Chap 4 Circuit-Switching Networks

• Provide **dedicated** circuits between users

**Example:**
1. telephone network: provides 64Kbps circuits for voice signals \(64\text{Kbps}=8\text{ k samples/sec} \times 8\text{ bits/sample}\)
2. transport network: high bandwidth circuit.
   • Backbone interconnects telephone switches
   • Backbone interconnects large routers (internet)
     – Provide the **physical layer** that transfer bits

• **Circuit switching networks require:**
  – Multiplexing & switching of circuits
  – Signaling & control for establishing circuits

---

4.1 Multiplexing

• Sharing of transmission systems by several connections

• Desirable when the bandwidth of individual connections is much smaller than that of the transmission system.
  – E.g. FM radio 25MHz (total) a standard FM radio signal 150Khz

• Cost can be reduced by combining many signals into one
  – Fewer wires/pole; fiber replaces thousands of cables

(a) (b)
4.1.1 Frequency-Division Multiplexing (FDM)

- Frequency slots: each connection uses different frequency slot
- Demultiplexer: recovers the signals
- Example:
  - Broadcast radio AM, FM, Television
    AM: 10 KHz, FM: 200KHz, Television: 6MHz
  - Cellular telephony: e.g. AMPS, 30KHz
  - Guard bands: voice signal 3.4KHz, assigned 4KHz to provide guard bands

**Frequency-Division Multiplexing**

- Channel divided into frequency slots (Fig 4.2)

![Diagram showing frequency slots](imaginary)

(a) Individual signals occupy $W_u$ Hz

(b) Combined signal fits into channel bandwidth
4.1.2 Time-Division Multiplexing (TDM)

- Share a high-speed digital transmission line using temporal interleaving (Fig 4.3)

![Diagram of TDM](image)

- Each signal transmits 1 unit every $3T$ seconds
- Combined signal transmits 1 unit every $T$ seconds

Digital Multiplexing Hierarchy

- TDM used in the telephone network from early 1960s
- Digital voice: $64$ Kbps = $8K$ samples/sec * $8$ bit/sample
- PCM sample (pulse code Modulation)
- T-1 carrier: 24 digital telephone connections
- T-1 frame: 24 slots (8 bits/slot) + 1 “framing bit”

![Diagram of TDM hierarchy](image)

Bit Rate = $8000$ frames/sec. x $(1 + 8 \times 24)$ bits/frame
= 1.544 Mbps
Digital Multiplexing Hierarchy

- T-1 or DS1 (Digital signal 1) North America and Japan basic building block of digital multiplexing hierarchy
- DS2: $4DS1 + 136Kbits$ synchronization information (per sec) = 6.312 Mbps
- DS3: $7DS2 + 552Kbits$ sync info = 44.736 Mbps
- In Europe: CEPT-1 (E-1) = 32 64Kbps channels (30 for voices and 2 for signaling, frame alignment etc)

Clock Synch & Bit Slips

- Digital streams cannot be kept perfectly synchronized
- If the clock of input stream is slower than that of the multiplexer, bit slips can occur (Fig 4.6)
- If faster, bits will accumulate at the multiplexer and get dropped
Clock Synch & Bit Slips

Solution:

– Multiplexer operates at a speed slightly higher than the combined speed of inputs
– Indicate to the receiving multiplexer when a slip occurs
– To extract an individual input stream, need to de-multiplex the entire combined signal.
  64 Kbps → DS1 → DS2 → DS3 → DS2 → DS1 → voice

4.1.3 Wavelength-Division Multiplexing (WDM)

• Optical domain version of FDM (λf=c)
• Electrical signals → optical signals ⇒ optical → electrical

  limited at tens of Gbps. fiber: tens of terahertz (THz)

  $1 \text{ THz} = 1000 \text{ GHz}$
  – e.g. 160 wavelengths * 10Gbps/wavelength = 1.6 Tbps

• Huge increase in available bandwidth without investment on additional optical fiber
4.2 SONET

- Synchronous optical network (SONET) – North America
- Synchronous Digital Hierarchy (SDH) – Europe
- S: synchronous (tightly synchronized to network based clocks, atomic clocks)

4.2.1 SONET Multiplexing

- STS-1 (Synchronous-transport signal level-1)
  - 51.84 Mbps is the basic building block
- STS-n: obtained by interleaving of bytes from n STS-1
  - no additional synchronization information needed
  - e.g. STS-3: $3 \times 51.84 = 155.52$ Mbps
- OC-n (optical carrier level-n)
  - Modulation STS-n electrical signal to optical signal
- In SDH, STM-n (Synchronous transfer module-n)
  - STM-1 $\leftrightarrow$ STS-3
- STS-48/STM-16 is widely deployed in the backbone of modern communication networks
4.2.1 SONET Multiplexing

- SONET uses the term "tributary" to refer to component streams that are multiplexed (Fig 4.10)
  - Flexible
- Several STS-1 frames can be concatenated to accommodate signals with bit rates that cannot be handled by a single STS-1, e.g. STS-3C

![SONET Multiplexing Diagram]

4.2.2 SONET Frame Structure

- Four layers: optical, section, line, path
  - Section: the span of fiber between two adjacent devices e.g. two regenerators
    - regenerator
  - Line: the span between two adjacent multiplexers
  - Path: the span between two SONET-terminals
    - e.g. large routers, can be SONET terminals
Section, Line, & Path in SONET

STE = Section Terminating Equipment, e.g., a repeater/regenerator
LTE = Line Terminating Equipment, e.g., a STS-1 to STS-3 multiplexer
PTE = Path Terminating Equipment, e.g., an STS-1 multiplexer

Fig 4.11

SONET Frame Structure

- STS-1 frame structure (Fig 4.12)
  - 9 rows x 90 columns per frame (810 bytes)
  - Frame rate: 8000 frames/sec
  - The bits are physically transmitted row by row and from left to right
  - Overall bit rate: \( 8 \times 9 \times 90 \times 8000 = 51.84 \text{ Mbps} \)
  - First three columns: section and line overhead
    - Section overhead: 3 rows (framing, error monitoring)
    - Line overhead: 6 rows (synchronization, multiplexing etc)
    - \( H_1, H_2, H_3 \), in line overhead; very important
  - Remaining 87 columns "information payload"
    - \( 8 \times 9 \times 87 \times 8000 = 52.122 \text{ Mbps} \)
SONET Frame Structure

- SPE (synchronous payload envelope)

Fig 4.13
- First column: path overhead
- SPE is not necessarily aligned to the information payload of an STS-1 frame
- $H_1, H_2$ (first two bytes of line overhead) are used as a pointer to indicate where the SPE begins
- When $n$ STS-1 signals are multiplexed, they are first synchronized to the clock of the multiplexer
- The STS-$n$ frame is produced by interleaving the bytes of the $n$ synchronized STS-1 frames

$\Rightarrow 9$ rows $x 90n$ columns ($3n$ section, line overhead, 87$n$ payload information)
First column is path overhead

Frame $k$

Frame $k+1$

First octet

Last octet

Synchronous payload envelope

87 Columns

9 Rows

First column is path overhead