Classification of Network Technologies

- Based upon *geographical area size*
- Local Area Network (LAN)
  - Optimized for a moderate size geographic area
  - generally owned, used, and operated by a single organization.
- Metropolitan Area Network (MAN)
  - Optimized for a larger geographical area than a LAN, ranging from several blocks of buildings to entire cities
  - Might be owned and operated by a single organization, but usually will be used by many individuals and organizations
- Wide Area Network (WAN)
  - Operate over geography of telecommunication carriers such as intra-/inter- area/city/country, more than tens km scope

➢ LAN and WAN are widely deployed

Local-Area Networks (LAN) and Devices

LAN characteristics:

- **Operate within a limited geographic area**
  ~ intra-/inter-building, a few km scope
- **Connect physically adjacent devices on the media**
  ~ including Hubs, Bridges, workgroup concentrators, Switches, Routers, etc.
- **Allow *multiaccess* to high bandwidth media**
  ~ media/bandwidth is shared by many devices
- **Provide full-time connectivity to local services**
  ~ LAN rarely shutdown or restrict access to connected devices
- **Control the network privacy under local administration**
  ~ privately control the LAN by renting/purchasing the media/connections
- **Channels are relatively error-free** **(BER < 1 in 10^9)**

Bit Error Rate

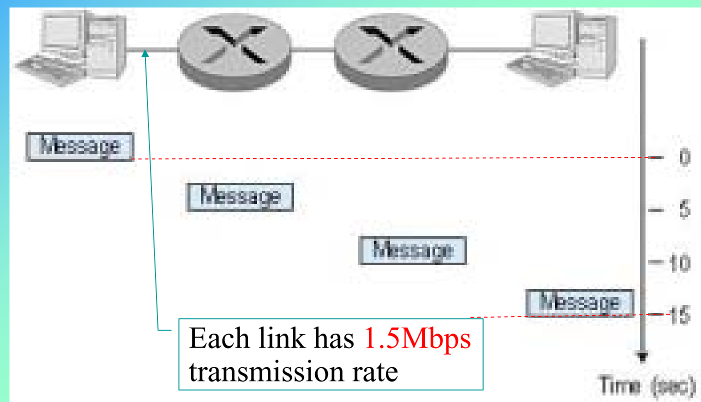
Switching Technology - I

(inside network core)

- **Data/signal forwarding over networks :**
  - Message switching (MS)
  - Circuit switching (CS)
  - Packet switching (PS)
- **Message switching**
  - Message (block data) is stored in a switching node and then forwarded later one hop at a time
  - Message received in its entirety , inspected for error, and then forwarded
  - Need "LARGE" storage space to store data in each node

Ex. Telegraph, military applications

Message Switching Concept



- Transfer a 7.5 Mbit message in a Message-Switched Network needs 5 sec, assuming immediately processing

Switching Technology - II

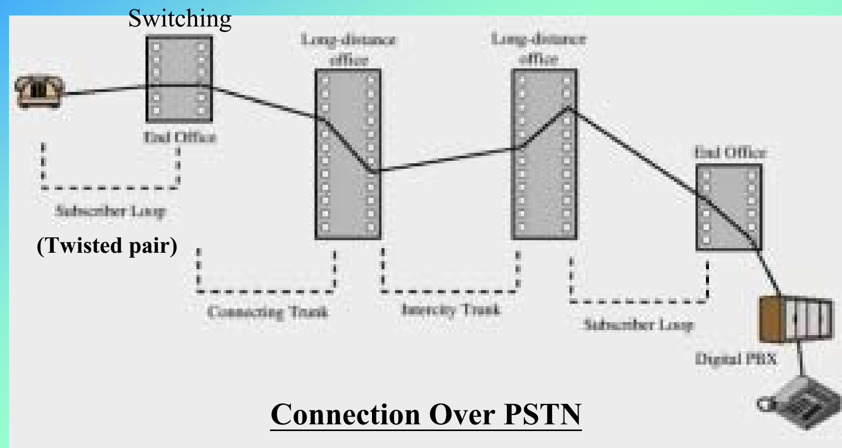
- **Circuit switching**
  - dedicated commu path(circuit) between an O-D pair
  - data are transmitted along the path with pre-negotiated rate
  - path (i.e., the link capacity/bandwidth) is occupied for the entire lifetime of communication
  - Three phases of the CS:
    1) ciircuit/connection establishment (call setup)
    2) data transfer
    3) circuit disconnect (release the granted capacity)
  - only propagation delay while transmission

Ex. Telephone network: dial .→ talk → hang up

(Example)

Circuit Switching Concept

* Example - Public (circuit-)Switched Telephone Network



Connection Over PSTN

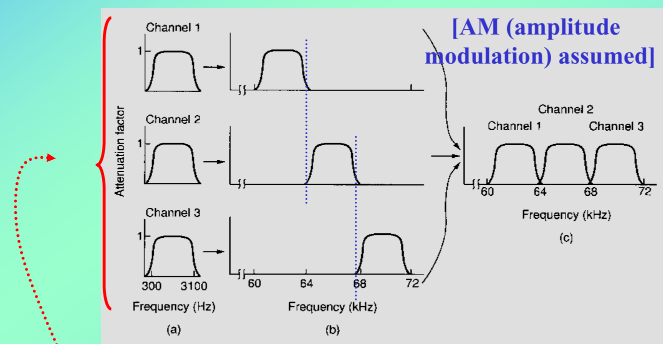
Multiplexing ⟺ Multiple Access

- **Multiple Access (MAC techniques)**
  - a set of rules to control the *access* to a shared communication channel
  - conflicting access to the channel may be happened
  - mostly for broadcasting channels
  - ***Ex***: Contention, Round-Robin (take turn), Reservation
- **Multiplexing**
  - given the instantaneous knowledge of all users' requirement
  - sharing the communication channel without contention
  - implemented at a local site, remote mat take the reverse action
  - ***Ex***: TDM, FDM,WDM systems

(a reminder)

CS Example - FDM

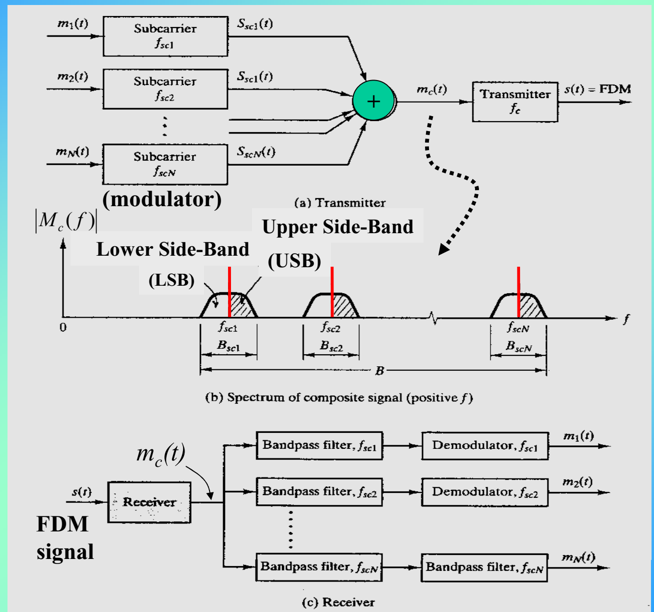
- FDM (Frequency Division Multiplexing)
  - Each signal is modulated onto (being shifted) a different carrier frequency (called *subcarrier*)
  - Each signal is exclusively possess its dedicated frequency band all the time
  - ***Ex*** : FM/AM broadcasting, Cable TV Spectrum allocation



Interfere to each other occurs if sending at the same time interval w/o FDM

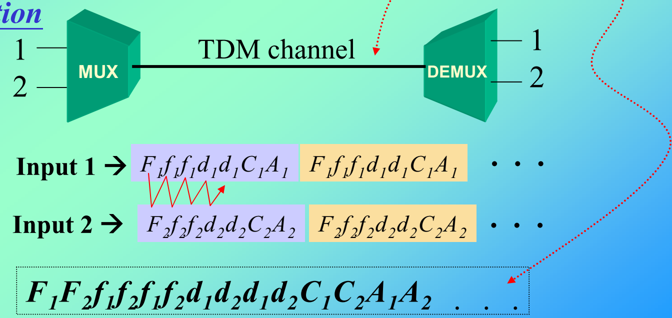
FDM system architecture (TX and RX)

FDM (cont'd)

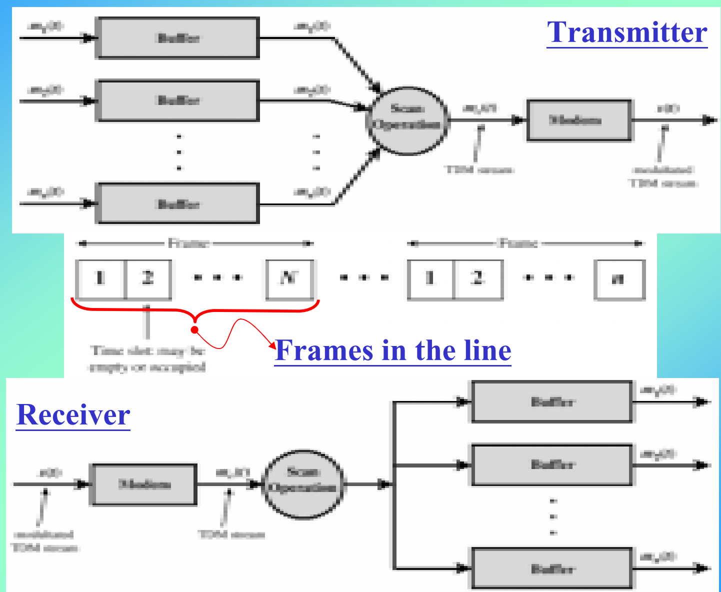


CS Example – (Synchronous) TDM

- **STDM (Time Division Multiplexing, or just TDM)**
  - Multiple digital signals can be carried on a single transmission path by interleaving portions of each data in time
  - Take turn to use the entire bandwidth
  - ***Ex***: voice communication in PSTN
- ***Illustration***

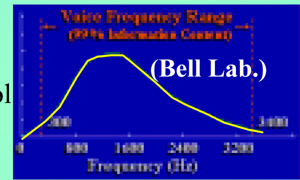


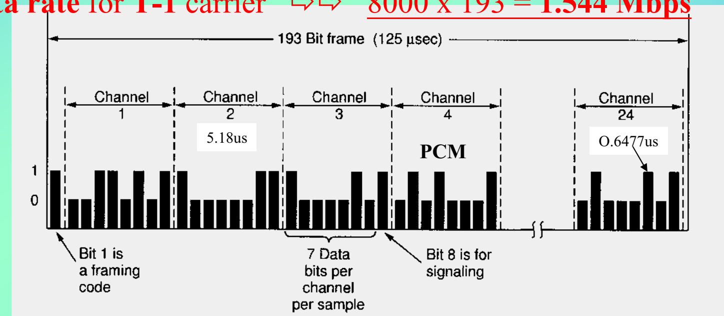
A TDM System



AT&T *T-1/DS-1 Carrier* : North America and Japan Standard

- Since 1962 . . . in New York, to reduce the cable congestion in urban area (7-bit PCM)
- A voice channel, band-limited to **4KHz**
  - 7-bit (digitized) data and 1-bit signaling control
- 24 voice channel integrated/Muxed together
- *Frame* = *24* × *8* + *1* (framing bit) = *193* bits
- Voice signal is sampled ***4kHz*** × ***2*** = **8,000 times/sec (125us/sample)**
- **Data rate** for **T-1** carrier ⇨⇨ 8000 x 193 = **1.544 Mbps**





Pulse Code Modulation – Brief Review

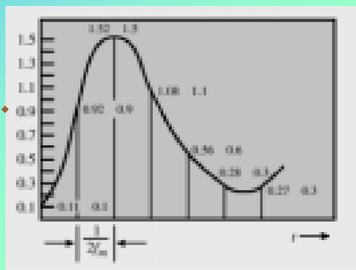
Sampling ← analog voice

↓

Quantization

↓

Encoding → digital waveform



Sampled according to Sampling/Nyquist Theorem.

• Encoding example (4-bit PCM)

Digit	Binary Equivalent	PCM waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	

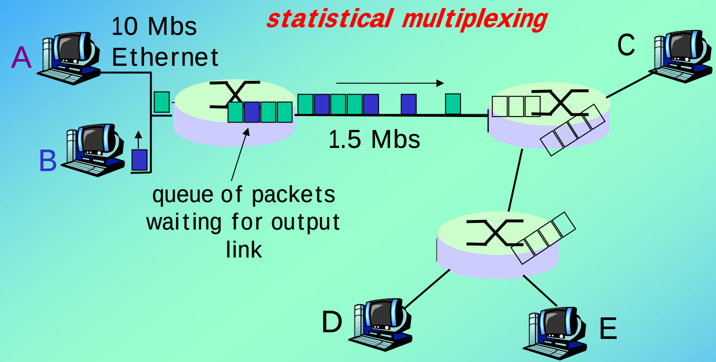
Switching Technology - III

- **Packet switching**

- data are sent in a sequence of "chunk" (called packet)
- each packet contains src addr, dest addr, and sequence # and is passed through the network from node to node along some paths
- packets are received , "may/may not" be stored briefly, and then forwarded to the next node
  (save entire packet and forward it to later on → store-and-forward; process the first few part of a packet and then forward it to transparently → cut through)
- no dedicated path allocated for an O-D pair

- Two forms of PS:
  (A) Datagram (DG)
  (B) Virtual circuit (VC)

Packet Switching Concept

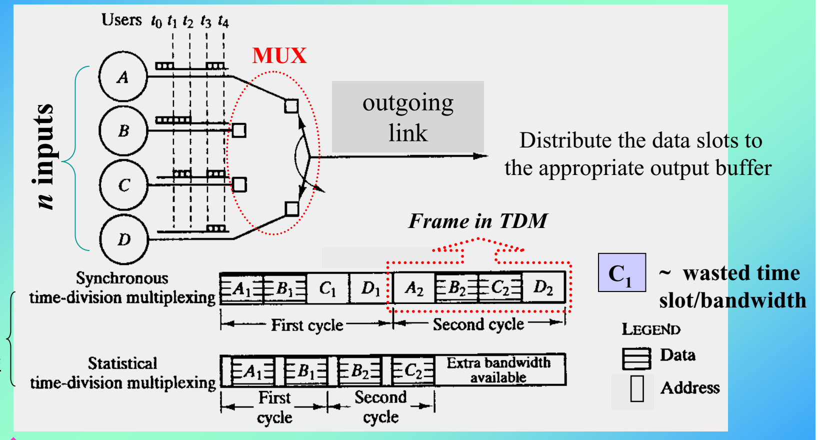


- Sequence of A & B packets does not have *fixed* pattern/frame
  → ***statistical multiplexing*** (統計多工).
- In TDM (circuit switching), each host gets same slot/circuit/bandwidth in revolving TDM frames.

Statistical TDM or Statistical Multiplexing

- ***Statistical*** **TDM,** ***Asynchronous*** **TDM or** ***Intelligent*** **TDM**
- Used to resolve the bandwidth waste (empty time slots) in STDM (The "gap" ~ not all transmitting all of the time)
- Scenario: n ports (I/O) with k time slots available, k < n
- **Operation:**
  - Scan input buffers, collect data until a frame is filled or a scanning cycle is finished, send frame out.
  - Statistical MUX (STDM) varies the bandwidth allocation based on the traffic presented at any given time instant.
  - The bandwidth (or time slot) is assigned to some one else if the current input device has no data to send at that time instant.
  - STDM buffers incoming data until outgoing bandwidth can be allocated.

Statistical TDM or Statistical Multiplexing



~ n inputs but only k active ($k \leq n$), no empty slots was sent in a frame

- use a "lower data rate" to support as many inputs as a TDM MUX does
- under a fixed data rate, STDM can support more inputs than a TDM does

Switching Technology - IV

- **Packet switching (cont'd)**

(A) DGPS

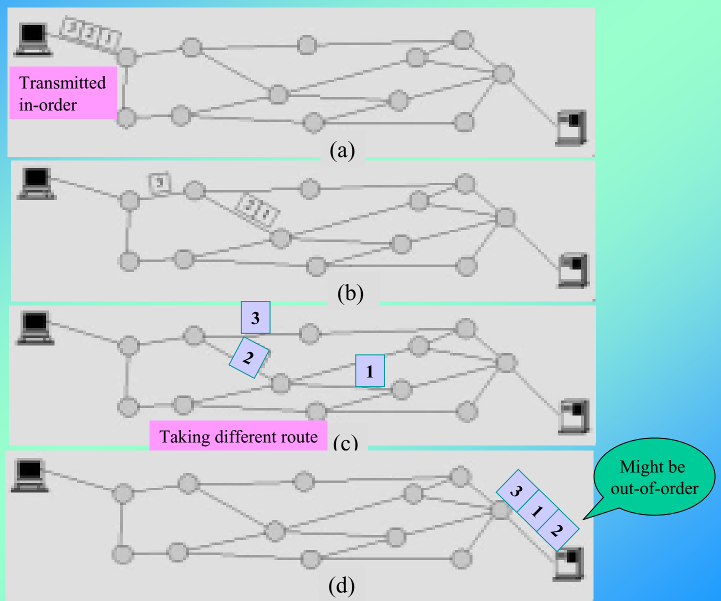
- Packet are routed independently (called datagram) of one another
- packets can be received in a different order (out-of-sequence delivery)

(B) VCPS

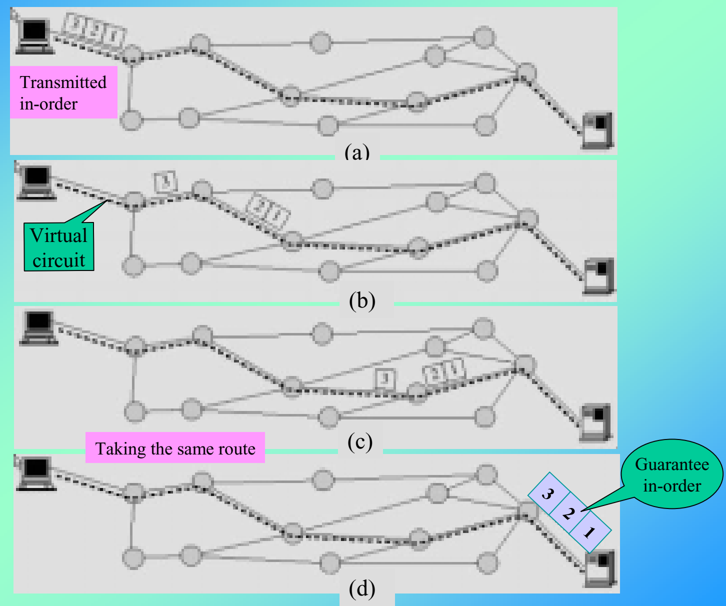
~ tries to combine the advantages of CS and DGPS

- all pkts (from one pkt stream) are sent along the same path (virtual circuit)
- guarantees in-sequence delivery
- similar to CS, needs:
  (1)VC setup, (2)packets transfer , (3)VC disconnection.

Packet Switching - Datagram

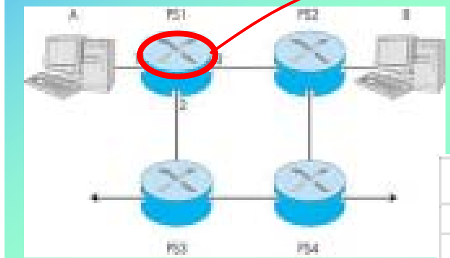


Packet Switching - Virtual Circuit



Virtual Circuit Routing Concept

- **Datagram network** ~ route packets according to host's destination addresses (IP, Ethernet)
- **Virtual circuit network** ~ route packets according to VC number (X.25, Frame relay, ATM)
- Ex:

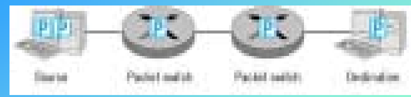


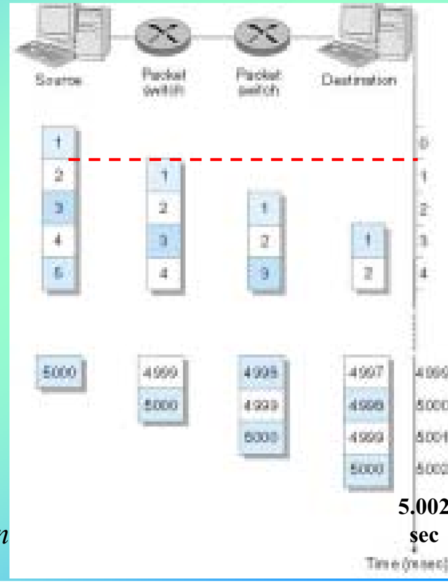
VC # translation table in PS1

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
...	...	...	...

- SWs need to maintain connection state info for ongoing connections

Packet Switching versus Message Switching





- Transfer 7.5 Mbit message in a Pkt-Switched network
  - Msg → 1.5 Kbit x 5,000 pkt

→ Packet switching has reduced the message-switching delay by a factor of three!

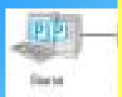
But why is this so?

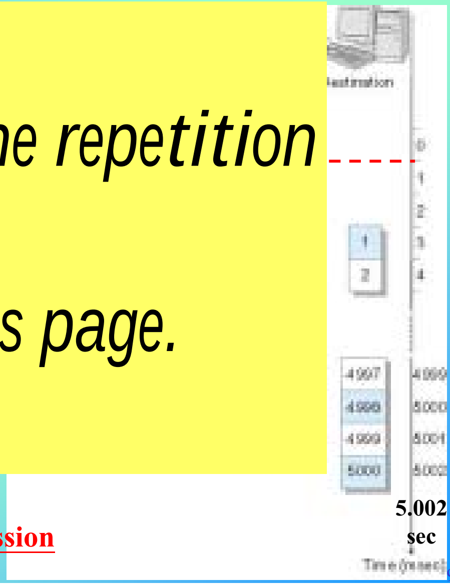
- Key different:

Parallel vs sequential transmission

✓

Packet Switching versus Message Switching





- Transf
  Pkt-Sw
  - Msg

→ Packet
message
factor o

But

Sorry for the repetition of this page.

- Key different:

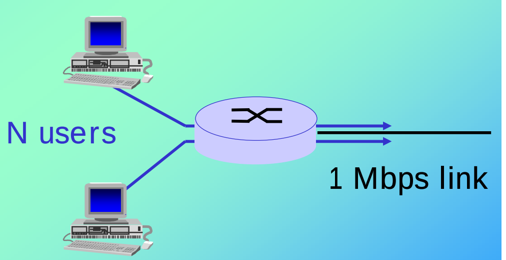
~ **Parallel *vs.* sequential transmission**

✓

Packet Switching versus Circuit Switching

(From Packet-switching's standing point)

- **Packet switching allows more users to use network**
- One 1 Mbps link for sharing
- Each user:
  - 100Kbps when "active"
  - "Active" → 10% of time
- By circuit-switching:
  - 10 users (N = 10)
- By packet switching:
  - Allowing *more than 10* user by taking the advantage of not simultaneously use the channel (higher usage)



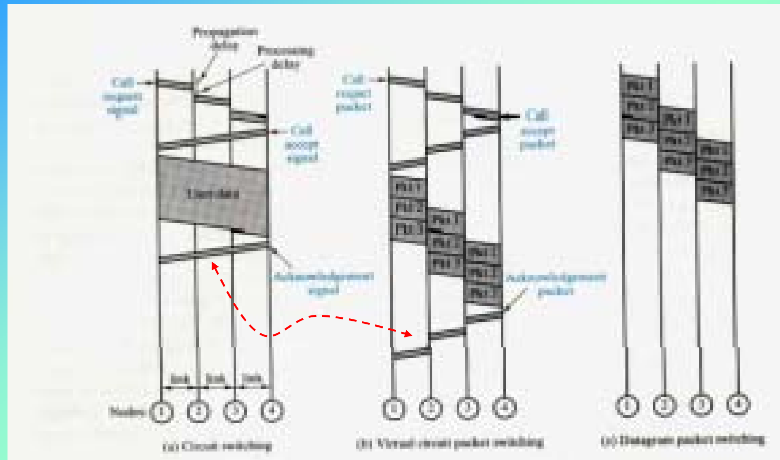
- **Great for bursty data**
  - resource sharing efficiently
  - no call setup
- **Excessive congestion**: packet <u>delay and loss</u> (coming next)
  - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior?**
  - bandwidth guarantees needed for audio/video apps

  still an unsolved problem (QoS issues)

- **<u>Viewpoints of Pros and Cons (try the following)</u>**

  - processing overhead? Setup? Store need?
  - more control over the traffic? Dynamic use of bandwidth/data rate?
  - maintaining system/node status? quality of services?
  - etc.

<u>Timing Comparisons of Switching Techniques</u>



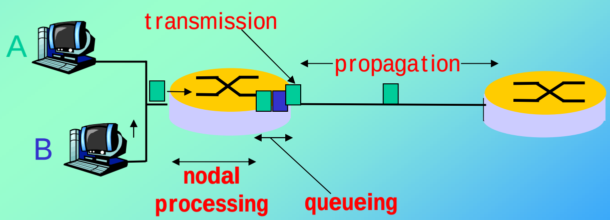
<u>Viewpoints:</u>

Dedicated communication path? The way of data transmission?
Message being stored? Call setup? Delay (propagation and transmission)?
Network overloading response? Overhead bits?

Delay in packet-switched networks

- Packets experience delay on end-to-end path
- Four sources of delay at each hop

1. ***Nodal processing*** delay
   - check bit errors
   - determine output link
2. ***Queueing*** delay
   - time waiting at output link for transmission
   - depends on congestion level of routers

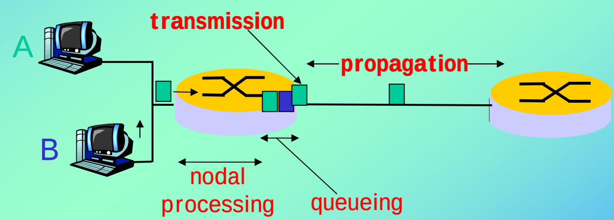


3. Transmission **delay:**

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = **L/R**

4. Propagation **delay:**

- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = **d/s**

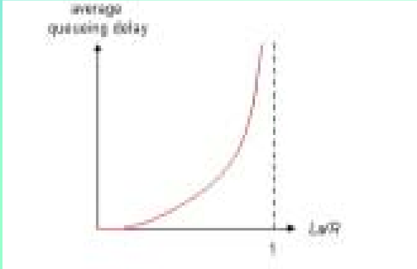


- **Total nodal delay :**

$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Queueing delay (revisited)

- R = link bandwidth (bps)
- L = packet length (bits)
- a = average packet arrival rate (packet/sec)



Traffic Intensity = L*a/R
(dimensionless)

- La/R $\approx$ 0: average queueing delay small
- La/R → 1: delays become large (queue length grows)
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

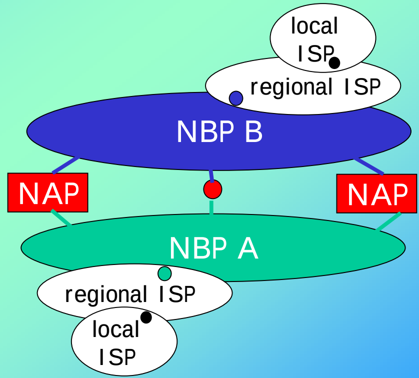
▣ **Golden rule → Do not design your network with T.I. > 1 or → 1.**

What is the " *Internet* " ?

- *Network of networks*

  (inter-connected set of networks)
- To interconnect different computers used by various organizations via the same ***TCP/IP protocol*** → it *treats all networks* (e.g., LAN, WAN, etc.) *equally* (i.e., a flat network)

* roughly hierarchical



A(B,S)P ~ Access (Backbone, Service) Providers

• New computers added to the Internet > ONE per second
• Internet ~ Doubling in size every nine to twelve months

(reference)

Internet History - I

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

(reference)

Internet History - II

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:
- minimalism, autonomy - no internal changes required to interconnect networks
- Best-effort service model
- stateless routers
- decentralized control

→ define today's Internet architecture

(reference)

Internet History - III

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control

- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

(reference)

Internet History - IV

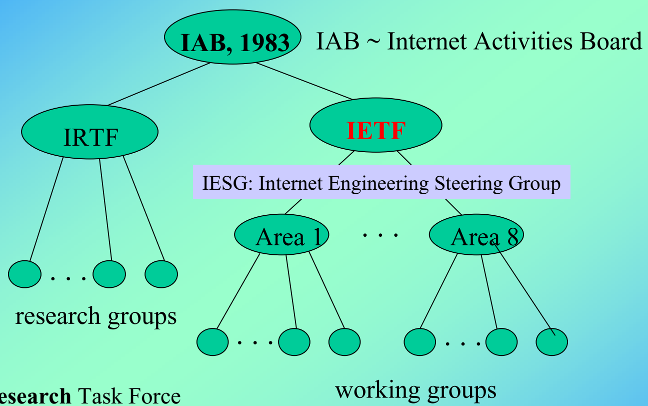
1990-2000's: commercialization, the Web, new apps.

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- Early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

Late 1990's – 2000's:

- more killer apps: instant messaging, peer-to-peer file sharing (e.g., Naptser)
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet Organizations



IRTF - Internet **Research** Task Force
- Responsible for research and development of the Internet protocol suite

IETF - Internet **Engineering** Task Force
- Responsible for solving short-term engineering needs of the Internet. It has over 40 Working Groups.

- **IANA** ~ Internet Assigned Number Authority
- NIC ~ Network Information Center TWNIC
  ⇨ APNIC (**TWNIC**, etc.), EURNIC, etc.
  RFC ~ Request For Comments
  FYI ~ For Your Information (RFC # > 1500)

How to get RFC ?

1. By ***FTP*** **:** Connect via FTP to *ds.internic.net* with Acc#: anonymous & Password: guest, then " get rfc/rfc1577.txt local filename "
2. By ***E-mail*** **:** Mail to "mailserv@ds.internic.net " with a message of " send rfc1577.txt "
   Mail to "rfc-info@ISI.EDU with Subject "getting rfcs" and Content "help: ways_to_get_rfcs"
3. **Web sites**: http://www.rfc-editor.org (many others)
4. ***Archie*** Search:

RFC Examples

Network Working Group   W. Laubach
Request for Comments: 1577   Hewlett-Packard Laboratories
Category: Standards Track   January 1994

- **RFC 1577** Classical IP and ARP over ATM

Network Working Group   J. Reynolds
Request for Comments: 1700   J. Postel
STD: 2   ISI
Obsoletes RFCs: 1340, 1060, 1010, 990, 960,   October 1994
943, 923, 900, 870, 820, 790, 776, 770,
762, 758,755, 750, 739, 604, 503, 433, 349
Obsoletes IENs: 127, 117, 93
Category: Standards Track

topic

- **RFC 1700**

ASSIGNED NUMBERS

- **Other RFCs:**

1. RFC1700 - assigned numbers (including all port numbers and constants)
2. RFC2700 - State (standard, draft standard, proposed standard, experimental, informational, or historic) of standardization of various internet protocols

Some Important RFCs

Protocol	Full Name	RFC #	Protocol	Full Name	RFC #	Protocol	Full Name	RFC #
TCP*	Transport Control Protocol	793 1323	BOOTP	Bootstrap Protocol	951 1048 1084	SNMP*	Simple Network Management Protocol	1067 1448
UDP*	User Datagram Protocol	768	URL	Uniform Resource Location	1738	SMTP	Simple Mail Transfer Protocol	821 822
IP*	Internet Protocol	791	DHCP*	Dynamic Host Configuration Protocol	1531 1541 2131	MIME	Multipurpose Internet Mail Extensions	2045 2046 2047 2048
ICMP*	Internet Control Message Protocol	792	Telnet*	Telnet (Remote login)	764 854	POP3	Post Office Protocol V.3	1939
ARP*	Address Resolution Protocol	826	FTP*	File Transfer Protocol	959	IMAP	Internet Mail Access Protocol	2060
RARP	Reverse Address Resolution Protocol	903	DNS*	Domain Name System	1034 1035	NNTP	Network News Transport Protocol	977
HTTP	Hypertext Transfer Protocol	2068	Cookies	HTTP State Management Protocol	2109	CIDR	Classless InterDomain Routing	1519
ISSP	Internet Standard Subnetting Procedure	950	PPP	Point to Point Protocol	1661	NAT	IP Network Address Translator	1631