Chapter 6. Bandwidth Utilization: Multiplexing and Spreading
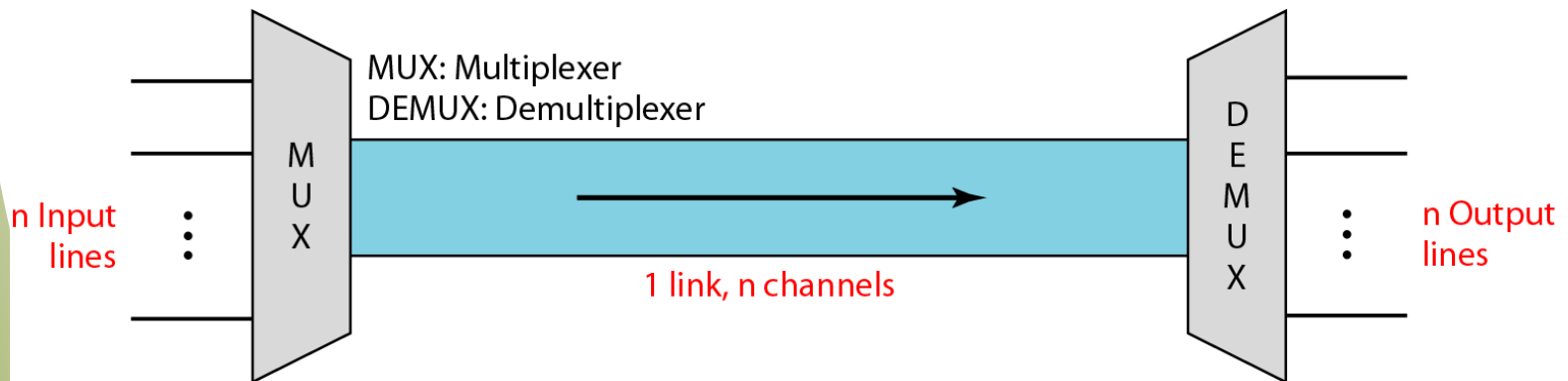
Multiplexing

Bandwidth Utilization

- Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.
- Two categories: multiplexing and spreading
- Efficiency can be achieved by multiplexing
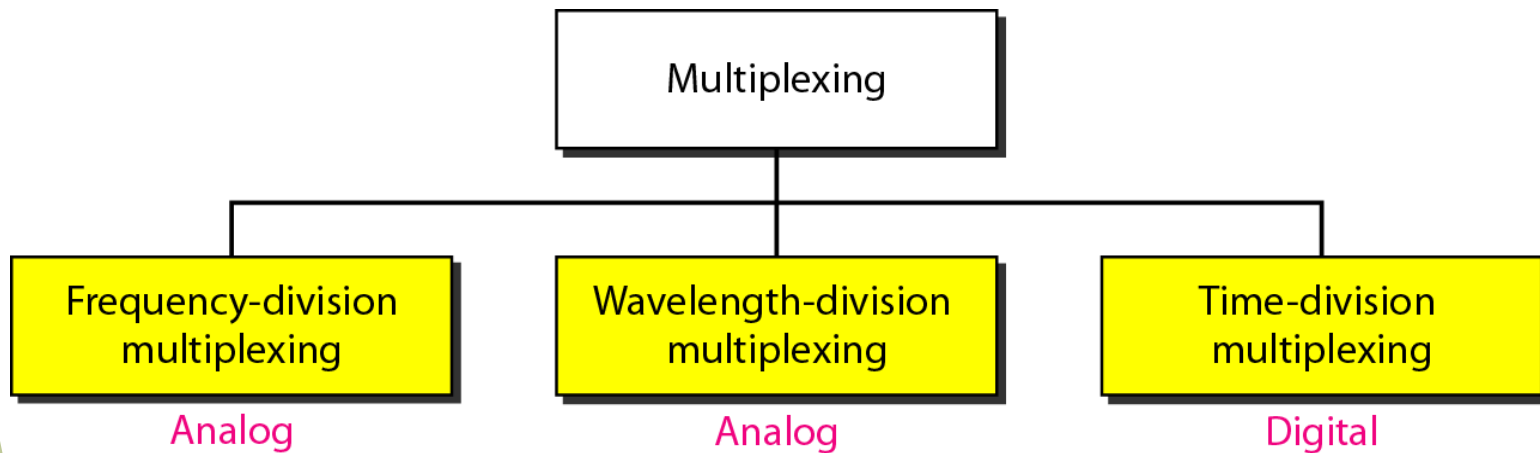- Privacy and anti-jamming can be achieved by spreading.

Multiplexing

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.

MUX: Multiplexer
DEMUX: Demultiplexer

n Input lines

M U X

1 link, n channels

D E M U X

n Output lines

Categories of Multiplexing

Frequency Division Multiplexing

- FDM is an analog multiplexing technique that combines analog signals
- Signals modulate different carrier frequencies
- Modulated signals are combined into a composite signal
- *Channel* - Bandwidth range to accommodate a modulated signal
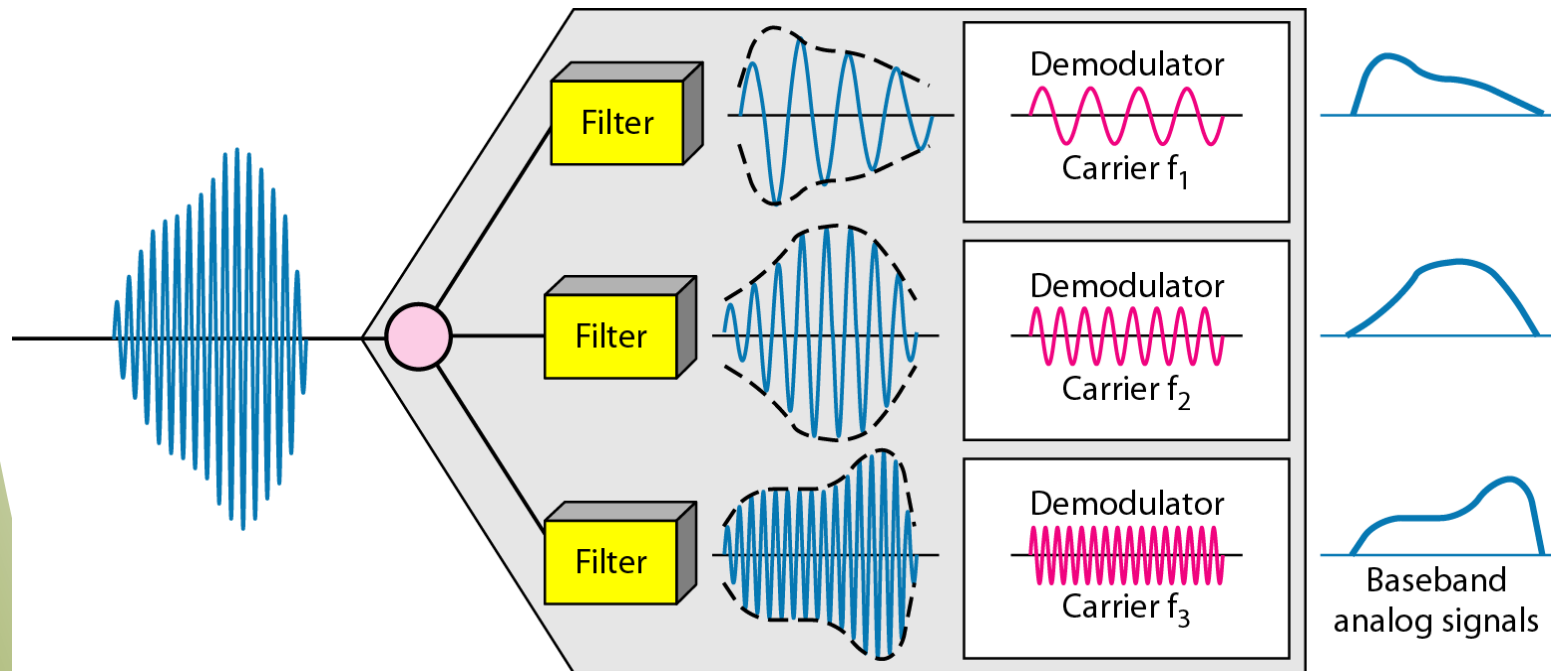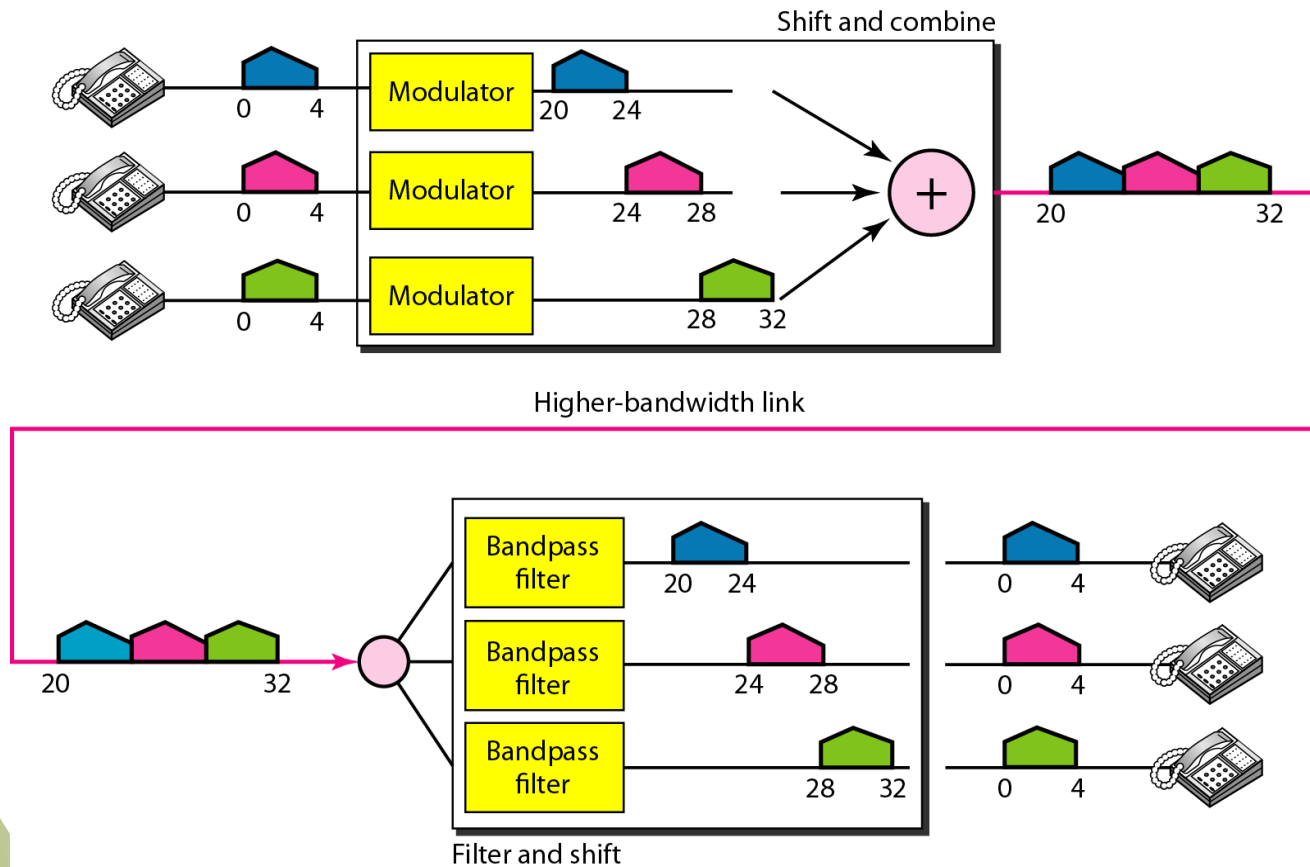- Channels can be separated by strips of unused bandwidth (**guard band**) to prevent overlapping

Input lines

M U X

Channel 1

Channel 2

Channel 3

D E M U X

Output lines
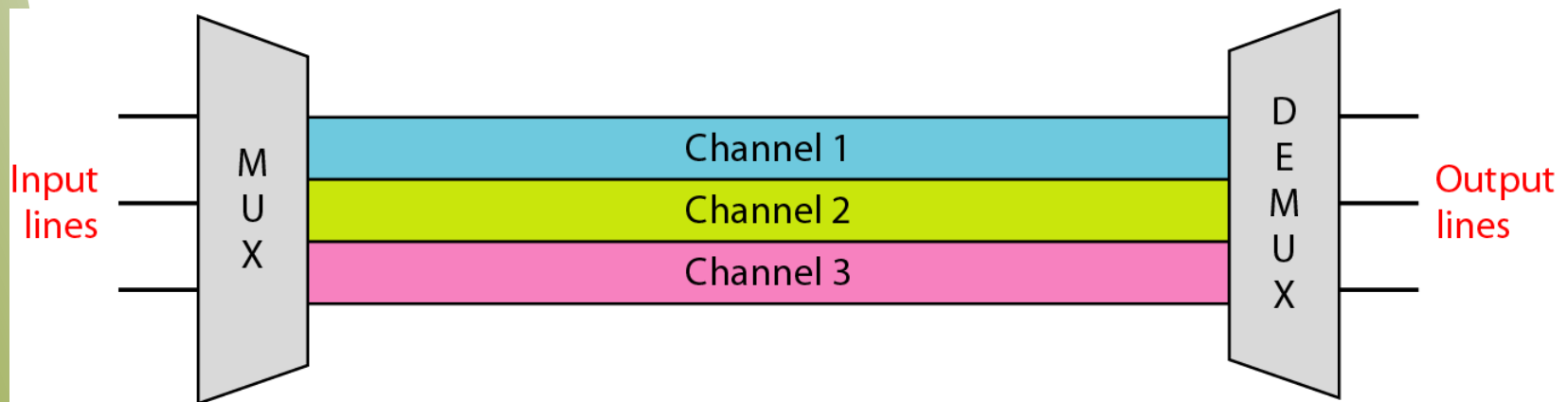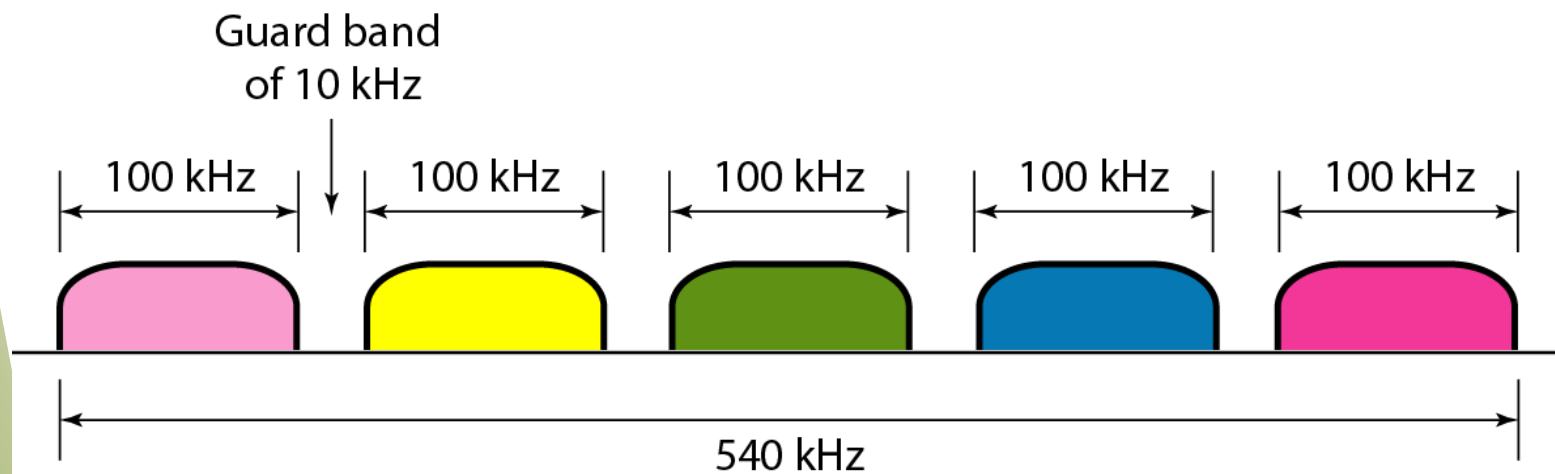
FDM Process
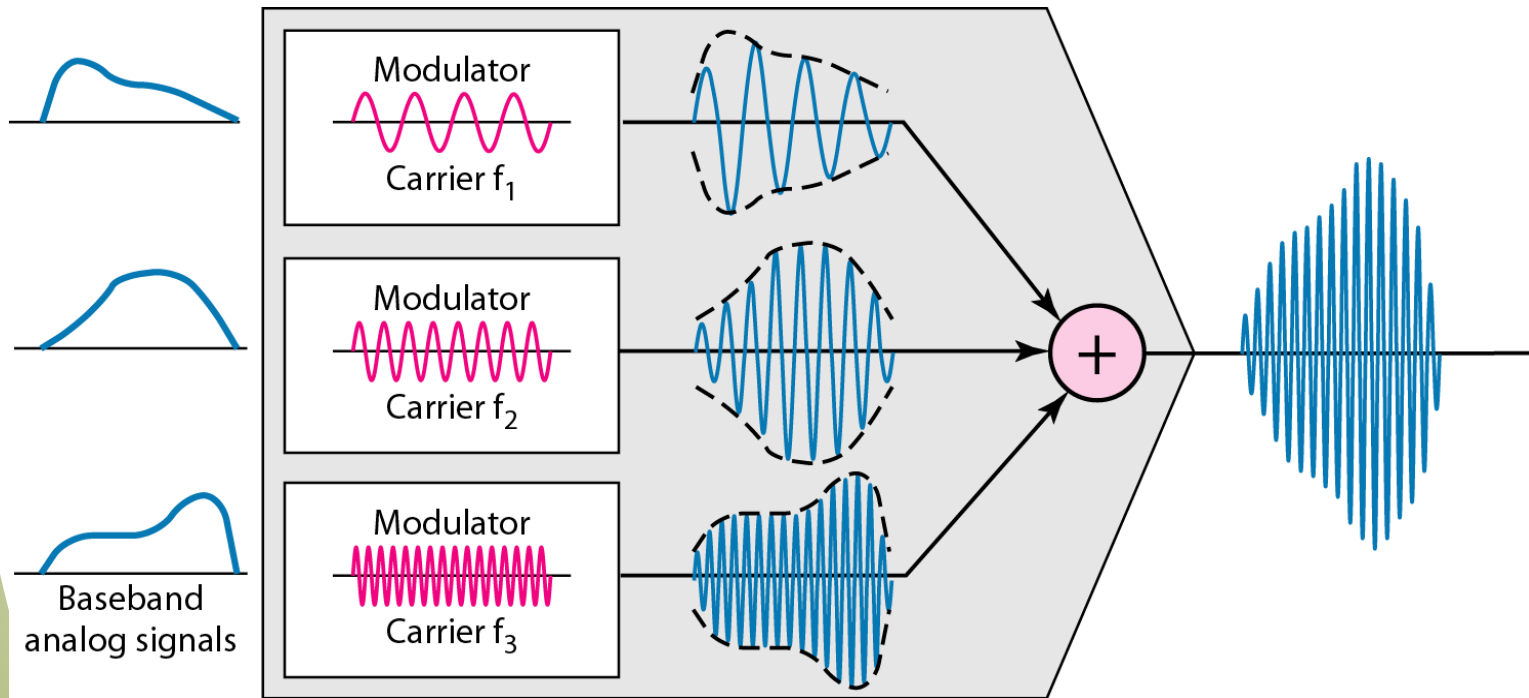
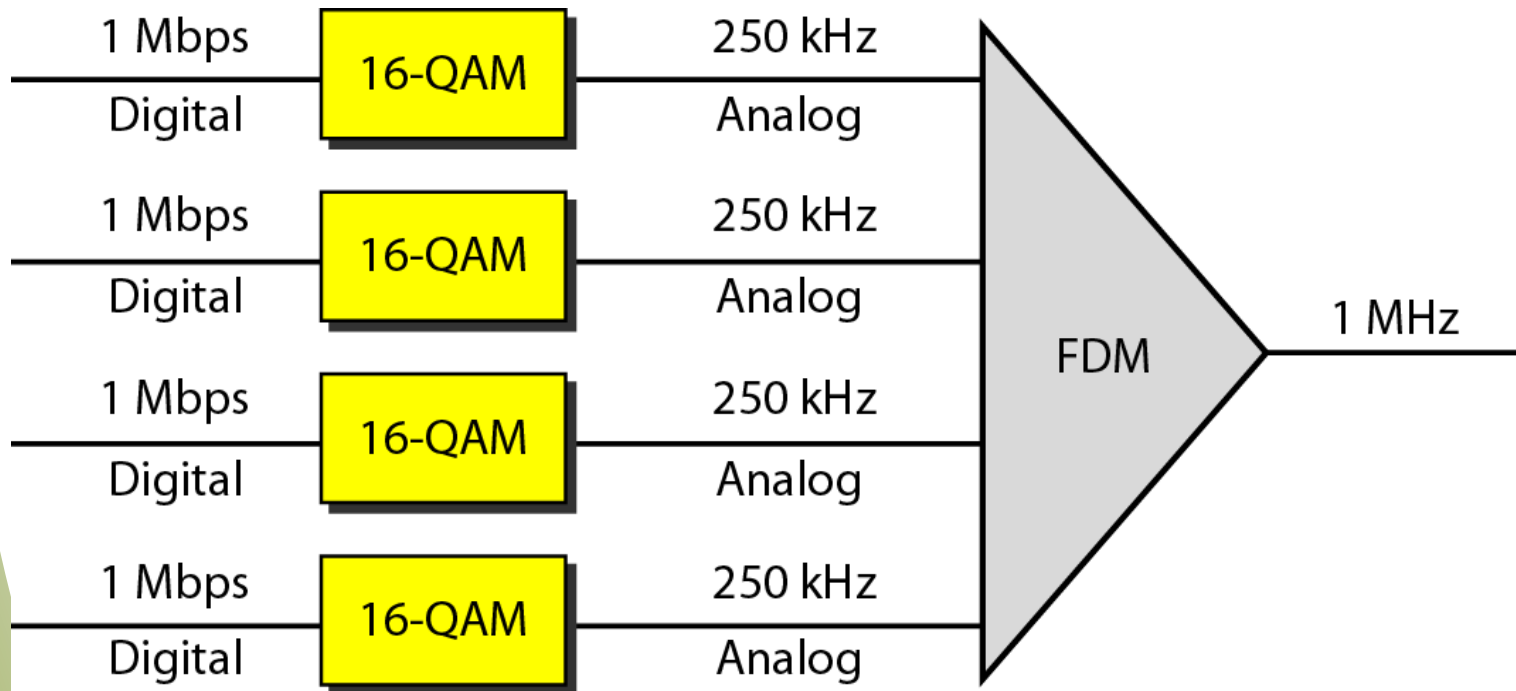# FDM Demultiplexing Example
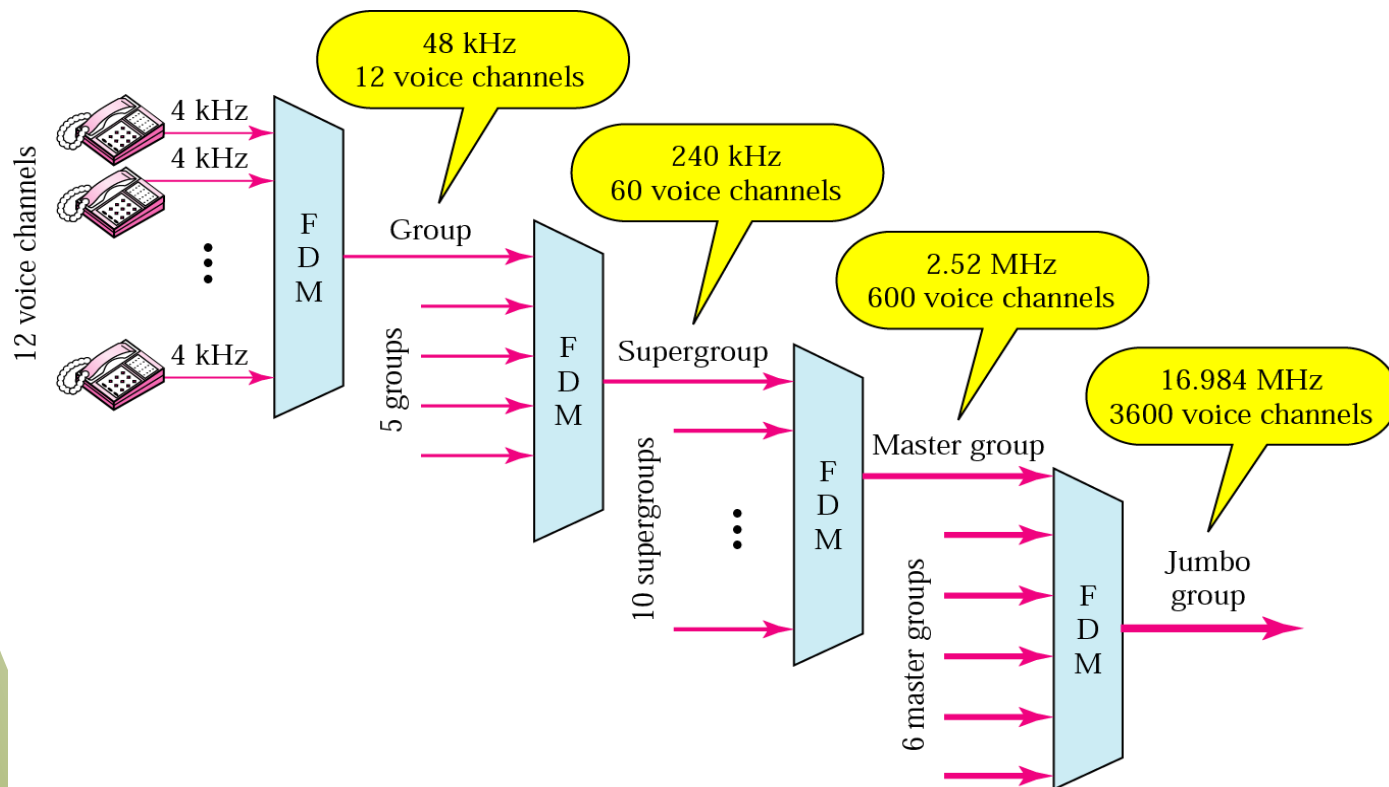
FDM: Example 1

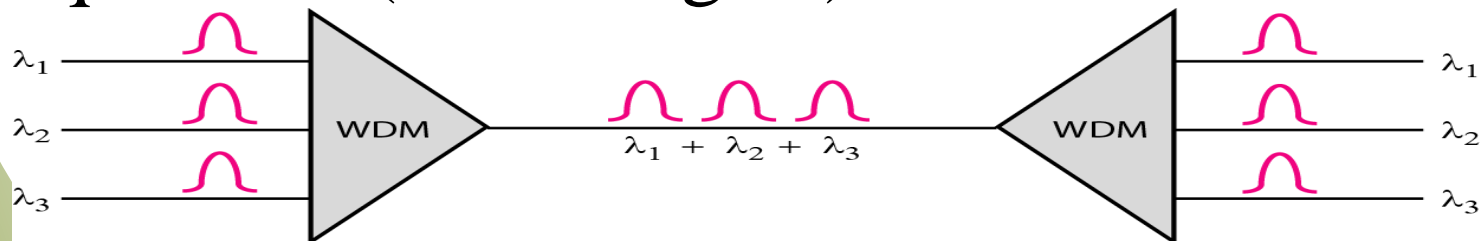# FDM: Example 2

FDM: Example 3

Analog Hierarchy

- Hierarchical system used by AT&T

Wave Division Multiplexing

- Analog multiplexing technique to combine optical signals

- Conceptually the same as FDM

- Light signals transmitted through fiber optic channels

- Combining different signals of different frequencies (wavelengths)

Prisms in WDM

- Combining and splitting of light sources are easily handled by a *prism*

- Prism bends a light beam based on the incidence angle and the frequency
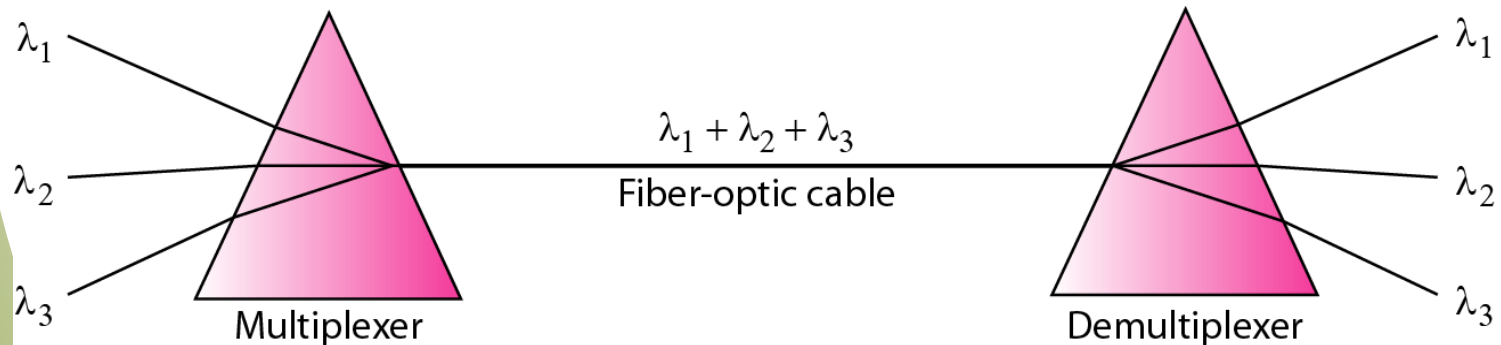
Time Division Multiplexing

- Digital multiplexing technique for combining several low-rate channels into one high-rate one
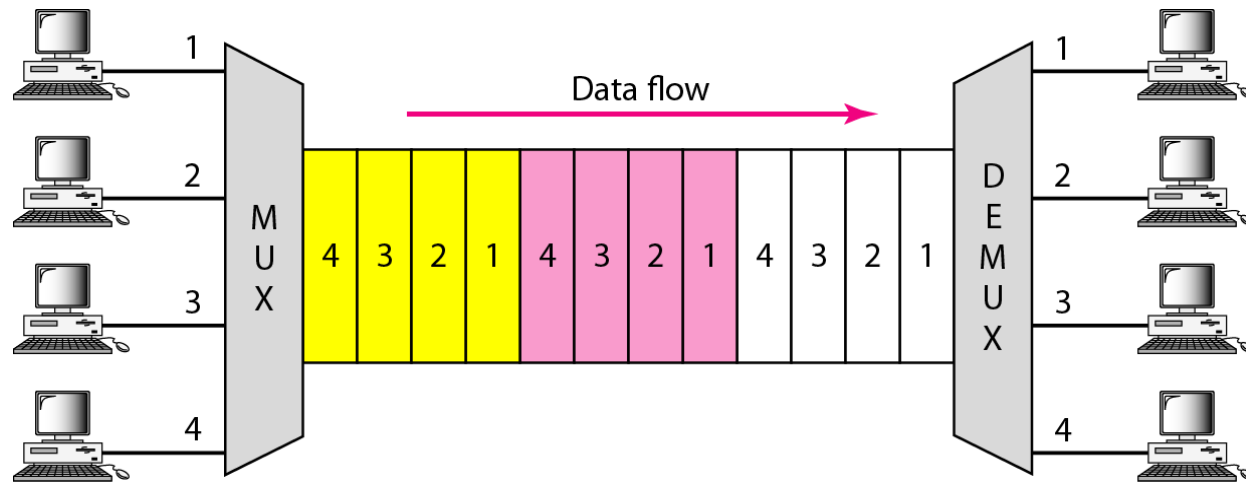
TDM: Time Slots and Frames

- In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter

Each frame is 3 time slots.
Each time slot duration is T/3 s.

TDM: Example 1

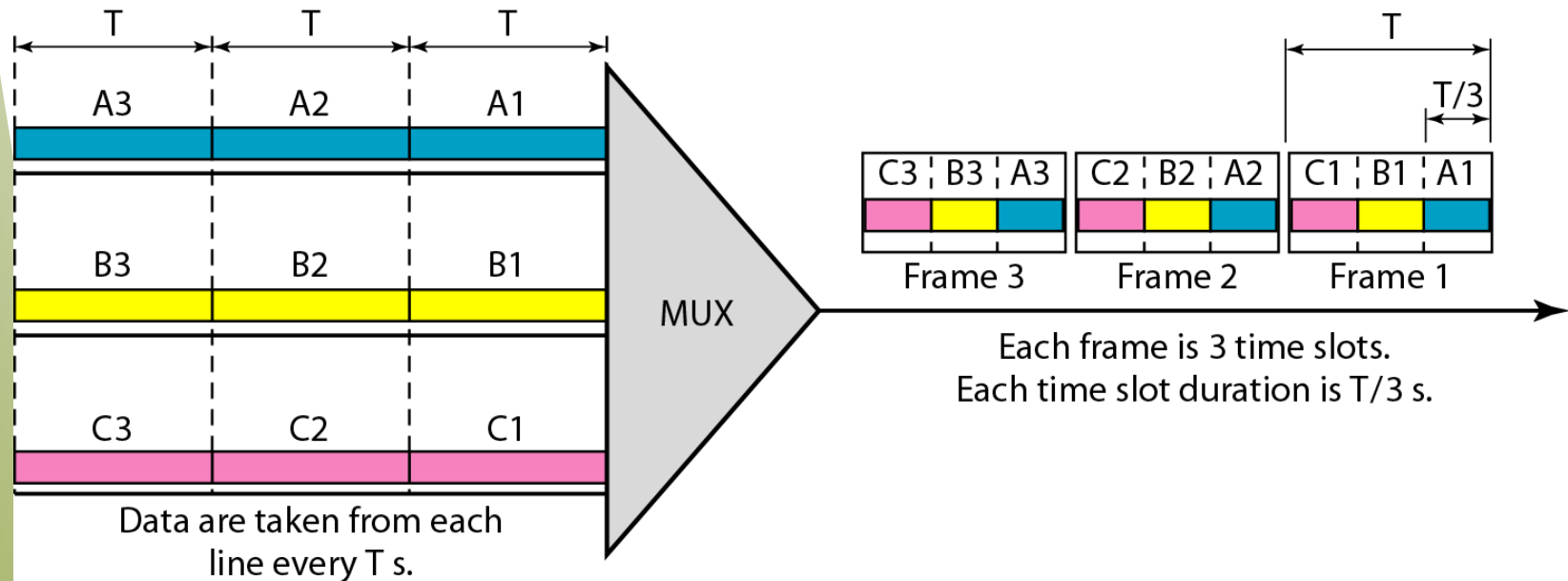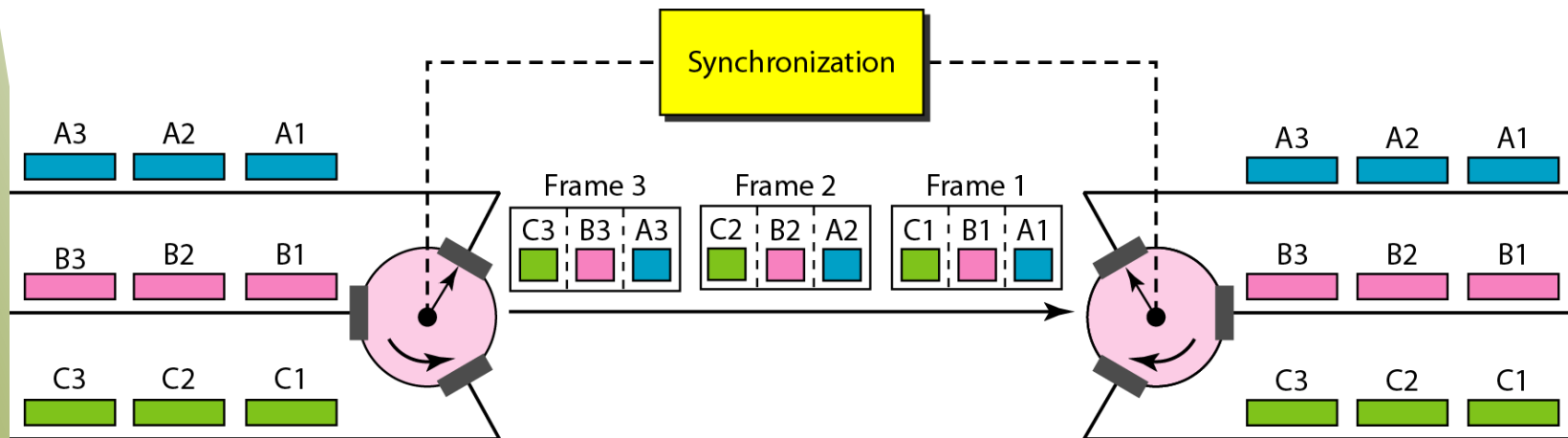- Four 1-Kbps connections are multiplexed together. A unit is 1 bit. Find (a) the duration of 1 bit before multiplexing, (b) the transmission rate of the link, (c) the duration of a time slot, and (d) the duration of a frame?

a) The duration of 1 bit is 1/1 Kbps, or 0.001 s (1 ms).

b) The rate of the link is 4 Kbps.

c) The duration of each time slot 1/4 ms or 250 μs.

d) The duration of a frame 1 ms.

Interleaving

- Interleaving can be done by bit, by byte, or by any other data unit
- The interleaved unit is of the same size in a given system

TDM: Example 2

TDM: Example 3

100 kbps — • • • 1 1 0 0 1 0

100 kbps — • • • 0 0 1 0 1 0

100 kbps — • • • 1 0 1 1 0 1

100 kbps — • • • 0 0 0 1 1 1

MUX

Frame duration = 1/50,000 s = 20 μs

Frame: 8 bits | Frame: 8 bits | Frame: 8 bits

• • • 00 10 00 11 | 01 11 10 00 | 11 01 10 10

50,000 frames/s
400 kbps
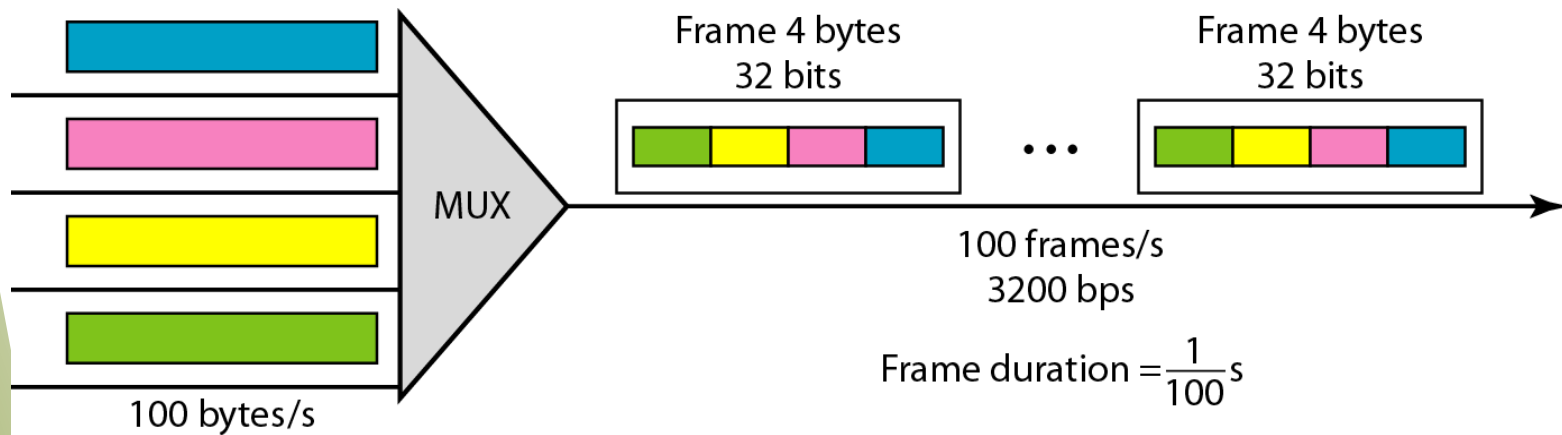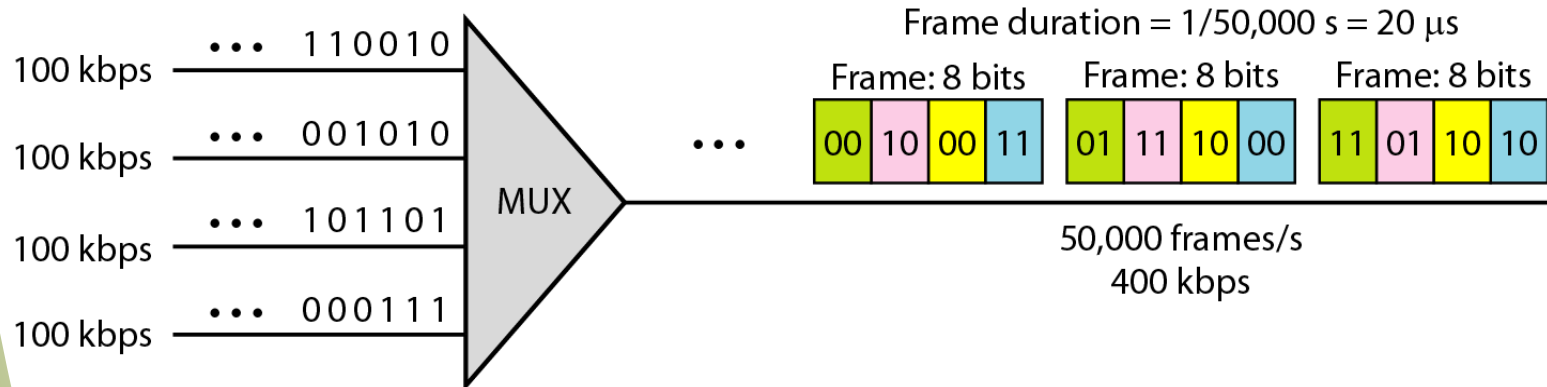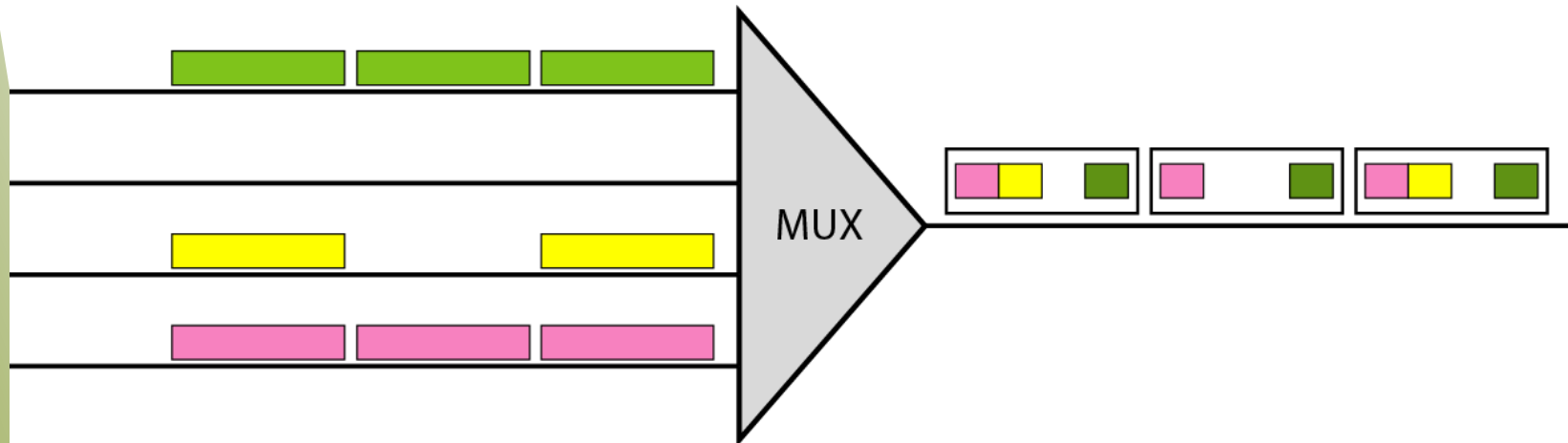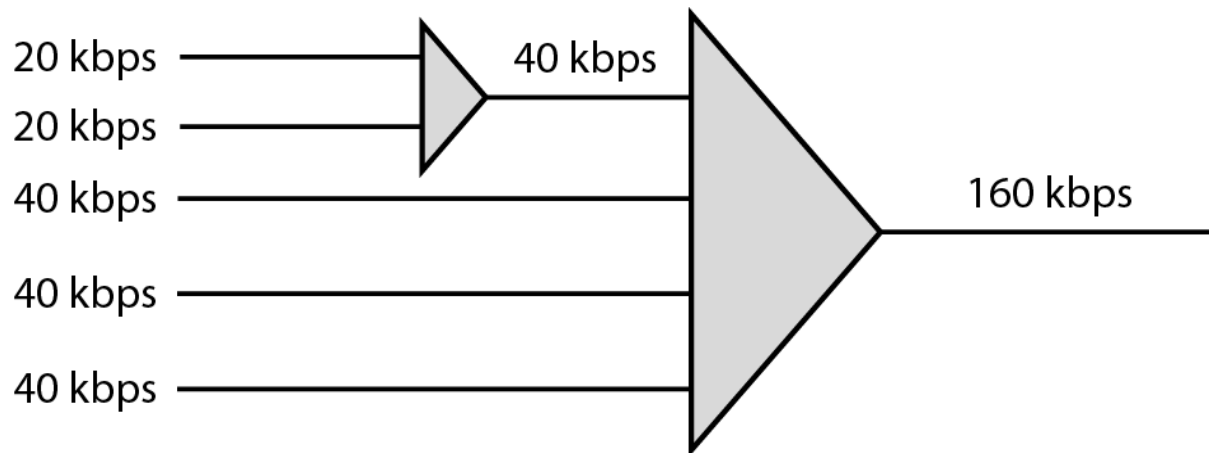
Empty Slots

- Synchronous TDM is not efficient in many cases
- Statistical TDM can improve the efficiency by removing the empty slot from the frame

Data Rate Management

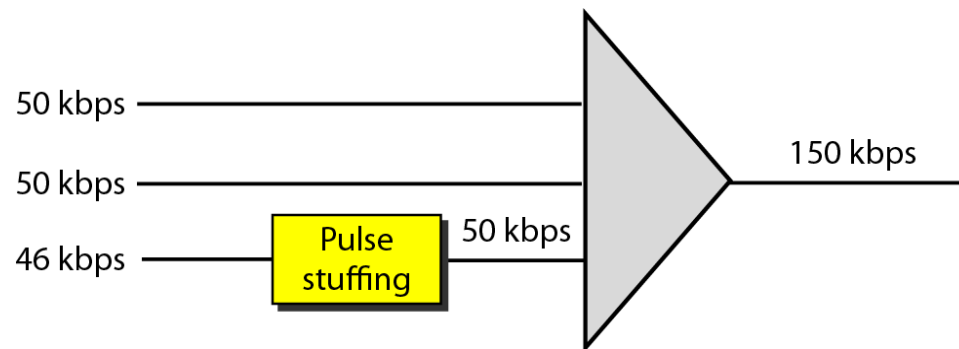- To handle a disparity in the input data rates
- **Multilevel multiplexing, multiple-slot allocation** and **pulse stuffing**
- Multilevel multiplexing

Data Rate Management

- Multiple-slot allocation / Pulse stuffing

25 kbps

50 kbps

25 kbps

25 kbps

25 kbps

25 kbps

125 kbps

The input with a
50-kHz data rate has two
slots in each frame.

50 kbps

50 kbps

46 kbps

Pulse stuffing

50 kbps

150 kbps
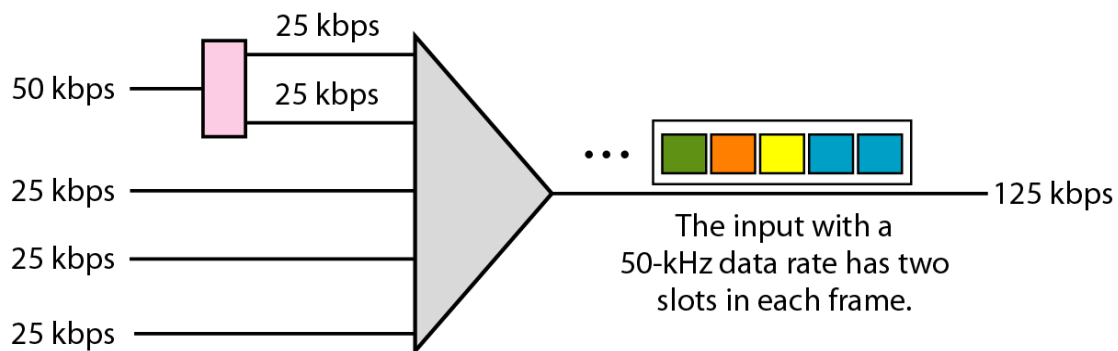
Frame Synchronizing

- Synchronization between the multiplexing and demultiplexing is a major issue in TDM

Synchronization pattern

| 1 | 0 | 1 |

Frame 3

| C3 | B3 | A3 | 1 |

Frame 2

| | B2 | A2 | 0 |

Frame 1

| C1 | | A1 | 1 |

TDM: Example 4

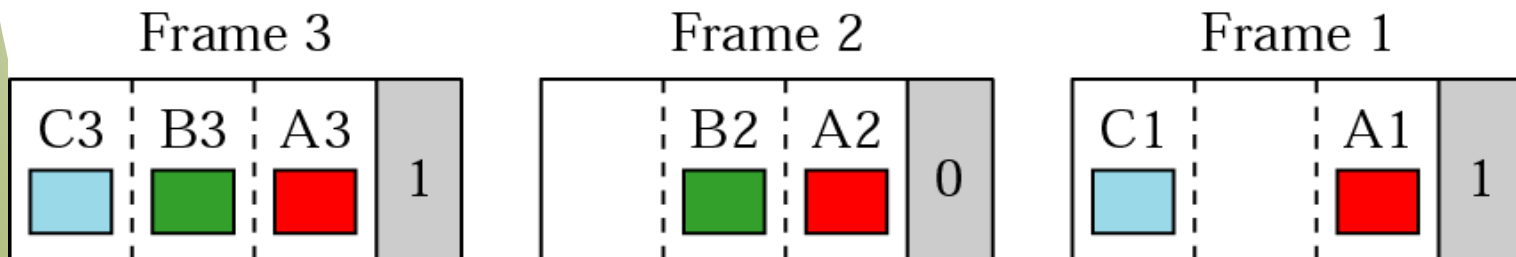We have four sources, each creating 250 characters per second. If the interleaved unit is a character and 1 synchronizing bit is added to each frame, find (a) the data rate of each source, (b) the duration of each character in each source, (c) the frame rate, (d) the duration of each frame, (e) the number of bits in each frame, and (f) the data rate of the link.

1. The data rate of each source is 2000 bps = 2 Kbps.

2. The duration of a character is 1/250 s, or 4 ms.
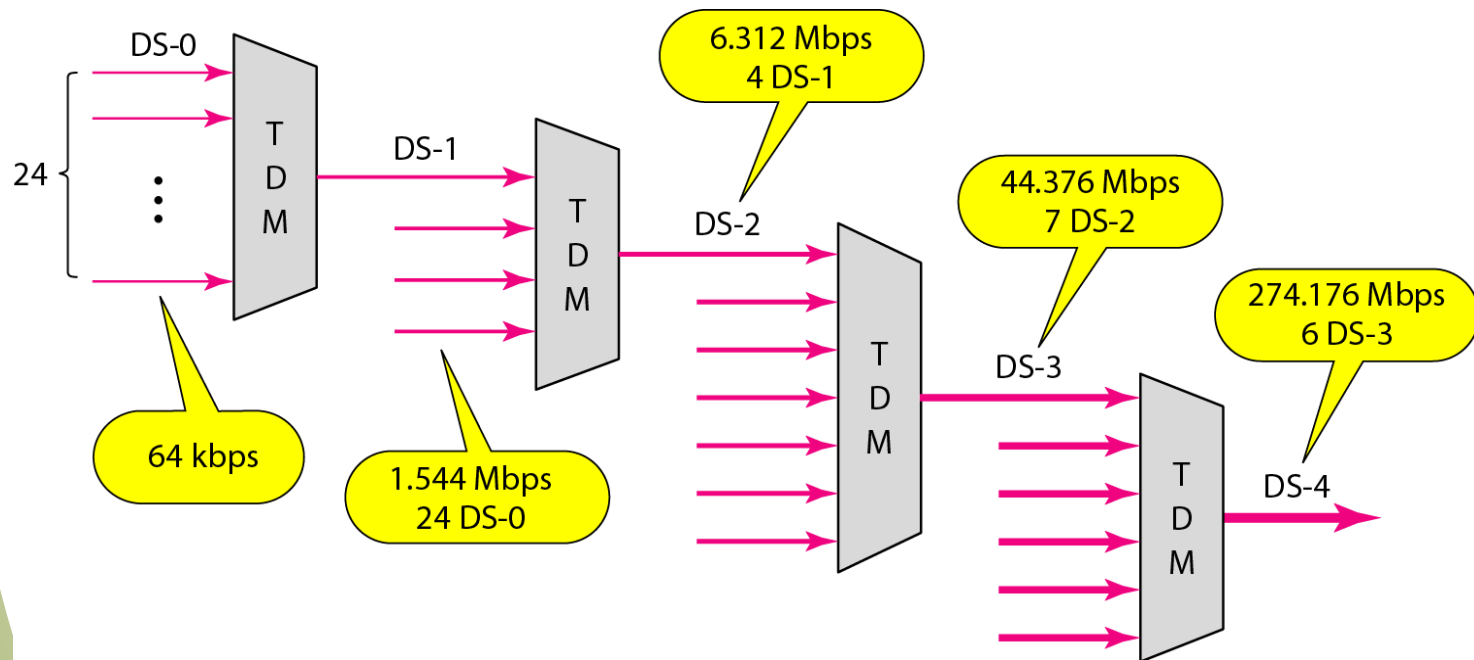
3. The link needs to send 250 frames per second.

4. The duration of each frame is 1/250 s, or 4 ms.

5. Each frame is 4 x 8 + 1 = 33 bits.

6. The data rate of the link is 250 x 33, or 8250 bps

Digital Hierarchy

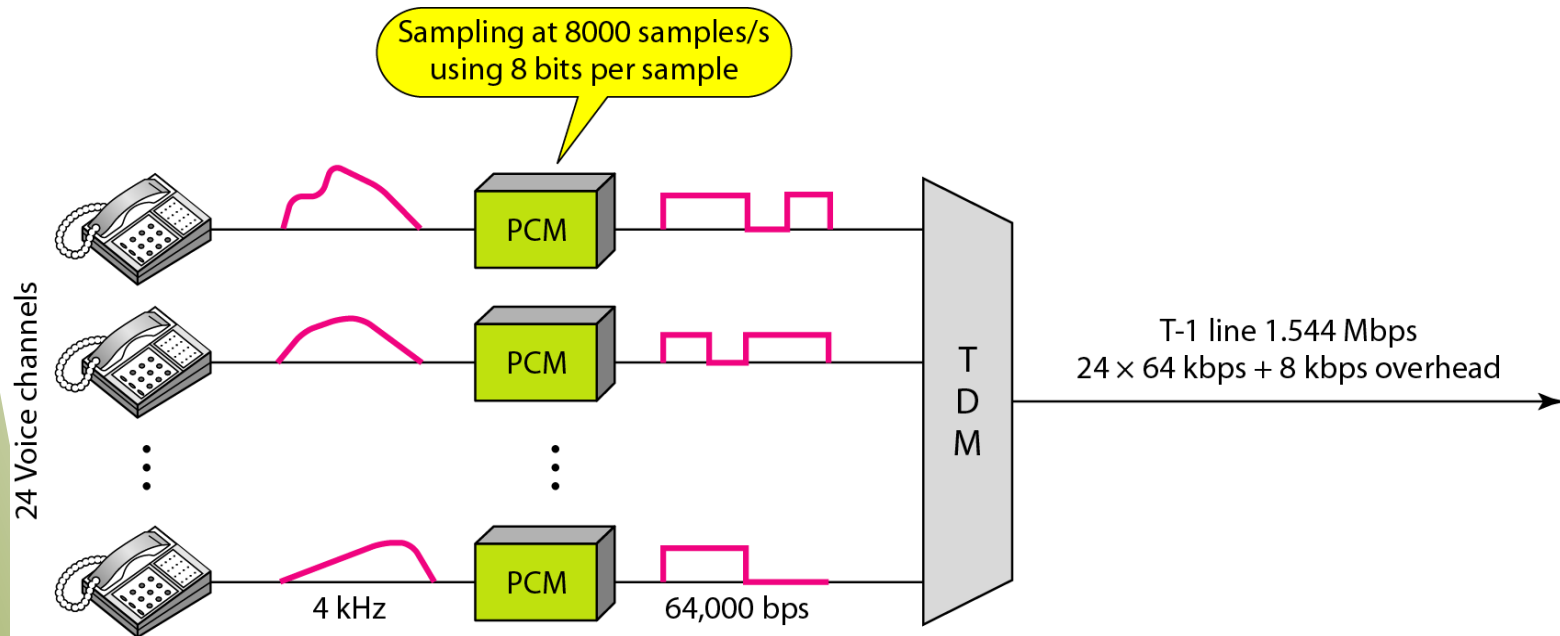# DS and T Line Rates

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

T-1 Line for Multiplexing Telephone Lines

Sampling at 8000 samples/s
using 8 bits per sample

24 Voice channels

PCM

PCM

PCM

4 kHz

64,000 bps

T
D
M

T-1 line 1.544 Mbps
24×64 kbps + 8 kbps overhead

T-1 Frame Structure

Sample n

	Channel 24	...	Channel 2	Channel 1
1 bit	8 bits		8 bits	8 bits

1 frame = 193 bits

Frame 8000	...	Frame n	...	Frame 2	Frame 1

T-1: 8000 frames/s = 8000 × 193 bps = 1.544 Mbps
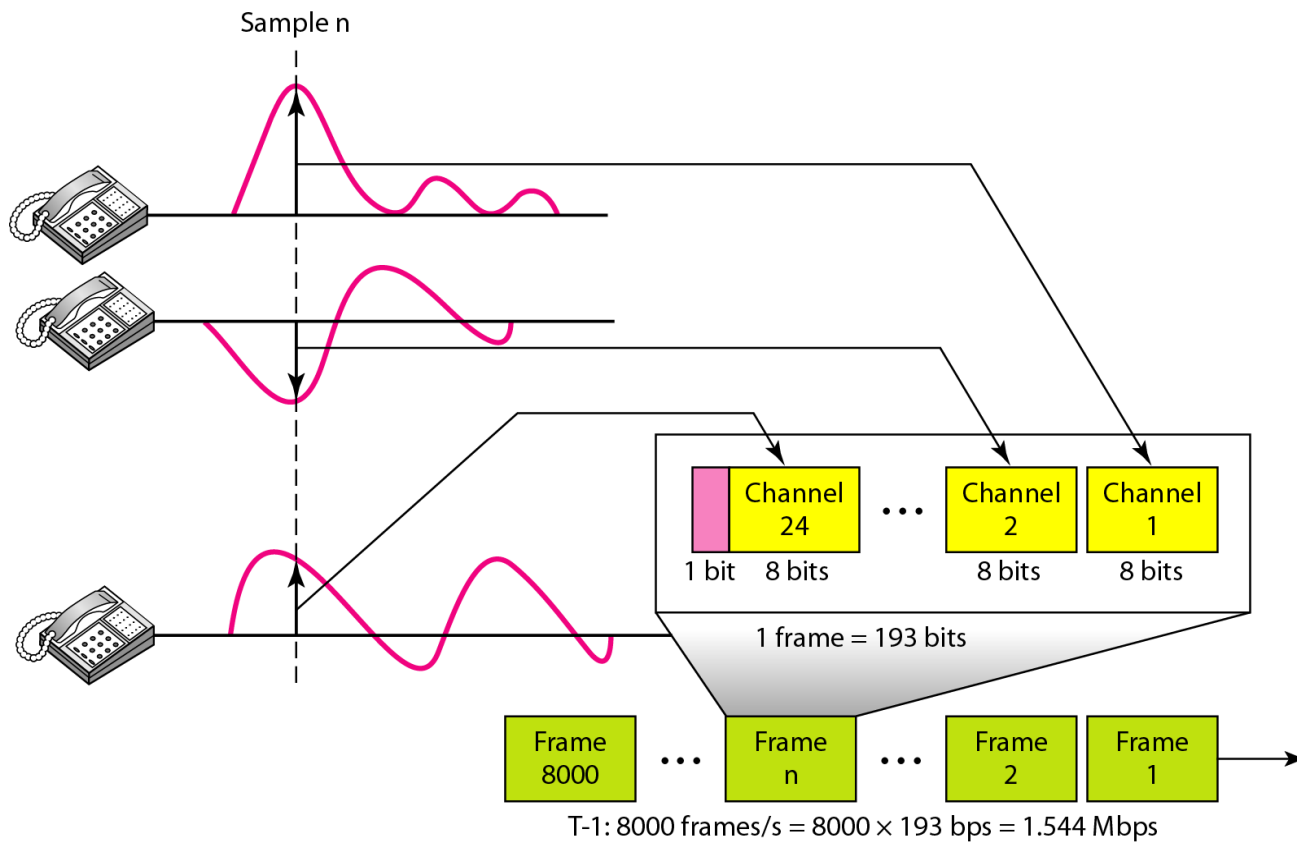
E Line Rates

- European use a version of T lines called E lines

Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Statistical TDM
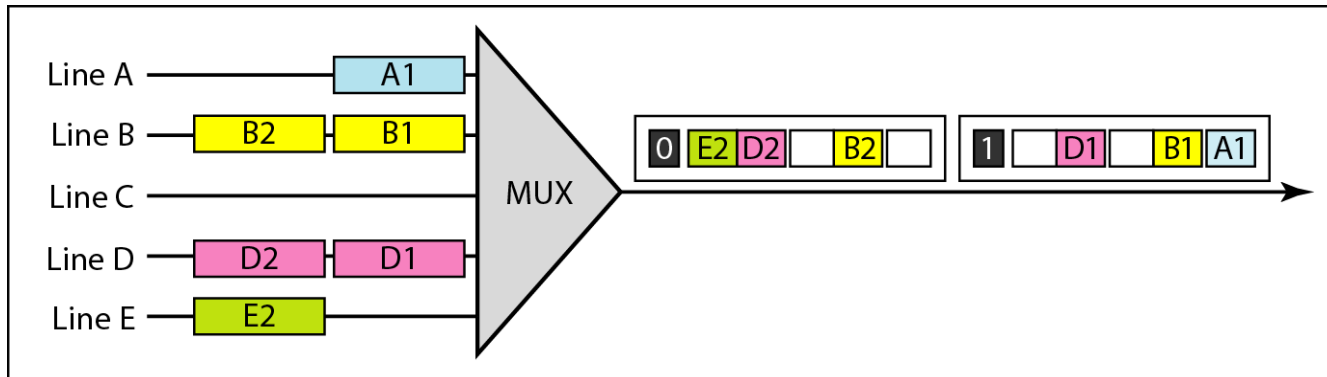
a. Synchronous TDM
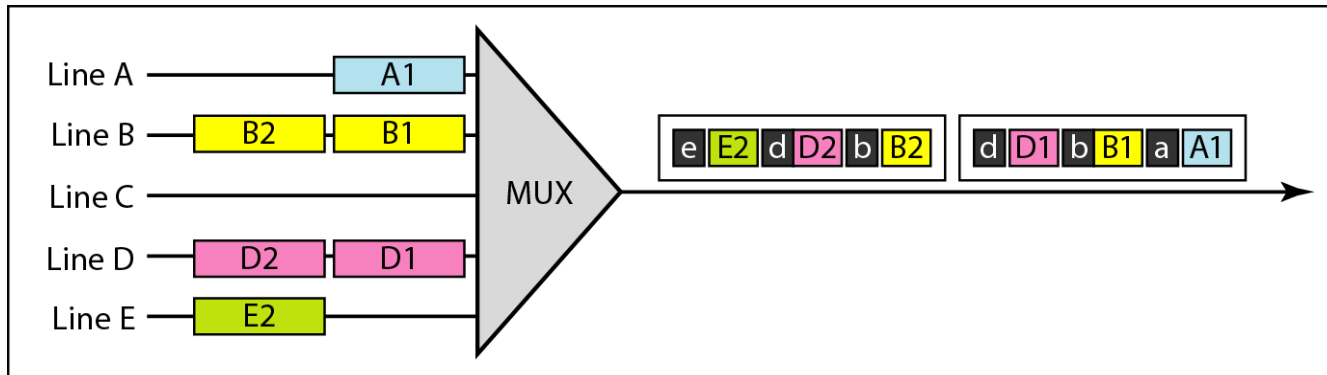
b. Statistical TDM

Statistical TDM

- Addressing is required in Statistical TDM
- Slot size: the ratio of the data size to address size must be reasonable to make transmission efficient
- No synchronization bit: no need for frame-level sync.
- Bandwidth: normally less than the sum of the capacities of each channel