Overview

Ø Administrative trivia
Ø Overview
Ø A taxonomy of communication networks
Ø Summary and question 1
Administrative trivia’s

- Course web page:
  - http://zoo.cs.yale.edu/classes/cs633
  - check it periodically to get the latest information
- Office hours: MW 1:30-2:30pm or by appointment
- Stop by: AKW 202
- e-mail is the best way to communicate with me

What Are the Goals Of This Course?

- Understand how Internet works
  - its philosophy
  - its basic protocols and mechanisms
  - its current issues
- Appreciate good networking research
  - problem selection
  - solution & research methodology
  - presentation
- Practice a small scale research in computer networks
- Have fun!
What Will We Cover?

- Internet architecture and philosophy
- MAC and link layer
- Routing and router design
- Traffic management—congestion control
- Traffic management—application adaptation
- Traffic management—router mechanisms
- New security issues
- Beyond unicast

What Do You Need To Do?

- Read and review papers
- Participate in class discussions
- Project and term paper
Paper Reviews and Class Participation

- Read and review papers before each class
  - goals
    - appreciate good research
    - synthesize main ideas and concepts in research papers
  - format
    - 23 classes, 1-3 papers per class
    - read all of required papers before class
    - submit a one page review for one paper
    - you can skip 3 reviews with no grading penalty (it is hoped that you still read the papers for a class)

- Participate in class discussions
  - ask questions, a lot of questions
  - lead class discussions (tentative)

Research Project

- Investigate ideas and solutions in a small scale research
- The topics can be
  - design/implementation
  - measurement
  - simulation
  - a survey
- Ideally, best projects can become conference papers (e.g., SIGCOMM, INFOCOM, ICNP)
Research Project: Steps

- I will present a problem at the end of most classes.
- I will also distribute a list of projects by the end of September.
- You can either choose one of these projects or come up with your own.
- Pick your project, partner, and submit a one page proposal describing:
  - the problem you are solving
  - your plan of attack with milestones and dates
  - any special resources you may need
- A midterm (Oct. 24) presentation of your topic and progress.
- Submit project papers (Dec. 19).

Grading

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
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<tbody>
<tr>
<td>Paper reviews</td>
<td>40%</td>
</tr>
<tr>
<td>Class participation</td>
<td>20%</td>
</tr>
<tr>
<td>Term paper</td>
<td>40%</td>
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</table>

- This is a seminar class: more important is what you realize/learn than the grade.
Enrollment and Class Survey

- The limit on this class is 15 students to maintain a small environment for class discussions
- Please take the class survey
  - help me to determine your background
  - suggest topics that you are interested

Questions?
Overview

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  - Overview
- A taxonomy of communication networks
- Summary and question 1

Thanks to Ion Stoica for making some slides available

What is a Communication Network? (end system point of view)

- Network offers a service: move information
  - bird, fire, messenger, truck, telegraph, telephone, Internet ...
  - another example, transportation service: move objects
    - horse, train, truck, airplane ...
- What distinguish different types of networks?
  - The services they provide
- What distinguish the services?
  - latency
  - bandwidth
  - loss rate
  - number of end systems
  - service interface (how to invoke?)
  - other details
    - reliability, unicast vs. multicast, real-time, ...
What is a Communication Network? (infrastructure point of view)

- Links: fiber, copper, satellite, ...
- Switches: mechanical/electronic/optical, ...
- Protocols: TCP/IP, ATM, MPLS, SONET, Ethernet, PPP, Frame Relay, SNA, ...
- Functionalities: routing, error control, congestion control, Quality of Service (QoS)
- Applications: WEB, FTP, Telnet, Voice over IP, ...

Different Classification of Communication Networks

- Geographical distance
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): ATM, frame relay
- Information type
  - data networks vs. telecommunication networks
- Application type
  - special purpose networks: airline reservation network, banking network, credit card network, telephony
  - general purpose network: Internet
- Right to use
  - private: enterprise networks
  - public: telephony network, Internet
- Ownership of protocols
  - proprietary: SNA
  - open: IP
The Internet

- Global scale, general purpose, heterogeneous-technologies, public, data network
- Internet Protocol
  - open standard: Internet Engineering Task Force (IETF) as standard body
- Developed by the research community

History of the Internet

- 70’s: started as a research project, 56 kbps, < 100 computers
- 80-83: ARPANET and MILNET split
- 85-86: NSF builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- 90-92: NSFNET moves to 45 Mbps
- 94: NSF backbone dismantled, multiple private backbones
- Today: backbones run at 9.9 Gbps, 10s millions computers in 150 countries
Growth of the Internet

- **Number of Hosts on the Internet:**
  - Aug. 1981: 213
  - Oct. 1984: 1,024
  - Dec. 1987: 28,174
  - Oct. 1990: 313,000
  - Oct. 1993: 2,056,000
  - Apr. 1995: 5,706,000
  - Jul. 1997: 19,540,000
  - Jul. 2000: 93,047,785

Who is Who on the Internet?

- **Internet Engineering Task Force (IETF):** The IETF is the protocol engineering and development arm of the Internet. It is subdivided into many working groups, which specify Request For Comments (RFC).
- **Internet Research Task Force (IRTF):** The Internet Research Task Force is composed of a number of focused, long-term and small Research Groups.
- **Internet Architecture Board (IAB):** The IAB is responsible for defining the overall architecture of the Internet, providing guidance and broad direction to the IETF.
- **The Internet Engineering Steering Group (IESG):** The IESG is responsible for technical management of IETF activities and the Internet standards process. Standards. Composed of the Area Directors of the IETF working groups.
Internet Standardization Process

- All standards of the Internet are published as RFC (Request for Comments). But not all RFCs are Internet Standards!
  - available: http://www.ietf.org

- A typical (but not only) way of standardization is:
  - Internet Draft
  - RFC
  - Proposed Standard
  - Draft Standard (requires 2 working implementations)
  - Internet Standard (declared by IAB)

- David Clark, 1992: "We reject: kings, presidents, and voting. We believe in: rough consensus and running code."

Services Provided by the Internet

- Shared access to computing resources
  - telnet (1970's)

- Shared access to data/files
  - FTP, NFS (1980's)

- Communication medium over which people interact
  - email (1980's), on-line chat rooms, instant messaging (1990's)
  - audio, video (1990's)
    - replacing telephone network?

- A medium for information dissemination
  - USENET (1980's)
  - WWW (1990's)
    - replacing newspaper, magazine?
  - audio, video (1990's)
    - replacing radio, CD, TV?
Today’s Vision

- Everything is digital: voice, video, music, pictures, live events
- Everything is on-line: bank statement, medical record, books, airline schedule, weather, highway traffic, toaster, refrigerator ...
- Everyone is connected: doctor, teacher, broker, mother, son, friends, enemies

What is Next?

- The positive—how to implement them?
  - Electronic commerce
    - virtual enterprise
  - World as a small village
    - community organized according to interests
    - enhanced understanding among diverse groups
  - Electronic democracy
    - little people can voice their opinions to the whole world
    - little people can coordinate their actions
    - bridge the gap between information haves and have no's
- The negative—how to prevent them?
  - Electronic terrorism
    - hacker can bring the whole world to its knee
Industrial Players

- Telephone companies
  - own long-haul and access communication links, customers
- Cable companies
  - own access links
- Wireless/Satellite companies
  - alternative communication links
- Utility companies: power, water, railway
  - own right of way to lay down more wires
- Medium companies
  - own content
- Internet Service Providers
- Equipment companies
  - switches/routers, chips, optics, computers
- Software companies

Internet Physical Infrastructure

- Residential Access
  - Modem
  - DSL
  - Cable modem
- Campus network
  - Ethernet
  - ATM
- Access to ISP, Backbone transmission
  - T1/T3, OC-3, OC-12
  - ATM vs. SONET, vs. WDM
- Internet Service Providers
  - Point of Presence (POP)
Access of the Internet from Yale through Internet2

cicada.cs.yale.edu% /usr/sbin/traceroute www.cs.utexas.edu

1 zoo-gateway.cs.yale.edu (128.36.232.1)  0.702 ms  0.546 ms  0.615 ms
2 bifrost.net.yale.edu (130.132.1.100)  1.229 ms  1.257 ms  1.499 ms
3 ATM10-540-OC3-68GAPPOPNE.NOX.ORG (192.5.89.69)  6.108 ms  6.676 ms  5.930 ms
4 ABILENE-GIGAPOPNE.NOX.ORG (192.5.89.102)  10.871 ms  11.004 ms  11.113 ms
5 wash-nycm.abilene.unc.edu (198.32.8.45)  15.256 ms  15.133 ms  14.917 ms
6 atlanta-abilene.unc.edu (198.32.8.65)  30.535 ms  30.557 ms  30.745 ms
7 hstn-abilene.unc.edu (198.32.8.33)  49.913 ms  49.776 ms  49.456 ms
8 ser3-a0-0-gw.utexas.edu (128.83.37.21)  59.538 ms  59.042 ms  58.852 ms
9 ser10-abilene-03.gw.utexas.edu (128.83.10.25)  58.517 ms  58.987 ms  58.818 ms
10 ser11-abilene-03.gw.utexas.edu (128.83.10.14)  58.485 ms  58.422 ms  59.967 ms
11 128.83.37.18 (128.83.37.18)  58.715 ms  58.545 ms  58.407 ms
12 net2.cs.utexas.edu (128.83.120.155)  58.775 ms  59.030 ms  58.539 ms

Access of the Internet from Yale through qwest

cicada.cs.yale.edu% /usr/sbin/traceroute www.amazon.com

1 zoo-gateway.cs.yale.edu (128.36.232.1)  0.720 ms  0.576 ms  1.333 ms
2 bifrost.net.yale.edu (130.132.1.100)  2.385 ms  2.346 ms  2.705 ms
3 bos-edge-02.inet.qwest.net (63.145.0.13)  6.064 ms  5.813 ms  5.852 ms
4 bos-core-02.inet.qwest.net (205.171.28.29)  5.546 ms  5.928 ms  5.521 ms
5 jfk-core-01.inet.qwest.net (205.171.8.19)  10.943 ms  11.335 ms  11.553 ms
6 ewr-core-03.inet.qwest.net (205.171.5.89)  11.621 ms  11.636 ms  11.603 ms
7 ewr-brdr-01.inet.qwest.net (205.171.17.98)  11.631 ms  11.414 ms  10.913 ms
8 qwest-gw.n54ny.ip.att.net (192.205.32.21)  11.866 ms  12.266 ms  12.443 ms
9 gbr3-p50.n54ny.ip.att.net (12.123.1.122)  11.758 ms  11.870 ms  11.929 ms
10 gbr3-p30.cgcil.ip.att.net (12.122.2.173)  30.303 ms  30.125 ms  29.834 ms
11 gbr4-p50.cgcil.ip.att.net (12.122.1.126)  30.646 ms  30.631 ms  29.854 ms
12 gbr4-p30.st6wa.ip.att.net (12.122.2.229)  84.371 ms  84.454 ms  84.627 ms
13 gbr1-p40.st6wa.ip.att.net (12.122.5.162)  84.816 ms  83.973 ms  84.702 ms
14 gar2-p360.st6wa.ip.att.net (12.123.44.113)  84.843 ms  84.093 ms  84.144 ms
15 12.124.173.22 (12.124.173.22)  87.488 ms  87.683 ms  88.392 ms
16 208-226-122-16.amazon.com (208.226.122.16)  89.485 ms  86.453 ms  86.157 ms
Overview

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  - A Taxonomy of communication networks
- Summary and question 1
A Taxonomy of Communication Networks

Communication networks can be classified based on the way in which the nodes exchange information:

- Communication network
  - Switched network
  - Broadcast communication
  - Circuit-switched network
  - Packet-switched network
    - Datagram network
    - Virtual circuit network

Broadcast vs. Switched Communication Networks

- Broadcast communication networks
  - Information transmitted by a node is received by all other nodes in the network
    - Examples: usually in LANs (Ethernet, Satellite, Wavelan)
  - Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)

- Switched communication networks
  - Information is transmitted to a small sub-set of designated nodes
  - Problem: how to forward information to intended node(s)
    - This is done by special nodes (e.g., routers, switches) running routing protocols
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Circuit Switching

- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

- Three phases
  1. Circuit establishment
     - A fixed slot is reserved for the transmission
  2. Data transfer
  3. Circuit termination

- If circuit not available: "Busy signal"
Timing in Circuit Switching

Communication networks can be classified based on the way in which the nodes exchange information:

- switched network
- packet-switched network
- broadcast network
- datagram network
- virtual circuit network

A Taxonomy of Communication Networks
Packet Switching

- Data are sent as formatted bit-sequences, so-called packets.
- Packets have the following structure:

  ![Packet Structure Diagram]

  - Header and Trailer carry control information (e.g., destination address, check sum)
  - Each packet is passed through the network from node to node along some path (Routing)
  - At each node the entire packet is received, stored briefly, and then forwarded to the next node (Store-and-Forward Networks)

Packet Switching

- A node in a packet switching network

![Node Diagram]
A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:
  - Communication network
    - Switched network
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Datagram Packet Switching

- Example: IP networks
- Each packet is independently switched
  - Each packet header contains destination address
- No resources are pre-allocated (reserved) in advance
Timing of Datagram Switching

Datagram Packet Switching
A Taxonomy of Communication Networks

Communication networks can be classified based on the way in which the nodes exchange information:

- Circuit-switched network
- Packet-switched network
- Virtual circuit network
- Datagram network

Example: ATM networks

- Hybrid of circuit switching and packet switching
  - Data is transmitted as packets
  - All packets from one stream are sent along a pre-established path (=virtual circuit)
- Guarantees in-sequence delivery of packets

However: Packets from different virtual circuits may be interleaved
Virtual-Circuit Packet Switching

- Communication with virtual circuits takes place in three phases
  1. VC establishment
  2. data transfer
  3. VC disconnect
Packet-Switching vs. Circuit-Switching

- Most important advantage of packet-switching over circuit switching: Ability to exploit statistical multiplexing:
  - Efficient bandwidth usage; ratio between peak and average rate is 3:1 for audio, and 15:1 for data traffic
- However, packet-switching needs to deal with congestion:
  - More complex routers
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice they are combined:
  - IP over SONET, IP over Frame Relay
Summary

- Course administrative trivia
- Overview and Internet history
- A taxonomy of communication networks
- Rest of the course a lot more technical and (hopefully) exciting

Readings for next class
- [Cla88] D. Clark, "The Design Philosophy of the DARPA Internet Protocols", 1988

Question 1: how to measure the Internet?

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How do you measure the number of hosts on the Internet?
What support from the network do you need?
How accurate can the measurement be?
How to validate your result?
Question 1: how to measure the Internet? (cont')

- Furthermore, how do you probe the topology of the CS department, Yale University, and the Internet? What support do you need?
- Even further, how do you probe the bandwidth of each link? What support the network should provide?

Backup Slides
**ADSL Access**

- Asymmetrical Digital Subscriber Loop (ADSL)
- Telephone company’s solution to “last mile problem”

**Access Based on Cable Modems**

- Regional headend: 200 K - 400 K homes
- Distribution hub: 20K - 40 K homes
- Fiber node: 500 - 1K homes
Network Access Point

- Interconnect multiple ISP's

Network Access Point

Pacific Bell NAP Interim Configuration

Network Access Point

Pacific Bell NAP Configuration