Evolution of Switching Techniques

1. Dedicate Channel. Separate wire frequency division multiplexing (FDM) time division multiplexing (TDM)

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Channel 2</th>
<th>Channel 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Multiplexor (MUX) (Concentrator)

Demultiplexor (DEMUX)

Individual lines shared high speed line

Frequency Division Multiplexing (FDM)

(a) Channel 1

(b) Channel 2

(c) Channel 3

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Frequency (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td>3100</td>
<td>64</td>
</tr>
<tr>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>72</td>
<td>72</td>
</tr>
</tbody>
</table>
Wavelength Division Multiplexing

Impact of WDM

- Many big organizations are starting projects to design WDM system or DWDN (Dense Wave Division Multiplexing Network). We may see products appear in next three years. In Fujitsu and CCL/Taiwan, 128 different wavelengths on the same strand of fiber was reported working in the lab.

- We may have optical routers between end systems that can take one wavelength signal, covert to different wavelength, send it out on different links. Some are designing traditional routers that covert optical signal to electronical signal, and use time slot interchange based on high speed memory to do the switching, the convert the electronic signal back to optical signal.

- With this type of optical networks, we will have a virtual circuit network, where each connection is assigned some wave length. Each connection can have 2.4 gbps tremendous bandwidth.

- With initial 128 different wavelength, we can have about 10 end users. If each pair of end users needs to communicate simultaneously, it will use 10*10=100 different wavelength.

- There is an issue of protocol layering. Should we have IP/DWDN directly, or IP/Sonet/DWDN? No one is talking about IP/ATM/Sonet/DWDN.
T1 and PCM

Every 6 frames it steals one bit from each channel for signaling purpose. What is the impact of this design on data comm.

Basic Digital Hierarchies

North American Digital Hierarchy

Primary Multiplex
Eg. Digital Switch
24 chan PCM

DS1 1.544 Mbps

M12 Multiplex
x4

DS2 6.312 Mbps

M23 Multiplex
x7

DS3 44.736 Mbps

M13 Multiplex

DS3 44.736 Mbps

28

European Digital Hierarchy

Primary Multiplex
Eg. Digital Switch
30 chan PCM

CEPT 1 2.048 Mbps

2nd order Multiplex
x4

8.448 Mbps

3rd order Multiplex
x4

34.368 Mbps

4th order Multiplex
x4

CEPT 4 139.264 Mbps
SONET (Synchronous Optical NETwork)

Dual ring is a common topology for SONET.

SPE: synchronous payload data
This is STS-1 frame with 9x90 bytes (51.84 Mbps).
STS-3 frame has 9x270 bytes (155.52 Mbps).
Frame rate is 8000 per second.

SONET and SDH Multiplex Rate

SDH (Synchronous Digital Hierarchy) STS (Synchronous Transport Signal)

<table>
<thead>
<tr>
<th>SONET</th>
<th>SDH</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>51.84</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>155.52</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>466.56</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>933.12</td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>1244.16</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>1866.24</td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>2488.32</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>9953.28</td>
</tr>
</tbody>
</table>

|          | STM-1 | 50.112           |
|          | STM-3 | 150.336          |
|          | STM-6 | 902.016          |
|          | STM-8 | 1202.688         |
|          | STM-12| 1804.032         |
|          | STM-16| 2405.376         |
|          | STM-64| 1188.864         |
|          |       | 49.536           |
|          |       | 148.608          |
|          |       | 445.824          |
|          |       | 594.432          |
|          |       | 891.648          |
|          |       | 1188.864         |
|          |       | 1783.296         |
|          |       | 2377.728         |
SONET Multiplexing

- **DS1**
- **DS2**
- **CEPT-1**
- **DS3**
- **CEPT-4**
- **ATM**

**Low-Speed Mapping Function**

**Medium-Speed Mapping Function**

**High-Speed Mapping Function**

- **STS-1**
- **51.84 Mbps**

**tributary: component streams**

SONET Add-Drop Multiplexor (ADM)

(a) pre-SONET multiplexing

(b) SONET Add-Drop multiplexing

Tributary can be inserted/removed without disturbing others
Configure Logical Networks Using ADM

(a) 3 ADMs connected in physical ring topology

(b) logical fully-connected net

SONET Self-Healing Ring

(a) Dual ring

(b) Loop-around in response to fault

restoration can be done in 50 msec
What is the Network Restoration Problem?

- Types of Failures: Channel, Link, Node, Area, and Transient Failures.
- Network Restoration: Process of recovering from network failures.
- Types of Restoration Approaches: Centralized, Distributed, Hierarchical.

Evolution of Switching Techniques

2. Circuit Switching
   - Using FDM or TDM with demand (dynamic channel assignment)
   - E.g. Old telephone networks, satellites.
   - Difficulties in handling computer data traffic:
     - Demand assignment per “message” ⇒ relative long set-up time.
     - Demand assignment per “session” ⇒ low utilization.

3. Message Switching
   - With data concentrator for long distance high-speed line
   - Also called statistical multiplexing or ATDM (Asynchronous Time-Division Multiplexing)
   - Used in stored-and-forward network.
   - Note: Addresses needed to identify messages.

4. Packet Switching
   - Variable size messages from host segmented into small packets.
   - Advantages—simultaneous parallel path possible;
     - Pipelining in multihop network.
   - Problems—disassembly, reassembly, sequencing, support real-time traffic.
Circuit Switching vs. Packet Switching: Network

![Diagram of Circuit Switching vs. Packet Switching](image)

Delay Analysis of a Circuit Switch Network

- **d**: propagation delay
- **CR**: Call Request message
- **CA**: Call Accept message
- **Tcsd**: Total call setup delay
- **Tmtd**: Total message transmission
- **L**: message length (bits)
- **b**: transmission speed (bps)

Assume all hops of the same **b** an then Total circuit switching delay =

\[ T_{csd} + T_{mtd} \]

\[ = T_{csd} + (3d + L/b) \]

\[ \text{no. of hops} + 1 \]
Timing Analysis of Ckt SW, Msg SW and Pkt SW

Important Network Design Parameters for Analyzing Network Performance

Propagation delay refers to how long it takes for a bit to traverse a link. It depends on the distance and the signal propagation speed.
Example: 10km distance, 2*10^8 m/sec propagation speed.

Propagation delay = distance / signal propagation speed
Transmission delay = message size / transmission speed
Queueing delay depends on
- how many requests on the queue and
- how fast the node can process them.
Evolution of Switching Techniques

5. Cell Switching
   - chop messages into tiny fixed size packets called ATM cell (53 bytes)
   - ATM: Asynchronous Transfer Mode
     - advantages—much better response time of small message traffic
     - provision for guarantee bandwidth ⇒ support real-time traffic.
     - disadvantages—too much overhead; (5 bytes header).

Packet Switching

additional segmentation/assembly required

Network with Links and Switches

Switches can be divided into two classes:
- Space-division switches: provide separate physical connections between inputs and outputs (ports).
- Time-division switches: network flow are time-division multiplexed streams.
Time Division Switch

Time division switch is used in the circuit switching systems. How to set up a connection through the time division switch? What is the relationship between the memory access time (T) of RAM buffer and the number of slots/channels (n) in the frame, assuming a frame period of 125 μsec (8000 frames/sec)?

Here we assume this a telephony network where frames (big or small) are sent at 8000 frames/sec frame rate, i.e., 125 μsec per frame.

A separate signaling (call setup) channel is used to tell the switch which pairs of users are trying communicate each other. It results in the mapping table content shown above. Here the mapping table shows (channel0 talks to channel 4, channel1 to channel7, channel2 to channel6)

There are two basic ways to implement this time slot interchange:

1. Sequential write to RAM, random read out of RAM:
   In this approach, channel data are written to the RAM sequentially, i.e., data of the first channel is written to the first word of the RAM. After all data is in, the data in RAM are read according to the mapping table to form the outgoing frame. For example, the first time slot of the outgoing frame is filled with the 4th word of RAM, the 2nd time slot is filled with 7th word.

2. Random write to RAM, sequential read out of RAM:
   In this approach, the time slot data in the incoming frame are written to the RAM “randomly” according to the mapping table. After all data is in, the data in RAM are read sequentially to form the outgoing frame.

The outgoing frame cannot be sent until the whole incoming frame is read.
Crosspoint Switch and Multistage Switch

A 8x8 crosspoint switch
How many crosspoints are needed in this switch?

A 3-stage switch
Why 3-stage? Why not 2-stage?

ATM 53 Byte Cell Structure

<table>
<thead>
<tr>
<th>ATM HEADER (5 OCTET)</th>
<th>ATM PAYLOAD (48 OCTET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENERIC FLOW CONTROL</td>
<td>VIRTUAL PATH IDENTIFIER (VPI)</td>
</tr>
<tr>
<td>VPI</td>
<td>VCI</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
</tr>
<tr>
<td></td>
<td>VCI, PAYLOAD TYPE, RESERVED</td>
</tr>
<tr>
<td></td>
<td>HEADER CHECK SEQUENCE (HCS)</td>
</tr>
<tr>
<td></td>
<td>SEGMENT TYPE, MESSAGE IDENTIFIER (MID)</td>
</tr>
<tr>
<td></td>
<td>INFORMATION FIELD REMAINING 44 OCTETS</td>
</tr>
<tr>
<td></td>
<td>LENGTH, CRC</td>
</tr>
<tr>
<td></td>
<td>CYCLIC REDUNDANCY CODE (CRC)</td>
</tr>
</tbody>
</table>
ATM Switch Structure

Control Processor: connection management, bandwidth allocation, maintenance.
IC: cell buffering, VCI/VPI translation, cell filtering, ATM policing, cell alignment,
and output port contention resolution.
OC: cell buffering, VCI/VPI translation for multicast cells.

Space Division Switching Elements
2x2 Switches

Possible States of 2x2 Sw
- 0 port
- straight-through
- cross-over
- 0-broadcast
- stuck on 0

Self-Routing
Using routing tag of cell to select the 2x2 Sw state

2x2 configure as router
bit in routing tag

2x2 configure as sorter
arrow point to the port to receive bigger routing tag
11>10
set 2x2 to cross-over state
Cell Routing in A Batcher-Banyan Switch

Those lines without input cell is assume to have very large routing tag value. Batcher sorting switch sorts the cells according to the routing tag values. For this work, in a given cycle, no two cells go to the same output port. The nth stage of banyan switch interprets the nth bit of routing tags as routing bit.

Exercise Cell Switching

Prob. 3. Batcher-Banyan Switch. Draw the 2x2 element configurations along the routes for those 4 cells.
Telephone Network: LEC(RBOC), IXC

- Local Exchange Carriers (LECs) consist of Regional Bell Operating Companies (RBOCs).
- Interexchange Carriers (IXCs) consist of AT&T, MCI, Sprint.
- LATA: Local Access and Transport Area operated by LECs.
- IXC has POP (point of presence) in some LATA switches.

![Diagram of Telephone Network: LEC(RBOC), IXC]

Signaling Network

- SSP = Service switching point (signal to message)
- STP = Signal transfer point (message transfer)
- SCP = Service control point (processing)
Intelligent Networks

Provides services using enhanced signaling networks.
- Caller ID, voice mail, voice recognition, call screening, call back...

Signalling System #7

a packet network that control the setting up, managing, and releasing of telephone call. It also supports, IN, mobile cellular networks, and ISDN.

It has its own layering called part and related message format. It is used by a cellular network to communication with LECs or IXCs.
Components of Cellular Networks

AC = authentication center
BSS = base station subsystem
EIR = equipment identity register
HLR = home location register

MSC = mobile switching center
PSTN = public switched telephone network
STP = signal transfer point
VLR = visitor location register

wireline terminal

Paging System vs. Cellular Phone System

one way communication vs. two way communications
Some companies to offer integrated system that provides both services.
Advanced paging system can relay email/bulletin board messages.

Fig. 2-53. (a) Paging systems are one way. (b) Mobile telephones are two way
Advanced Mobile Phone System (AMPS)

invented by Bell Lab. and deployed in US in 1982.
10-km cell. Mobile phone put out 0.6 watts; transmitter in cards are 3 watts.
AMPS uses 832 full duplex channels. 832 simplex channels from 824-849,
another 832 simplex channels from 869-894MHz. Each channel is 30kHz wide. FDM is used. They are divided into two carriers (B-side and A-side).

AMPS Call Management

Registration: (register once every 15 minutes)
- When a cellular phone is switched on, it scans 21 control channels, picks the strongest one, broadcasts the 32 bit serial number and 34 bit telephone number (10 bits for 3 digit area code, 24 bits for 7 digit subscriber number), in digital form, multiple times with ECC code.
- Base station hears the registration msg, keeps record, and inform the customer’s home MTSO(Mobile Telephone Switching Office).

Making cellular call:
- Enter number in keypad and press SEND button. The destination phone number and its ID are sent over the shared access channel. If collision occurs, retry it later.
- Base station relays info to MTSO, which allocate idle channel, and make phone call to destination.

Incoming call to a cellular phone:
- a packet first sends to the callee’s home MTSO to find out its current location.
- a packet then sends to the current base station, which broadcasts on the paging channel for the called phone.
- When the called phone responded, a voice channel is assigned and rings.
Personal Communications Services (PCS)

- Use CDMA (Code Division Multiplexing Access).
- Microcell (50-100 meters) 0.25 watt light weight terminal.
- Small base station, toaster size, called telepoints, on top of telephone/light pole.
- Use 1.7-2.3 GHz spectrum.
- FCC auction off licenses to use PCS spectrum in 1994-5. Get 7.7 billion dollars.
- The original users in the spectrum needs to be relocated. Who should pay that?

Iradium Project

- Use 77 LEO (low earth orbit) satellites.
- Revised to 66 LEO, 1628 moving cells.
- Provide world-wide telecommunication services among hand-held devices using those LEO satellites.
- The coverage areas of PCS or Current Cellular systems are limited. You pay more for access if you are not in the area of your subscriber.

Fig. 2-57. (a) The Iridium satellites form six necklaces around the earth. (b) 1628 moving cells cover the earth.