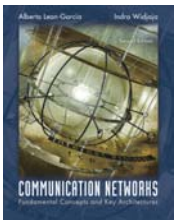
Chapter 1 Communication Networks and Services



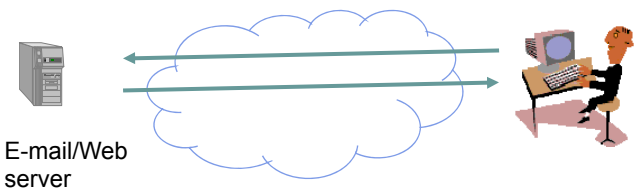
Network Architecture and Services
Telegraph Networks & Message Switching
Telephone Networks and Circuit Switching
Computer Networks & Packet Switching
Future Network Architectures and Services
Key Factors in Network Evolution

1

Communication Services & Applications

- A communication service enables the exchange of information between users at different locations.
- Communication services & applications are everywhere.

E-mail/Web Browsing/messaging



Exchange of text messages/information via servers

2

Many other examples!

- Peer-to-peer applications
  - Napster, Gnutella, KaZaA file exchange
- Audio & video streaming
- Network games
- On-line purchasing
- Text messaging in PDAs, cell phones (SMS)
- Voice-over-Internet
- E-healthcare

3

What is a communication network?

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

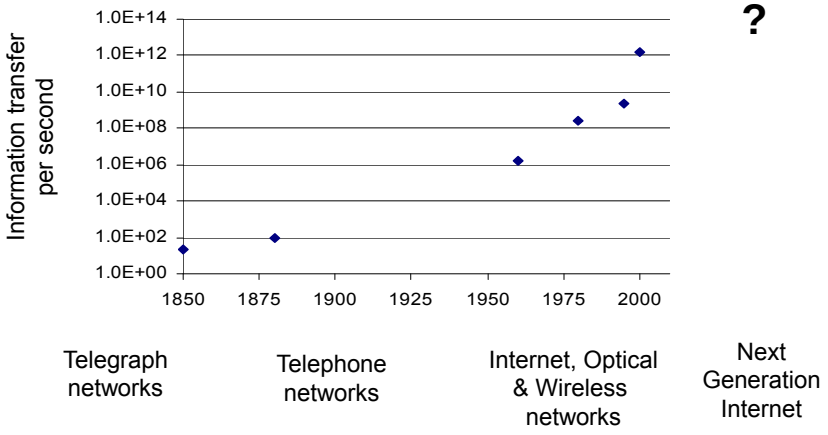
4

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 builds on Internet reliable stream service and cellular telephone text messaging

5

Network Architecture Evolution



6

Network Architecture Evolution

- Telegraph Networks
  - Message switching & digital transmission
- Telephone Networks
  - Circuit Switching
  - Analog transmission → digital transmission
  - Mobile and wireless communications
- Internet
  - Packet switching & computer applications
- Next-Generation Internet
  - Multi-service packet switching network

7

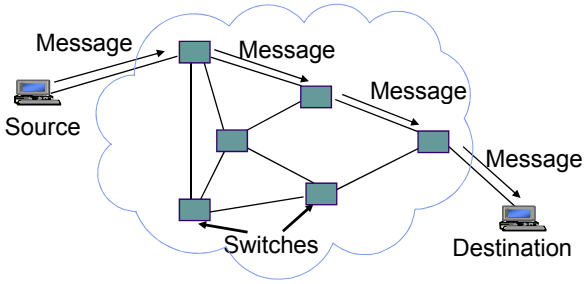
Telegraph Networks

- Telegraph: a message is transmitted across a network using signals
  - Drums, beacons, mirrors, smoke, flags, semaphores…
  - Electricity, light

8

Electric Telegraph Networks

- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Framing, Multiplexing, Addressing, Routing, Forwarding
  - Optical telegraph networks disappeared



9

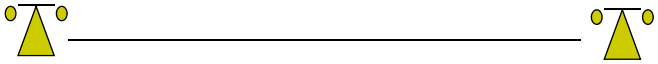
Elements of Telegraph Networks

- Digital transmission
  - Text messages converted into symbols (dots/dashes, zeros/ones)
  - Transmission system designed to convey symbols
- Multiplexing
  - *Framing* needed to recover text characters
- Message Switching
  - Messages contain source & destination *addresses*
  - *Store-and-Forward: m*essages forwarded hop-by-hop across network
  - *Routing* according to destination address

10

Bell's Telephone

- Alexander G. Bell (1875) working on harmonic telegraph to multiplexing discovered voice signals can be transmitted directly
  - Microphone converts voice pressure variation (sound) into *analogous* electrical signal
  - Loudspeaker converts electrical signal back into sound
  - Telephone patent granted in 1876
- Signaling required to establish a call
- Bell Telephone Company founded in 1877

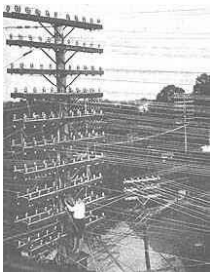


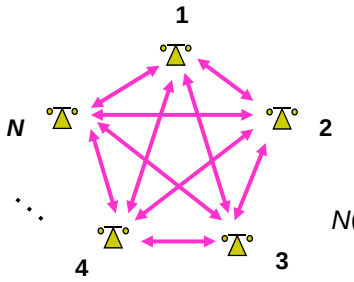
Signaling + voice signal transfer

11

The N^2 Problem

- Initially, p2p direct communications - for *N* users to be fully connected *directly*
  - How many connections required? key problems?
    - Requires too much space for cables
    - Inefficient & costly since connections not always on



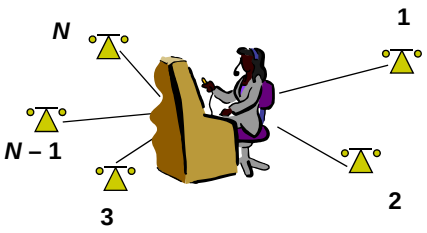


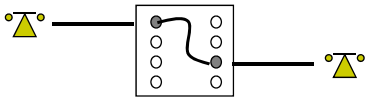
N = 1000
N(*N* – 1)/2 = 499500

12

Circuit Switching

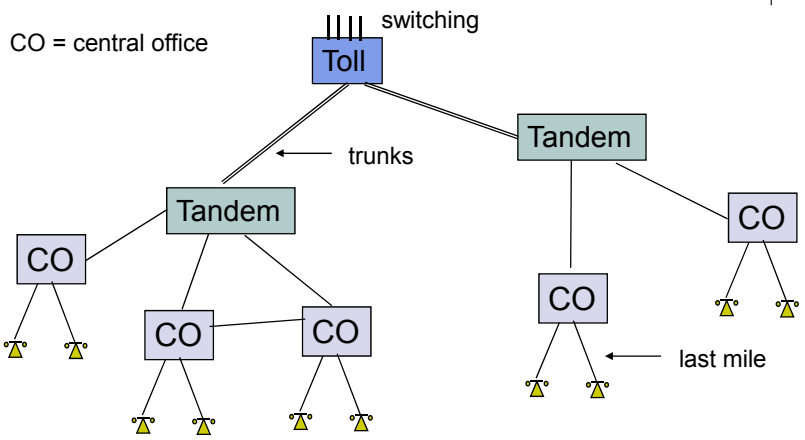
- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish *circuit* to allow electrical current to flow from inlet to outlet
- Only *N* connections required to central office





13

Hierarchical Network Structure



Telephone subscribers connected to local CO (central office)
Tandem & Toll switches connect CO's

14

Digitization of Telephone Network

- Pulse Code Modulation digital voice signal
  - Voice gives 8 bits/sample x 8000 samples/sec = 64×10^3 bps
- Time Division Multiplexing for digital voice
  - T-1 multiplexing (1961): 24 voice signals = 1.544×10^6 bps
- Digital Switching (1980s)
  - Switch TDM signals without conversion to analog form
- Digital Cellular Telephony (1990s)
- Optical Digital Transmission (1990s)
  - One OC-192 optical signal = 10×10^9 bps
  - One optical fiber carries 160 OC-192 signals = 1.6×10^{12} bps!

All digital transmission, switching, and control

15

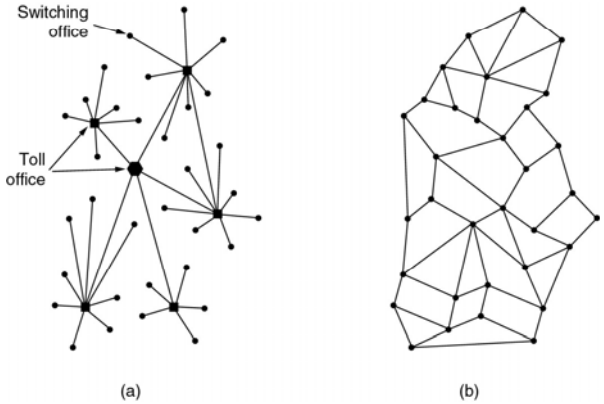
Elements of Telephone Networks

- Digital transmission & switching
  - Digital voice; Time Division Multiplexing
- Circuit switching
  - User signals for call setup and tear-down
  - Route selected during connection setup
  - End-to-end connection across network
  - Signaling coordinates connection setup
- Hierarchical Network
  - Decimal numbering system
  - Hierarchical structure; simplified routing; scalability
- Signaling Network
  - Intelligence inside the network

16

The ARPANET

What is the vulnerability of the telephone system?



- (a) Structure of the telephone system.
- (b) Baran's proposed distributed switching system.

17

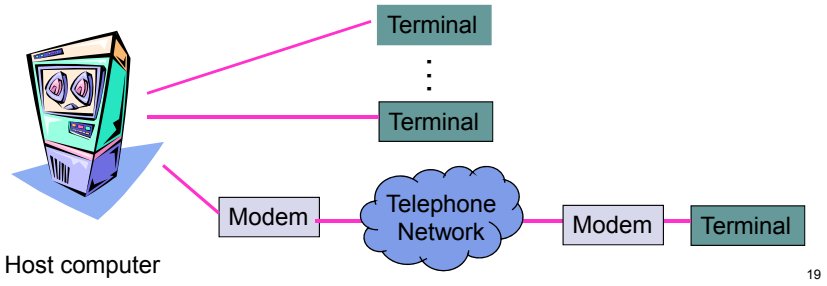
Computer Network Evolution

- *1950s*: Telegraph technology adapted to computers
- *1960s*: Dumb terminals access shared host computer
  - SAGE air defense system, SABRE airline reservation system
  - Tree-topology terminal-oriented networks
- *1970s*: Computers connect directly to each other
  - ARPANET packet switching network
  - TCP/IP Internet protocols
  - Ethernet local area network
- *1980s & 1990s*: New applications and Internet growth
  - Commercialization of Internet
  - E-mail, file transfer, web, P2P, . . .
  - Internet traffic surpasses voice traffic

18

Terminal-Oriented Networks

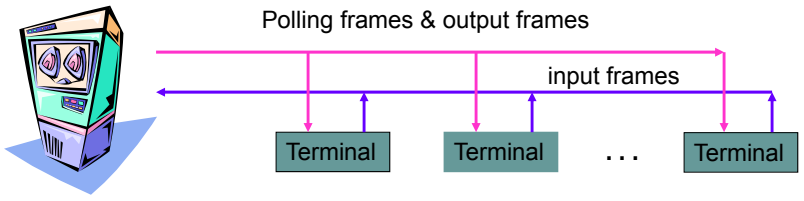
- Early computer systems very expensive
- Time-sharing methods allowed multiple terminals to share local computer
- Remote access via telephone modems



19

Medium Access Control

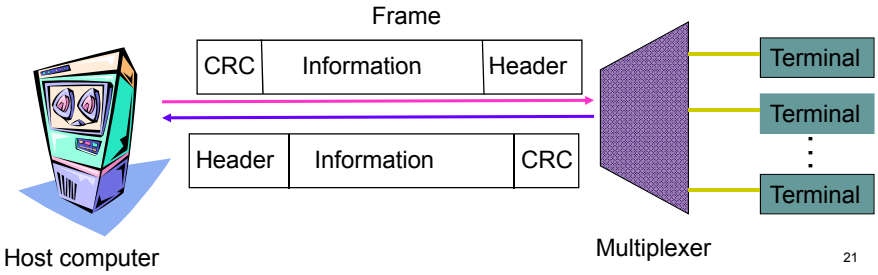
- Dedicated communication lines were expensive
- Terminals generated messages sporadically
- Frames carried messages to/from attached terminals
- Address in frame header identified terminal
- *Medium Access Controls* for sharing a line were developed
- Example: Polling protocol on a multi-drop line



20

Multiplexing

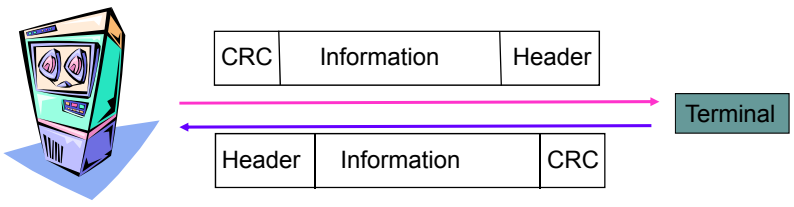
- Multiplexer allows a line to carry *frames* that contain messages to/from multiple terminals
- Frames are buffered at *multiplexer* until line becomes available, i.e. store-and-forward
- *Address* in frame header identifies terminal
- Header carries other *control* information



21

Error Control Protocol

- Communication lines introduced errors
- Error checking codes used on frames
  - "Cyclic Redundancy Check" (CRC) calculated based on frame header and information payload, and appended
  - Header also carries ACK/NAK control information
- Retransmission requested when errors detected



22

Computer-to-Computer Networks

- As cost of computing dropped, terminal-oriented networks viewed as too inflexible and costly
- Need to develop flexible computer networks
  - Interconnect computers as required
  - Support many applications
- Application Examples
  - File transfer between arbitrary computers
  - Execution of a program on another computer

23

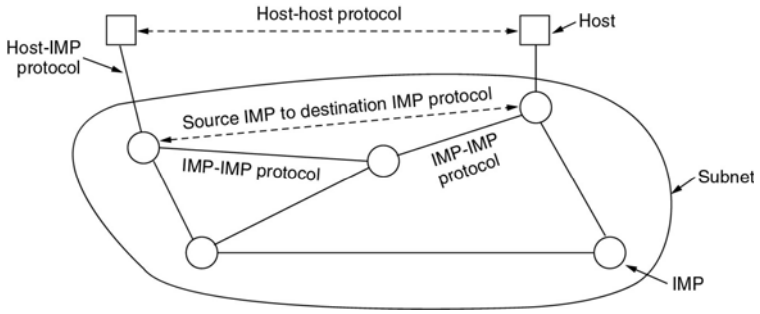
Packet Switching

- Network should support multiple applications
  - Transfer arbitrary message size
  - Low delay for interactive applications
  - But in store-and-forward operation, long messages induce high delay on interactive messages
- Packet switching introduced
  - Network transfers packets using store-and-forward
  - Packets have maximum length
  - Break long messages into multiple packets
- ARPANET testbed led to many innovations

24

The ARPANET

- The subnet consists of computers called IMPs (Interface Message Processors) connected by 56-kbps lines, each connected to at least two other IMPs: first store-and-forward packet switching network (datagram-oriented)

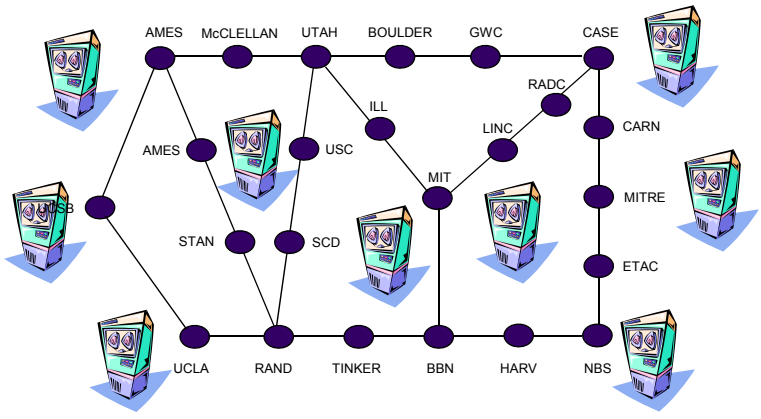


The original ARPANET design.

25

ARPANET Applications

- ARPANET (NSF-NET) introduced new applications
  - Email, remote login, file transfer, …



26

Scale Classification

- Classification of networks by scale.

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

27

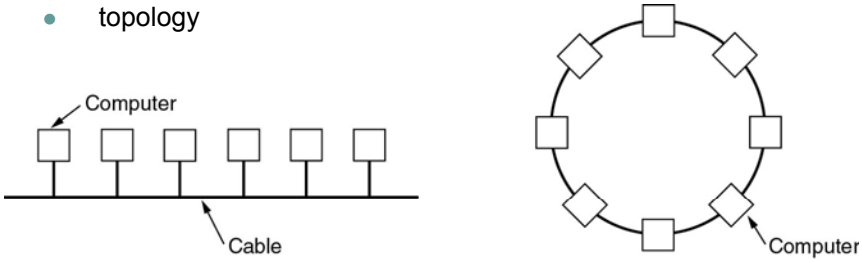
Ethernet Local Area Network

- In 1980s, affordable workstations available
- Need for low-cost, high-speed networks
  - To interconnect local workstations
  - To access local shared resources (printers, storage, servers)
- Low cost, high-speed communications with low error rate possible using coaxial cable
- Ethernet is the standard for high-speed wired access to computer networks

28

LAN Classifications

- How LANs are distinguished from other networks?
  - Scale, 10m – 1 Km
  - transmission technology
  - topology



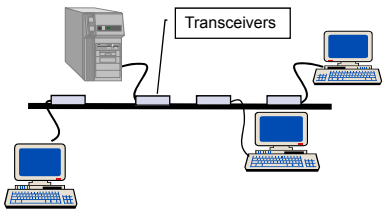
Two broadcast networks (a) Bus, (b) Ring

What is the benefit from the restricted network size?
What happens if more than one machine want to transmit?

29

Ethernet Medium Access Control

- Network interface card (NIC) connects computers to LAN
- Each NIC has globally unique address
- Frames are broadcast into coaxial cable
- NICs listen to medium for frames with their address
- Transmitting NICs listen for collisions with other stations, and abort and reschedule retransmissions



30

The Internet

- Different network types emerged for data transfer between computers
- ARPA also explored packet switching using satellite and packet radio networks
- Each network has its protocols and is possibly built on different technologies
- *Internetworking protocols* required to enable communications between computers attached to *different* networks
- ***Internet***: a network of networks

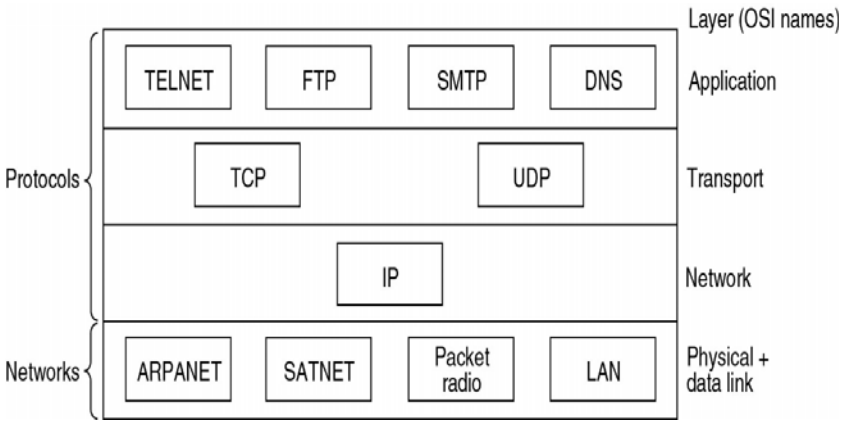
31

What is a protocol?

- Communications between computers requires very specific unambiguous rules
- A protocol is a set of rules that governs how two or more communicating parties are to interact
  - Internet Protocol (IP)
  - User Datagram Protocol (UDP)
  - Transmission Control Protocol (TCP)
  - HyperText Transfer Protocol (HTTP)
  - Simple Mail Transfer Protocol (SMTP)

32

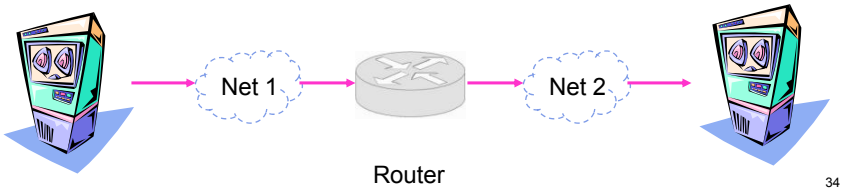
TCP/IP Suite



33

Internet Protocol (IP)

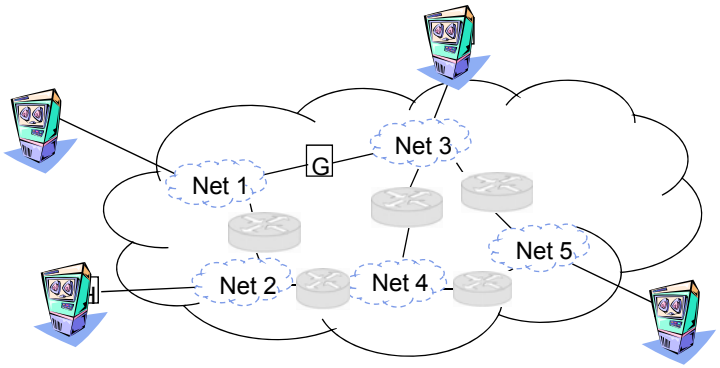
- *Routers (gateways)* interconnect different networks
- Host computers prepare IP packets and transmit them over their attached network
- Routers forward IP packets across networks
- *Best-effort* IP transfer service, no retransmission



34

Addressing & Routing

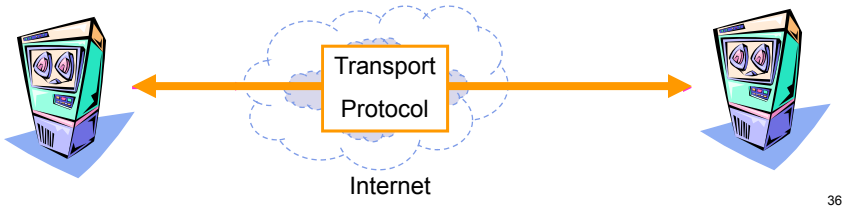
- Hierarchical address: Net ID + Host ID
- IP packets routed according to Net ID
- Routers compute routing tables using distributed algorithm



35

Transport Protocols

- Host computers run two transport protocols on top of IP to enable process-to-process communications
- *User Datagram Protocol* (UDP) enables best-effort transfer of individual block of information
- *Transmission Control Protocol* (TCP) enables reliable transfer of a stream of bytes



36

Names and IP Addresses

- Routing is done based on 32-bit IP addresses
- Dotted-decimal notation
  - 128.100.11.1
- Hosts are also identified by name
  - Easier to remember
  - Hierarchical name structure
  - tesla.comm.utoronto.edu
- Domain Name System (DNS) provided conversion between names and addresses

37

Internet Applications

- All Internet applications run on TCP or UDP
- TCP: HTTP (web); SMTP (e-mail); FTP (file transfer; telnet (remote terminal)
- UDP: DNS, RTP (voice & multimedia)
- TCP & UDP incorporated into computer operating systems
- Any application designed to operate over TCP or UDP will run over the Internet!!!

38

Elements of Computer Networks

- *Digital transmission*
- Exchange of *frames* between adjacent equipment
  - Framing and error control
- *Medium access control* regulates sharing of broadcast medium.
- *Addresses* identify attachment to network or internet.
- Transfer of *packets* across a packet network
- Distributed calculation of *routing tables*

39

Elements of Computer Networks II

- *Congestion control* inside the network
- *Internetworking* across multiple networks using routers
- *Segmentation and reassembly* of messages into packets at the ingress to and egress from a network or internetwork
- *End-to-end transport protocols* for process-to-process communications
- *Applications* that build on the transfer of messages between computers.
- *Intelligence is at the edge of the network.*

40

Principal Metric Units

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

41

Links to Information Assurance related Websites

- National Security Agency: http://www.nsa.gov/
- NIST, Computer Security Division, Computer Security Resource Center: http://csrc.nist.gov/
- Common Criteria for Information Technology Security Evaluation: http://www.commoncriteriaportal.org/
- U.S. Department of Homeland Security: http://www.dhs.gov/
- ITU (International Telecommunication Union: http://www.itu.int/
- Internet Society (ISOC): http://www.isoc.org/
- The Internet Engineering Task Force (IETF): http://www.ietf.org/
- Internet Architecture Board (IAB): http://www.iab.org/
- International Organization for Standardization (ISO): http://www.iso.org
- IEEE Computer Society: http://www.computer.org
- Association for Computing Machinery (ACM): http://www.acm.org/
- USENIX: The Advanced Computing Systems Association: http://www.usenix.org/