Logistics

- Office Hours
  - <u>Today</u> 2-4pm, Tues or Weds by appt. (**<u>Malone 313</u>**)
  - **Increased the enrollment limit** (68+2 / 80)
  - **<u>Registration signatures today after class</u>**
  - TAs posted hours on Piazza

- Assignments
  - Web server programming assignment out today!
  - Chapter 2 and reading HW2
  - **<u>Both due Sun 2/12 10pm</u>**

- Slides now on main course website

Programming Assignment

- Build a web server and client
  - Python makes this super easy
  - You'll get a skeleton for the server
- Grading
  - We will provide a reference Ubuntu VM
  - (JHU provides a VMWare license for students)
  - <u>Your code must run the first time on that machine</u>
- You can test on localhost

Two Arrested in London for Infecting Washington's CCTV Network with Ransomware

By Catalin Cimpanu   February 3, 2017   05:15 AM   0

Telecom

AT&T raises SDN network transformation goal to 55% for 2017

by *Sean Buckley* | Feb 2, 2017 12:35pm

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AT&T raises SDN network transformation goal to 55% for 2017

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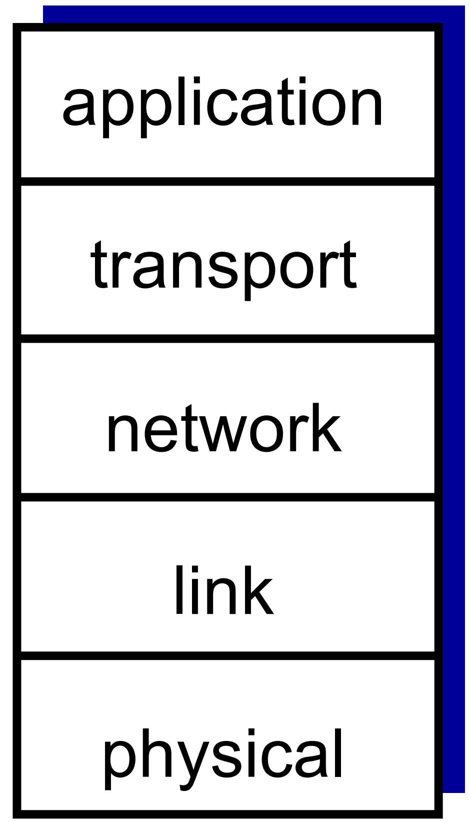
AT&T said that data on its mobile network has increased about 250,000% since 2007, and most of that traffic is video. SDN will be an important tool to handle this data growth that will continue to accelerate.

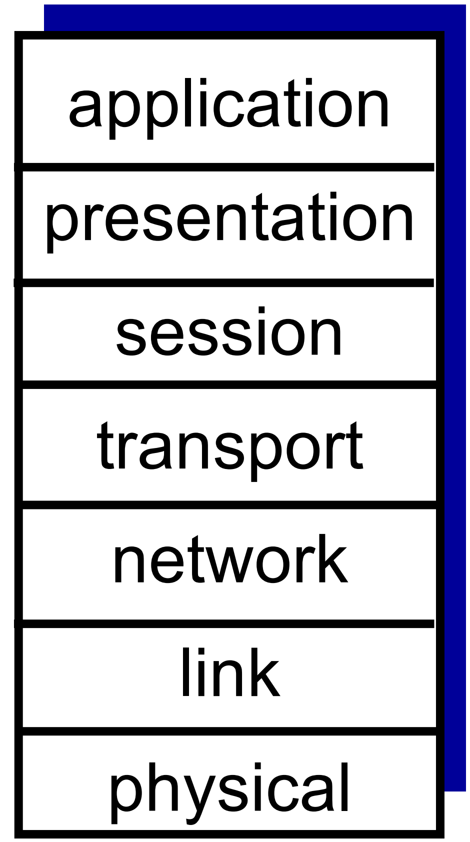
Recap: Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP, Skype
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP, LTE
- *physical:* bits "on the wire"



Recap: ISO/OSI reference model

- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



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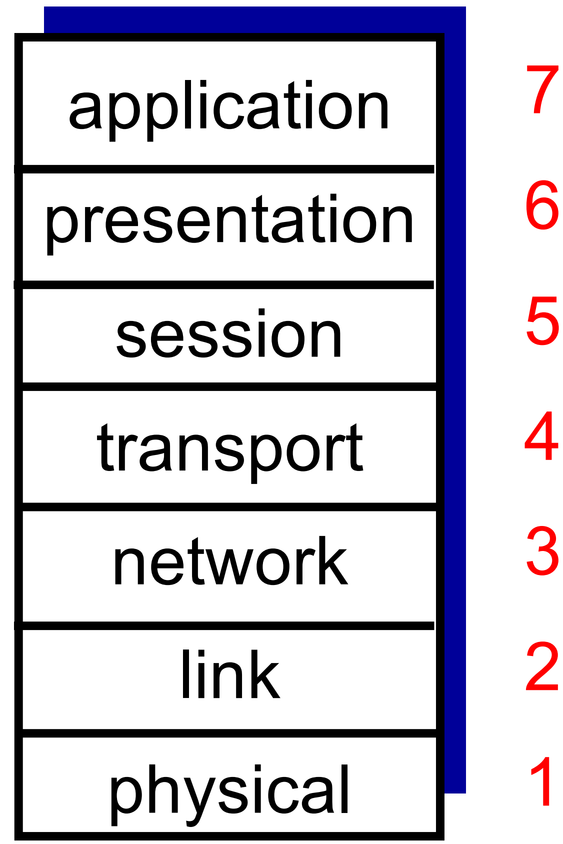
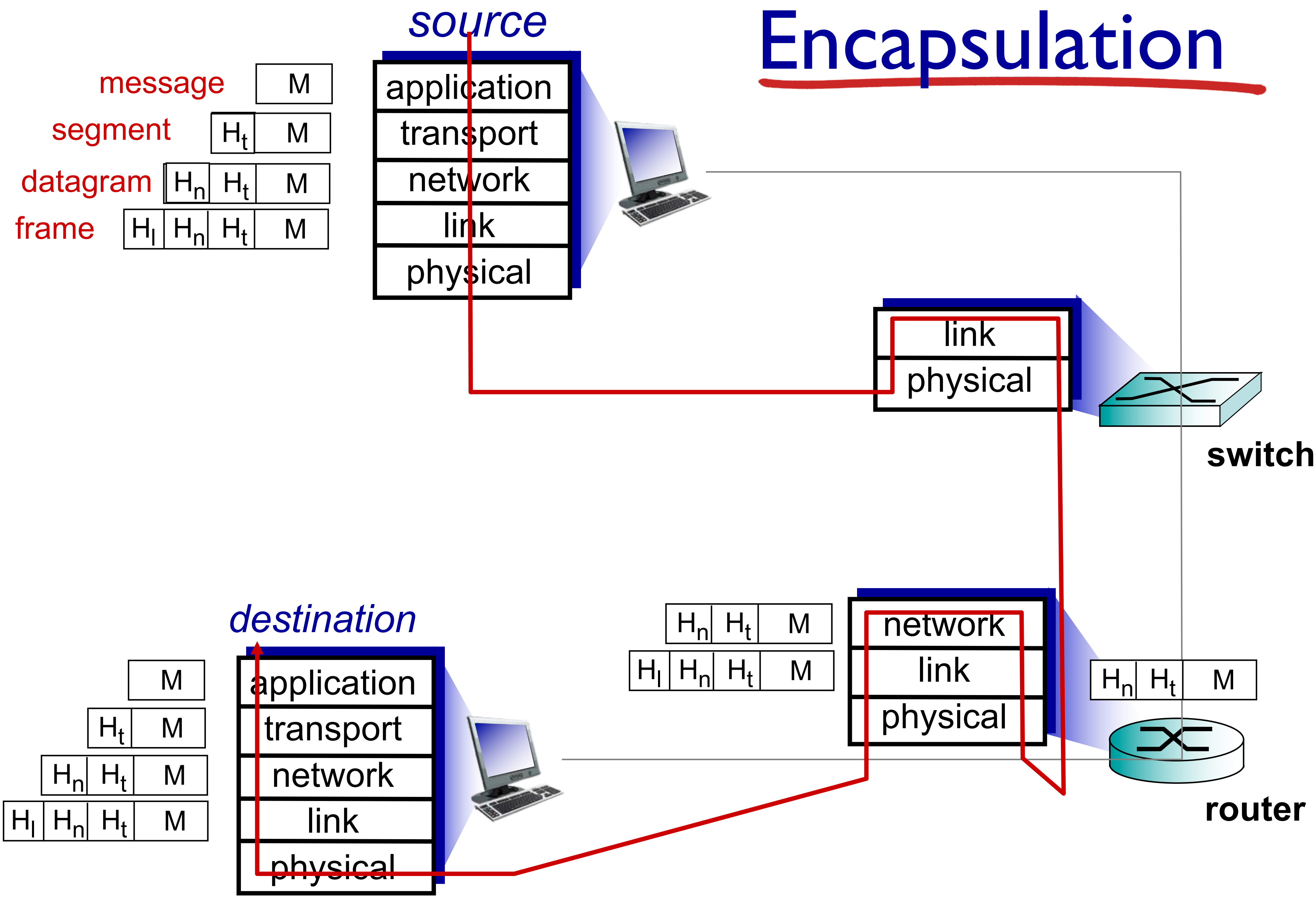
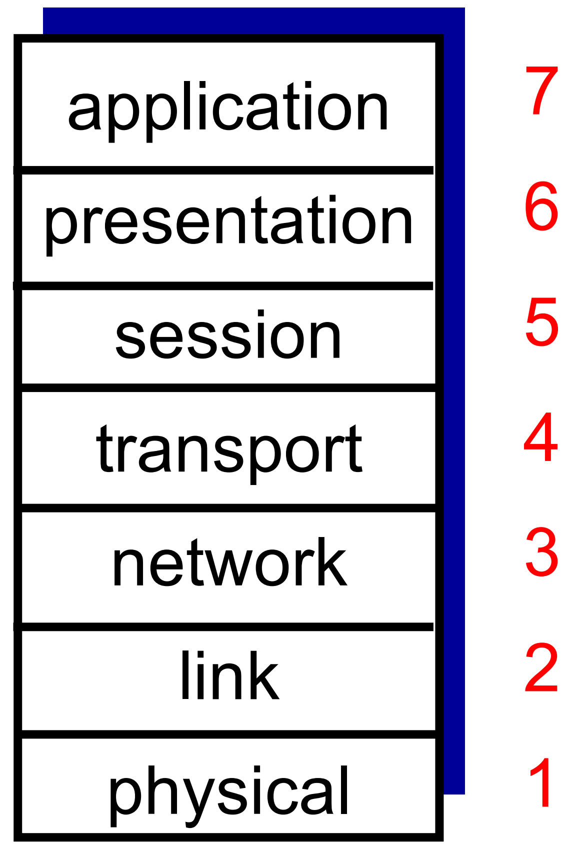


Encapsulation



Chapter 2
Application Layer



Some network apps

- e-mail
- web
- text messaging
- remote login
- P2P file sharing
- multi-user network games
- streaming stored video (YouTube, Hulu, Netflix)
- voice over IP (e.g., Skype)
- real-time video conferencing
- social networking
- search
- …
- …

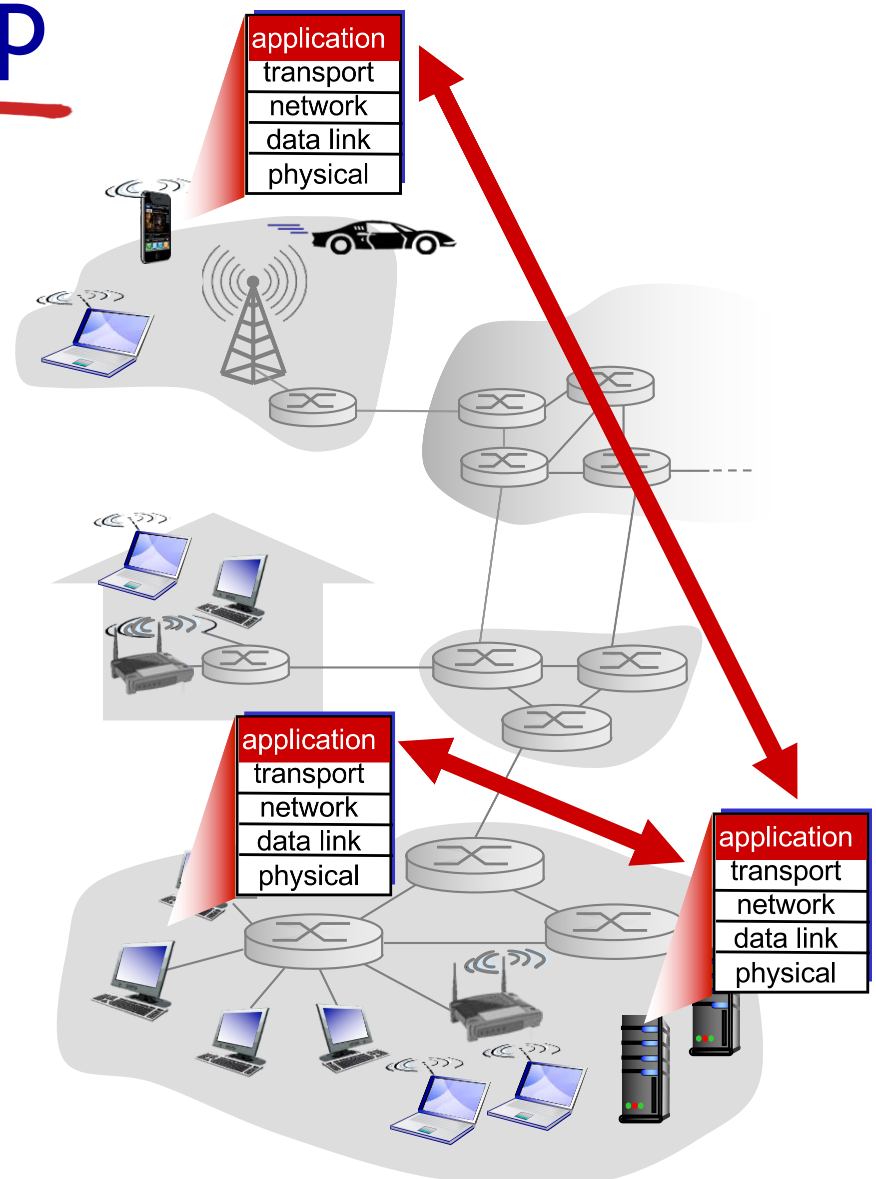
Creating a network app

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

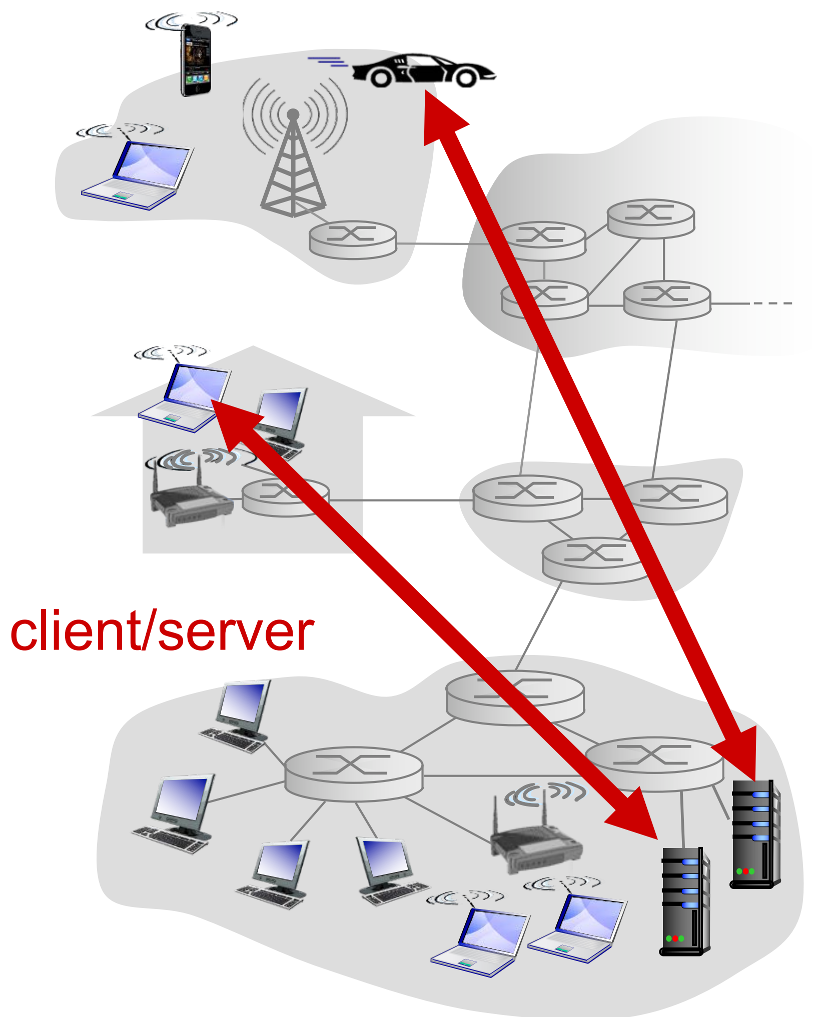


Application architectures

possible structure of applications:

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

Client-server architecture



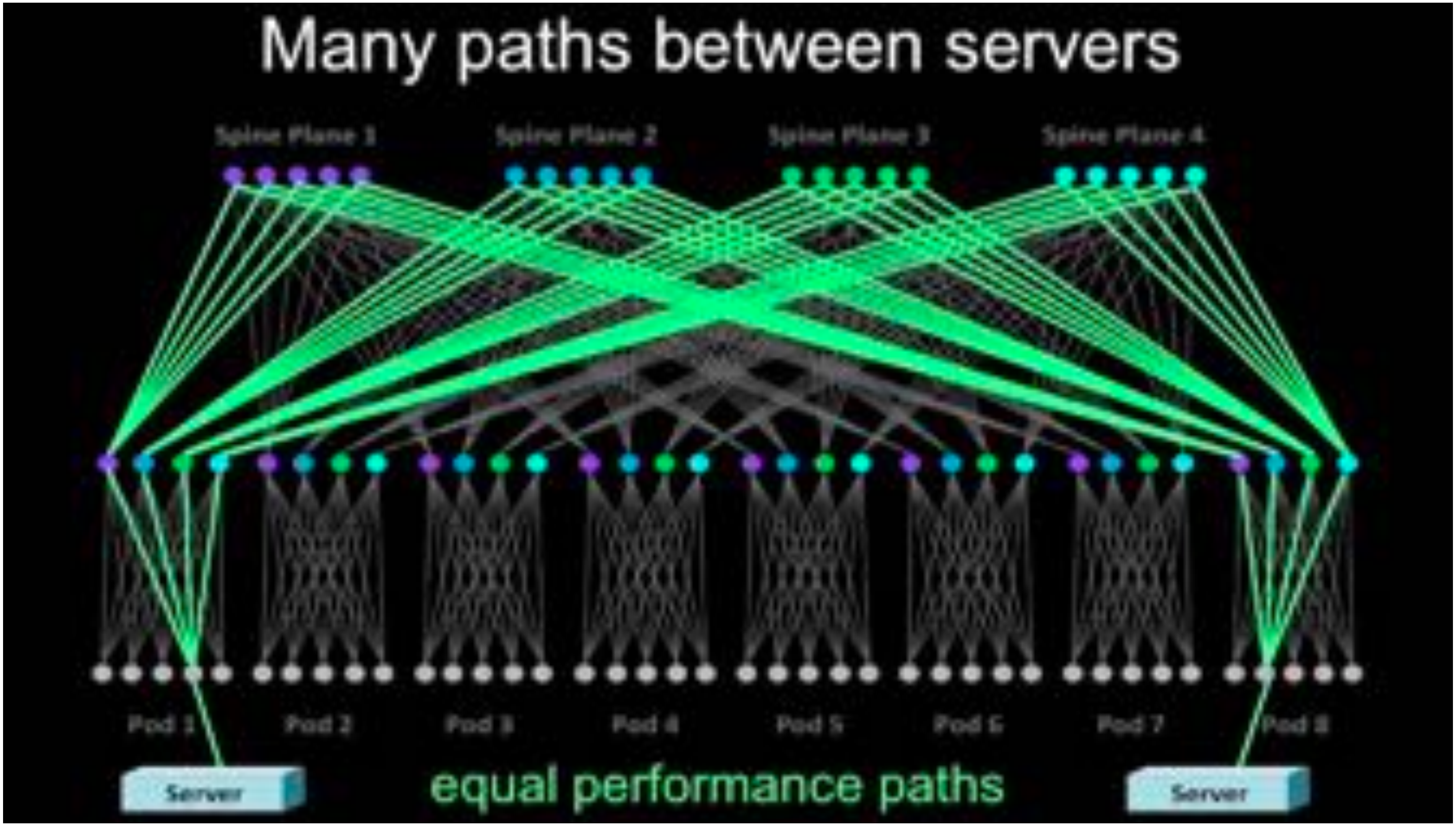
server:
- always-on host
- permanent IP address
- data centers for scaling

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

Client/Server Example: Facebook

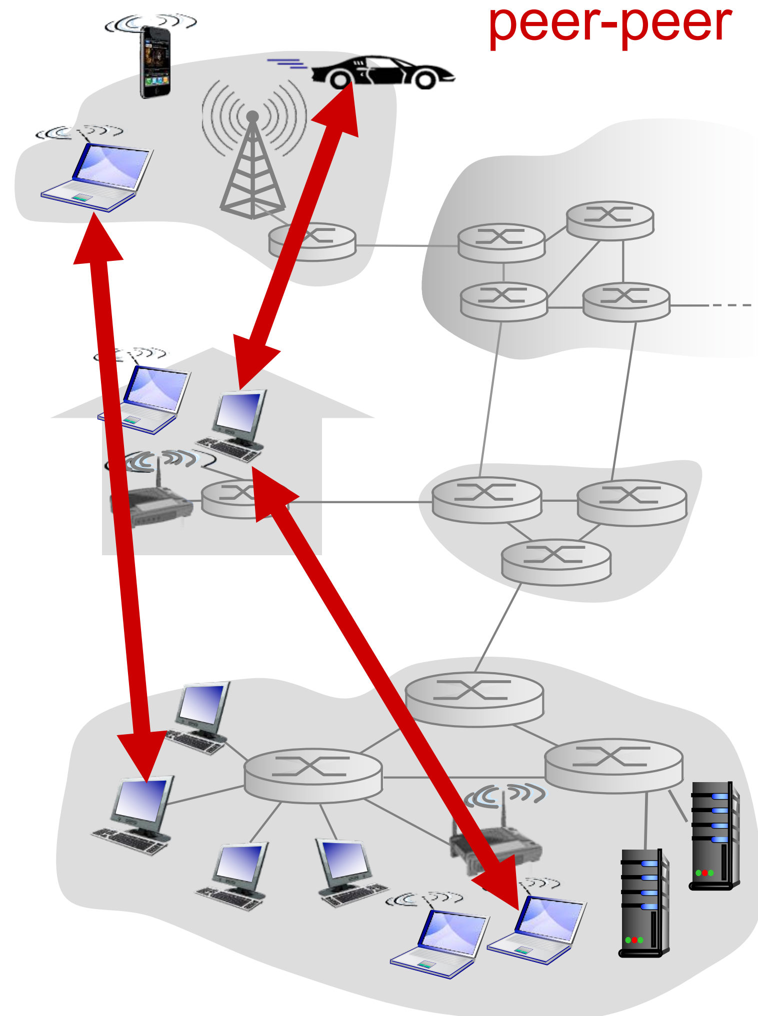
Client/Server Example: Facebook

Client/Server Example: Facebook

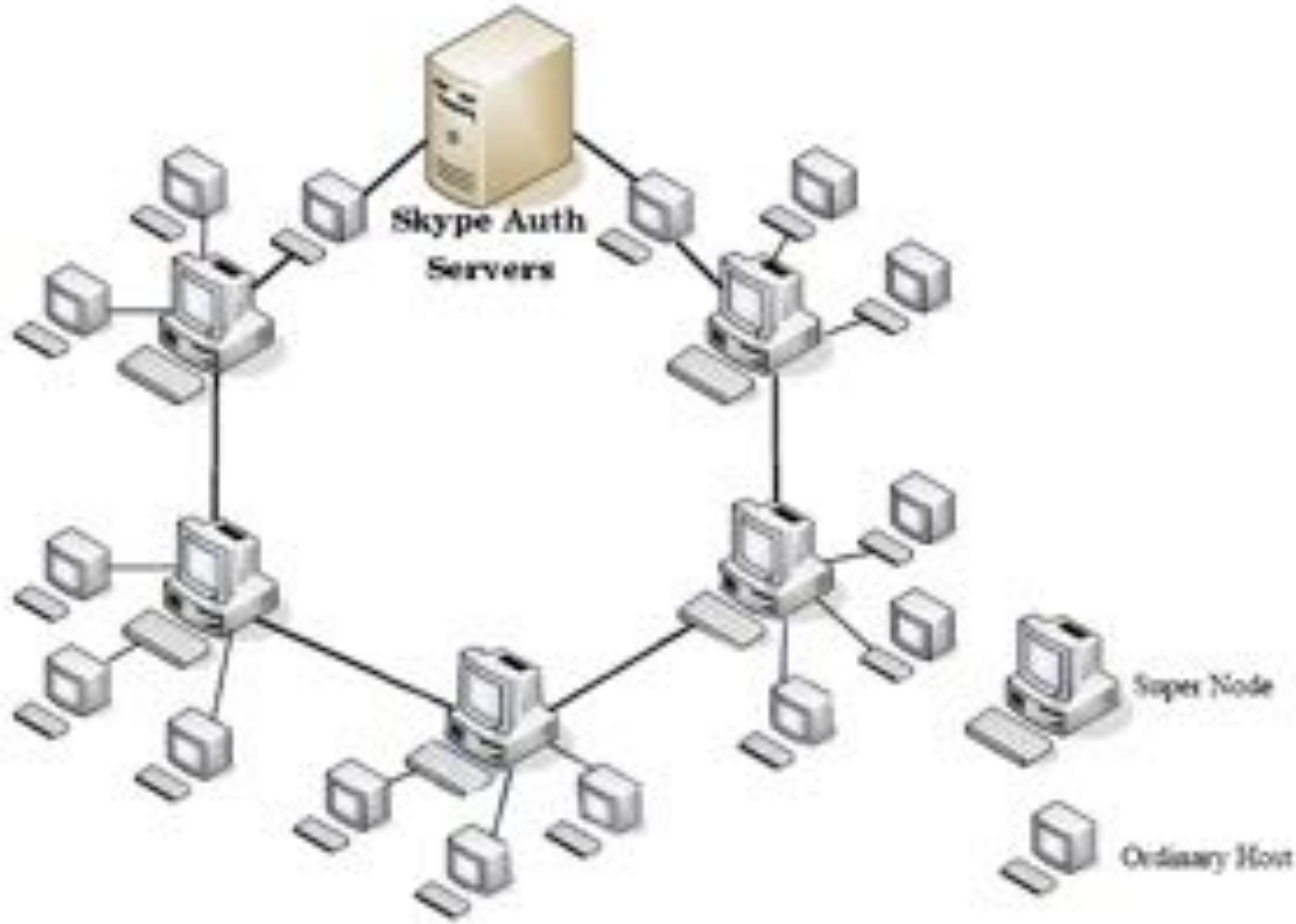


P2P architecture

- *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

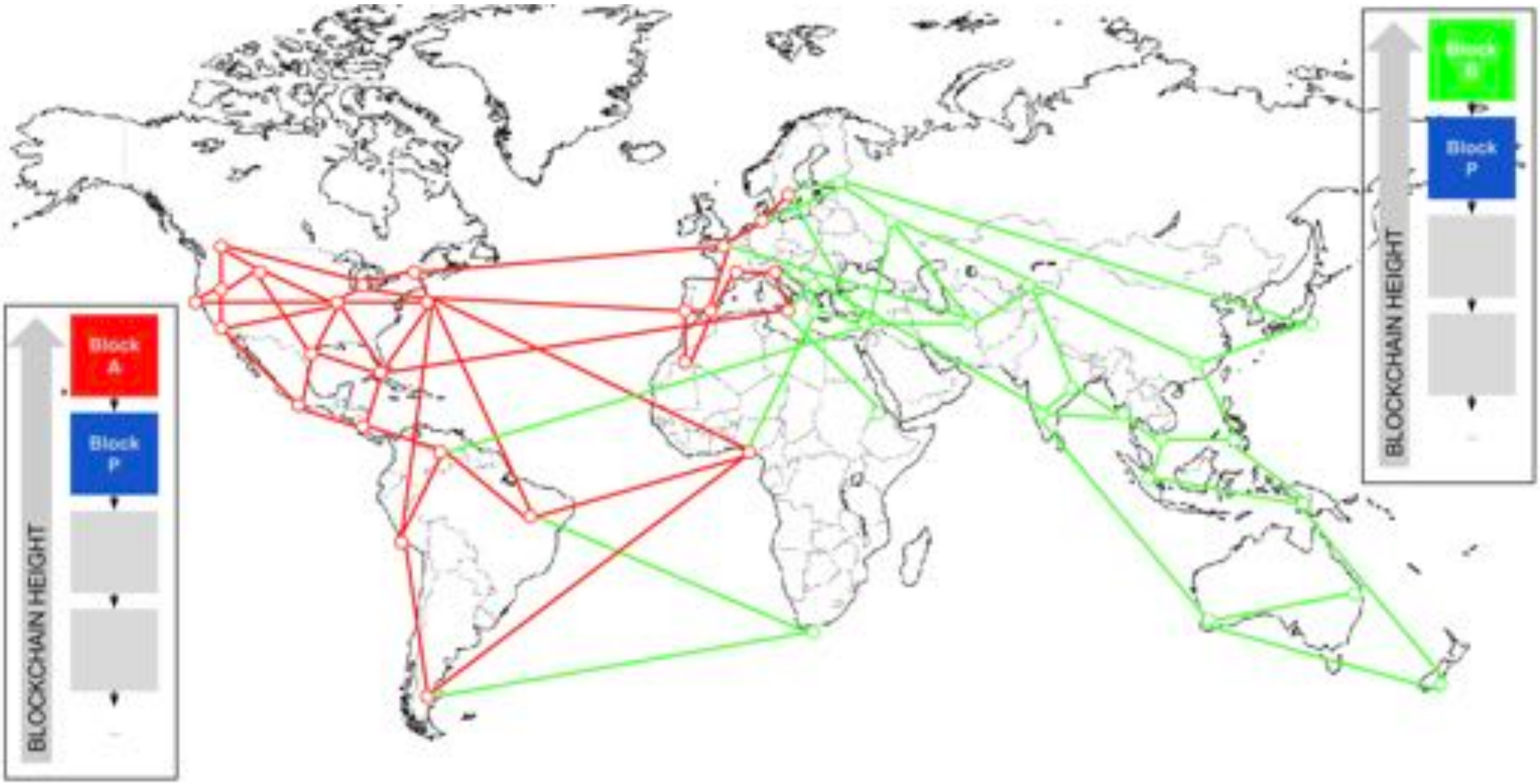


P2P Example: Skype (early days)



From: http://blog.miconda.eu/2011/05/sip-for-skype.html

P2P Example: Bitcoin



From: http://blog.miconda.eu/2011/05/sip-for-skype.html

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

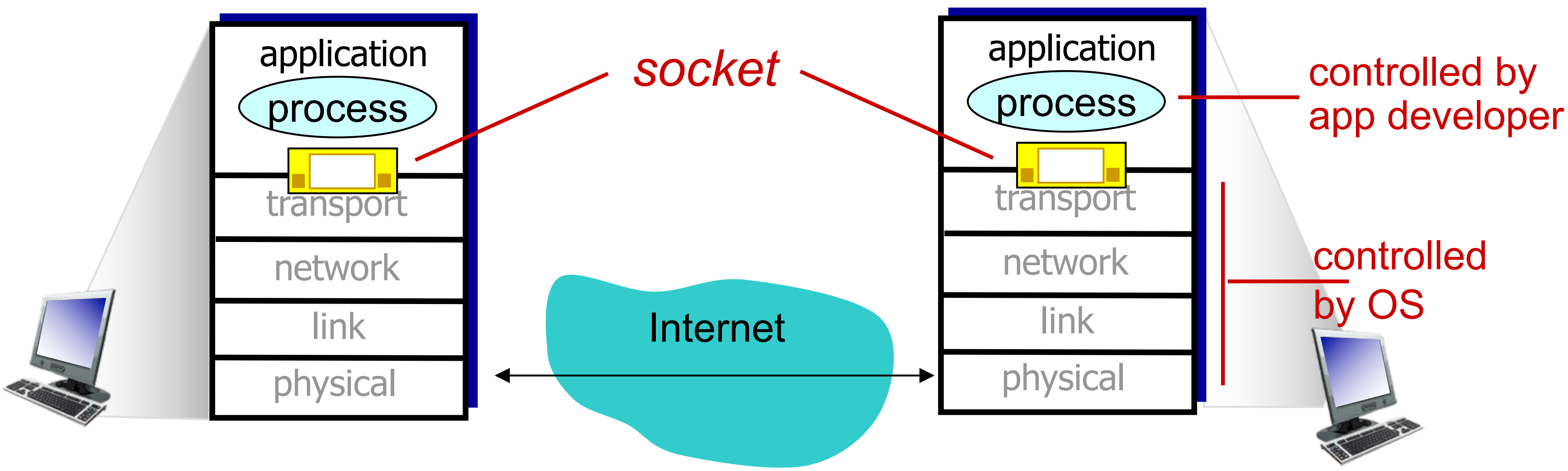
client process: process that initiates communication

server process: process that waits to be contacted

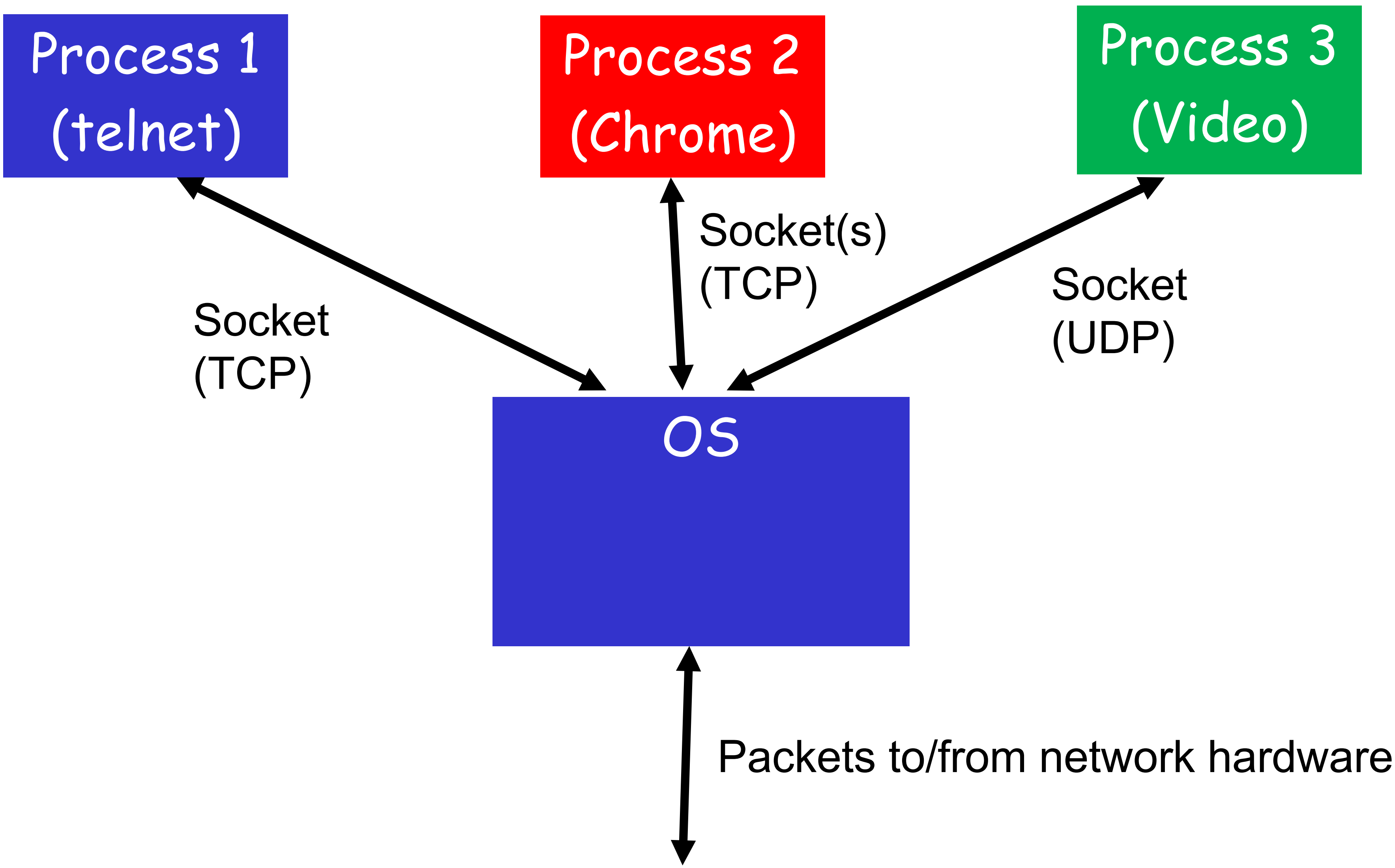
- aside: applications with P2P architectures have client processes & server processes

Sockets

- 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



Sockets


Process 1
(telnet)
Process 2
(Chrome)
Process 3
(Video)
Socket
(TCP)
Socket(s)
(TCP)
Socket
(UDP)
OS
Packets to/from network hardware

Addressing processes

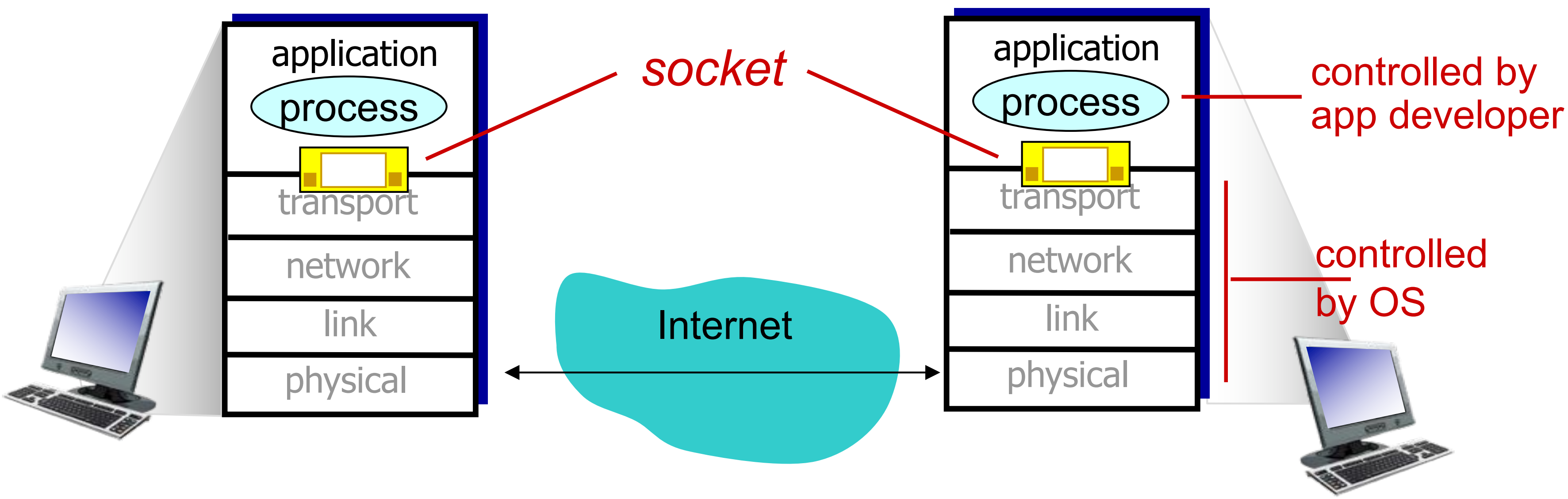
- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- *Q:* does IP address of host on which process runs suffice for identifying the process?
  - *A:* no, *many* processes can be running on same host

- *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…

Socket programming

goal: learn how to build client/server applications that communicate using sockets

socket: door between application process and end-end-transport protocol



“Packets” vs. “connections”

- Connection-oriented transport
  - Mimics a “serial cable”
  - Sends streams of bytes in order, gets them to destination reliably
  - <u>Example: TCP</u>

- Packet-oriented (”datagram”) transport
  - Take advantage of the underlying packet network
  - Send short, independent messages
  - May not get to destination, or get there in order
  - <u>Example: UDP</u>
- <u>Application Examples?</u>

Socket programming

Two socket types for two transport services:

- *UDP:* unreliable datagram
- *TCP:* reliable, byte stream-oriented

Application Example:

1. Client reads a line of characters (data) from its keyboard and sends the data to the server.
2. The server receives the data and converts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.

Socket programming *with TCP*

client must contact server

- server process must first be running
- server must have created socket (door) that welcomes client's contact

client contacts server by:

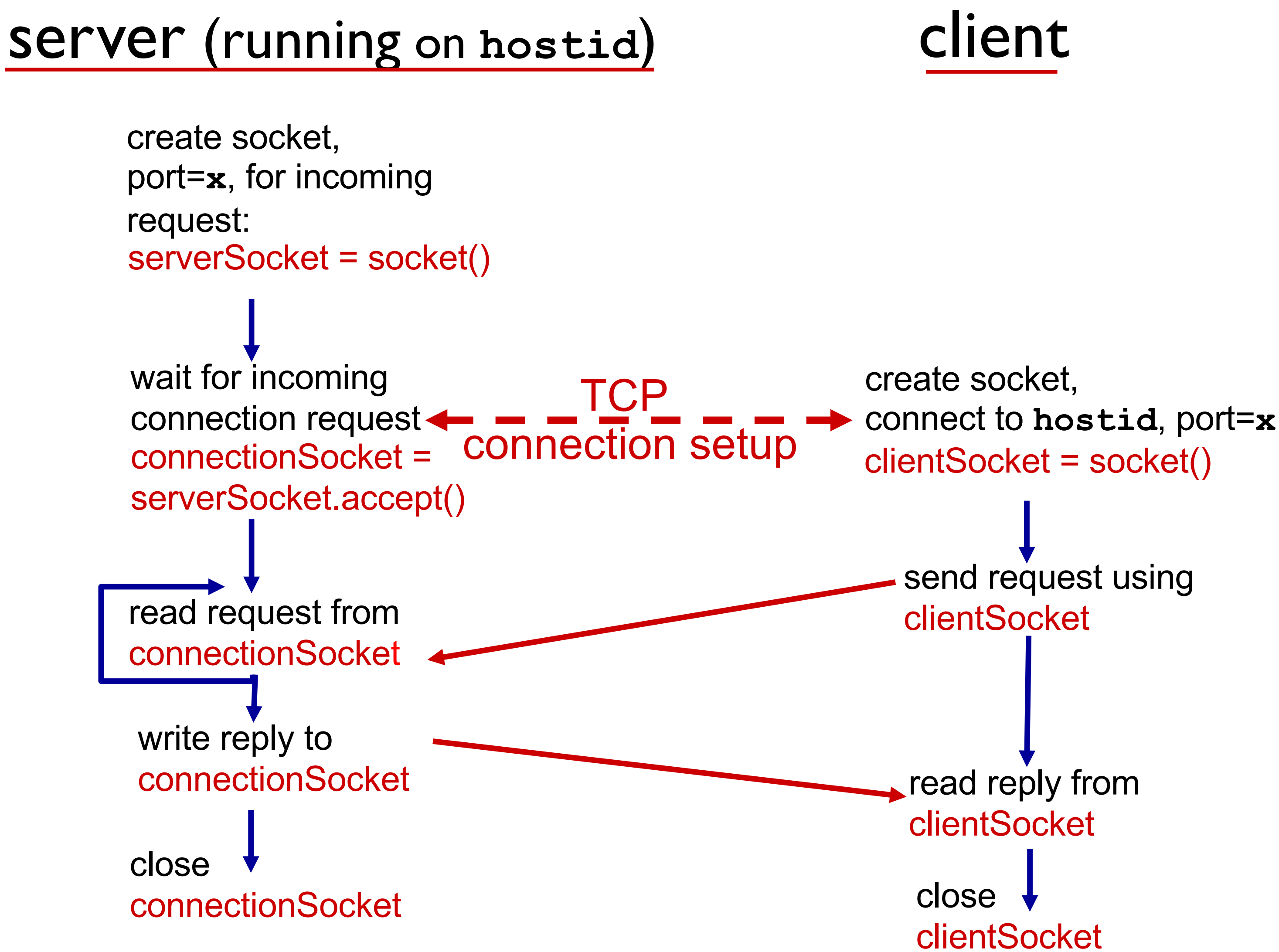
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients (more in Chap 3)

application viewpoint:

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

Client/server socket interaction: TCP



Example app: TCP client

Python TCPClient

create TCP socket for server, remote port 12000

No need to attach server name, port

```
from socket import *
serverName = 'servername'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
sentence = raw_input('Input lowercase sentence:')
clientSocket.send(sentence)
modifiedSentence = clientSocket.recv(1024)
print 'From Server:', modifiedSentence
clientSocket.close()
```

Example app: TCP server

Python TCPServer

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

server waits on accept() for incoming requests, new socket created on return

read bytes from socket (but not address as in UDP)

close connection to this client (but *not* welcoming socket)

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(1)
print 'The server is ready to receive'
while 1:
    connectionSocket, addr = serverSocket.accept()

    sentence = connectionSocket.recv(1024)
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence)
    connectionSocket.close()
```

Socket programming *with UDP*

UDP: no "connection" between client & server

- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- rcvr extracts sender IP address and port# from received packet

UDP: transmitted data may be lost or received out-of-order

Application viewpoint:

- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server

Client/server socket interaction: UDP

server (running on serverIP)

create socket, port= x:
serverSocket =
socket(AF_INET,SOCK_DGRAM)

read datagram from
serverSocket

write reply to
serverSocket
specifying
client address,
port number

client

create socket:
clientSocket =
socket(AF_INET,SOCK_DGRAM)

Create datagram with server IP and
port=x; send datagram via
clientSocket

read datagram from
clientSocket

close
clientSocket

Example app: UDP client

Python UDPClient

include Python's socket library

```
from socket import *
serverName = 'hostname'
serverPort = 12000
```

create UDP socket for server

```
clientSocket = socket(socket.AF_INET,
                      socket.SOCK_DGRAM)
```

get user keyboard input

```
message = raw_input('Input lowercase sentence:')
```

Attach server name, port to message; send into socket

```
clientSocket.sendto(message,(serverName, serverPort))
```

read reply characters from socket into string

```
modifiedMessage, serverAddress =
                      clientSocket.recvfrom(2048)
```

print out received string and close socket

```
print modifiedMessage
clientSocket.close()
```

Example app: UDP server

Python UDPServer

	from socket import *
	serverPort = 12000
create UDP socket	serverSocket = socket(AF_INET, SOCK_DGRAM)
bind socket to local port number 12000	serverSocket.bind(('', serverPort))
	print "*The server is ready to receive*"
loop forever	while 1:
Read from UDP socket into message, getting client's address (client IP and port)	message, clientAddress = serverSocket.recvfrom(2048)
	modifiedMessage = message.upper()
send upper case string back to this client	serverSocket.sendto(modifiedMessage, clientAddress)

App-layer protocol defines

- types of messages exchanged,
  - e.g., request, response
- message syntax:
  - what fields in messages & how fields are delineated
- message semantics
  - meaning of information in fields
- rules for when and how processes send & respond to messages

open protocols:

- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

proprietary protocols:

- e.g., Skype

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	yes, few secs
interactive games	loss-tolerant	few kbps up	yes, 100's msec
text messaging	no loss	elastic	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
- *does not provide:* timing, minimum throughput guarantee, security
- *connection-oriented:* setup required between client and server processes

UDP service:

- *unreliable data transfer* between sending and receiving process
- *does not provide:* reliability, flow control, congestion control, timing, throughput guarantee, security, orconnection 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
- cleartext passwds sent into socket traverse Internet in cleartext

SSL

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

SSL is at app layer

- Apps use SSL libraries, which "talk" to TCP

SSL socket API

- cleartext passwds sent into socket traverse Internet encrypted
- See Chapter 7

Telnet

TCP based terminal

- Simplest app-layer protocol
- Full-duplex connection
- No encryption (largely replaced by SSH)
- Server listens on port 22 (default)

- Examples:
  - telnet telehack.com
  - telnet forgottenkingdoms.org 4000