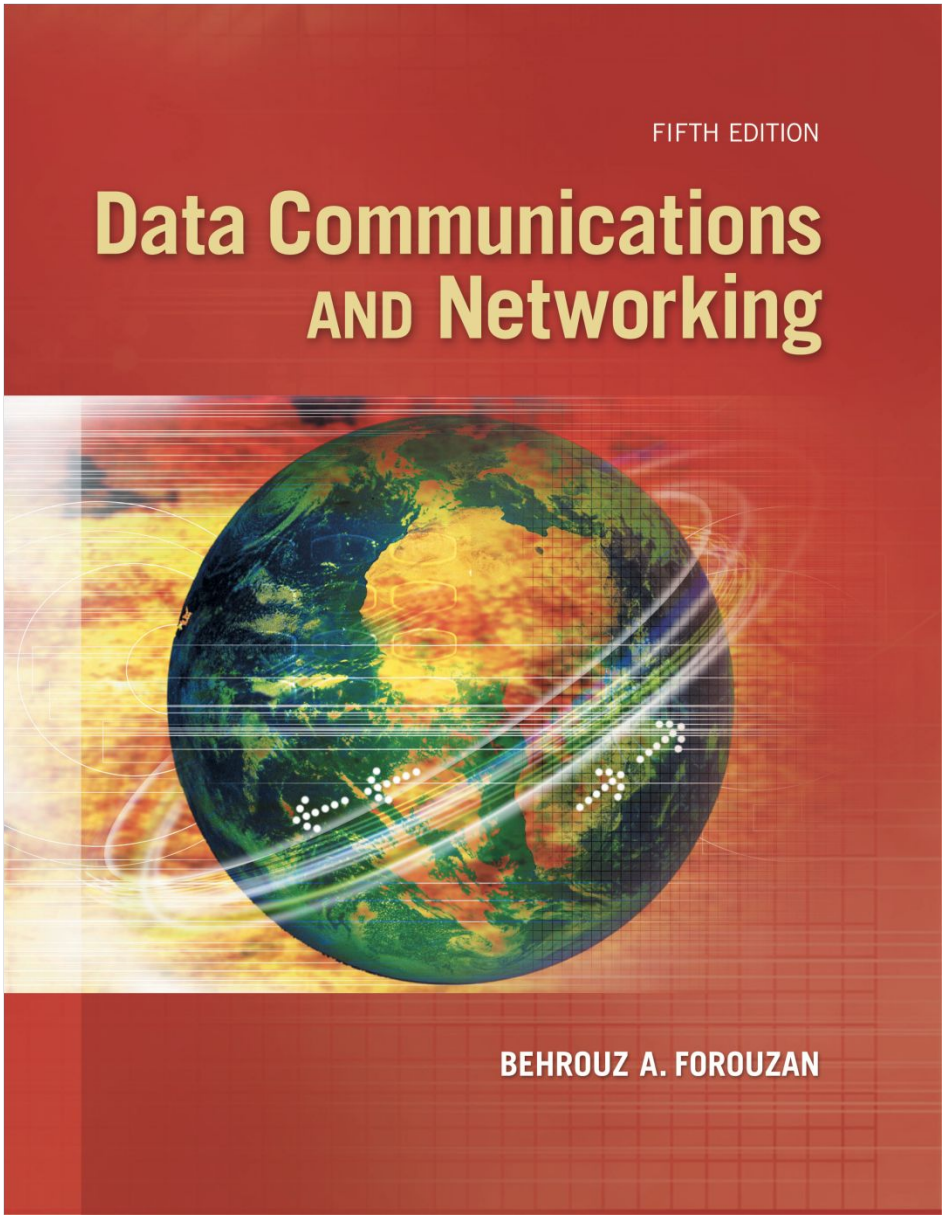
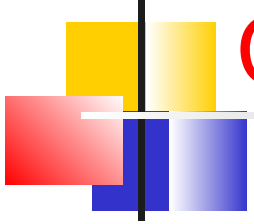
Chapter 6

Bandwidth Utilization





Chapter 6: Outline

6.1 MULTIPLEXING

6.2 SPREAD SPECTRUM

6-1 MULTIPLEXING

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.

Figure 6.1: Dividing a link into channels

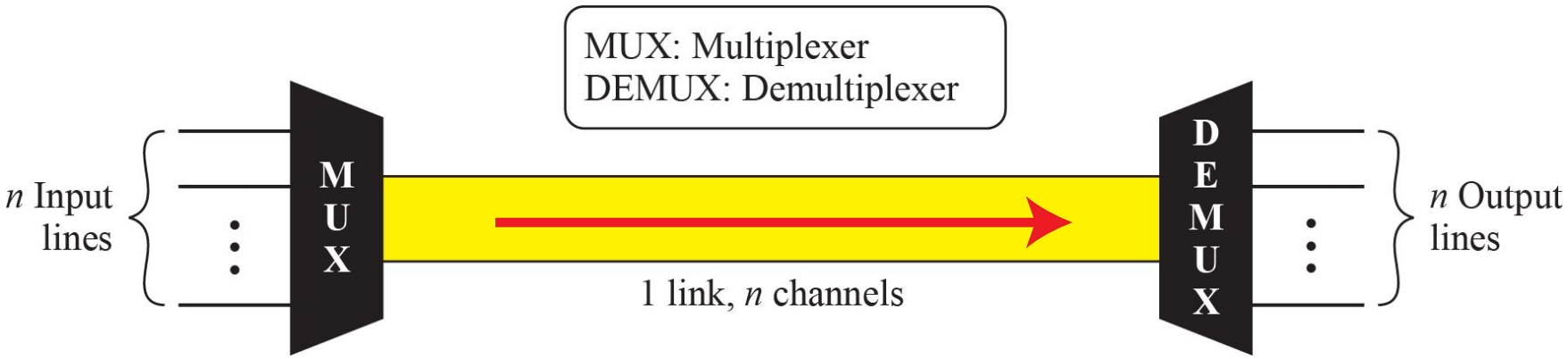
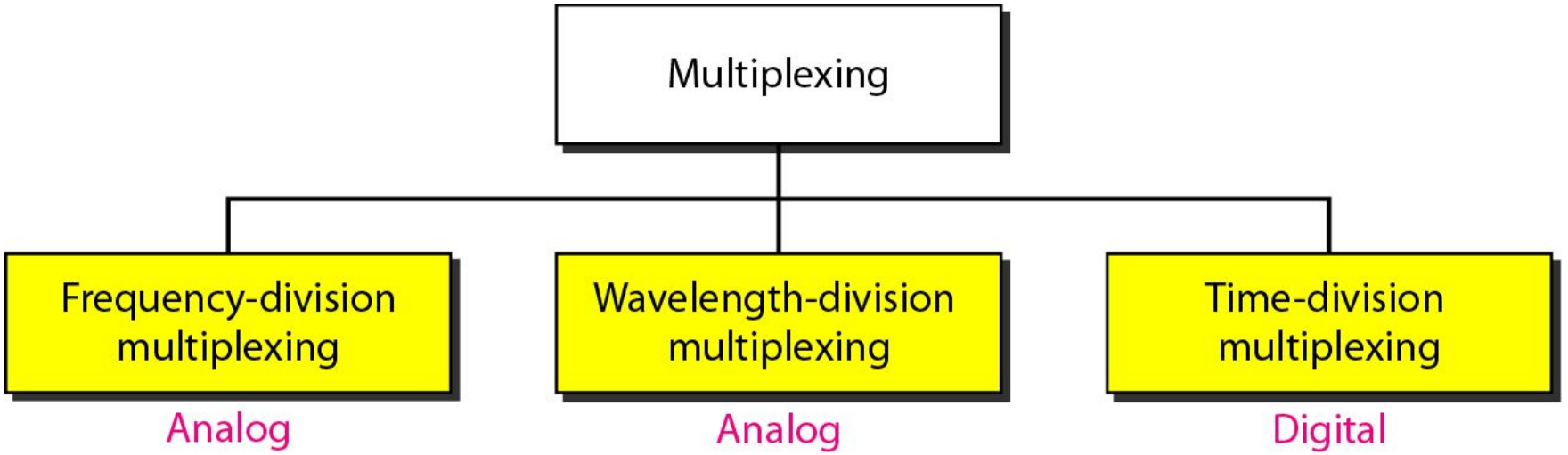
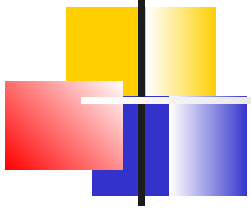


Figure 6.2: Categories of multiplexing





6.6.1 Frequency-Division Multiplexing

Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.

Figure 6.3: Frequency-division multiplexing

Figure 6.4: FDM Process

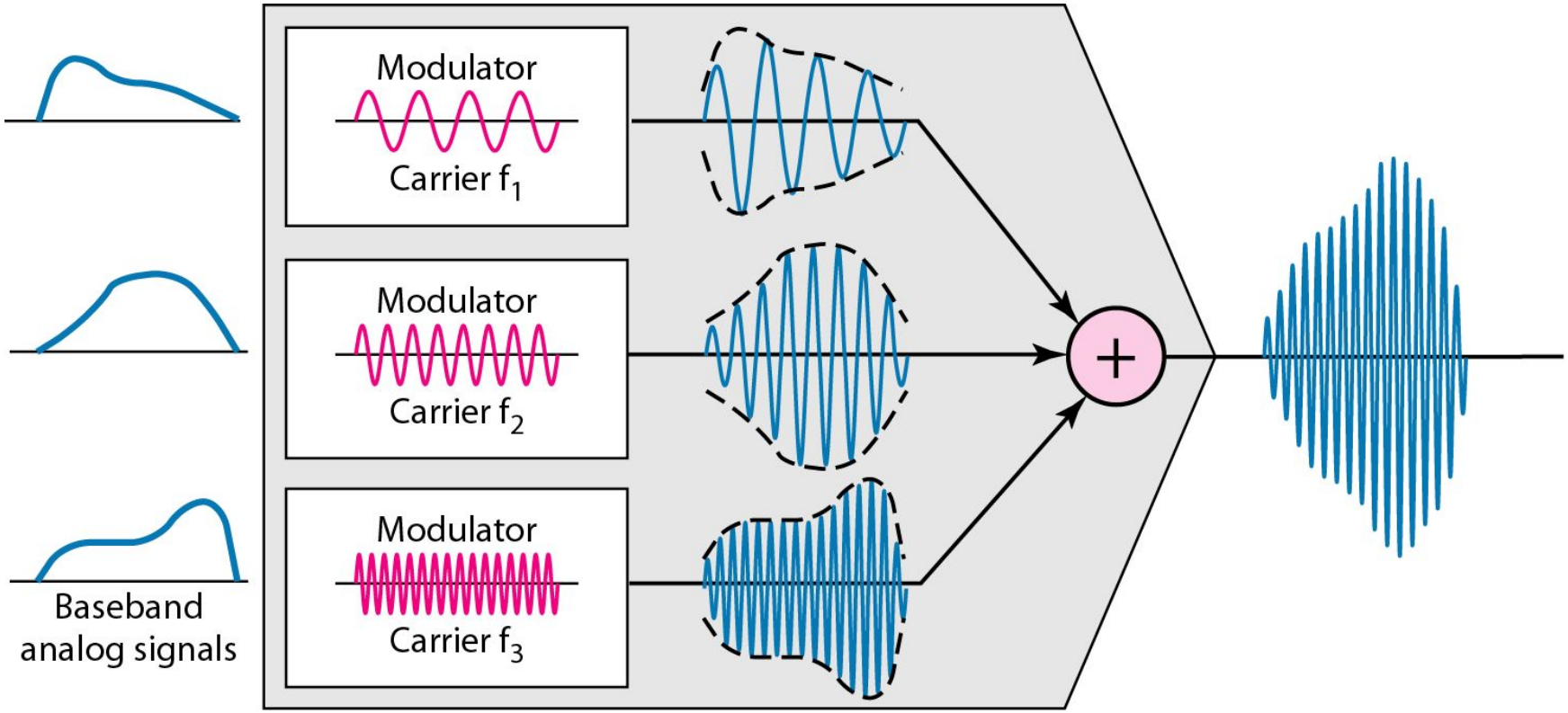
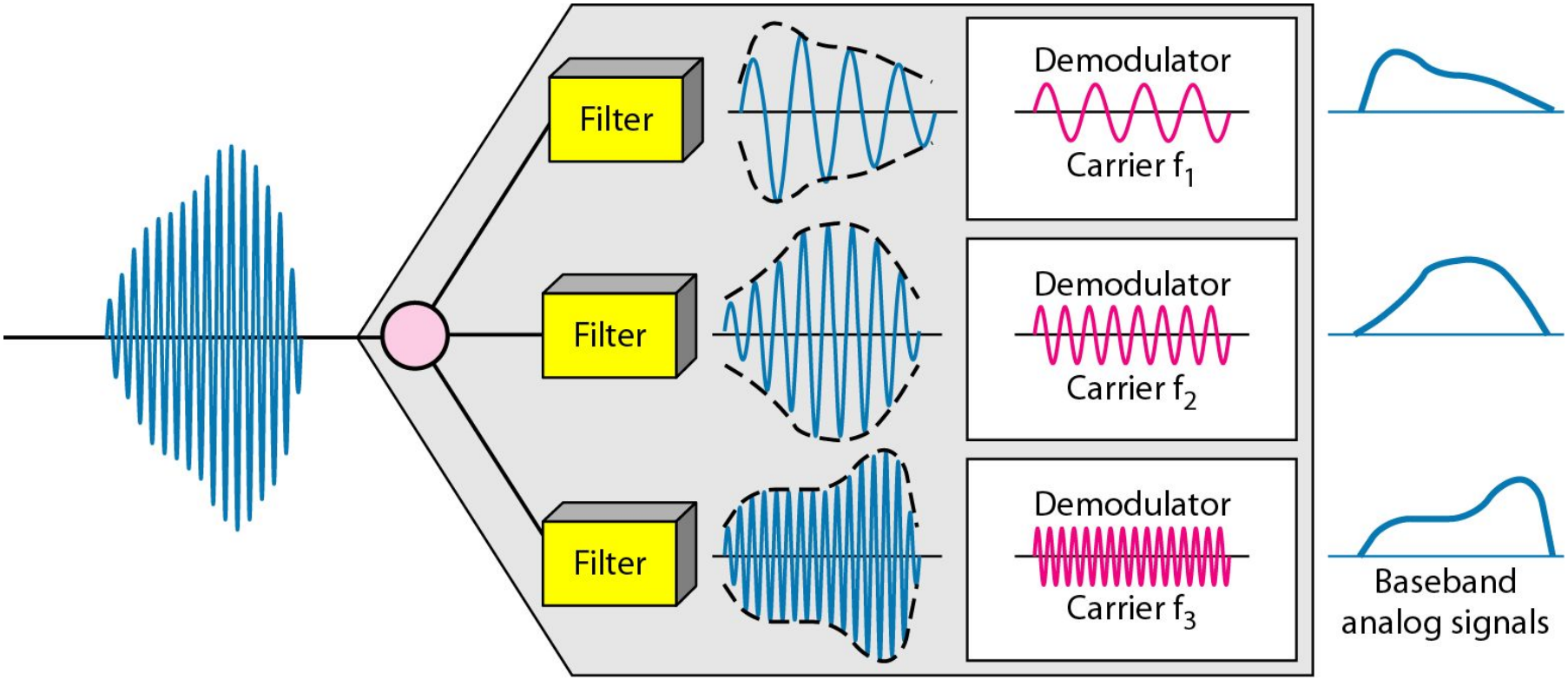


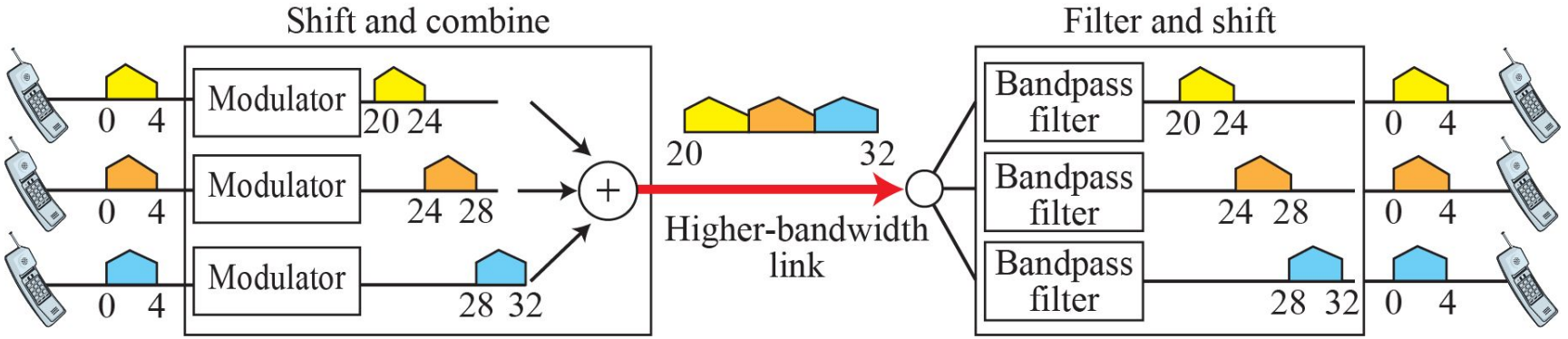
Figure 6.5: FDM demultiplexing example



Example 6.1

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

Figure 6.6: Example 6.1



Example 6.2

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Figure 6.7: Example 6.2

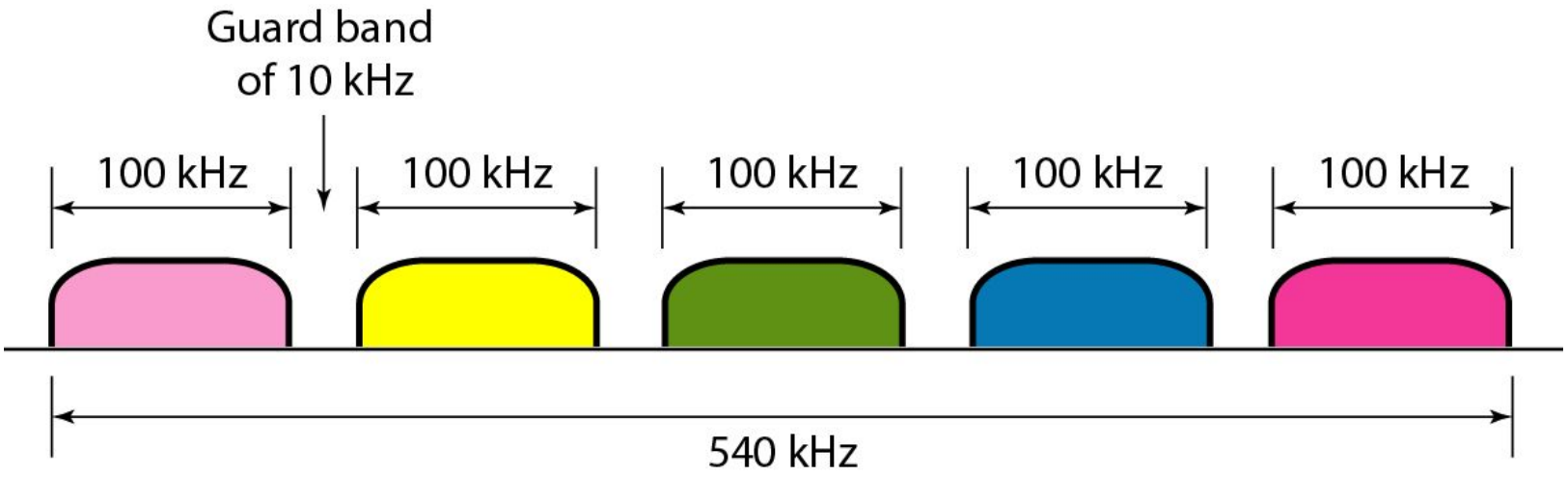


Figure 6.8: Example 6.3

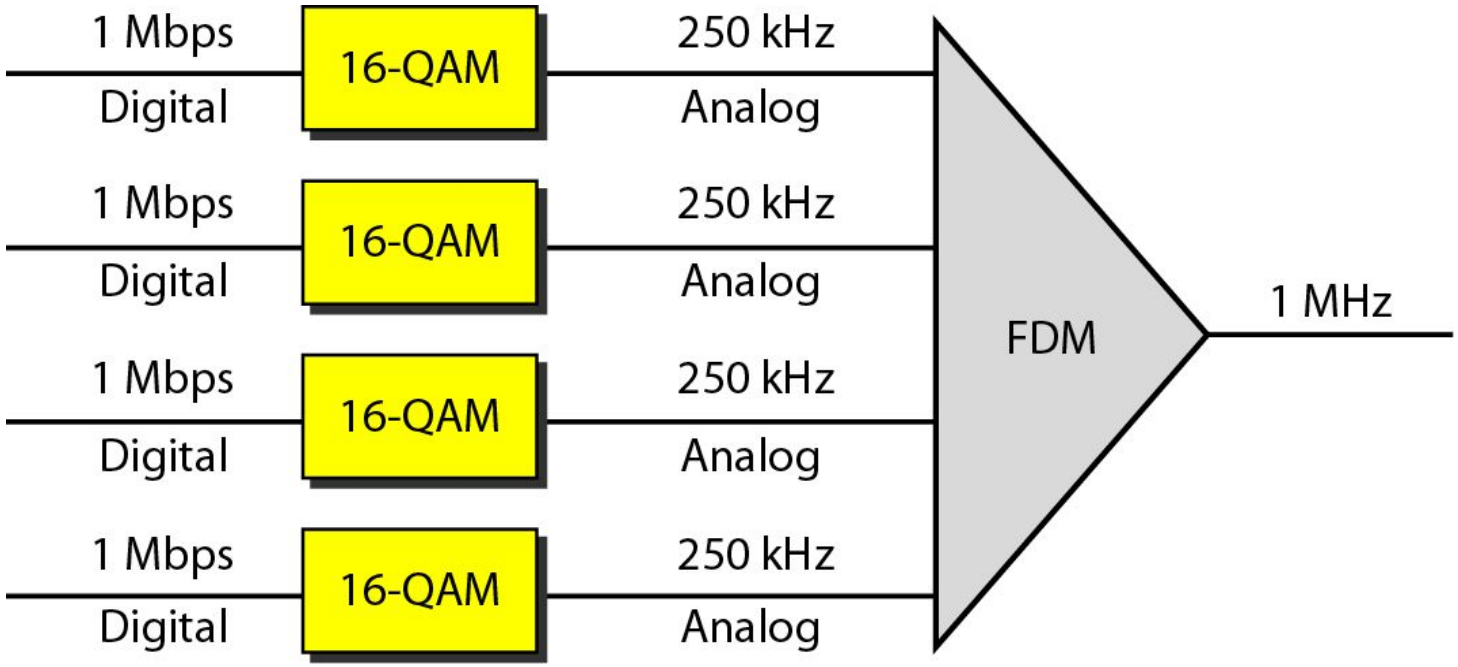
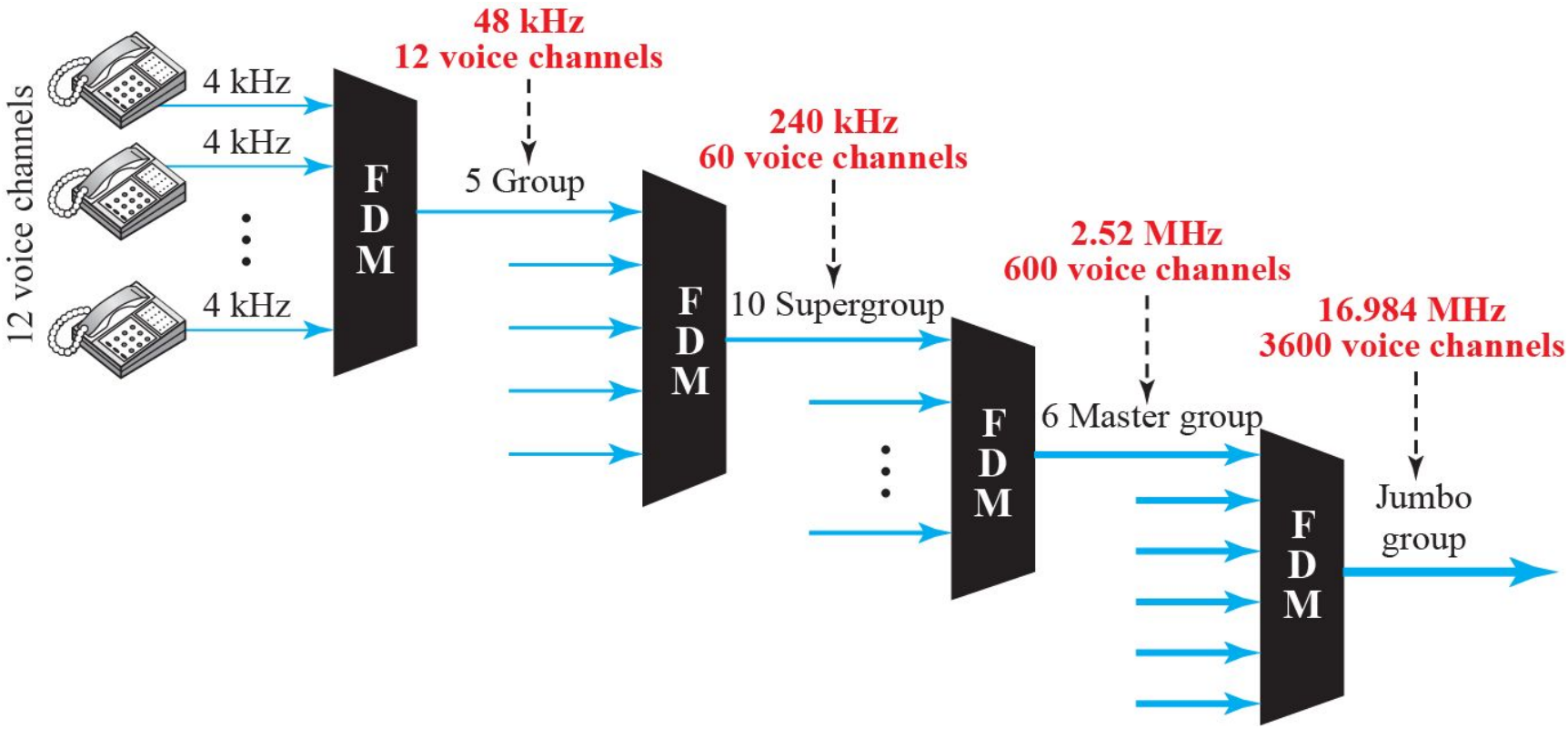


Figure 6.9: Analog hierarchy



Example 6.4

The Advanced Mobile Phone System (AMPS) uses two bands. The first band of 824 to 849 MHz is used for sending, and 869 to 894 MHz is used for receiving. Each user has a bandwidth of 30 kHz in each direction. The 3-kHz voice is modulated using FM, creating 30 kHz of modulated signal. How many people can use their cellular phones simultaneously?.

Example 6.4

The Advanced Mobile Phone System (AMPS) uses two bands. The first band of 824 to 849 MHz is used for sending, and 869 to 894 MHz is used for receiving.

25MHz send
25MHz receive

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Solution

Each band is 25 MHz. If we divide 25 MHz by 30 kHz, we get 833.33. In reality, the band is divided into 832 channels. Of these, 42 channels are used for control, which means only 790 channels are available for cellular phone users.

6.6.2 Wavelength-Division Multiplexing

Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.

6.6.2 Wavelength-Division Multiplexing

The optical fiber data rate is higher than the data rate of metallic transmission cable, but using a fiber-optic cable for a single line wastes the available bandwidth. Multiplexing allows us to combine several lines into one.

Figure 6.10: Wavelength-division multiplexing

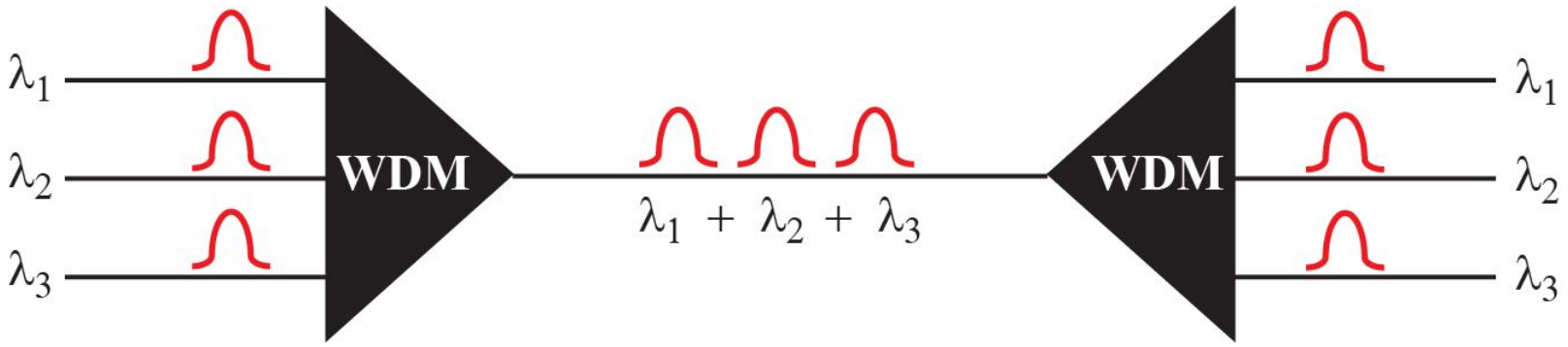
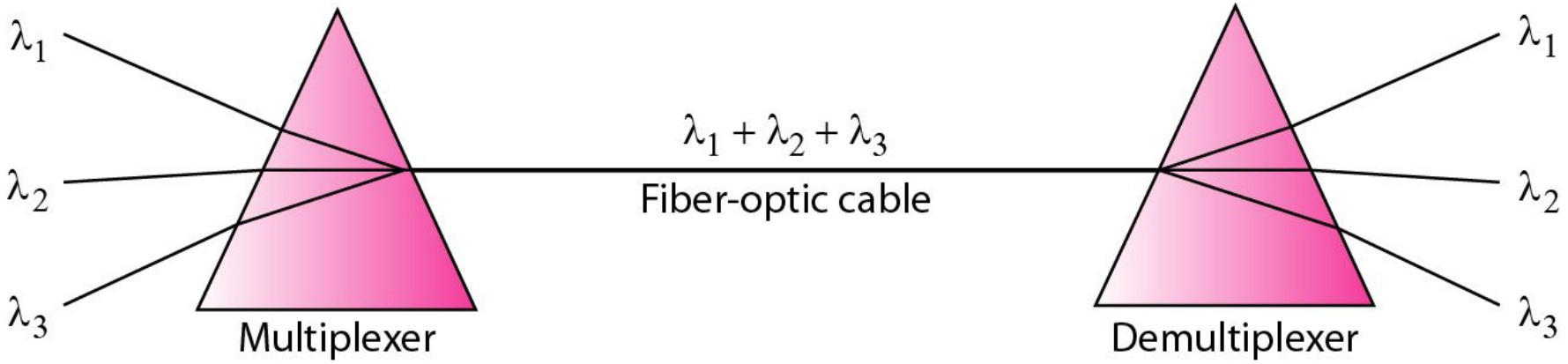


Figure 6.11: Prisms in wave-length division multiplexing



6.6.3 Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.

6.6.3 Time-Division Multiplexing

Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.

Figure 6.12: TDM

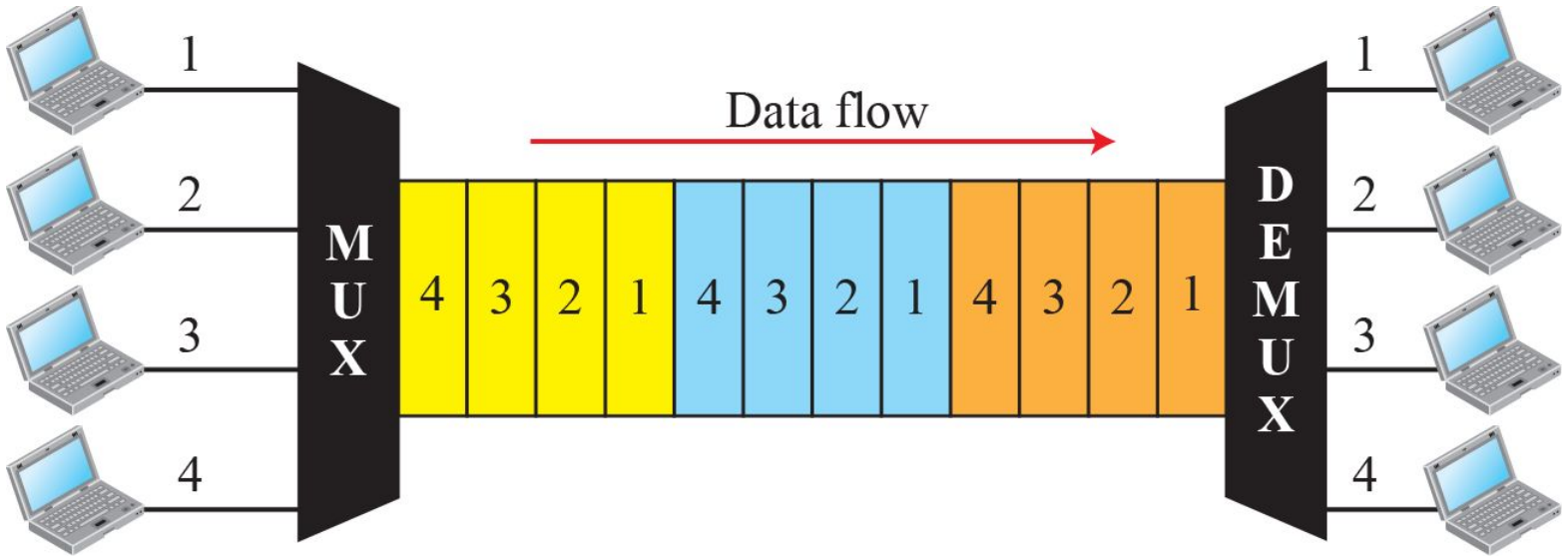
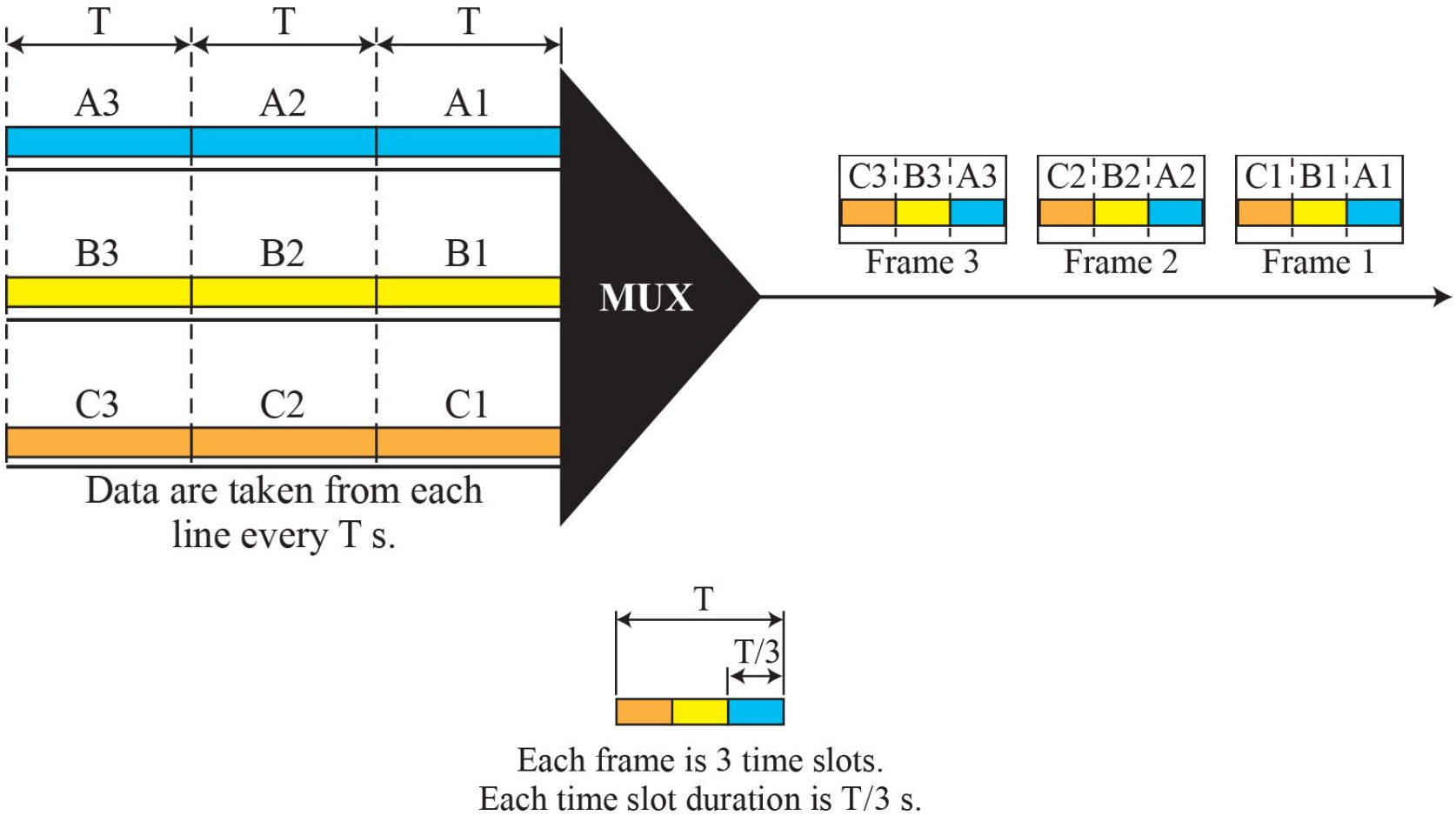


Figure 6.13: Synchronous time-division multiplexing



Example 6.5

In Figure 6.13, the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

6. each input slot,
2. each output slot, and
3. each frame?

Example 6.5 (continued)

Solution

We can answer the questions as follows:

6. The data rate of each input connection is 1 kbps. This means that the bit duration is 1/1000 s or 1 ms. The duration of the input time slot is 1 ms (same as bit duration).

2. The duration of each output time slot is one-third of the input time slot. This means that the duration of the output time slot is 1/3 ms.

3. Each frame carries three output time slots. So the duration of a frame is 3 × (1/3) ms, or 1 ms. The duration of a frame is the same as the duration of an input unit.

Figure 6.14: Example 6.6

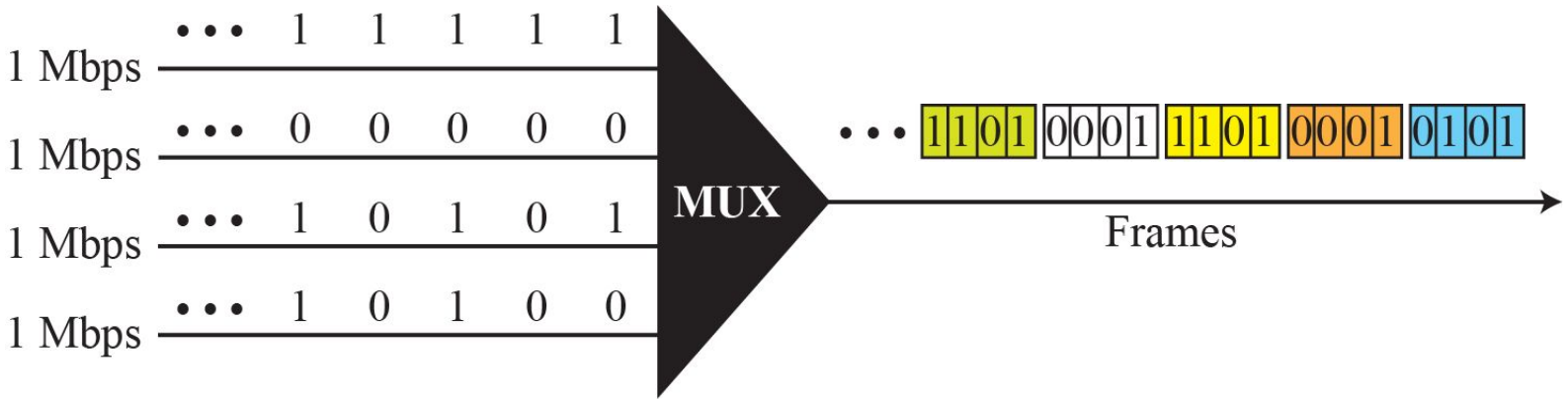


Figure 6.15: Interleaving

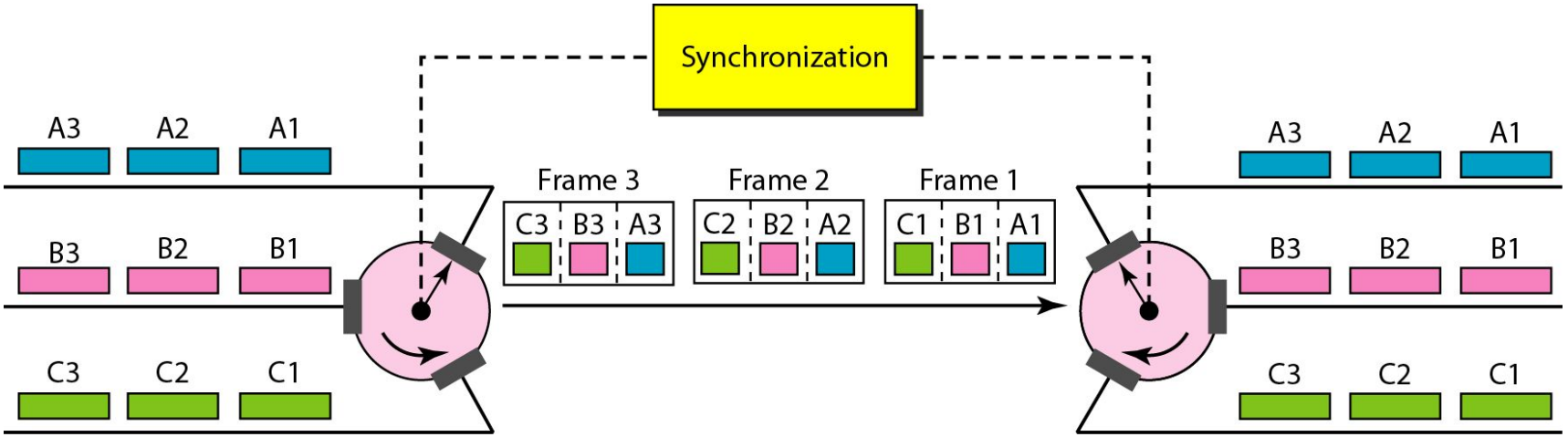


Figure 6.16: Example 6.8

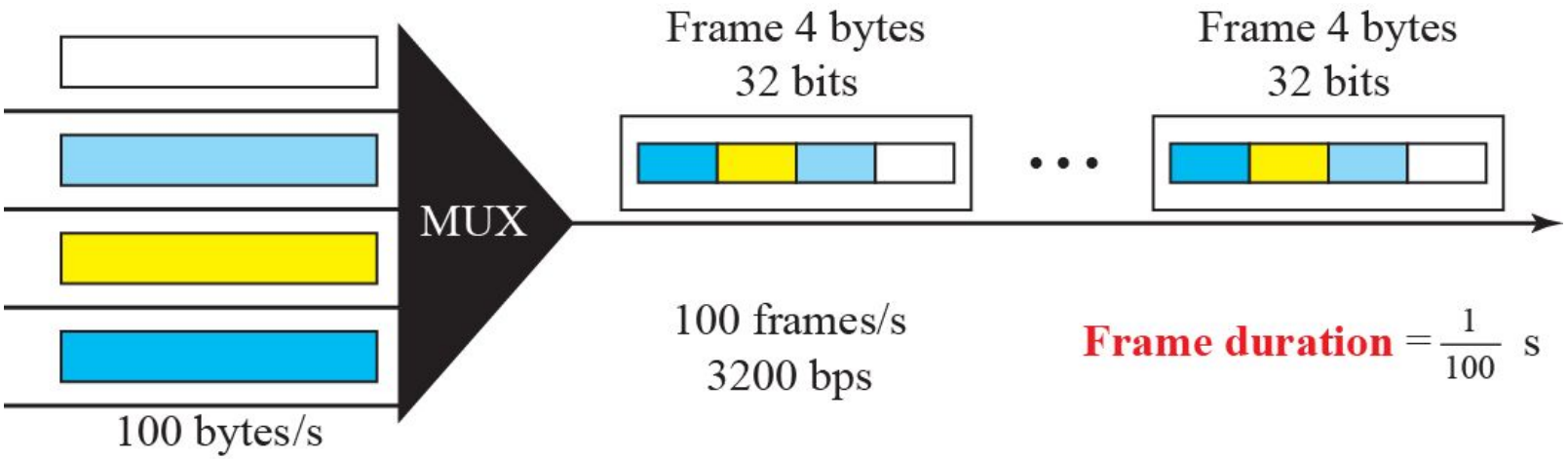
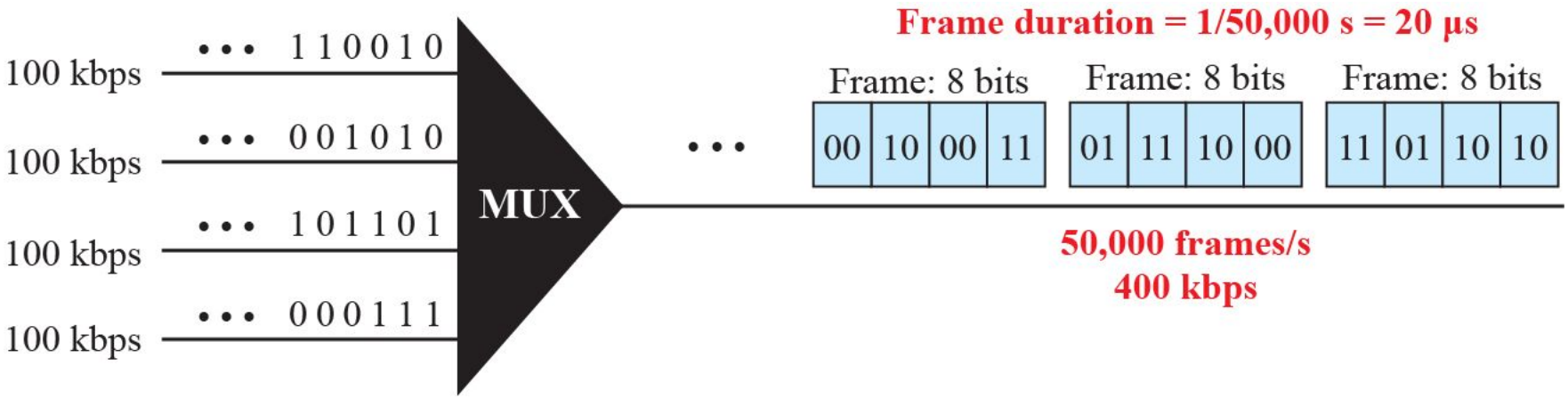


Figure 6.17: Example 6.9



Variations to TDM

Empty slots

Multi-level

Multiple slot

Pulse stuffing

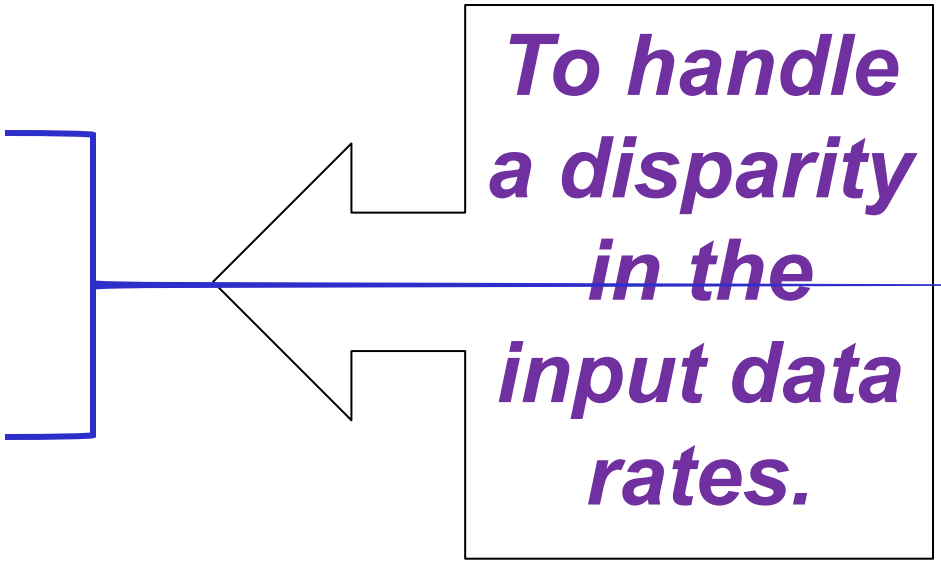


Figure 6.18: Empty slots

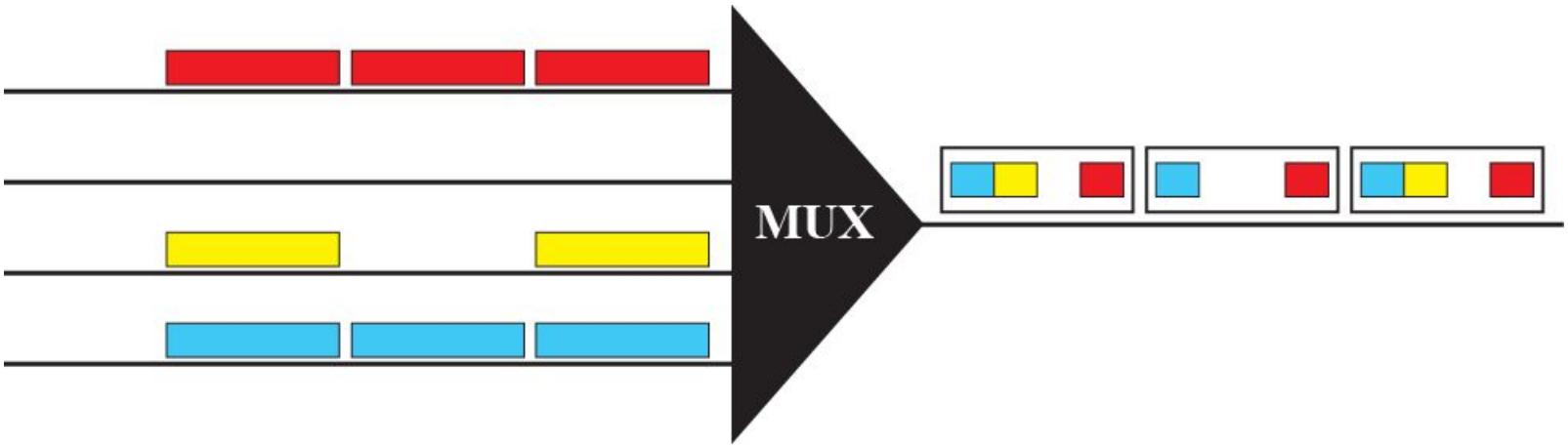


Figure 6.19: Multilevel multiplexing

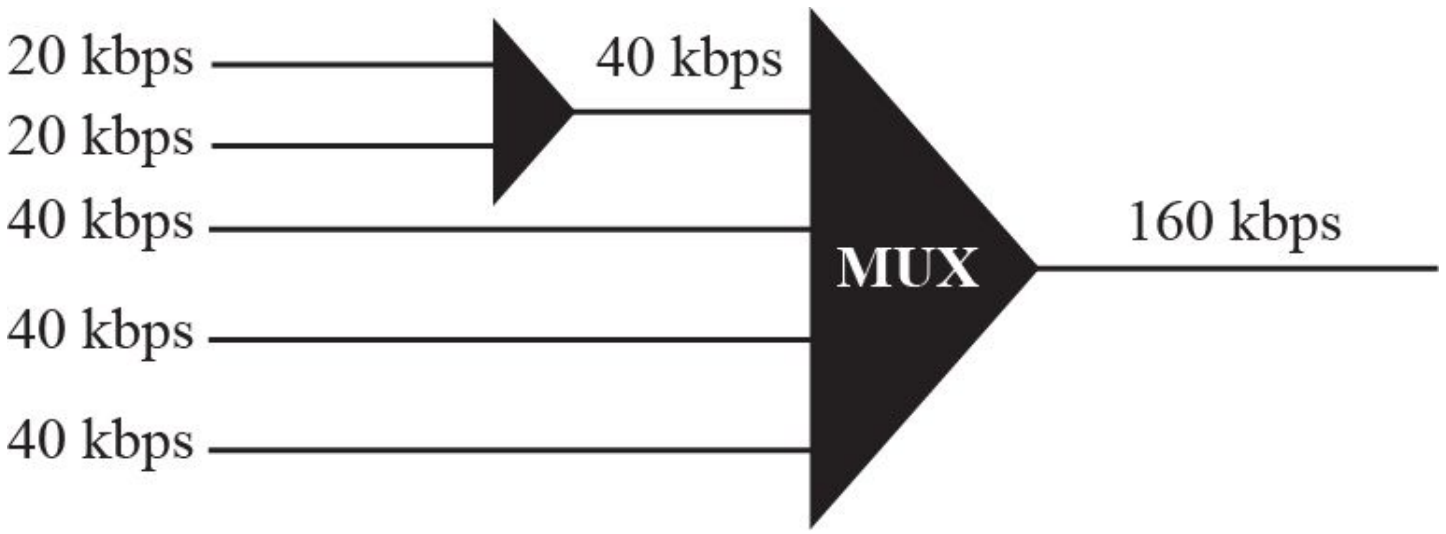


Figure 6.20: Multiple-slot multiplexing

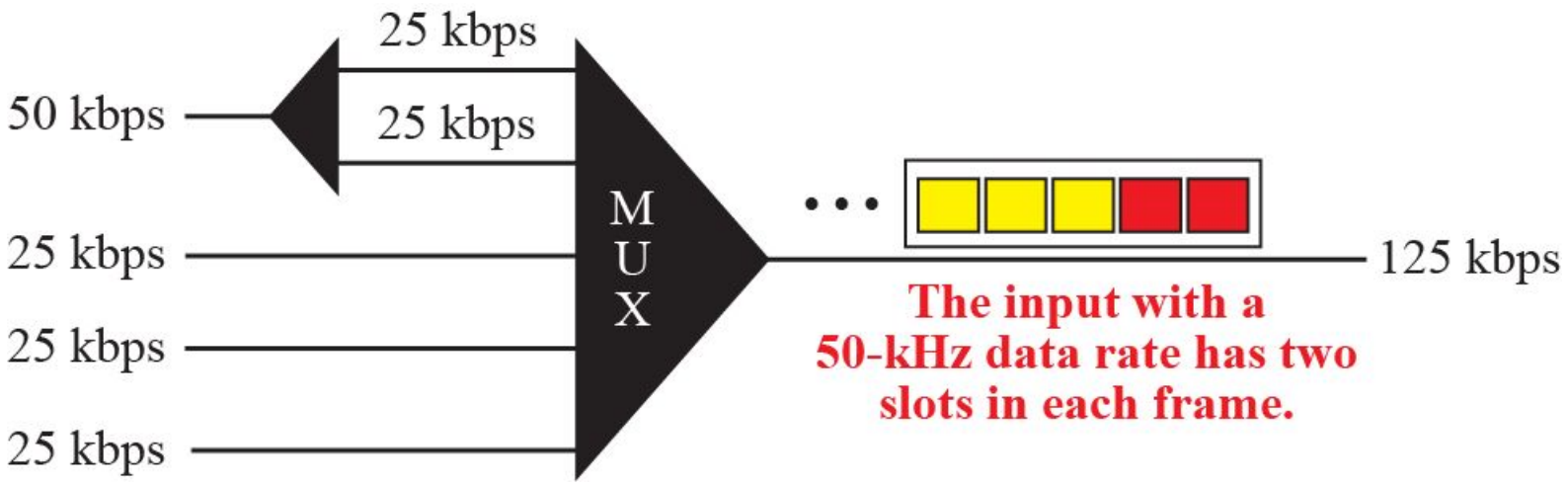
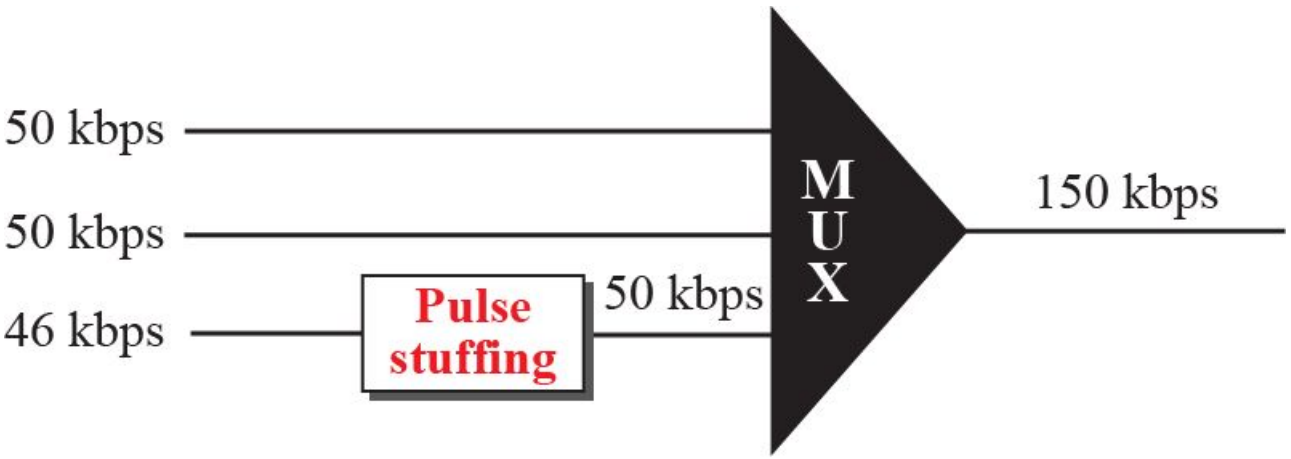


Figure 6.21: Pulse stuffing



TDM Implementation

Figure 6.23: Digital hierarchy

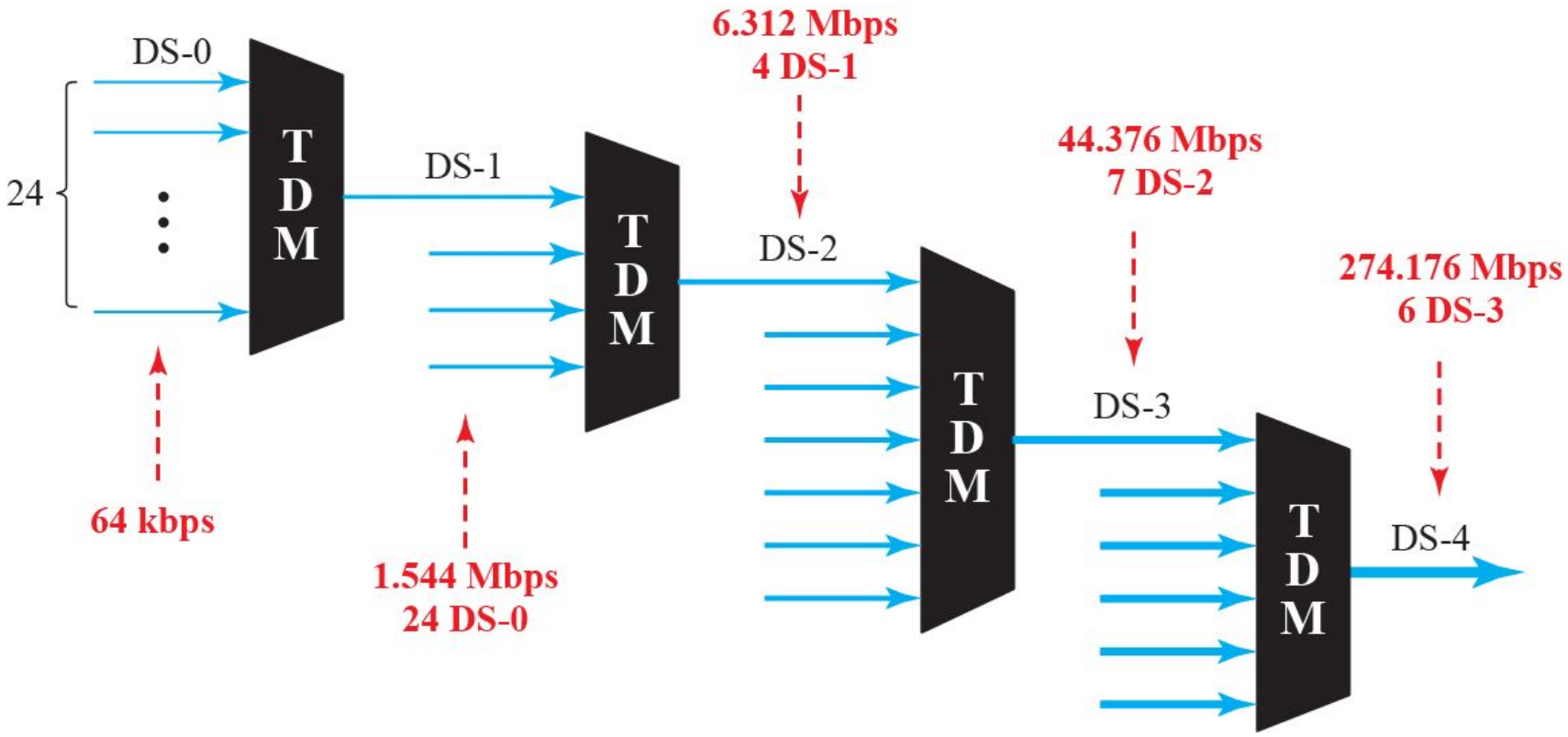


Table 6.1: DS and T line rates

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

Figure 6.24: T-1 line

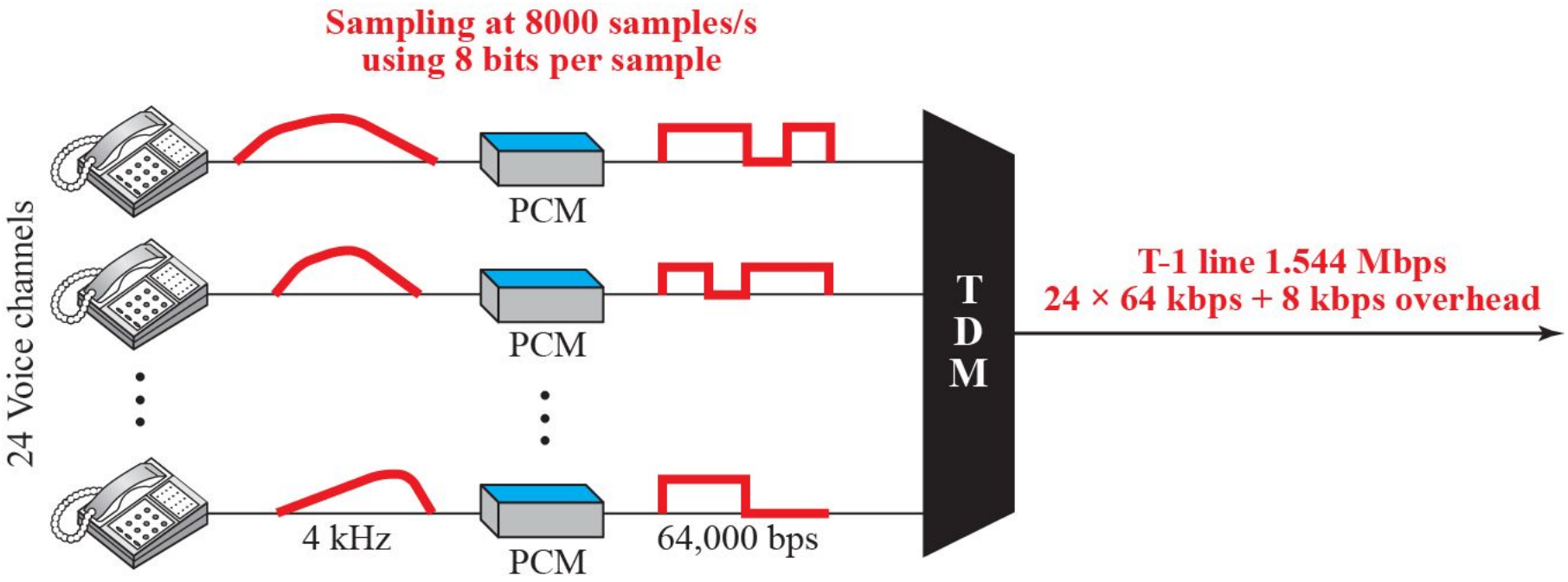


Figure 6.25: T-1 line frame structure

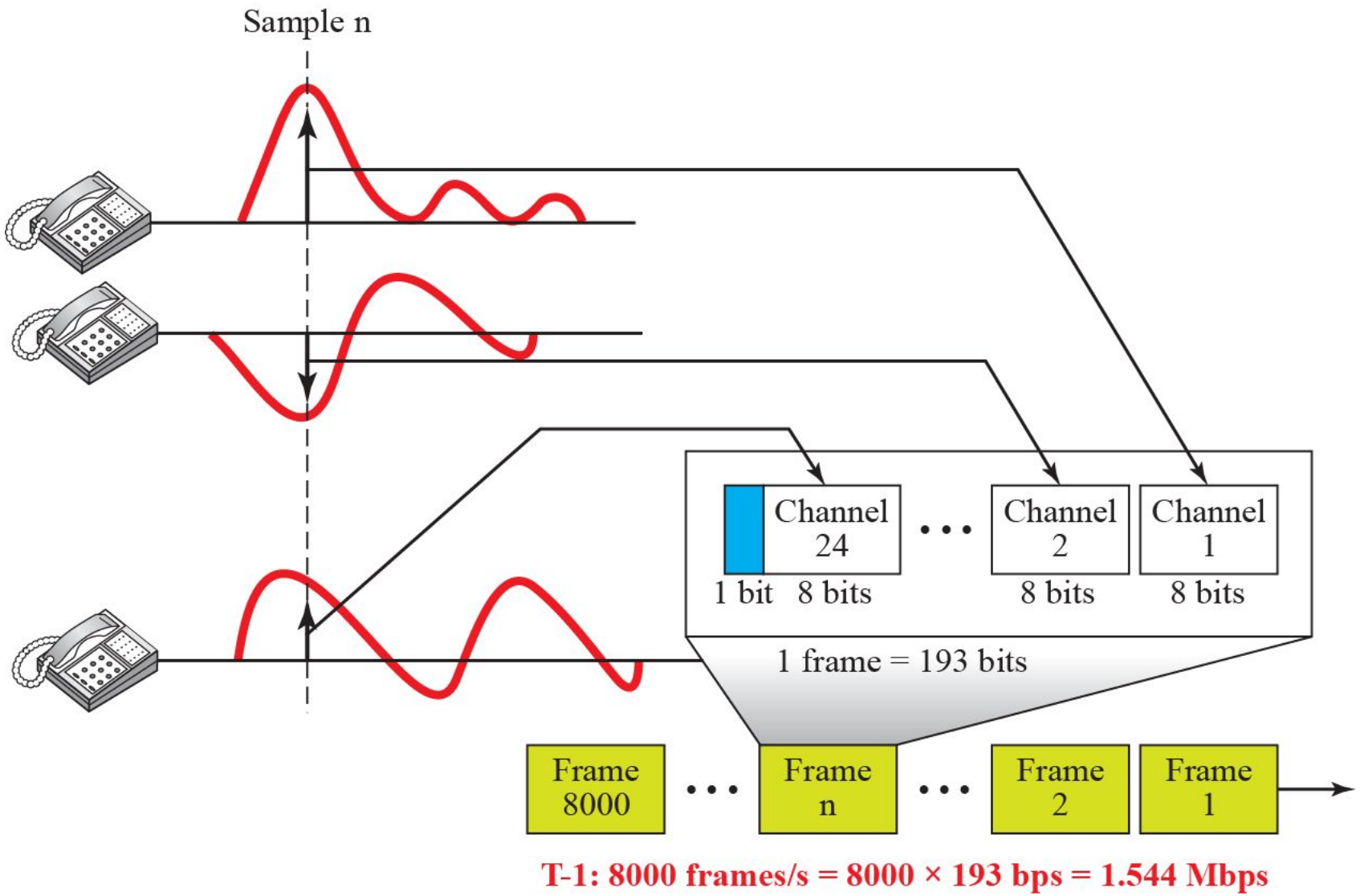


Figure 6.26: TDM slot comparison