Revolutions in Communications

- Telegraph
- Telephone
- Radio
- Television
- Commercialization of the Internet
  - Differences from previous revolutions?
  - Potential applications?

Goals of CSC 335

- Learn the fundamentals of computer networking.
- Understand how these fundamentals are applied in real networks, in particular, the Internet.
- Understand the relationship between theory and practical design issues in network hardware and software.
- Gain an in-depth understanding of how network applications software is supported by underlying protocols.
- Gain hands-on experience with network programming.
- Learn that computer networks evolve.
- Assigned reading: Tanenbaum, Chapter 1

Definitions

- Definition: A computer network is an interconnected collection of autonomous computers.
  - Two computers are interconnected if they are able to exchange information.
  - Two computers are autonomous if they capable of operating independently of one another, that is, neither is capable of forcibly starting, stopping, or controlling the other.
- What does this definition exclude?
  - master/slave systems, in which one computer controls several others
  - single-host network, consisting of a single computer with an attached collection of terminals.
  - multicomputers, such as hypercubes, which normally operate as a back-end to a host system and in which processors are not mutually suspicious or autonomous
- In terms of (operating) systems, some confusion between network systems and distributed systems

Network Systems

- An interconnection of computers through a communication subnet
- The user is aware of the networking of different computers
- Network services
  - remote login
  - remote file transfer
  - remote job execution
  - mail service
Distributed Systems

- Combination of an interconnection of computers and distributed control programs
- User sees an integrated service environment; distributed system is hidden from the user
- Provides location-independent services
- Allows concurrent processing and greater sharing of resources
- Permits development of distributed application programs
- Ongoing problems in distributed systems
  - load balancing
  - fault-tolerance
- How to classify a collection of workstations connected to a file server?

Reasons for Computer Networks

- Human communication
  - electronic mail
  - “news” services and bulletin boards
  - conferencing, groupware
- Resource sharing
  - shared data
  - common access to special resources, such as high-performance systems or scientific equipment
  - load sharing using geographically distributed processors
- Improved reliability
  - replication of files
  - redundancy or resiliency of processes
  - is this goal being met?
- Economy
  - multiple workstations are less expensive than a single mainframe
  - allows the total processing power to be increased gradually
  - success of NOWs

Network Services

- Human access to remote information
- Integrated human-to-human communication
- Interactive entertainment
- Integrated process-to-process communication

Client-Server vs Peer-to-Peer

- Client-server:
  - server: powerful computer on which data is stored
  - client: simpler computer used by someone to access server
- Peer-to-peer: no fixed clients or servers

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Mobile Uses

Mobile computation in various forms is growing very fast...

- Wireless connectivity is an important enabling technology
  - Cellular networks
  - WiFi hotspots

- Common applications
  - Text messaging
  - GPS
  - Near field communication
  - Sensor networks

Social/Legal Issues Regarding...

- Internet services
- Telephone services
- Web services
- Others/Combinations

Classes of Interconnected Processors

- Shared-memory multiprocessors
- Non-shared memory multiprocessors
  (multicomputers)
- Personal area networks
- Local area networks
- Metropolitan area networks
- Wide-area (long haul) networks
- Internetworks

Multiprocessors and Multicomputers

- Shared-memory multiprocessors
  - usually connected by a bus
  - share memory and communicate through it
  - share I/O devices
  - examples of bus architectures: Sun Servers, dual-processor PCs, etc.
  - examples of interconnection network architectures: BBN butterfly, many research projects

- Distributed-memory multiprocessors
  (multicomputers)
  - connected to “front-end” host
  - regular (usually multiple-hop) topology
  - point-to-point or multipoint links
  - do not share memory
  - communicate via messages
  - example: NCUBE, Intel Paragon, Cray T3D, CM-5
Shared Memory Interconnects

(a) single bus network

(b) two-level hierarchical buses

(c) four-bus network

Example Multicomputer Topologies

(a) 2-ary 4-cube (hypercube)

(b) 3-ary 2-cube (torus)

(c) 3 x 3 x 3 3D mesh

Types of Computer Networks

- Local Area Networks (LANs)
  - within a building or campus
  - usually based on broadcast channels
  - often connected via gateway to wide area network
  - Examples: (Fast) Ethernet, FDDI ring, Myrinet, ATM LANs
  - Bit rates: 10-1000 Mbps

- Metropolitan Area Networks (MANs)
  - covers area of a city
  - usually based on LAN technology
  - Example: cable TV-based network

Example LANs and MANs

LAN topologies: (a) bus (b) ring.

Other major type(s) of LANs?

Architecture of cable TV MAN:
Types of Computer Networks (cont.)

- Wide Area (Long Haul) Networks
  - may cover continent or planet
  - most communication links are point-to-point
  - usually organized as a “subnet” to which hosts have access
  - switching elements are generically referred to as routers

Communication Subnet

- Physical Architecture
  - transmission lines
    - channels, trunks
    - physical transmission media
  - switching elements
    - connect two or more transmission lines
    - provide message forwarding
    - previously called IMPs (interface message processors)

Wireless Networks

- Cordless telephones
- Analog cellular telephone
- Digital cellular telephone
- Personal communication networks
- System interconnection
- Wireless LANs
- Wireless WANs

Many developments are taking place in both wired and wireless networks. In CSC 335, we will focus on wired networks.
Internetworks

- Definition: An internetwork, or internet, is a unified, cooperative interconnection of networks that supports a universal communication service. Software hides the low-level network differences from the user and application programs; the interconnected networks appear as a single large network.
  - component networks may be LANs, MANs, or WANs
  - gateway nodes are used to interconnect different networks
  - a gateway has at least two addresses, one on each network
- The canonical example of an internet connects almost all major businesses, universities, countries, etc. It is derived from the ARPANET and is usually called, simply, the Internet. The Internet employs the TCP/IP Protocol Suite, developed with support from DARPA.

Network Architecture

- A set of layers and protocols
- Peer processes
  - the entities making up the corresponding layers on different machines
- Protocol
  - a set of rules governing the format and meaning of the information that is exchanged by the peer processes within the same layer
- Layer interaction
  - each layer offers primitive operations and services to higher layers
  - the interface between each pair of adjacent layers defines these primitives and services
  - interfaces should be clean and well-defined
- Why a layered architecture?
- Potential disadvantage of layered approach?

Layered Network Architecture

- Layers on the sending side may add headers, add trailers, or partition messages as they proceed down the stack.
- Layers on receiving sending side remove headers and trailers, and may combine segments as they proceed up the stack.
- Example information in headers?
- Example information in trailers?
- Why do some layers partition messages?
Layer Design Issues

- Every layer requires a mechanism for connection establishment and termination, the former entailing some form of addressing.
- Rules for data transfer
  - simplex communication - data only in one direction
  - half duplex communication - data both directions, but not simultaneously
  - full-duplex communication - data concurrently in both directions
- Error detection and correction
- Ordered delivery (sequencing)
- Fragmentation and reassembly
- Flow control
- Multiplexing and demultiplexing
- Addressing and routing
- Connection-oriented or connectionless

Network Services

- Most network services can be classified as either connection-oriented or connectionless.
- Connection-oriented service
  - real world example: phone call
  - establish connection, use it, disconnect
  - reliable connection-oriented service
    - cyberspace example: file transfer
    - message sequences - message boundaries preserved
    - byte streams - message boundaries not preserved
  - unreliable connection-oriented service
    - example?
    - why unreliable?
- Connectionless service
  - each message routed independently through system
  - real world example: postal letter
  - cyberspace example?
  - datagram service - no acknowledgement
  - acknowledged datagram service
  - request-reply service - ack contains answer
- Connection-oriented vs. connectionless service depends on the layer of the protocol stack under consideration.
- These services may be “mixed and matched” along the protocol stack.

Network Services (cont.)

OSI Reference Model

- ISO defined a seven layer model
- Open Systems Interconnection (OSI) Reference Model
- Guidelines
  - Each layer well-defined
  - Minimize information flow across layer boundaries
  - Target layers for standardization
- OSI has not come to dominate computer networking, as some had once expected
- It is still useful as a pedagogical tool, however. (yeah, right, how not to develop a networking standard...)
OSI Reference Model

- Lower four layers are concerned with providing reliable end-to-end communication
- Upper three layers provide user-oriented services.

Layer          | Name of unit exchanged
---------------|---------------------------
Presentation   | Application protocol      |
Application    | Presentation protocol     |
Session        | Session protocol          |
Transport      | Transport protocol        |
Network        | Communication subnet boundary |
Data link      | Internal subnet protocol  |
Physical       | Network                   |
Host A         | Router                    |
                  | Data link layer host-router protocol |
                  | Physical layer host-router protocol |
Host B         | Router                    |
                  | Data link layer host-router protocol |
                  | Physical layer host-router protocol |

OSI Reference Model (cont.)

- Network Layer
  - Controls operation of the subnet
  - Most important function is routing of packets through the subnet
  - Also handles congestion within the network
  - Has responsibility for billing customers for use of subnet
  - Must provide internetworking of both homogeneous and heterogeneous networks
  - Thin or non-existent in broadcast networks
  - Most OSI network protocols are connection-oriented

- Transport Layer
  - Provides host-to-host connections
  - Implements packetization
    - why?
    - implications at receiver?
  - Supports multiplexing and demultiplexing

OSI Reference Model (cont.)

- Session Layer
  - Support user connections
  - Examples?

- Presentation Layer
  - Provides general solutions to common requests
  - Examples?

- Application Layer
  - Common protocols for heterogeneous systems
  - Examples?
**OSI Nomenclature**

- **Acronyms**
  - SAP - Service Access Point
    - place where one layer can access lower layer
  - SDU - Service Data Unit
    - information from higher layer that is passed across network to peer entity
  - ICI - Interface Control Information
    - control information used in communication between adjacent layers
  - IDU - Interface Data Unit
    - SDU + ICI
  - PDU - Protocol Data Unit
    - unit of SDU, plus header, passed across network
  - TPDU, SPDU, APDU layers
    - PDUs for transport, session, and application

**TCP/IP Reference Model**

- Arose from networking research; developed as part of original DOD ARPANET project.
- Four conceptual layers:
  - Application layer: (application programs)
    - choose and utilize an appropriate transport service
  - Transport layer:
    - enables end-to-end communication between applications
    - implements packetization (segmentation)
    - can provide reliability and sequencing
  - Internet layer:
    - provides communication between machines
    - handles routing of datagrams
    - detects and reports problems (errors, congestion)
  - Network interface (host-to-network) layer:
    - encapsulates datagrams in frames and sends over physical network
    - may be a simple device driver
    - may include a data link protocol

**Protocol Layers in TCP/IP**

- All user-oriented services are grouped together as applications.
- Data link and physical layers are grouped together as the network interface
- Better reflects necessary services and software organization found in real systems. How so?

**Specific Protocols in TCP/IP**

- Internet Protocol (IP)
  - basic unit of data transfer is IP datagram
  - unreliable, connectionless datagram delivery among machines
  - performs routing using IP addresses
  - currently undergoing major revision to IPv6
- User Datagram Protocol (UDP)
  - allows processes to send datagrams to one another.
  - unreliable, connectionless, no ordering
  - uses abstraction called protocol port within machine.
- Transmission Control Protocol (TCP)
  - full-duplex, reliable transport service
  - flow control and congestion control
  - stream delivery service, that is, precisely the same sequence of bytes is delivered to the receiver as was transmitted by the sender
  - also uses protocol port to match stream to process
  - does not include details of application interface
Data Flow in a TCP/IP Internet

The TCP/IP Internet

- Motivations
  - □ Most networks are established and maintained by independent entities.
  - □ Recognized need for universal connection for computer networks, as is provided by the phone network for voice
  - □ Implemented in software rather than hardware. Why?
  - □ True or false? No universal hardware network can be built for data.

- Services
  - □ Provides a universal connection and services independent of technology
  - □ Provides end-to-end connections (incl. end-to-end reliability, as required)
  - □ Protocol standards provided at application level (email, ftp, http, etc.)

- The OSI model did not originally include the concept of an internetwork layer. Why?

Shortcomings of OSI Model

- “At the time the second edition of this book was published (1989), it appeared to most experts in the field that the OSI model and its protocols were going to take over the world and push everything else out of the way.” – Tanenbaum, 5th ed., p. 51.

- The above statement epitomizes one of the major reasons for the failure of the OSI model...

- Other reasons:
  - □ Bad timing – “apocalypse of the two elephants”
  - □ Bad design philosophy (technology):
    - ◦ too many, redundant, layers.
    - ◦ ignored connectionless services
    - ◦ in short, based on telephony, rather than data communications
  - □ Bad implementations – poor code quality, compared to excellent work on TCP/IP, which was also free.
  - □ Bad politics...

Shortcomings of TCP/IP

- It does not clearly distinguish the concepts of services, interfaces, and protocols

- It is not general; it is only suitable for describing itself

- The link layer is ill-defined

- The physical and data link layers are combined

- There are many deeply-entrenched ad hoc protocols

- (See Tanenbaum, pp. 53-54)

- Probably the biggest criticism of these protocols is true of almost any software designed for a new technology: the designers did not anticipate the tremendous growth of the Internet. (But, if these protocols had not been so good in the first place, would such growth have occurred, so fast?)

- What is the most critical shortcoming of IPv4 that will be fixed in IPv6?
Brief History of the Internet

- **ARPANET**
  - funded by Defense Advanced Research Projects Agency (DARPA)
  - original 4-node network begun in 1969
  - conventional point-to-point leased lines, fault-tolerant topology
  - switches were called IMPs (Interface Message Processors)

- Early experiments with the ARPANET revealed need for better protocols.

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Brief History of the Internet (cont.)

- **TCP/IP development**
  - 1977-1979: current form evolved through informal meetings
  - 1979-1983: Internet Control and Configuration Board (ICCB) met to guide design of protocols and Internet architecture
  - Circa 1980: beginning of conversion of ARPANET to TCP/IP; ARPANET became backbone of the Internet
  - Distribution strategy: DARPA funded BBN to develop protocols and funded Berkeley to integrate TCP/IP into Unix BSD, which became very widespread. Unix BSD provided a large set of utility programs and network programming primitives (sockets)... for free!
  - 1983: ARPANET split into ARPANET and MILNET
  - Besides universities, many corporations began using TCP/IP, either privately or as part of the Internet
  - Domain Name Service (DNS) added in mid-1980s

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Internet Management

- **IAB**
  - 1983-1989: Internet Activities (or Architecture) Board
  - evolved from a DARPA-specific research group into an autonomous organization
  - divided into task forces
  - proposals for new protocols and documentation distributed in Requests For Comments (RFCs)
  - IAB reorganized in 1989 to account for growth and commercial success of the Internet
  - split into IRTF and IETF

- **IRTF and IETF**
  - IRTF - Internet Research Task Force
    - researchers from earlier IAB
  - IETF - Internet Engineering Task Force
    - represents commercial interests as well
    - divided into working groups
    - Draft Standard (RFC), after implemented and tested, becomes Internet Standard

- Internet Society (1992) – body with elected officials, much like IEEE

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Internet Growth

• Growth
  □ 1990: 3000 active networks, 200,000 computers.
  □ 1992: over 1M hosts
  □ by 1995, tens of thousands of LANs, several million hosts
  □ by 2010, approximately 700 - 800 million (see Hobbes' Internet Timeline)
  □ Size historically grows exponentially

• WWW Revolution
  □ Berners-Lee and Andreesen
  □ WWW and Mosaic/Netscape

• New applications made possible?

• Problems presented by this rapid growth?

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Simplified Internet Architecture

Big picture of Internet architecture:

• Point Of Presence (POP) - location at which customer data enters ISP network
• Home access is DSL, dial-up, or cable modem
• ISPs interact at Internet eXchange Points (IXPs)

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Other Example Networks

• Mobile phone networks
  □ Enables global human communication
  □ Very quickly evolving architecture
  □ Most successful network in the world

• Wireless LANs
  □ Enables rapid use of Internet without rewiring buildings
  □ Security is an ongoing issue
  □ Rapidly evolving architectures

• RFID and sensor networks
  □ Enables monitoring and tracking of objects/activities
  □ Use of chips embedded on objects or in other machines

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3G Mobile Phone Networks (1)

• Basic construction of all cellular networks:

  • First generation: analog; only voice data
  • Second generation: GSM etc. Used digital transmission, mainly offered text messaging
  • Third generation: Primarily, WCDMA, aka UMTS; voice + broadband

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3G Mobile Phone Networks (2)

- Simplified UMTS Architecture:
  - Air interface is based on CDMA
  - Radio access network controls the wireless side
  - Core network carries the traffic

802.11 Wireless LANs (1)

- Construction: Infrastructure-based (a) or ad-hoc (b)
- Uses ISM radio frequency bands

802.11 Wireless LANs (2)

- Multipath Fading:
  - Uses ISM RF bands
  - Construction is APs and clients, although it may be ad hoc

RFID

- Everyday objects being networked:
  - Idea is to embed chips into these objects for tracking purposes
  - All power is supplied by radio frequency contact
  - Issues:
    - Tag differentiation
    - Security
Sensor Networks

- Monitoring aspects of the physical world
- Nodes are battery-powered tiny computers
- Embedded sensors are used to collect data
- Networks may often be self-organizing

IEEE Standards (1)

- 802 working groups

<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>
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<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>

IEEE Standards (2)

- 802 working groups (cont.)

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<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, 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 802.16)</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>

Outline of Remainder of CSC 335

- Physical layer (Chapter 2)
  - theoretical limitations
  - fundamental techniques
- Data link layer (Chapter 3)
  - error correction and detection
  - sliding window protocols
- MAC layer (Chapter 4)
  - basic principles
  - Ethernet and fast Ethernet
  - Wireless Ethernet
- (Inter)Network layer (Chapter 5)
  - routing algorithms; IP: IPv6