CS 268: Graduate Computer Networks – Spring 2003

- Instructor:
  - Ion Stoica (istoica@cs.berkeley.edu, 645 Soda Hall)
- Lecture time: TT, 12:30-2:00 pm
- Place: 310 Soda Hall
- Office hour: Tu, 2 - 3 pm

Overview

- Administrative trivia
- Overview and history of the Internet
- A Taxonomy of Communication Networks
- Router Architecture in Packet-Switching Networks

Administrative Trivia’s

- Course Web page:
  - http://inst.eecs.berkeley.edu/~cs268/sp03
  - Check it periodically to get the latest information
- Deadline means deadline
  - Unless otherwise specified, it means 12:20pm on the date (10 minutes before lecture)
  - Special circumstances should be brought to my attention way ahead of deadlines
- Exams are close-book

Goals of this Course

- Understand how the Internet works
- Get familiar with current Internet research efforts
- Understand solutions in context
  - Goals
  - Assumptions
- Appreciate what is good research
  - Problem selection
  - Solution & research methodology
  - Presentation
- Apply what you learned in a class project
### What Do You Need To Do?

- A research-oriented class project
- Two exams
- Paper reading

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### Research Project

- Investigate new ideas and solutions in a class research project
  - Define the problem
  - Execute the research
  - Work with your partner
  - Write up and present your research
- Ideally, best projects will become conference papers (e.g., SIGCOMM, INFOCOM, MOBICOM)

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### Research Project: Steps

- I’ll distribute a list of projects
  - 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 presentation of your progress (five minutes)
- Final project presentation (ten minutes) + poster session
- Submit project papers

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### Paper Reviews

- Goal: synthesize main ideas and concepts in the papers
- Number: up to two papers per class
- Length: no more than half page per paper
- Content
  - Main points intended by the author
  - Points you particularly liked/disliked
  - Other comments (writing, conclusions…)
- Submission:
  - Submit each review via e-mail before 12:20 pm on lecture day
  - See class web page for details

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## Grading

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term project</td>
<td>50%</td>
</tr>
<tr>
<td>Final exam</td>
<td>15%</td>
</tr>
<tr>
<td>Midterm exam</td>
<td>15%</td>
</tr>
<tr>
<td>Class participation</td>
<td>10%</td>
</tr>
<tr>
<td>Paper reviews</td>
<td>10%</td>
</tr>
</tbody>
</table>

- This is a graduate networking class: more important is what you realize/learn than the grade

## Enrollment Policy

- Graduate students get highest priority
- Among other students, priority given to those who
  - Have backgrounds in networking, operating systems
  - Have relatively light course load
- Procedure of enrollment for undergraduate students
  - Be officially on the waiting list
  - Send me an email with URL that has pointers to
    - Your resume
    - A short statement of relevant courses (textbook, university, grade) and experiences
    - Other courses you are taking this semester

## Send the Following Information

- Please send me (stoica@cs.berkeley.edu) an e-mail with the subject "CS268 registration" and the following information:
  - Last and first name
  - Student ID
  - Your department
  - Preferred email address
  - URL of your home page

- Please indicate explicitly if we can add you to the on-line web page that lists each student enrolled in the class (only your name and URL will be made publicly available here).

## Overview

- Administrative trivia
  - Overview and history of the Internet
  - A Taxonomy of Communication Networks
What is a Communication Network?
(End system 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, message vs. byte ...

What is a Communication Network?
(Infrastructure Centric View)

- Electrons and photons as communication medium
- Links: fiber, copper, satellite, ...
- Switches: electronic/optical, crossbar/Banyan
- Protocols: TCP/IP, ATM, MPLS, SONET, Ethernet, PPP, X.25, Frame Relay, AppleTalk, IPX, SNA
- Functionalities: routing, error control, congestion control, Quality of Service (QoS)
- Applications: FTP, WEB, X windows, ...

Types of Networks

- Geographical distance
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): X.25, ATM, frame relay
  - Caveat: LAN, MAN, WAN may mean different things
    • service, network technology, networks
- 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

Types of Networks

- Right to use
  - private: enterprise networks
  - public: telephony network, Internet
- Ownership of protocols
  - proprietary: SNA
  - open: IP
- Technologies
  - terrestrial vs. satellite
  - wired vs. wireless
- Protocols
  - IP, AppleTalk, SNA
The Internet

- Global scale, general purpose, heterogeneous-technologies, public, computer network
- Internet Protocol
  - Open standard: Internet Engineering Task Force (IETF) as standard body
  - Technical basis for other types of networks
    - Intranet: enterprise IP network
- 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
- 87-90: link regional networks, NIS (NASA), ESNet(DOE), DARTnet, TWBNet(DARPA), 100,000 computers
- 90-92: NSFNET moves to 45 Mbps, 16 mid-level networks
- 94: NSF backbone dismantled, multiple private backbones
- Today: backbones run at 10 Gbps, 10s millions computers in 150 countries

Time Line of the Internet

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Hosts on the Internet</th>
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<tbody>
<tr>
<td>1981</td>
<td>213</td>
</tr>
<tr>
<td>1984</td>
<td>1,024</td>
</tr>
<tr>
<td>1987</td>
<td>28,174</td>
</tr>
<tr>
<td>1990</td>
<td>313,000</td>
</tr>
<tr>
<td>1993</td>
<td>2,056,000</td>
</tr>
<tr>
<td>1995</td>
<td>5,706,000</td>
</tr>
<tr>
<td>1997</td>
<td>19,540,000</td>
</tr>
<tr>
<td>1999</td>
<td>56,218,000</td>
</tr>
<tr>
<td>2001</td>
<td>125,888,197</td>
</tr>
<tr>
<td>2002</td>
<td>162,128,493</td>
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</table>
Recent Growth (1991-2002)

Who is Who in the Internet?

- Internet Engineering Task Force (IETF): The IETF is the protocol engineering and development arm of the Internet. Subdivided into many working groups, which specify Request For Comments or RFCs.
- IRTF (Internet Research Task Force): The Internet Research Task Force is a 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 Drafts
  - RFC
  - Proposed Standard
  - Draft Standard (requires 2 working implementation)
  - Internet Standard (declared by IAB)
- David Clark, MIT, 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, AFS (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 (2000’s)
  - Replacing radio, CD, TV?
Internet Physical Infrastructure

- Residential Access
  - Modem
  - DSL
  - Cable modem
  - Satellite
- Enterprise/ISP access, Backbone transmission
  - T1/T3, DS-1 DS-3
  - OC-3, OC-12
  - ATM vs. SONET, vs. WDM
- Campus network
  - Ethernet, ATM
- Internet Service Providers
  - access, regional, backbone
  - Point of Presence (POP)
  - Network Access Point (NAP)

UNET's Global Internet Backbone

UNET'S North American Internet Backbone

UNET'S European Internet Backbone
Overview

• Administrative trivia
• Overview and history of the Internet

A Taxonomy of Communication Networks

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

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

Switched communication networks
- information is transmitted to a sub-set of designated nodes
  - examples: WANs (Telephony Network, Internet)
  - Problem: how to forward information to intended node(s)
    - this is done by special nodes (e.g., routers, switches) running routing protocols

Broadcast vs. Switched Communication Networks
Circuit Switching

- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination
- If circuit not available: "Busy signal"
- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

Timing in Circuit Switching

A node (switch) in a circuit switching network

Circuit Switching:
Multiplexing/Demultiplexing

- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
- Needs synchronization between sender and receiver
  - In case of non-permanent conversations
    - Needs to dynamic bind a slot to a conversation
    - How to do this?
Communication networks can be classified based on the way in which the nodes exchange information:

- Switcheed Communication Network
- Circuit-switched Communication Network
- Packet-switched Communication Network
- Broadcast Communication Network
- Datagram Network
- Virtual Circuit Network

Packet-switched networks:

- Data are sent as formatted bit-sequences, so-called packets.
- Packets have the following structure:
  - 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)
  - Typically no capacity is allocated for packets

Packet switching: multiplexing/demultiplexing

- Data from any conversation can be transmitted at any given time
- How to tell them apart?
  - Use meta-data (header) to describe data
**A Taxonomy of Communication Networks**

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

  - Switched Communication Network
  - Packet-Switched Communication Network
  - Circuit-Switched Communication Network
  - Datagram Network
  - Virtual Circuit Network

**Datagram Packet Switching**

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

**Timing of Datagram Packet Switching**

- Host 1: Packet 1, Packet 2, Packet 3
- Host 2: Packet 1, Packet 2, Packet 3
- Node 1: Packet 1, Packet 2, Packet 3
- Node 2: Packet 1, Packet 2, Packet 3
- Node 3: Packet 1, Packet 2, Packet 3
- Node 4: Packet 1, Packet 2, Packet 3
- Node 5: Packet 1, Packet 2, Packet 3
- Node 6: Packet 1, Packet 2, Packet 3
- Node 7: Packet 1, Packet 2, Packet 3
- Node 8: Packet 1, Packet 2, Packet 3
- Node 9: Packet 1, Packet 2, Packet 3
- Node 10: Packet 1, Packet 2, Packet 3

**Datagram Packet Switching**

- Host A
- Host B
- Host C
- Host D
- Host E
- Node 1
- Node 2
- Node 3
- Node 4
- Node 5
- Node 6
- Node 7
- Node 8
- Node 9
- Node 10
A Taxonomy of Communication Networks

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

Virtual-Circuit Packet Switching

- Hybrid of circuit switching and packet switching
  - data is transmitted as packets
  - all packets from one packet 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
- Example: ATM networks

Virtual-Circuit Packet Switching

- Communication with virtual circuits takes place in three phases
  1. VC establishment
  2. data transfer
  3. VC disconnect
- Note: packet headers don’t need to contain the full destination address of the packet

Timing of Datagram Packet Switching
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
- Internet history and trivia
- Rest of the course a lot more technical and (hopefully) exciting