eecs489 COMPUTER NETWORKS

Lecture 2: Network Protocols
and Sockets Programming (TCP Client)

What is the Internet?

Last lecture we said . . . on the Internet
- data is parceled into packets
- each packet carries a destination address
- each packet is routed independently
- packets can arrive out of order
- packets may not arrive at all

On top of this packet-switched network, the Internet provides two types of delivery service:
- connectionless (datagram, UDP, e.g., streaming media, games)
- connection oriented (byte stream, TCP, e.g., web, email)

What is the Internet?

Connection oriented service provides:
- end-to-end reliability (sender retransmits lost packets)
- in-sequence delivery (receiver buffers incoming packets until it can deliver them in order)

Some fundamental questions about packet-switched network:
- how does a router know which router to forward a packet to?
- how does a receiver know the correct ordering of packets?
- how does a sender know which packet is lost and must be retransmitted?

The answer to all of these rely on network protocols

Network Protocols

Network protocols – rules ("syntax" and "grammar") governing communication between nodes (sender, router, or receiver)
- example protocols?

> Protocols define the format, order of messages sent and received among network entities, and actions taken to transmit message, and on message received

Internet Protocol Stack

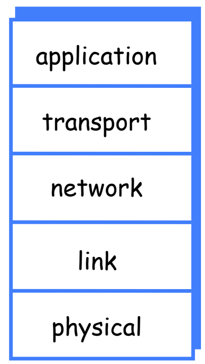
application protocol: support network applications
- HTTP, SMTP, FTP, etc.

transport protocol: endhost-to-endhost data transfer
- TCP, UDP

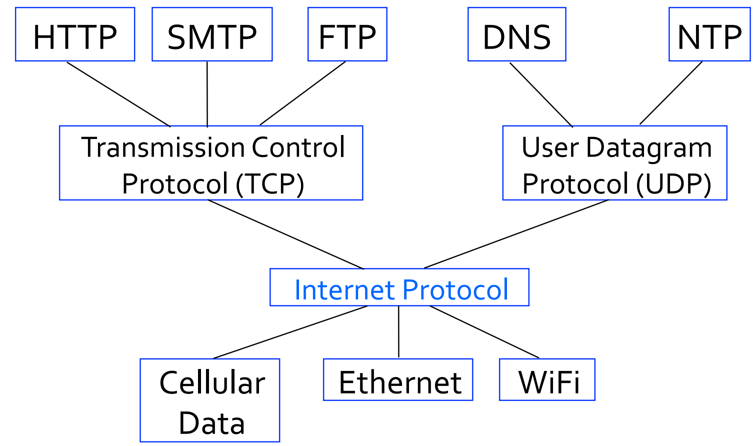
network protocol: routing of datagrams from source to destination
- IP, routing protocols

link layer protocol: data transfer between neighboring network elements
- Ethernet, WiFi

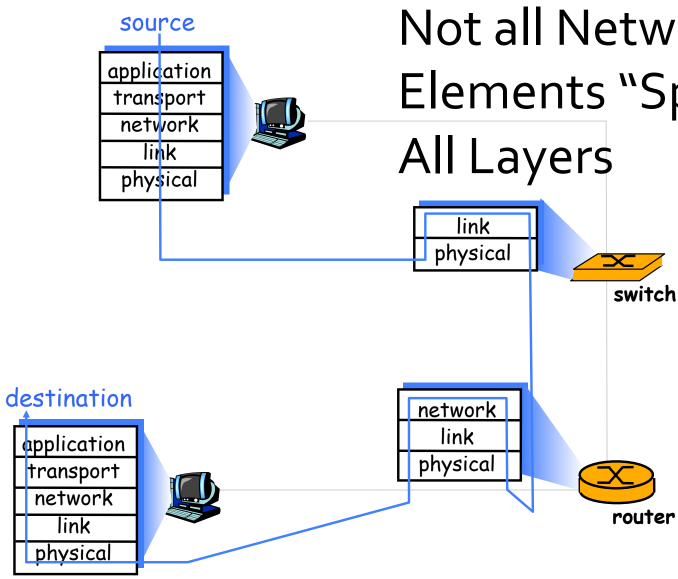
physical protocol: getting bits "on the wire"



Layering in the IP Protocols



Not all Network Elements "Speak" All Layers



Why Layering?

Networks are complex! Many "pieces":
- applications
- hosts
- routers
- links of various media

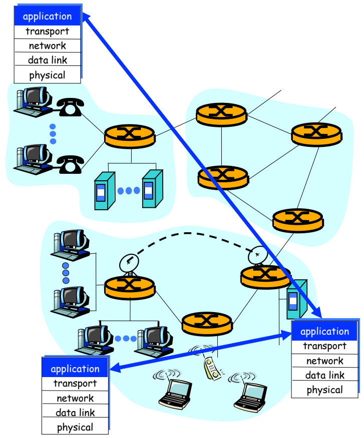
One way to deal with complex systems:
- explicit structure separates out the pieces
- modularization makes system easier to maintain and update
  - changing the implementation of a layer is transparent to the rest
  - change of implementation ≠ change of service definition!

Creating a Network Application

Example benefits of layering:

- programmers can write apps that
  - run on different end systems and
  - communicate over a network
  - e.g., browser communicates with web server
- no software written for devices in network core
  - network core devices do no function at app layer

This design allows for rapid app development

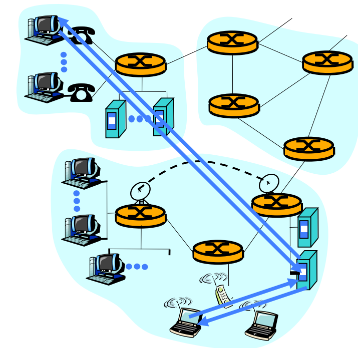


Client-Server Computing

Server:

- a process that manages access to a resource
  - process or machine?
- usually has a well-known, permanent IP address
- waits for connection
- can use server farm/cluster or cloud computing for scaling
  - how do server farms maintain a single IP address externally?

Email (SMTP) uses the client-server paradigm



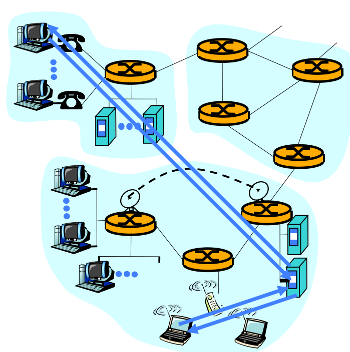
Client-Server Computing

Client:

- a process that needs access to a resource
- initiates connection with server
- may be intermittently connected
- may have dynamic IP addresses
- clients do not communicate directly with each other

Alternative(s) to client-server?

Email (SMTP) uses the client-server paradigm

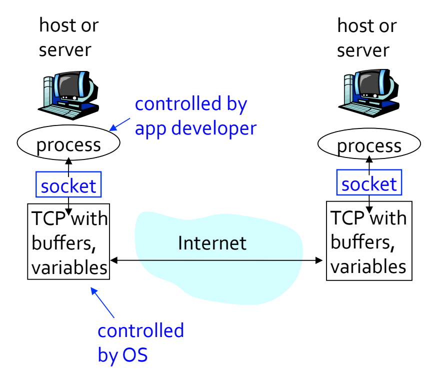


Sockets

Process sends/receives messages to/from its socket

Socket analogous to door

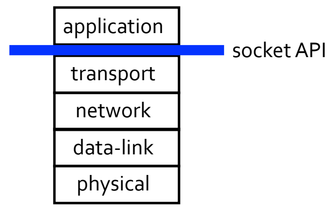
- sending process shoves messages out the door
- sending process relies on transport infrastructure on the other side of the door to deliver message to the socket at the receiver process



Sockets API

An Application Programmer Interface (API) to access the network

- set of function prototypes, data structures, and constants
- allows programmer to learn once, write anywhere
- greatly simplifies the job of application programmers



Addressing Socket

A server host may support many simultaneous application processes, each with one or more sockets

- web servers, for example, uses a different socket for each connecting client

When a packet arrives, how does the kernel know which socket to forward it to?

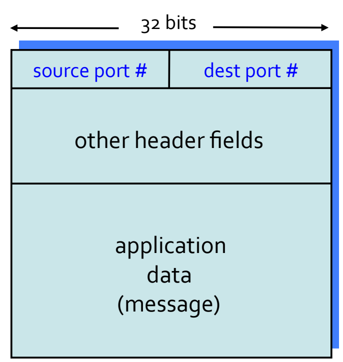
- by the host's unique 32-bit IP address?
- is the IP address sufficient to identify a socket?

How Demultiplexing Works

Host receives IP packets

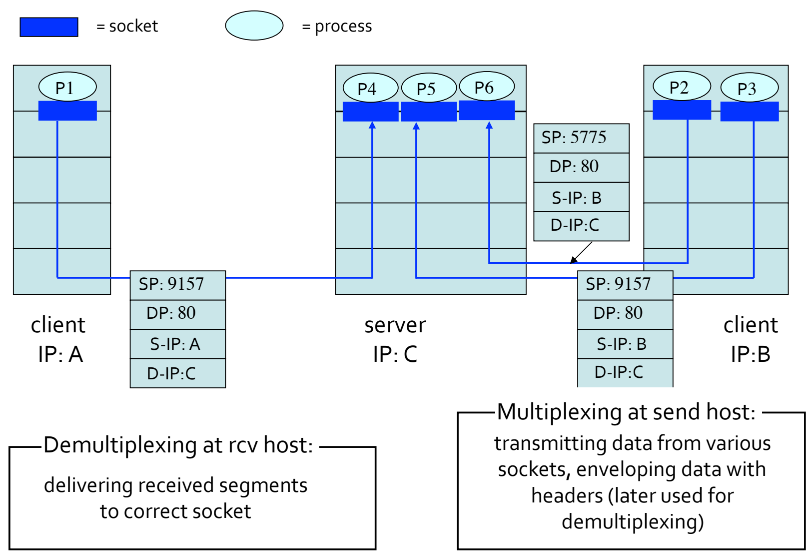
- each packet has source and destination IP addresses
- each packet carries 1 transport-layer segment
- each segment has source and destination port numbers

Host uses IP addresses & port numbers to direct segment to the appropriate socket



TCP/UDP segment format

Multiplexing/Demultiplexing



Connection-oriented Demux

Socket identifier includes both the IP addresses and port numbers associated with the socket on the host

Example port numbers:

- HTTP server: 80
- Mail server: 25
- See `/etc/services`

Receiver kernel uses all four values to direct packet to appropriate socket

Socket Addresses

Somewhere in the socket structure:

	IP address	Port#	
`bind()`			matched against incoming packet destination
`connect()`			copied to outgoing packet destination

TCP Server:

IP address	Port#
INADDR_ANY	well-known
client's address	ephemeral

TCP Client:

IP address	Port#
client's address	ephemeral
server's address	well-known

Sockets

What exactly are sockets?

- an endpoint of a connection
  - identified by the IP address and port number of both sender and receiver
- API similar to UNIX file I/O API (provides a file descriptor)

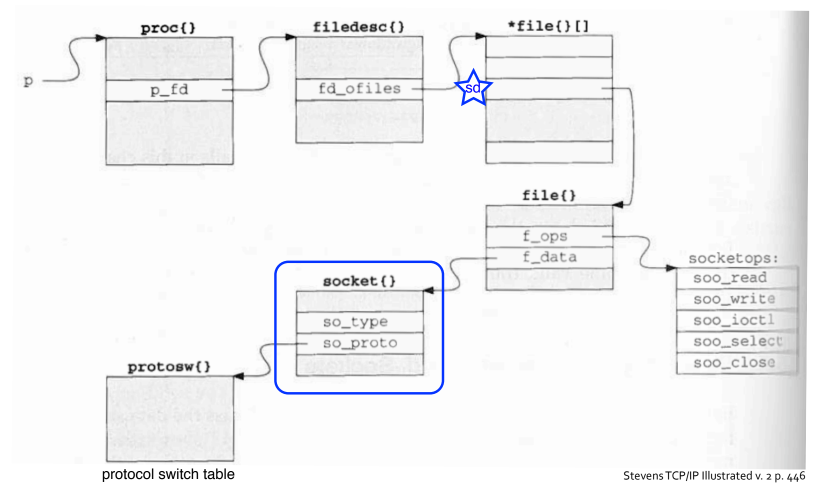
Berkeley sockets is the most popular network API

- runs on Linux, Mac OS X, Windows
- can build higher-level interfaces on top of sockets
  - e.g., Remote Procedure Call (RPC)

Based on C, single threaded model

- does not require multiple threads

Process File Table and Socket Descriptor



Stevens TCP/IP Illustrated v. 2 p. 446

Types of Sockets

Different types of sockets implement different service models
- data stream vs. datagram

Data stream socket (e.g., TCP)
- connection-oriented
  - reliable, in order delivery
  - at-most-once delivery, no duplicates
- used by e.g., smtp, http, ssh

Datagram socket (e.g., UDP)
- connectionless (just data-transfer)
  - "best-effort" delivery, possibly lower variance in delay
- used by e.g., IP telephony, streaming audio, streaming video, multi-player gaming, etc.

Data Stream vs. Datagram

Data stream treats data as one continuous stream, not chopped up into separate "chunks"

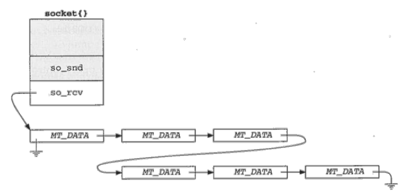


Figure 16.36 so_rcv buffer for TCP.

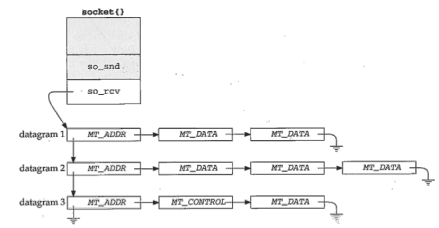


Figure 16.35 UDP receive buffer consisting of three datagrams.

Stevens

Simplified E-mail Delivery

You want to send email to `friend@cs.usc.edu`

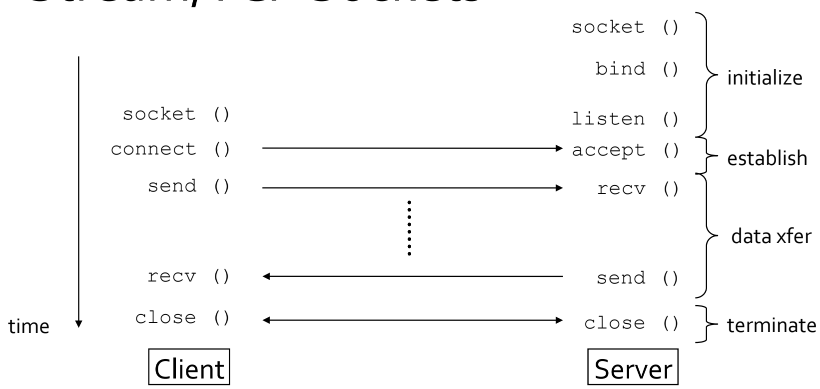
At your end, your mailer (client)
- translates `cs.usc.edu` to its IP address (`128.125.1.45`)
- decides to use TCP as the transport protocol (Why?)
- creates a socket
- `connect`s to `128.125.1.45` at the well-known SMTP port # (`25`)
- parcels out your email into packets
- `send`s the packets out

Simplified E-mail Delivery

On the Internet, your packets got:
- transmitted
- routed
- buffered
- forwarded, or
- dropped

At the receiver, `smtpd` (server)
- must make a "receiver" ahead of time:
- creates a socket
- decides on TCP
- `bind`s the socket to `smtp`'s well-known port #
- `listen`s on the socket
- `accept`s your `smtp` connection requests
- `recv`es your email packets

Stream/TCP Sockets



When a TCP server `accept`s a client, it returns a new socket to communicate with the client

- allows server to talk to multiple clients
- source address & port number used to distinguish clients

Initialize (TCP Client)

```
int sd;
if ((sd = socket(PF_INET, SOCK_STREAM,
  IPPROTO_TCP)) < 0) {
  perror("socket");
  printf("Failed to create socket\n");
  abort();
}
```

`socket()` creates a socket data structure and attaches it to the process's file descriptor table

Handling errors that occur rarely usually consumes most of systems code

Establish (TCP Client)

```
unsigned short server_port;
char *servername;          // both assume initialized
struct sockaddr_in sin;

struct hostent *host = gethostbyname(servername);

memset(&sin, 0, sizeof(sin));
sin.sin_family = AF_INET;
sin.sin_addr.s_addr = *(unsigned long *) host->h_addr_list[0];
sin.sin_port = htons(server_port);

if (connect(sd, (struct sockaddr *) &sin, sizeof (sin)) < 0) {
  perror("connect");
  printf("Cannot connect to server\n");
  abort();
}
```

`connect()` initiates connection (for TCP)

Sending Data Stream (TCP Client)

```
int
send_packets(char *buffer, int buffer_len)
{
  sent_bytes = send(sd, buffer, buffer_len, 0);

  if (send_bytes < 0)
      perror("send");

  return 0;
}
```

- returns how many bytes are actually sent
- must loop to make sure that all is sent (unless blocking I/O)

What is blocking and non-blocking I/O?

Why do you want to use non-blocking I/O?