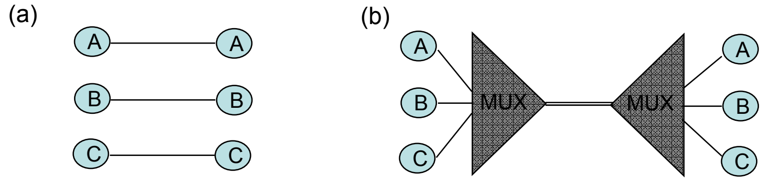
Chap 4 Circuit-Switching Networks

- Provide dedicated circuits between users
- Example:
  1. telephone network: provides 64Kbps circuits for voice signals *64Kbps=8 k samples/sec * 8 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

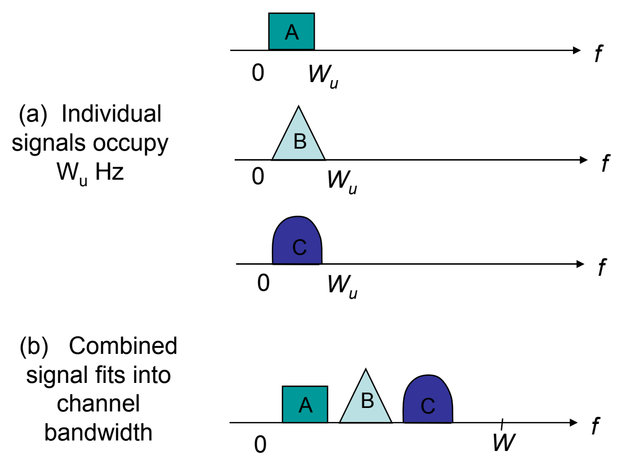


4.1.1 Frequency-Division Multiplexing (FDM)

- 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

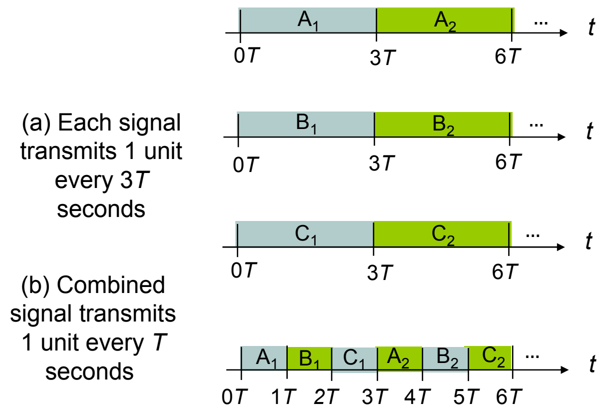
Frequency-Division Multiplexing

- Channel divided into frequency slots (Fig 4.2)



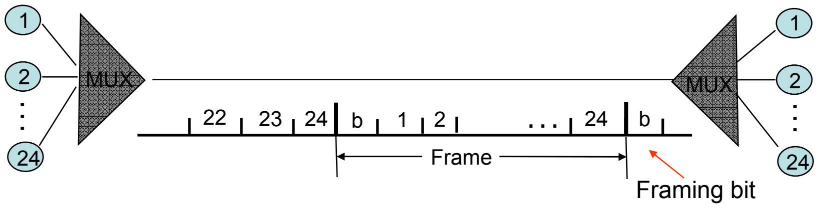
4.1.2 Time-Division Multiplexing (TDM)

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



Digital Multiplexing Hierarchy

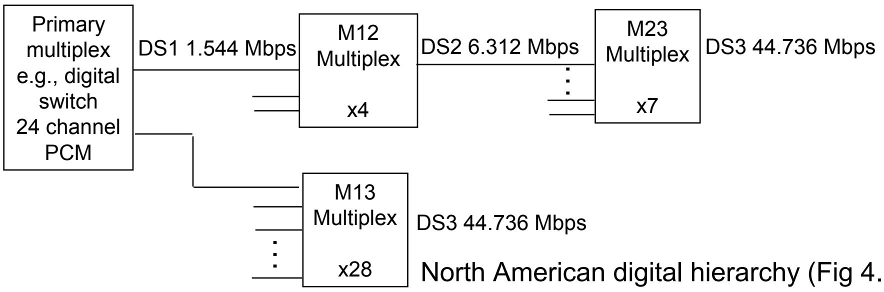
- TDM used in the telephone network from early 1960s
- Digital voice: *64 Kbps = 8K samples/sec *8 bit/sample* PCM sample (pulse code Modulation)
- T-1 carrier: 24 digital telephone connections
- T-1 frame: *24 slots (8 bits/slot)* + *1 "framing bit"*



Bit Rate = 8000 frames/sec. x (1 + 8 x 24) bits/frame
= 1.544 Mbps

Digital Multiplexing Hierarchy

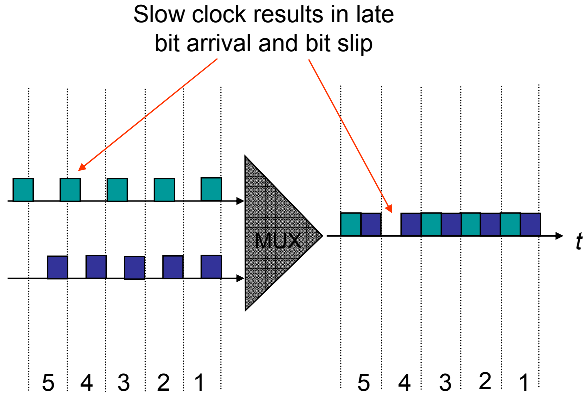
- T-1 or DS1 (Digital signal 1) North America and Japan basic building block of digital multiplexing hierarchy
- DS2: *4DS1 + 136Kbits synchronization information (per sec) = 6.312 Mbps*
- DS3: *7DS2 + 552Kbits sync info = 44.736 Mbps*
- In Europe: CEPT-1 (E-1) = *32 64Kbps channels* (*30* for voices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



North American digital hierarchy (Fig 4.5)

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 ($\lambda f=c$)
- *Electrical signals → optical signals ⇒ optical → electrical*

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

1 THz = 1000 GHz

  – e.g. *160 wavelengths * 10Gbps/wavelength = 1.6 Tbps*
- Huge increase in available bandwidth without investment on additional optical fiber

4.2 SONET

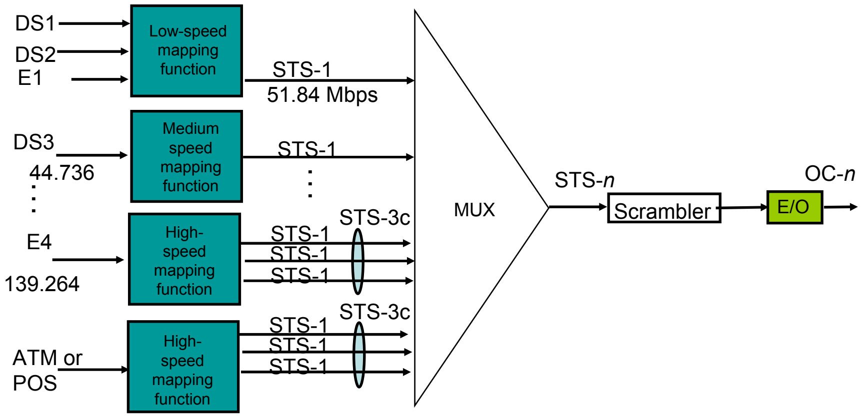
- Synchronous optical network (SONET) North America
- Synchronous Digital Hierarchy (SDH) Europe
- S: synchronous (tightly synchronized to network based clocks, atomic clocks)

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 x 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 ⇔ STS-3
- STS-48/STM-16 is widely deployed in the backbone of modern communication networks

4.2.1 SONET Multiplexing

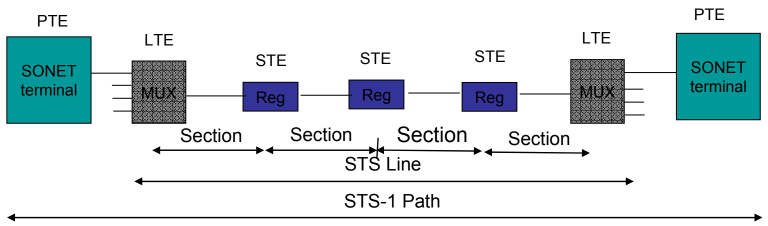
- SONET uses the term "tributary" to refer to component streams that are multiplexed (Fig 4.10)
  - Flexible
- Several STS-1 frames can be concatenated to accommodate signals with bit rates that cannot be handled by a single STS-1, e.g. STS-3C



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



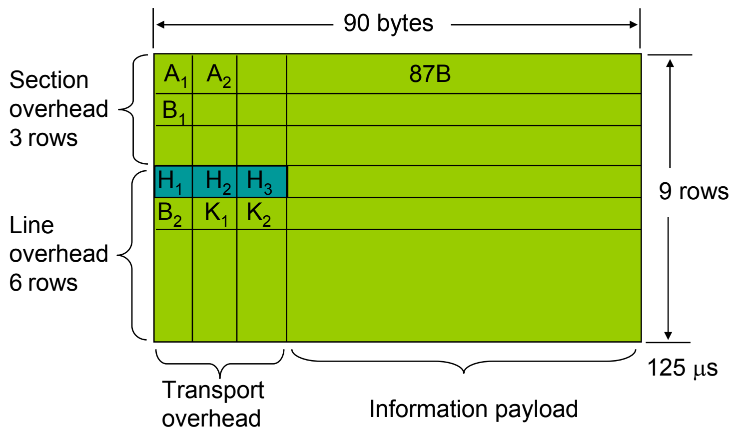
STE = Section Terminating Equipment, e.g., a repeater/regenerator
LTE = Line Terminating Equipment, e.g., a STS-1 to STS-3 multiplexer
PTE = Path Terminating Equipment, e.g., an STS-1 multiplexer

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 x 9 x 90 x 8000 = 51.84 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 x 9 x 87 x 8000 = 52.122 Mbps*

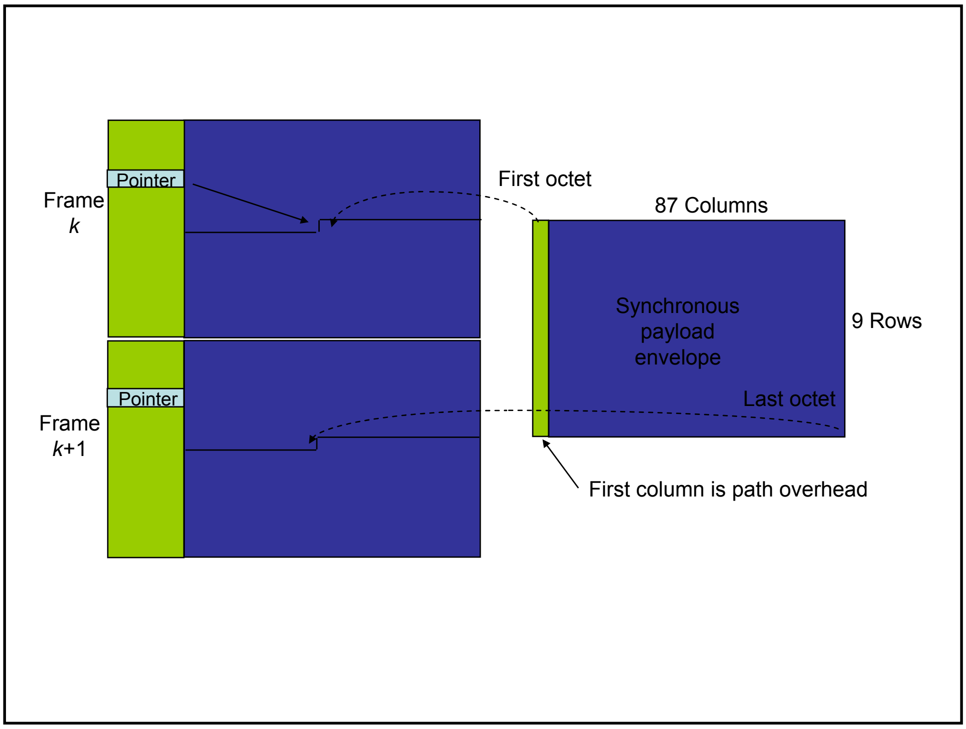
SONET Frame Structure



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 <u>pointer</u> 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, *87n* payload information)


Frame
k
Pointer
Frame
k+1
Pointer
First octet
87 Columns
Synchronous
payload
envelope
9 Rows
Last octet
First column is path overhead