General

• Instructor - Ashok K. Agrawala
  – agrawala@cs.umd.edu
  – 4149 AVW
• TA - Gleneesha Johnson
  – Office Hours – Tu Th 9:30-10:30
• Class Meets – Tu Th 8:00 – 9:30 CSIC 1115
Prerequisite

• Required Background
  – must have 351 and 330 (412 or 430 would be helpful)

• Expectations
  – Understand the basics of Computer Architecture
  – Experience in implementing non-trivial systems-type projects
  – Should know
    • Processor
    • Memory
    • Kernel vs. user process
  – Familiar with basic probability
Expectations – After the course

- Understand the fundamentals of networking protocols, including protocol layering, basic
- medium access including wireless protocols, routing, addressing, congestion control
- Understand the principles behind the Internet protocols and some application layer
- protocols such as http, ftp, and DNS, and a few peer-to-peer systems/protocols such
- as Gnutella and Chord.
- Understand some of the limitations of the current Internet and its service model
- Understand the causes behind network congestion, and explain the basic methods for alleviating congestion
- Design, implement, and test substantial parts of network protocols
Announcements

• Required Work
  – will require about the same amount of effort as 412
    • 412 a (slightly) harder project to debug
    • 417 project is (by design) more ambiguous

• Required Texts
Other Material

• Recommended Texts

• RFCs
Grading

- Final 30%
- InTerm Exam(s) 30%
- Programming Assignments 35%
- Class Participation 5%
What is this course all about?

• Computer Networking
  – ???
Uses of Computer Networks

• Business Applications
• Home Applications
• Mobile Users
• Social Issues
Business Applications of Networks

- A network with two clients and one server.
The client-server model involves requests and replies.
Home Network Applications

- Access to remote information
- Person-to-person communication
- Interactive entertainment
- Electronic commerce
In a peer-to-peer system there are no fixed clients and servers.
Home Network Applications (3)

- Some forms of e-commerce.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Full name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2C</td>
<td>Business-to-consumer</td>
<td>Ordering books on-line</td>
</tr>
<tr>
<td>B2B</td>
<td>Business-to-business</td>
<td>Car manufacturer ordering tires from supplier</td>
</tr>
<tr>
<td>G2C</td>
<td>Government-to-consumer</td>
<td>Government distributing tax forms electronically</td>
</tr>
<tr>
<td>C2C</td>
<td>Consumer-to-consumer</td>
<td>Auctioning second-hand products on-line</td>
</tr>
<tr>
<td>P2P</td>
<td>Peer-to-peer</td>
<td>File sharing</td>
</tr>
</tbody>
</table>
Mobile Network Users

- Combinations of wireless networks and mobile computing.

<table>
<thead>
<tr>
<th>Wireless</th>
<th>Mobile</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>Desktop computers in offices</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>A notebook computer used in a hotel room</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Networks in older, unwired buildings</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Portable office; PDA for store inventory</td>
</tr>
</tbody>
</table>
Network Hardware

• Local Area Networks
• Metropolitan Area Networks
• Wide Area Networks
• Wireless Networks
• Home Networks
• Internetworks
Broadcast Networks

• Types of transmission technology
• Broadcast links
• Point-to-point links
Broadcast Networks (2)

- Classification of interconnected processors by scale.

<table>
<thead>
<tr>
<th>Interprocessor distance</th>
<th>Processors located in same</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>Square meter</td>
<td>Personal area network</td>
</tr>
<tr>
<td>10 m</td>
<td>Room</td>
<td>Local area network</td>
</tr>
<tr>
<td>100 m</td>
<td>Building</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1 km</td>
<td>Campus</td>
<td>Wide area network</td>
</tr>
<tr>
<td>10 km</td>
<td>City</td>
<td>The Internet</td>
</tr>
<tr>
<td>100 km</td>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>1000 km</td>
<td>Continent</td>
<td></td>
</tr>
<tr>
<td>10,000 km</td>
<td>Planet</td>
<td></td>
</tr>
</tbody>
</table>
Local Area Networks

- Two broadcast networks
  - (a) Bus
  - (b) Ring
Metropolitan Area Networks

- Antenna
- Head end
- Junction box
- Internet
Wide Area Networks

• Relation between hosts on LANs and the subnet.
Wide Area Networks (2)

- A stream of packets from sender to receiver.
Wireless Networks

• Categories of wireless networks:
  • System interconnection
  • Wireless LANs
  • Wireless WANs
Wireless Networks (2)

- (a) Bluetooth configuration
- (b) Wireless LAN
Wireless Networks (3)

- (a) Individual mobile computers
- (b) A flying LAN
Home Network Categories

• Computers (desktop PC, PDA, shared peripherals)
• Entertainment (TV, DVD, VCR, camera, stereo, MP3)
• Telecomm (telephone, cell phone, intercom, fax)
• Appliances (microwave, fridge, clock, furnace, airco)
• Telemetry (utility meter, burglar alarm, babycam).
Network Software

- Protocol Hierarchies
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols
Network Software
Protocol Hierarchies

- Layers, protocols, and interfaces.
Protocol Hierarchies (2)

- The philosopher-translator-secretary architecture.
Protocol Hierarchies (3)

- Example information flow supporting virtual communication in layer 5.
Design Issues for the Layers

• Addressing
• Error Control
• Flow Control
• Multiplexing
• Routing
Connection-Oriented and Connectionless Services

- Six different types of service.

<table>
<thead>
<tr>
<th>Service</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable message stream</td>
<td>Sequence of pages</td>
</tr>
<tr>
<td>Reliable byte stream</td>
<td>Remote login</td>
</tr>
<tr>
<td>Unreliable connection</td>
<td>Digitized voice</td>
</tr>
<tr>
<td>Unreliable datagram</td>
<td>Electronic junk mail</td>
</tr>
<tr>
<td>Acknowledged datagram</td>
<td>Registered mail</td>
</tr>
<tr>
<td>Request-reply</td>
<td>Database query</td>
</tr>
</tbody>
</table>
Service Primitives

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISTEN</td>
<td>Block waiting for an incoming connection</td>
</tr>
<tr>
<td>CONNECT</td>
<td>Establish a connection with a waiting peer</td>
</tr>
<tr>
<td>RECEIVE</td>
<td>Block waiting for an incoming message</td>
</tr>
<tr>
<td>SEND</td>
<td>Send a message to the peer</td>
</tr>
<tr>
<td>DISCONNECT</td>
<td>Terminate a connection</td>
</tr>
</tbody>
</table>

- Five service primitives for implementing a simple connection-oriented service.
Service Primitives (2)

- Packets sent in a simple client-server interaction on a connection-oriented network.
Services to Protocols Relationship

• The relationship between a service and a protocol.

Layer $k + 1$  
\[\text{Service provided by layer } k\]

Layer $k$  

Layer $k - 1$  

Layer $k + 1$  

Layer $k$  

Layer $k - 1$
Reference Models

- The OSI Reference Model
- The TCP/IP Reference Model
- A Comparison of OSI and TCP/IP
- A Critique of the OSI Model and Protocols
- A Critique of the TCP/IP Reference Model
Reference Models

The OSI reference model.
## Reference Models (2)

### OSI

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>

### TCP/IP

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Transport</td>
</tr>
<tr>
<td>5</td>
<td>Internet</td>
</tr>
<tr>
<td>1</td>
<td>Host-to-network</td>
</tr>
</tbody>
</table>

- **The 7 Layers**
- **Not present in the model**
Reference Models (3)

Layer (OSI names)
- Application
- Transport
- Network
- Physical + data link

Protocols
- TELNET
- FTP
- SMTP
- DNS
- TCP
- UDP
- IP

Networks
- ARPANET
- SATNET
- Packet radio
- LAN
Comparing OSI and TCP/IP Models

- Concepts central to the OSI model
- Services
- Interfaces
- Protocols
A Critique of the OSI Model and Protocols

- Why OSI did not take over the world
- Bad timing
- Bad technology
- Bad implementations
- Bad politics
Bad Timing

- The apocalypse of the two elephants.

Research

Standards

Billion dollar investment

Activity

Time
A Critique of the TCP/IP Reference Model

- Problems:
  - Service, interface, and protocol not distinguished
  - Not a general model
  - Host-to-network “layer” not really a layer
  - No mention of physical and data link layers
  - Minor protocols deeply entrenched, hard to replace
Hybrid Model

- The hybrid reference model to be used in this book.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Application layer</td>
</tr>
<tr>
<td>4</td>
<td>Transport layer</td>
</tr>
<tr>
<td>3</td>
<td>Network layer</td>
</tr>
<tr>
<td>2</td>
<td>Data link layer</td>
</tr>
<tr>
<td>1</td>
<td>Physical layer</td>
</tr>
</tbody>
</table>
Example Networks

- The Internet

- Connection-Oriented Networks: X.25, Frame Relay, and ATM

- Ethernet

- Wireless LANs: 802:11
The ARPANET

- (a) Structure of the telephone system.
- (b) Baran’s proposed distributed switching system.
The ARPANET (2)

- The original ARPANET design.
• Growth of the ARPANET  (a) December 1969.  (b) July 1970.  
NSFNET

- NSF Supercomputer center
- NSF Midlevel network
- Both
Internet Usage

- Traditional applications (1970 – 1990)
- E-mail
- News
- Remote login
- File transfer
Architecture of the Internet

- Overview of the Internet.
ATM Virtual Circuits

- A virtual circuit.
ATM Virtual Circuits (2)

• An ATM cell.

<table>
<thead>
<tr>
<th>Bytes</th>
<th>5</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Header</td>
<td>User data</td>
</tr>
</tbody>
</table>
The ATM Reference Model

- Plane management
  - Layer management
    - Control plane
      - Upper layers
        - CS/SAR
        - ATM adaptation layer
      - ATM layer
        - TC/PMD
        - Physical layer
    - User plane
      - Upper layers
        - Sublayer

CS: Convergence sublayer
SAR: Segmentation and reassembly sublayer
TC: Transmission convergence sublayer
PMD: Physical medium dependent sublayer
The ATM Reference Model (2)

<table>
<thead>
<tr>
<th>OSI layer</th>
<th>ATM layer</th>
<th>ATM sublayer</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>AAL</td>
<td>CS</td>
<td>Providing the standard interface (convergence)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAR</td>
<td>Segmentation and reassembly</td>
</tr>
<tr>
<td>2/3</td>
<td>ATM</td>
<td></td>
<td>Flow control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cell header generation/extraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Virtual circuit/path management</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cell multiplexing/demultiplexing</td>
</tr>
<tr>
<td>2</td>
<td>ATM</td>
<td>TC</td>
<td>Cell rate decoupling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Header checksum generation and verification</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cell generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Packing/unpacking cells from the enclosing envelope</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Frame generation</td>
</tr>
<tr>
<td>1</td>
<td>ATM</td>
<td>PMD</td>
<td>Bit timing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Physical network access</td>
</tr>
</tbody>
</table>

- The ATM layers and sublayers and their functions.
Ethernet

• Architecture of the original Ethernet.
Wireless LANs

- (a) Wireless networking with a base station.
- (b) Ad hoc networking.
Wireless LANs (2)

- The range of a single radio may not cover the entire system.
Wireless LANs (3)

- A multicell 802.11 network.
Network Standardization

- Who’s Who in the Telecommunications World
- Who’s Who in the International Standards World
- Who’s Who in the Internet Standards World
ITU

• Main sectors
  • Radiocommunications
  • Telecommunications Standardization
  • Development

• Classes of Members
  • National governments
  • Sector members
  • Associate members
  • Regulatory agencies
# IEEE 802 Standards

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.1</td>
<td>Overview and architecture of LANs</td>
</tr>
<tr>
<td>802.2</td>
<td>Logical link control</td>
</tr>
<tr>
<td>802.3 *</td>
<td>Ethernet</td>
</tr>
<tr>
<td>802.4</td>
<td>Token bus (was briefly used in manufacturing plants)</td>
</tr>
<tr>
<td>802.5</td>
<td>Token ring (IBM's entry into the LAN world)</td>
</tr>
<tr>
<td>802.6</td>
<td>Dual queue dual bus (early metropolitan area network)</td>
</tr>
<tr>
<td>802.7</td>
<td>Technical advisory group on broadband technologies</td>
</tr>
<tr>
<td>802.8 †</td>
<td>Technical advisory group on fiber optic technologies</td>
</tr>
<tr>
<td>802.9</td>
<td>Isochronous LANs (for real-time applications)</td>
</tr>
<tr>
<td>802.10</td>
<td>Virtual LANs and security</td>
</tr>
<tr>
<td>802.11</td>
<td>Wireless LANs</td>
</tr>
<tr>
<td>802.12</td>
<td>Demand priority (Hewlett-Packard's AnyLAN)</td>
</tr>
<tr>
<td>802.13</td>
<td>Unlucky number. Nobody wanted it</td>
</tr>
<tr>
<td>802.14</td>
<td>Cable modems (defunct: an industry consortium got there first)</td>
</tr>
<tr>
<td>802.15 *</td>
<td>Personal area networks (Bluetooth)</td>
</tr>
<tr>
<td>802.16 *</td>
<td>Broadband wireless</td>
</tr>
<tr>
<td>802.17</td>
<td>Resilient packet ring</td>
</tr>
</tbody>
</table>

The 802 working groups. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up.
## Metric Units

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>0.001</td>
<td>milli</td>
<td>$10^3$</td>
<td>1,000</td>
<td>Kilo</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>0.000001</td>
<td>micro</td>
<td>$10^6$</td>
<td>1,000,000</td>
<td>Mega</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>0.00000001</td>
<td>nano</td>
<td>$10^9$</td>
<td>1,000,000,000</td>
<td>Giga</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>0.0000000001</td>
<td>pico</td>
<td>$10^{12}$</td>
<td>1,000,000,000,000</td>
<td>Tera</td>
</tr>
<tr>
<td>$10^{-15}$</td>
<td>0.0000000000000001</td>
<td>femto</td>
<td>$10^{15}$</td>
<td>1,000,000,000,000,000,000</td>
<td>Peta</td>
</tr>
<tr>
<td>$10^{-18}$</td>
<td>0.000000000000000000001</td>
<td>atto</td>
<td>$10^{18}$</td>
<td>1,000,000,000,000,000,000,000</td>
<td>Exa</td>
</tr>
<tr>
<td>$10^{-21}$</td>
<td>0.0000000000000000000000001</td>
<td>zepto</td>
<td>$10^{21}$</td>
<td>1,000,000,000,000,000,000,000,000</td>
<td>Zetta</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>0.0000000000000000000000000000001</td>
<td>yocto</td>
<td>$10^{24}$</td>
<td>1,000,000,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
</tr>
</tbody>
</table>

- The principal metric prefixes.