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# Computer Networks

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# Internet Applications

- Internet Applications Overview
- Domain Name Service (DNS)
- Electronic Mail
- File Transfer Protocol (FTP)



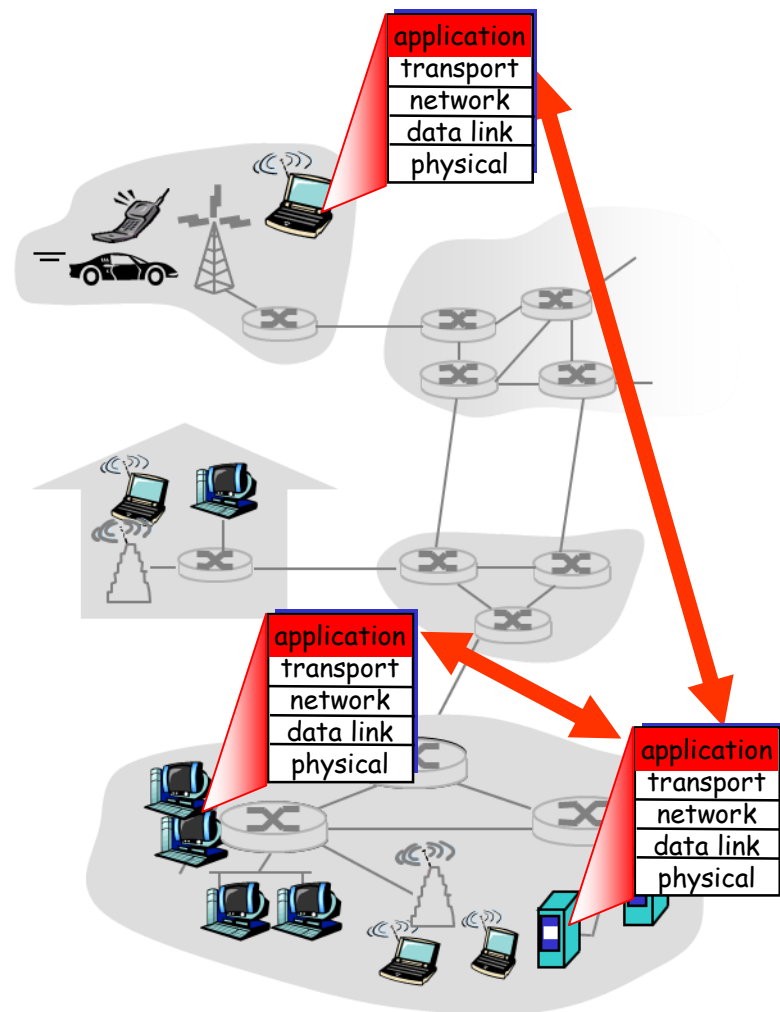
# Internet Applications Overview

**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



# Application Architectures

possible structure of applications:

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



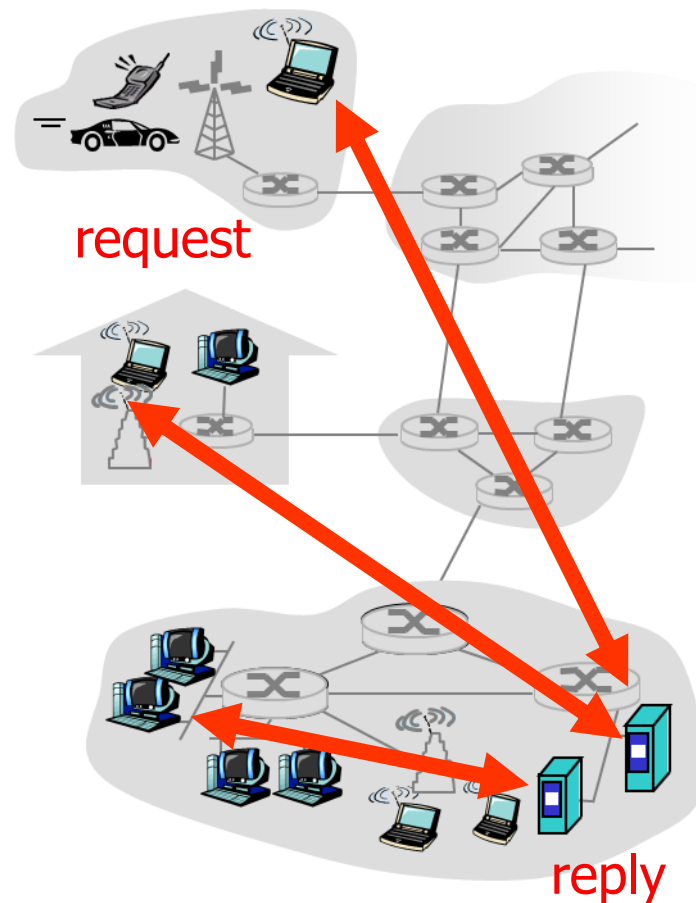
# Client-Server Paradigm

## 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:

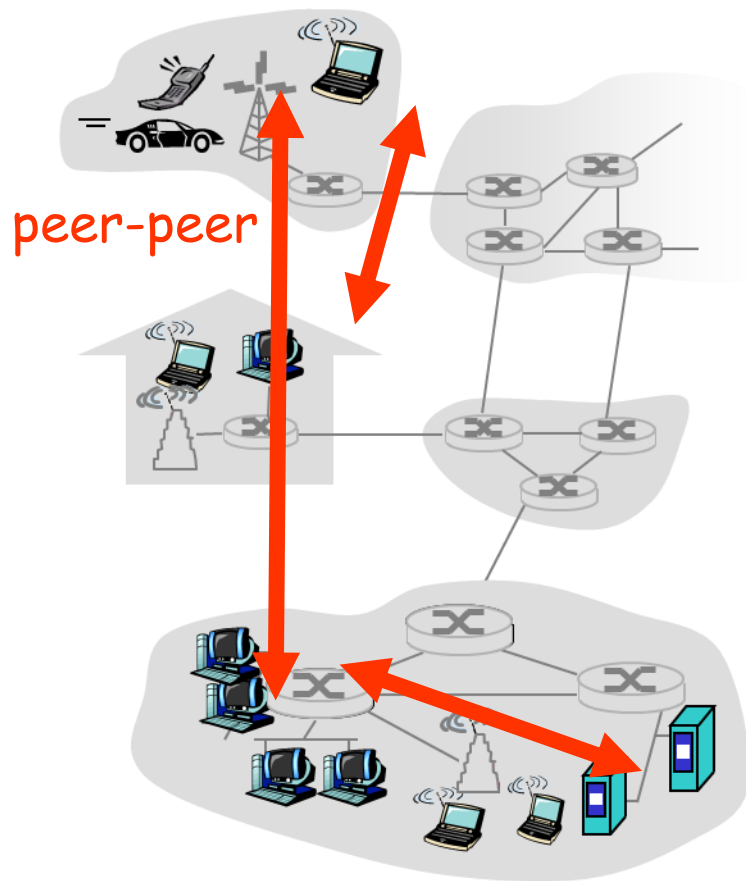
- Run as daemon (always-on)
- Provides requested service to Client
- Host has permanent IP address
- e.g. *Web* server sends requested *Web* page, *mail* server delivers *Email*





# Peer-to-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)



# 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!*



# Goals

- Uniqueness: no naming conflicts
- Scalable
  - Many names and frequent updates (secondary)
- Distributed, autonomous administration
  - Ability to update my own (machines') names
  - Don't have to track everybody's updates
- Highly available
- Lookups are fast
- Perfect consistency is a **non-goal**



# How?

- Partition the namespace
- Distribute administration of each partition
  - Autonomy to update my own (machines') names
  - Don't have to track everybody's updates
- Distribute name resolution for each partition
- How should we partition things?

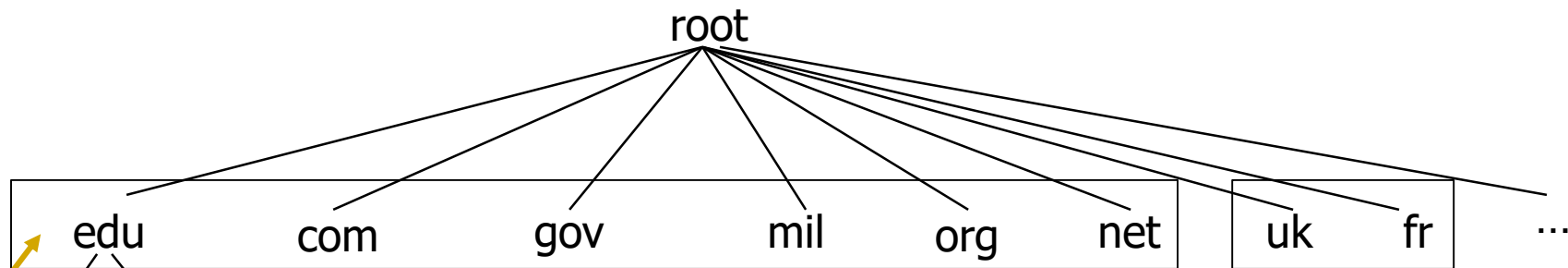


# Key idea: Hierarchy

- Three intertwined hierarchies
  - Hierarchical namespace
    - As opposed to original flat namespace
  - Hierarchically administered
    - As opposed to centralized
  - (Distributed) hierarchy of servers
    - As opposed to centralized storage



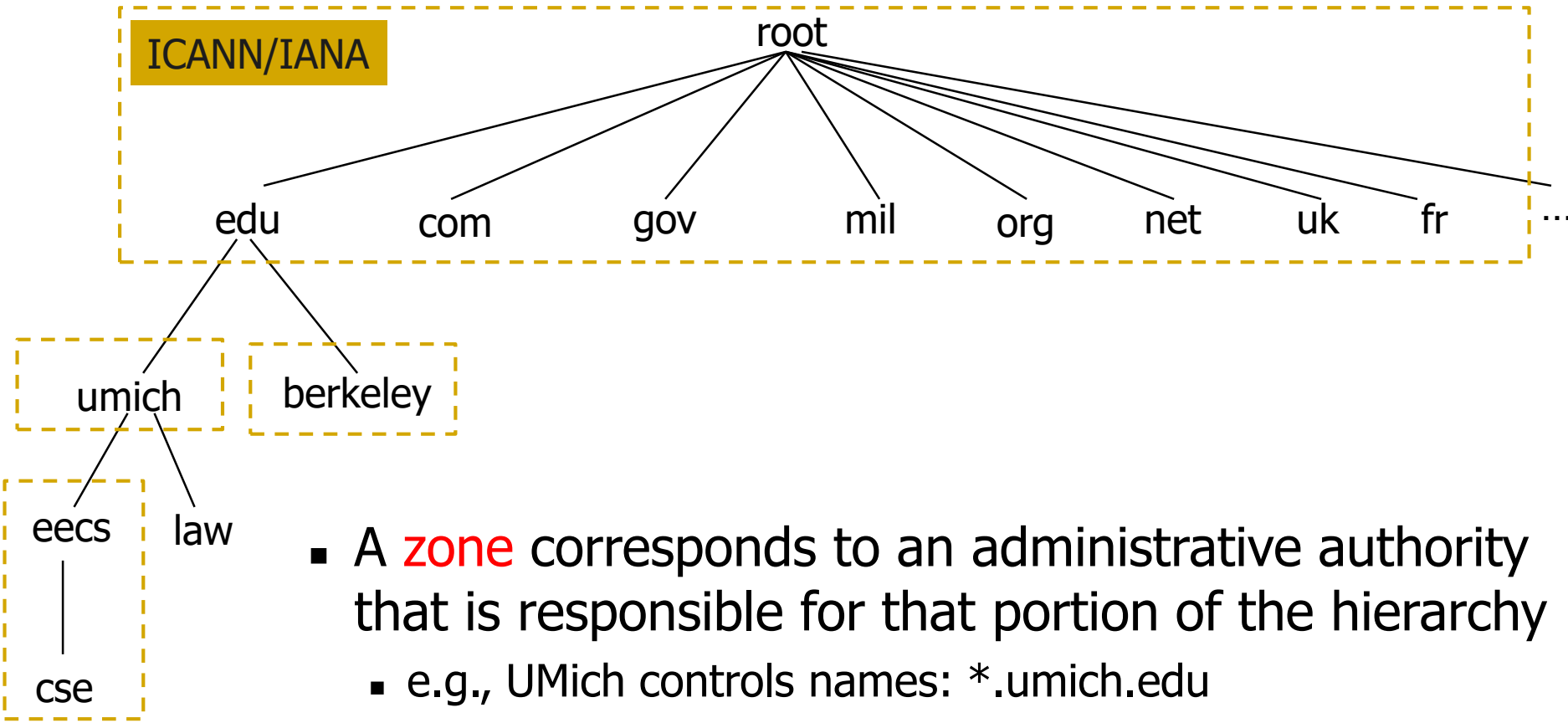
# Hierarchical namespace



- “Top Level Domains” are at the top
- Domains are subtrees
  - e.g., .edu, umich.edu, eecs.umich.edu
- Name is leaf-to-root path
  - cse.eecs.umich.edu
- Depth of tree is arbitrary (limit 128)
- Name collisions trivially avoided
  - Each domain is responsible



# Hierarchical administration



- A **zone** corresponds to an administrative authority that is responsible for that portion of the hierarchy
  - e.g., UMich controls names: \*.umich.edu
  - e.g., EECS controls names: \*.eecs.umich.edu



# 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

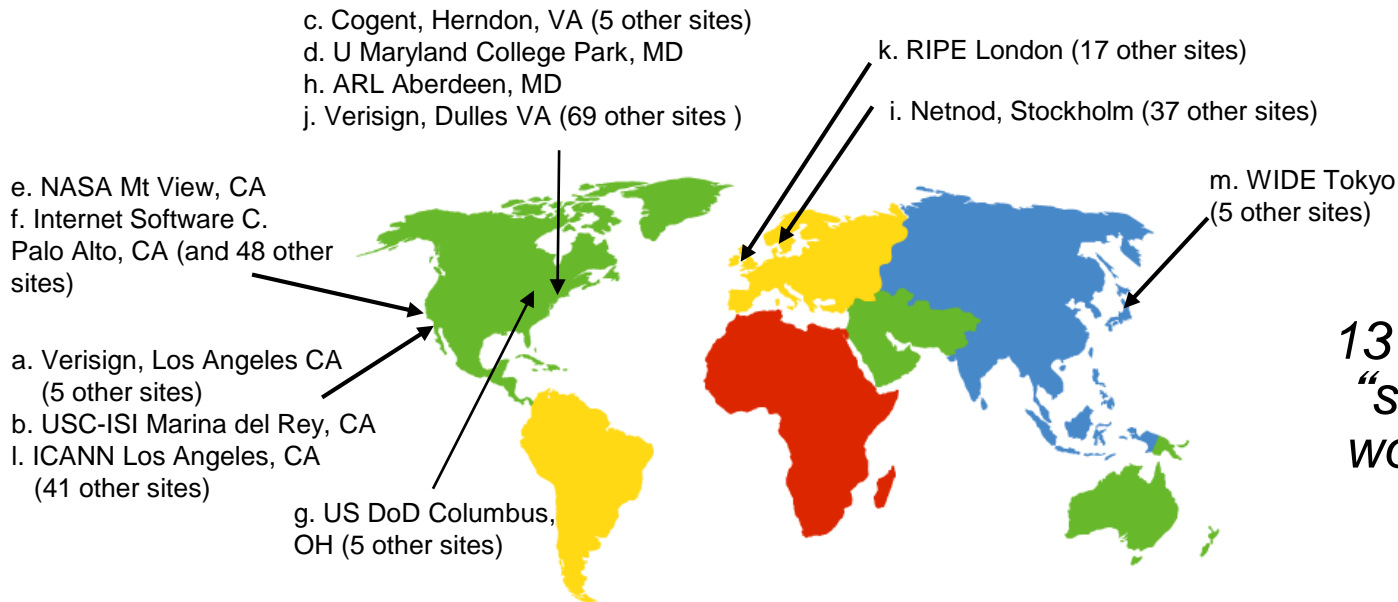


- Each server stores a (small!) subset of the total DNS database
- An authoritative DNS server stores “**resource records**” for all DNS names in the domain that it has authority for
- Each server needs to know other servers that are responsible for the other portions of the hierarchy
  - Every server knows the root
  - Root server knows about all top-level domains



# 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



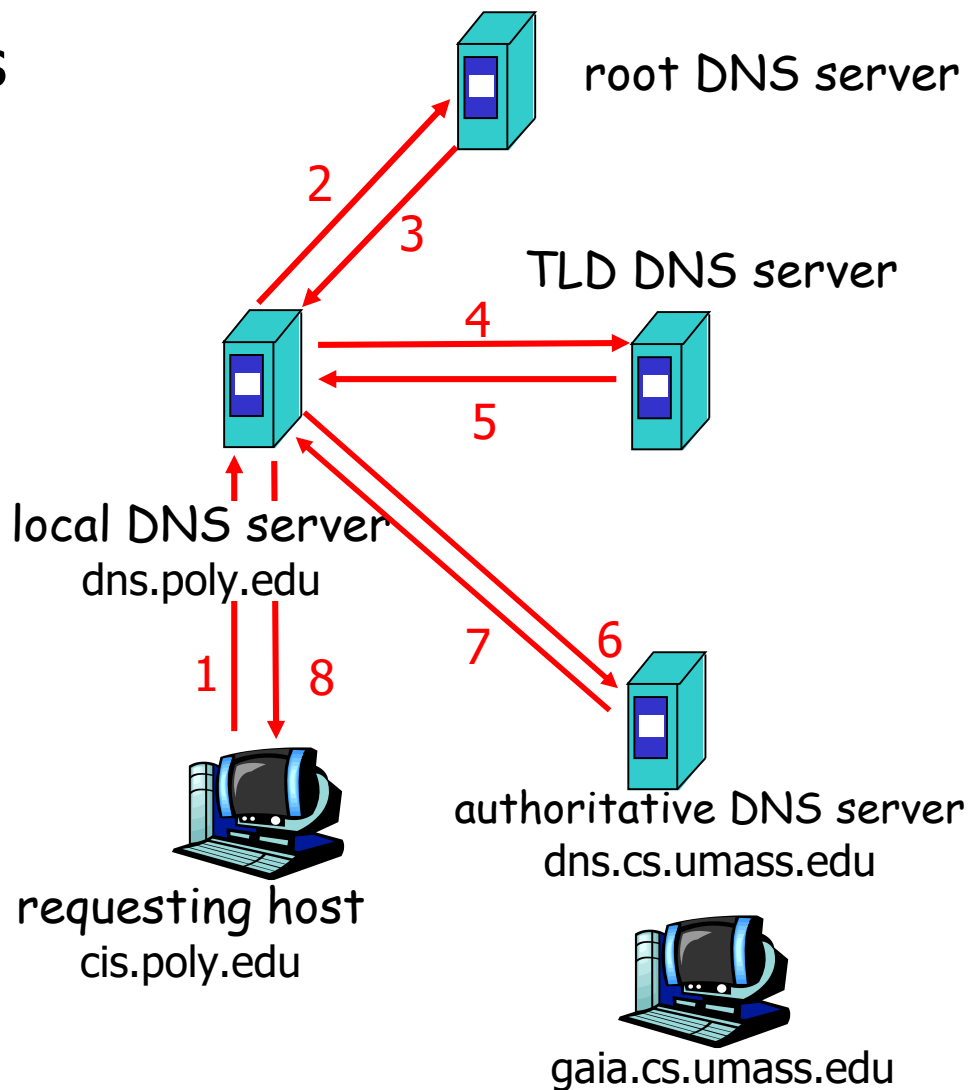
# Local DNS name server

- 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

- 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)



# DNS protocol

- **Query** and **Reply** messages; both with the same message format
  - Header: identifier, flags, etc.
  - Plus resource records
  - See text/section for details
- Client–server interaction on UDP Port 53
  - Spec supports TCP too, but not always implemented



# Goals: Are we there yet?

- Uniqueness: No naming conflicts
- Scalable
- Distributed, autonomous administration
- Highly available?



# Reliability

- **Replicated** DNS servers (primary/secondary)
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries
  - Reliability, if needed, must be implemented on UDP
- Try alternate servers on timeout
  - **Exponential backoff** when retrying same server
- Same identifier for all queries
  - Don't care which server responds



# Goals: Are we there yet?

- Uniqueness: No naming conflicts
- Scalable
- Distributed, autonomous administration
- Highly available
- Fast lookups?



# DNS caching

- Performing all these queries takes time
  - Up to 1-second latency before starting download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., [www.cnn.com](http://www.cnn.com)) visited often
  - Local DNS server often has the information cached
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a “time to live” (TTL) field
  - Server deletes cached entry after TTL expires



# 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 replies 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



# 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



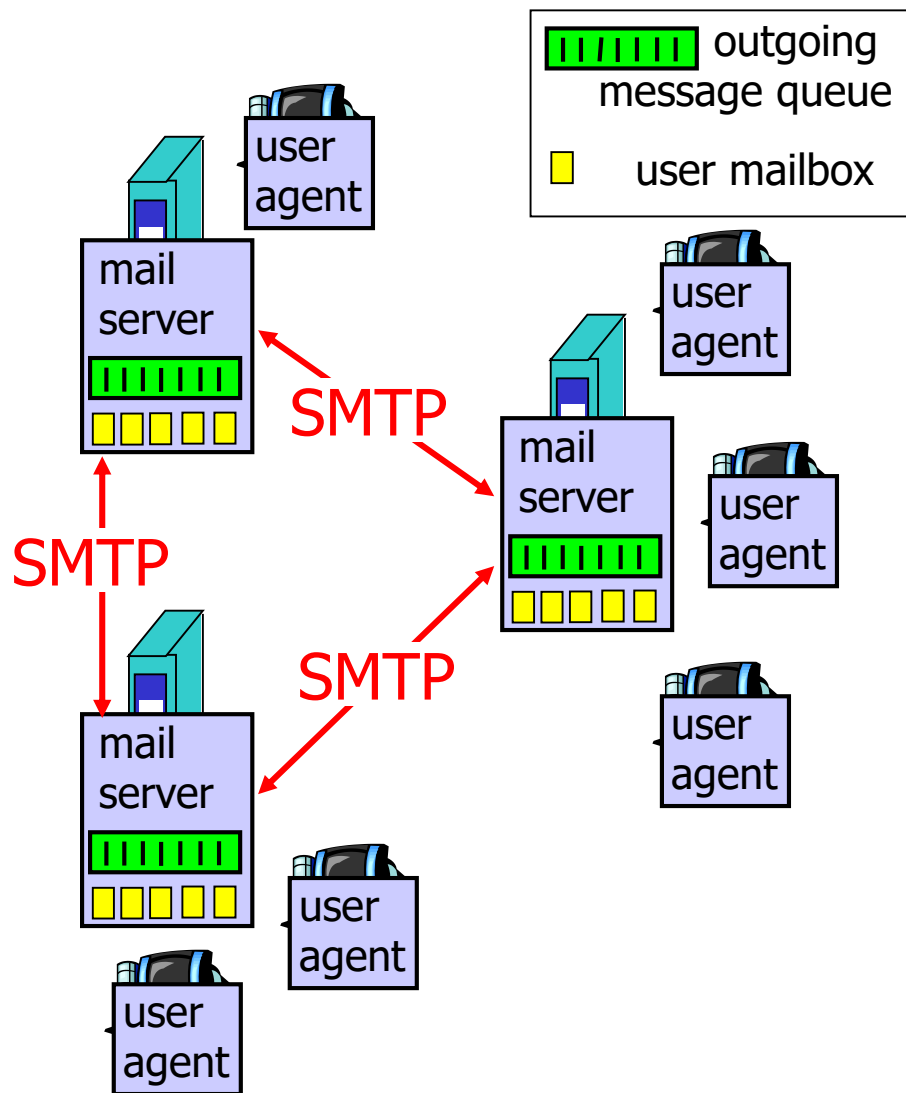
# Components of Email System

## 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



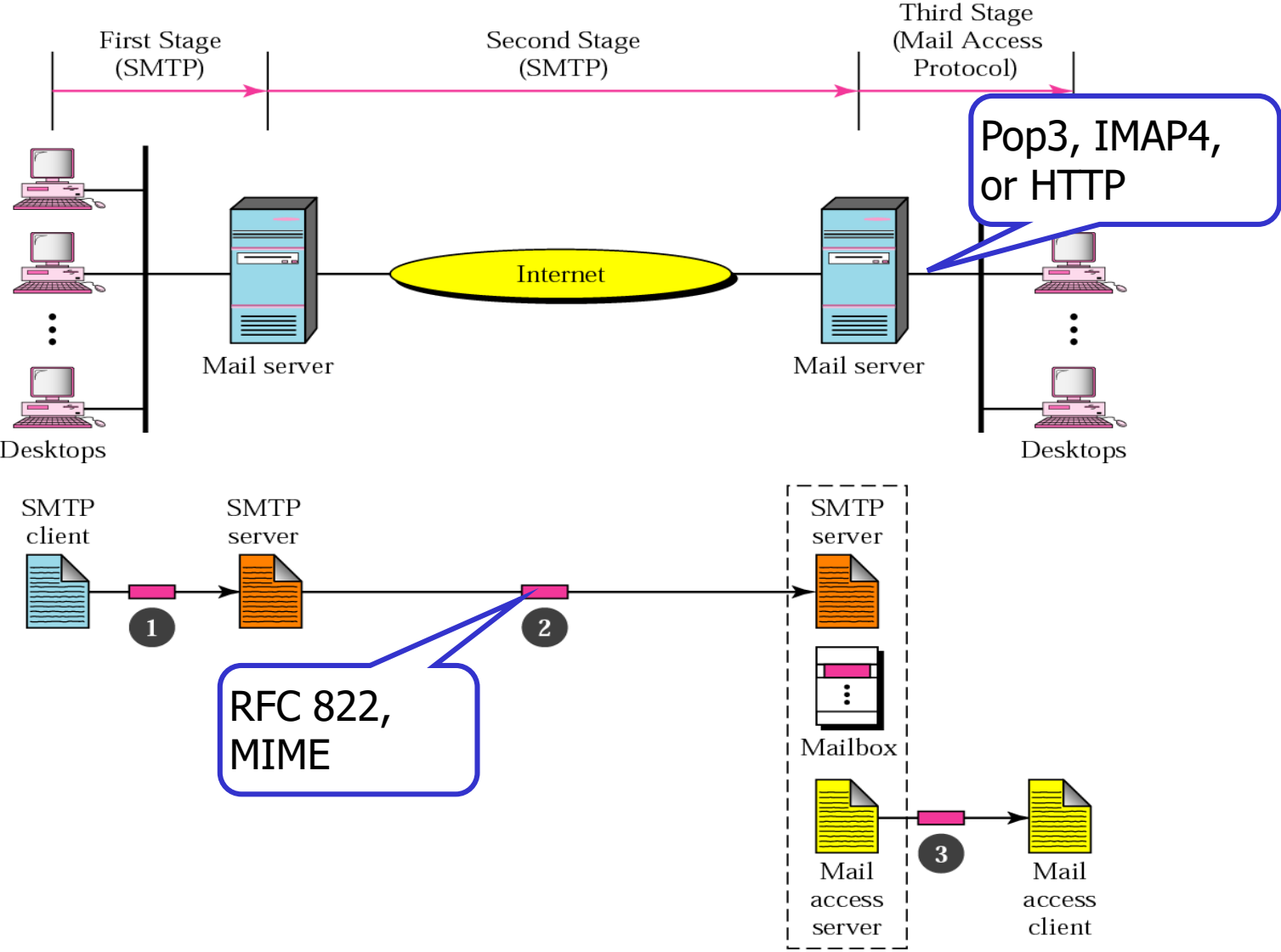


# 3 Stages of Mail Delivery

- 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



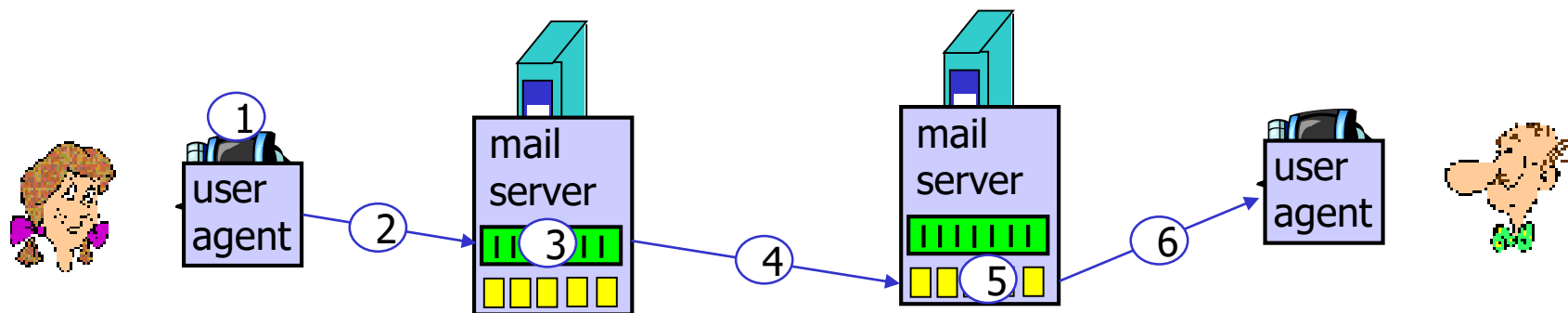
# Illustration of Mail Delivery





# A Mail Delivery Scenario

- 1) Alice uses UA to compose a mail message and to `bob@some school.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





# SMTTP

- **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

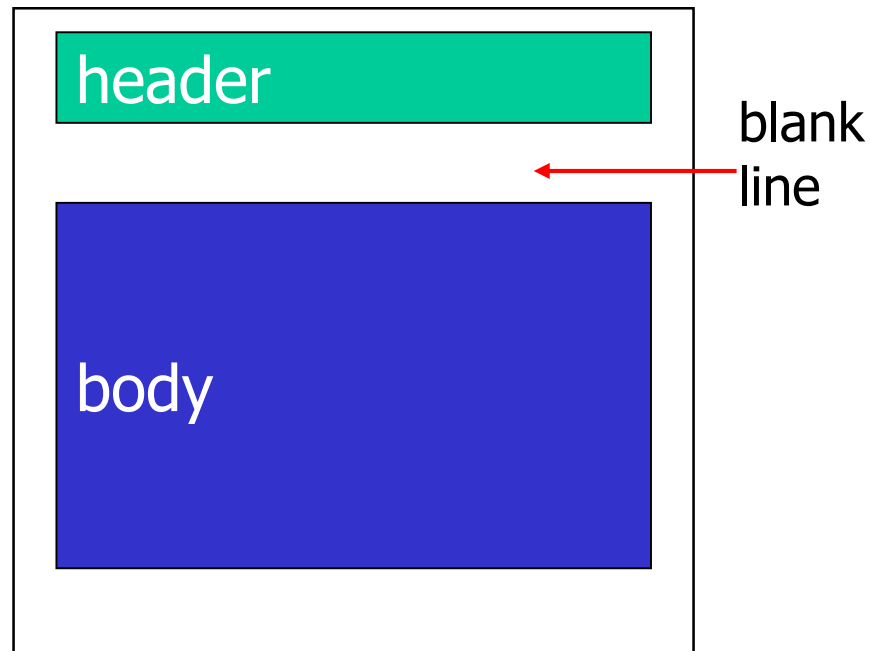
- Transfer mails from sender to receiver over TCP connection
  - Rely on TCP to provide reliable service
- No guarantee to **recover lost mails**
- No end to end **acknowledgement to originator** (user)
- **Error indication delivery** not guaranteed
  - Indicates mail has **arrived at host**, but **not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



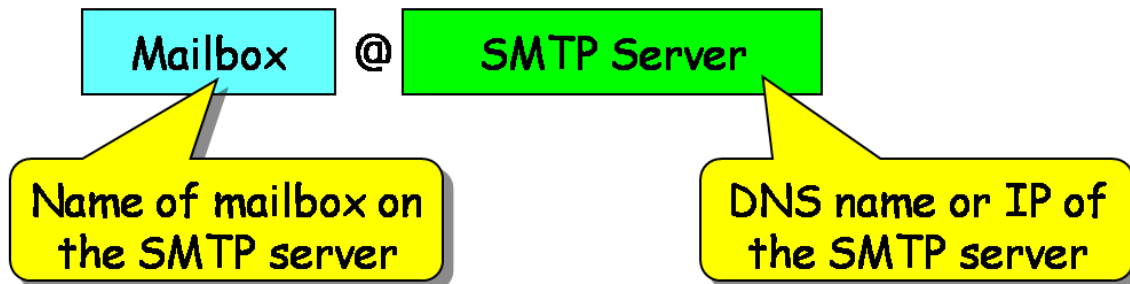
# An Email Message

- **Header lines**, e.g.
  - To: Alice@sina.com
  - From: Bob@gmail.com
  - Subject: Dinner tonight

- **Body**
  - Mail contents, ASCII characters only



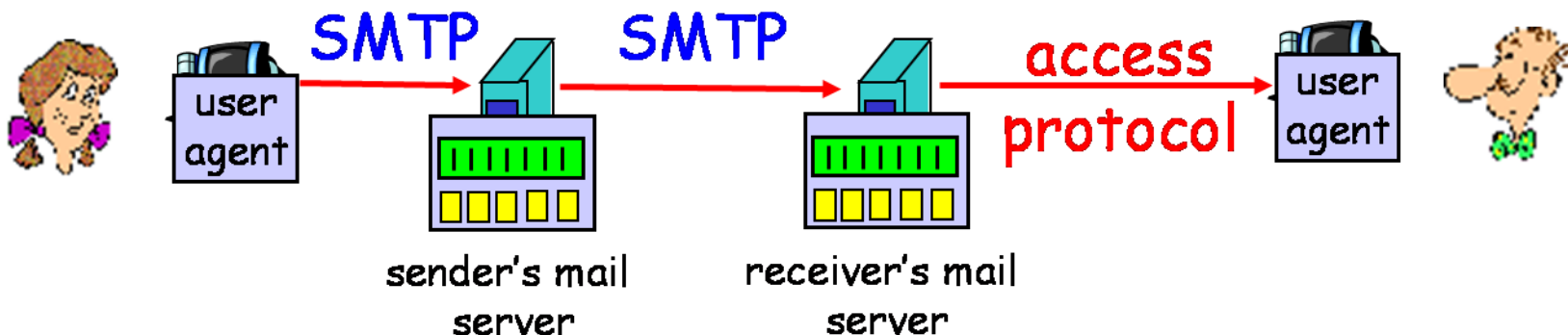
- **Mail destinations**





# 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--
```



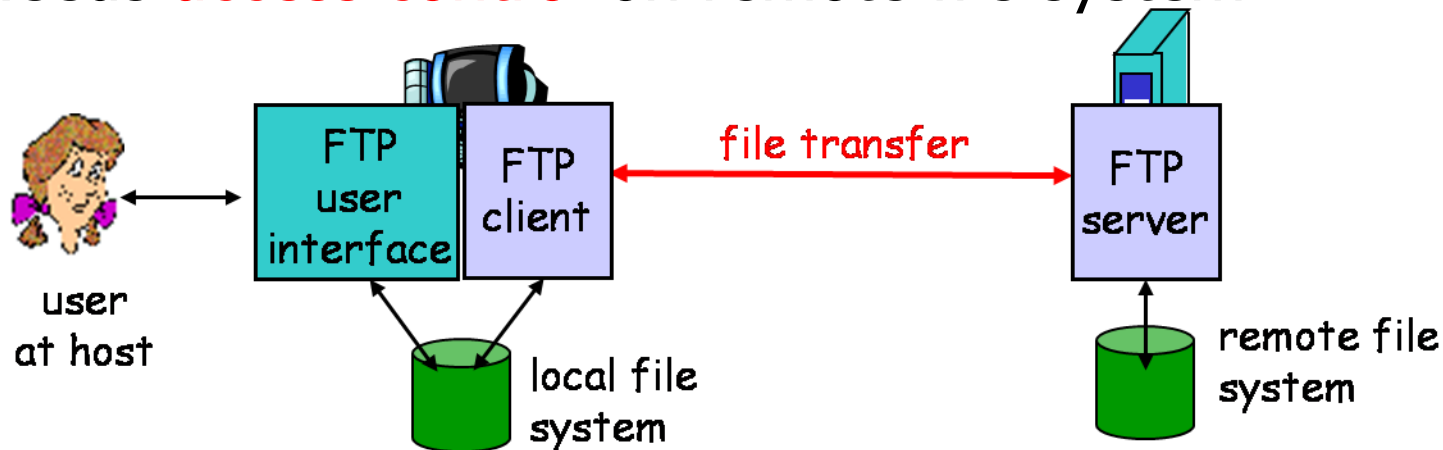


# File Transfer Protocol (FTP)



# File Transfer Protocol (FTP)

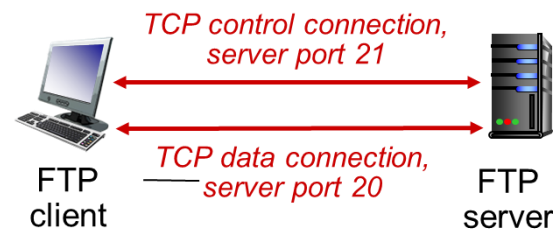
- RFC 959, use TCP, port 21/20
- Transfer file to/from remote host
- Client/Server model, client side initiates file transfer (either to/from remote)
- Deals with **heterogeneous** OS and file systems
- Needs **access control** on remote file system





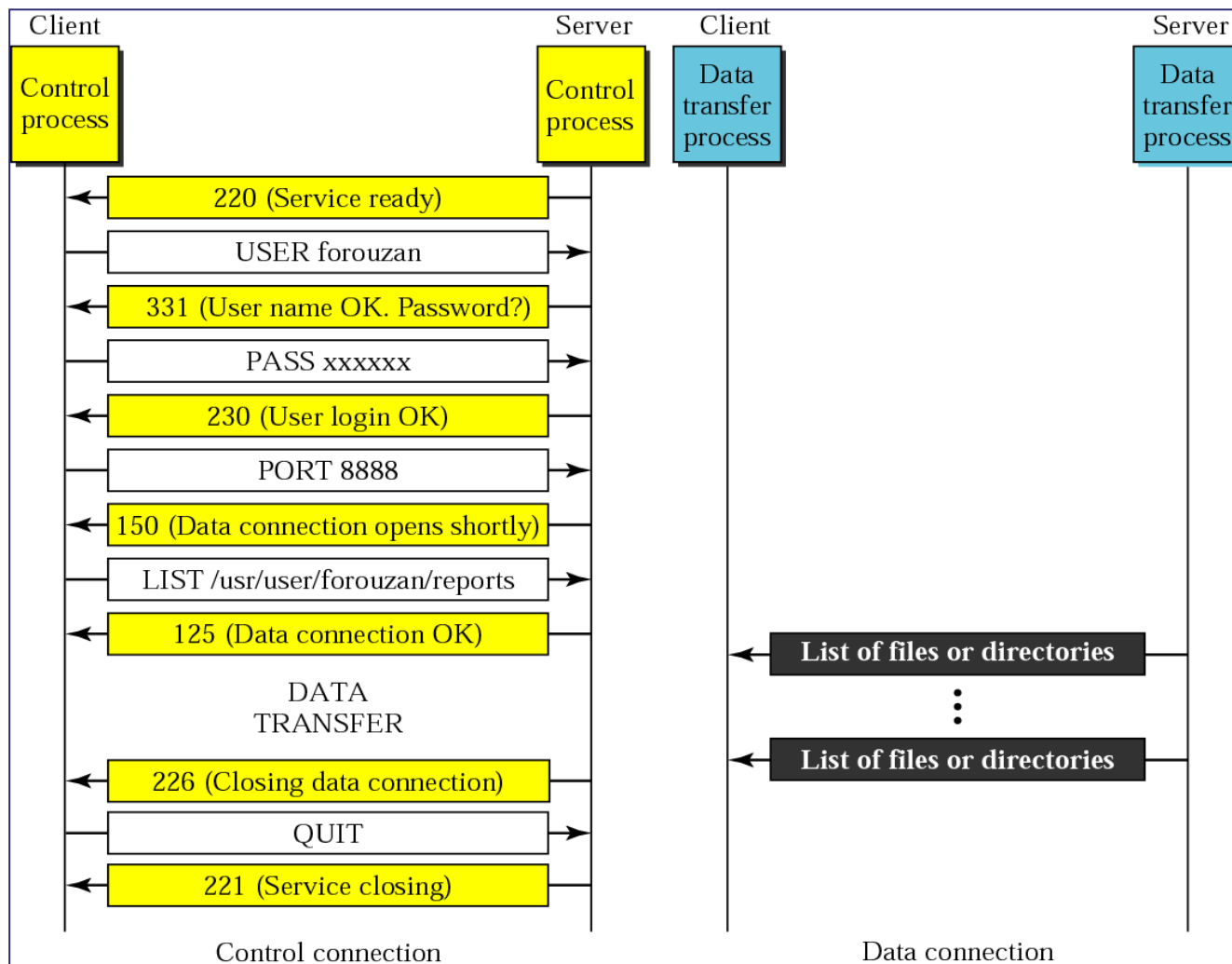
# Control and Data Connections

- 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 2<sup>nd</sup> 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)