CS 455/555
Intro to Networks and Communications

Applications & Application-Layer Protocols:
FTP and Email (SMTP & POP)

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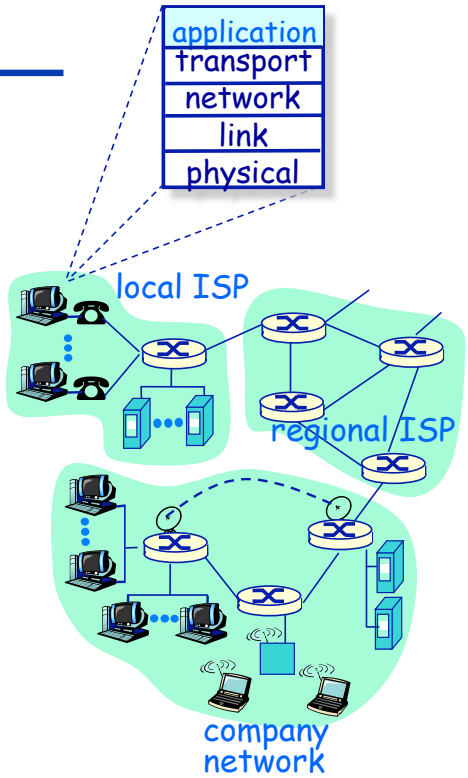
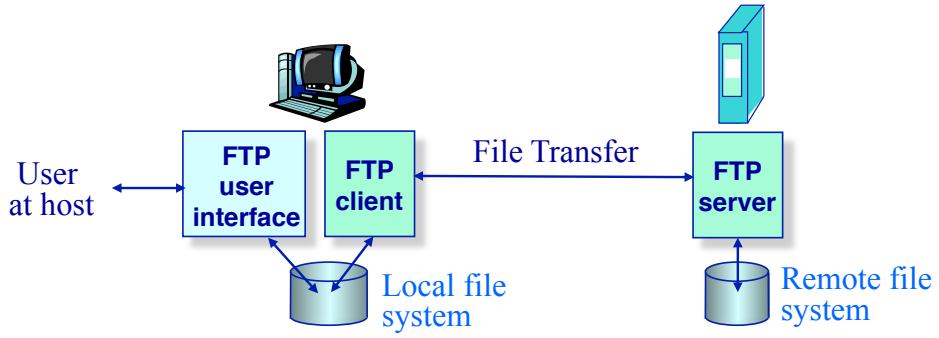
Application-Layer Protocols
Outline

- The architecture of distributed systems
  - » Client/Server computing
  - » P2P and Hybrid computing
- The programming model used in constructing distributed systems
  - » Socket programming
- Example client/server systems and their application-layer protocols
  - » The World-Wide Web (HTTP)
  - » Reliable file transfer (FTP)
  - » E-mail (SMTP & POP)
  - » Internet Domain Name System (DNS)



Application-Layer Protocols

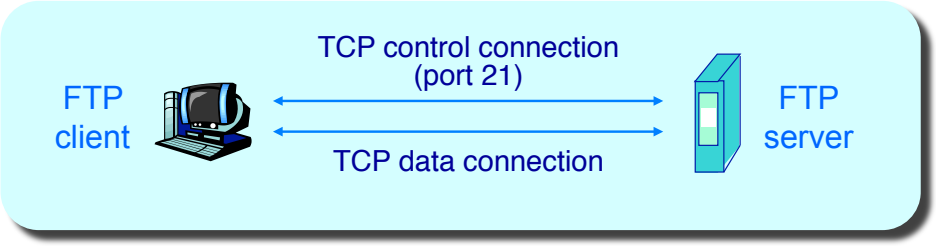
FTP: The Internet file transfer protocol (RFC 959)



- FTP is used to transfer a file to/from remote host
- FTP uses a client/server model
  - » Client: side that initiates transfer (either to/from remote)
  - » Server: remote host
- FTP server listens for connections on port 21

FTP Protocol Design

Control and data sockets



- FTP client contacts FTP server on port 21, using TCP as the transport protocol
- Two parallel TCP connections opened:
  - » A single control connection for exchanging commands, responses ("out of band control")
  - » *n* data connections for transferring file data to/from server
- FTP server maintains "state"
  - » Remembers current directory, earlier authentication

FTP Protocol Design

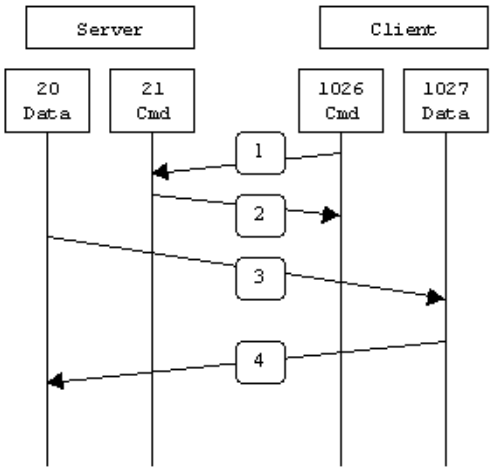
Active vs. Passive FTP

- Traditional use of FTP is "active"
  - » client contacts server on control port
  - » server uses data port to contact client and transfer data
- Use of firewalls has made "passive" more common
  - » client contacts server on control port
  - » client and server agree on a new server port for data
  - » client contacts server on data port for data transfer

FTP Protocol Design

Active FTP

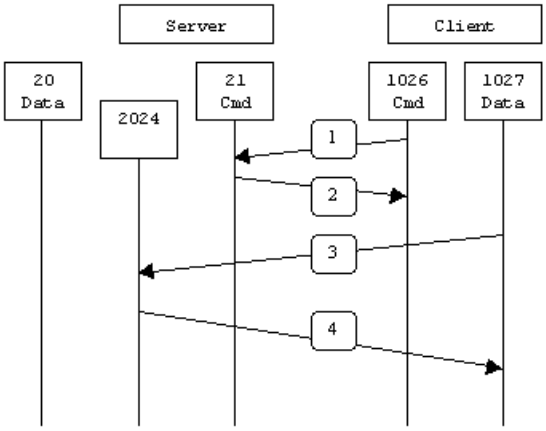
- The client connects from a random unprivileged port (N > 1023) to the FTP server's command port, port 21
- The client starts listening to port N+1 and sends the FTP command PORT N+1 to the FTP server
- The server will then connect back to the client's specified data port from its local data port, which is port 20.



FTP Protocol Design

Passive FTP

- The client initiates both connections to the server
- When opening an FTP connection, the client opens two random unprivileged ports locally (N > 1023 and N+1).
- The first port is used to contact the server on port 21
- The client then issues the PASV command.
- The server then opens a random unprivileged port (P > 1023) and sends the PORT P command back to the client.
- The client then initiates the connection from port N+1 to port P on the server to transfer data.



FTP Protocol Design

FTP commands, responses

- Sample commands:
  - » Sent as ASCII text on control socket

USER <*username*>

PASS <*password*>

LIST

Return list of file in current directory

RETR <filename>

Retrieves (gets) file

STOR <filename>

Stores (puts) file onto remote host

- 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

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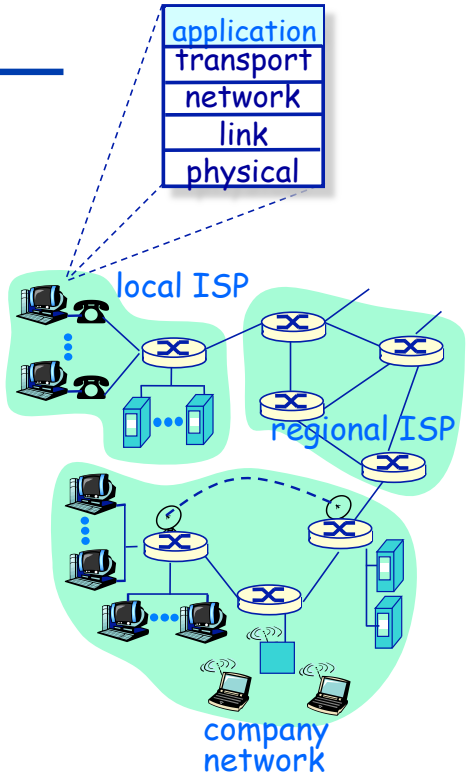
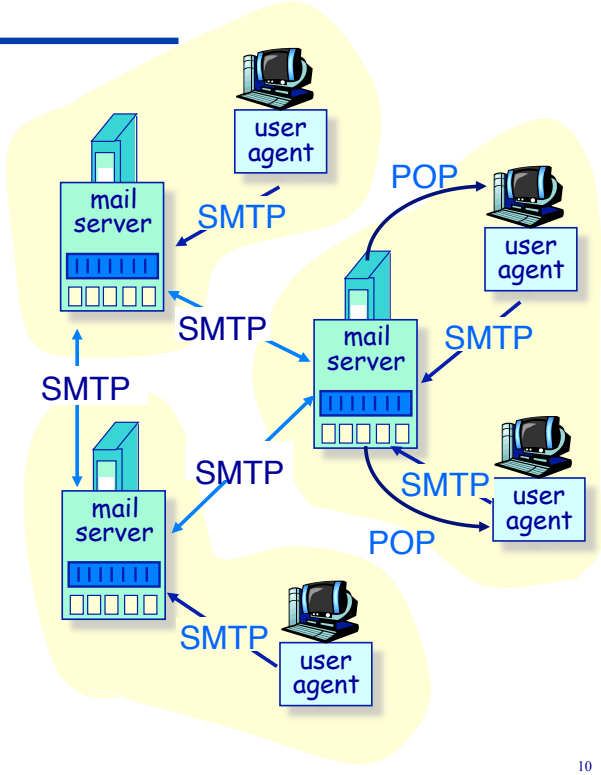


Application-Layer Protocols
Electronic mail

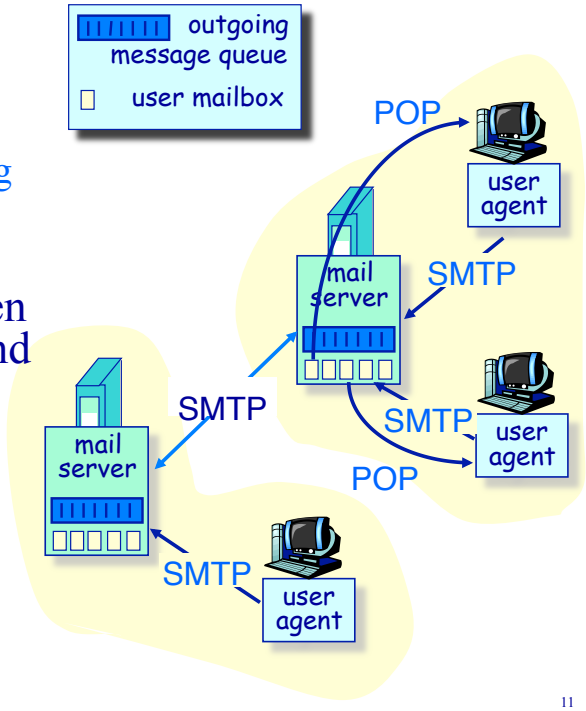
- Major components:
  - » User agents
  - » Mail servers
  - » Mailboxes
- Protocols:
  - » Simple Mail Transfer Protocol (SMTP) delivers mail to servers
    - ❖ From clients to local mail server
    - ❖ Inter-mail server delivery
  - » Post Office Protocol (POP) for user access to delivered email



Electronic Mail

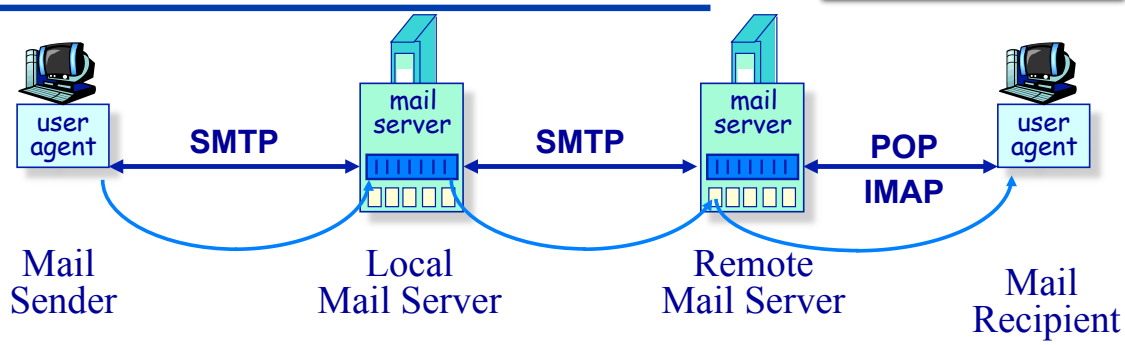
Mail servers

- Servers maintain:
  - » A message queue of outgoing email messages
  - » A mailbox containing incoming messages for each user
- SMTP protocol is run between mail agents and servers to send email messages
  - » Client — the sending mail server or agent
  - » Server — the receiving mail server



Electronic Mail

The email delivery process



- User's mail agent contacts its local mail server
- Local mail server contacts the destination mail server(s)
- Destination mail server places the mail into the appropriate user's mailbox
- User retrieves mail via a mail access protocol

The Email Delivery Process

SMTP [RFC 2821]

- SMTP uses a TCP socket on port 25 to transfer email reliably from client to server
- Email is temporarily stored on the local server and eventually transferred directly to receiving server
  - » Intermediate relay is a special case
- Three phases of the protocol:
  - » Handshaking ("greeting")
  - » Transfer of messages
  - » Closure
- Client/server interaction follows a command/response paradigm
  - » Commands are plain ASCII text
  - » Responses are a status code and an optional phrase
  - » Command and response lines terminated with **CRLF**

The Email Delivery Process

Sample SMTP interaction

- SMTP client establishes TCP connection to server hamburger.edu at port 25
  - » (SMTP is non-standard in that the server "talks first")

```
Server: 220 hamburger.edu
Client: 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
```

Line with single '.' is the message delimiter

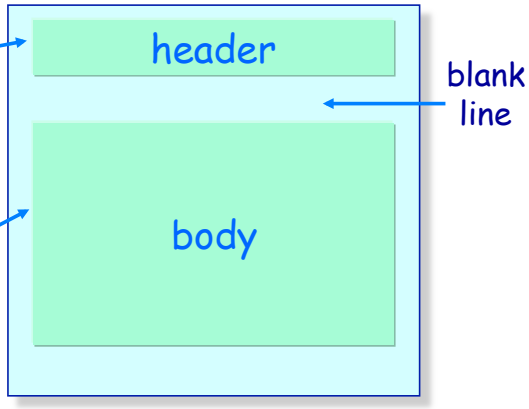
Electronic Mail

Mail message format (RFC 2822)

- Header lines, e.g.,
  - » From:
  - » To:
  - » Subject:

  these are different from SMTP commands!

- Body
  - » The "message", ASCII characters only



Electronic Mail

Mail message format example

```
Server: 220 hamburger.edu
Client: 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: From: alice@crepes.fr
     C: To: bob@hamburger.edu
     C: Subject: food
     C:
     C: Do you like ketchup?
     C:   How about pickles?
     C: .
     S: 250 Message accepted for delivery
     C: QUIT
     S: 221 hamburger.edu closing connection
```

Mail Message Format

MIME — Multimedia mail extensions (RFC 2045, 2056)

- SMTP requires all data to be 7-bit ASCII characters
  - » All non-ASCII data must be encoded as ASCII strings
- Additional lines in the message header declare MIME content type

MIME version

Method used to encode data

Multimedia data type, subtype, parameter declaration

ASCII 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
```


MIME Multimedia Mail Extensions

MIME types

```
Content-Type:  <type>/<subtype>[; <parameters>]
```

```
Content-Type: text/plain; charset=us-ascii
```

```
Content-Type: application/pdf; filename=foo.pdf
```

- Text
  - » Subtypes: `plain`, `html`
- Image
  - » Subtypes: `jpeg`, `gif`
- Audio
  - » Subtypes: `basic` (8-bit μ-law encoded), `32kadpcm` (32 kbps ADPCM)
- Video
  - » Subtypes: `mpeg`, `quicktime`
- Application
  - » Other data that must be processed by reader before it is "viewable"
  - » Subtypes: `msword`, `octet-stream`

MIME Types

Multipart Type

MIME version

Header/Body separators

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary=98766789

--98766789
Content-Transfer-Encoding: quoted-printable
Content-Type: text/plain

Dear Bob,
Please find a picture of a crepe.
--98766789
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
--98766789--
```


MIME Types

Multipart Type

MIME version

Indicates multiple, mixed types

Defines parts separator

1 part

1 part

Encoding & type specified for each part

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary=98766789

--98766789
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Dear Bob,
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Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
--98766789--
```

Electronic Mail

SMTP notes

- SMTP uses persistent connections
- SMTP is a "push" protocol
- SMTP requires that message (header & body) be in 7-bit ASCII
  - » All binary objects must be ASCII encoded
  - » Certain character strings are not permitted in a message
  - » Message has to be encoded if these strings are used
- With MIME extensions, multiple objects can be sent in a single multipart message
- SMTP server uses `CRLF.CRLF` to determine end of message

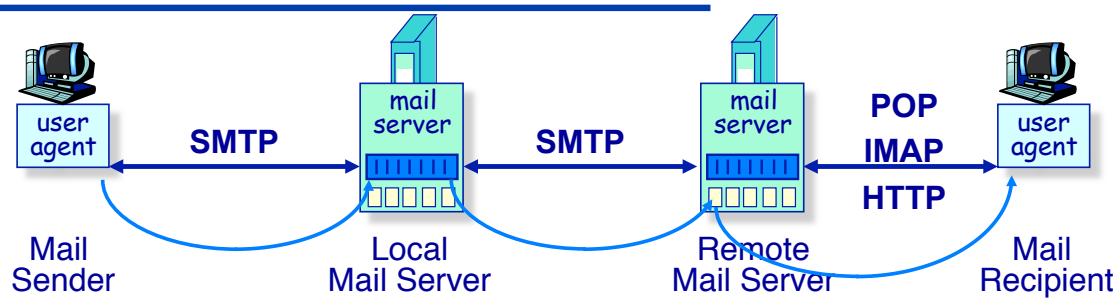
Application-Layer Protocols

HTTP *v.* SMTP

- HTTP is a "pull" protocol, SMTP is a "push" protocol
- Persistence:
  - » SMTP uses persistent connections
  - » HTTP may or may not
- Message/object content:
  - » Both have ASCII command/response interaction and status codes
  - » SMTP requires that messages be in 7-bit ASCII — multiple objects message sent in a multipart message
  - » HTTP can transfer anything —each object is encapsulated in its own response headers

Electronic Mail

Mail access protocols



- SMTP: Delivery to receiver's server
- Mail access protocol: Retrieval from server by a user
  - » POP [RFC 1939] — Authorization and download
  - » IMAP (Internet Mail Access Protocol) [RFC 2060]
    - ❖ More features (more complex)
    - ❖ Manipulation of stored messages on server
  - » HTTP: Gmail, Yahoo! Mail, *etc.*

Mail Access Protocols

The POP-3 protocol

- Authorization phase
  - » Client commands:
    - ❖ `user`: declare username
    - ❖ `pass`: password
  - » Server responses
    - ❖ `+OK`
    - ❖ `-ERR`
- Transaction phase
  - » `list`: list message numbers and sizes
  - » `retr`: retrieve message by number
  - » `dele`: delete
  - » `quit`

```
S: +OK POP3 server ready
C: user alice
S: +OK
C: pass hungry
S: +OK user 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 2 contents>
S: .
C: dele 2
C: quit
S: +OK POP server sign off
```

Mail Access Protocols
POP-3 and IMAP

More about POP3

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

IMAP

- Keep all messages in one place: the server
- Allows user to organize messages in folders
- IMAP keeps user state across sessions:
  - » names of folders and mappings between message IDs and folder name

Mail Access Protocols
Web-Based Email

- User agent is a web browser
- User communicates with remote mailbox via HTTP
- When recipient wants to access a message
  - » email message is sent from mail server to browser using HTTP
- When sender wants to send a message
  - » email is sent from browser to mail server using HTTP
  - » mail server still uses SMTP to communicate with other mail servers

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