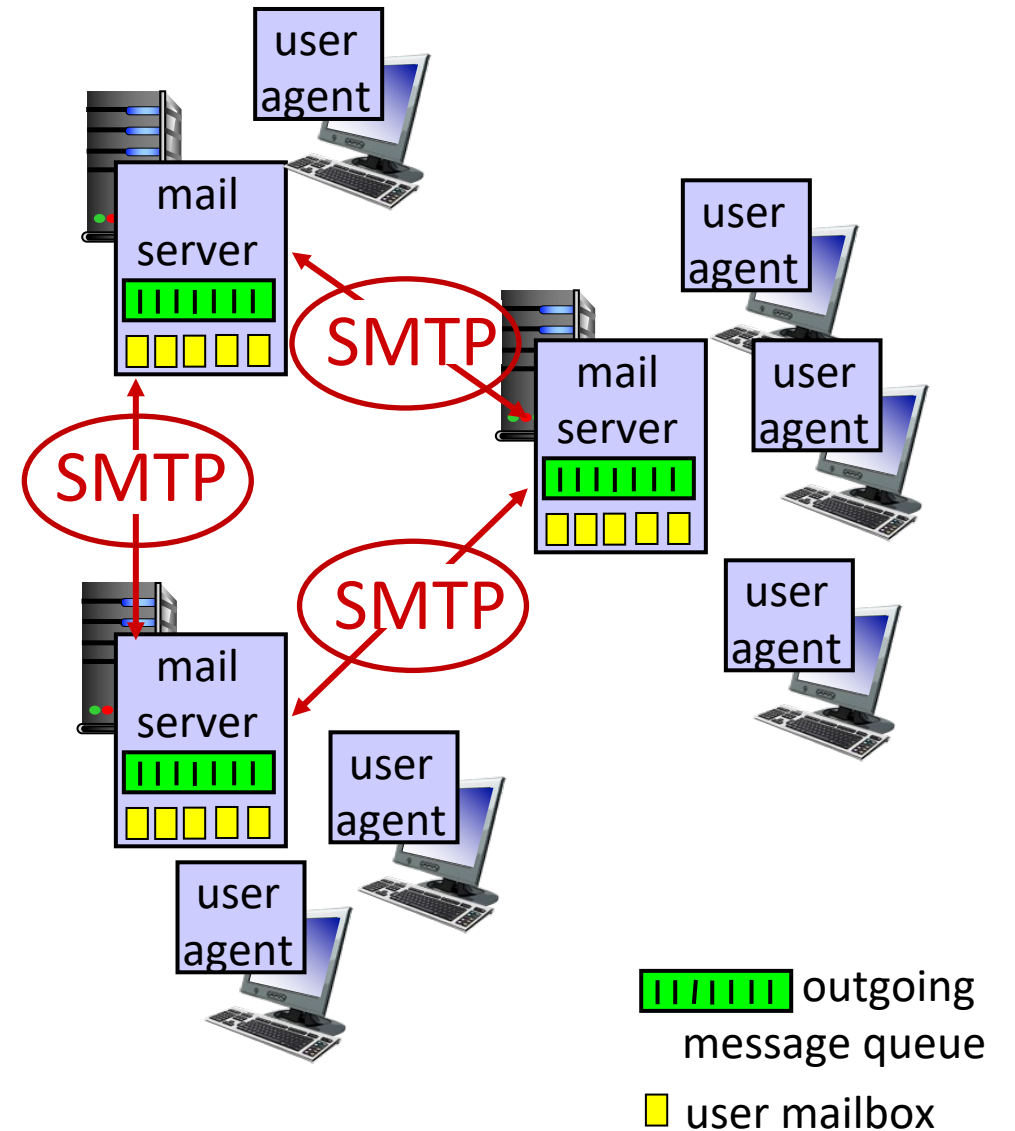
SMTP protocol between mail servers to send email messages

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

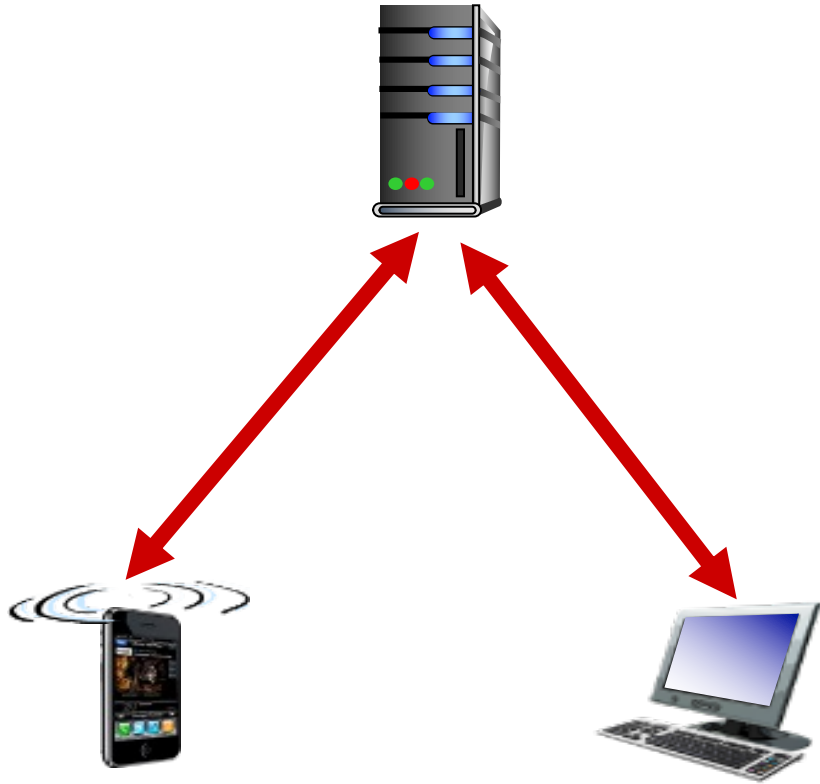


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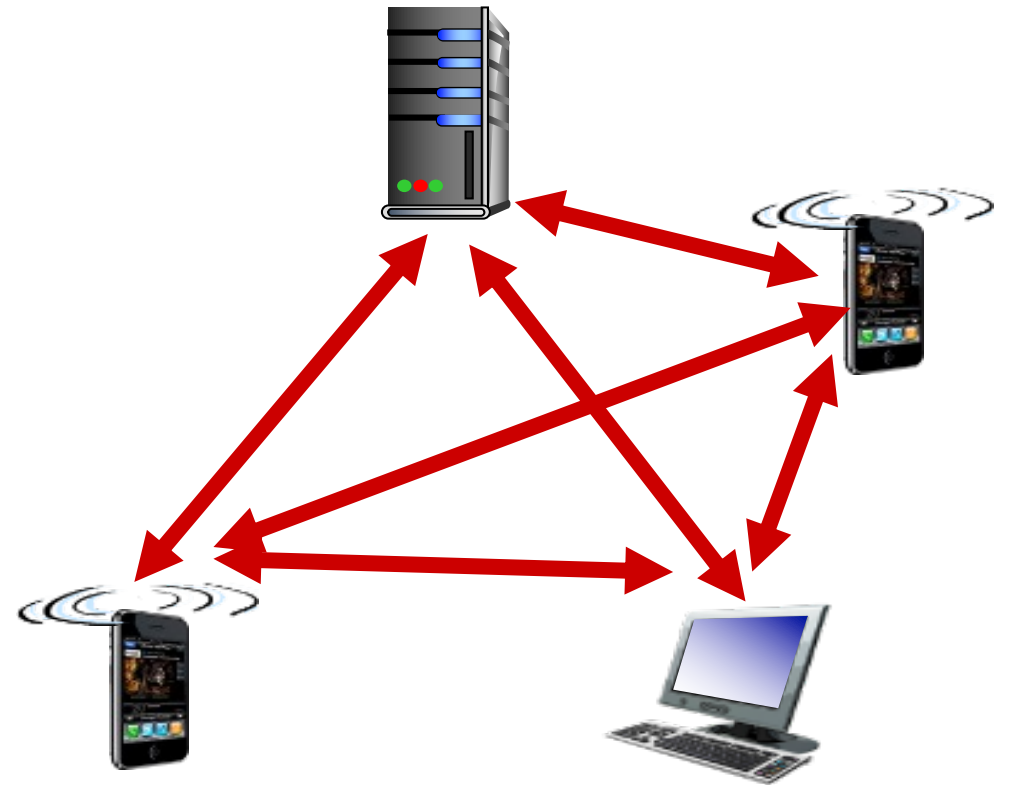
SMTP protocol between mail servers to send email messages



Two widely adopted paradigm



Server-Client Mode

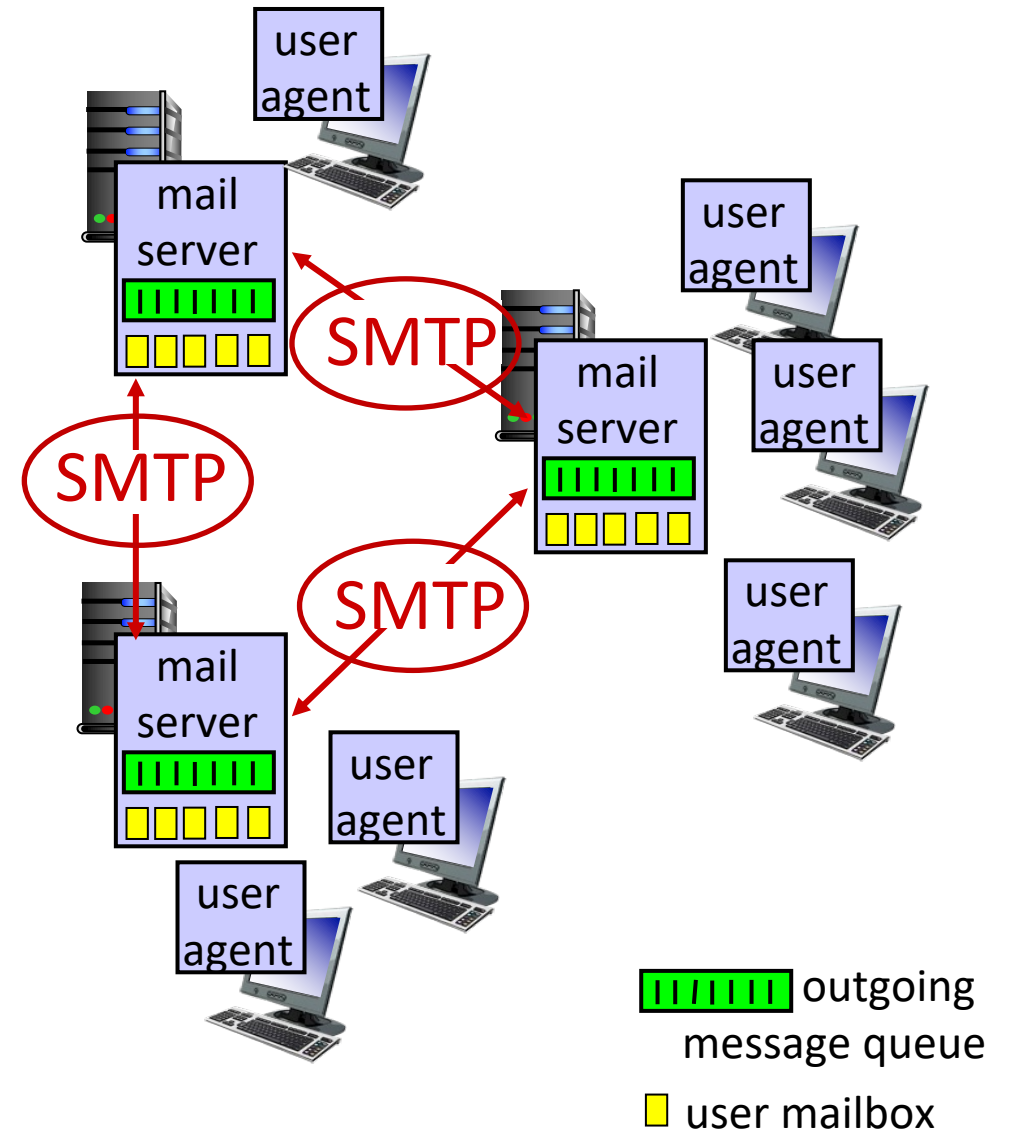
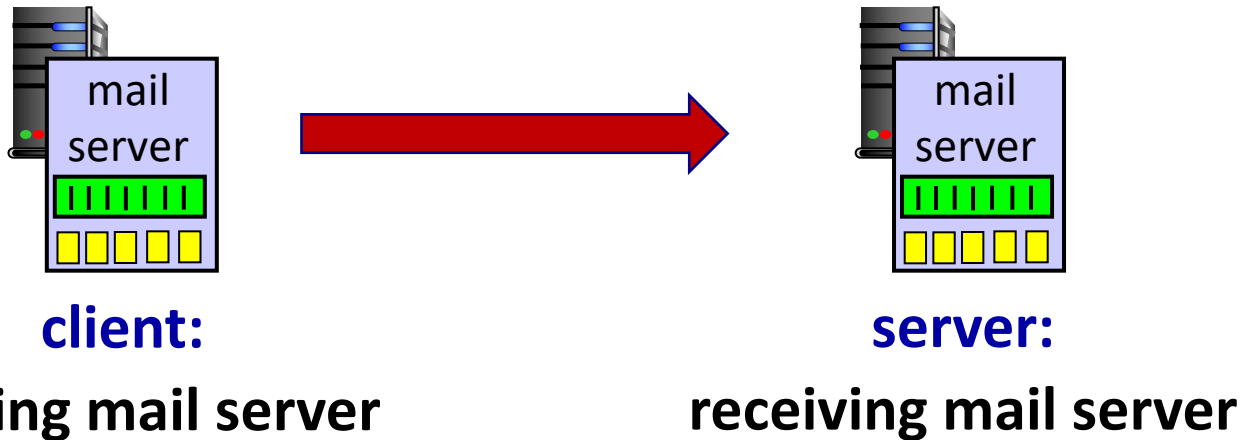


P2P Mode

E-mail: mail servers

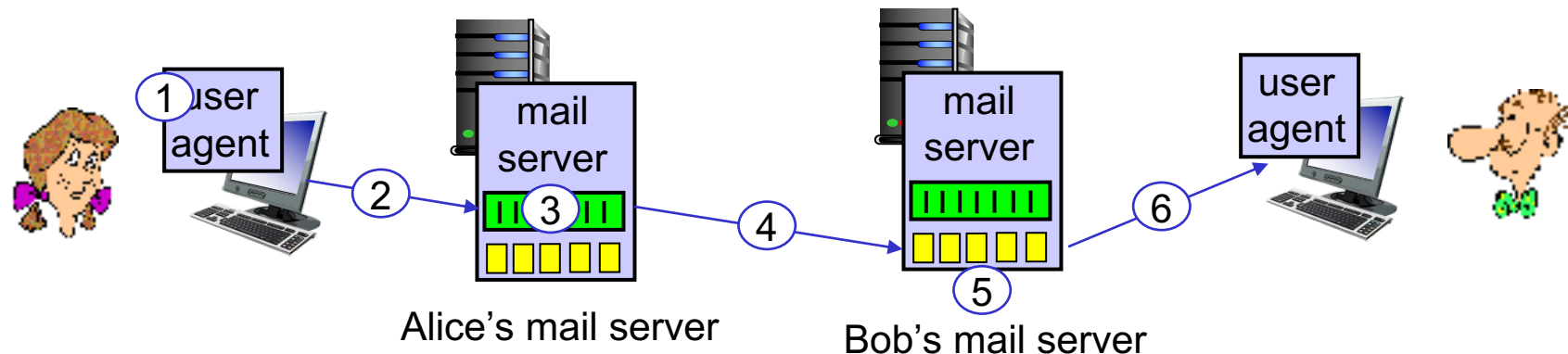
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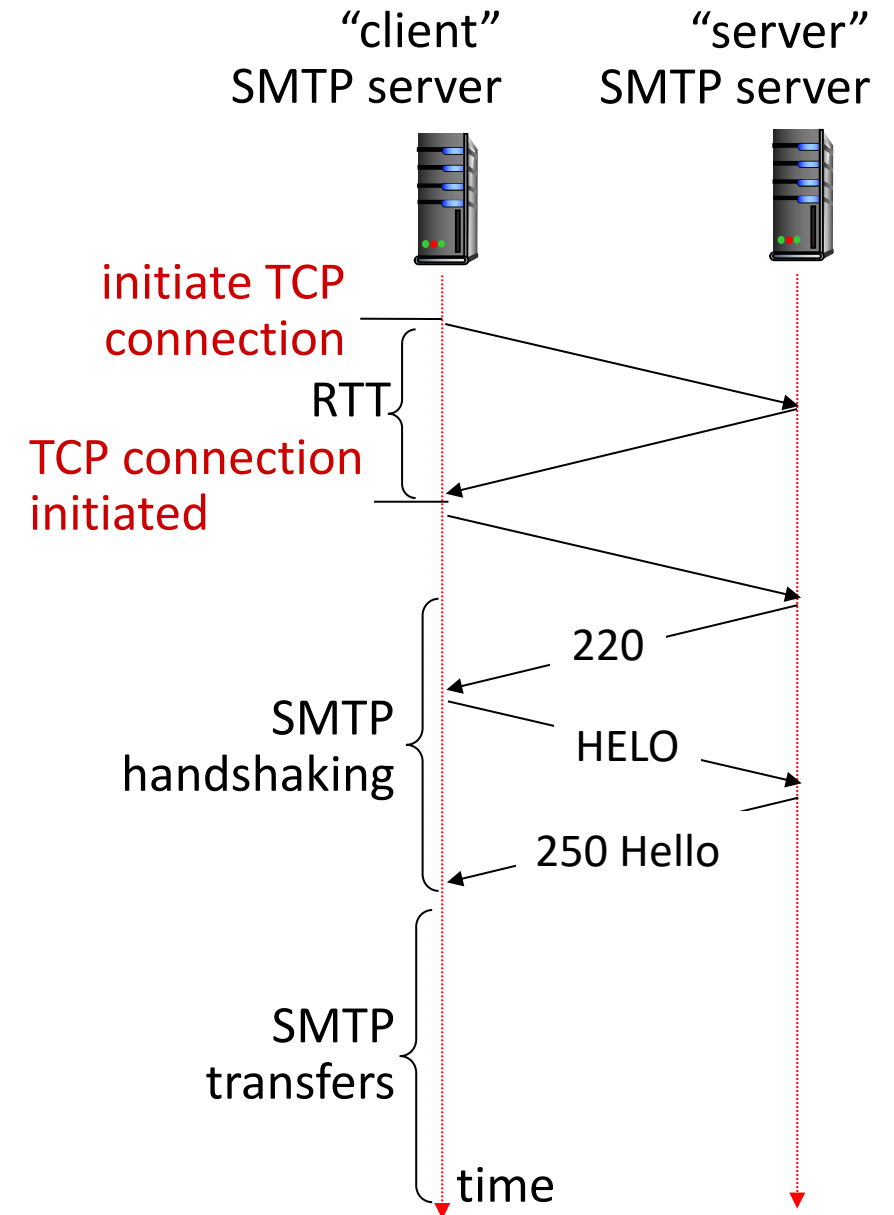
Scenario: Alice sends e-mail to Bob

- 1) Alice uses UA to compose e-mail message "to" bob@some school.edu
- 2) Alice's UA sends message to her mail server using SMTP; message placed in message queue
- 3) client side of SMTP at mail server 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



SMTP RFC (5321)

- uses TCP to reliably transfer email messages from client (mail server initiating connection) to server, port 25
 - direct transfer: sending server (acting like client) to receiving server
- three phases of transfer
 - SMTP handshaking (greeting)
 - SMTP transfer of messages
 - SMTP closure
- command/response interaction (like HTTP)
 - **commands**: ASCII text
 - **response**: status code and phrase



Sample SMTP interaction

S: 220 hamburger.edu

SMTP: observations

comparison with HTTP:

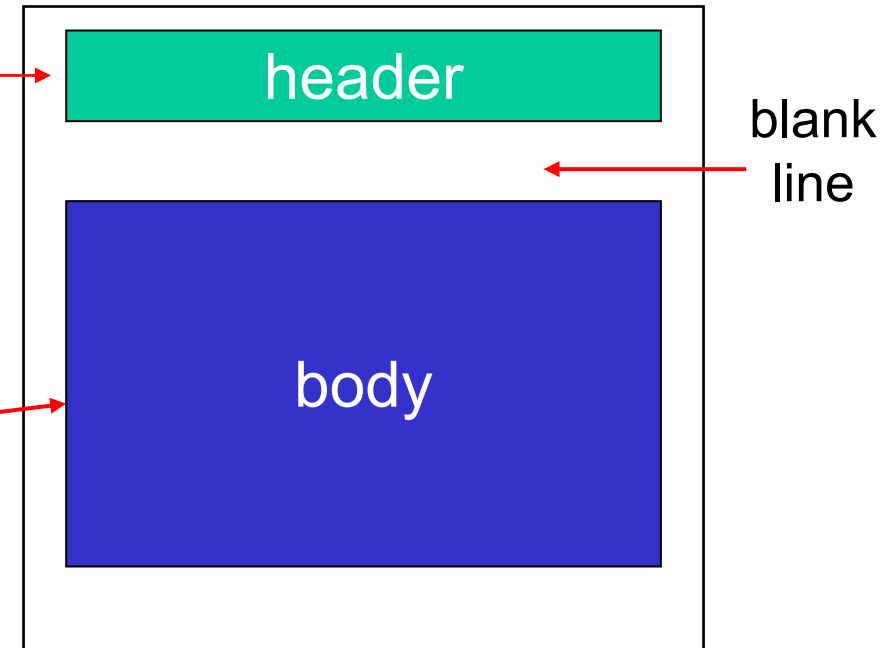
- HTTP: client pull
- SMTP: client push
- both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response message
- SMTP: multiple objects sent in multipart message
- SMTP uses persistent connections
- SMTP requires message (header & body) to be in 7-bit ASCII
- SMTP server uses CRLF.CRLF to determine end of message

Mail message format

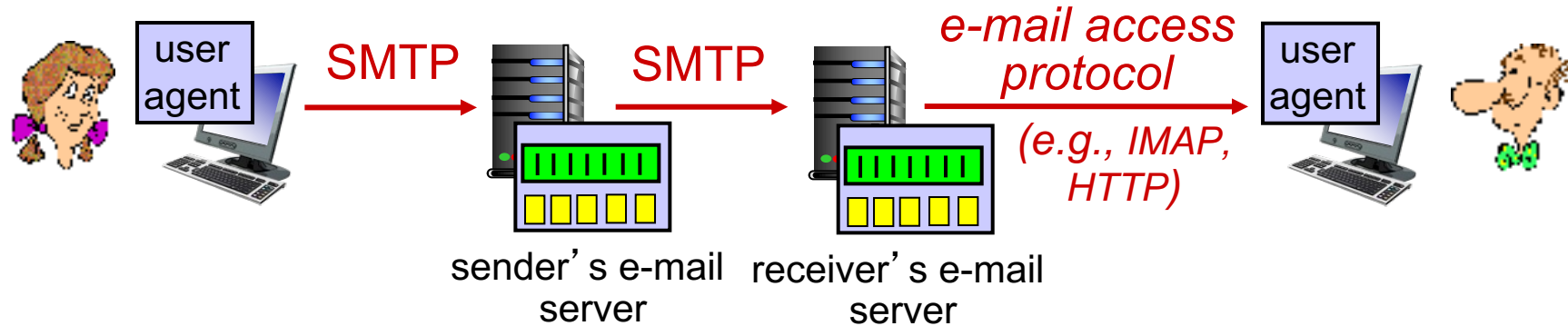
SMTP: protocol for exchanging e-mail messages, defined in RFC 5321 (like RFC 7231 defines HTTP)

RFC 2822 defines *syntax* for e-mail message itself (like HTML defines syntax for web documents)

- header lines, e.g.,
 - To:
 - From:
 - Subject:these lines, within the body of the email message area different from SMTP MAIL FROM:, RCPT TO: commands!
- Body: the “message” , ASCII characters only



Retrieving email: mail access protocols



- **SMTP**: delivery/storage of e-mail messages to receiver's server
- mail access protocol: retrieval from server
 - **IMAP**: Internet Mail Access Protocol [RFC 3501]: messages stored on server, IMAP provides retrieval, deletion, folders of stored messages on server
- **HTTP**: gmail, Hotmail, Yahoo!Mail, etc. provides web-based interface on top of SMTP (to send), IMAP (or POP) to retrieve e-mail messages

Application Layer: Overview

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- socket programming with UDP and TCP



DNS: Domain Name System

people: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

- IP address (32 bit, e.g. 12.115.66.89) - used for addressing datagrams
- “name”, e.g., cs.umass.edu - used by humans

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

Domain Name System (DNS):

- *distributed database* implemented in hierarchy of many *name servers*
- *application-layer protocol*: hosts, DNS 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

Q: Why not centralize DNS?

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

A: doesn't scale!

- Comcast DNS servers alone: 600B DNS queries/day
- Akamai DNS servers alone: 2.2T DNS queries/day

Thinking about the DNS

humongous distributed database:

- ~ billion records, each simple

handles many *trillions* of queries/day:

- *many* more reads than writes
- *performance matters*: almost every Internet transaction interacts with DNS - msec count!

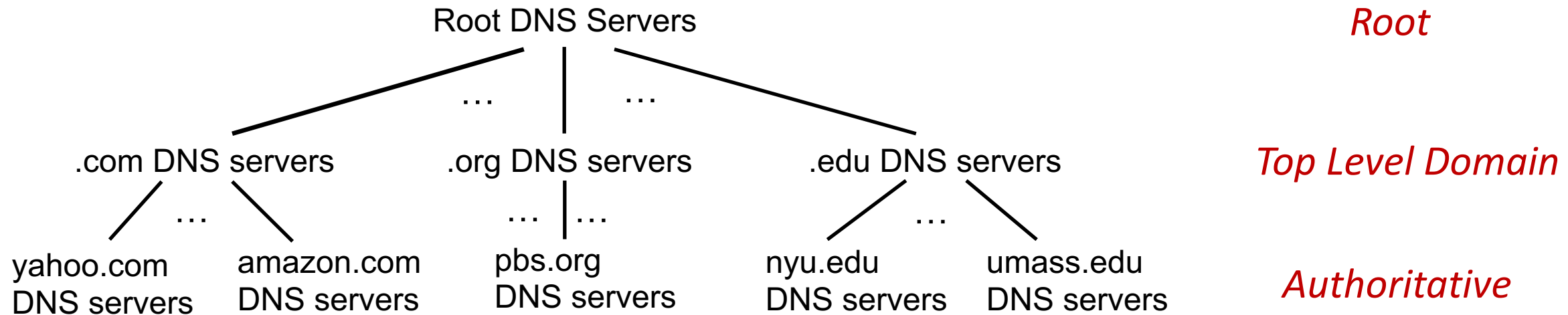
organizationally, physically decentralized:

- millions of different organizations responsible for their records

“bulletproof”: reliability, security



DNS: a distributed, hierarchical database

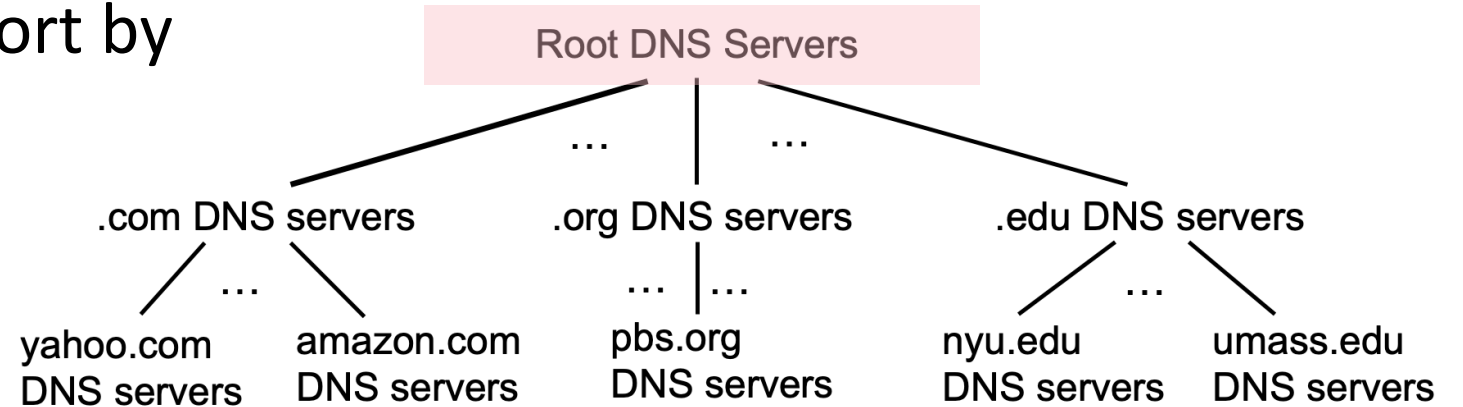


Client wants IP address for `www.amazon.com`; 1st approximation:

- 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

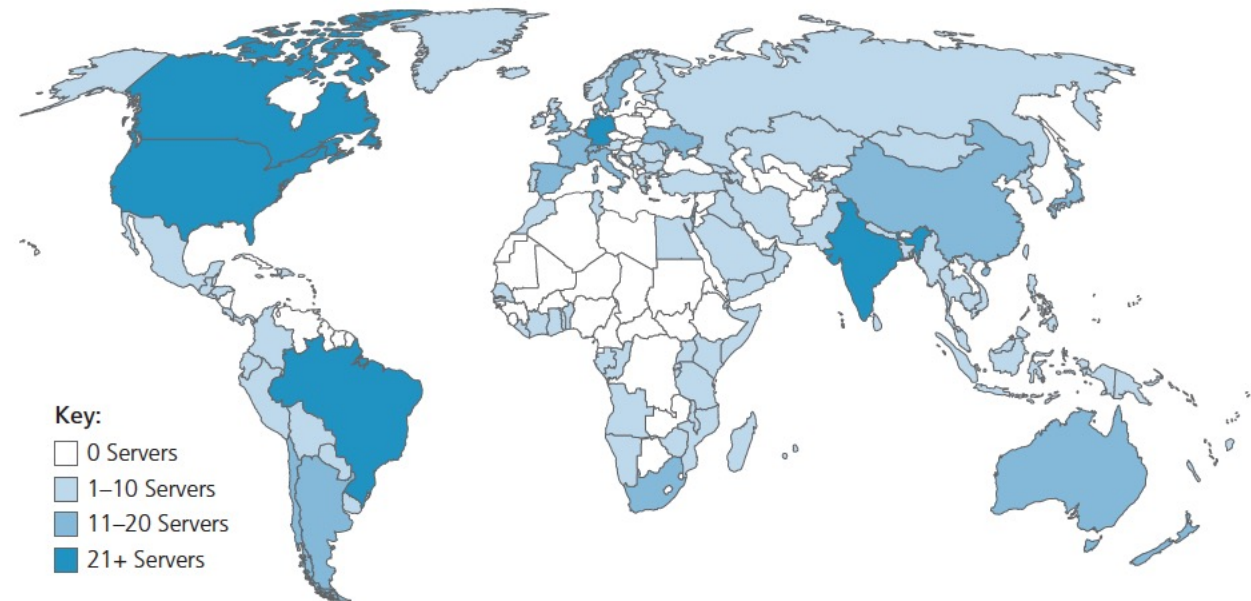
- official, contact-of-last-resort by name servers that can not resolve name



DNS: root name servers

- official, contact-of-last-resort by name servers that can not resolve name
- *incredibly important* Internet function
 - Internet couldn't function without it!
 - DNSSEC – provides security (authentication, message integrity)
- ICANN (Internet Corporation for Assigned Names and Numbers) manages root DNS domain

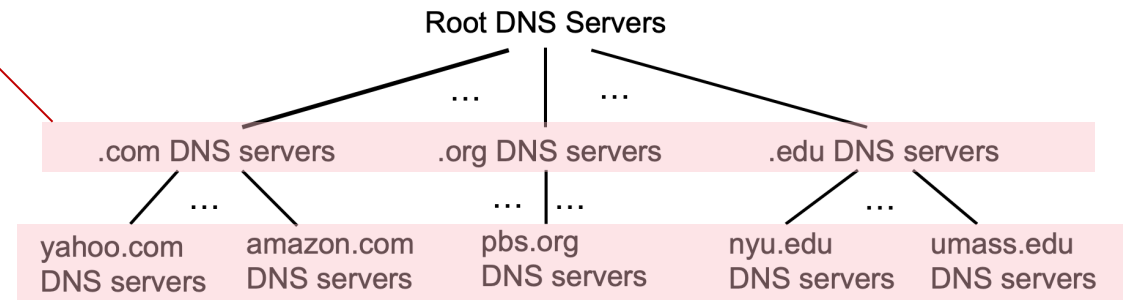
13 logical root name “servers”
worldwide each “server” replicated
many times (~200 servers in US)



Top-Level Domain, and authoritative servers

Top-Level Domain (TLD) servers:

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

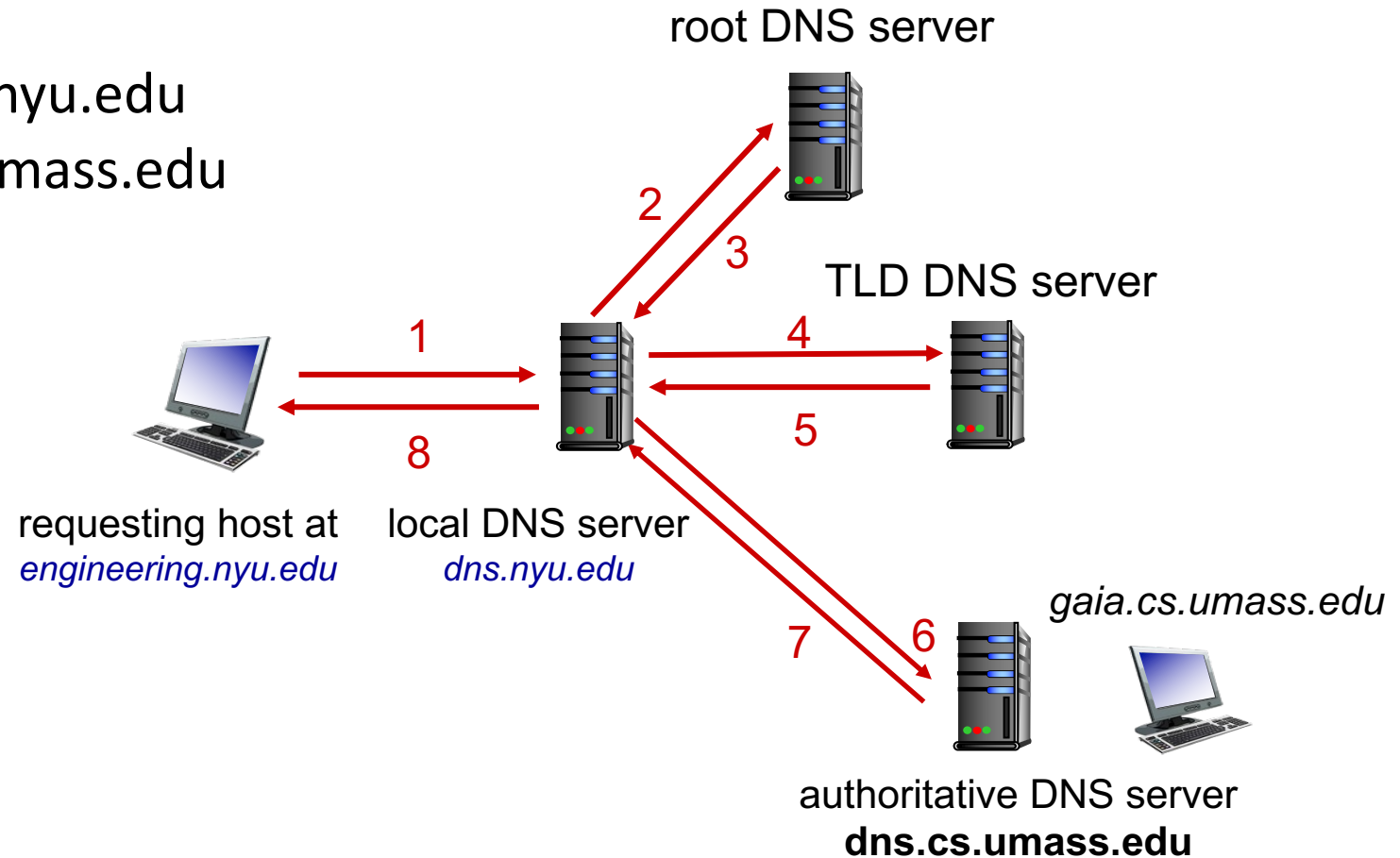
- when host makes DNS query, it is sent to its *local* DNS server
 - Local DNS server returns reply, answering:
 - from its local cache of recent name-to-address translation pairs (possibly out of date!)
 - forwarding request into DNS hierarchy for resolution
 - each ISP has local DNS name server; to find yours:
 - MacOS: `% scutil --dns`
 - Windows: `>ipconfig /all`
- local DNS server doesn't strictly belong to hierarchy

DNS name resolution: iterated query

Example: host at `engineering.nyu.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”

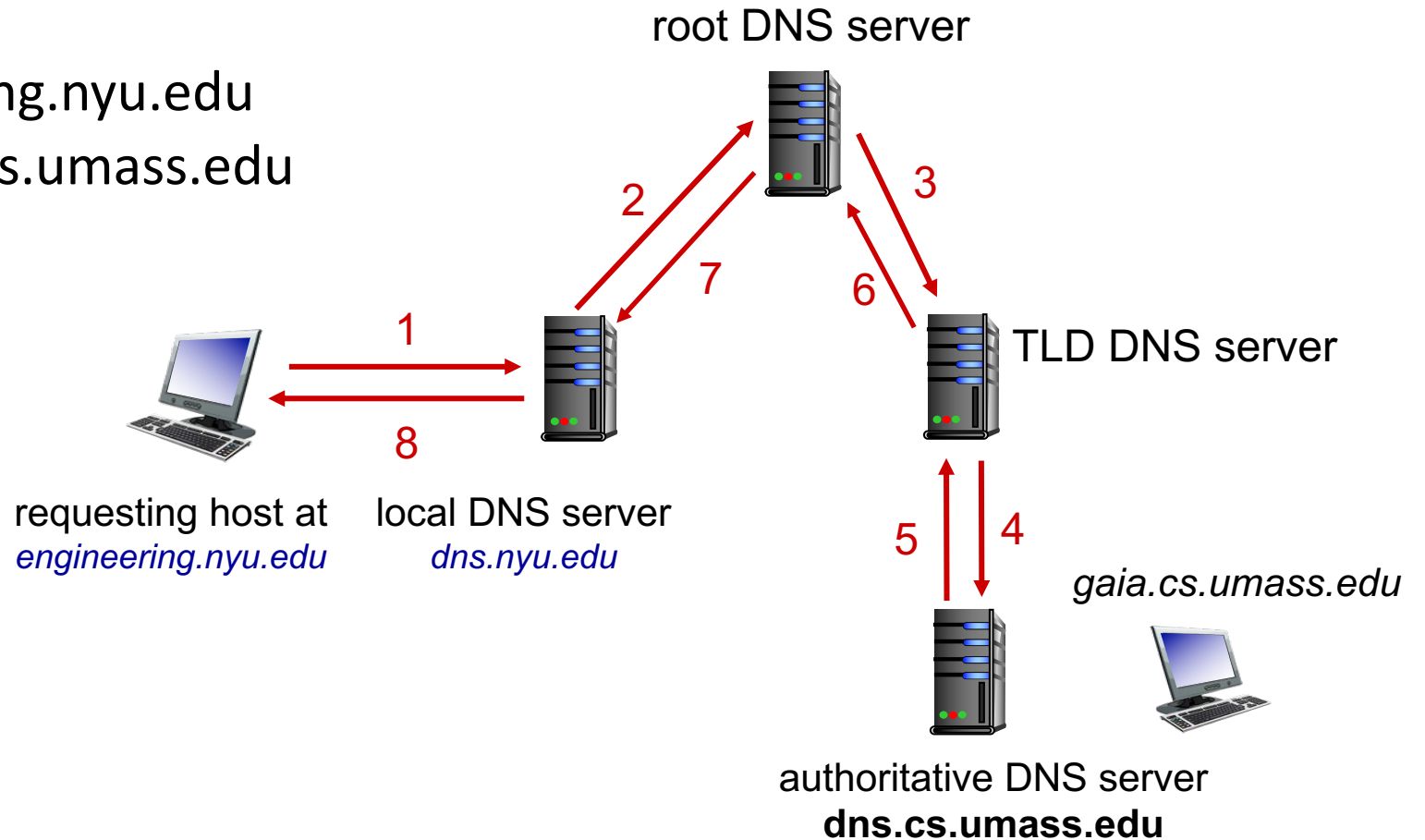


DNS name resolution: recursive query

Example: host at `engineering.nyu.edu` wants IP address for `gaia.cs.umass.edu`

Recursive query:

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



Caching DNS Information

- once (any) name server learns mapping, it *cached* mapping, and *immediately* returns a cached mapping in response to a query
 - caching improves response time
 - cache entries **timeout (disappear) after some time (TTL)**
 - TLD servers typically cached in local name servers
- cached entries may be *out-of-date*
 - if the named host changes IP address, may not be known Internet-wide until all TTLs expire!
 - *best-effort name-to-address translation!*

Getting your info into the 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 info into .com TLD server:
`(networkutopia.com, dns1.networkutopia.com, NS)`
`(dns1.networkutopia.com, 212.212.212.1, A)`
- create authoritative server locally with IP address `212.212.212.1`

Q: Does DNS use UDP or TCP?

DNS security

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

Spoofing attacks

- intercept DNS queries, returning bogus replies
 - DNS cache poisoning
 - RFC 4033: DNSSEC authentication services