CMPE 150: Introduction to Computer Networks

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Class Information

- Class web site:  
  www.soe.ucsc.edu/classes/cmpe150/Spring03/

- Class Newsgroup  
  ucsc.class.cmpe150

- TA Section  
  First session – Monday 5:00PM  
  Baskin *White Boards* area
(Optional) Class Project

- Network programming project
  - In lieu of taking final examination
- Goal:
  - Build an FTP client/server from scratch
  - Using ‘C’ language
- Details on web page.. now...
  - Due by June 4th...
Homework Assignments

Homework assignment #1
Problems from text at end of chapter
See web page for problem numbers

Due by April 8 (next Tuesday)
CMPE 150: Introduction to Computer Networks

LECTURE 2:

Introduction and Background (Cont.)
Principles of Computer Communication

- Protocol specification: The description of the protocol is complete and accurate.
- Safety: A protocol does what it is supposed to do, all the time.
- Liveness: A protocol does not leave any deadlocks.
- Efficiency: A protocol makes efficient use of available resources.
- Fairness: Fair or contractual use of resources
- Simplicity is desirable, but not necessary.
Internet Elements

Hosts: The computers running user applications (clients, servers, proxies).

Routers/bridges/switches: Devices used to interconnect hosts and to forward data from source to destination host.

Networks: Aggregations of hosts and routers.

Links between devices.
What Is The Internet

- **protocols**
- **Internet:** “network of networks”
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
Internet Example

What does it take to get a page from the web?

- Your client computer and attached router have to be configured.
- Host and router communicate with each other (typically through a LAN).
- Host obtains the IP address of remote server from a name resolver.
- Host starts an end-to-end reliable connection with remote server (TCP is the protocol used end to end).
- Data is broken into “packets,” which are routed from host to server and from server to back over a large number of links, computers dedicated to routing, and networks.
- Today, you typically wait for a long time; sometimes the server comes back and tells you that the page has not been found :-(

Layering Model

- Purpose is to divide and conquer complex software and hardware needed to implement services
- Partition services and functions needed in system into layers
- Each layer of service is provided by peer protocol entities
- Communication can be point-to-point or multipoint
The OSI Architecture

- Proposed by the International Standards Organization
- Specifies the functions at each layer, not the protocols that implement them

**APPLICATION**
- End-user services (e.g., mail, file transfer)
- Web access

**PRESENTATION**
- Formatting, encryption, compression of data

**SESSION**
- Setup and management of end-to-end dialogue

**TRANSPORT**
- End-to-end delivery of messages to processes
- TCP

**NETWORK**
- End-to-end transmissions (of packets) in net
- IP

**LINK**
- Transmissions (of packets) over a link
- PPP, CSMA/CD

**PHYSICAL**
- Transmission of bit over physical media
- SONET
Protocol Description

- Specify the service to be provided by the protocol
- Specify assumptions about environment
- Specify vocabulary (messages) needed in the protocol
- Specify the algorithms used to process and exchange information in the protocol
- Specify format of messages in vocabulary
Protocol Correctness

- A protocol must be safe and live
  - **Safety:**
    - Protocol provides the desired service all the time
  - **Liveness:**
    - Protocol has no deadlocks (no process waits forever for an event to occur)
- Proving one may depend on the other
Protocol Performance

- **Average delay**
  - Time between transmission of an information bit and reception of the bit at the receiver

- **Throughput or capacity**
  - Number of information bits sent divided by the time between transmission of first bit and delivery of the last bit

- Computations will make strong assumptions; in most cases, results of analytical model provide only a rough approximation

- Most effective for comparative analysis
Basic Network Services

Connection-oriented service:

- Reliable data transfer: In-order delivery, no duplicates or missing data.
- Flow control: Do not congest the receiver.
- Congestion control: Do not congest the network(s).
Basic Network Services

Connection-oriented service:

- **Reliable data transfer**: In-order delivery, no duplicates or missing data.
- **Flow control**: Do not congest the receiver(s).
- **Congestion control**: Do not congest the network(s).

Data may take different paths to destination

Shared network resources
Basic Network Services

Connectionless service:
- No delivery guarantees needed from the network.
- Any connection-oriented service to application is provided by end-to-end protocol.
Switching Methods

- Allocation of shared network resources to the transport of user data.
- Circuit switching and packet switching are the two main types we will consider.
Circuit Switching

Portion of physical resource is assigned to a single connection. Delay and signaling overhead in establishing and ending connections.
Multiplexing in Circuit Switching

- Share a given communication channel among multiple connections.
- Frequency division multiplexing (FDM):
  - Frequency spectrum of a link is partitioned into multiple bands, and each band is assigned to zero or one connection at any given time.
- Time division multiplexing (TDM):
  - Time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots. A connection is assigned to a time slot, and occupies the same time slot for multiple frames.
FDM and TDM

**FDM**
- Frequency
- Time

**Example:**
- 4 users

**TDM**
- Frequency
- Time

- 4 users
Message Switching

Message from sender is sent on a **store-and-forward** basis.
Message has a header used for forwarding.
Resources shared among different calls.
Statistical Multiplexing

- Share the same communication channel among multiple connections without fixed allocations of the resource to those connections.

**Limitation:**
Entire message must be received at a switch before it can be forwarded.
Packet Switching

Message from sender is broken into packets.
Each packet consists of a header and a payload.
Header information is used to forward packet to destination.
A packet switch stores each packet it receives and determines how to forward it based on the header information in the packet.
Packet Switching

Resources are shared among connections
Packets from the same connection can be processed concurrently
Connection setup delay can be avoided using datagrams
Packet Switching vs Message Switching

Processing message as packets in store-and-forward mode saves time!
Packet Switching

- Information is organized into packets
- A packet consists of a header and a payload
- Header specifies the control information needed to transport the packet from origin to destination
- Packets are forwarded from source to destination using routing tables
- There are two basic approaches to packet switching:
  - datagrams
  - virtual circuits
Routing table specifies next hop to each destination

- Packets are forwarded based on the routing table

- **Each packet is routed independently**
Virtual circuits are established and terminated much like circuits in circuit switching.

Statistical multiplexing using packets, rather than FDM or TDM is used to share links among connections.
Virtual Circuits

- Routing table specifies the next hop of an established VC.
- Packet header specifies VC to be used for the packet.
- **All packets of the same VC are routed the same way.**
Virtual Circuits

For VC5 in, use 4 and label as VC2
For VC3 in, use 5 and label as VC3
...

- Relative or global VC names can be used.
- Relative VC names require “label swapping.”
Packet Switching versus Circuit Switching

Packet switching allows more users to use network!

- 1 Mbit link
- Each user:
  - 250 kbps when “active”
  - active 10% of time
- Circuit-switching:
  - 4 users
- Packet switching:
  - With 10 users, the probability of having more than 4 active is 0.0016!
  - The average number of users active on the link is one.

Look at the probability of having up to 10 active users. Look at the arithmetic average.
Packet Switching versus Circuit Switching

- Works great on the average!
- However, more than 10 users may be active at the same time.
- In that case, packets are queued at the switch, and congestion occurs.
- Queuing delays are important.

![Diagram](Image)
By Contrast: FDM and TDM

Example:

2 active users

FDM

TDM
Packet Switching versus Circuit Switching

Is packet switching a “slam dunk winner?”

- Great for bursty data
  - Resource sharing
  - Simpler, no call setup (with datagrams!)
- Excessive congestion: packet delay and loss
  - Protocols needed for reliable data transfer, congestion control, etc.
- Q: How to provide circuit-like behavior?
  - Bandwidth guarantees needed for audio/video applications.
  - Answer: Still an unsolved problem (see Chapter 6).
Transmission Media

- We consider the physical layer as a “black box”
- We are interested in the characteristics and services provided by the transmission media that impact the link layer and higher layers.

Parameters:
- Bandwidth
- Delay or latency: average and variance (aka jitter)
- Storage capacity (bandwidth-delay product)
- Reliability and security
- Order of delivery
- Type of sharing or access
Bandwidth

- We can communicate information over transmission media using energy, by varying some physical property (e.g., voltage or current).

- **Problem:** What the sender transmits is not exactly what the receiver obtains from the communication link.

- **Reasons:** Link incurs some energy loss and delays, and there are other interfering sources.
Bandwidth

- We think of the bandwidth of a network or link as the number of information bits that can be transmitted over it in a certain period of time (e.g., bits per second).
- The bandwidth of a link is really the frequency range tolerated by the channel without major attenuation.
  
  Telephone line is 3000 Hz (300Hz to 3300 Hz)
- Available bandwidth depends on the rate at which channel can change stored energy.
- We can model waveforms as sums of sine waves of different frequencies.
- Channel attenuates and delays each frequency component differently, causing distortion.
Bandwidth

- Signals are run through a low-pass filter, and a signal can have $V$ discrete levels.
- Maximum data rate of a **noiseless channel** of bandwidth $B$ when $V$ discrete levels are used is

  \[
  \text{Data Rate} = 2B \log_2 V \text{ bps} \quad \text{(Nyquist, 1924)}.
  \]

  Keep increasing $V$ to achieve higher data rates with same $B$?

- Regardless of $V$, the maximum data rate (capacity) of a **noisy channel** with bandwidth $B$ and signal-to-noise ratio $S/N$ is

  \[
  C = B \log_2 (1+S/N) \text{ bps} \quad \text{(Shannon, 1948)}
  \]

  $S$ is the average signal power and $N$ is the average noise power.

- Example: For a telephone line,

  $B$ is 3000 Hz, with a typical $S/N$ ratio of 1000, so $C$ is $30Kbps$ or so

  **We can achieve higher capacity only by increasing $S/N$!**
Sources of Packet Delay

What contributes to the delay from the time the first information bit is sent by the source (t1) to the time when the last information bit is obtained by the receiver?
Sources of Packet Delay

transmission time of packet over each link
	nodal processing delay

propagation delay of each link
	nodal processing delay

queueing delay
Sources of Packet Delay

- **Nodal processing:**
  - Checking for bit errors.
  - Determining output link.

- **Queueing delay:**
  - Time waiting at output link for transmission.
  - Depends on congestion level of router.

- **Transmission delay:**
  - Time to send bits into link: \( L/R \), where
    \( R = \) link bandwidth (bps) and \( L = \) packet length (bits)

- **Propagation delay:**
  - Time for each bit to traverse a link: \( d/s \), where
    \( d = \) length of physical link and
    \( s = \) propagation speed in medium (\( \sim 2 \times 10^8 \) m/sec)
Packet Delay

- Packet delay is the time elapsed between the instant when the sender transmits the first bit of a packet and the receiver obtains the last bit of the packet.
- \( \text{Packet delay} = \text{Processing delay} + \text{Propagation delay} + \text{Transmission delay} + \text{Queuing delay} \)
- \( \text{Propagation delay} = \frac{\text{Distance}}{\text{Speed of light}} \)
  \( \text{Speed of light} = 3 \times 10^8 \text{ meters/sec in the vacuum} \)
  \( \sim 2 \times 10^8 \text{ meters/sec in fiber} \)
- We can reduce processing, transmit, and queue components using higher link speeds and faster processors, but we cannot increase the speed of light!

**Long distances mean long latency!**
Total Nodal Delay

\[ d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}} \]

- \( d_{\text{proc}} \) = local processing delay
  - typically a few microsecs or less
- \( d_{\text{queue}} \) = local queuing delay
  - depends on congestion
- \( d_{\text{trans}} \) = link transmission delay
  - \( = \frac{L}{R} \), significant for low-speed links
- \( d_{\text{prop}} \) = link propagation delay
  - a few microsecs to hundreds of msecs
Queueing delay (revisited)

- $R =$ link bandwidth (bps)
- $L =$ packet length (bits)
- $a =$ average packet arrival rate

**traffic intensity $= \frac{a}{R}$**

- $\frac{a}{R} \sim 0$: average queueing delay small
- $\frac{a}{R} \rightarrow 1$: delays become large
- $\frac{a}{R} > 1$: more “work” arriving than can be serviced, average delay infinite!
Internet Delays and Routes

- What do “real” Internet delay and loss look like?
- **Traceroute program**: provides delay measurement from source to router along end-end Internet path towards destination.

For all \( i \):

- sends three packets that will reach router \( i \) on path towards destination
- router \( i \) will return packets to sender
- sender times interval between transmission and reply.
Internet Delays and Routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms  5 ms  5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17  ***
18  ***  * means no response (probe lost, router not replying)
19  fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link
Packet Loss

- Queue (i.e., the buffer) of each outgoing link has finite capacity.
- When packet arrives to a full queue, packet is dropped (lost).
- Lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all.
Bandwidth-Delay Product

- The amount of data “stored” in the link.
- Think of a link as a pipe; the latency is the length of the pipe and the bandwidth is its diameter.
- The BD product gives the volume of the pipe.
- Example: A channel of 50 ms latency and just 45 Mbps bandwidth can hold 2.25 million bits (the same as the memory of a PC of early 80s!).
- We are moving to Gigabit networks...
- Big bandwidth and big distances require:
  - Big aggregation and big memories at hosts
  - New reliable transmission algorithms
  - Migration from client-server to client-content models.
Bandwidth-Delay Product

- Links stretching long distances have large storage capacity.
- **Problem**: How do we provide feedback to senders? TCP was originally designed for such applications as telnet and ftp over paths with small BDP.
Other Parameters

- **Reliability:** We will assume that information is transmitted correctly across a link or network with a given likelihood.

- **Security:** We will likely not cover this aspect in much detail :(.

- **Order of delivery:** We will assume FIFO and non-FIFO delivery of packets or messages, depending on the protocol and transmission media.

- **Access:** We will consider point-to-point and broadcast links.
Internet Structure: Network of Networks

- Roughly hierarchical
- At its center: “tier-1” ISPs
  (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - Treat each other as equals

Tier-1 providers also interconnect at public network access points (NAPs)

Tier-1 providers interconnect (peer) privately
Tier-1 ISP Example: Sprint US Backbone Network
“Tier-2” ISPs: Smaller (often regional) ISPs

- Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is customer of tier-1 provider

Tier-2 ISPs also peer privately with each other, interconnect at NAP
Internet Structure

- “Tier-3” ISPs and local ISPs
  - last hop (“access”) network (closest to end systems)

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet.
Internet Structure

- Each packet passes through many networks!
- Limiting factor: Speed of light!
Internet Structure

- Why we need user-to-content rather than client-server approach.

Content comes from nearest outlet to client. Content needs to be routed to nearest outlets.