Lecture 7

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Mantey

P.E.
CMPE 150 -- Introduction to Computer Networks

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- Text: Tannenbaum: Computer Networks
  (4th edition – available in bookstore, etc.)
# Syllabus

<table>
<thead>
<tr>
<th>Lecture</th>
<th>Date</th>
<th>Topic</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6-Jan</td>
<td>Intro / Overview</td>
<td>Chapter 1</td>
</tr>
<tr>
<td>2</td>
<td>8-Jan</td>
<td>Internet Architecture</td>
<td>Chapter 1, 2</td>
</tr>
<tr>
<td>3</td>
<td>13-Jan</td>
<td>Physical Layer</td>
<td>Chapter 2</td>
</tr>
<tr>
<td>4</td>
<td>15-Jan</td>
<td>Physical Layer</td>
<td>Chapter 2</td>
</tr>
<tr>
<td>5</td>
<td>20-Jan</td>
<td>Link Layer</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>6</td>
<td>22-Jan</td>
<td>Link Layer / MAC</td>
<td>Chapter 3, 4</td>
</tr>
<tr>
<td>7</td>
<td>27-Jan</td>
<td>MAC Sublayer</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>8</td>
<td>29-Jan</td>
<td>Wireless</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>9</td>
<td>3-Feb</td>
<td>Network Layer</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>10</td>
<td>5-Feb</td>
<td>Midterm Exam 1</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>11</td>
<td>10-Feb</td>
<td>IP</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>12</td>
<td>12-Feb</td>
<td>IP</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>13</td>
<td>17-Feb</td>
<td>IP Routing</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>14</td>
<td>19-Feb</td>
<td>IP QOS, Congestion</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>15</td>
<td>24-Feb</td>
<td>Transport Layer</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>16</td>
<td>26-Feb</td>
<td>Midterm Exam 2</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>17</td>
<td>3-Mar</td>
<td>Transport Layer / QOS</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>18</td>
<td>6-Mar</td>
<td>Multimedia</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>19</td>
<td>10-Mar</td>
<td>Applications / Summary</td>
<td>Chapter 7</td>
</tr>
<tr>
<td>20</td>
<td>13-Mar</td>
<td>Buffer / Review</td>
<td>Chapter 7</td>
</tr>
<tr>
<td><strong>Final Exam</strong></td>
<td>18-Mar</td>
<td>12-3 PM</td>
<td></td>
</tr>
</tbody>
</table>
Today’s Agenda

- Flow Control Protocols (continued)
- Link Layer
  - Point-to-point Protocols
  - Standards (Data Link: HDLC, PPP)
- MAC Sub-layer
  - Link Sharing
  - Aloha
  - Ethernet
Sliding Window Protocols

- Supports bi-directional data transfer
- Full-duplex
- “piggy backing” of acks
Sliding Window Protocols

- A One-Bit Sliding Window Protocol
- A Protocol Using Go Back N
- A Protocol Using Selective Repeat
A Protocol Using Go Back N

- **Pipelining** and error recovery. Effect on an error when

- (a) Receiver’s window size is 1.

Tannenbaum Figure 3-16
Simulation of multiple timers in software.

Tannenbaum Figure 3-18
A Sliding Window Protocol Using Selective Repeat

<table>
<thead>
<tr>
<th>Sender</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image1.png" alt="Image" /></td>
<td><img src="Image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- **(a)** Initial situation with a window size seven.
- **(b)** After seven frames sent and received, but not acknowledged.
- **(c)** Initial situation with a window size of four.
- **(d)** After four frames sent and received, but not acknowledged.

Tannenbaum Figure 3-20
Protocol Verification

- Finite State Machine Models
- Petri Net Models
Finite State Machine Models

(a) State diagram for protocol 3.
(b) Transmissions.
Petri Net Models

- A Petri net with two places and two transitions.
A Petri net model for protocol 3.
Transparency

??
Transparency

Dictionary

Transparency: the quality or state of being transparent

Transparent: Function: adjective

Etymology: Middle English, from Medieval Latin transparent-, transparens, present participle of transparEre to show through, from Latin trans- + parEre to show oneself

1a (1): having the property of transmitting light without appreciable scattering so that bodies lying beyond are seen clearly.

http://www.m-w.com/cgi-bin/dictionary?va=transparency
Packet Switching

<table>
<thead>
<tr>
<th>Item</th>
<th>Circuit-switched</th>
<th>Packet-switched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call setup</td>
<td>Required</td>
<td>Not needed</td>
</tr>
<tr>
<td>Dedicated physical path</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Each packet follows the same route</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Packets arrive in order</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Is a switch crash fatal</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bandwidth available</td>
<td>Fixed</td>
<td>Dynamic</td>
</tr>
<tr>
<td>When can congestion occur</td>
<td>At setup time</td>
<td>On every packet</td>
</tr>
<tr>
<td>Potentially wasted bandwidth</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Store-and-forward transmission</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Transparency</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Charging</td>
<td>Per minute</td>
<td>Per packet</td>
</tr>
</tbody>
</table>

A comparison of circuit switched and packet-switched networks. Tannenbaum Figure 2-40
“Another difference is that circuit switching is completely transparent. The sender and receiver can use any bit rate, format or framing method they want. The carrier does not know or care....” ... “It is this transparency that allows voice, data, and fax to coexist within the phone system.”
ARQ Protocols

- **Automatic Repeat ReQuest.**
  - Protocols that wait for ACK before sending more data.

- ACKs now are used for flow AND error control.

- What can happen?
  - At receiver: frame arrives correctly, frame arrives damaged, frame does not arrive.
  - At sender: ACK arrives correctly, ACK arrives damaged, ACK does not arrive.
ARQ Protocols

Sender:
- Send frame 0.
- Start timer.
- If ACK 0, arrives, send frame 1.
- If timeout, re-send frame 0.

Receiver:
- **Waits for frame.
- If frame arrives, check if correct sequence number.
- Then send ACK for that frame.
- Go to (**)
Sliding Window Protocol
Using Go Back N

Simulation of multiple timers in software.

Tannenbaum Figure 3-18
Animations / Simulation

http://netbook.cs.purdue.edu/othrpags/page15.htm

http://www.humboldt.edu/%7Eaeb3/telecom/SlidingWindow.html

http://media.pearsoncmg.com/aw/aw_kurose_network_2/applets/go-back-n/go-back-n.html
Data Link Protocols

- HDLC – High-Level Data Link Control
- The Data Link Layer in the Internet
High-Level Data Link Control

Derived from SDLC of IBM
(Synchronous Data Link Control Protocol)

Frame format for bit-oriented protocols.
High-Level Data Link Control (2)

Control field of
(a) An information frame.
(b) A supervisory frame.
(c) An unnumbered frame.

<table>
<thead>
<tr>
<th>Bits</th>
<th>1</th>
<th>3</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>0</td>
<td>Seq</td>
<td>P/F</td>
<td>Next</td>
</tr>
<tr>
<td>(b)</td>
<td>1</td>
<td>0</td>
<td>Type</td>
<td>P/F</td>
</tr>
<tr>
<td>(c)</td>
<td>1</td>
<td>1</td>
<td>Type</td>
<td>P/F</td>
</tr>
</tbody>
</table>
DLL Protocols

- **SLIP: Serial Line IP**
  - Dial-up protocol.
  - No error control.
  - Not standardized.

- **PPP: Point-to-Point Protocol**
  - Internet standard for dial-up connections.
  - Provides framing similar to HDLC.
The Data Link Layer in the Internet

A home personal computer acting as an internet host.
The PPP full frame format for unnumbered mode operation.
PPP – Point to Point Protocol (2)

A simplified phase diagram for bringing a line up and down.
PPP – Point to Point Protocol (3)

<table>
<thead>
<tr>
<th>Name</th>
<th>Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configure-request</td>
<td>I → R</td>
<td>List of proposed options and values</td>
</tr>
<tr>
<td>Configure-ack</td>
<td>I ← R</td>
<td>All options are accepted</td>
</tr>
<tr>
<td>Configure-nak</td>
<td>I ← R</td>
<td>Some options are not accepted</td>
</tr>
<tr>
<td>Configure-reject</td>
<td>I ← R</td>
<td>Some options are not negotiable</td>
</tr>
<tr>
<td>Terminate-request</td>
<td>I → R</td>
<td>Request to shut the line down</td>
</tr>
<tr>
<td>Terminate-ack</td>
<td>I ← R</td>
<td>OK, line shut down</td>
</tr>
<tr>
<td>Code-reject</td>
<td>I ← R</td>
<td>Unknown request received</td>
</tr>
<tr>
<td>Protocol-reject</td>
<td>I ← R</td>
<td>Unknown protocol requested</td>
</tr>
<tr>
<td>Echo-request</td>
<td>I → R</td>
<td>Please send this frame back</td>
</tr>
<tr>
<td>Echo-reply</td>
<td>I ← R</td>
<td>Here is the frame back</td>
</tr>
<tr>
<td>Discard-request</td>
<td>I → R</td>
<td>Just discard this frame (for testing)</td>
</tr>
</tbody>
</table>

The LCP frame types.
Other DLL Protocols

LLC: Logical Link Control.

- Part of the 802 protocol family for LANs.
- Link control functions divided between the MAC layer and the LLC layer.
- LLC layer operates on top of MAC layer.

| MAC control | Dst. MAC addr | Src. MAC addr | Dst. LLC addr | Src. LLC addr | LLC ctrl. | Data | FCS |
Medium Access Control Sublayer
Chapter 4

• Shared Media
  – Broadcast Network
  – Multiaccess Channel
  – Random Access Channel

• Local Area Networks (LANS)
Link Sharing

• Issues:
  – Traffic separation (from different users)
  – Link utilization

• Examples:
  – Ethernet
  – 802.11
Multiplexing

- Sharing a link/channel among multiple source-destination pairs.
- Example: high-capacity long-distance trunks (fiber, microwave links) carry multiple connections at the same time.

![Multiplexing Diagram]
Multiplexing Techniques

• 3 basic types:
  – Frequency-Division Multiplexing (FDM).
  – Time-Division Multiplexing (TDM).
  – Statistical Time-Division Multiplexing (STDM).
FDM

- High bandwidth medium when compared to signals to be transmitted.
- Widely used (e.g., TV, radio).
- Various signals carried simultaneously where each one modulated onto different carrier frequency, or channel.
- Channels separated by guard bands (unused) to prevent interference.
FDM
TDM

- TDM or synchronous TDM.
- High data rate medium when compared to signals to be transmitted.
TDM

- Time divided into time slots.
- Frame consists of cycle of time slots.
- In each frame, 1 or more slots assigned to a data source.

![Diagram of TDM]
TDM

- No control info at this level.
- Flow and error control?
  - To be provided on a per-channel basis.
  - Use DLL protocol such as HDLC.
- Examples: SONET (Synchronous Optical Network) for optical fiber.
- +’s: simple, fair.
- -’s: inefficient.
Statistical TDM

• Or asynchronous TDM.
• Dynamically allocates time slots on demand.
• $N$ input lines in statistical multiplexer, but only $k$ slots on TDM frame, where $k < n$.
• Multiplexer scans input lines collecting data until frame is filled.
• Demultiplexer receives frame and distributes data accordingly.
STDM

• Data rate on mux’ed line < sum of data rates from all input lines.
• Can support more devices than TDM using same link.
• Problem: peak periods.
  – Solution: multiplexers have some buffering capacity to hold excess data.
  – Tradeoff data rate and buffer size (response time).
Channel Allocation

- Network traffic is “bursty”
- Static Allocation wastes bandwidth
  - FDM or TDM
- Dynamic Allocation used in LANs (and MANs)
Dynamic Channel Allocation in LANs and MANs

1. Station Model.

2. Single Channel Assumption.

3. Collision Assumption.

4. (a) Continuous Time.
   (b) Slotted Time.

5. (a) Carrier Sense.
   (b) No Carrier Sense.
Multiple Access Protocols

- ALOHA
- Carrier Sense Multiple Access Protocols
- Collision-Free Protocols
- Limited-Contention Protocols
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols
In pure ALOHA, frames are transmitted at completely arbitrary times.
Vulnerable period for the shaded frame.
Slotted ALOHA

- Time divided into discrete intervals
  - Each corresponds to one frame
- Sender must wait for beginning of next time slot before attempting to transmit
- Reduces vulnerability period by 50%
- Improves throughput by factor of 2 over Pure ALOHA
Throughput versus offered traffic for ALOHA systems.
Collision Sense Multiple Access Protocols (CSMA)

- Listen for carrier (“carrier sense protocols”)
- 1-persistent CSMA: listen, send if idle, else wait
  - Sends as soon as channel is free
  - If collision, waits random time, tries again
- Non-persistent CSMA
  - Less greedy
  - If busy, waits random period before sending
- P-persistent CSMA
  - If idle, transmit with probability “p”
  - If busy, waits random time to begin again
Persistent and Nonpersistent CSMA

Comparison of the channel utilization versus load for various random access protocols.
CSMA with Collision Detection

- If collision detected, immediately abort transmission
- CSMA/CD can be in one of three states: contention, transmission, or idle.
Time to Detect Collision

If line is of length $l$ (meters)
And propagation speed is $v$ (meters/second)
Then it takes $\tau = l/v$ (seconds) to get signals from one end to the other
And it takes – worst case -- $2\tau$ seconds to detect a collision
Collision-Free Protocols

The basic bit-map protocol.
Collision-Free Protocols (2)

The binary countdown protocol. A dash indicates silence.
Limited-Contestion Protocols

Acquisition probability for a symmetric contention channel.
Adaptive Tree Walk Protocol

The tree for eight stations.
Wavelength Division Multiple Access Protocols

Wavelength division multiple access.
Wireless LAN Protocols

A wireless LAN. (a) A transmitting. (b) B transmitting.
The MACA protocol. (a) A sending an RTS to B. (b) B responding with a CTS to A.
Ethernet

- Ethernet Cabling
- Manchester Encoding
- The Ethernet MAC Sublayer Protocol
- The Binary Exponential Backoff Algorithm
- Ethernet Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- IEEE 802.2: Logical Link Control
- Retrospective on Ethernet
# Ethernet Cabling

The most common kinds of Ethernet cabling.

<table>
<thead>
<tr>
<th>Name</th>
<th>Cable</th>
<th>Max. seg.</th>
<th>Nodes/seg.</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Base5</td>
<td>Thick coax</td>
<td>500 m</td>
<td>100</td>
<td>Original cable; now obsolete</td>
</tr>
<tr>
<td>10Base2</td>
<td>Thin coax</td>
<td>185 m</td>
<td>30</td>
<td>No hub needed</td>
</tr>
<tr>
<td>10Base-T</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>1024</td>
<td>Cheapest system</td>
</tr>
<tr>
<td>10Base-F</td>
<td>Fiber optics</td>
<td>2000 m</td>
<td>1024</td>
<td>Best between buildings</td>
</tr>
</tbody>
</table>
Three kinds of Ethernet cabling.
(a) 10Base5, (b) 10Base2, (c) 10Base-T.
Ethernet Cabling (3)

Cable topologies.  (a) Linear, (b) Spine, (c) Tree, (d) Segmented.
(a) Binary encoding, (b) Manchester encoding,  
(c) Differential Manchester encoding.
Frame formats. (a) DIX Ethernet, (b) IEEE 802.3.
Collision detection can take as long as $2\tau$. 
Efficiency of Ethernet at 10 Mbps with 512-bit slot times.
Switched Ethernet

A simple example of switched Ethernet.
## Fast Ethernet

The original fast Ethernet cabling.

<table>
<thead>
<tr>
<th>Name</th>
<th>Cable</th>
<th>Max. segment</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Base-T4</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>Uses category 3 UTP</td>
</tr>
<tr>
<td>100Base-TX</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>Full duplex at 100 Mbps</td>
</tr>
<tr>
<td>100Base-FX</td>
<td>Fiber optics</td>
<td>2000 m</td>
<td>Full duplex at 100 Mbps; long runs</td>
</tr>
</tbody>
</table>
Gigabit Ethernet

(a) A two-station Ethernet. (b) A multistation Ethernet.
Gigabit Ethernet (2)

<table>
<thead>
<tr>
<th>Name</th>
<th>Cable</th>
<th>Max. segment</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000Base-SX</td>
<td>Fiber optics</td>
<td>550 m</td>
<td>Multimode fiber (50, 62.5 microns)</td>
</tr>
<tr>
<td>1000Base-LX</td>
<td>Fiber optics</td>
<td>5000 m</td>
<td>Single (10 μ) or multimode (50, 62.5 μ)</td>
</tr>
<tr>
<td>1000Base-CX</td>
<td>2 Pairs of STP</td>
<td>25 m</td>
<td>Shielded twisted pair</td>
</tr>
<tr>
<td>1000Base-T</td>
<td>4 Pairs of UTP</td>
<td>100 m</td>
<td>Standard category 5 UTP</td>
</tr>
</tbody>
</table>

Gigabit Ethernet cabling.