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

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 $10^9$)

Switching Technology - I

- **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

- Each link has a 1.5 Mbps transmission rate

  - 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. circuit/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

**Circuit Switching Concept**

* Example - Public (circuit-)Switched Telephone Network

- Switching

**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

- **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
**Overview**

**FDM system architecture (TX and RX)**

![FDM System Diagram]

- **FDM (cont'd)**
  - **Lower Side-Band (LSB)**
  - **Upper Side-Band (USB)**

**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**

- **Illustration of TDM channel MUX and DEMUX**
- **Input 1**: $F_1 f_1 f_1 d_1 d_1 C_1 A_1$
- **Input 2**: $F_2 f_2 f_2 d_2 d_2 C_2 A_2$

**A TDM System**

- **Transmitter**
  - Frames in the line
  - 24 voice channel integrated/Muxed together
  - Frame = $24 \times 8 + 1$ (framing bit) = 193 bits
  - Voice signal is sampled $4kHz \times 2 = 8,000$ times/sec (125us/sample)

- **Receiver**
  - Buffer
  - SCAN
  - Frame

**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
- A voice channel, band-limited to 4kHz
  - 7-bit (digitized) data and 1-bit signaling control
  - 24 voice channel integrated/Muxed together
  - Frame = $24 \times 8 + 1$ (framing bit) = 193 bits
  - Voice signal is sampled $4kHz \times 2 = 8,000$ times/sec (125us/sample)

- **Data rate for T-1 carrier**: $8000 \times 193 = 1.544$ Mbps

**Bell Lab.**

- Voice Frequency Range
  - 300Hz to 3,400Hz
**Pulse Code Modulation – Brief Review**

- **Sampling**
- **Quantization**
- **Encoding**

Sampling → analog voice
Quantization → digital waveform
Encoding → sampled according to Sampling/Nyquist Theorem.

- Encoding example (4-bit PCM)

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<th>Binary Equivalent</th>
<th>PCM waveform</th>
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<td>15</td>
<td>1111</td>
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**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

- **MUX Frame in TDM**
  - Users $A_i$, $i = 1, 2, 3, 4$
  - outgoing link
  - link usage
  - link time-division multiplexing
  - Synchronous time-division multiplexing
  - Statistical time-division multiplexing
  - Frame in TDM
  - $n$ inputs but only $k$ active ($k \leq n$), no empty slots was sent in a frame

Packet Switching - Datagram

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

Packet Switching - Virtual Circuit

- 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.
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 PSI
- 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 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 delay and loss (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)

• **Viewpoints of Pros and Cons (try the following)**
  - processing overhead? Setup? Store need?
  - more control over the traffic? Dynamic use of bandwidth/data rate?
  - maintaining system/node status? quality of services?
  - etc.

### 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

### Timing Comparisons of Switching Techniques

- **Viewpoints:**
  - 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

1. **Nodal processing delay**
   - $d_{\text{proc}} = \frac{L}{R}$
2. **Queueing delay**
   - $d_{\text{queue}} = \frac{L}{R}$
3. **Transmission delay**
   - $d_{\text{trans}} = \frac{L}{R}$
4. **Propagation delay**
   - $d_{\text{prop}} = \frac{d}{s}$

- **Total nodal delay**:
  
  $d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$
Queueing delay (revisited)

- $R = \text{link bandwidth (bps)}$
- $L = \text{packet length (bits)}$
- $a = \text{average packet arrival rate (packet/sec)}$

Traffic Intensity = $L*a/R$
(dimENSIONLESS)

- $La/R \approx 0$: average queueing delay small
- $La/R \rightarrow 1$: 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 $\rightarrow 1$.

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)

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

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

Internet History - II

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHA network in Hawaii
- 1973: Metcalfe’s PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late 70’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

Internet History - IV

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

- Early 1990’s: ARPAnet decommissioned
- 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., Napster)
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps

Internet Organizations

IAB, 1983

IAB ~ Internet Activities Board

- IAB
  - IETF
  - IRTF

- 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
- 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

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

- **RFC 1700**
  - Assigned numbers (including all port numbers and constants)

**Other RFCs:**
1. RFC 1700 - assigned numbers (including all port numbers and constants)
2. RFC 2700 - State (standard, draft standard, proposed standard, experimental, informational, or historic) of standardization of various internet protocols

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### Some Important RFCs

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<th>Protocol</th>
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<td>User Datagram Protocol</td>
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<td>1541</td>
<td>MIME</td>
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<td>Telnet</td>
<td>Telnet (Remote login)</td>
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