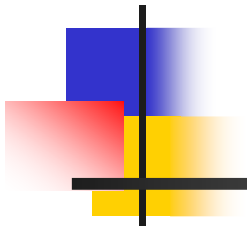
Data Communications



Multiplexing

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Syllabus

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Figure 6.1 *Dividing a link into channels*

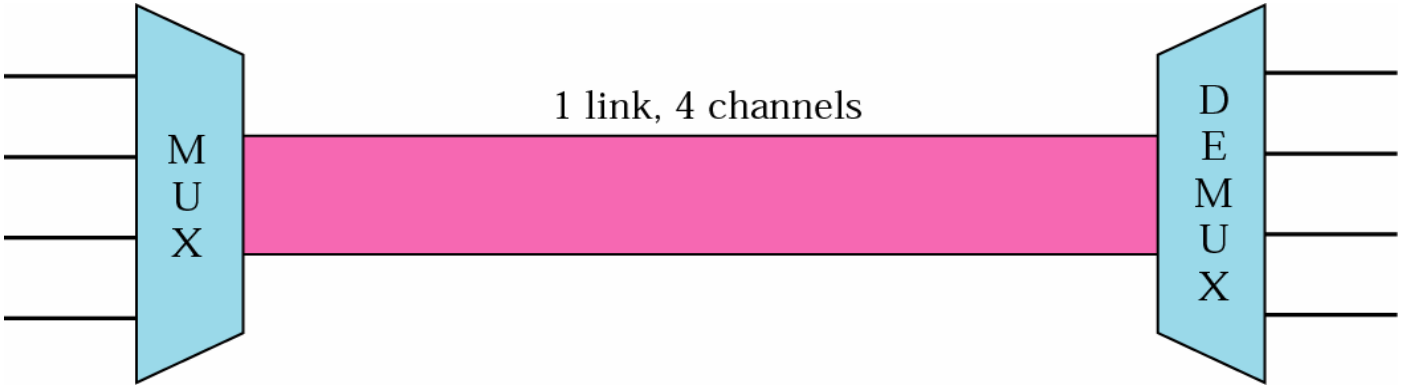
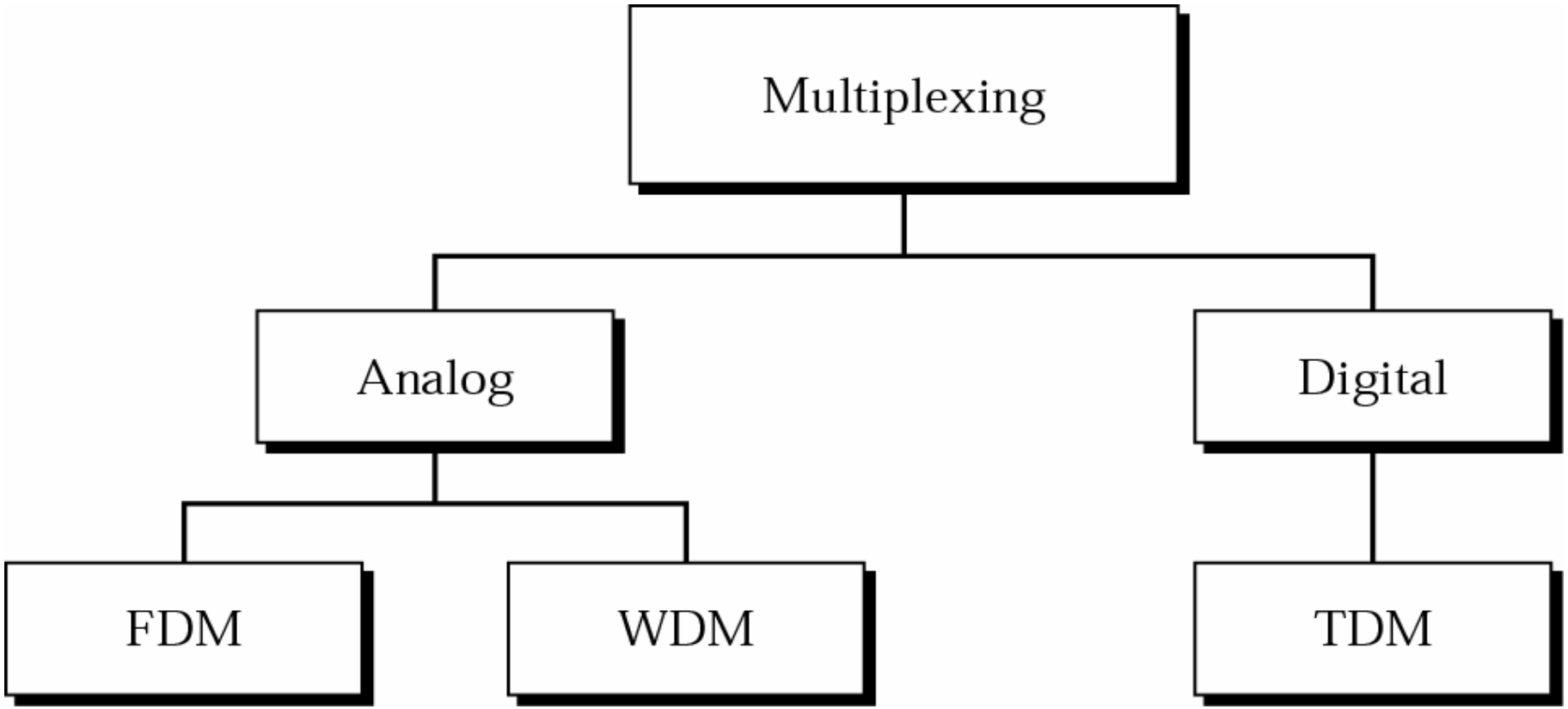


Figure 6.2 *Categories of multiplexing*

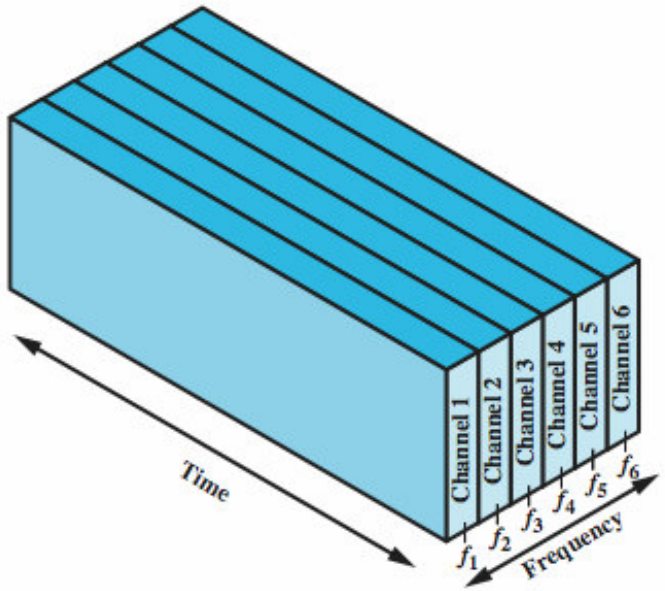


6.1 FDM

Multiplexing Process
Demultiplexing Process
The Analog Hierarchy

Figure 6.3 *FDM*

FDM is an analog multiplexing technique that combines signals.



(a) Frequency division multiplexing

Figure 6.4 *FDM process*

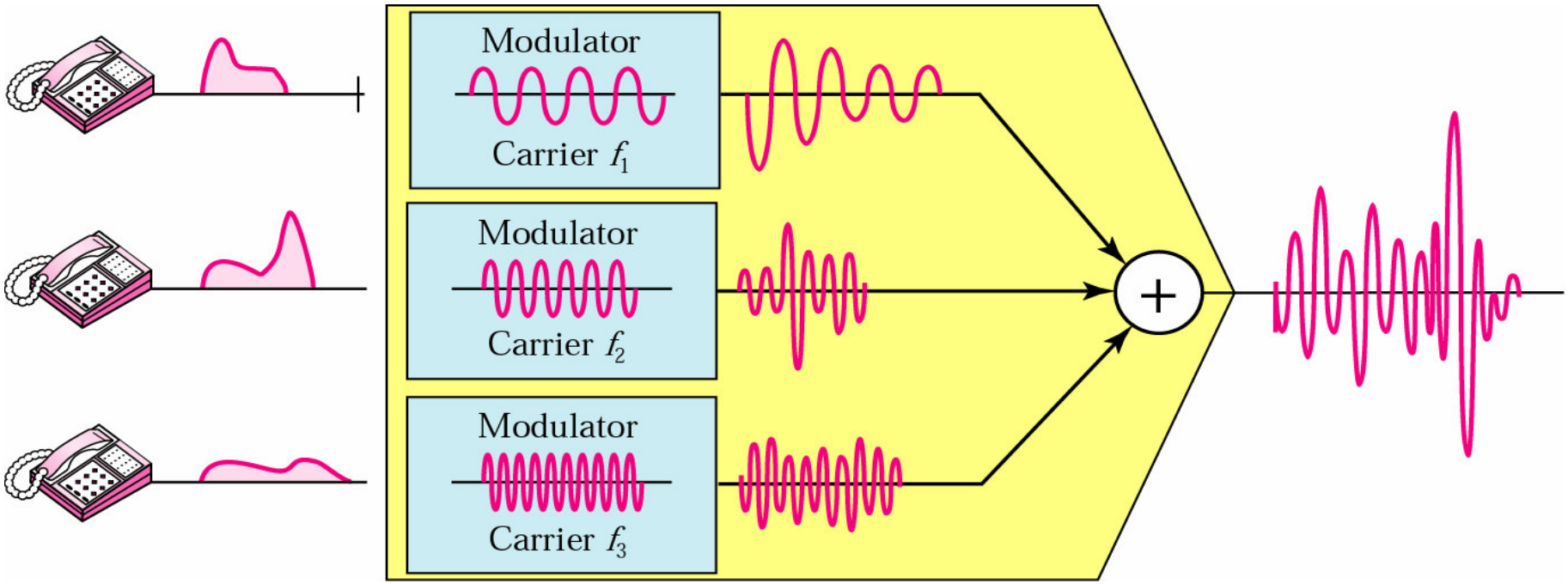
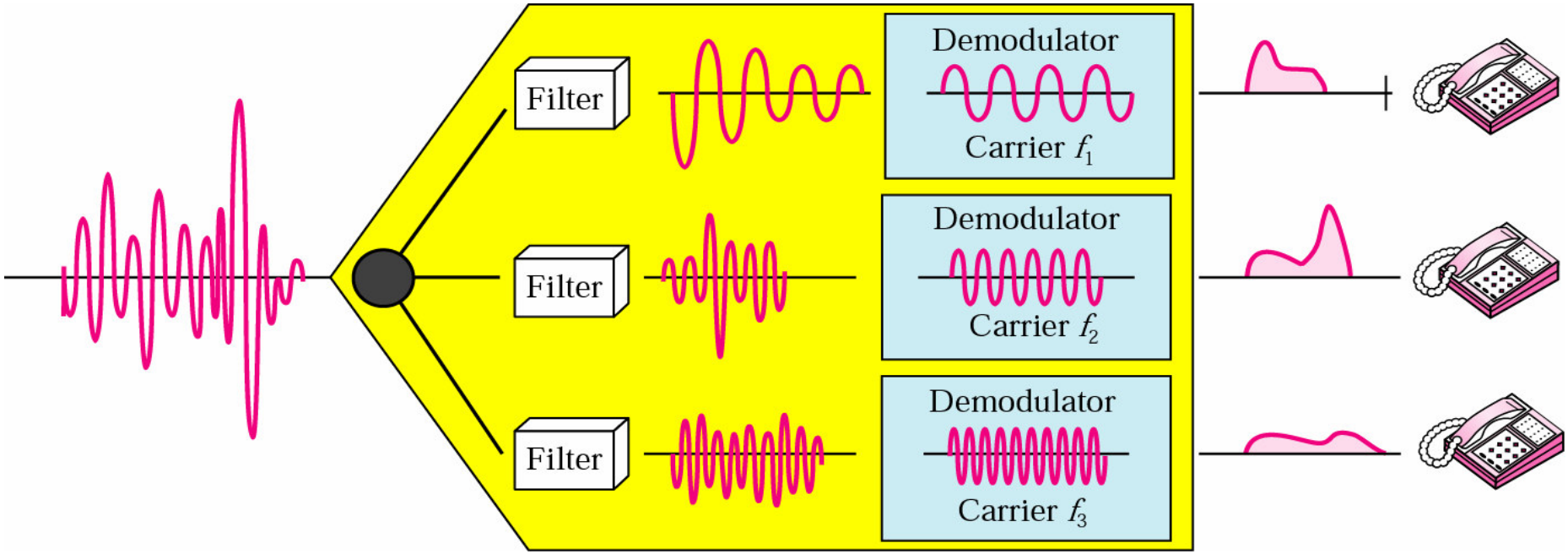


Figure 6.5 *FDM demultiplexing example*



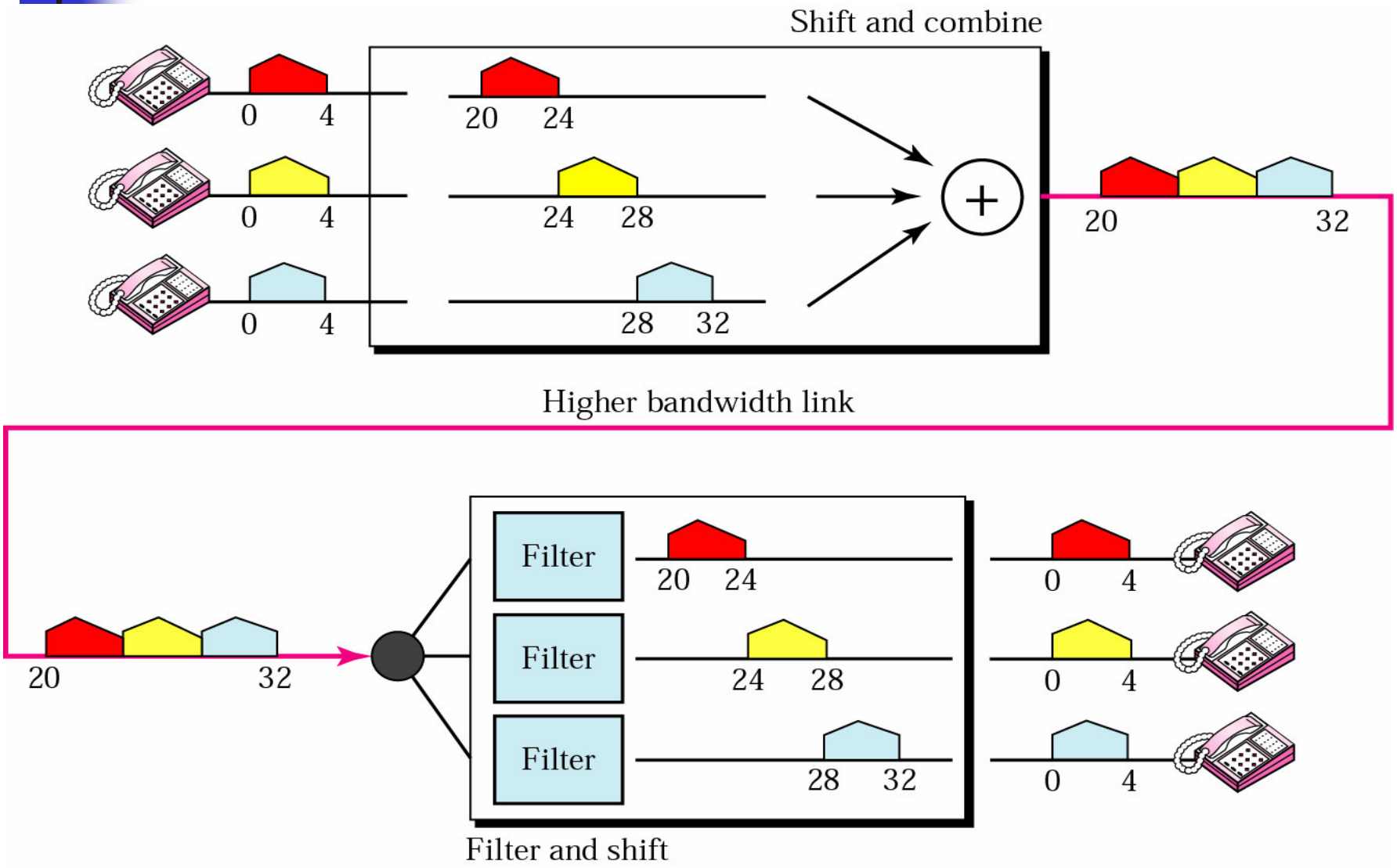
Example 1

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 without the use of guard bands.

Solution

Shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure 6.6.

Figure 6.6 *Example 1*



Example 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?

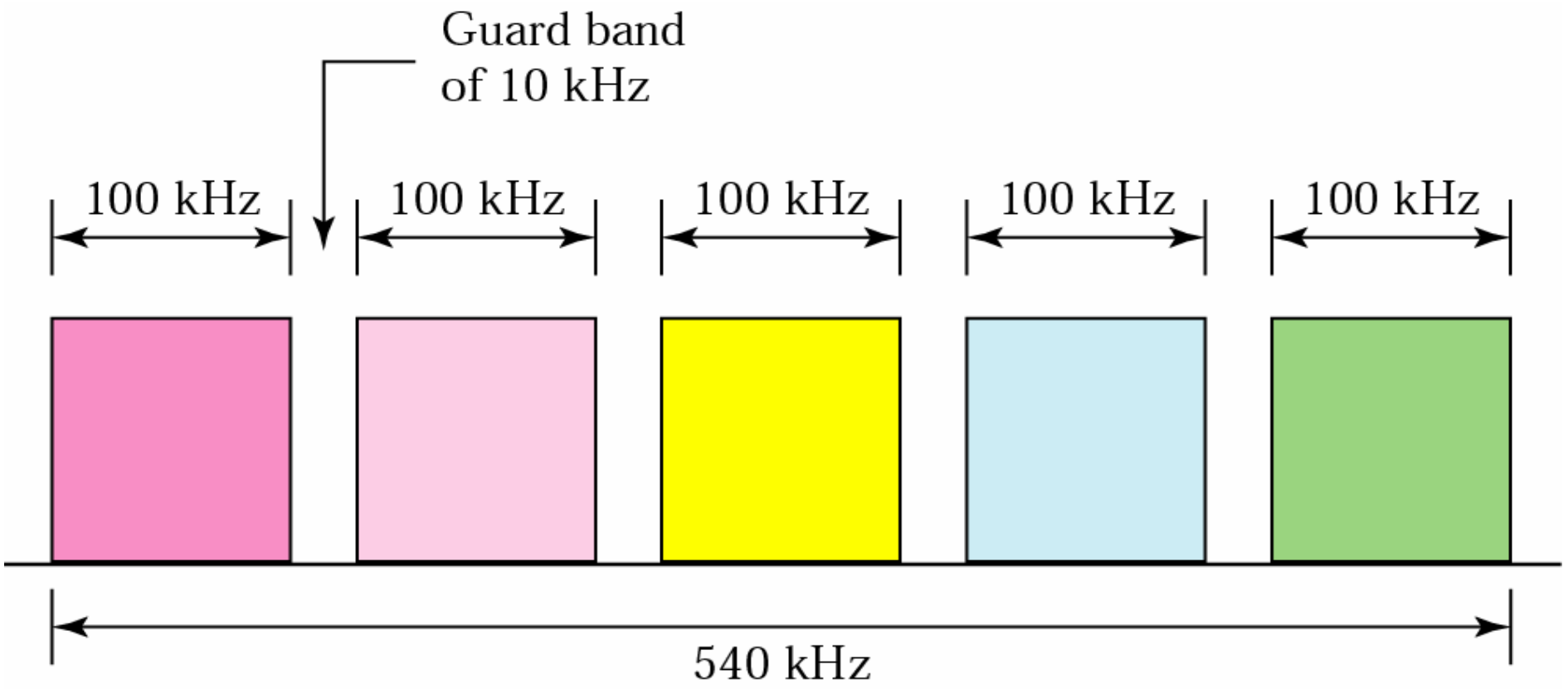
Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ KHz},$$

as shown in Figure 6.7.

Figure 6.7 Example 2



Example 3

Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration using FDM

Solution

The satellite channel is analog. We divide it into four channels, each channel having a 250-KHz bandwidth. Each digital channel of 1 Mbps is modulated such that each 4 bits are modulated to 1 Hz. One solution is 16-QAM modulation. Figure 6.8 shows one possible configuration.

Figure 6.8 *Example 3*

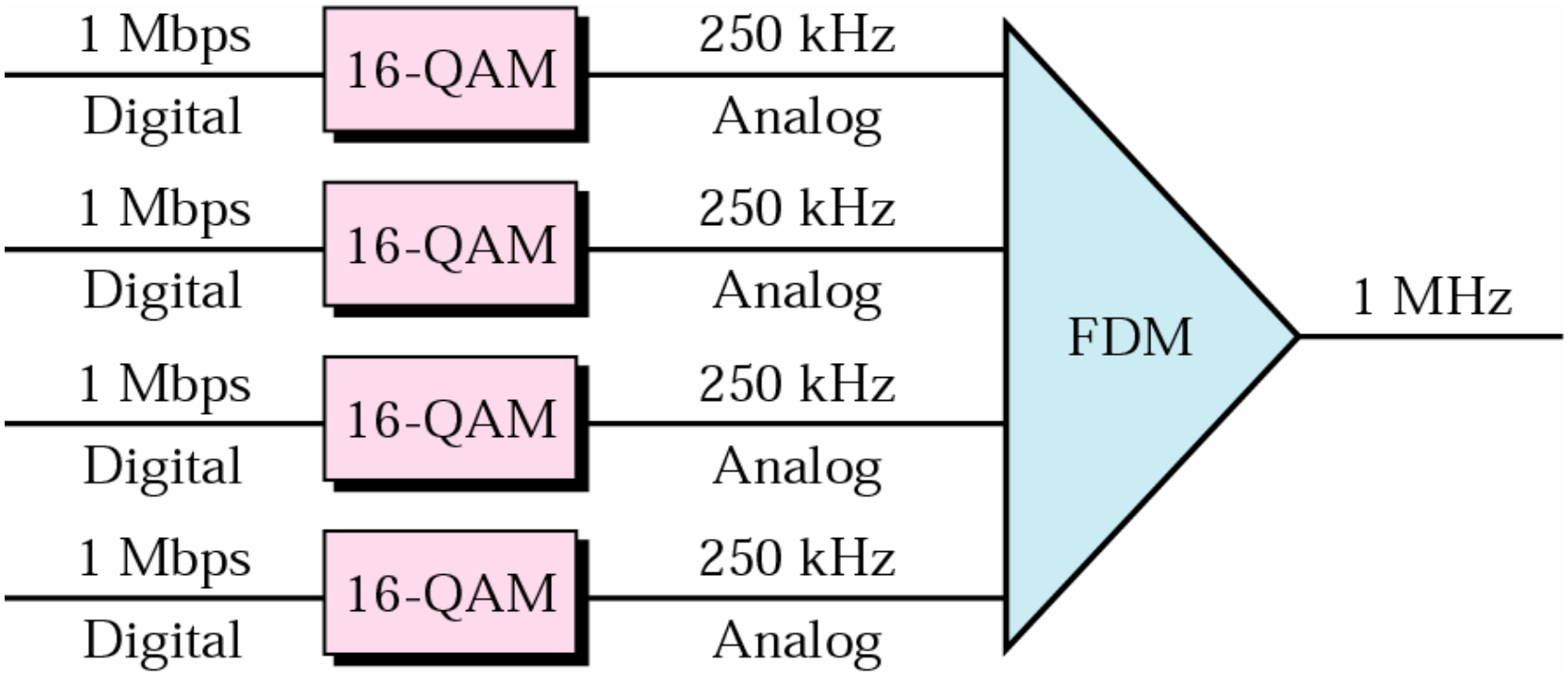
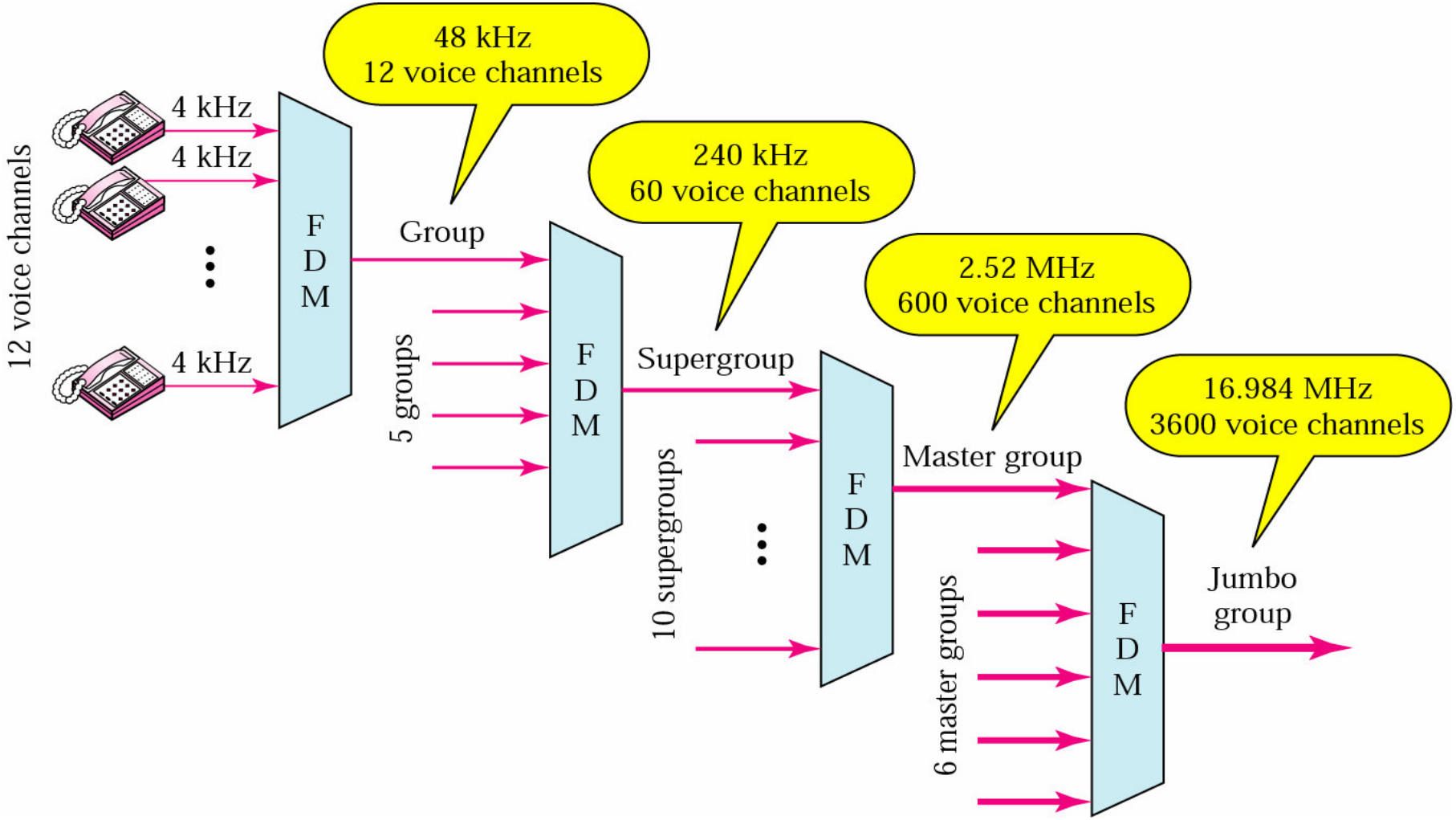


Figure 6.9 *Analog hierarchy*



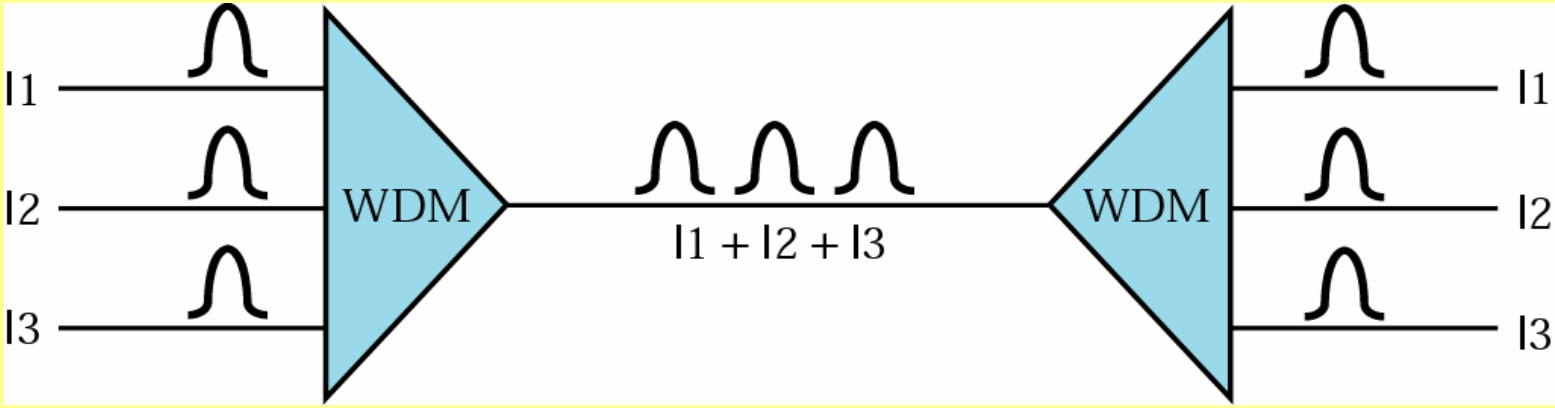
Example 4

The Advanced Mobile Phone System (AMPS) uses two bands. The first band, 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?

Solution

Each band is 25 MHz. If we divide 25 MHz into 30 KHz, we get 833.33. In reality, the band is divided into 832 channels.

6.2 WDM *Wave Division Multiplexing*

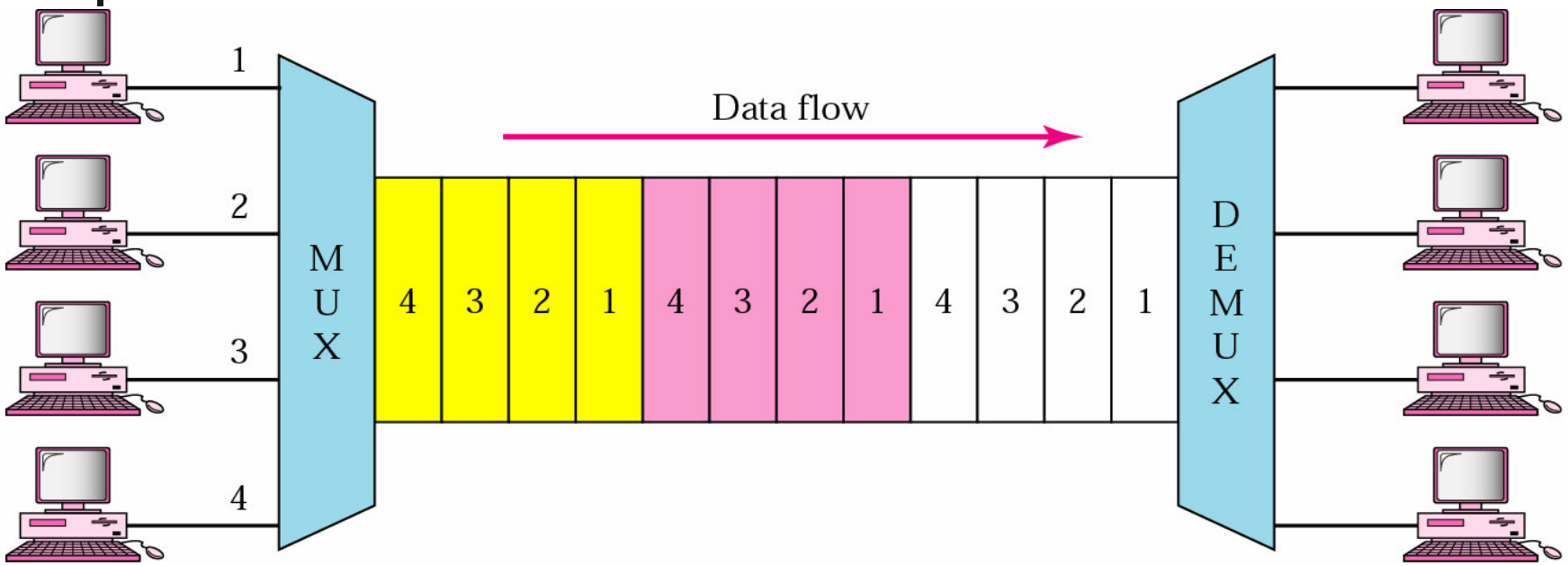


WDM is an analog multiplexing technique to combine optical signals.

6.3 TDM

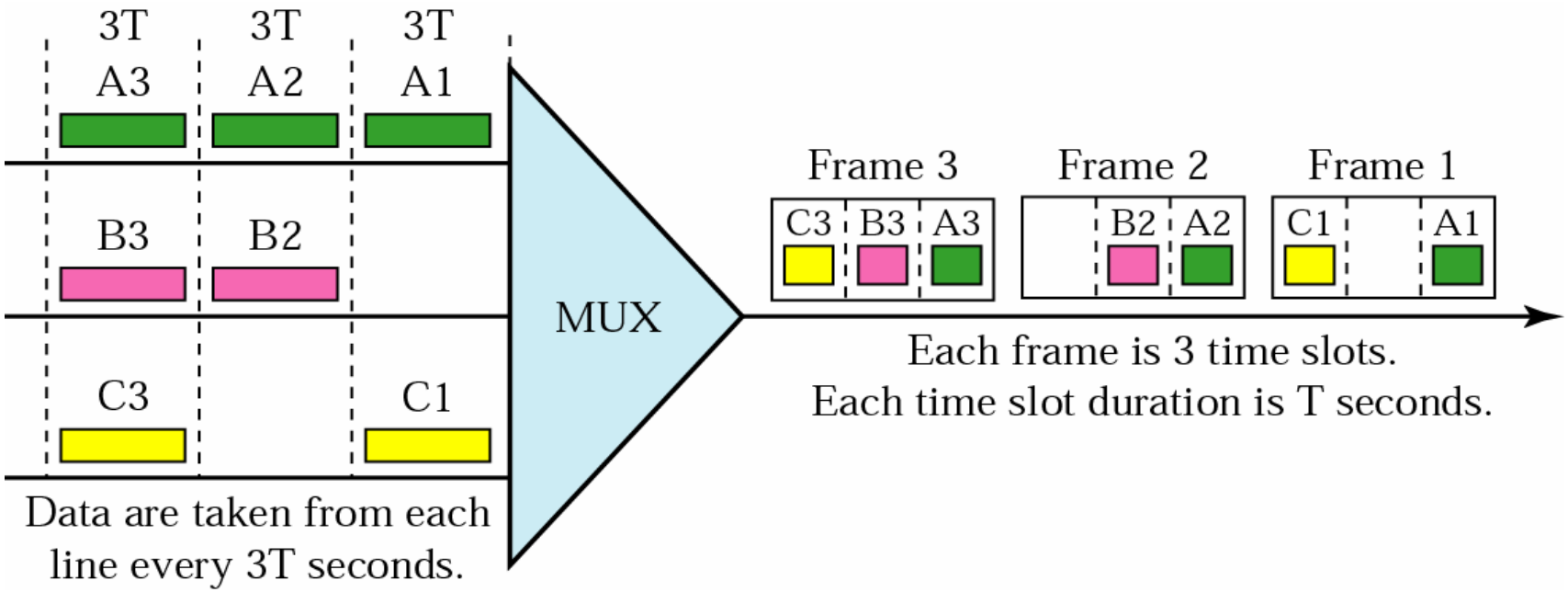
Time Slots and Frames
Interleaving
Synchronizing
Bit Padding
Digital Signal (DS) Service
T Lines

Figure 6.12 *TDM*



TDM is a digital multiplexing technique to combine data.

Figure 6.13 *TDM frames*



In a TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.

Example 5

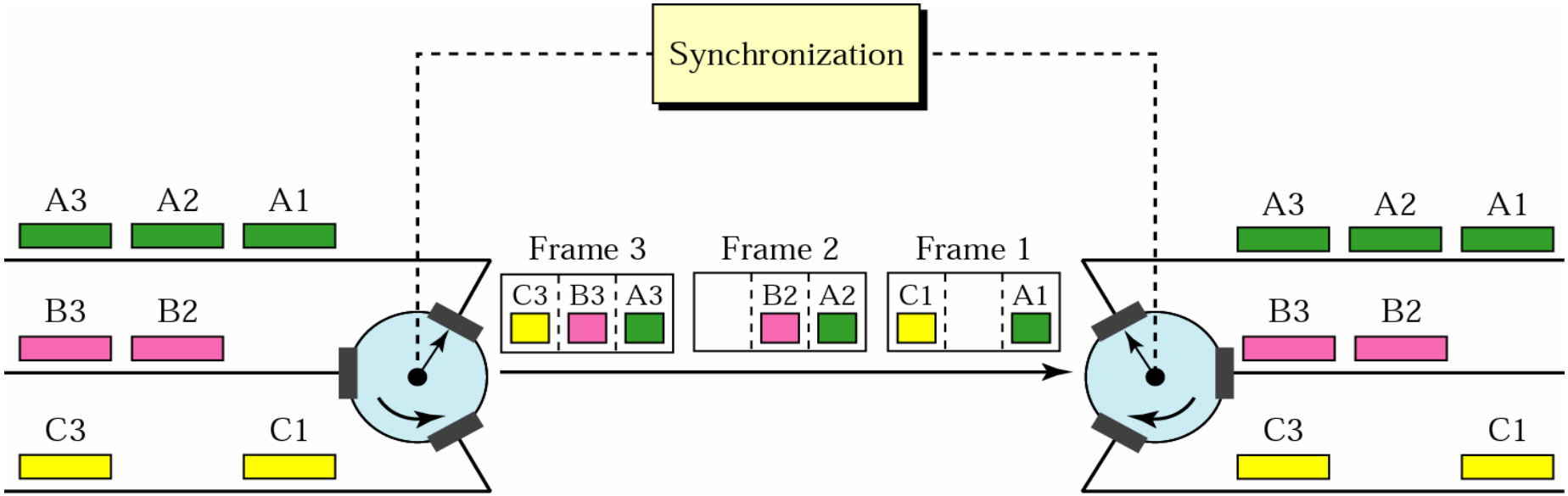
Four 1-Kbps connections are multiplexed together. A unit is 1 bit. Find (1) the duration of 1 bit before multiplexing, (2) the transmission rate of the link, (3) the duration of a time slot, and (4) the duration of a frame?

Solution

We can answer the questions as follows:

1. The duration of 1 bit is 1/1 Kbps, or 0.001 s (1 ms).
2. The rate of the link is 4 Kbps.
3. The duration of each time slot 1/4 ms or 250 μs.
4. The duration of a frame 1 ms.

Figure 6.14 *Interleaving*



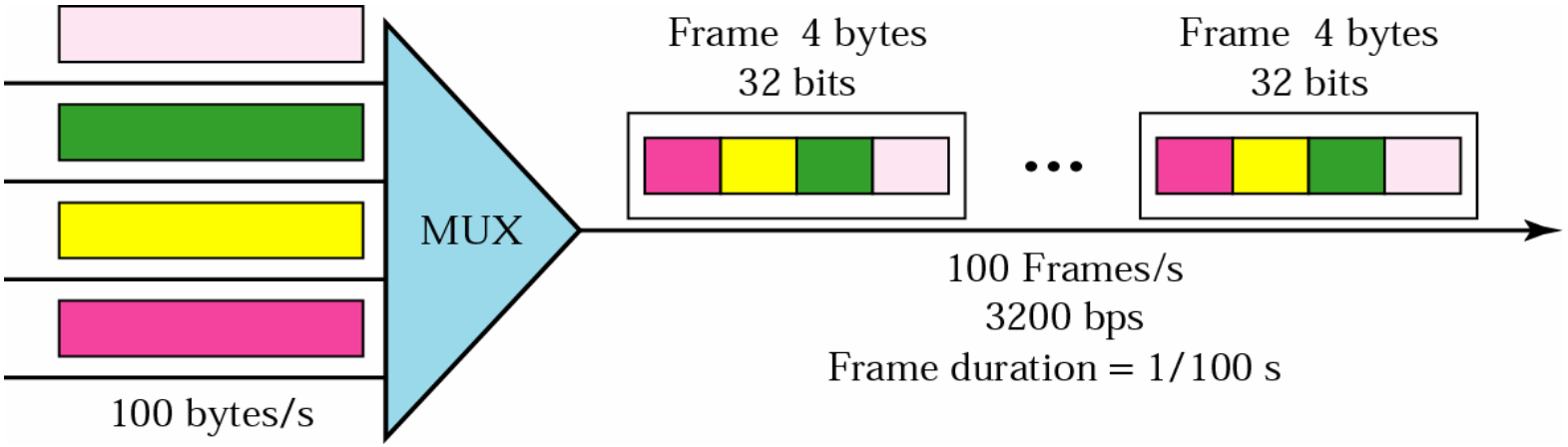
Example 6

Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.

Solution

The multiplexer is shown in Figure 6.15.

Figure 6.15 *Example 6*



Example 7

A multiplexer combines four 100-Kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?

Solution

Figure 6.16 shows the output for four arbitrary inputs.

Figure 6.16 *Example 7*

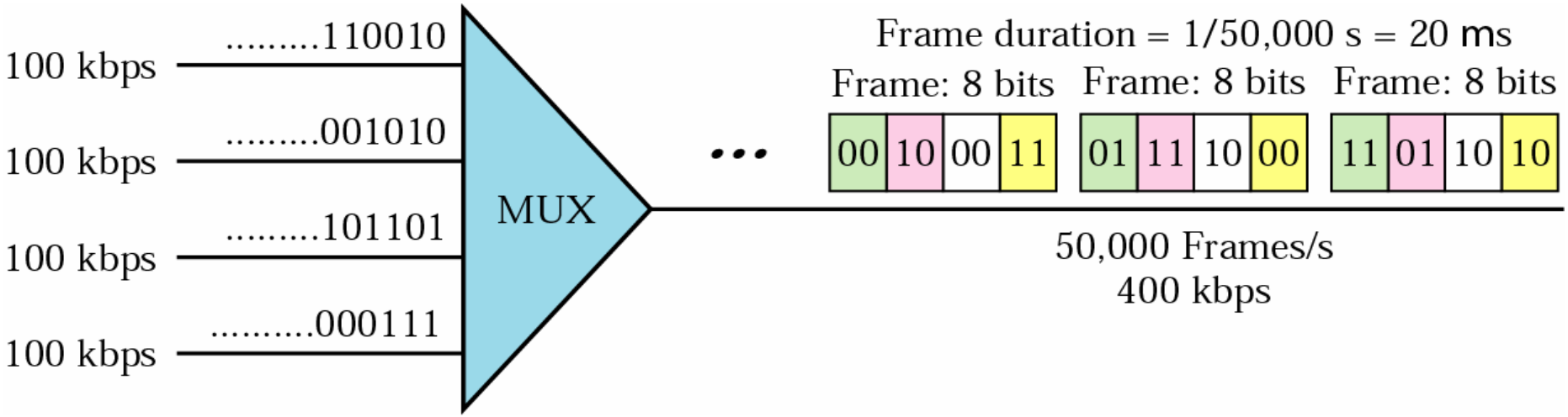
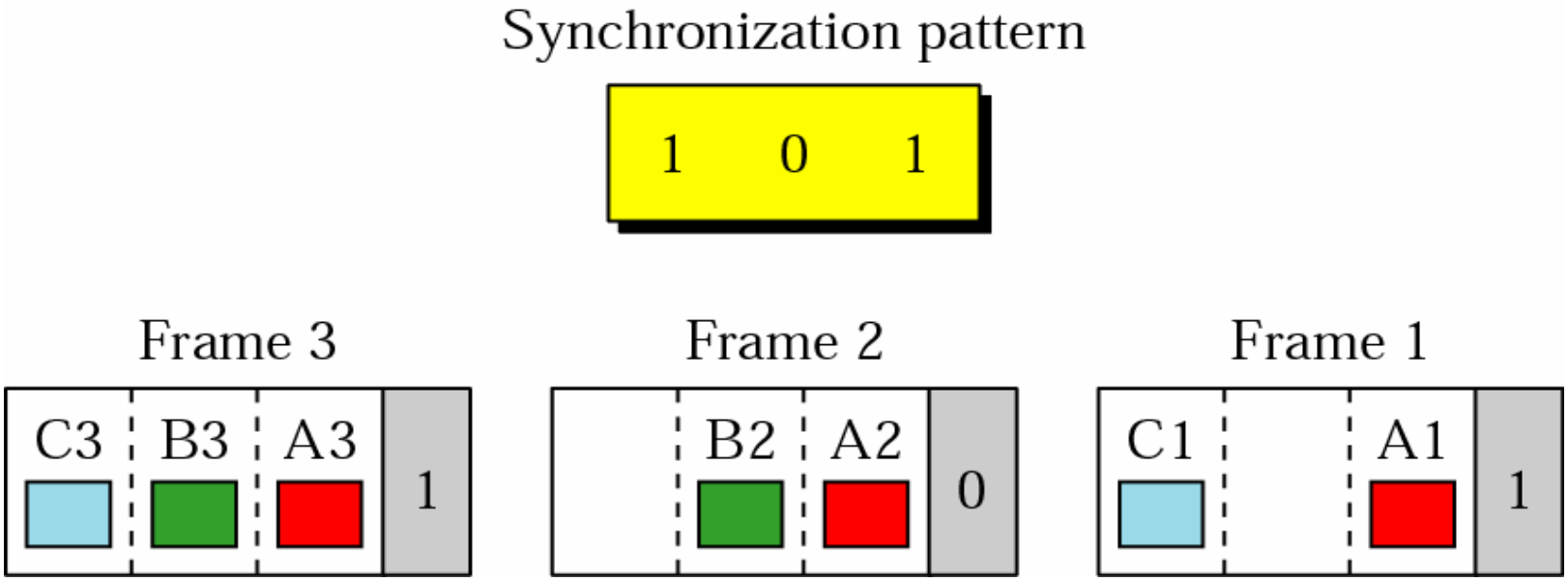


Figure 6.17 *Framing bits*



Example 8

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 (1) the data rate of each source, (2) the duration of each character in each source, (3) the frame rate, (4) the duration of each frame, (5) the number of bits in each frame, and (6) the data rate of the link.

Solution

See next slide.

Solution (continued)

We can answer the questions as follows:

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.

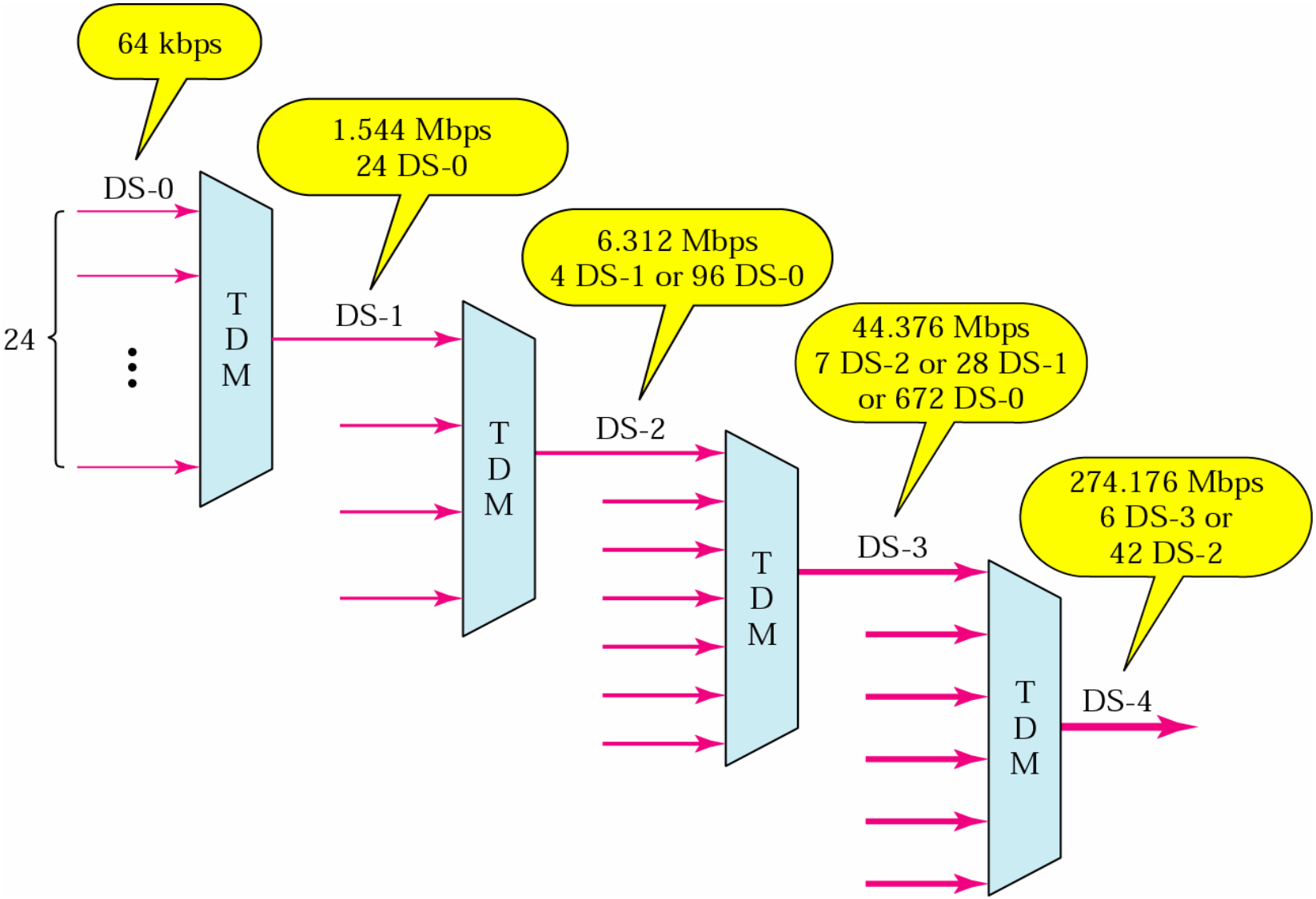
Example 9

Two channels, one with a bit rate of 100 Kbps and another with a bit rate of 200 Kbps, are to be multiplexed. How this can be achieved? What is the frame rate? What is the frame duration? What is the bit rate of the link?

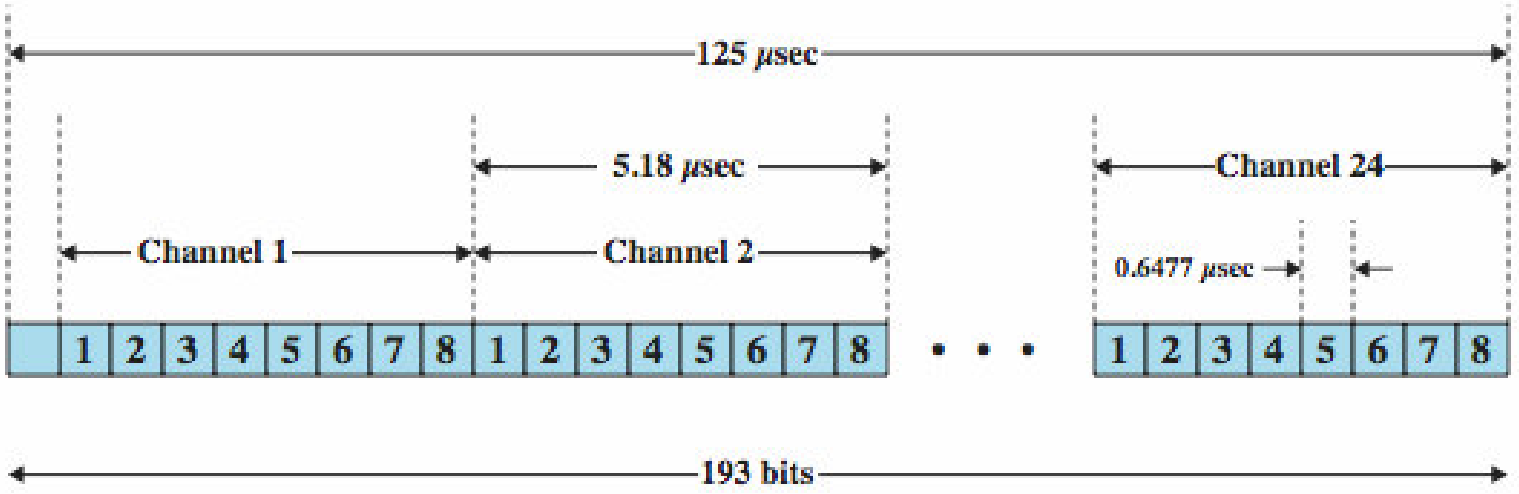
Solution

We can allocate one slot to the first channel and two slots to the second channel. Each frame carries 3 bits. The frame rate is 100,000 frames per second because it carries 1 bit from the first channel. The frame duration is 1/100,000 s, or 10 ms. The bit rate is 100,000 frames/s x 3 bits/frame, or 300 Kbps.

Figure 6.18 *DS hierarchy*



DS-1 Transmission Format



Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 is used for signaling only in some schemes.
   - Bits 1-7 used for 56 kbps service
   - Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

Table 6.1 DS and T lines 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 6.19 *T-1 line for multiplexing telephone lines*

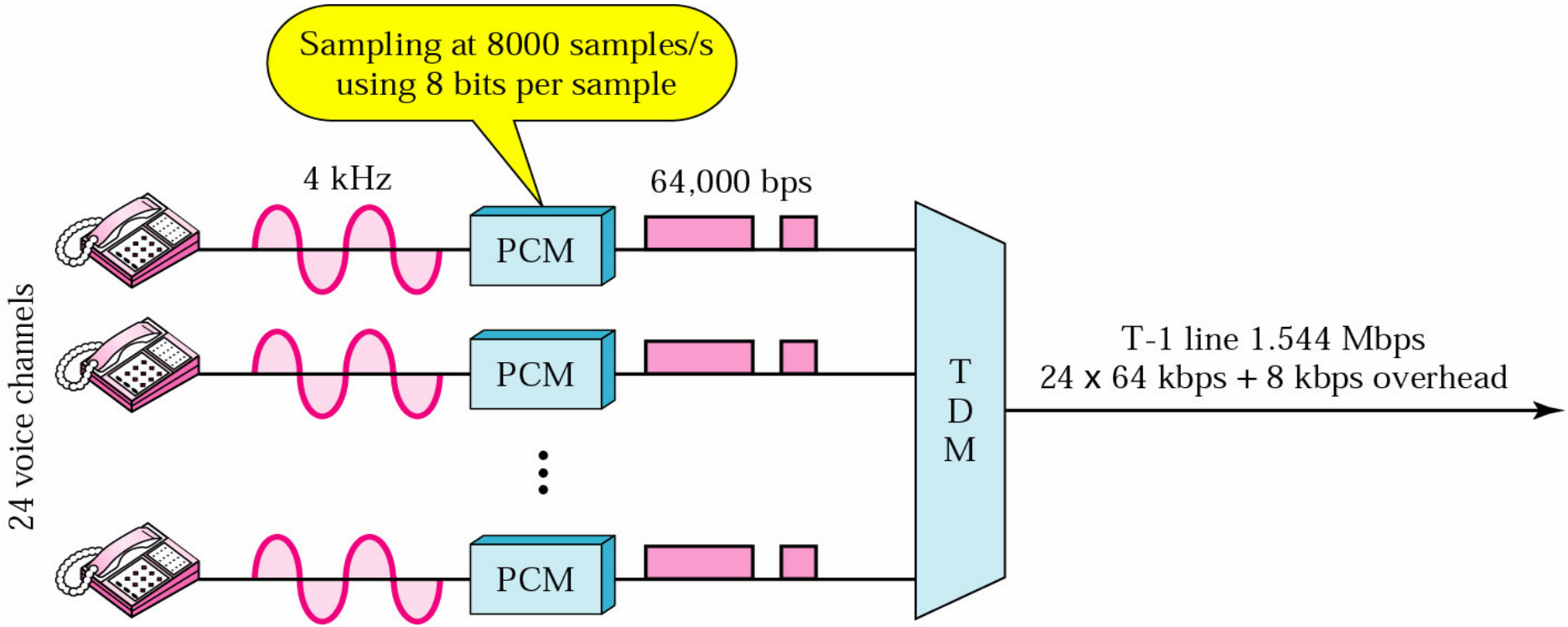


Figure 6.20 *T-1 frame structure*

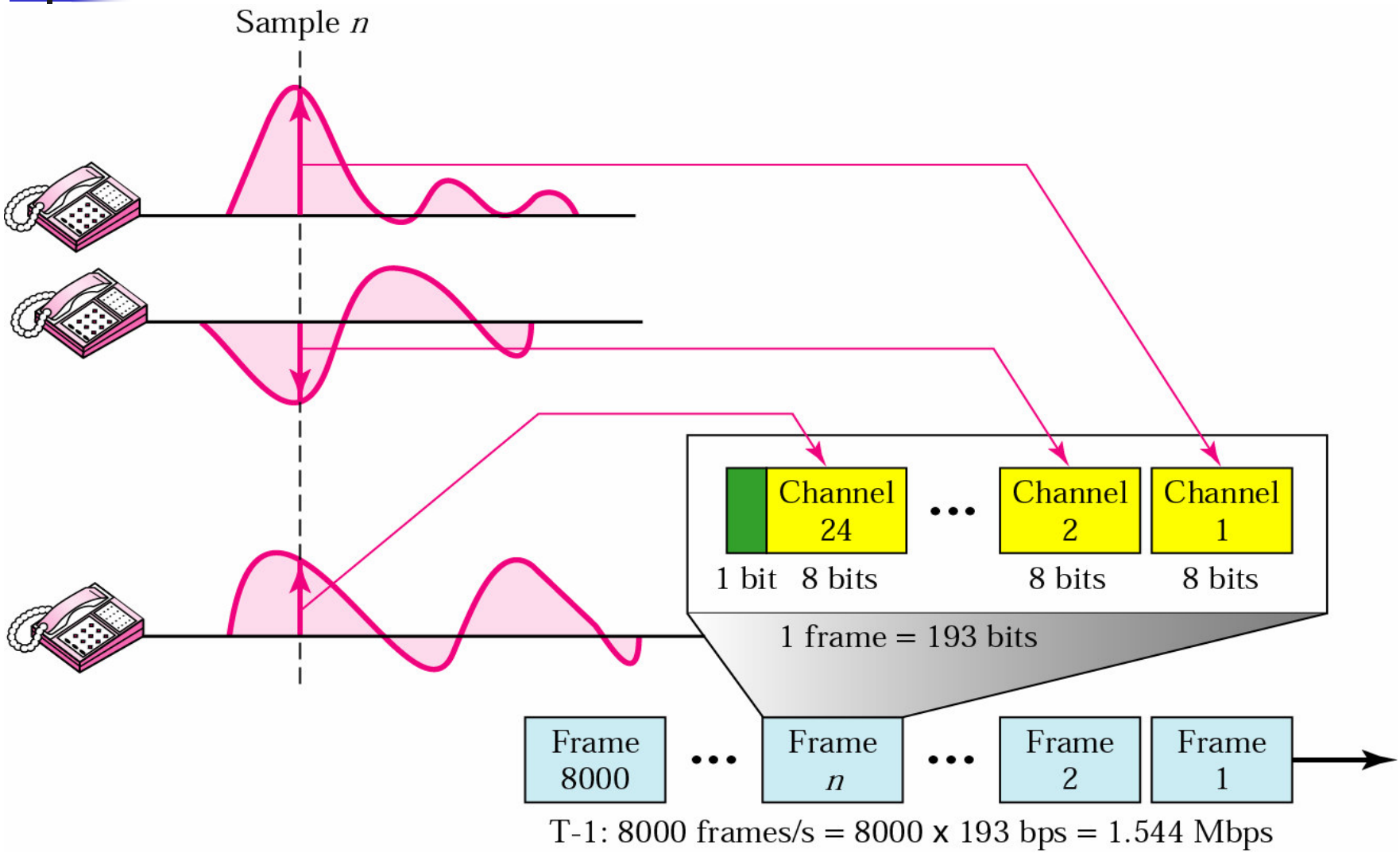


Table 6.2 E line rates

E 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

Figure 6.21 *Multiplexing and inverse multiplexing*