CSE 3461 / 5461:

Computer Networking & Internet Technologies

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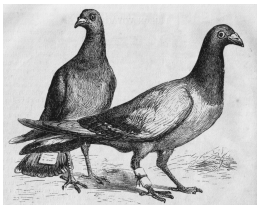
- *The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point*
  "*The Mathematical Theory of Communication*" Claude Shannon

Studying Assignment: Chapters 1 & 2 in the textbook

History of Communication Networks

- Earliest ways of Long Distance Communication
  - Smoke Signals/Fires (Pre-historic)
    - Ancient China
    - Japan
    - Greece …
  - Drums/Horns (Pre-historic)
    - Africa
    - Native Americans …
  - Mail (~600 BC)
    - Persia (600 BC), India (300 BC)
  - Pigeon Post (~500 BC)
    - Persia



History of Communication Networks

- Hydraulic Semaphore System (4th Century BC)
  - Greece (BC); England (1800s AD)
- Mechanical Acoustic Telephone (1672 AD)
  - Britain
- Signal Lamps (1876)
  - Typically in Naval operations
  - Later used Morse code
- First "cordless" telephone (1880)
  - Photophone by Alexander Graham Bell
  - Similar to a modern phone except that it used **modulated light** as a means of wireless communication instead of modulated electricity

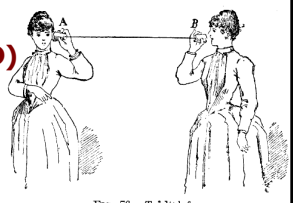
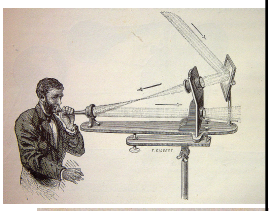
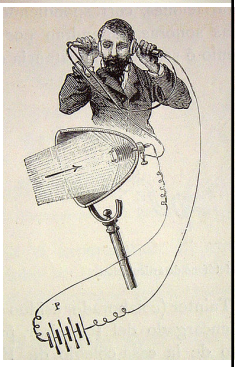


Fig. 76. Trådtelefon.

Photophone

- Illustration of a **photophone transmitter**, showing the path of reflected sunlight, before and after being modulated
  - Under the action of the voice, mirror changes from convex to concave creating modulation of light…
- Illustration of a **photophone receiver**, depicting the conversion of modulated light to sound, as well as its electrical power source.





History of Communication Networks

- **Two "recent" parallel developments**
  - **Telegraph Networks (1837)**
  - **Telephone Networks (1876)**

History of Communication Networks

- **Telegraph Networks**
  - In 1837, Samuel Morse demonstrated a practical telegraph that provided the basis for **telegram** service, the transmission of text messages over long distances [Leon Garcia and Wididja, 2000].
  - The text was encoded using the Morse code into sequences of dots and dashes.
  - Each dot and dash was communicated by transmitting short and long pulses, respectively, of electrical current over copper wire.
  - By relying on two signals, telegraphy made use of a **digital or binary transmission** system.
  - The time required to transmit a message is minimized by having more frequent letters assigned to shorter duration strings (e.g., "E = dot"; "T = dash"; "A = dot dash"; "Z=dash dash dot dot").
  - Precursor of modern digital communication system, in which all transmissions take place in terms of binary signals and all user information must first be converted to binary form.

History of Communication Networks

- **Networks of Telegraph stations**
  - In 1851, the first submarine cable was established between London and Paris, which eventually led to the creation of **networks of telegraph stations** covering entire continents [Leon-Garcia and Wididja, 2000].
  - In these *networks*, a message or telegram would arrive at a telegraph switching station, and an operator would make a *routing* decision based on the destination *address* information.
  - Operator would then *store* the message until the communication line became available to *forward* the message to the next station.
  - This process was repeated until the message reached its destination.
  - This approach is what we would now call **message switching.** And *addressing, routing, storing,* and *forwarding* are all elements of the operation of modern computer networks.

History of Communication Networks

- **Limitations**
  - Information transmission rate (e.g., words per minute) was limited by the rate at which a human operator could enter the sequence of symbols. Typical speeds of 25 to 30 words per minute translated into roughly 20 bps.
  - Also the Morse code uses a variable number of symbols to represent a character. This makes it harder to design automatic decoders.
  - Attempts were made to increase the rate at which information could be transmitted over a single telegraph circuit by multiplexing the symbols from different sources onto the same communication line (e.g., using modulation schemes).
  - Also, attempts were made to represent each character with the same number of symbols (fixed length codes). The most common used code in the United States is the ASCII (American Standard Code for Information Interchange).

Salient Features

- **Digital** Transmission.
- A **Framing** method is required to indicate the beginning and end of messages.
- A system for specifying the destination **address** of messages is required.
- A **routing** procedure that determines the path that a message follows across a network of telegraph stations needs to be determined.

The above elements and functions are in fact also fundamental to the design of modern computer networks.

History of Communication Networks

- **Telephone Networks** (1876)
  - In 1875, Alexander Graham Bell recognized that direct transmission of voice signals over telephone wires was possible.
  - In 1876, Bell developed a system that could transmit the entire voice signal between a pair of telephones.
  - The telephone system was quite different from the telegraph system in that
    - The telegraph required an expert operator with the knowledge of the Morse code
    - While the telephone terminal was simple and required little expertise.
  - Hence, the telephone system which was targeted for direct service to end users (first in business, later for residences), captured a much larger market share (from 1000 phones in 1877 to 250,000 in 1890).
  - **Lesson?**

Telephone Networks

- Circuit Switched (will talk about this later)
- A telephone switch takes a call at one input and transmits it to the appropriate output (for routing).
- Mostly analog line between user and switch (local loop).
- Digital line between switches (change took place in 1998)
- Currently, signaling channel is separate from the communication channel (common channel signaling).
  - Allows flexibility and separation of call control from voice transfer
  - Facilitates services such as call waiting, call forwarding, call back, etc.
  - Problems?

Telephone Networks

- Much less tolerant to failures
- If one signaling line goes down it impacts a large number of connections
- Bell Atlantic and Pacific Bell were hit with a series of failures that resulted in considerable down-time in the early 1990s.

Computer Networks

- First computer network was the semi-automatic ground environment (SAGE) system developed between 1950 to 1956 for air defense systems [Green 1984].
- SAGE consisted of 23 computer networks, each network connecting radar sites, ground-to-air data links, and other locations to a central computer.
- Early computers were extremely expensive, so techniques were developed to allow them to be shared by many users.
- Time-sharing led to the development of **terminal-oriented networks.**
- Architecture: tree topology with with the host computer as the root node.

ARPANET

- As the cost of computers dropped, it became important to connect more than one computer.
- The ARPANET was the first major effort at developing a network to interconnect *computers* over a wide geographic area.
- Funding was provided by the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense (now DARPA).
- Users of this network were actual computers, not terminals, hence it became possible to develop sophisticated networking protocols.
- These protocols were developed at the edge of the network (at the computers) to simplify the operation within the network (*in significant contrast to the telephone network, where the intelligence resides within the network and not the telephone sets*).

ARPANET

- Packet Switched Network
- Concept of store and forward results in more efficient link utilization
- **Why?**

ARPANET

- Packet Switched Network
- Concept of store and forward results in more efficient link utilization
- **Why?**
- Statistical multiplexing possible versus reservation (e.g., FDM or TDM type of multiplexing)
- Tremendous success -- network has grown exponentially.
  - 500 hosts in 1983
  - 5 Million in 1995
  - 20 Million in 1997
  - 170 Million in 2003
  - 450 Million in 2007

Current: > 900M hosts & 2B+ users

Internet Growth

- Years it took to reach 50 Million users
  - Radio: 38 years
  - Television: 13 years
  - Internet (post Web): 4 years

Scope of the Course

- The scope of this course is broad, covering three general areas:
  - — data communications,
  - — networking, and
  - — protocols.
- Data communications deals with the transmission of signals in a reliable and efficient manner.
- Networking deals with the technology and architecture of the communications networks used to interconnect communicating devices.
- A communication protocol is a set of rules governing the exchange of data between two entities
- Protocol architecture is a structured set of modules that implements the communication function

Contemporary Communication

- Trends
  - — traffic growth at a high & steady rate
  - — development of new services
  - — advances in technology
- Significant change in requirements
  - — emergence of high-speed LANs (local area networks)
  - — corporate WAN (wide area network) needs
  - — digital electronics
- What is a computer network? What does it include?
  - — end-systems: workstations, servers, smart-phones
  - — communication links: fiber, copper, radio, satellite
  - — communication nodes: routers, switches, bridges

Simplified Basic Communication Model

Serial communication (bit by bit)

Figure 1.2

(b) Example

Communication Tasks

- Source: Generates data to be transmitted
- Transmitter: Converts data into transmittable signals
- Transmission System: a single line or a complex network
- Receiver: Converts received signal into data
- Destination: Takes incoming data

Table 1.1

Transmission system utilization	Addressing
Interfacing	Routing
Signal generation	Recovery
Synchronization	Message formatting
Exchange management	Security
Error detection and correction	Network management
Flow control	

Networking

- Growth of number & power of computers is driving need for interconnection
- Point to point communication is not usually practical since:
  - devices are too far apart
  - large set of communication devices would need impractical number of connections
- Also seeing rapid integration of voice, data, image & video technologies
- Solution is a communications network
- Two broad categories of communications networks:
  - Local Area Network (LAN)
  - Wide Area Network (WAN)

Wide Area Networks – WANs

- Large geographical area
- Crossing public rights of way
- Rely in part on common carrier circuits
- Typically, a WAN consists of a number of interconnected switching nodes.
- WANs employ point-to-point approach and switching.
- Technologies used:
  - circuit switching
  - packet switching
  - frame relay
  - Asynchronous Transfer Mode (ATM)

Wide Area Networks Technologies

- Circuit switching:
  - Dedicated communications path established for the duration of the conversation; comprising a sequence of physical links between nodes with a logical channel dedicated to the connection
  - E.g. telephone network
- Packet switching:
  - Small chunks (packets) of data at a time
  - Packets passed from node to node between source and destination
  - Data may be received out of sequence
  - Used for terminal to computer and computer to computer communications

Wide Area Networks Technologies (continued)

- Frame relay:
  - evolution from packet switching
  - packet switching systems have large overheads to compensate for errors, but modern systems are more reliable and errors can be caught by end systems
  - most overhead for error control is stripped out
  - user data rates up to 2Mbps
- Asynchronous Transfer Mode – ATM:
  - evolution of frame relay
  - little overhead for error control
  - fixed packet (called cell) length
  - designed to work in the range of 10s and 100s of Mbps

Local Area Networks – LANs

- Smaller scope
  - — building or small campus
- Usually owned by same organization as attached devices
- Data rates much higher than those of WAN
- Use broadcasting
- Switched LAN systems are being introduced
  - — switched Ethernet (most common)
    - may be single or multiple switches
  - — ATM LAN
- Wireless LANs
  - — mobility
  - — ease of installation
- **Metropolitan Area Networks – MANs**: Middle ground

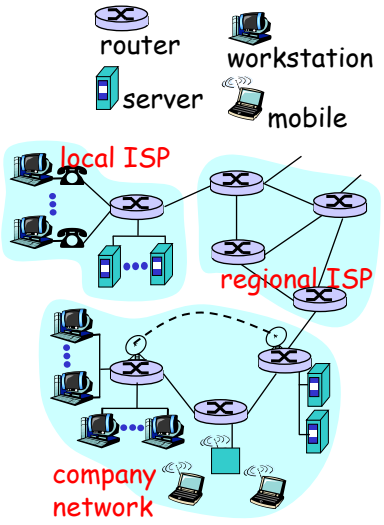
Internet

- Internet evolved from ARPANET (started in late 1960)
- ARPANET:
  - — first operational packet network
  - — applied to tactical radio & satellite nets also
  - — had a need for interoperability
  - — led to standardized TCP/IP protocols

What's the Internet: "nuts and bolts" view A

- millions of connected computing devices: *hosts, end-systems*
  - pc's workstations, servers
  - PDA's phones, toasters

  running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
- *routers:* forward packets (chunks) of data through network



Key Internet Elements

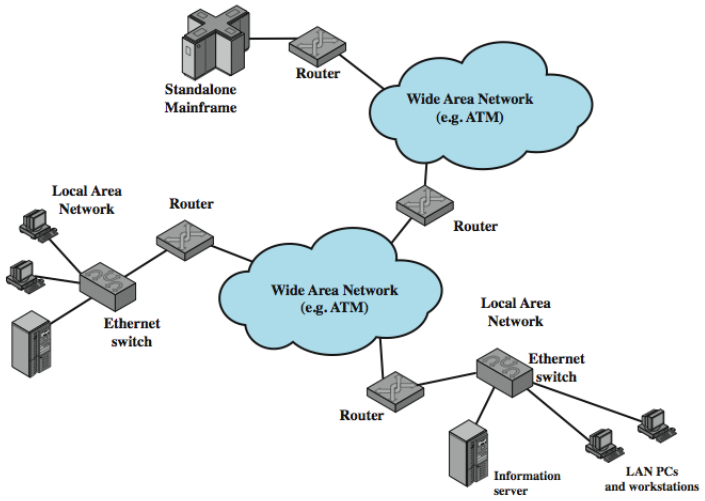


Figure 1.4

Internet Architecture

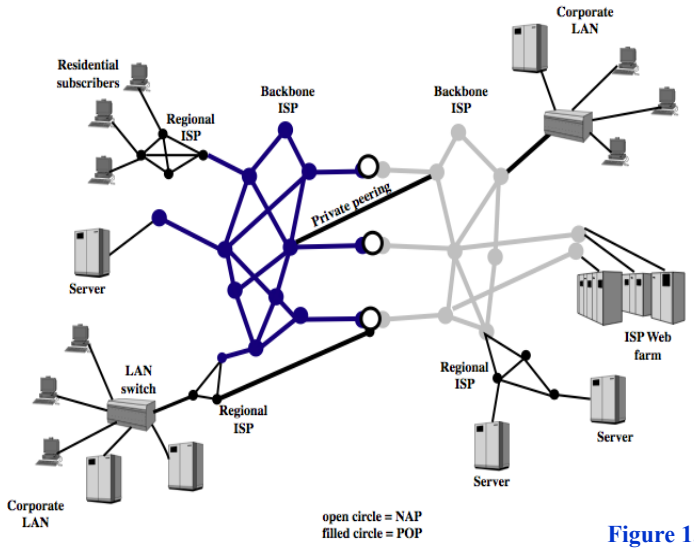
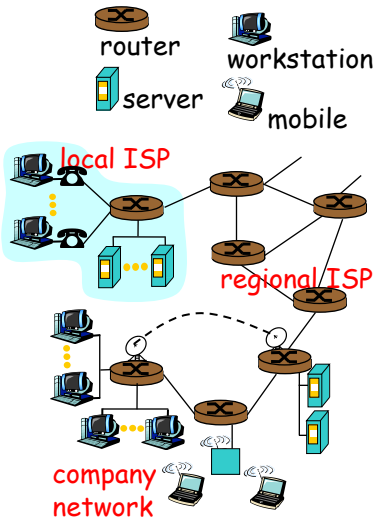


Figure 1.5

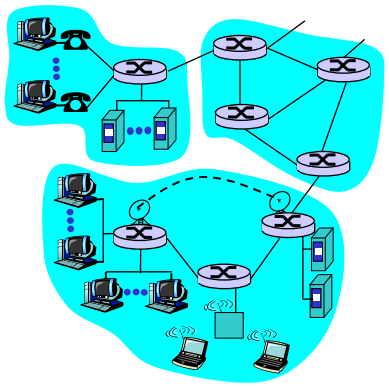
What's the Internet: "nuts and bolts" view B

- *protocols*: control sending, receiving of messages
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet vs. private intranet
- *Internet standards:*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - WWW, email, games, e-commerce, database, voting, file (MP3) sharing
- communication services provided:
  - connectionless
  - connection-oriented



What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

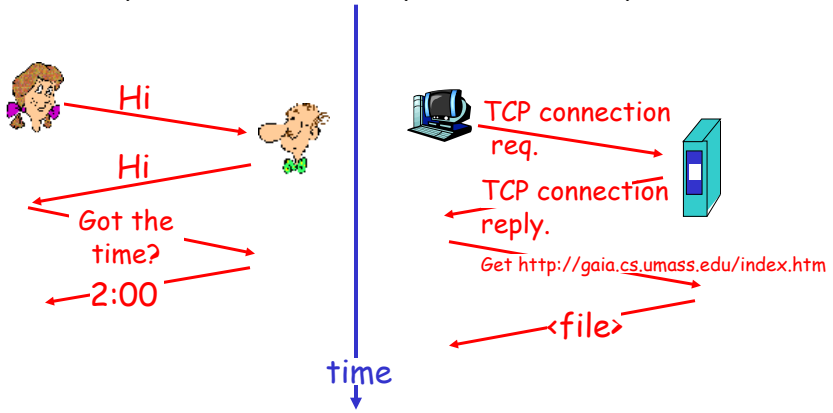
… specific actions taken when messages received, or other events

network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols
- *protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt*

What's a protocol?

a human protocol and a computer network protocol:

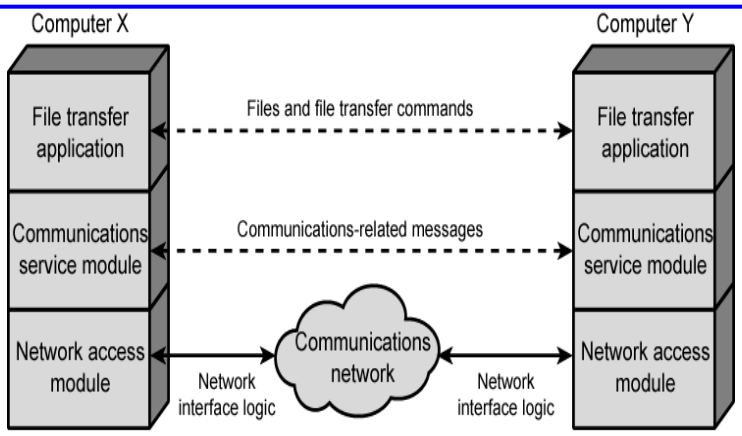


Q: Other human protocol?

Need For Protocol Architecture

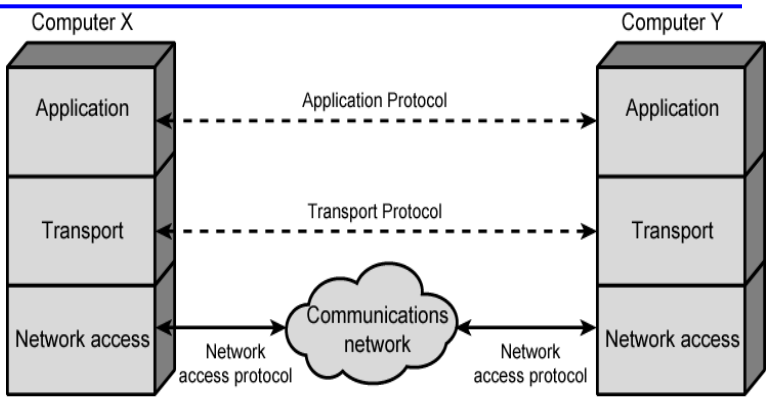
- Example: File transfer
  - source must activate communication path or inform network of destination
  - source must check destination is prepared to receive
  - file transfer application on source must check if destination file management system will accept and store file for his user
  - may need file format translation
- Instead of implementing the complex logic for this as a single module
  - task has to be broken into subtasks
  - implemented separately in layers in stack
  - functions needed in both systems
  - peer layers communicate

Simplified Network Architecture



- Key elements of a protocol
  - syntax: concerns the format of data blocks
  - semantics: includes control info & error handling
  - timing: includes speed matching & sequencing

Protocols in Three Layer Architecture

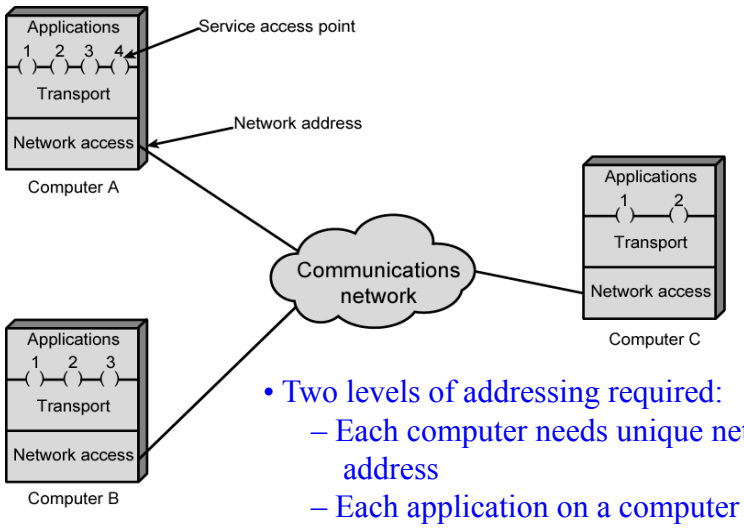


- Protocol architecture is a structured set of modules that implements the communication function
- A communication protocol is a set of rules governing the exchange of data between two entities

Three Layer Model

- Network Access Layer
  - — exchange of data between the computer and the network
  - — sending computer provides address of destination
  - — dependent on type of network used (LAN, packet switched etc.)
- Transport Layer
  - — reliable data exchange
  - — independent of network being used
  - — independent of application
- Application Layer
  - — support for different user applications, e.g. e-mail, file transfer

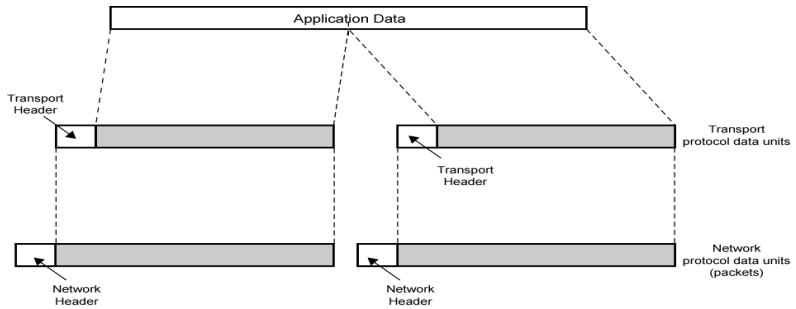
Addressing in Three Layer Architectures



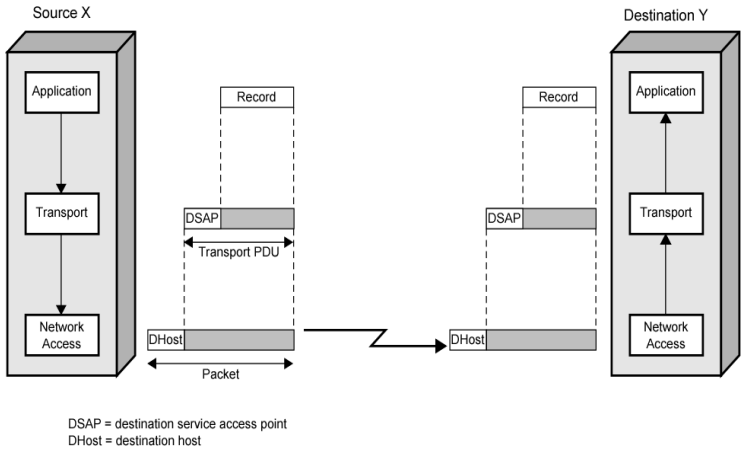
- Two levels of addressing required:
  - – Each computer needs unique network address
  - – Each application on a computer needs a unique address within the computer

Protocol Data Units - PDU

- At each layer, protocols are used to communicate
- Transport layer may fragment user data
  - Each fragment has a transport header with destination SAP, sequence number and error detection code; This gives a transport protocol data unit
- Network layer adds network header with network address for destination computer; This gives a network protocol data unit



Operation of Protocol Architecture



DSAP = destination service access point
DHost = destination host

Standardized Protocol Architecture

- Required for devices to communicate
- Vendors have more marketable products
- Customers insist on standards based equipment
- Two standards:
  - OSI (Open Systems Interconnection) Reference model
    - Developed by the International Organization for Standardization (ISO)
    - A theoretical system delivered too late!
    - Never lived up to early promises
  - TCP/IP protocol suite
    - Most widely used
    - It is the de facto standard

TCP/IP Protocol Architecture

- Developed by the US Defense Advanced Research Project Agency (DARPA) for its packet switched network (ARPANET)
- Used by the global Internet
- Protocol suite comprises a large collection of standardized protocols (by the Internet Activities Board – IAB).
- No official model but a working one:
  - physical layer
  - network access layer (data link layer)
  - internet layer (IP)
  - host to host or transport layer
  - application layer

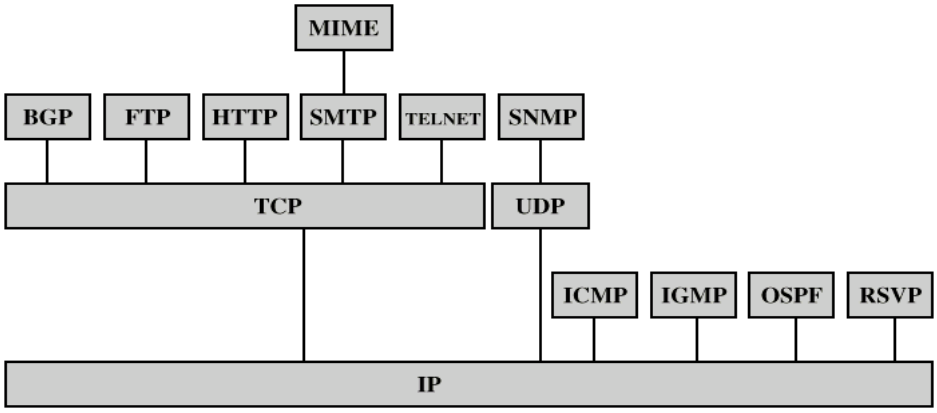
TCP/IP Protocol Suite

- Physical Layer
  - —concerned with physical interface between computer and network
  - —concerned with issues like:
    - characteristics of transmission medium
    - signal levels
    - data rates
    - other related matters
- Network Access Layer
  - —exchange of data between an end system and attached network
  - — concerned with issues like :
    - destination address provision
    - invoking specific services like priority
    - access to & routing data across a network link
    - allows layers above to ignore link specifics

TCP/IP Protocol Suite (continued)

- Internet Layer (IP)
  - — routing functions across multiple networks
  - — for systems attached to different networks
  - — using IP protocol
  - — implemented in end systems and routers
  - — routers connect two networks and relays data between them
- Transport Layer
  - — common layer shared by all applications
  - — provides reliable delivery of data
  - — in same order as sent
  - — commonly uses TCP
- Application Layer
  - — provide support for user applications
  - — need a separate module for each type of application

Some Protocols in TCP/IP Suite



BGP = Border Gateway Protocol
FTP = File Transfer Protocol
HTTP = Hypertext Transfer Protocol
ICMP = Internet Control Message Protocol
IGMP = Internet Group Management Protocol
IP = Internet Protocol
MIME = Multi-Purpose Internet Mail Extension
OSPF = Open Shortest Path First
RSVP = Resource ReSerVation Protocol
SMTP = Simple Mail Transfer Protocol
SNMP = Simple Network Management Protocol
TCP = Transmission Control Protocol
UDP = User Datagram Protocol

Figure 2.5

TCP/IP Concepts

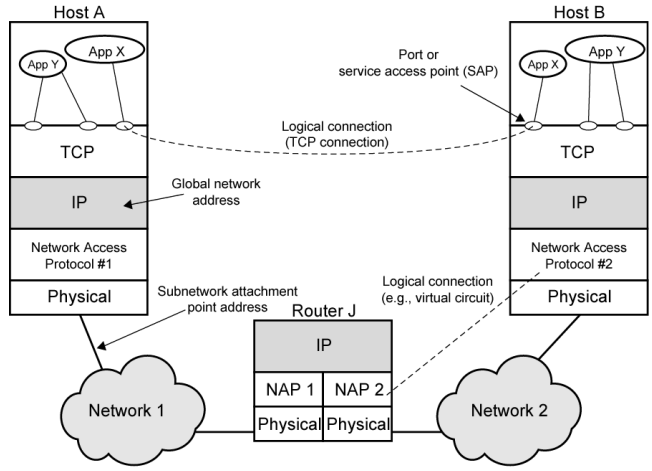


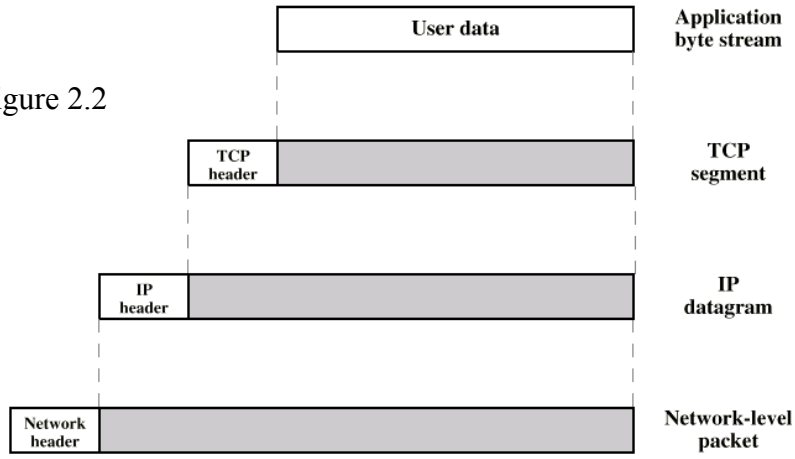
Figure 2.1

Address Requirements

- Two levels of addressing required
- Each host on a subnet needs a unique global network address
  - its IP address
- Each application on a (multi-tasking) host needs a unique address within the host
  - known as a port
- In addition there may be a local network address assigned to a host

PDUs in TCP/IP

Figure 2.2



OSI Layers

- Physical: transmission of unstructured bit stream over physical medium
- Data Link: Higher layers may assume error free transmission
- Network: Transport of information, not needed on direct links and higher layers do not need to know about underlying technology
- Transport: Exchange of data between end systems, error free, in sequence, no losses, no duplicates
- Session: Control of dialogues between applications
- Presentation: data formats and coding, data compression, encryption
- Application: Means for applications to access OSI environment

TCP/IP vs. OSI

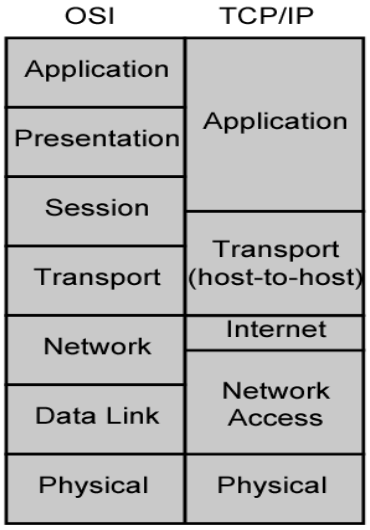
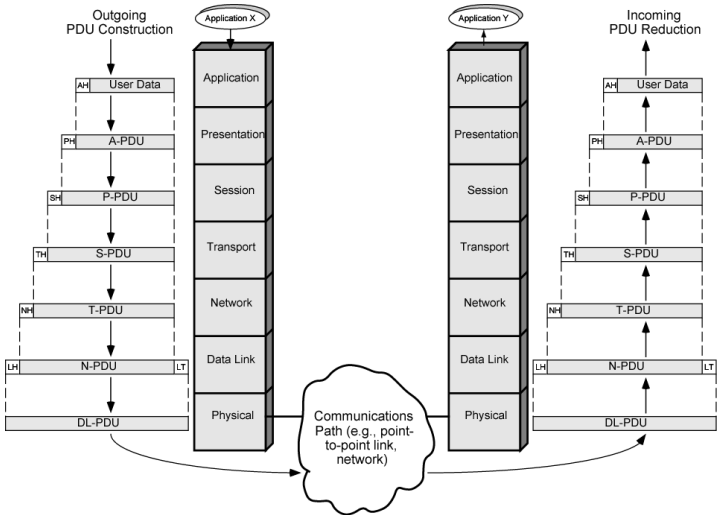
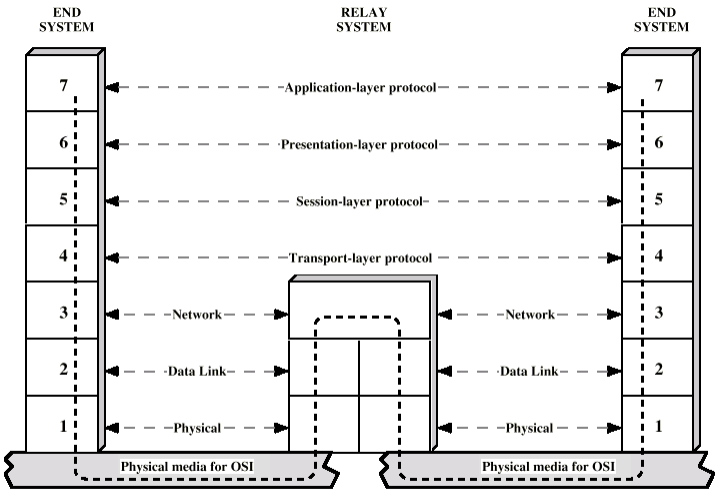


Figure 2.7

The OSI Environment



OSI Protocols



OSI – The Model

- Layered model
- Each layer performs a subset of the required communication functions
- Each layer relies on the next lower layer to perform more primitive functions
- Each layer provides services to the next higher layer
- Changes in one layer should not require changes in other layers
- Services between adjacent layers expressed in terms of primitives and parameters
- Primitives specify function to be performed
- Parameters pass data and control information