What are communication networks?

The equipment (hardware & software) and facilities that provide the basic communication service

- A computer network is a collection of autonomous computers interconnected by a single technology

- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, ...

- Facilities
  - Copper wires, coaxial cables, optical fiber
  - Ducts, conduits, telephone poles ...

How are communication networks designed and operated?
Uses of Computer Networks

- Business Applications
- Home Applications
- Mobile Users
- Social Issues

What applications and services you are familiar?

Client/Server Model - Functionality

- Business Applications of Networks: a network with two clients and one server.

What are the key issues here?

How clients and the server communicate and interact?
Client/Server Model(2) - Reliability

- The client-server model involves requests and replies.

What happens if the reply got lost?

Do you like that your money saving request got done twice?

Client/Server Model(3) - Performance

- The performance of a client-server system is influenced by two factors: the bandwidth of the network (how many bits/sec it can transport) and the propagation latency (how much time it takes for the first bit to get from the client to the server).

Please give an example of a network that exhibits high bandwidth and high latency. Then give an example of one with low bandwidth and low propagation latency.

Propagation delay is independent to the bandwidth, but the distance.
Home Network Applications

- Access to remote information
- Person-to-person communication
- Interactive entertainment
- Electronic commerce

Examples?

What are important things in those applications?

Home Network Applications (2)

- In peer-to-peer system there are no fixed clients and servers.

Why Napster was shut down?
Services & Applications

° Service: Basic information transfer capability
  • Internet transfer of individual block of information
  • Internet reliable transfer of a stream of bytes
  • Real-time transfer of a voice signal

° Applications build on communication services
  • E-mail & web build on reliable stream service
  • Fax and modems build on basic telephone service

° New applications build on multiple networks
  • SMS (short message service) builds on Internet reliable stream service and cellular telephone text messaging

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

Classifications: Size, transmission technology, and topology

Transmission Technology Classification

- Two Types of transmission technology
  - Broadcast links
  - Point-to-point links

- Broadcast Networks have a single communication channel that is shared by all the machines on the network
  - Can a broadcast network support 1-1, 1-many communications? And How?

- Point-to-point networks consist of many connections between individual pairs of machines
  - Can a point-to-point network support 1-many and 1-all communications? And how?

General rule: smaller and geographically localized networks tend to use broadcasting while larger networks usually are point-to-point.
Scale Classification

- Classification of networks 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 motor</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 (LAN)

- LANs are privately-owned networks within a single building or campus of up to a few KMs in size.

- How LANs are distinguished from other networks?
  - Size
  - Transmission technology
  - Topology

How to arbitrate?

Two broadcast networks (a) Bus-based, (b) Ring

What is the benefit from the restricted network size?

What happens if more than one machine want to transmit?
Metropolitan Area Networks (MAN)

- A metropolitan area network based on cable TV.

Is the cable always faster than DSL?

Wide Area Networks (WAN)

- Relation between hosts on LANs and the subnet.

Transmission line: P2P links
Wide Area Networks (2)

- Store-and-forward (packet-switched): a packet is stored in an intermediate router in its entirety, stored there until the required output line is free, and then forwarded.

A stream of packets from sender to receiver.

Must all packets of a message follow the same route?

How packets are forwarded at the router?

Wide Area Networks (3)

- A factor in the delay of a store-and-forward packet-switching system is how long it takes to store and forward a packet through a network. If switching is 10 $\mu$sec, is this likely to be a major factor in the response of a client-server system where the client is in NYC and the server is in LA? Assume the propagation speed in copper and fiber to be 2/3 of the speed of light in vacuum.
Wide Area Networks (4)

- A collection of 4 routers is to be connected by a point-to-point subnet. Between each pair of routers, the designers may put a high-speed line and a low-speed line. If it takes 100ms of computer time to generate and inspect each topology, how long will it take to inspect all of them?

Wireless Networks

Three Categories of wireless networks:

- System interconnection
- Wireless LANs
- Wireless WANs
Wireless Networks (2)

- (a) Bluetooth configuration for system interconnection
- (b) Wireless LAN (802.11)

Wireless Networks (3)

- Wireless WANs
  - The radio network for cell phones (3G)
  - The local multipoint distribution service (802.16)

Bandwidth vs. scope/coverage
Almost all wireless networks hook up to the wired network at some point to provide access to the Internet.

(a) Individual mobile computers  (b) A flying LAN

Home Network Categories

Devices are capable of being networked:

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

What they need to be networked?

Embedded computing + mobile computing $\rightarrow$ ubiquitous computing
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

Networks are organized as a stack of layers/levels, each one built upon one below it.

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

- The philosopher-translator-secretary architecture.

![Diagram of the philosopher-translator-secretary architecture](image)

Protocol Hierarchies (3)

- The relation between the virtual and actual communication and the difference between protocols and interfaces.

![Diagram of protocol hierarchies](image)

What is the effective bandwidth utilization?
Design Issues for the Layers

- Addressing
- Framing
- Error Control
- Flow Control
- Ordering
- Multiplexing
- Routing
- Congestion control
- Quality of Service (QoS)

Connection-Oriented and Connectionless Services

Layers can offer two different types of services to the layer above them: telephone systems vs. postal systems.

<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>

Six different types of service.

What is reliable and unreliable communication? Think about postal services. Can a unreliable service be made reliable by using a network software? Why would anyone actually prefer unreliable to reliable communication?
Service Primitives

- A service is specified by a set of primitives (operations) available to a user process to access the service.

<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.

Life is not so simple. What could be wrong?

Why a connectionless protocol is not used instead?
ACK Strategies

- To transfer a file between two computers, two acknowledgement strategies are possible. In the first one, the file is chopped up into packets, which are individually acknowledged by the receiver. In the second one, the packets are not acknowledged individually, but the entire file is acknowledged when it arrives.

What are advantages and disadvantage of these two strategies?

Services to Protocols Relationship

- A service is a set of primitives (operations) available to a user process to access the service.

- A protocol is a set of rules/agreements governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer (relates to the implementation of a service).

The relationship between a service and a protocol.

Are there any other services implicitly in this figure?
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

Why Layering Architectures?

- Layering simplifies design, implementation, and testing by partitioning overall communications process into parts
  - Information hiding, abstracted data types, data encapsulation
- Protocol in each layer can be designed separately from those in other layers
- Protocol makes “calls” for services from layer below
- Layering provides flexibility for modifying and evolving protocols and services without having to change layers below
- Monolithic non-layered architectures are costly, inflexible, and soon obsolete
OSI Reference Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name of unit exchanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Application</td>
<td>Application APDU</td>
</tr>
<tr>
<td>Interface</td>
<td></td>
</tr>
<tr>
<td>6 Presentation</td>
<td>Presentation PPDU</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Session</td>
<td>Session SPDU</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Transport</td>
<td>Transport TPDU</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Network</td>
<td>Packet</td>
</tr>
<tr>
<td></td>
<td>Frame</td>
</tr>
<tr>
<td>2 Data link</td>
<td></td>
</tr>
<tr>
<td>1 Physical</td>
<td></td>
</tr>
</tbody>
</table>

Physical Layer

- Transfers bits across link

- Definition & specification of the physical aspects of a communications link
  - Mechanical: cable, plugs, pins...
  - Electrical/optical: modulation, signal strength, voltage levels, bit times, ...
  - functional/procedural: how to activate, maintain, and deactivate physical links...

- Ethernet, DSL, cable modem, telephone modems...

- Twisted-pair cable, coaxial cable, optical fiber, radio, ...
### Data Link Layer

- **Transfers frames across direct connections**
  - Groups bits into frames
  - Detection of bit errors; Retransmission of frames
- **Activation, maintenance, & deactivation of data link connections**
- **Medium access control for local area networks**
- **Node-to-node flow control**

![Diagram of Data Link Layer](image)

### Network Layer

- **Transfers packets across multiple links and/or multiple networks**
  - **Addressing** must scale to large networks
  - Nodes jointly execute routing algorithm to determine paths across the network
  - **Forwarding** transfers packet across a node
  - **Congestion control** to deal with traffic surges
  - **Others**: tunneling, fragmentation and reassembly, Connection setup, maintenance, and teardown when connection-based

![Diagram of Network Layer](image)

G = gateway  
H = host
**Transport Layer**

- Transfers data end-to-end from process in a machine to process in another machine
  - **Reliable** stream transfer or quick-and-simple single-block transfer
  - Port numbers for addressing (and multiplexing)
  - Message segmentation and reassembly
  - Connection setup, maintenance, and release
  - End-to-end congestion control vs. node-to-node flow control

What data link layer and transport layer have in common and differ?

**Application & Upper Layers**

- **Application Layer**: Provides services that are frequently required by applications: DNS, web access, file transfer, email...
- **Presentation Layer**: Machine-independent representation of data...
- **Session Layer**: Dialog management, recovery from errors, ...

Incorporated into Application Layer
**Headers & Trailers**

- Each protocol uses a header that carries addresses, sequence numbers, flag bits, length indicators, etc…

---

**The TCP/IP Reference Model**

- **ARPANET**
  - To connect multiple networks in a seamless way, TCP/IP
  - To enable networks survive loss of subnet hardware

---
Protocols and networks in the TCP/IP model initially.

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

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

What is NSF FIND?
Hybrid Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</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>

The hybrid reference model to be used in this book.

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.

What is the vulnerability of the telephone system?
Why the distributed switching system is more reliable?

The subnet consists of minicomputers called IMPs (Interface Message Processors) connected by 56-kbps transmission lines, each connected to at least two other IMPs.

- First store-and-forward switching network

Why the subnet was to be a datagram subnet?
The ARPANET (3)


NSFNET

- To design a successor to the ARPNET that would be open to all university research groups.
  - First TCP/IP WAN

The NSFNET backbone in 1988.
Internet Usage

Traditional applications (1970 – 1990)

- E-mail
- News
- Remote login
- File transfer

What is the glue that holds the Internet together?
What does it actually mean to be on the Internet?

Architecture of the Internet

Overview of the Internet.

What are ISPs for? Who are at the top of the food chain?
**Connection-Oriented Networks: ATM Virtual Circuits**

- A virtual circuit is a connection with resources reserved.

- A Cell is a **small and fixed-size** packet, delivered **in order**.

<table>
<thead>
<tr>
<th>Bytes</th>
<th>5</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A war: why do the telephone companies like connection-oriented and why ARPANET goes for connectionless instead?

---

**The ATM Reference Model**

- The **3D ATM reference model**.

- **CS**: Convergence sublayer
- **SAR**: Segmentation and reassembly sublayer
- **TC**: Transmission convergence sublayer
- **PMD**: Physical medium dependent sublayer
LAN: Ethernet

- Architecture of the original (Xerox) Ethernet.

- DIX (DEC, Intel, Xerox) standard in 1978, a 10-Mbps Ethernet
  - Other LAN standards: token bus and token ring
  - Modern Ethernet is switched based with point-to-point links

In classical Ethernet, what happens if two or more computers all wait until the current transmission completes and then all start at once?

Wireless LANs

- (a) Wireless networking with a base station (802.11, WiFi).
- (b) Ad hoc networking.

Compatible with Ethernet at the data link layer: to send an IP packet over the wireless LAN the same way a wired computer sent an IP packet over Ethernet.

What are typical problems?
Wireless LANs (2)

- The range of a single radio may not cover the entire system

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>0.000000000001</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>0.000000000000001</td>
<td>femto</td>
<td>10^{15}</td>
<td>1,000,000,000,000,000</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</td>
<td>Exa</td>
</tr>
<tr>
<td>10^{-21}</td>
<td>0.000000000000000000000000001</td>
<td>zepto</td>
<td>10^{21}</td>
<td>1,000,000,000,000,000,000,000</td>
<td>Zetta</td>
</tr>
<tr>
<td>10^{-24}</td>
<td>0.000000000000000000000000000000001</td>
<td>yocto</td>
<td>10^{24}</td>
<td>1,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
</tr>
</tbody>
</table>

- The principal metric prefixes.
Example

- An image is 640 X 480 pixels with 2 bytes/pixel. Assume the image is uncompressed. How long does it take to transmit it over a 56-kbps modem channel? Over a 1.5 Mbps DSL?

A Typical Portion of the Internet

Is Internet a computer network?
A Typical Intranet

- Desktop computers
- Print and other servers
- Email server
- Web server
- File server
- Local area network
- Router/firewall
- Other servers
- The rest of the Internet
- The Internet
- Email server
- Desktop computers
- Print

Reading

- Chapter 1 of the textbook.