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Textbook

- Text:
  - "Data Communications and Networking," by B. Forouzan, McGraw Hill, 2013
- Reference:
  - J. Kurose and K. W. Ross, "Computer Networking," Pearson, 2017
  - W. Stallings, "Data and Computer Communications," Prentice Hall, 2013

Course

- Evaluation:
  - Attendance: 10 %
  - Assignment: 25 %
    - HW + Term project
  - Midterm exam: 30 %
  - Final exam: 35 %

Objectives and Plan

- Objectives
  - (1) To discuss the fundamental concepts and technologies relating with the physical layer and data link layer of communication networks/systems
  - (2) To learn the basic concepts and design principles on computer/communication networks
- Plan
  - ✶ Introduction & Layers (Ch 1-2)
  - ✶ Physical Layer (Ch 3-8)
    - ➢ Digital/Analog Transmission, Multiplexing, Switching
  - ✶ Data Link Layer (Ch 9-13)
    - ➢ Error Detection/Correction, Media Access Control (MAC), Ethernet
    - ➢ Wireless LAN (WiFi) (Ch 14 Optional)

Vision of Communications/Networks

Anybody, Anywhere,

Anytime, Anything...

Internet Appliances

IP picture frame

http://www.ceiva.com/

Web-enabled toaster +

weather forecaster

Tweet-a-watt:

monitor energy use

Slingbox: watch,

control cable TV remotely

Internet

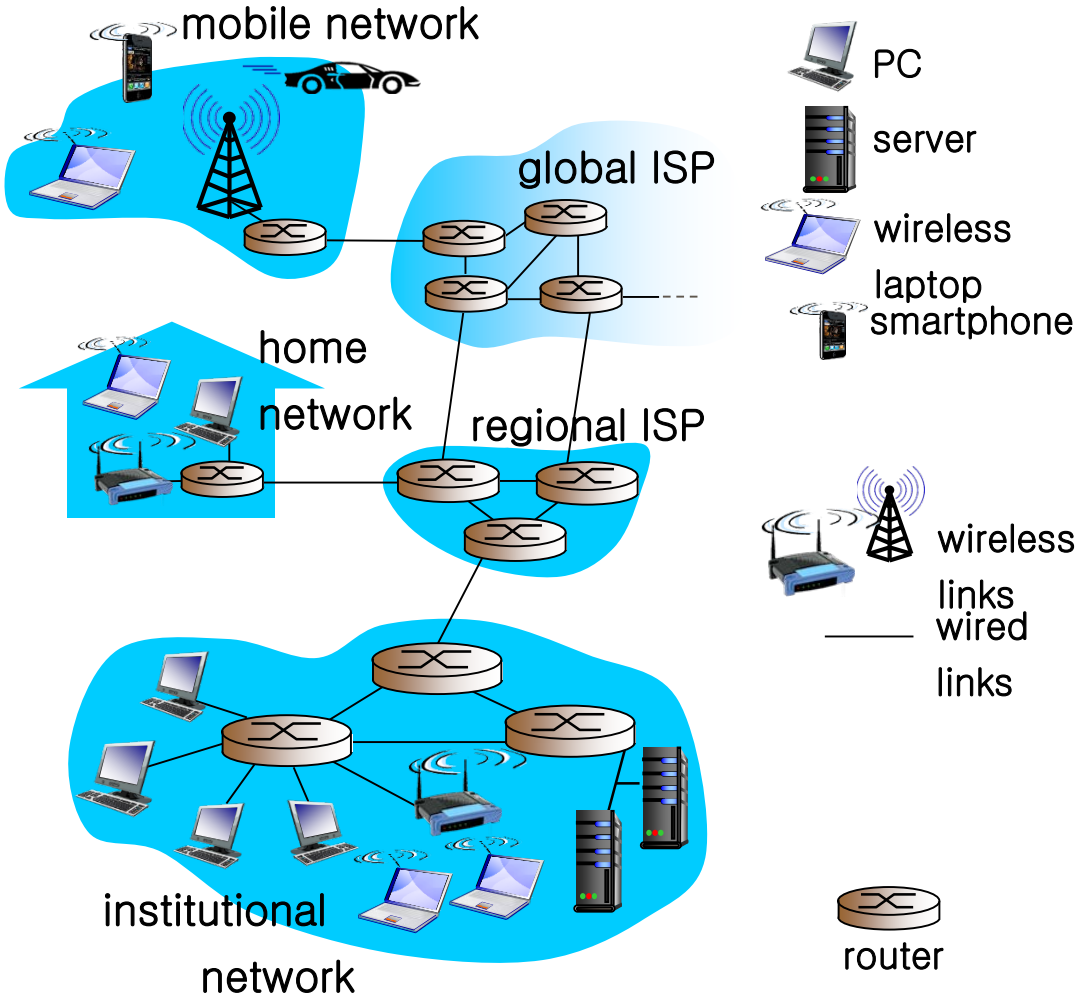
refrigerator

Internet phone

WiFi+NFC Bunny

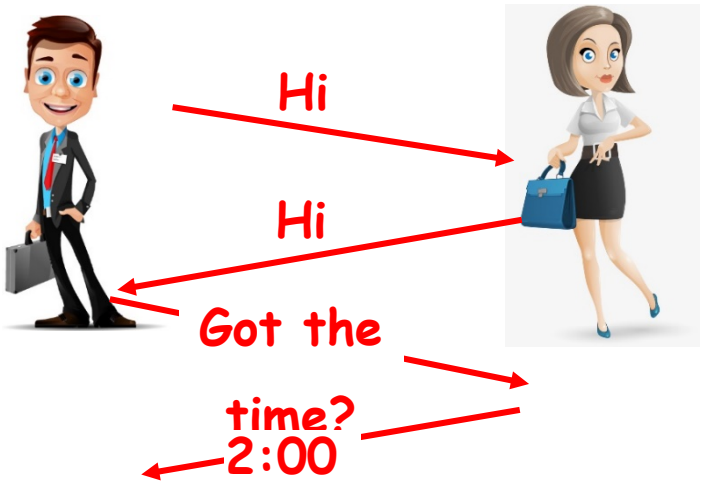
Smart speaker

Internet


mobile network
global ISP
home
network
regional ISP
institutional
network
PC
server
wireless
laptop
smartphone
wireless
links
wired
links
router

Protocol

human protocol



communication protocol

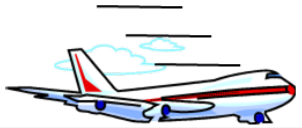
time

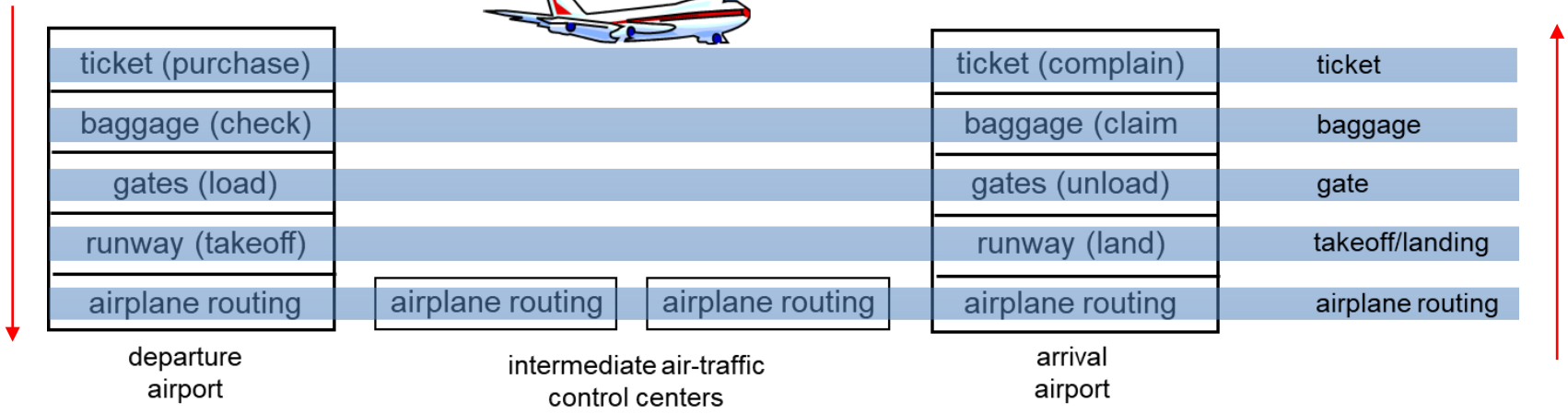
protocols define

- ***Message format***
- ***Order of msgs sent and received among network entities, and***
- ***Actions taken on msg transmission, reception***

Protocol Layering

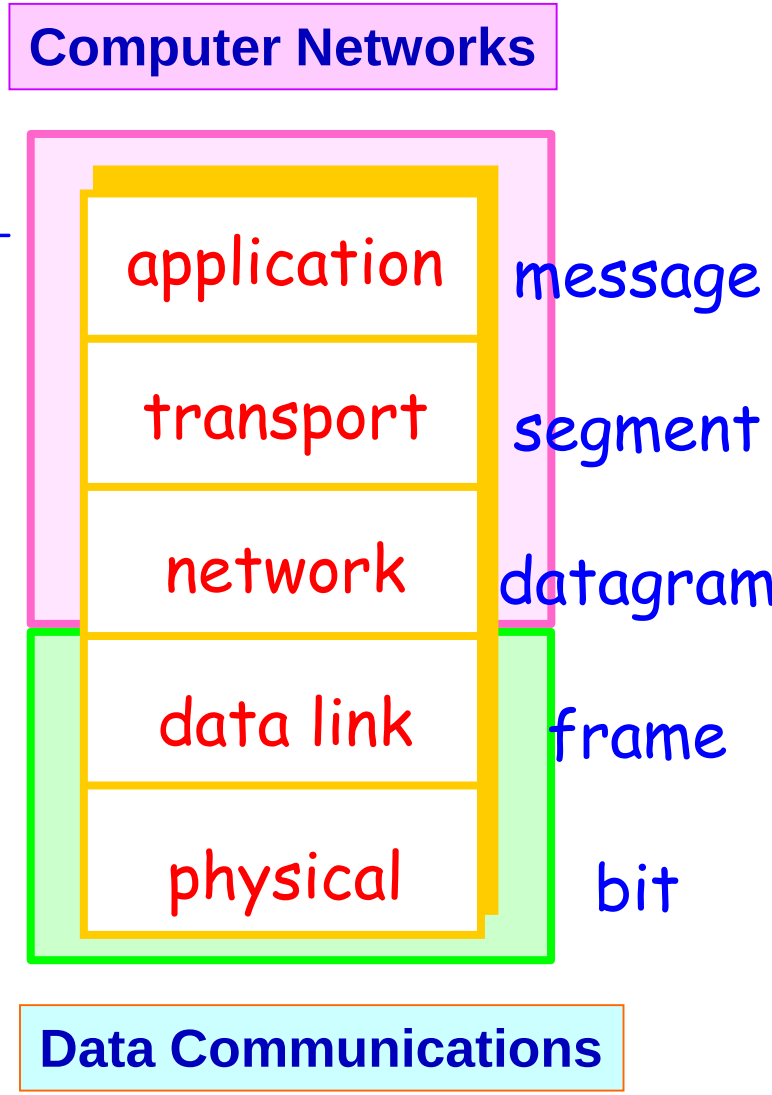
- Layering
  - ✶Splits a complex system into pieces
    - ➢ Modularization
    - ➢ Easy maintenance and update



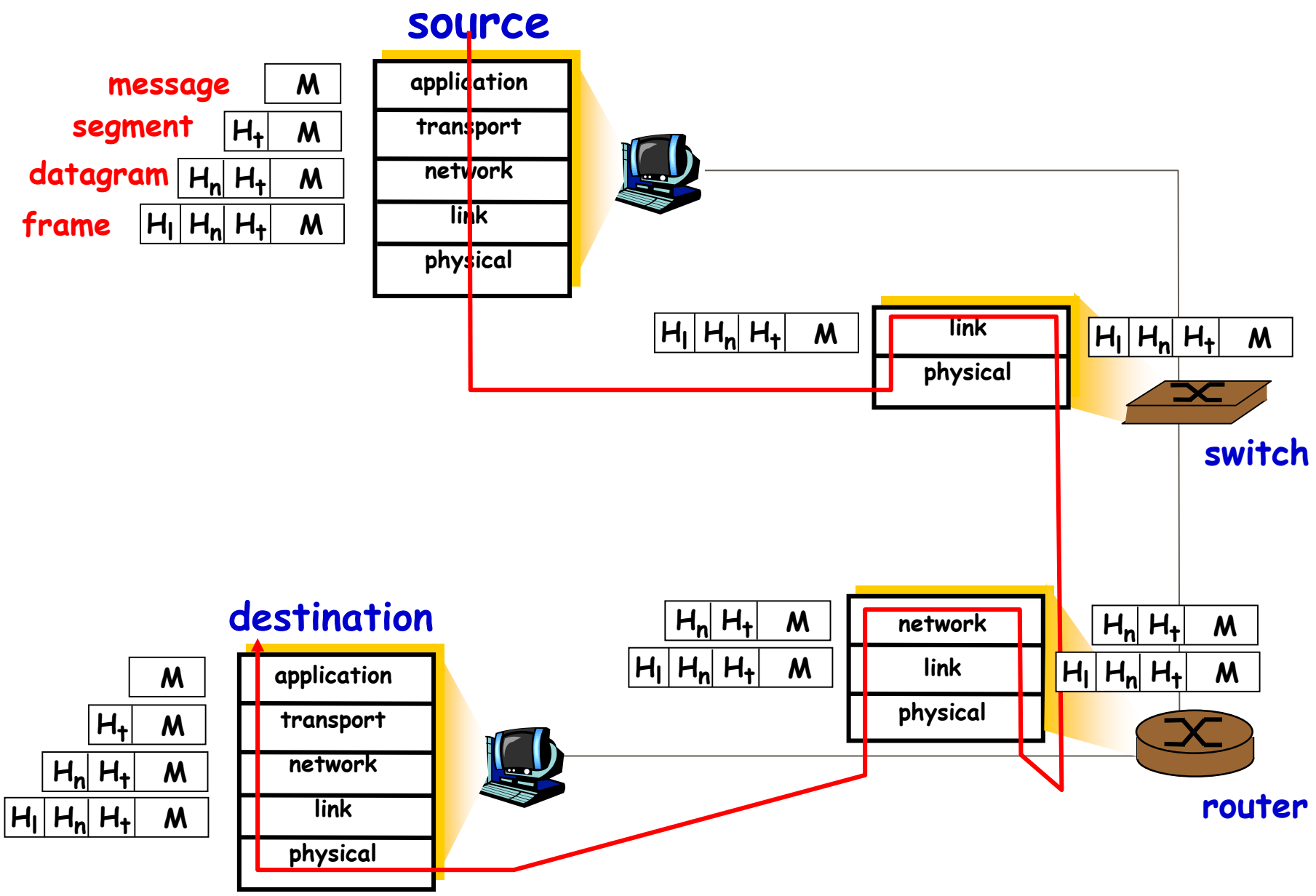


Network Protocol Layers

- Application: supporting network applications
  - HTTP, SMTP, FTP
- Transport: (guaranteed) transporting of application-layer messages from source to destination process
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Data link: data(frame) transfer between neighboring network elements (links)
  - Ethernet, PPP, Wireless LAN
- Physical: bits "on the wire"



Transmission of Message



Data Communications vs. Computer Networks

- Data Communications
  - Focuses on
    - Physical Layer
    - Data Link Layer
  - Transmission media-dependent issues
- Computer Networks
  - Focuses on
    - Network Layer
    - Transport Layer
    - Application Layer
  - Network and above layers issues

•*Closely related with each other !*

•introduction to issues and concepts of data communication & networking

•chapter 1 and 2

Part 1 : Overview of Data Comm. and Networking

- introduction to issues and concepts of data communication & networking
- chapter 1 and 2

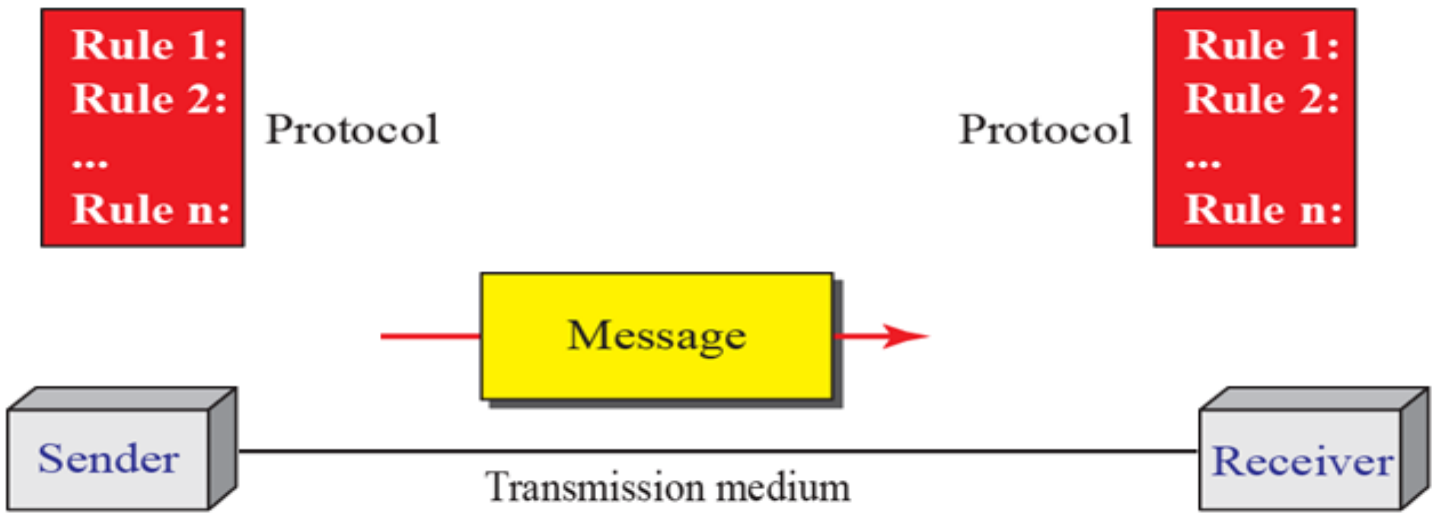
Ch. 1 Introduction

1.1 Data Communications

- Communication
  - Sharing information : local or remote
  - Telecommunication : communication at a distance
    (tele is Greek for far)
- Data
  - Information presented in whatever form
- Data comm.
  - Exchange of data between two devices via some form of transmission medium such as a wire cable
- Effectiveness of a data communication system depends on four fundamental characteristics
  - Delivery : must deliver data to the correct destination
  - Accuracy : must deliver data accurately
  - Timeliness : must deliver data in a timely manner
  - Jitter : variation in the packet arrival time, uneven delay in the delivery of audio or video packets

Ch. 1 Introduction

1.1.1 Components



1. Message : information (data) to be communicated
2. Sender : device that sends the data messages
3. Receiver : device that receives the data messages
4. Transmission medium : physical transmission path between sender and receiver
5. Protocol
   - ✶A set of rules that govern data communications
   - ✶An agreement between the communicating devices

Ch. 1 Introduction

1.1.2 Data Representation : information today comes in different forms

(1) Text

- Represented as a sequence of bits
- Different sets of bit patterns have been designed to represent text symbols
  - ✶ code
- Prevalent coding system
  - ✶ Unicode
    - ➢ 32 bits for a symbol or character
    - ➢ See Appendix A
      - Korean Character: 11,172
        - √ 가 (0xAC01, 44032) ~ 힣 (0x D7A3, 55203)
      - Alphabet : 26
        - √ A (0x0041, 65) ~ Z (0x005A, 90)
  - ✶ ASCII(American Standard Code for Information Interchange)
    - ➢ 127 char in Unicode
    - ➢ Basic Latin

Ch. 1 Introduction

ASCII Code

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
0	00	Null	32	20	Space	64	40	@	96	60	`
1	01	Start of heading	33	21	!	65	41	A	97	61	a
2	02	Start of text	34	22	"	66	42	B	98	62	b
3	03	End of text	35	23	#	67	43	C	99	63	c
4	04	End of transmit	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
6	06	Acknowledge	38	26	&	70	46	F	102	66	f
7	07	Audible bell	39	27	'	71	47	G	103	67	g
8	08	Backspace	40	28	(	72	48	H	104	68	h
9	09	Horizontal tab	41	29	)	73	49	I	105	69	i
10	0A	Line feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage return	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift out	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	47	2F	/	79	4F	O	111	6F	o
16	10	Data link escape	48	30	0	80	50	P	112	70	p
17	11	Device control 1	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	50	32	2	82	52	R	114	72	r
19	13	Device control 3	51	33	3	83	53	S	115	73	s
20	14	Device control 4	52	34	4	84	54	T	116	74	t
21	15	Neg. acknowledge	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	54	36	6	86	56	V	118	76	v
23	17	End trans. block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitution	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	63	3F	?	95	5F	_	127	7F	□

Ch. 1 Introduction

ASCII Code

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
128	80	Ç	160	A0	á	192	C0	└	224	E0	α
129	81	ü	161	A1	í	193	C1	┴	225	E1	ß
130	82	é	162	A2	ó	194	C2	┬	226	E2	Γ
131	83	â	163	A3	ú	195	C3	├	227	E3	π
132	84	ä	164	A4	ñ	196	C4	─	228	E4	Σ
133	85	à	165	A5	Ñ	197	C5	┼	229	E5	σ
134	86	å	166	A6	ª	198	C6	╞	230	E6	µ
135	87	ç	167	A7	º	199	C7	╟	231	E7	τ
136	88	ê	168	A8	¿	200	C8	╚	232	E8	Φ
137	89	ë	169	A9	⌐	201	C9	╔	233	E9	Θ
138	8A	è	170	AA	¬	202	CA	╩	234	EA	Ω
139	8B	ï	171	AB	½	203	CB	╦	235	EB	δ
140	8C	î	172	AC	¼	204	CC	╠	236	EC	∞
141	8D	ì	173	AD	¡	205	CD	═	237	ED	ø
142	8E	Ä	174	AE	«	206	CE	╬	238	EE	ε
143	8F	Å	175	AF	»	207	CF	╧	239	EF	∩
144	90	É	176	B0	░	208	D0	╨	240	F0	≡
145	91	æ	177	B1	▒	209	D1	╤	241	F1	±
146	92	Æ	178	B2	▓	210	D2	╥	242	F2	≥
147	93	ô	179	B3	│	211	D3	╙	243	F3	≤
148	94	ö	180	B4	┤	212	D4	╘	244	F4	⌠
149	95	ò	181	B5	╡	213	D5	╒	245	F5	⌡
150	96	û	182	B6	╢	214	D6	╓	246	F6	÷
151	97	ù	183	B7	╖	215	D7	╫	247	F7	≈
152	98	ÿ	184	B8	╕	216	D8	╪	248	F8	°
153	99	Ö	185	B9	╣	217	D9	┘	249	F9	∙
154	9A	Ü	186	BA	║	218	DA	┌	250	FA	·
155	9B	¢	187	BB	╗	219	DB	█	251	FB	√
156	9C	£	188	BC	╝	220	DC	▄	252	FC	ⁿ
157	9D	¥	189	BD	╜	221	DD	▌	253	FD	²
158	9E	₧	190	BE	╛	222	DE	▐	254	FE	■
159	9F	ƒ	191	BF	┐	223	DF	▀	255	FF	

Ch. 1 Introduction

(2) Numbers

- Are also represented by bit patterns
- Code such as ASCII is not used
  - ✶ directly converted to a binary number to simplify mathematical operations
- See Appendix B

(3) Images

- Presented by bit patterns
- A matrix of pixels (picture elements)
  - ✶ Pixel: small dot, size of pixel depends on the resolution
  - ✶ Each pixel is assigned a bit pattern
    - ➢ Black and white : 1-bit pattern is enough
      - needs more bits to present multi levels of gray scale
    - ➢ Color images
      - RGB
        - √ pixel is decomposed into three primary colors : red, green, blue
        - √ intensity of each color is assigned a bit pattern (usually 8 bits)
      - YCM
        - √ color is made of a combination of yellow, cyan, and magenta

(4) Audio

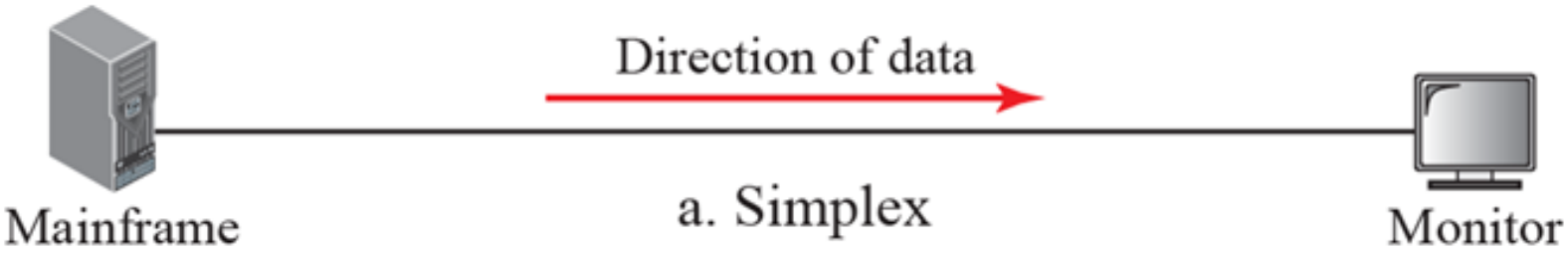
- Representation of sound or music
  - ✶ Continuous entity, not discrete
  - ✶ May be converted to digital

(5) Video

- Representation of picture or video
  - ✶ Continuous entity
  - ✶ May be converted to digital

1.1.3 Direction of Data Flow

- Communication between two devices
  - ✶ Simplex
    - ➢ Communication is unidirectional like a one-way street
      - Keyboard or monitor



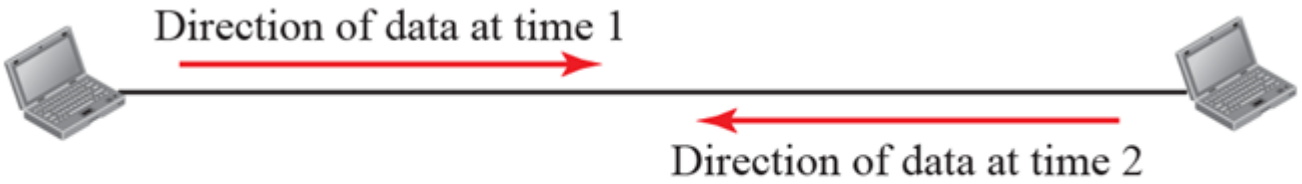
a. Simplex

Ch. 1 Introduction

★Half-duplex

➢Bidirectional , but not at the same time like a one-lane road

- walkie-talkies and CB (citizens band) radios



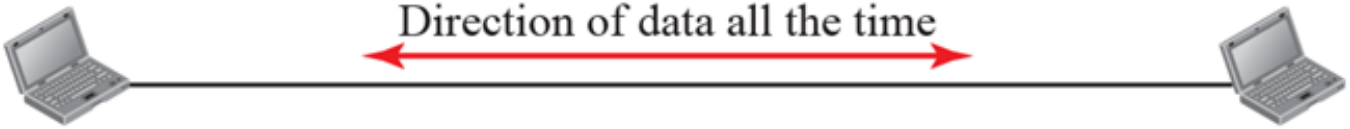
b. Half-duplex

★Full-duplex

➢Both stations can transmit and receive simultaneously like a two-way street

➢Signals going in either direction share the capacity of the link

- telephone network



c. Full-duplex

Ch. 1 Introduction

1.2 Networks

- Network
  - ✶ Interconnection of a set of devices capable of communication
  - ✶ Device can be
    - ➢ a host (computer, laptop, cellular phone etc.)
    - ➢ a connecting device (router, switch, modem)
  - ✶ Devices are connected using wired or wireless media

Ch. 1 Introduction

1.2 Networks

1.2.1 Network Criteria

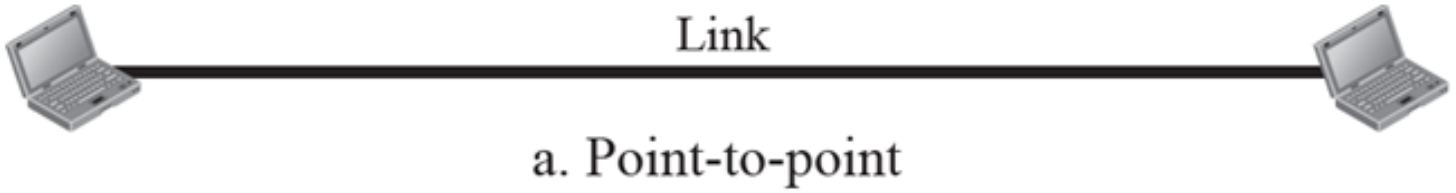
- A network must meet a certain number of criteria
  - Performance
    - Can be measured in many ways
      - Transit time or response time
      - General measures: throughput and delay
    - Depends on a number of factors
      - No. of users, type of transmission medium, capabilities of hardware and software
  - Reliability
    - Frequency of failure
      - Recovery time from a failure, network's robustness in a catastrophe
  - Security
    - Protecting data from unauthorized access or damage

Ch. 1 Introduction

1.2.2 Physical Structures

(1) Type of Connection

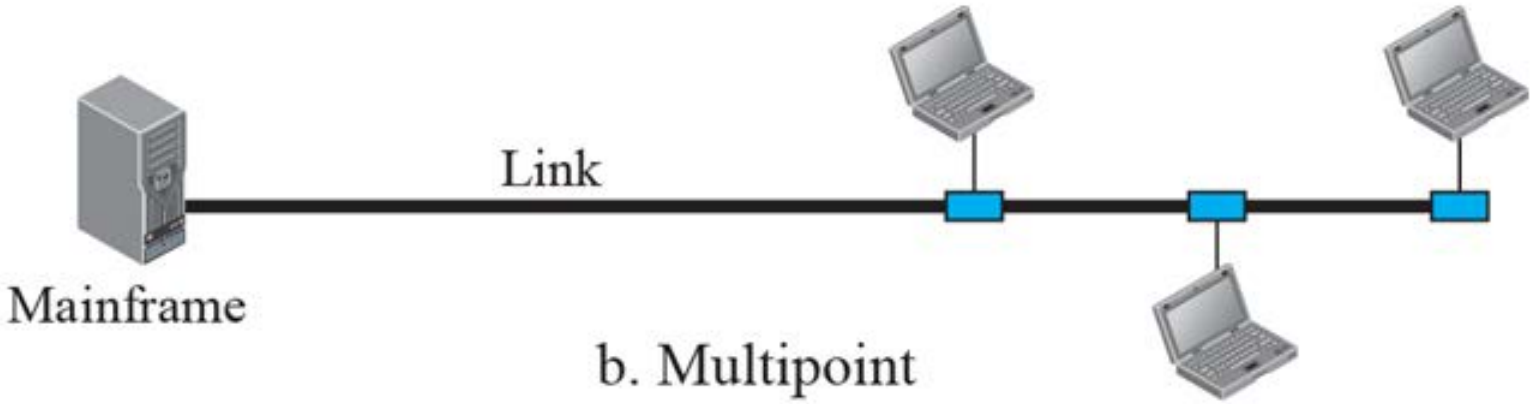
- Link
  - ✶ Physical communication pathway to transfer data from one device to another
    - ➢ Wired: copper wire, optical fiber
    - ➢ Wireless: microwave or satellite links
- Two types
  - ✶ Point-to-point
  - ✶ Multipoint (or multidrop)
- Point-to-Point
  - ✶ PTP connection provides a dedicated link between two devices
  - ✶ Entire capacity of the channel is reserved for two devices



a. Point-to-point

Ch. 1 Introduction

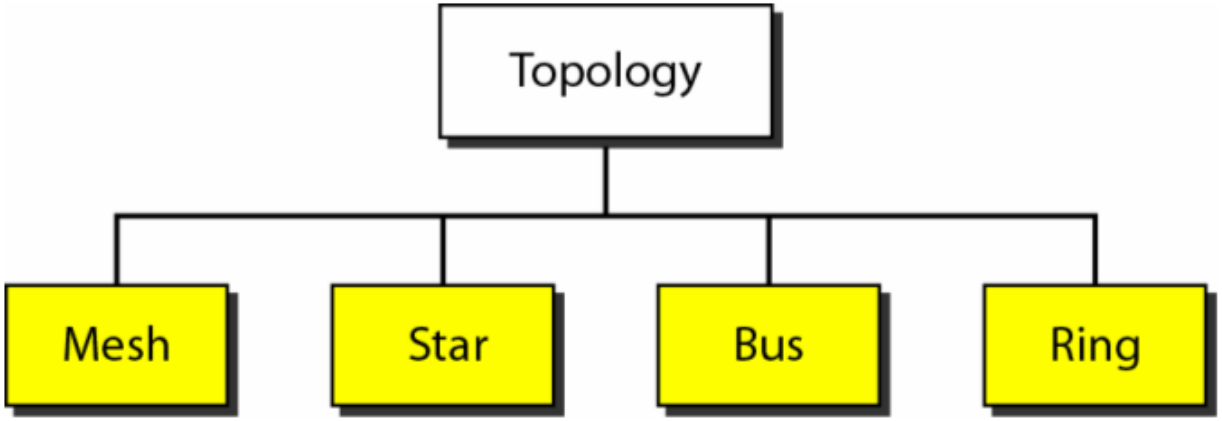
- Multipoint (multidrop)
  - ✶ More than two specific devices share a single link
  - ✶ Channel capacity is shared among the devices
    - ➢ Spatially shared
      - Several devices can use the link simultaneously
    - ➢ Time shared
      - Users must take turns



b. Multipoint

(2) Physical Topology

- The way in which a network is laid out physically
- Geometric representation of the relationship of all the links and devices
  - ✶Usually called nodes



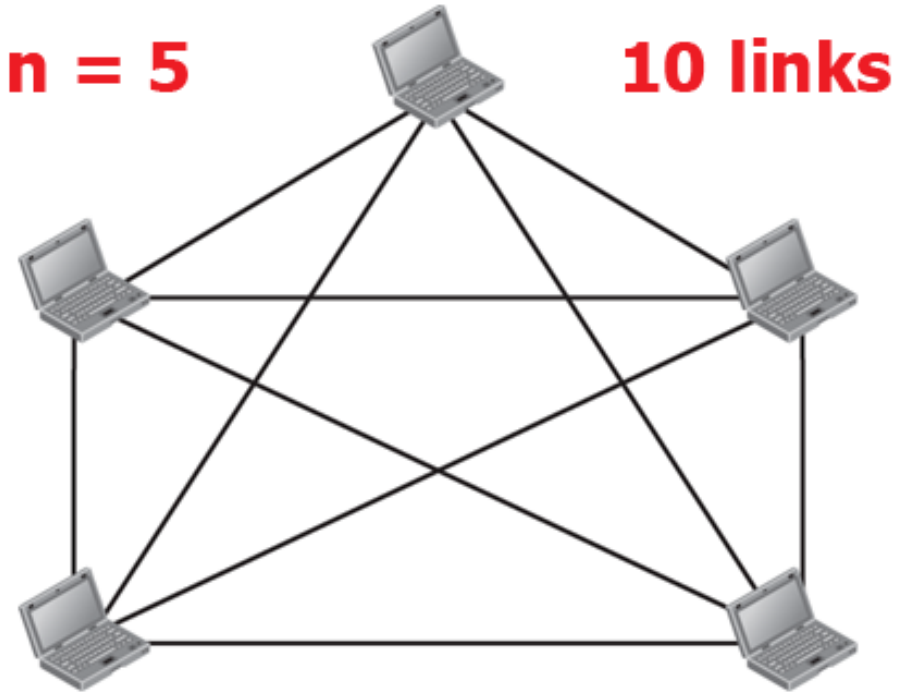
Ch. 1 Introduction

i) Mesh

- Every device has a dedicated point-to-point link to every other device
  - ‘Dedicated’
    - The link carries traffic only between the two devices
  - Need $n(n-1)/2$ links in a network with n devices
  - Every device must have $n-1$ input/output ports
- Advantages
  - Each connection can carry its own data
  - Robust
    - Single failure does not incapacitate the entire system
  - Privacy, security
    - Messages travel along a dedicated line
  - Easy fault identification and fault isolation
- Disadvantages
  - Difficult to install and reconfigure
  - Bulk of the wiring
  - Expensive connection cost
- Usually implemented in a limited fashion
  - Ex: network of telephone regional offices

i) Mesh (Cont.)

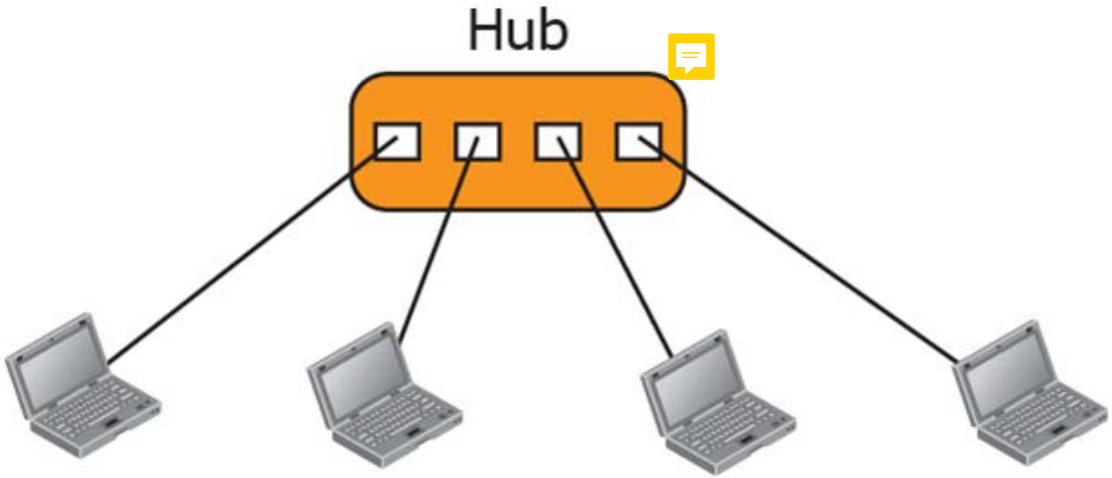
- Figure 1.4 A fully connected mesh topology (five devices)



Ch. 1 Introduction

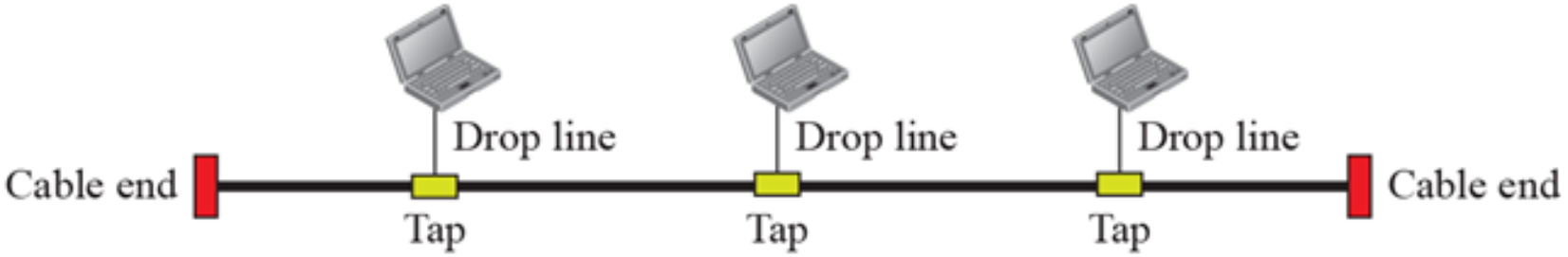
ii) Star

- Each device has a dedicated PTP link only to a central controller
  - A hub or a switch
  - Controller acts as an exchange
- Characteristics
  - Less expensive than a mesh
  - Easy to install and reconfigure
  - Robust
    - If one link fails, only that link is affected
    - But, depends on one single point of failure, hub/switch
  - More cabling is required than in some other topologies (bus/ring)
- Figure 1.5 A star topology connecting four stations



iii) Bus

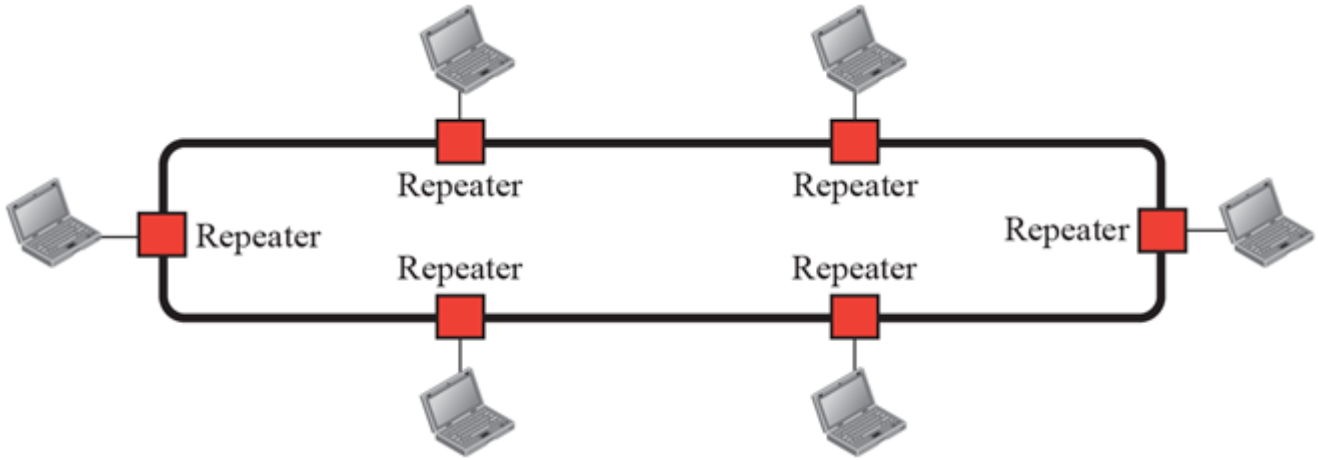
- Multipoint configuration
  - ✶ One long cable acts as a backbone to link all devices
- Because of signal attenuation, there is a limit on
  - ✶ The number of taps a bus can support
  - ✶ The distance between the taps
- Characteristics
  - ✶ Ease of installation
  - ✶ Uses less cabling than mesh/star topologies
  - ✶ Difficult to reconfigure
    - ➢ Designed to be optimally efficient at installation
  - ✶ Fault in the bus cable stops all transmission
- Figure 1.6 A bus topology connecting three stations



Ch. 1 Introduction

iv) Ring

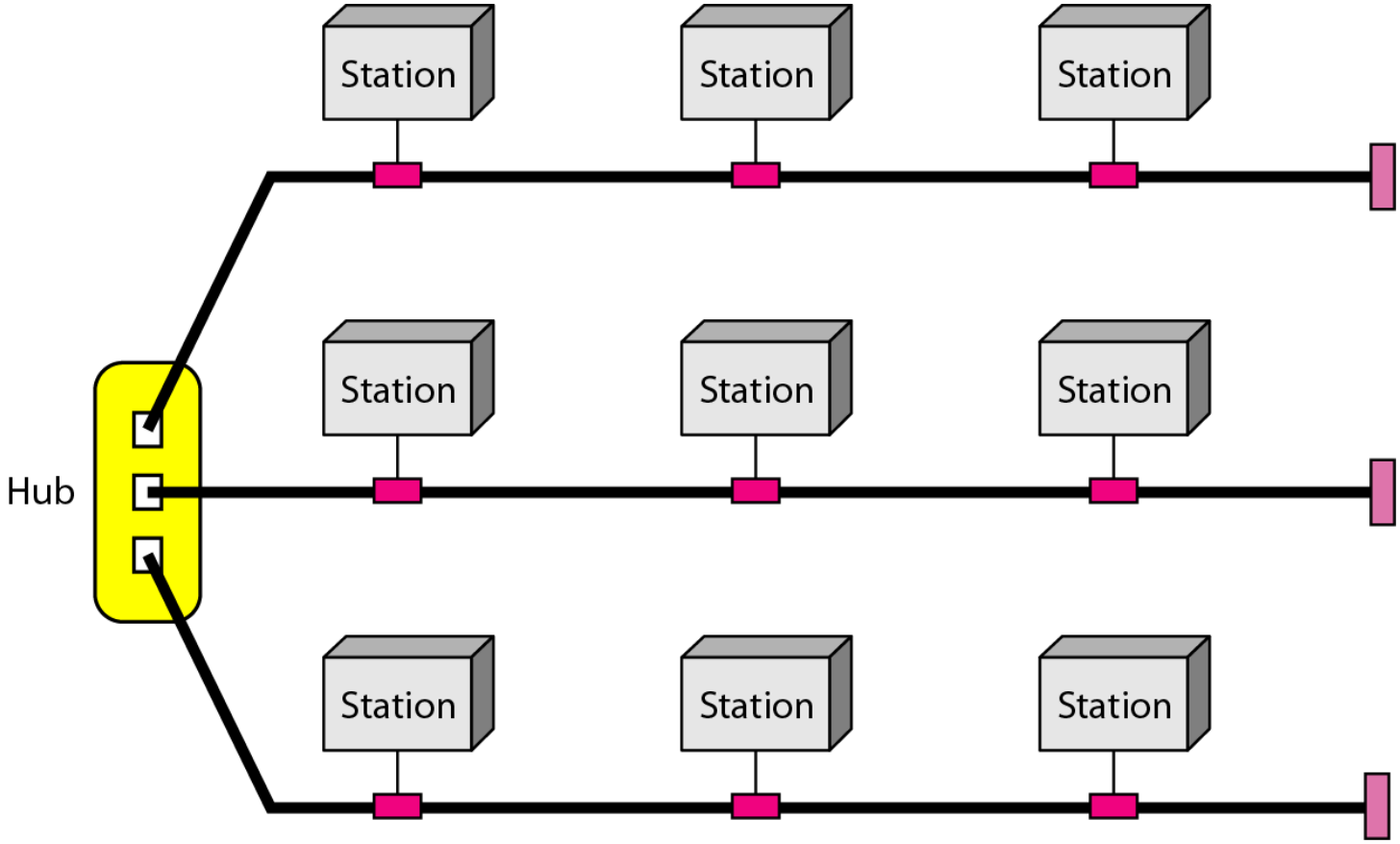
- Each device has a dedicated point-to-point line only with the two devices on either side of it
  - ✶Signal is passed along the ring in one direction, from device to device
  - ✶Each device incorporates a repeater
- Characteristics
  - ✶Relatively easy to install and reconfigure
  - ✶Media and traffic constraint
  - ✶Fault isolation is simplified (alarm)
  - ✶Break in a simple ring can disable the entire network
    - ➢Dual ring
- Figure 1.7 A ring topology connecting six stations



Ch. 1 Introduction

cf. Hybrid

- Hybrid topology: a star backbone with three bus networks



Ch. 1 Introduction

1.3 Network Types

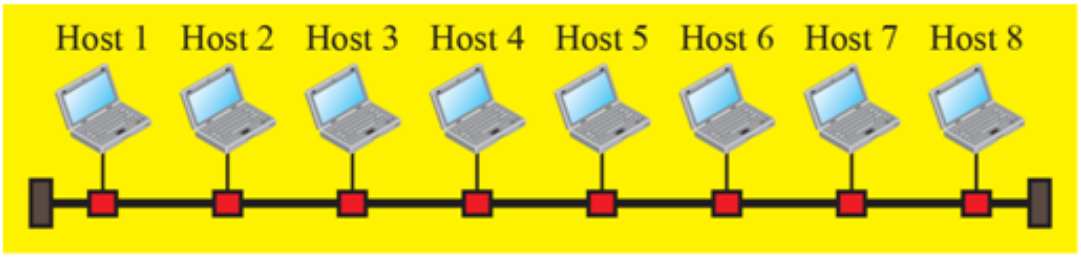
- We use a few criteria such as
  - ✶ Size, geographical coverage, and ownership

1.3.1 Local Area Network (LAN)

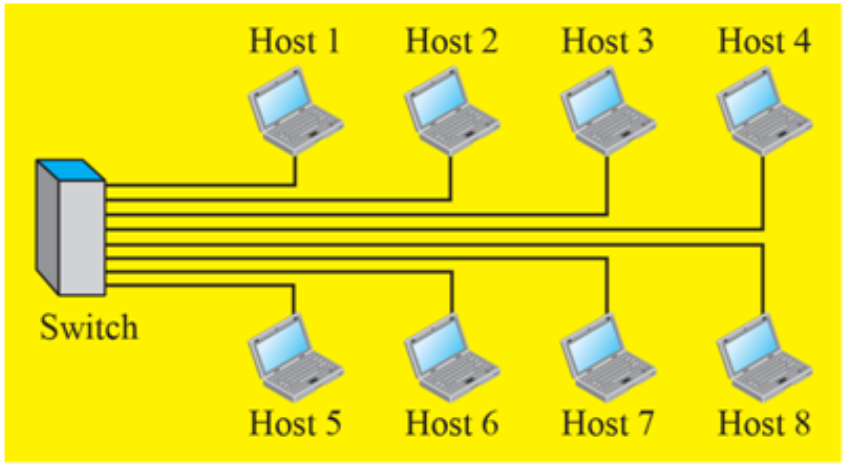
- ✶ Usually privately owned and connects some hosts in a single office, building, or campus
  - ➢ Can be as simple as two PCs and a printer in someone's home office
  - ➢ Or can extend throughout a company and include audio and video devices
- ✶ Each host in a LAN has an identifier, an address
  - ➢ That uniquely defines the host in the LAN
  - ➢ A packet sent by a host to another host carries both
    - The source host's address and
    - The destination host's address

1.3.1 LAN (cont.)

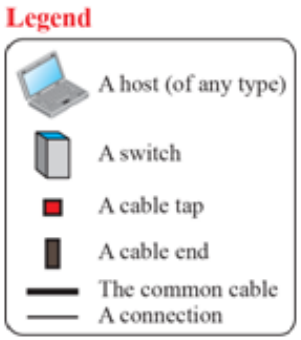
- In the past, all hosts in a network were connected through a common cable
- Today, most LANs use a smart connecting switch
- Figure 1.8 An isolated LAN in the past and today



a. LAN with a common cable (past)



b. LAN with a switch (today)



Ch. 1 Introduction

1.3.2 Wide Area Network (WAN)

- Also a connection of devices capable of communication
- Has a wider geographical span, spanning a town, a state, a country, or even the world
- Interconnects connecting devices
  - ✶ Such as switches, routers, or modems
- Normally created and run by communication companies and leased by an organization that uses it

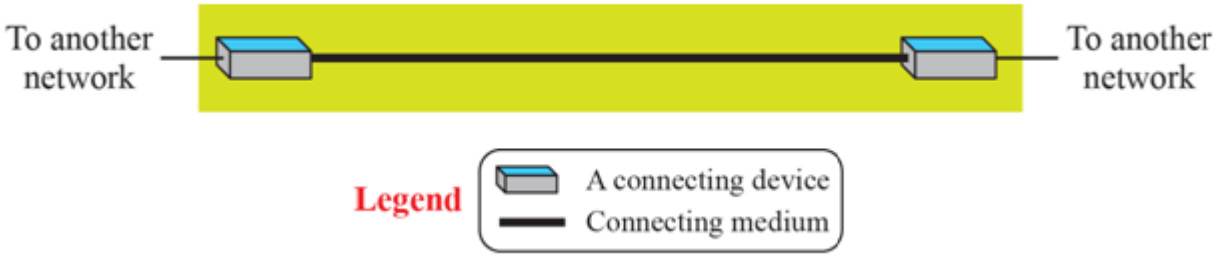
- Two distinct examples of WANs today
  - ✶ Point-to-point WANs
  - ✶ Switched WANs

Ch. 1 Introduction

1.3.2 WAN (cont.)

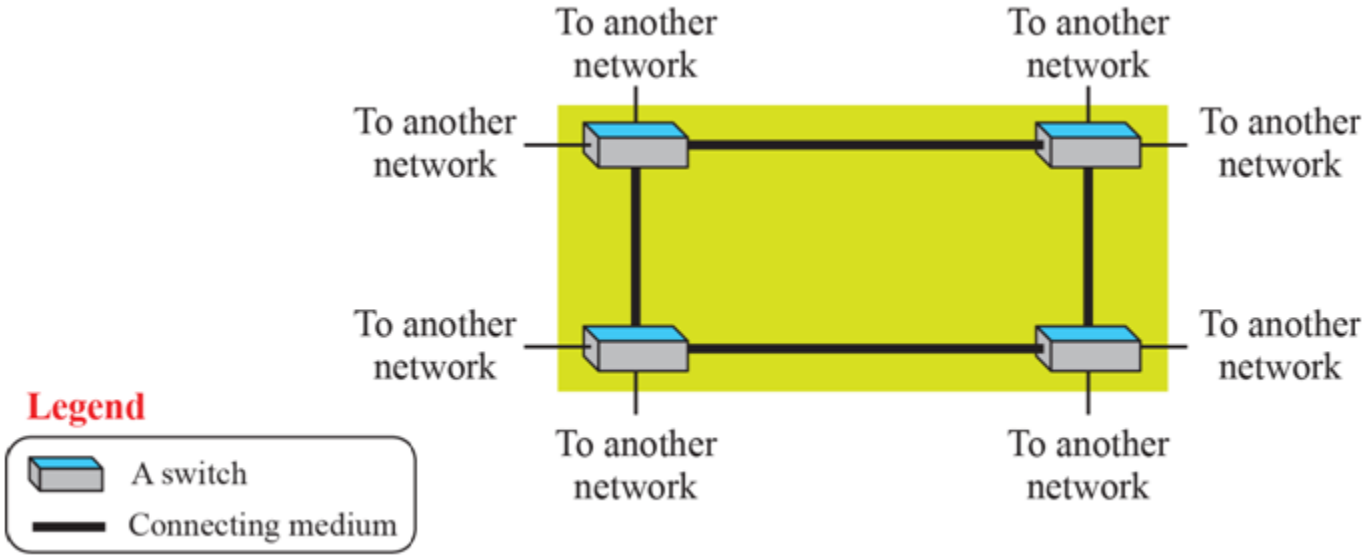
(1) Point-to-Point WAN

- A network that connects two communicating devices through a transmission media



(2) Switched WAN

- A combination of several point-to-point WANs that are connected by switches

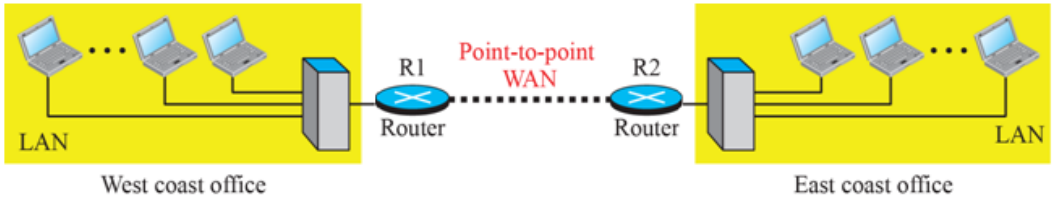


Ch. 1 Introduction

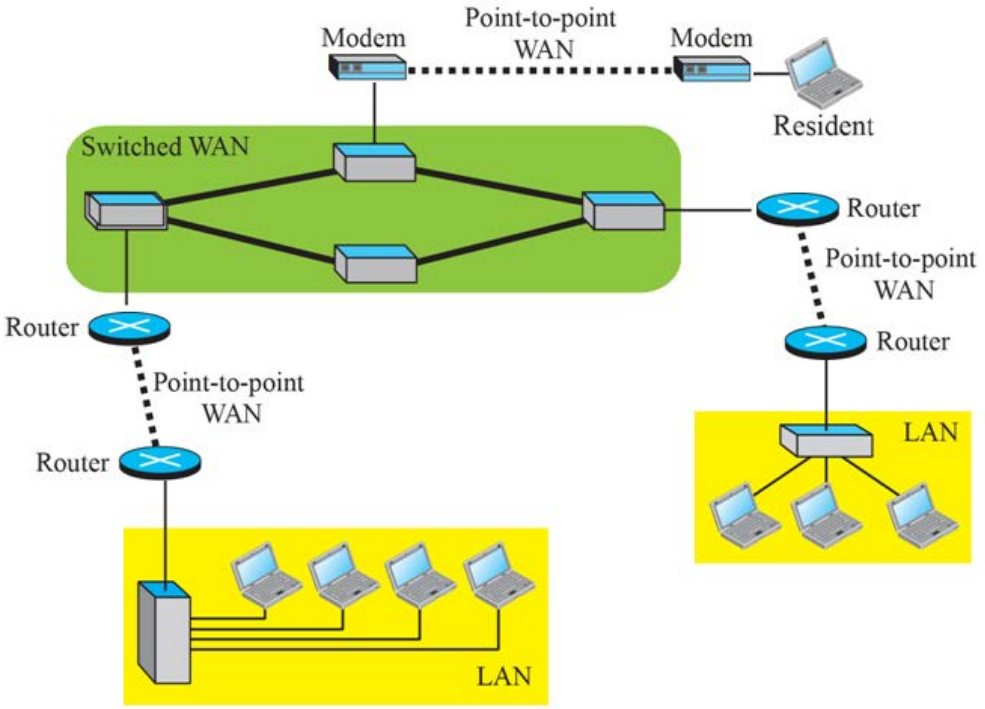
1.3.2 WAN (cont.)

(3) Internetwork (internet)

- When two or more networks are connected, they become an internet, or internetwork
- Figure 1.11 An internetwork made of two LANs and one point-to-point WAN



- Figure 1.12
  A heterogeneous network made of WANs and LANs



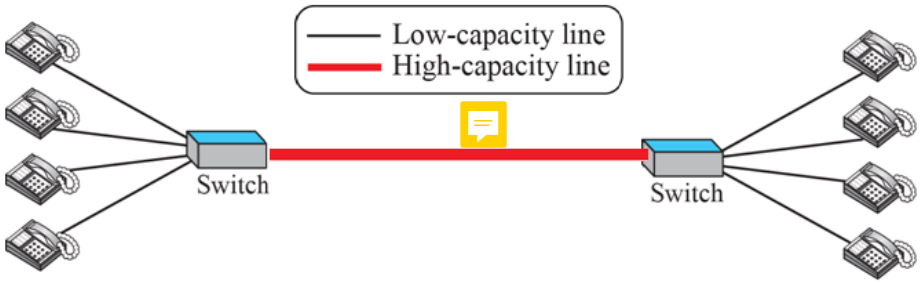
Ch. 1 Introduction

1.3.3 Switching

- An internet is a switched network in which a switch connects at least two links together
- A switch needs to forward data from a network to another network when required
- Two most common types of switched networks
  - ✶Circuit-switched networks
  - ✶Packet-switched networks

(1) Circuit-Switched Network

- A dedicated connection, a circuit, is always available between the two end systems
- Very common in telephone networks in the past
  - ✶Part of the telephone network today is a packet-switched network
- Figure 1.13 A circuit-switched network



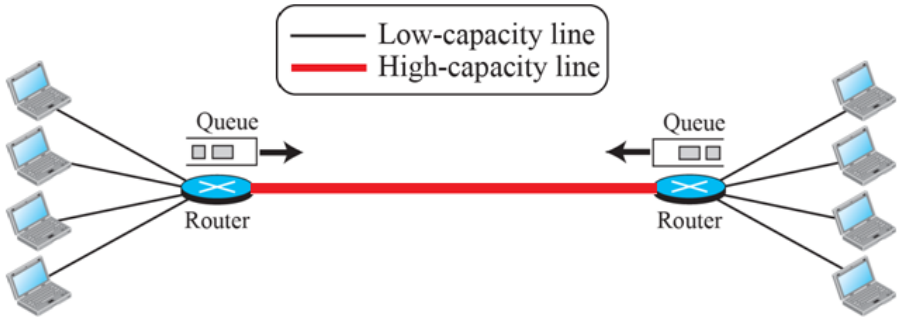
  - ✶Four voice communications can be supported at the same time

Ch. 1 Introduction

1.3.3 Switching (cont.)

(2) Packet-Switched Network

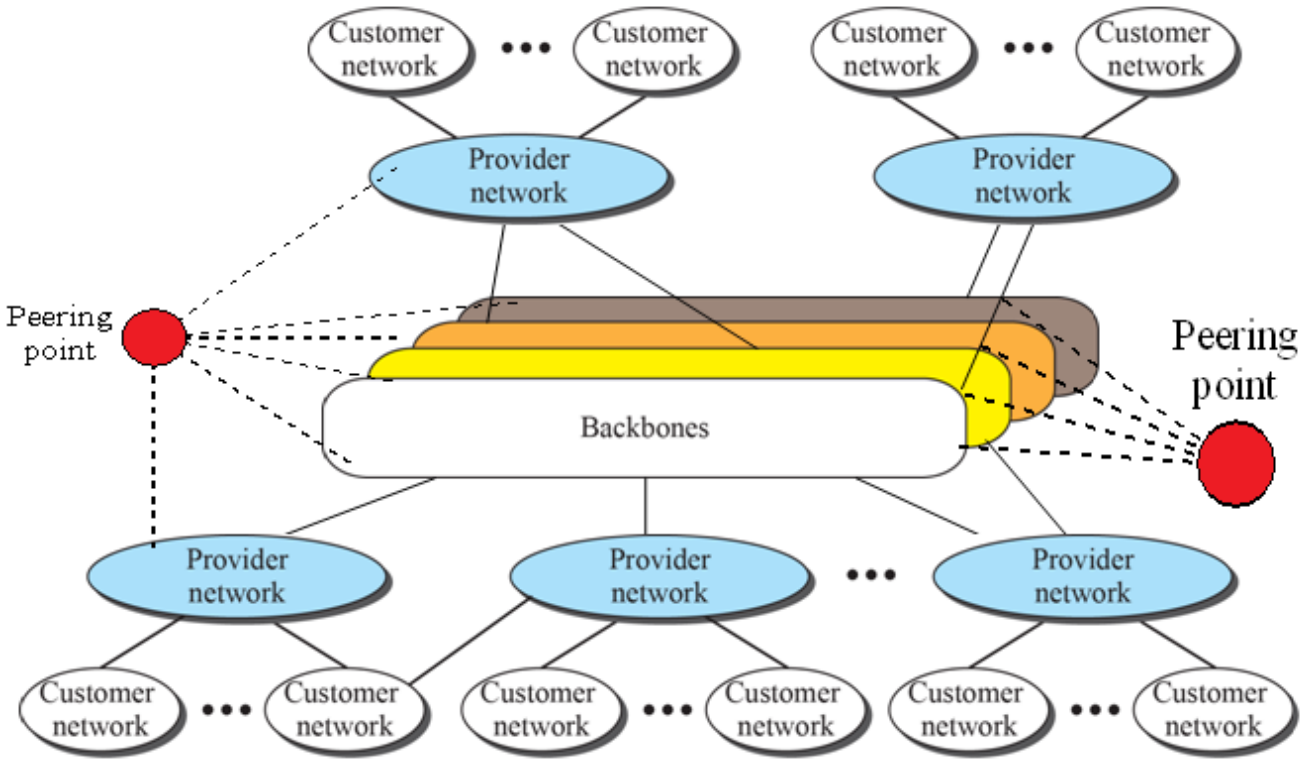
- In computer network, the communication between the two ends is done in blocks of data called packets
- Instead of continuous communication between two telephone sets in circuit-switched networks,
  - ✶Data packets are individually exchanged between the two computers
- Each router has both store and forwarding functions
  - ✶A packet is an independent entity that can be stored and sent later
- In general, a packet-switched network is more efficient than a circuit-switched network
  - ✶But, packets may experience some delays
- Figure 1.14 A packet-switched network



Ch. 1 Introduction

1.3.4 The Internet

- An internet (note the lowercase i)
  - ✶Two or more networks that can communicate with each other
- The Internet (uppercase I)
  - ✶Worldwide network
- Figure 1.15 The Internet Today
  - ✶Backbone
  - ✶Provider network
  - ✶Customer network
  - ✶Peering point
  - ✶Internet service provider (ISP)



Ch. 1 Introduction

1.3.5 Accessing the Internet

- The Internet today is an internetwork that allows any user to become part of it
- The user, however, needs to be physically connected to an ISP

(1) Using Telephone Networks

- ✶ Dial-up service
  - ➢ Be very slow and cannot be used for telephone (voice) connection
- ✶ Digital subscriber line (DSL) service
  - ➢ Provides higher speed Internet services to residences and small offices
  - ➢ Allows the line to be used simultaneously for voice and data

(2) Using Cable Networks

- ✶ Provides a higher speed connection, but the speed varies depending on the number of neighbors that use the same cable

(3) Using Wireless Networks

- ✶ With the growing wireless WAN access, a household or a small business can be connected to the Internet through a wireless WAN

(4) Direct Connection to the Internet

- ✶ A large organization or a large corporation can become a local ISP
  - ➢ leases a high-speed WAN from a carrier provider and connects itself to a regional ISP

Ch. 1 Introduction

1.4 Internet History

1.4.1 Early History

- Before 1960, there were some communication networks, such as telegraph and telephone networks

(1) Birth of Packet-Switched Networks

- ✶ In 1961 at MIT, Leonard Kleinrock firstly presented the theory of packet switching for burst traffic
- ✶ At the same time, Paul Baran at Rand Institute and Donald Davies at National Physical Lab. in England, published some papers about packet-switched net

(2) Advanced Research Projects Agency Network (ARPANET)

- ✶ In the mid-1960s
  - ➢ ARPA(Advanced Research Projects Agency) in the DoD(Department of Defense) was interested in finding a way to connect computers
    - So that the researchers they funded could share their findings
- ✶ In 1967
  - ➢ ARPA presented ARPANET, a small network of connected computers
  - ➢ Use IMP(Interface Message Processor) as a switching node
- ✶ By 1969
  - ➢ A network connecting 4 nodes was constructed

Ch. 1 Introduction

1.4.2 Birth of the Internet

(1) TCP/IP

- In 1973, Vint Cerf and Bob Kahn
  - Proposed transmission control protocol (TCP) which later to be split into two protocols: TCP and Internet protocol (IP)
- In Oct. 1977
  - An internet consisting of three different networks was successfully demonstrated
- In 1981
  - UC Berkeley modified the UNIX operating system to include TCP/IP
- In 1983
  - Instead of ARPANET protocols, TCP/IP became the official protocol for the ARPANET

(2) MILNET

- In 1983, ARPANET split into two networks
  - Military network (MILNET) for military users
  - ARPANET for non-military users

Ch. 1 Introduction

1.4.2 Birth of the Internet (cont.)

(3) CSNET

- In 1981
  - Computer Science Network (CSNET) sponsored by the National Science Foundation (NSF) was created
- By the mid-1980s
  - Most U.S. universities with computer departments were part of CSNET

(4) NSFNET

- In 1986
  - With the success of CSNET, the NSFNET as a backbone was constructed
    - Connect five super computer centers located throughout the U.S.
    - Access to the backbone with a 1.544 Mbps data rate
- In 1990, NSFNET replaced ARPANET
- In 1995
  - NSFNET reverted back to its original concept of a research network

(5) ANSNET

- In 1991, a nonprofit organization Advanced Network & Services (ANS) built a new, high-speed backbone Advanced Network Services Network (ANSNET)

1.4.3 Internet Today

- What has made the Internet so popular is the invention of new applications

(1) World Wide Web

- The 1990s saw the explosion of Internet applications due to the World Wide Web (WWW) invented at CERN by Tim Berners-Lee

(2) Multimedia

- Multimedia applications such as
  - voice over IP (telephony), voice over IP (Skype)
  - view sharing (YouTube), and
  - TV over IP (PPLive)
  - Video on demand (Netflix)
- Have increased the number of users and the amount of time each user spends on the network

(3) Peer-to-Peer Applications

- Be a new area of communication with a lot of potential

Ch. 1 Introduction

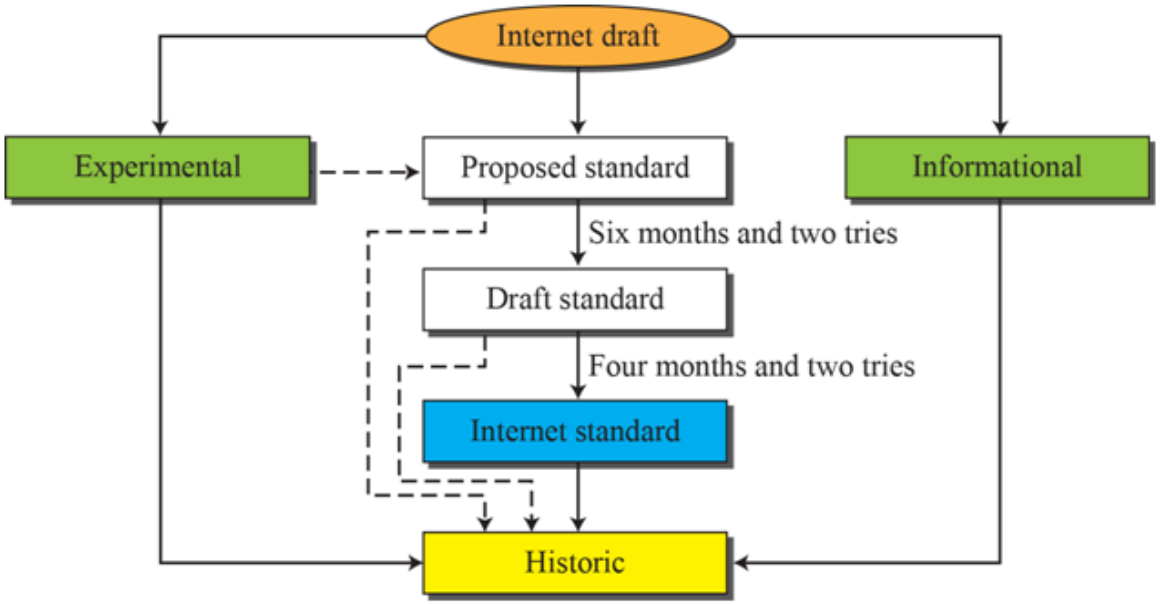
1.5 Standards and Administration

1.5.1 Internet Standards

- A specification begins as an Internet draft
- An Internet draft is a working document (a work in progress) with no official status and a six-month lifetime
- Upon recommendation from the Internet authorities, a draft may be published as a Request for Comment (RFC)

(1) Maturity Levels

- A RFC falls into one of six maturity levels
  - ✶proposed standard, draft standard, Internet standard, historic, experimental, and informational



Ch. 1 Introduction

1.5.1 Internet Standards (cont.)

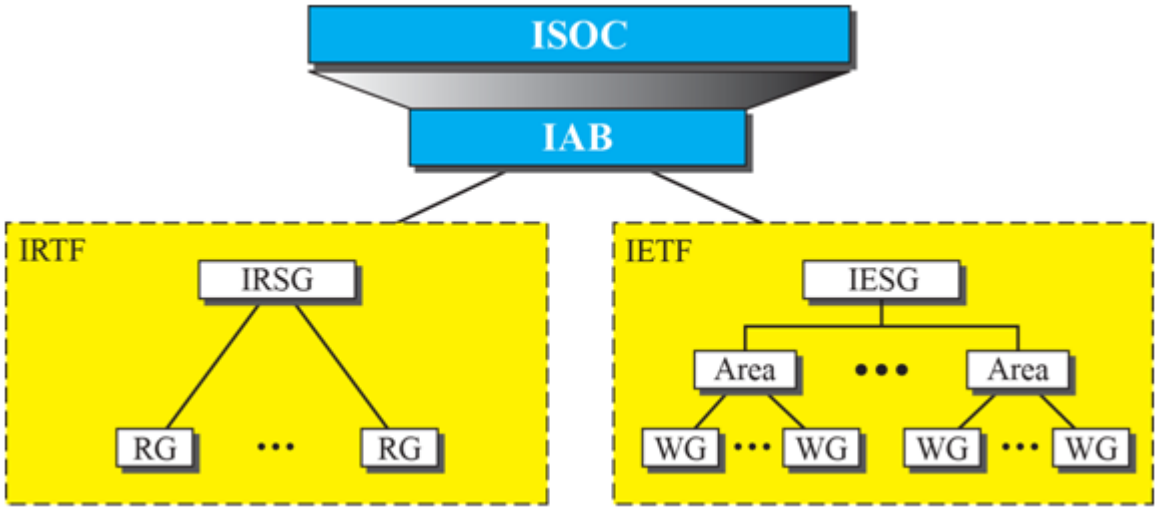
(2) Requirement Levels

- RFCs are classified into five requirement levels
  - ✶ Required, recommended, elective, limited use, and not recommended
    - ➢ Required
      - Must be implemented by all Internet systems to achieve minimum conformance
        - √ IP & ICMP (Chap. 19)
    - ➢ Recommended
      - Is not required for min conformance
      - It is recommended because of its usefulness
        - √ FTP and TELNET (Ch. 26)
    - ➢ Elective
      - Is not required and not recommended
      - A system can use it for its own benefit
    - ➢ Limited Use
      - Should be used only in limited situations
      - Most of the experimental RFCs fall under this category
    - ➢ Not Recommended
      - Inappropriate for general use
      - Normally a historic (deprecated) RFC may fall under this category

Ch. 1 Introduction

1.5.2 Internet Administration

- Various groups that coordinate Internet issues have guided this growth and development
- Appendix G gives the addresses, e-mail addresses, and telephone numbers for some of these groups
- Figure 1.17 Internet administration.



- ✶ Internet Society (ISOC)
- ✶ Internet Architecture Board (IAB)
- ✶ Internet Engineering Task Force (IETF)
- ✶ Internet Research Task Force (IRTF)

Ch. 1 Introduction

1.5.2 Internet Administration (cont.)

- Internet Society (ISOC)
  - An international, nonprofit organization formed in 1992 to provide support for the Internet standards process
- Internet Architecture Board (IAB)
  - Technical advisor to the ISOC
- Internet Engineering Task Force (IETF)
  - A forum of working groups managed by the Internet Engineering Steering Group (IESG)
  - Responsible for identifying operational problems and proposing solutions to these problems
- Internet Research Task Force (IRTF)
  - A forum of working groups managed by the Internet Research Steering Group (IRSG)
  - Focuses on long-term research topics related to Internet protocols, applications, architecture, and technology