General

• Instructor - Ashok K. Agrawala
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  – 4149 AVW

• TA -
  – Office Hours –

• Class Meets – Tu Th 8:00 – 9:30 CSIC 3117
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.
Business Applications of Networks (2)

- The client-server model involves requests and replies.

![Diagram of client-server model](image)
Home Network Applications

• Access to remote information
• Person-to-person communication
• Interactive entertainment
• Electronic commerce
Home Network Applications (2)

- 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>
Social Issues

- Network neutrality
- Digital Millennium Copyright Act
- Profiling users
- Phishing
Network Hardware

• Local Area Networks
• Metropolitan Area Networks
• Wide Area Networks
• Wireless Networks
• Home Networks
• Internetworks
Personal Area Network
Local Area Networks

(a) 802.11

(b) Switched Ethernet
Local Area Networks

- Two broadcast networks
  - (a) Bus
  - (b) Ring
A metropolitan area network based on cable TV.
Wide Area Networks

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

- A stream of packets from sender to receiver.
Wide Area Networks (1)

WAN that connects three branch offices in Australia
Wide Area Networks (2)

WAN using a virtual private network.

Wide Area Networks (3)

WAN using an ISP network.
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>
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.
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 $k + 1$  
```
Layer $k$
```

Service provided by layer $k$

Layer $k - 1$  
```
Layer $k$
```

Layer $k + 1$  
```
Layer $k - 1$
```

Protocol
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.

Layer

7 Application

6 Presentation

5 Session

4 Transport

3 Network

2 Data link

1 Physical

Host A

Interface

Application protocol

Presentation protocol

Session protocol

Transport protocol

Communication subnet boundary

Internal subnet protocol

Network layer host-router protocol

Data link layer host-router protocol

Physical layer host-router protocol

Name of unit exchanged

Application

Presentation

Session

Transport

Network

Data link

Physical

Host A

Host B

APDU

PPDU

SPDU

TPDU

Packet

Frame

Bit

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OSI Reference Model Layers

- Physical layer
- Data link layer
- Network layer
- Transport layer
- Session layer
- Presentation layer
- Application layer
The TCP/IP Reference Model Layers

- Link layer
- Internet layer
- Transport layer
- Application layer
### Reference Models (2)

#### OSI

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

#### TCP/IP

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Host-to-network</td>
</tr>
<tr>
<td>2</td>
<td>Internet</td>
</tr>
<tr>
<td>3</td>
<td>Transport</td>
</tr>
<tr>
<td>4</td>
<td>Application</td>
</tr>
</tbody>
</table>

- The 7 layers of the OSI model are presented, but note that the presentation layer is not present in the TCP/IP model.
Reference Models (3)
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.

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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.

<table>
<thead>
<tr>
<th></th>
<th>Layer</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.
• (c) March 1971. (d) April 1972. (e) September 1972.
The NSFNET backbone in 1988.

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

• Traditional applications (1970 – 1990)
• E-mail
• News
• Remote login
• File transfer
Overview of the Internet architecture
Third-Generation Mobile Phone Networks (1)

Cellular design of mobile phone networks
Third-Generation Mobile Phone Networks (2)

Architecture of the UMTS 3G mobile phone network.
Third-Generation Mobile Phone Networks (3)

Mobile phone handover (a) before, (b) after.
Fourth-Generation Mobile Phone Networks

• Technologies
  – WiMAX
    • MAXWell Lab at UMd
  – LTE

• TDM Based

• Higher user level bandwidth
Ethernet

• Architecture of the original Ethernet.
Wireless LANs

- (a) Wireless networking with a base station.
- (b) Ad hoc networking.
Wireless LANs: 802.11 (2)
Wireless LANs (3)

- The range of a single radio may not cover the entire system.
Wireless LANs (4)

• A multicell 802.11 network.
Wireless LANs: 802.11 (3)

The range of a single radio may not cover the entire system.
RFID and Sensor Networks (1)

RFID used to network everyday objects.
RFID and Sensor Networks (2)

Multihop topology of a sensor network
Ad hoc Networks

• Similar to Sensor Networks
• All nodes are equal
  – Some distinguished nodes may have servers/external connections
• Information moves from node to node
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
Who’s Who in International Standards (1)

<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 (WiFi)</td>
</tr>
<tr>
<td>802.12↓</td>
<td>Demand priority (Hewlett-Packard’s AnyLAN)</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 and disbanded itself.
## Who’s Who in International Standards (2)

<table>
<thead>
<tr>
<th>802.13</th>
<th>Unlucky number; nobody wanted it</th>
</tr>
</thead>
<tbody>
<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, Zigbee)</td>
</tr>
<tr>
<td>802.16 *</td>
<td>Broadband wireless (WiMAX)</td>
</tr>
<tr>
<td>802.17</td>
<td>Resilient packet ring</td>
</tr>
<tr>
<td>802.18</td>
<td>Technical advisory group on radio regulatory issues</td>
</tr>
<tr>
<td>802.19</td>
<td>Technical advisory group on coexistence of all these standards</td>
</tr>
<tr>
<td>802.20</td>
<td>Mobile broadband wireless (similar to 802.16e)</td>
</tr>
<tr>
<td>802.21</td>
<td>Media independent handoff (for roaming over technologies)</td>
</tr>
<tr>
<td>802.22</td>
<td>Wireless regional area network</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 and disbanded itself.
## 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>
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<tr>
<td>$10^{-12}$</td>
<td>0.0000000001</td>
<td>pico</td>
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<td>Tera</td>
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<tr>
<td>$10^{-15}$</td>
<td>0.00000000000001</td>
<td>femto</td>
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<td>Peta</td>
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<td>0.00000000000000001</td>
<td>atto</td>
<td>$10^{18}$</td>
<td>1,000,000,000,000,000,000</td>
<td>Exa</td>
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<tr>
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<td>0.00000000000000000001</td>
<td>zepto</td>
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<td>Zetta</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>0.000000000000000000000001</td>
<td>yocto</td>
<td>$10^{24}$</td>
<td>1,000,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
</tr>
</tbody>
</table>

- The principal metric prefixes.
## Metric Units (1)

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>0.001</td>
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</tr>
<tr>
<td>$10^{-6}$</td>
<td>0.000001</td>
<td>micro</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>0.00000001</td>
<td>nano</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>0.0000000001</td>
<td>pico</td>
</tr>
<tr>
<td>$10^{-15}$</td>
<td>0.000000000001</td>
<td>femto</td>
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<tr>
<td>$10^{-18}$</td>
<td>0.000000000000001</td>
<td>atto</td>
</tr>
<tr>
<td>$10^{-21}$</td>
<td>0.000000000000000001</td>
<td>zepto</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>0.000000000000000000001</td>
<td>yocto</td>
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The principal metric prefixes
## Metric Units (2)

<table>
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<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
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<tbody>
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<td>$10^3$</td>
<td>1,000</td>
<td>Kilo</td>
</tr>
<tr>
<td>$10^6$</td>
<td>1,000,000</td>
<td>Mega</td>
</tr>
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<td>$10^9$</td>
<td>1,000,000,000</td>
<td>Giga</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>1,000,000,000,000,000</td>
<td>Tera</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>1,000,000,000,000,000,000</td>
<td>Peta</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>1,000,000,000,000,000,000,000</td>
<td>Exa</td>
</tr>
<tr>
<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>1,000,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
</tr>
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The principal metric prefixes