Computer Networks

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Chapter 8. Internet Applications

- Internet Applications Overview
- Domain Name Service (DNS)
- Electronic Mail
- File Transfer Protocol (FTP)
- WWW and HTTP
- Content Distribution Networks (CDNs)

Creating a network app

write programs that:

- run on (different) *end systems*
- communicate over network
- e.g., web server software communicates with browser software

no need to write software for network-core devices

- network-core devices do not run user applications
- applications on end systems allows for rapid app development, propagation

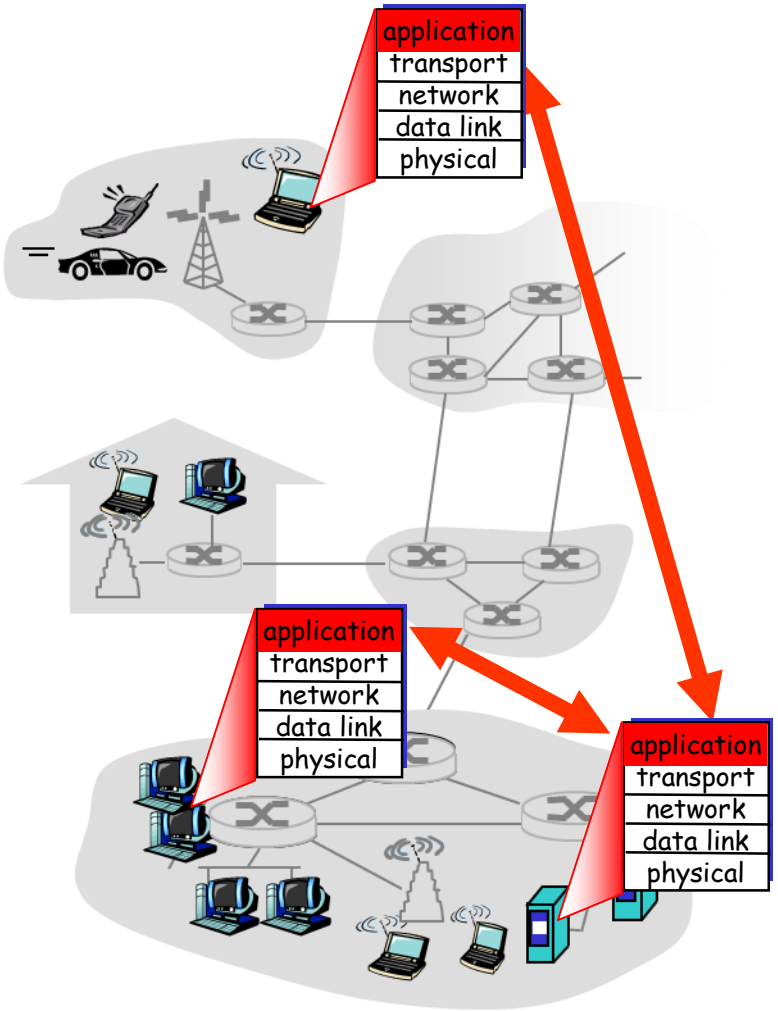
Internet Applications Overview

Application: communicating, distributed processes

- e.g., Email, Web, P2P file sharing, instant messaging
- Running in end systems (hosts)
- Exchange messages to implement application

Application-layer protocols

- One "piece" (agent) of an app
- Define messages exchanged by apps and actions taken
- Use communication services provided by lower layer protocols (TCP, UDP, RTP)



Typical Internet Applications

Application	App-Layer Protocol	Underlying Transport Protocol
Email	SMTP [RFC 2821]	TCP
Remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
File transfer	FTP [RFC 959]	TCP
Streaming multimedia	Proprietary e.g. RealNetworks	RTP, RTSP TCP or UDP
Internet telephony	Proprietary e.g. Dialpad	SIP on UDP

Jargons of Internet Applications

- Process: program running within a host
  - Within same host, 2 processes communicate using inter-process communication (defined by *OS*)
  - Processes running in different hosts communicate with an app-layer protocol

- User agent: interfaces with app "above" and network "below"
  - Implements user interface & app-layer protocol, e.g.
  - *Web*: browser, web server
  - *Email*: mail reader, mail server
  - Streaming audio/video: media player, media server

App-Layer Protocols

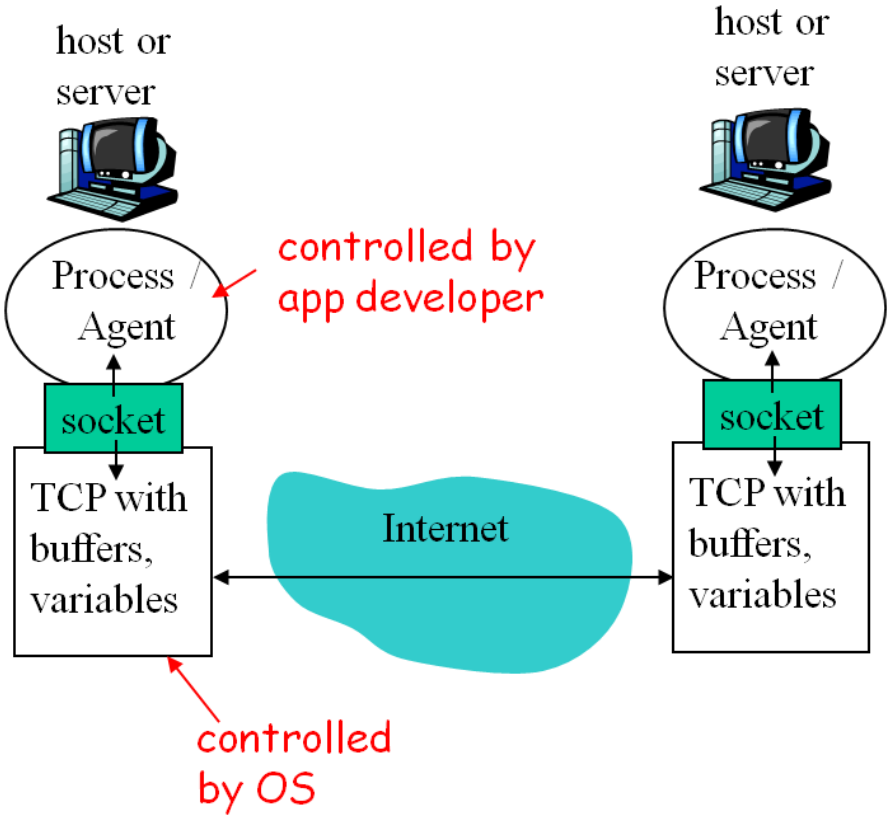
- Types of messages exchanged
  - e.g. request & response messages
- Syntax of message types
  - What fields in messages & how fields are delineated
- Semantics of the fields
  - Meaning of information in fields
- Rules for when and how processes send & respond to messages

Sockets

- Process sends/receives app messages to/from its socket
- Each socket is mapped by the OS to a communicating app process

Different types of sockets

- Stream sockets: by TCP
- Datagram sockets: by UDP
- Raw sockets: by-pass the transport layer



Application Architectures

possible structure of applications:

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

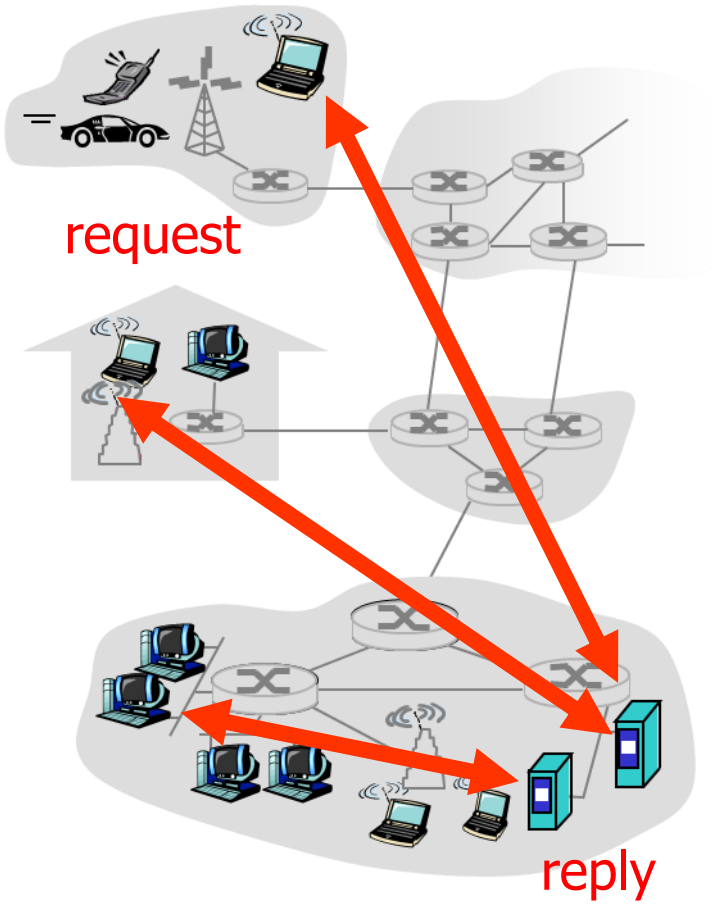
Client-Server Paradigm

Client:

- Start as required
- Initiates contact with server, "speaks first"
- Host may have dynamic IP addresses
- e.g. Web: client implemented in browser; Email: in mail reader

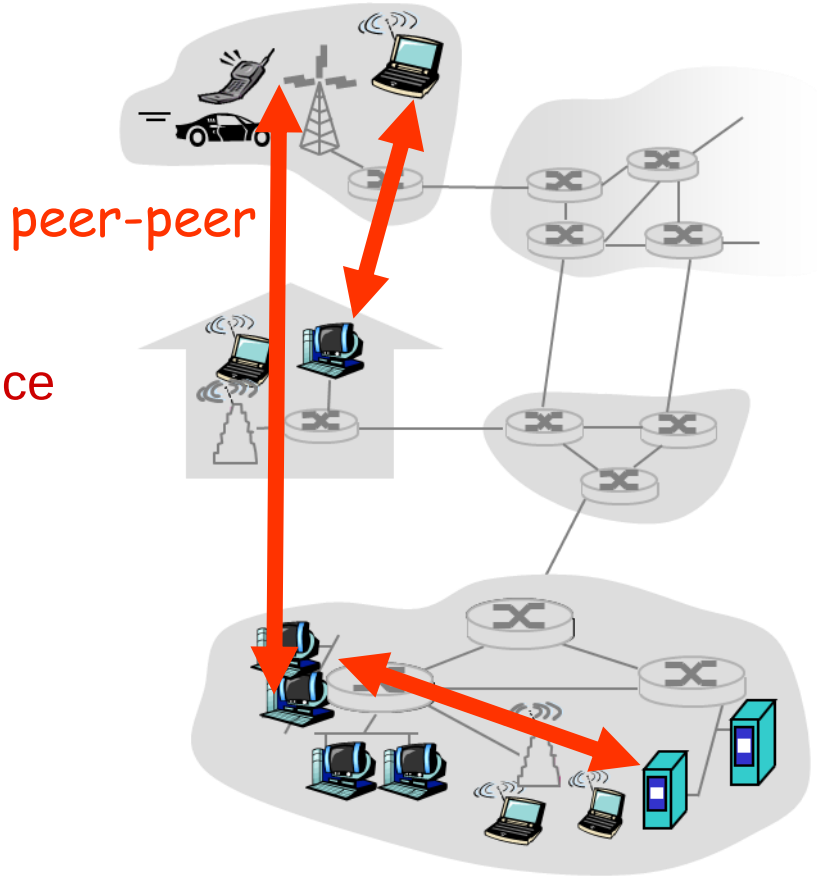
Server:

- Run as daemon (always-on)
- Provides requested service to Client
- Host has permanent IP address
- e.g. Web server sends requested Web page, mail server delivers Email



Peer-2-Peer Paradigm

- 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
- Highly scalable but difficult to manage
- Examples: Gnutella, BitTorrent, Skype



Client-Server and P2P

Skype

- Voice-over-IP P2P application
- Centralized server: finding address of remote party
- Direct client-client connection

Instant messaging

- Chatting between two users is P2P
- Centralized service: user presence detection/location
- User registers its IP address with central server when it comes online
- User contacts central server to find IP addresses of parties

Typical Applications

- DNS
- Email
- FTP
- Web and HTTP
- CDN
- P2P Applications

Domain Name Service (DNS)

- Function
  - Map "domain names" into IP addresses
  - e.g. www.baidu.com → 119.75.217.109
- Domain Name System
  - Distributed database implemented in hierarchy of many name servers
  - App-layer protocol host and name servers to communicate to resolve "domain names"
  - Load balancing: set of IP addresses for one server name

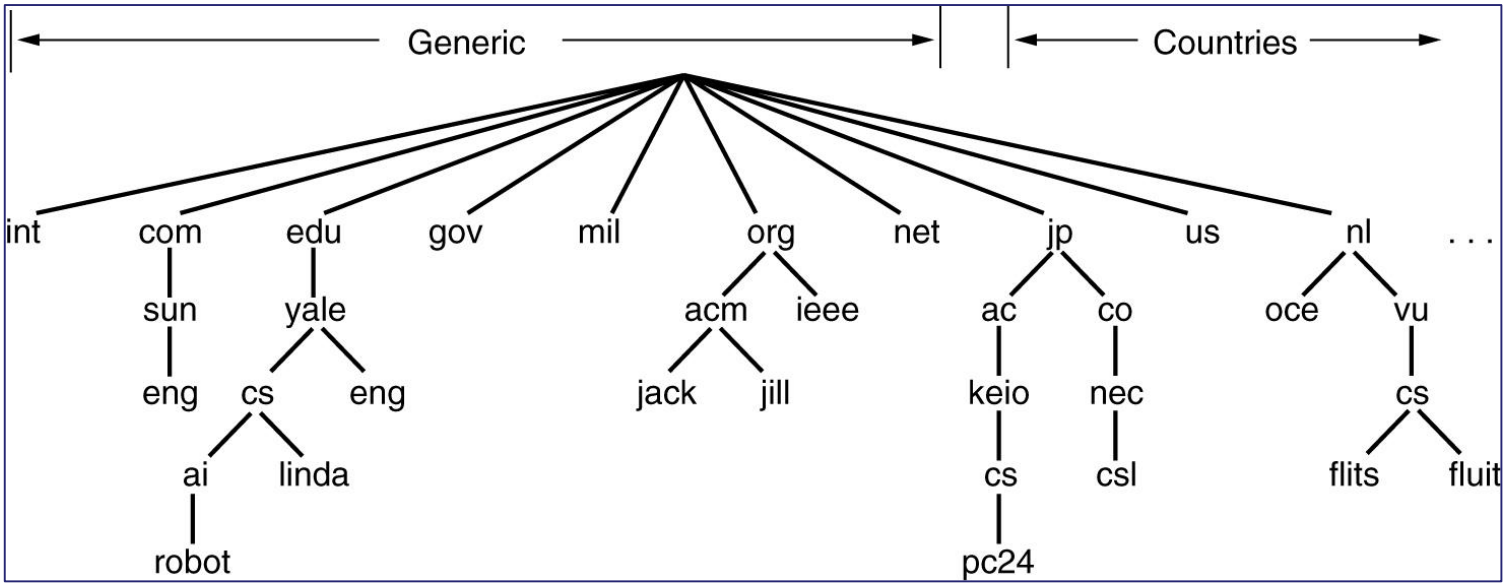
Q: why not centralize DNS?

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

A: doesn't scale!

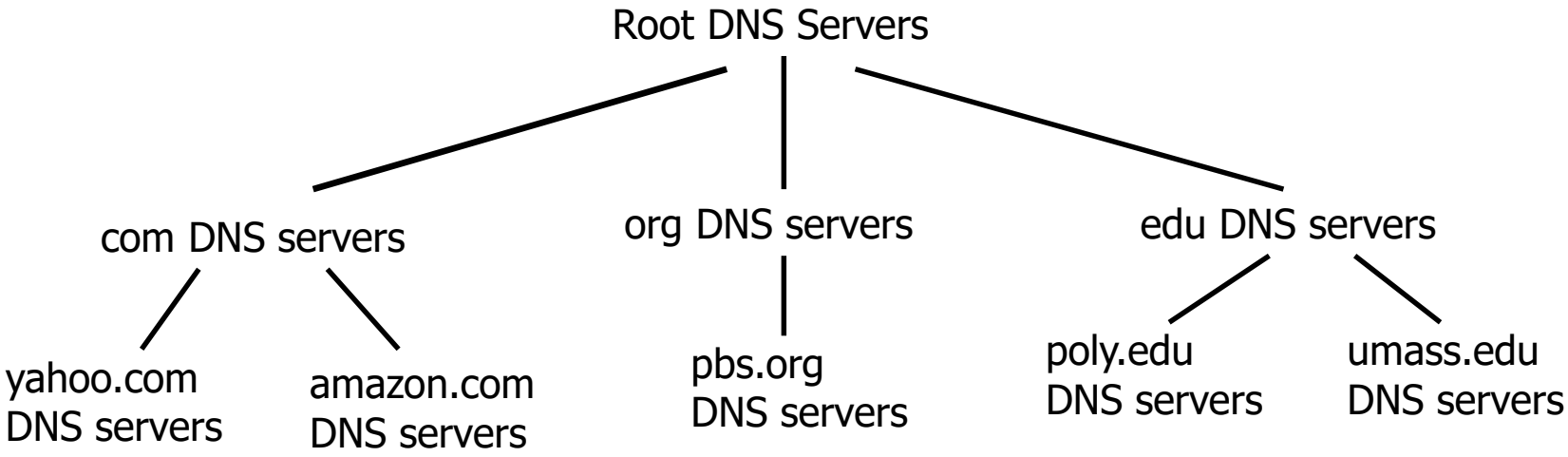
Domain Name Space

- Consist of a tree (hierarchy) of domain nodes
- A canonical name starts from a leaf node, and ends with a root node
- e.g. robot.ai.ca.yale.edu



Distributed, Hierarchical Database

- A domain zone is a subtree of the domain nodes
- One domain server maintains a domain zone



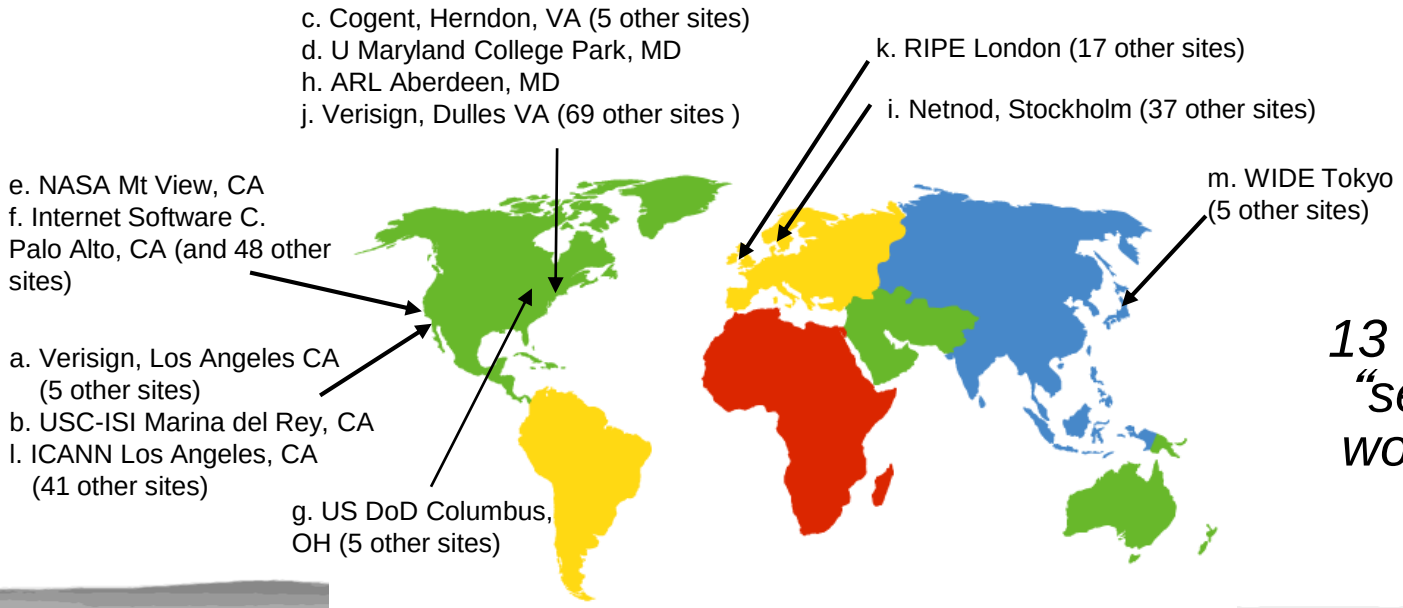
- Client Bob wants IP for www.amazon.com
- Bob queries a root server to find com DNS server
- Bob queries com DNS server to get amazon.com DNS server
- Bob queries amazon.com DNS server to get IP address for www.amazon.com

Hierarchy of DNS Servers

- Root name servers
  - Contacted by local name server that can not resolve name
- Top-level domain servers
  - Responsible for com, org, net, edu, etc, and all top-level country domains, e.g. cn, uk, fr
- Authoritative DNS servers
  - Organization's DNS servers, providing authoritative hostname to IP mappings
- Local Name Servers
  - Maintained by each residential ISP, company, university
  - When host makes DNS query, query is sent to its local DNS server

DNS: root name servers

- root name server:
  - contacts authoritative name server if name mapping not known
  - gets mapping
  - returns mapping to local name server



13 root name "servers" worldwide

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

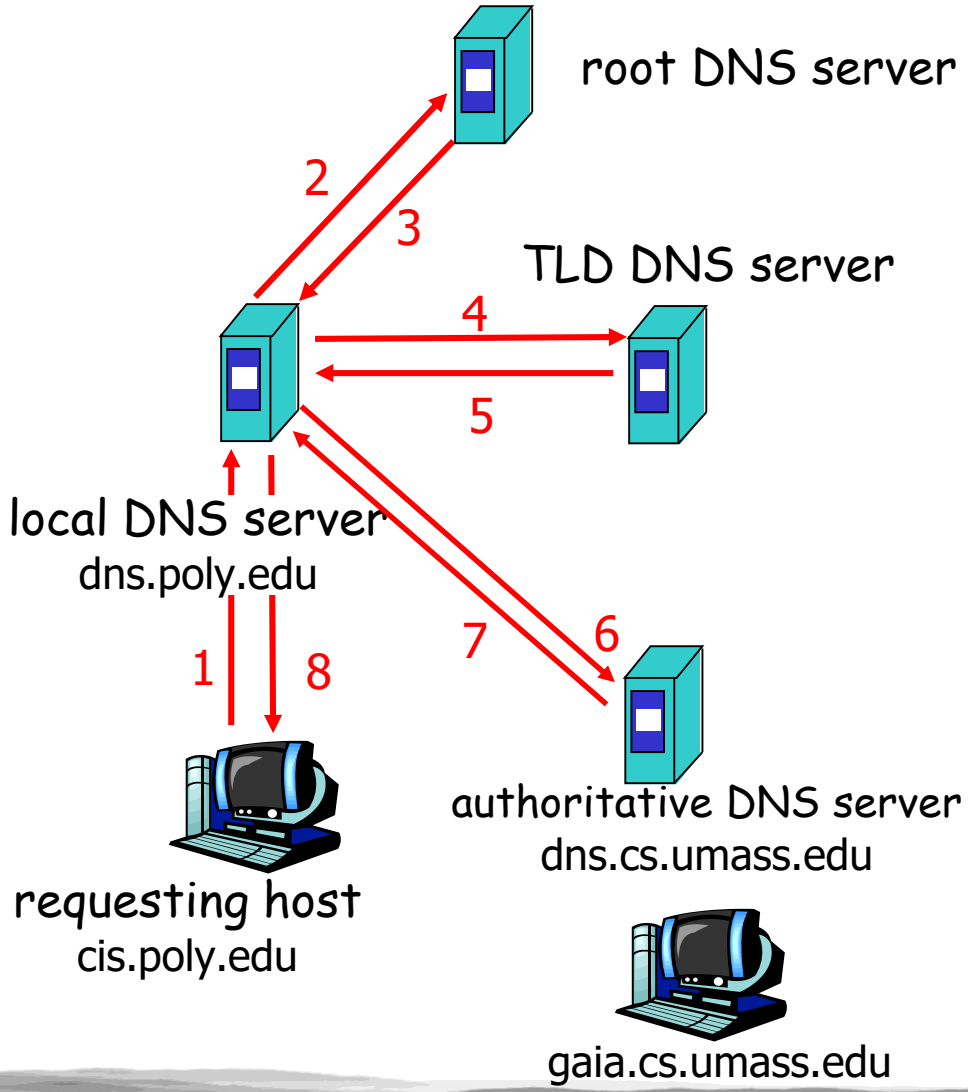
DNS Name Resolution Example

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

Iterated query:

- Contacted server replies with name of next server to contact

- Host-Server: iterative query
- Server-Server: one-step query



DNS Records

- Once a name server learns mapping, it caches the mapping
  - Cache entries timeout (disappear) after some time, re-consult needed
  - TLD servers typically cached in local name servers

- A DNS resource record (RR)

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

- "Name" is the domain name, "type" denotes how "value" is explained
  - e.g. Name Server records (NS), Mail Exchangers (MX), Host IP Address (A), Canonical name (CNAME)

- Examples
  - (networkutopia.com, dns1.networkutopia.com, NS, 32768)
  - (dns1.networkutopia.com, 212.212.212.1, A, 5600)

Attacking DNS

DDoS attacks

- 2002年10月，攻击者利用僵尸网络向13个root服务器发送大量ICMP报文
  - 攻击并未奏效
  - 大部分DNS根服务器执行分组过滤，阻止ICMP报文
  - 很多域名被本地缓存，可以绕过根服务器得到解析
- 更有效的攻击应该向顶级域名服务器发送大量DNS请求（近年来较常见）

Redirect attacks

- Man-in-middle
  - Intercept queries
- DNS poisoning
  - Send bogus relies to DNS server, which caches
  - DNS污染（解决办法：修改host文件）

Exploit DNS for DDoS

- Send queries with spoofed source address: target IP
- Requires amplification

Electronic Mail

- One of most heavily used apps on Internet
- SMTP: Simple Mail Transfer Protocol
  - Delivery of simple text messages
- MIME: Multi-purpose Internet Mail Extension
  - Delivery of other types of data, e.g. voice, images, video clips
- POP: Post Office Protocol
  - Msg retrieval from server, including authorization and download
- IMAP: Internet Mail Access Protocol
  - Manipulation of stored msgs on server

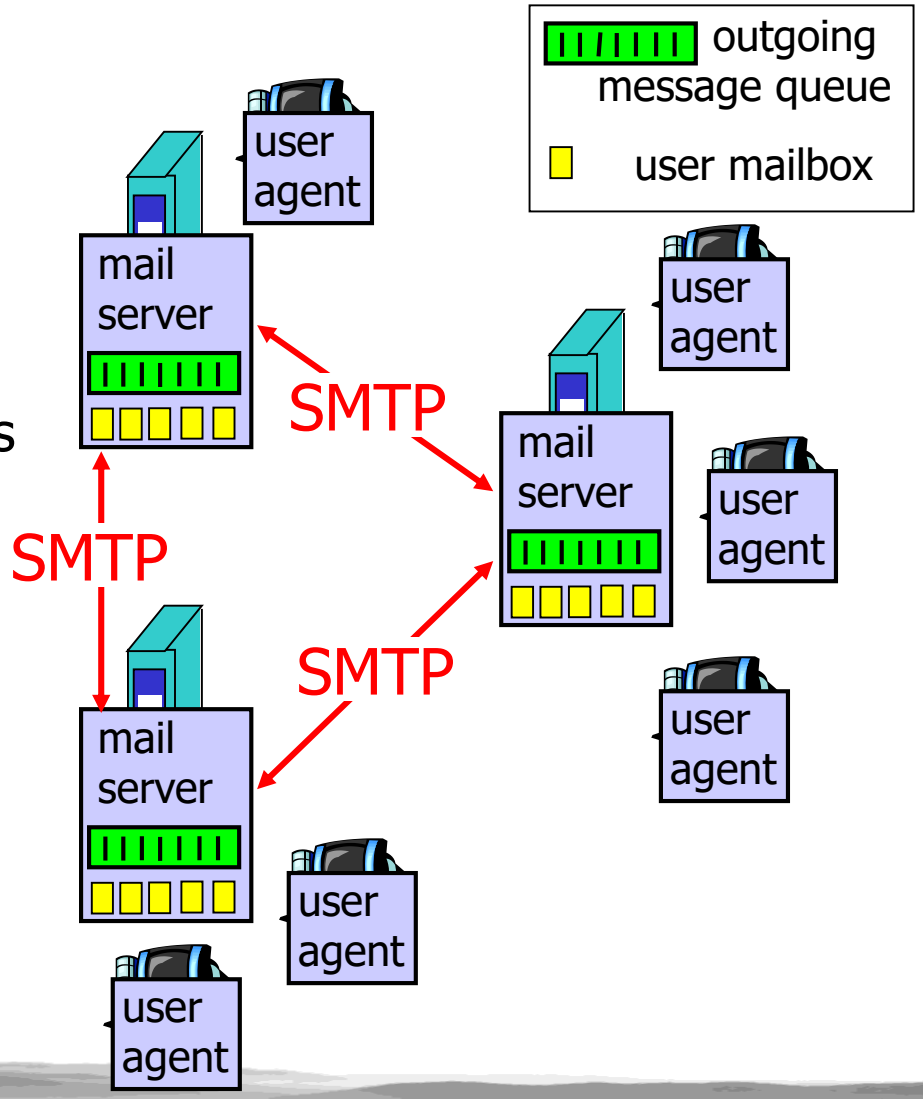
Components of Email System

User Agent

- Composing, editing, reading mail messages
- e.g. Eudora, Outlook, Foxmail, Netscape Messenger
- Outgoing, incoming mail messages stored on server

Mail Servers (Host)

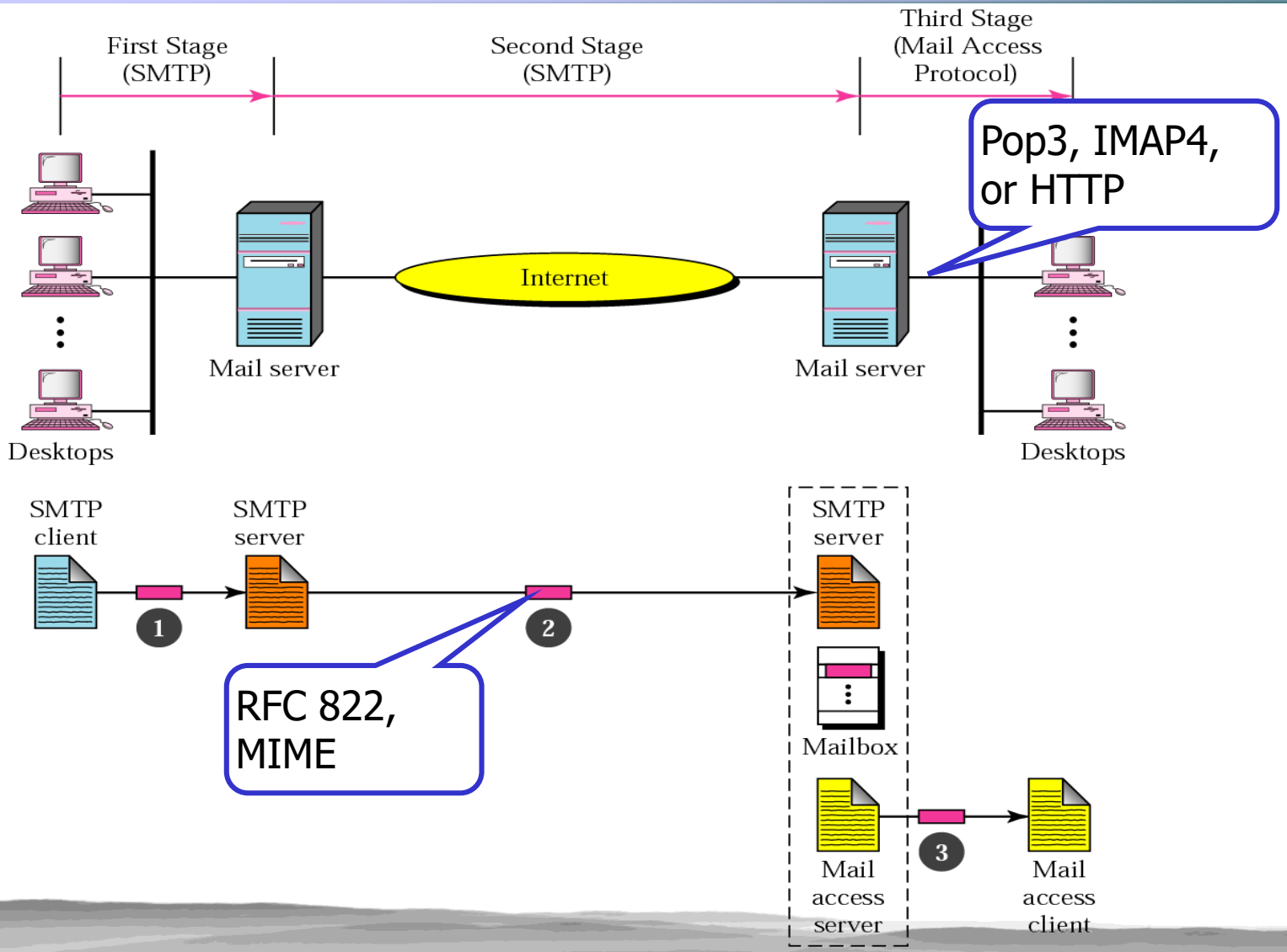
- Mailbox contains incoming mail messages for user
- Message queue of outgoing mail messages
- SMTP protocol between mail servers to send mail messages



3 Stages of Mail Delivery

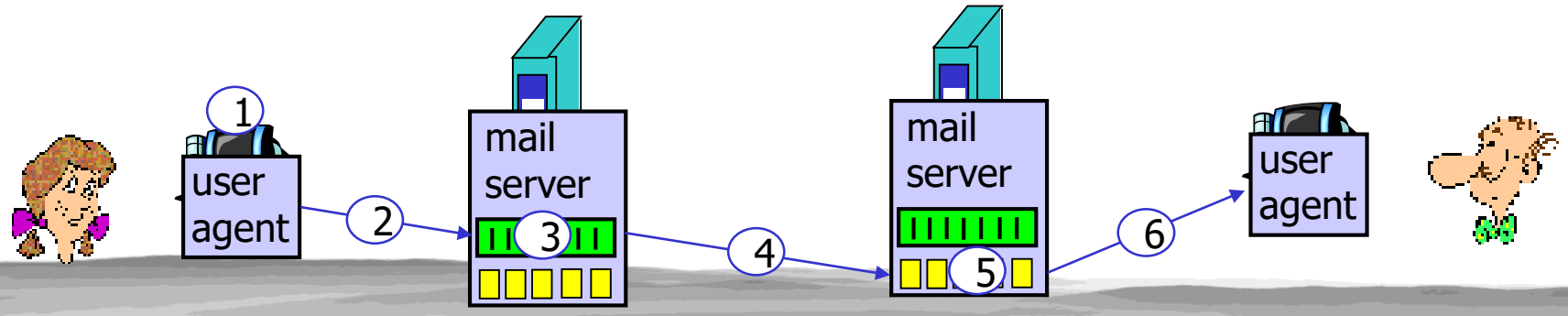
- 1st Stage
  - Email goes from local user agent to the local SMTP server
  - User agent acts as SMTP client
  - Local server acts as SMTP server
- 2nd Stage
  - Email is relayed by the local server to the remote SMTP server
  - Local server acts as SMTP client now
- 3rd Stage
  - The remote user agent uses a mail access protocol to access the mailbox on remote server
  - POP3 or IMAP4

Illustration of Mail Delivery



A Mail Delivery Scenario

- 1) Alice uses UA to compose a mail message and to bob@someschool.edu
- 2) Alice's UA sends mail to her mail server using SMTP, mail placed in message queue
- 3) Client side of SMTP opens TCP connection with Bob's mail server
- 4) SMTP client sends Alice's mail over the TCP connection
- 5) Bob's mail server places the mail in Bob's mailbox
- 6) Bob invokes his UA to read the mail, e.g. by Pop3



SMTP

- RFC 821:
  - Uses TCP, port 25
  - Direct transfer: transfer Email message from client to server
  - Needs info written on envelope of a mail (i.e. message header)
  - May add log info to message header to show the path taken
- Does not cover format of mail messages or data
  - Defined in RFC 822 or MIME
  - Messages must be in 7-bit ASCII

SMTP Transaction

3 phases of transfer

- Handshaking (greeting)
- Transfer of one or more mails data
- Close connection

```
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: RCPT TO: <Johm@hamburger.edu>
S: 550 No such user here
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
```

Command/response interaction

- Commands: ASCII text
- Response: status code and phrase

Try SMTP interaction for yourself:

- **`telnet servername 25`**
- see 220 reply from server
- enter HELO, MAIL FROM, RCPT TO, DATA, QUIT commands

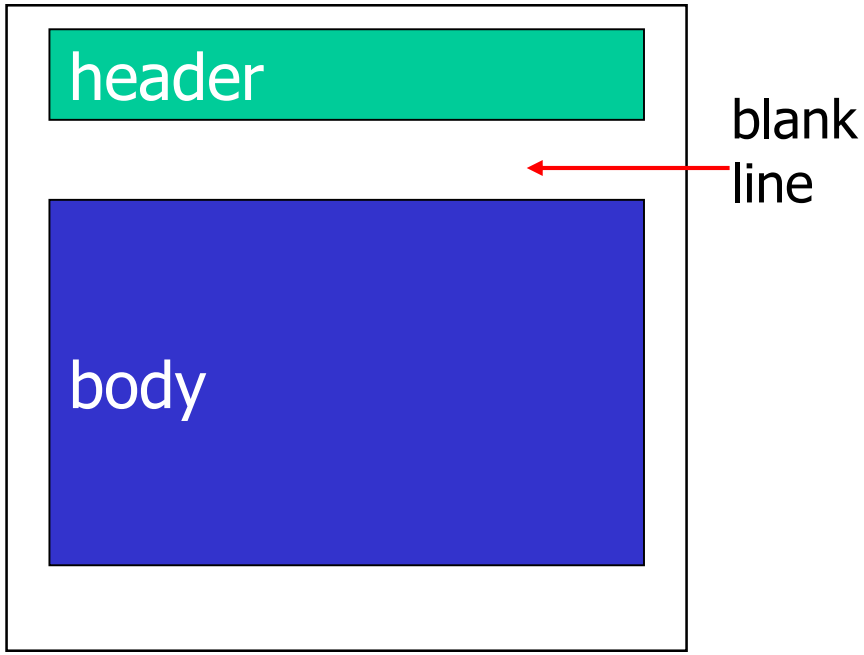
above lets you send email without using email client (reader)

Reliability of SMTP

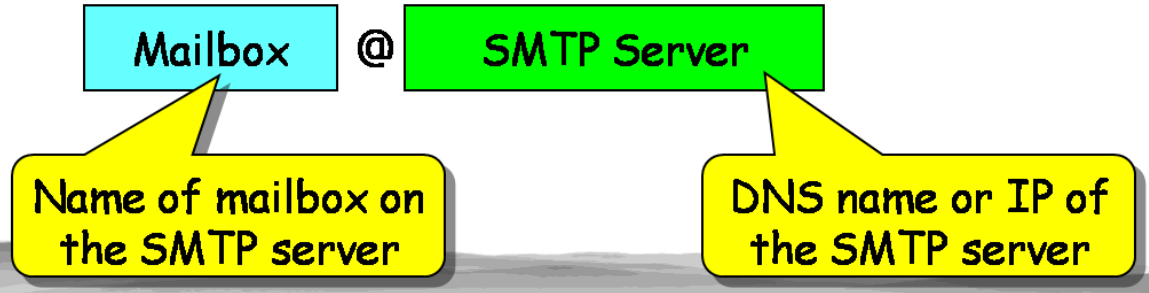
- Transfer mails from sender to receiver over TCP connection
  - Rely on TCP to provide reliable service
- No guarantee to recover lost mails
- No end to end acknowledgement to originator (user)
- Error indication delivery not guaranteed
  - Indicates mail has arrived at host, but not user
- Generally considered reliable

An Email Message

- Header lines, e.g.
  - To: Alice@sina.com
  - From: Bob@gmail.com
  - Subject: Dinner tonight
- Body
  - Mail contents, ASCII characters only

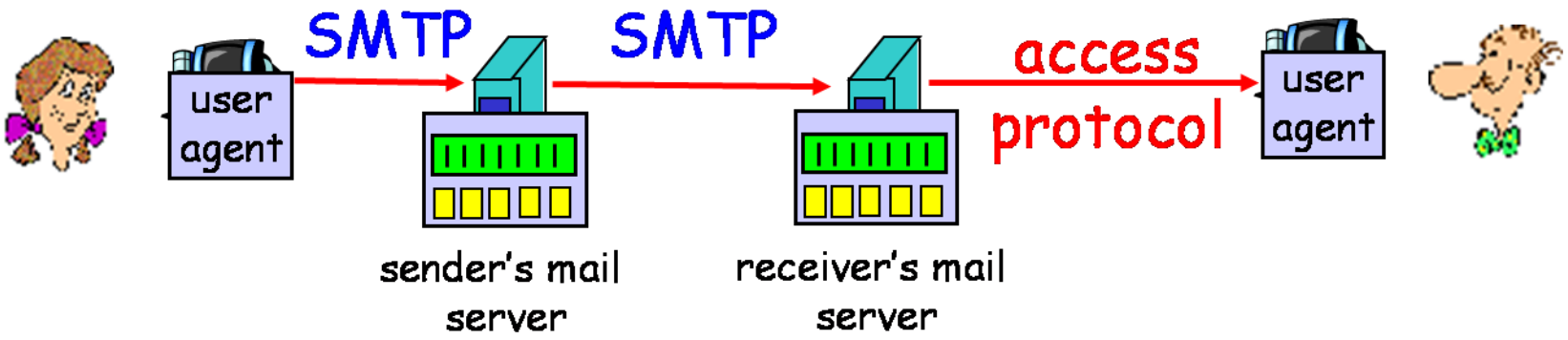


- Mail destinations



Mail Access Protocols

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



POP3 Protocol

Authorization phase

- Client commands
  - user: declare username
  - pass: password
- Server responses
  - +OK
  - -ERR

Transaction phase, by client

- list: list mail numbers
- retr: retrieve mail by number
- dele: delete
- quit

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

```
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

- Internet Mail Access Protocol, RFC 1730
- keeps all messages in one place: at server
  - A complicated use case
    - Bob reads emails at his office while his wife is simultaneously reading from same mailbox at home
- allows user to organize messages in folders
- keeps user state across sessions:
  - names of folders and mappings between message IDs and folder name
  - Keeps track of mail states (read, replied, deleted)

RFC 822 – Format for Text Mails

- Simple 2-part format
  - Header (envelope) includes transmit and delivery info
  - Lines of text in format keyword: information value
  - Body (contents) carries text of message
  - Header and body separated by a blank line
- Mail is a sequence of lines of text
  - Ends with two <CRLF>

```
From: John@hamburger.edu
To: Alice@crepes.fr
Cc: bob@hamburger.edu
Date: Wed, 4 Sep 2003 10:21:22 EST
Subject: Lunch with me

Alice,
   Can we get together for lunch
when you visit next week? I'm free
on Tuesday or Wednesday. Let me
know which day you would prefer.

John
```

MIME

- Multipurpose Internet Mail Extension
  - Extends and automates encoding mechanisms
  - Allows inclusion of separate components in a single mail
    - e.g. programs, pictures, audio clips, videos
- Features
  - Compatible with existing mail systems
    - Everything encoded as 7-bit *ASCII*
    - Headers and separators ignored by non-MIME mail systems
  - MIME is extensible
    - As long as sender and receiver agree on encoding scheme

Overview of MIME

- 5 new mail header fields
  - MIME version
  - Content type
  - Content transfer encoding
  - Content Id
  - Content Description
- Number of content formats defined
- Transfer encoding defined

A MIME Mail Example

MIME version

Method used to encode data

Type of data

encoded data

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
```

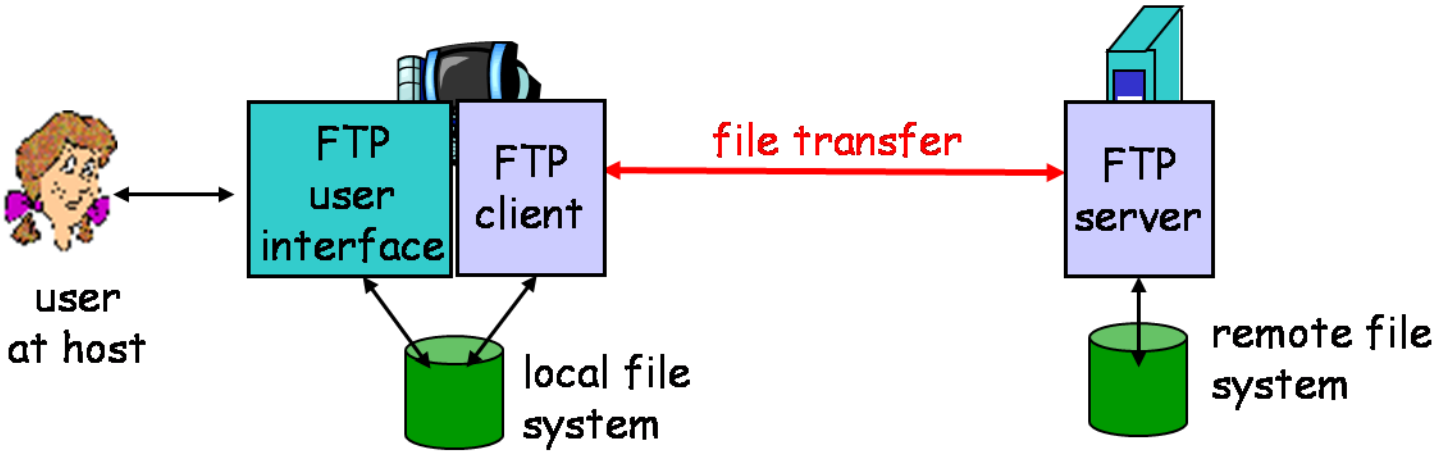
A Multi-Part Example

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="StartOfNextPart"

--StartOfNextPart
Dear Bob, Please find a picture of a crepe.
--StartOfNextPart
Content-Transfer-Encoding: base64
Content-Type: image/jpeg
base64 encoded data .....
.........................
......base64 encoded data
--StartOfNextPart
Do you want the recipe?
--StartOfNextPart--
```

File Transfer Protocol (FTP)

- RFC 959, use TCP, port 21/20
- Transfer file to/from remote host
- Client/Server model, client side initiates file transfer (either to/from remote)
- Deals with heterogeneous OS and file systems
- Needs access control on remote file system



Control and Data Connections

- FTP client contacts FTP server at port 21, opens a control connection
- Client authorized over control connection
- Client browses remote directory by sending commands over control connection
- When server receives file transfer command, *server* opens *2nd* TCP data connection (for file) *to* client
  - One connection for each file transferred
- After transferring one file, server closes data connection
- Control connection stays "out of band"
- FTP server maintains "user state": current directory, earlier authentication

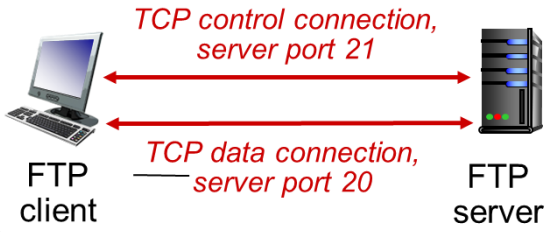
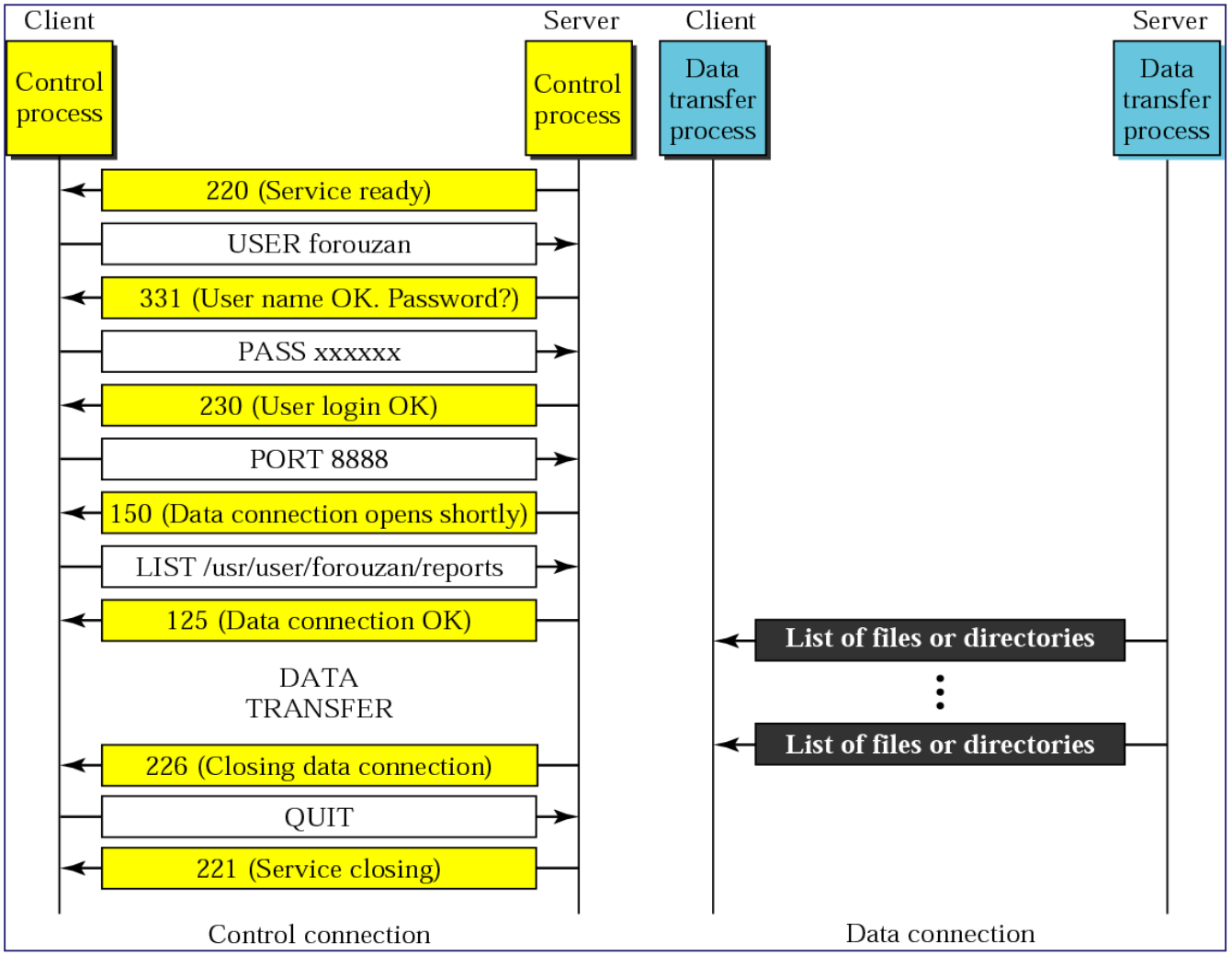


Illustration of FTP Session



FTP Commands and Responses

Sample commands:

- Sent as ASCII text over control channel
- USER username
- PASS password
- LIST return list of file in current directory
- RETR filename retrieves (gets) file
- STOR filename stores (puts) file onto remote server

Sample return codes:

- Status code and phrase (as in HTTP)
- 331 Username OK, password required
- 125 data connection already open; transfer starting
- 425 Can't open data connection
- 452 Error writing file

Summary

- Internet Applications
  - C/S & P2P
  - Domain Name Service (DNS)
  - Electronic Mail
  - File Transfer Protocol (FTP)