Announcements

Assignment 2 Due Now
Lab 2 Due Now
Exam Notes

Thursday, May 1st, 2014
12:00 – 1:20 pm (80 minutes)
One-sided note-sheet, 8.5x11”
Calculators OK (no cell phones)
Vocabulary, Multiple-choice Conceptual, and Math (work-out)
Difficulty between self-check and homework
One work-out problem is will be more difficult
Chapter 1

Network
- System for connecting computers using single transmission technology

Internet
- Network of networks
- Each using their own transmission technology
Chapter 1 - Continued

Network edge
- Hosts / End Systems
- Applications

Network core
- Routers, Switches

Access networks
- Physical media
- Communication Links
What is a protocol
- Define Format/Order of messages sent/received among network entities
- Define actions taken on message Tx, Rx

Circuit Switching
- Time Division Multiplexing
- Frequency Division Multiplexing

Packet Switching
- Statistical Multiplexing
- Probability that too many users on network?
Chapter 1 – ISP Tiers

- **Tier 1**
  - Own the network (Don’t buy access from anyone)
  - Interconnect with other ISPs privately and at IXPs

- **Tier 2**
  - Customer of Tier 1 ISPs
  - May peer privately with each other or with Tier 1 networks
  - May interconnect at IXP with other Tier 2 or lower ISPs
  - Some Tier 2 ISPs have their own (provider) networks on top of this, like Google

- **Tier 3 & local ISPs**
  - Last hop to end systems
  - Strictly customers of higher-tier ISPs
Chapter 1 – Five Layer Model

- **Layer 1 – Physical**
  - Bits on the wire

- **Layer 2 – Data Link (Ethernet)**
  - Data transfer between neighboring network elements, defines access schemes to physical

- **Layer 3 – Network (IP)**
  - Routing of datagrams source to destination (IP)

- **Layer 4 – Transport (TCP, UDP) (Ch. 3)**
  - Process-process data transfer (reliability? flow control? congestion control?)

- **Layer 5 – Application (FTP, HTTP, SMTP)**
  - Supports network applications
Chapter 1-Packet-switched Network Delays

R: link bandwidth (bps)
L: packet length (bits)
d: length of physical link (meters)
s: propagation speed of medium (meters/second)

Transmission Delay: $d_{\text{trans}} = \frac{L}{R}$
Propagation Delay: $d_{\text{prop}} = \frac{d}{s}$

Transmission Delay vs. Propagation Delay

Nodal delay: $d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$
Chapter 1-Packet-switched Network Delays

Queueing Delay

Packet Arrival Rate: \( a \) (packets per second)

Bit arrival rate \( a \times L \) (bits per second)

Traffic Intensity: \( a \times L / R \) (dimensionless)

- Approaching 1?
- Greater than 1?

Average Queueing Delay? Scenario-based

\[ d_{\text{queue},n} = d_{\text{queue},n-1} + d_{\text{trans},n-1} \]

End-to-end Delay?
Chapter 1-Packet-switched Network Delays

Suppose: Host A has huge file of size F bits to send to Host B
File is split into N packets, each of length L bits (i.e., N=F/L)
Do NOT ignore propagation delay (assume prop. speed = s m/s)

**Question 1:** How long it takes to send the file?

**A:** \((N+2)L/R + d/s = (F+2L)/R + d/s\)

**Question 2:** What is the average throughput achieved when sending the file?

**A:** \(NL/[(N+2)L/R +d/s]=FR/[(N+2)L + dR/s] = FR/[F+2L+dR/s]\)
Chapter 1 – Packet-Switched Transmission Delay

- Packet-switched network
- Two hosts transmitting over the same 10 Mbps link.
  - Host A: 1,560,000 byte file
  - Host B: 15,600 byte file
- Packet size 1600 bytes (including 20-byte IP header, 20-byte TCP header)
- Assume transmitter is never throttled.
- Host B gets first access to the medium.

Question 1) When does Host A finish transmitting?
Question 2) When does Host B finish transmitting?
Chapter 3 – The Transport Layer

Services & Protocols

• **Sender side**
  • Break application messages into segments
  • Attach header implementing services
  • Pass segments to network layer

• **Receive side**
  • Reassemble segments into messages
  • Implement Services
  • Pass to application layer
Chapter 3 – Reliable Data Transfer

Acknowledgements to deal with bit-flipped segments
- Cumulative
- Selective

Retransmission to handle dropped packets
- Go-Back-N
- Selective Repeat

Sequence Numbers to keep retransmitted packets in order
- How many required for certain window size?
- \( W \leq n/2 \)
Chapter 3 – More Concepts

Pipelining
- Used to increase Utilization
  - Base Utilization (no pipelining) \( U = \frac{L}{R} \div \left( \frac{L}{R} + RTT \right) \)
  - Pipelined Utilization?

Congestion Control
- End-to-End congestion control
  - Sender intuits congestion from ‘signs’ of congestion
- Network-Assisted Congestion Control
  - Network tells sender (directly or indirectly) of congestion issues
Chapter 3 – More Concepts

Flow Control
- Advertise the remaining space in the receive buffer

Message Boundary Preservation
- [ABC] [DEF] -> [AB] [CD] [EF] ??

Terminology – Table 3.1 Page 230
Chapter 3 – Workhorse Protocol: TCP

Connection Control
- Connection Setup
  - Sender SYN
  - Receiver SYN, ACK
  - Sender ACK
- Maximum Segment Size (MSS)
  - Find sender MTU (Max Transmission Unit)
  - Set MSS (Max Segment Size) so TCP segment plus TCP/IP header fit into MTU
  - MSS is actually an amount of application data
- Connection Takedown
  - Sender FIN -> Receiver ACK
  - Receiver Closed
  - Receiver FIN -> Sender ACK
Chapter 3 – TCP Continued

Reliable Data Transfer

- Cumulative ACK (ACK # is next expected byte #)
- Check TCP ACK generation Table 3.2 Page 247
- Sequence number is byte-stream number of first data byte in segment

- Timeout: Retransmit
- 3x Duplicate Acknowledgement: Fast Retransmit

\[
\begin{align*}
\text{DevRTT}_{\text{new}} &= (1-\beta) \cdot \text{DevRTT}_{\text{recent}} + \beta \cdot |\text{SampleRTT}_{\text{recent}} + \text{EstimatedRTT}_{\text{recent}}| \\
\text{EstimatedRTT}_{\text{next}} &= (1-\alpha) \cdot \text{EstimatedRTT}_{\text{recent}} + \alpha \cdot \text{SampleRTT}_{\text{recent}} \\
\text{TimeoutInterval}_{\text{next}} &= \text{EstimatedRTT}_{\text{next}} + 4 \cdot \text{DevRTT}_{\text{new}}
\end{align*}
\]
Chapter 3 – TCP Continued

Congestion Control

- Sender limits rate as a function of perceived network congestion
- Congestion Window
  - Pipeline Restriction
  - Combined with Receive Window... use the lesser of the two
- Slow-Start
- Threshold
- Congestion Avoidance (AIMD) after reaching Threshold

- Drop rate and threshold after hitting congestion
- TCP Tahoe (full restart on timeout or 3x duplicate acks)
- TCP Reno (Fast Recovery from 3x duplicate acks)
- FSM Figure 3.52 Page 275
Chapter 3 – TCP Continued

Flow Control
- Pipeline Restriction
- Combined with Congestion Control – Use lesser of the two
- Receive Window
- \( \text{rwnd} = \text{RcvBuffer} - \left[ \text{LastByteRcvd} - \text{LastByteRead} \right] \)

Fairness
- Partly Achieved through Congestion Control
- Doesn’t work for parallel TCP connections, or with UDP

Message boundaries not preserved
Chapter 3 – Workhorse Protocol: UDP

- No Connection Setup
- Unreliable Data Transfer
- No Congestion Control
- No Flow Control
- No Fairness
- Preserves message boundaries

Why is it around?
- Faster!
- Less Overhead!