Communication Protocols
and Internet Architectures
CSCI-SI
Harvard University

Lecture #1

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Lecture Agenda

• Course Goals and Objectives
• Review of Course Syllabus & Logistics
• Network Building Blocks
• Network Standards Issues
• Network Models, Services versus Protocols
• Data Link Layer Design Issues
• What is the Internet
• Real World Network Design Issues
• Three Minute Wrap-Up

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Course Goals

• This course will provide:
  * Tools and a framework for understanding the constantly changing communications environment
  * In-depth technical understanding of current network architectures and protocols
  * Understanding of the design trade-offs that have to be made when building large networks
  * Appreciation of the evolution of communication networks and services

• What this course is not about:
  * Programming specific network protocols
  * Installing specific communication products

What is Wrong with the Following Statements?

• “Don’t worry, we have an extremely reliable network since we are using nothing but fiber.”

• “I was at a seminar and they explained that VLANs and Layer 3 switches are replacing routers so we don’t need to worry about IPv6.”

• “No problem, we can use frame relay to connect our Win2003 servers in Toledo to our TCP/IP UNIX systems here and all the users will be able to share information.”

• “Doing a network design will take too long, we’ll just use the Internet.”

• “Easy, just use gigabit ethernet to provide QoS for the Internet video.”

• “Of course adding a Web interface solves the problem.”
Course Logistics

- Check the Summer School web site for registration dates and course fees.
- Textbook and Readings - The required textbook is available at the Harvard Coop and via the web. Links to other materials such as RFCs will be available on the web.
- Course work load – about 20 hours/week
- The syllabus contains the schedule and other information. Reading assignments will be distributed at each lecture.
- The schedule for optional section meetings will be set this week. Please check the course web site.

Course Logistics - part 2

- There will be an in-class, closed book midterm exam and final exam. (There is no final project.)
- There will be five or six homework assignments (including a possible design project.)
- The course web site contains course and schedule information, late-breaking news and a discussion group.
- This is not a distance ed course, there are no videos of the lectures.
- Grades will be based on your performance on homework, the midterm and the final exam.
Some Final Logistics

• The course web site will have copies of the lecture handouts a day or so before the lecture is given.
• Please print and bring copies of the handouts to lecture. We will not provide copies of the handouts at lecture.
• A small number of the slides that I use in lecture will not be included in the handout.
• The use of any particular vendor, product or service is not intended as an endorsement by Harvard or the Instructor.
• What is a three minute wrap-up and why is it so important?

What is a Network?
Typical Network Operations Center Picture
Source and copyright is Harvard UIS

Harvard Core Network, Fall 1999
Source and copyright is Harvard UIS
Evolution of Network Technology

Consider the evolution of each of the following network building blocks:

- Transmission
- Multiplexing
- Switching
- Signaling
- Network Management
- Network Applications
- Interfaces and Protocols
- etc.
Transmission Media in the Network:

- Magnetic -- disk, tape, etc. ("sneaker net")
- Electrical -- copper pairs, coax cable
- Radio -- RF, microwave, satellite, cellular
- Optical -- fiber, free-space infrared or laser

Each medium has its own noise and attenuation characteristics

A Seemingly Simple Question?

What is the speed of the connection between your home and the telephone company switching office?
**Limitations on Transmission**

- "Bandwidth" is the maximum frequency at which a signal on a given channel can change and still be intelligible.
- The bandwidth of a channel puts both a theoretical and a practical limit on the data rate of the channel.
- Bandwidth will be naturally limited by physical characteristics of the medium, or artificially limited for other reasons.
- Noise will limit the data rate of a channel. There are many sources of noise. The required BER (bit error rate) determines the practical, available data rate.
- Sophisticated signaling methods using multiple signal levels and data compression can maximize the data rate on a channel but cannot overcome the fundamental physical limits.

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**Why Multiplex?**

- Imagine you need to connect 24 users in Boston to 24 users in NYC and that each user wants 64kbps.
Why Multiplex?

- Imagine you need to connect 24 users in Boston to 24 users in NYC and that each user wants 64kbps.
- Two simple options:

```
<table>
<thead>
<tr>
<th></th>
<th>Use 24 wires between locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Share one high speed link between locations</td>
</tr>
</tbody>
</table>
```

2,700 Pair Telephone Cable

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**Multiplexing**

- The division of a single physical channel into two or more logical channels.
- Users can share a channel. This provides equipment and cost savings. The question is how to share it.
- Frequency Division Multiplexing is one option
- Time Division Multiplexing is another option
  - Slotted TDM - each user is assigned a particular slot (time interval), whether it is needed or not - this provides guaranteed delay and bandwidth
  - Statistical TDM - each user requests access or enters a queue and waits for access to the shared medium. What about the queuing delay and resulting QoS?
  - Many other combinations possible

**What About the 25th User?**

- Now, imagine that you need to connect a 25th user between Boston and NYC.
- A couple of options exist, what are they?
Switching

- Circuit Switching
- Message Switching
- Packet Switching
- Cell Switching

Circuit Switched versus Packet Networks

- How did these two types of networks develop?
- How is a system designed for one used with the other?

POTS, ISDN, T1, T3, SONET

Ethernet, Frame Relay, Internet
Evolution of Circuit Switched Networks

- Evolved to support telephone voice communications
  - Analog telephone service was/is the primary driver
  - Dedicated physical circuit put in place for the entire call
  - Virtual circuit approach developed, but still circuit switched
    - 8KHz samples @ 8 bits = 64Kbps per voice call
    - Allows muxing of multiple calls, each at 64kbps, on a single physical circuit line (T1 and T3 TDM systems.)
    - Continuous stream of bits for duration of the phone call
  - Emphasis on reliable connection of a large number of continuous 64Kbps flows (phone conversations)
**Evolution of Packet Switched Networks**

- Evolved to support computer to computer communications
  - Move a packet of data from one computer to another
  - Packet contains a header and a payload, and a minimum and maximum packet size is set by the protocol
- Emphasis is on efficiently moving blocks of data with no errors
- Individual packets utilize the entire capacity of the link, but for a short period of time.

**Who Establishes Protocols and Standards**

- Standards bodies and other organizations:
  - IETF, Internet Engineering Task Force
    www.ietf.org
  - ISO, International Organization for Standards
  - NIST, National Institute for Standards and Technology
  - ITU-T (CCITT)
    plus ... IEEE, EIA, ECMA, etc...
- Computer, software and communication companies
- Large users and user groups
Things that need standardizing

- Types of connectors
- Physical media
- Signaling techniques
- Addressing
- Message sizes
- Path setup and teardown procedures
- Routing selection techniques
- Video and audio encoding techniques
- Division of management authority and responsibility
- Error detection techniques and recovery procedures
- etc., etc.
Why Layered Network Architectures?

- To help manage complexity
- To facilitate the building block approach to implementation & management

How Many Layers are Enough?

Depends on who's counting.
- OSI / ISO model “said” 7 about 20 years ago and this is still talked about quite a lot
- Internet model uses 5 and most systems are built using this approach

However, counting the number of layers is more art than science when you build systems for the real world.

Communication Functionality

You can divide up the functionality required in a communication system in many different ways.
OSI Layers

- Application
- Presentation
- Session
- Transport
- Network
- Data link
- Physical

Internet Layers

- Application
- Transport
- Network
- Link
- Physical
### Simplified OSI and TCP/IP Models

<table>
<thead>
<tr>
<th>OSI Layer No.</th>
<th>OSI Name</th>
<th>OSI Protocols</th>
<th>TCP/IP Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
<td>FTAM X.400</td>
<td>Telnet FTP SMTP SNMP WWW H.323 VoIP</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
<td>8823 ASN.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
<td>8327</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
<td>TP0 TP4</td>
<td>TCP UDP</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
<td>CLNP X.25</td>
<td>IP</td>
</tr>
<tr>
<td>2</td>
<td>Data Link</td>
<td>Frame Relay, HDLC, ISDN, 802.X</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### "Services" vs "Protocols"

- Entities in each layer offer *services* to entities in the layer above.
- Same-layer entities implement services by conversing according to *protocols*.
- Both services and protocols must be documented.
- Protocols can change while services stay the same.

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Data Link Layer Services

Imagine that you wanted to transfer data between two systems. What services might you offer?

Why Distinguish Services from Protocols?

- Imagine you are asked to add a communication service to an old system (which cannot be changed for some arcane reason.)

Old System, which CANNOT be changed

New Communication Subsystem

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What Does a Frame Look Like on an Ethernet?

Ethernet Frame
(Sometimes incorrectly called a Packet)

Frame starts here … . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . and continues off the page….

00 00 a7 11 57 dd 08 00 09 38 24 31 08 00 45 00 00 38 b3 ....

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**Ethernet Frame**

```
00 to 15: 00 00 a7 11 57 dd 08 00 - 09 38 24 31 08 00 45 00
16 to 31: 00 38 b3 e3 00 00 1e 06 - 8b 3e 06 04 69 c9 c6 04
32 to 47: 69 cf 05 bd 17 70 3a e4 - 44 b9 2c 0a 9e ad 50 18
48 to 63: 20 00 88 53 00 00 3d 11 - 11 04 11 80 11 02 34 a3
64 to 69: 00 76 34 0c 00 13
```

**Ethernet and IEEE 802.3 Frame Formats**

**Ethernet**

```
<table>
<thead>
<tr>
<th>Bytes</th>
<th>7</th>
<th>1</th>
<th>6</th>
<th>6</th>
<th>2</th>
<th>0 - 1500</th>
<th>0 - 46</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preamble</td>
<td>Destination address</td>
<td>Source address</td>
<td>Data</td>
<td>Pad</td>
<td>Checksum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Start of frame delimiter

Protocol Type

**IEEE 802.3**

```
<table>
<thead>
<tr>
<th>Bytes</th>
<th>7</th>
<th>1</th>
<th>6</th>
<th>6</th>
<th>2</th>
<th>0 - 1500</th>
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<td>Checksum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Start of frame delimiter

Length Field

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But a Single Header is Rarely Enough

<table>
<thead>
<tr>
<th>Header 1</th>
<th>Header 2</th>
<th>Header 3</th>
<th>User Payload</th>
</tr>
</thead>
</table>

Ethernet Frame Trace

- Network analysis tool is called Ethereal and it is available from www.ethereal.com
- Wiretapping or monitoring of any Harvard network traffic is strictly forbidden under any circumstances at all. See the FAS Computer Rules & Responsibilities website for the details.
To deliver a specific level of service, the Data Link Level must tackle the following problems:

- Synchronization and framing
- Data transparency
- Data transfer
- Addressing
- Flow control
- Error control (detection only, or detection and correction)
### Data Link Layer Protocol Example (HDLC Type)

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Information (variable)</th>
<th>Frame Check Sequence</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>01111110</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>variable</td>
<td>16</td>
</tr>
</tbody>
</table>

#### Information frame
- **Function:** N(S) P F N(R)

#### Supervisory frame
- **Sup. Func:** 1 0
- **Function:** P F N(R)

#### Unnumbered frame
- **Func. Mod:** 1 1
- **Function:** P F Func.

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### Generic Protocol Functions

- Addressing
- Multiplexing
- Sequencing
- Error control
- Flow control
- Option negotiation
- Fragmentation and reassembly
- *plus others...*

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**What is the Internet**

- A network of networks with millions of users
- With large national and international ISPs as the core networks
- With regional ISPs connected to national ISPs
- With local ISPs connected to national/regional ISPs
- All ISPs exchanging inbound and outbound traffic with other ISPs across public and/or private peering points.
- All using the TCP/IP suite of protocols
Internet Trace from Harvard to MIT

fas% traceroute www.mit.edu
traceroute to DANDELION-PATCH.MIT.edu (18.181.0.31), 40 byte packets
  1 scmr-gw.fas.harvard.edu (140.247.30.1)  1 ms  1 ms  1 ms
  2 sc-gw.fas.harvard.edu (140.247.6.2)  1 ms  1 ms  0 ms
  3 camgw1-fas.harvard.edu (140.247.20.1)  1 ms  2 ms  1 ms
  4 192.5.66.18 (192.5.66.18)  2 ms  1 ms  1 ms
  5 192.5.66.50 (192.5.66.50)  1 ms  1 ms  1 ms
  6 192.5.66.41 (192.5.66.41)  1 ms  2 ms  1 ms
  7 192.5.66.34 (192.5.66.34)  1 ms  2 ms  1 ms
  8 MIT-MEDIAONE/MIT.EDU (18.95.0.1)  30 ms  2 ms  2 ms
  9 W20-RTR-FDDI/MIT.EDU (18.168.0.8)  3 ms  3 ms  3 ms
 10 DANDELION-PATCH.MIT.EDU (18.181.0.31)  2 ms *  4 ms
fas%
Internet Trace to Oxford University

fas% traceroute www.oxford.edu
traceroute to www.OXFORD.edu (163.1.0.45), 30 hops max, 40 byte packets
1  scmr-gw.fas.harvard.edu (140.247.30.1) 1 ms 1 ms 1 ms
2  sc-gw.fas.harvard.edu (140.247.6.2) 1 ms 1 ms 0 ms
3  camgw1-fas.harvard.edu (140.247.20.1) 0 ms 0 ms 1 ms
4  192.5.66.18 (192.5.66.18) 2 ms 1 ms 1 ms
5  192.5.66.9 (192.5.66.9) 2 ms 2 ms 2 ms
6  12.127.80.125 (12.127.80.125) 3 ms 3 ms 3 ms
7  br2-a3110s1.cb1ma.ip.att.net (12.127.5.10) 3 ms 3 ms 3 ms
8  br3-h20.wswdc.ip.att.net (12.127.15.177) 12 ms 13 ms 11 ms
9  gr1-a3100s1.wswdc.ip.att.net (192.205.31.185) 13 ms 13 ms 13 ms
10 - 15 …. multiple hops in ALTER.NET, only a few shown in this slide
16 - 21 …. multiple hops in Teleglobe.net, only a few shown in this slide
22  external-gw.ja.net (128.86.1.40) 145 ms 145 ms 143 ms
23  london-core.ja.net (146.97.251.58) 152 ms 142 ms 145 ms
24  146.97.251.82 (146.97.251.82) 150 ms 148 ms 149 ms
25  noucs2.backbone.ox.ac.uk (192.76.35.2) 152 ms 155 ms 150 ms
26  wwwtest.ox.ac.uk (163.1.0.45) 152 ms 150 ms 152 ms
fas% © 1998-2005 L. Evenchik
Three Minute Wrap-Up

- Please write down the three or four major points that were discussed during the lecture.
- Note whether the material was presented clearly and/or how it should have been done differently.
- Ask any questions that I should address next time.
- Please do a Wrap-Up at the end of lecture and hand it in as you leave or fill out the form on the web site.
- Do not sign your form. (The form on the web site is also anonymous.)
- Thank you!