CS 442
Data Communications

Introduction

What is this course about?

⌘ *Networking*: system for connecting computer using a single transmission technology

⌘ *Internet*: set of networks connected by routers that are configured to pass traffic among any computers attached to networks in the set

⌘ Data transmission - media, data encoding
⌘ Packet transmission - data exchange over a network
⌘ Internetworking - universal service over a collection of networks
⌘ Network applications - programs that use an internet

First, a Brief History of the Internet

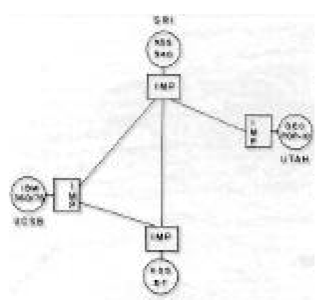
ARPAnet (Advanced Research Projects Agency) in 1969

- •Early computers were *expensive*
  - •Large footprint , Centralized
- •Programs took a long time to run
- •Couldn't afford to put computers everywhere

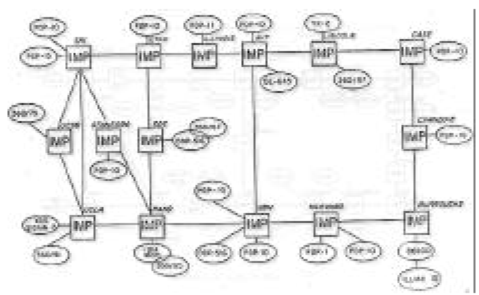
- •Distributed communication system
- •Enable research communication
- •Enable dissimilar computers to share information
- •Reroute information automatically
- •Act as a network of networks; internetworking

Originally just 4 sites!

Original ARPANet Sites



ARPANet in 1972



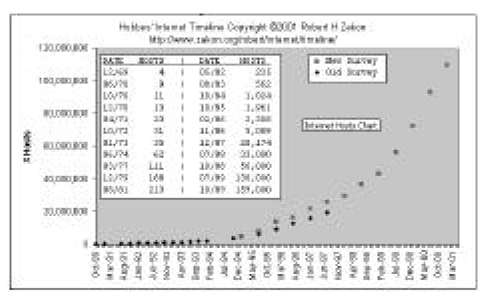
More Internet History

- ⌘1975 – ARPAnet splits into MILNET and NSFNet
- ⌘1979 – Usenet/UUCP over modems
- ⌘1982 – DARPA uses TCP/IP over Ethernet
- ⌘1983 – BSD Unix over Ethernet
- ⌘1984 – DNS
- ⌘1988 – Morris worm
- ⌘1993 – Web starts to take over
  - www.whitehouse.gov
- ⌘1994 – Big business online booms

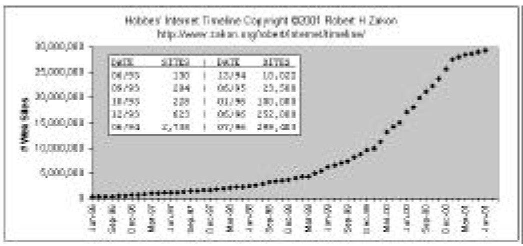
Evolution of the Internet

- ⌘Commercial networks
  - AOL, Compuserve, et. al. grow in the 80's, incorporated into Internet in 90's
- ⌘NSFNet shut down in 1995 in favor of NAP structure, commercial backbones

Exponential Growth
Hosts (Computers connected)



of Web Sites



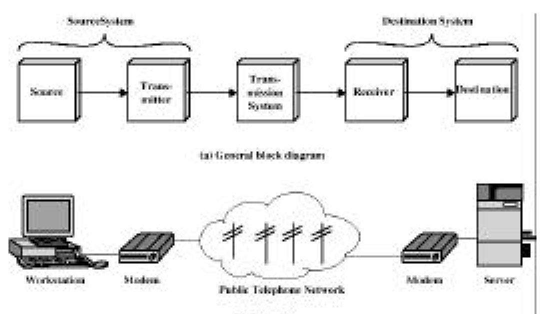
Creation of the WWW

- Technologies required: HTML, Browser
- HTML : Designed by Tim Berners-Lee at CERN. HTML = Hypertext Markup Language, text format for describing layout, multimedia, hyperlinks
- Mosaic : First browser created by Marc Andreessen at NCSA in 1993. Went on to found Netscape.
- HTML, browsers spec continues to change today

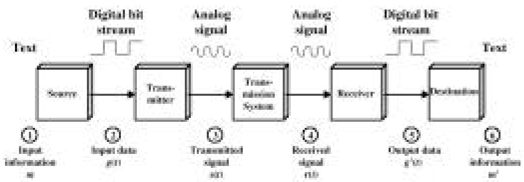
A Communications Model

- Source
  - generates data to be transmitted
- Transmitter
  - Converts data into transmittable signals
- Transmission System
  - Carries data
- Receiver
  - Converts received signal into data
- Destination
  - Takes incoming data

Simplified Communications Model - Diagram



Simplified Data Communications Model



Key Communications Tasks

- ⌘ Transmission System Utilization
- ⌘ Interfacing
- ⌘ Signal Generation
- ⌘ Synchronization
- ⌘ Exchange Management
  - Error detection and correction
  - Flow control
- ⌘ Addressing and routing
- ⌘ Recovery
- ⌘ Message formatting
- ⌘ Security
- ⌘ Network Management

Networking

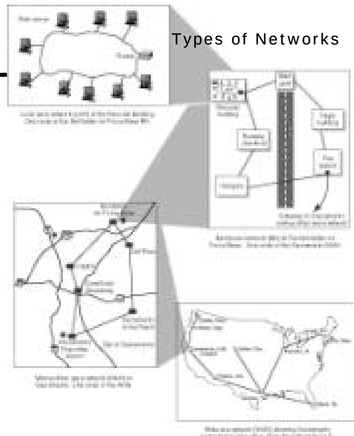
- ⌘Previous simplified model was Point to Point
- ⌘Point to Point communication not usually practical
  - Devices are too far apart
  - Large set of devices would need impractical number of connections
- ⌘Solution is a communications network
  - Many different topologies, or ways to connect the network

Types of Networks

Networks can be classified in many different ways. One of the most common is by geographic scope:

- Local Area Networks (LAN)
- Backbone Networks (BNs)
- Metropolitan Area Networks (MANs)
- Wide Area Networks (WANs)

Types of Networks



Types of Networks

⌘Local Area Networks (LAN)

A group of microcomputers of terminals located in the same general area and connected by a common circuit.

Covers a clearly defined small area, such as within or between a few rooms or buildings.

Generally support data rates of 10 to 100 million bits per second (Mbps).

Types of Networks

⌘Backbone Network (BN)

A larger, central network connecting several LANs, other BNs, metropolitan area networks, and wide area networks.

Typically span up to several miles.

Generally supports data rates from 64 Kbps to 45 Mbps.

Sometimes this term is also applied to WAN’s

Types of Networks

⌘Metropolitan Area Network (MAN)

Connects LANs and BNs located in different areas to each other and to wide area networks.

Typically span from 3 - 30 miles.

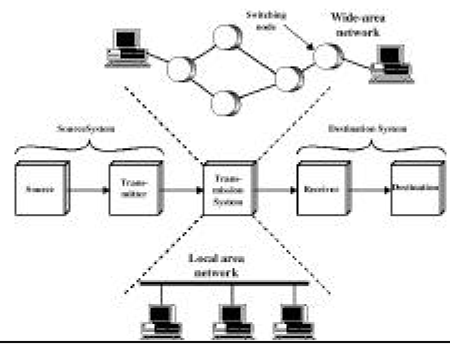
Generally supports data rates of 100 to 1000 Mbps.

Types of Networks

⌘Wide Area Network (WAN)

- Connects BNs and MANs and are usually leased from inter-exchange carriers (IXC's), i.e. common carriers
- Typically span hundreds or thousands of miles.
- Crossing public rights of way
- Generally supports data rates of 28.8 Kbps to 2 Gbps.

Simplified Network Model



How does the data travel?

⌘When data may travel different paths in a network, there are currently two different approaches to implement this:

- Circuit switching
- Packet switching

Circuit Switching

⌘ Dedicated end-to-end communications path established for the duration of the conversation

⌘ Path between the sender and receiver is called a circuit

⌘ Circuit also serves as a constant transmission rate for the duration of the connection – *guaranteed* constant rate

⌘ Might use multiplexing, where multiple devices share the same communications line

⌘ Example of circuit switching: telephone network, ISDN

Packet Switching

- Data may be sent out of sequence
- Small chunks (packets) of data at a time
- Packets passed from node to node between source and destination
- Used for terminal to computer and computer to computer communications
- Packet Switching examples: X.25, Frame Relay, TCP/IP

Circuit vs. Packet Switching

- Packet switching not suitable for real-time services?
- But:
  - Better sharing of bandwidth
    - Consider statistical usage
  - Simpler, more efficient, less costly
- Trend toward packet switching
- ATM: Asynchronous Transfer Mode, Packet switching, but allows constant data rate channel similar to circuit switching... we will examine it more later!

Software and Protocols

- LAN/WAN hardware can't solve all computer communication problems
  - Sending data through raw hardware is awkward and inconvenient - doesn't match programming paradigms well
  - Imagine reading a disk by having to write your own code each time to position the read/write head, seek, etc.
- Network software provides a high-level interface to applications
  - But this software for LAN and WAN systems is large and complicated
- *Layering* is a structuring technique to organize networking software design and implementation

Layers and Protocols

- The software at each layer adheres to a *protocol*
- A *network protocol* is a set of rules that specify the format and meaning of messages exchanged between computers across a network
  - Format is sometimes called *syntax*
  - Meaning is sometimes called *semantics*
- Protocols are implemented by *protocol software*

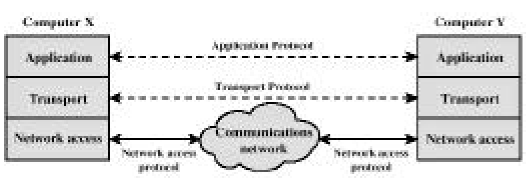
Protocol Suites

- A set of related protocols that are designed for compatibility is called a *protocol suite*
- Protocol suite designers:
  - Analyze communication problem
  - Divide problems into subproblems
  - Design a protocol for each subproblem
- A well-designed protocol suite
  - Is efficient and effective - solves the problem without redundancy and makes best use of network capacity
  - Allows replacement of individual protocols without changes to other protocols

Example: Protocol Architecture

- For example a file transfer problem might use three layers, each is independent with their own protocol
  - File transfer application
    - Transmits file transfer commands, e.g. "Send File X"
  - Communication transport service layer
    - Data integrity, break data into packets
  - Network access layer
    - Interface to hardware, addressing, routing
- If multiple protocols at each layer, since they are independent, one could invoke other protocols!

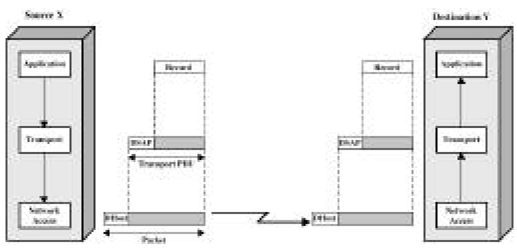
Example: Protocols in Simplified File Transfer App



Example: Protocol Data Units (PDU)

- At each layer, protocols are used to communicate
- Control information is added to the packet of data at each layer
  - Start with a packet at the Application Layer
  - The Transport Layer adds its own header of control information to the packet
    - Might even fragment a big packet into multiple little packets
    - If so, must add sequence numbers, ID of sending application or there may be confusion if multiple apps, data arrives out of sequence
  - The Network layer may in turn add its own header of control information to the Transport Layer packets
    - E.g., addressing information

Example: Operation of a Protocol Architecture



TCP/IP Protocol Architecture

- ⌘ Developed by the US Defense Advanced Research Project Agency (DARPA) for its packet switched network (ARPANET)
- ⌘ TCP/IP are protocols in the suite; there are many other protocols as well
- ⌘ Used by the global Internet
  - Open system, not proprietary (e.g. Appletalk, IPX/SPX, netbeui)
  - Many vendors for the different layers of the stacks
- ⌘ No official model but a working one.
  - Application layer
  - Host to host or Transport layer
  - Internet layer
  - Network access layer or Data Link layer or Device layer
  - Physical layer
- ⌘ Layers is a logical idea - can be ignored in implementation

Application Layer

- ⌘Support for user applications
  - The application software used by the network user, allows the user to define what message are sent over the network.
- ⌘e.g. HTTP, SMTP

Transport Layer (TCP)

- ⌘Takes the message generated by the application layer and performs these functions before passing them to the IP layer.
  1. Attaches application identifier (i.e. the port number)
  2. Splits data into packets for ordering of delivery
  3. Collects message accounting information that can be used to identify how many messages each user has sent and to track errors. This provides the reliable delivery of data.

Internet Layer (IP)

⌘Takes each packet generated by the TCP layer and performs the following functions before passing it to the Data Link / Network Access layer:

- Determines an address for the destination understood by the network
- Systems may be attached to different networks, provides routing functions from source to destination across multiple networks

Device / Data Link / Network Access Layer

⌘Takes the message generated by the IP layer and performs three functions before passing the message on the physical layer.

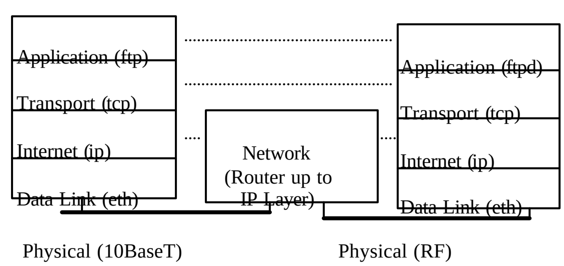
1. It controls the physical layer by deciding when to transmit messages over the media.
2. It formats the message by indicating where messages start and end, and which part is the address.
3. It detects and corrects any errors that have occurred in the transmission of the message.

Physical Layer

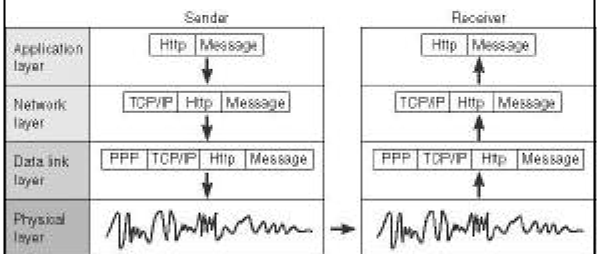
⌘Physical interface between data transmission device (e.g. computer) and transmission medium or network. It transfers a series of electrical, radio, or light signals through the circuit from sender to receiver.

- Characteristics of transmission medium
- Signal levels
- Data rates
- etc.

TCP/IP Layering



Data Encapsulation



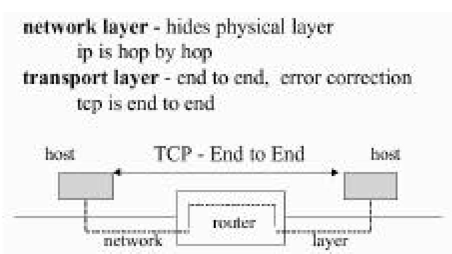
Network layer in this picture includes Transport and Internet Layers

Some Protocols

Application	Email (SMTP/POP) Telnet/rlogin FTP Web/HTTP	DNS NFS SNMP RIP/Bootp	Ping traceroute
Transport	TCP	UDP	
Internet	IP / ICMP / IGMP		
Data Link	Ethernet / ARP SLIP, PPP Token Ring, Xmodem, HDLC		

Transport / Internet Layer

Remember that the layers are independent!



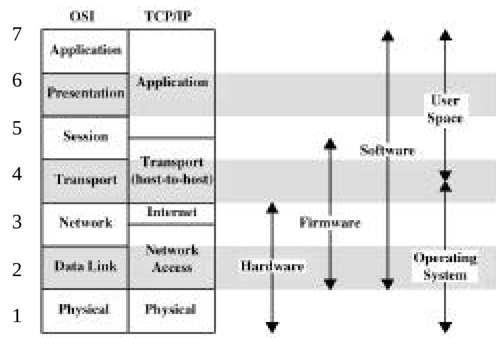
Design of TCP/IP Stack

- ⌘Layers in the protocol physically communicate either up or down the stack
  - Transport layer talks to Internet and Application layer, never directly to the Physical layer
  - Hides details of other layers
- ⌘Layers in the protocol logically communicate with the peer layer of the recipient
  - FTP source client talks to FTPD on recipient
  - TCP source talks to remote endpoint TCP
  - IP source talks to remote endpoint IP, maybe routers

OSI Model

- ⌘Open Systems Interconnection
- ⌘Developed by the International Organization for Standardization (ISO)
- ⌘Seven layers
- ⌘A theoretical system delivered too late!
- ⌘TCP/IP is the de facto standard

OSI v TCP/IP



The Importance of Standards

Standards are necessary in almost every business and public service entity.

The primary reason for standards is to ensure that hardware and software produced by different vendors can work together.

The use of standards makes it much easier to develop software and hardware that link different networks because software and hardware can be developed one layer at a time.

The Standards Making Process

Two types of standards:

- Formal standards are developed by an official industry or government body.
- Defacto standards emerge in the marketplace and supported by several vendors, but have no official standing.

The Standards Making Process

Formal standardization process has three stages

1. Specification stage: developing a nomenclature and identifying the problems to be addressed.
2. Identification of choices stage: those working on the standard identify the various solutions and choose the optimum solution from among the alternatives.
3. Acceptance, the most difficult stage: defining the solution and getting recognized industry leaders to agree on a single, uniform solution

Telecommunications Standards Organizations

- International Organization for Standards (ISO)
  - Member of the ITU, makes technical recommendations about data communications interfaces.
- ITU-T (formally CCITT)
- ATM forum
- Frame Relay forum
- IETF

Telecommunications Standards Organizations

- International Telecommunications Union - Telecommunication Standardization Sector (ITU-TSS)
  - Technical standard setting organization of the UN ITU. Formerly called the Consultative Committee on International Telegraph and Telephone (CCITT)
  - Comprised of representatives of over 150 Postal Telephone and Telegraphs (PTTs), like AT&T, RBOCs, or common carriers.

Other Standards Organizations

- American National Standards Institute (ANSI)
- Institute of Electrical and Electronics Engineers (IEEE)
- Electronic Industries Association (EIA)
- National Institute of Standards and Technology (NIST)
- National Exchange Carriers Association (NECA)
- Corporation for Open Systems (COS)
- Electronic Data Interchange -(EDI) of Electronic Data Interchange for Administration Commerce and Transport (EDIFACT).

Some Standards

- Application Layer
  - HTTP, HTML, POP, MPEG, HTTPS
- Network Layer
  - TCP/IP, IPX/SPX
- Data Link Layer
  - 802.3 Ethernet, Token Ring, PPP, X-modem, H.283
- Physical Layer
  - RS-232, IEEE CAT 5 Cable, V.90, V.34

Standards

- Required to allow for interoperability between equipment
- Advantages
  - Ensures a large market for equipment and software
  - Allows products from different vendors to communicate
- Disadvantages
  - Freeze technology
  - May be multiple standards for the same thing

Probing The Internet: Apps

- Two tools are common:
- ping - sends message that is echoed by remote computer
  - Arguments and behavior varies a bit between Windows/Unix
- traceroute - reports path to remote computer
  - Use tracert in Windows
- Both tools are quite useful for rudimentary debugging of the network. We will examine both in more detail later, but first here is a look at their high-level usage.

Ping Example

- Sends packet to remote computer
- Remote computer replies with echo packet
- Local computer reports receipt of reply
- May include **round trip** time

```
mazzy> ping beowulf.alaska.net
PING beowulf.alaska.net (209.112.130.8): 56 data bytes
64 bytes from 209.112.130.8: icmp_seq=0 ttl=237 time=140.3 ms
64 bytes from 209.112.130.8: icmp_seq=1 ttl=237 time=139.6 ms
64 bytes from 209.112.130.8: icmp_seq=2 ttl=237 time=151.0 ms
64 bytes from 209.112.130.8: icmp_seq=3 ttl=237 time=137.0 ms

--- beowulf.alaska.net ping statistics ---
5 packets transmitted, 4 packets received, 20% packet loss
round-trip min/avg/max = 137.0/141.9/151.0 ms
```

Traceroute Example

- •Sends series of packets along path to destination
  - •Each successive packet identifies next router along path
  - •Packets have a "Time To Live" option that is incremented
  - •Uses *expanding ring* search
- •Reports list of packets

```
mazzy> traceroute styx.gci.net
traceroute to styx.gci.net (208.138.129.15), 30 hops max, 46 byte packets
 1  137.229.114.101 (137.229.114.101)  0.896 ms  0.737 ms  0.694 ms
 2  swa-7206-1.uaa.alaska.edu (137.229.101.2)  1.540 ms  0.836 ms 0.896 m
 3  121-village-net.gci.net (209.165.156.121)  1.589 ms  2.062 ms 1.574 m
 4  * styx.gci.net (208.138.129.15)  5.530 ms *
```

From UAA, try a traceroute to www.alaska.net!

Protocols in Ping/Traceroute

⌘What protocols were involved?

- At a high level...
- Ping : The app sent data in some format that was recognized by the receiver. The receiver was running a program whose responsibility was to echo the packet back.
- Traceroute : The app sent data with increasing TTL fields. There must be some receiver program that will report back "Your packet died here"

Discussion Problem: Email Delivery

⌘Say you want to devise a protocol that can receive data from a client and eventually pass it on to the recipient (i.e. sendmail).

⌘What should be in this protocol? What layer are we talking about? Ideas for defining it? We will look at email a bit more in a homework exercise.