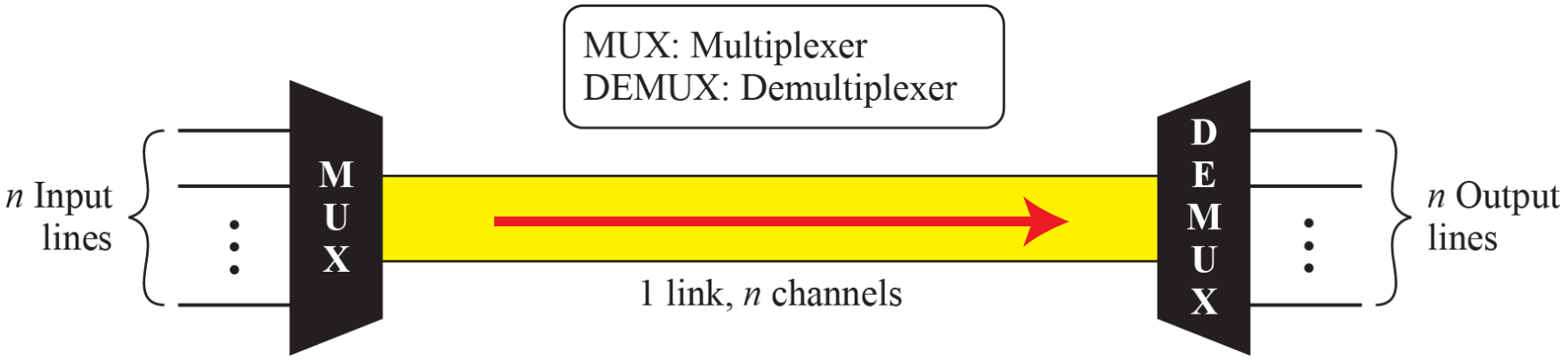
Chapter 6

Bandwidth Utilization

MULTIPLEXING

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

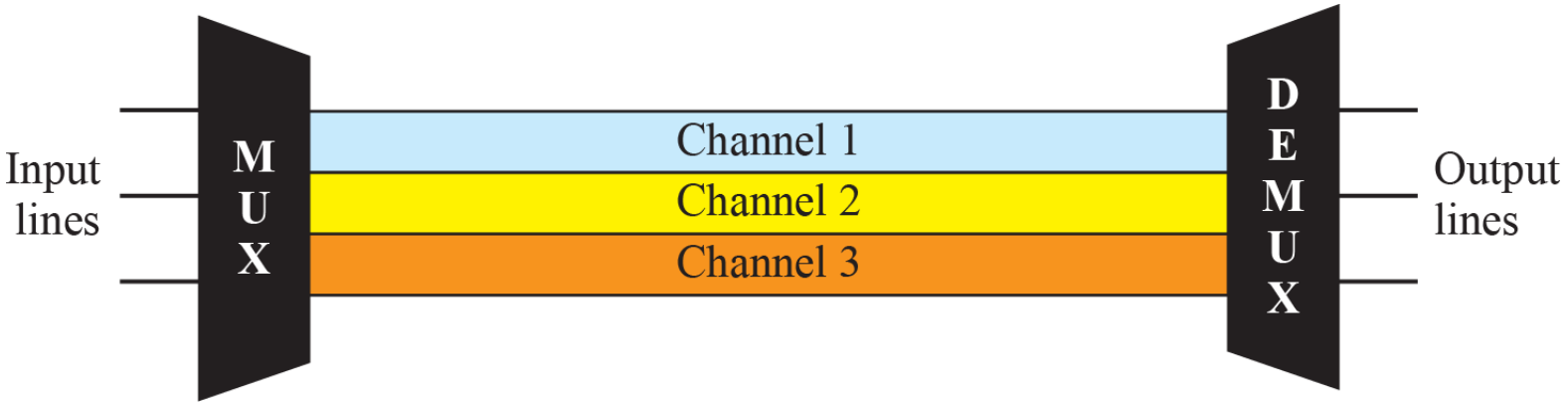
Dividing a link into channels



Frequency-Division Multiplexing

- 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

Frequency-division multiplexing



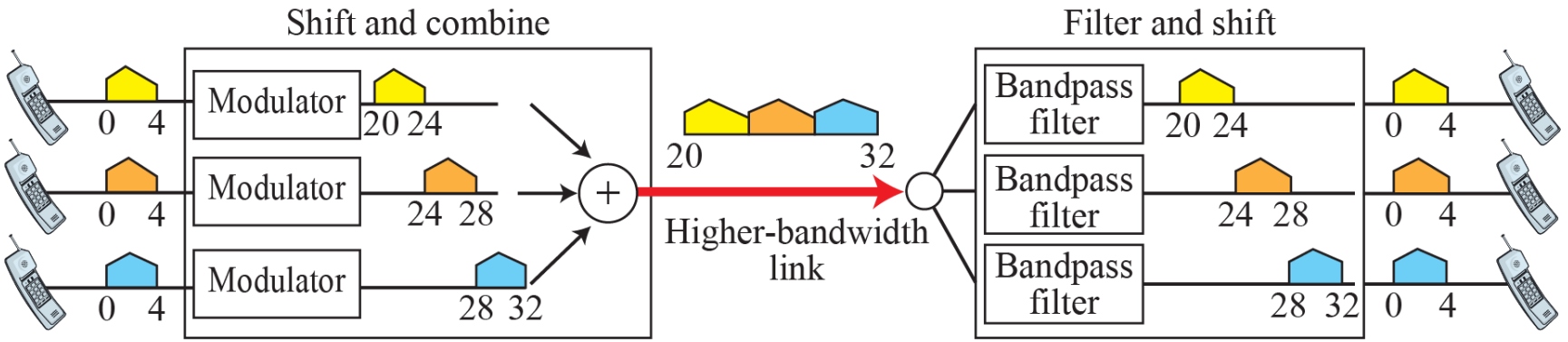
Example 6.1

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.

Solution

We shift (modulate) each of the three voice channels to a different bandwidth.

Figure 6.6: Example 6.1

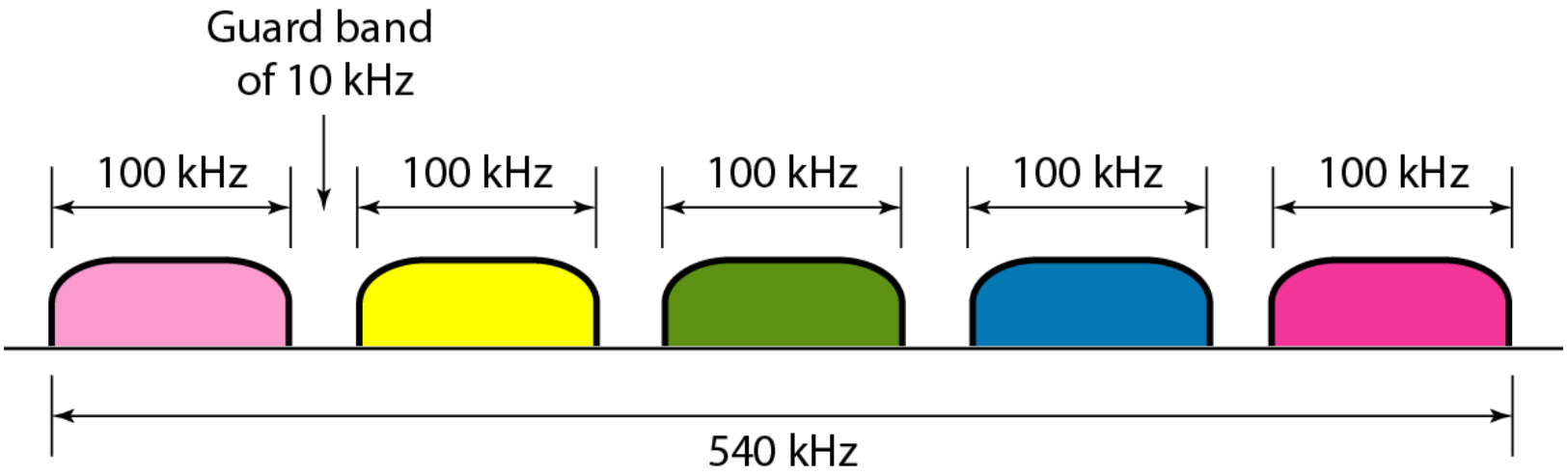


Example 6.2

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?

Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz.

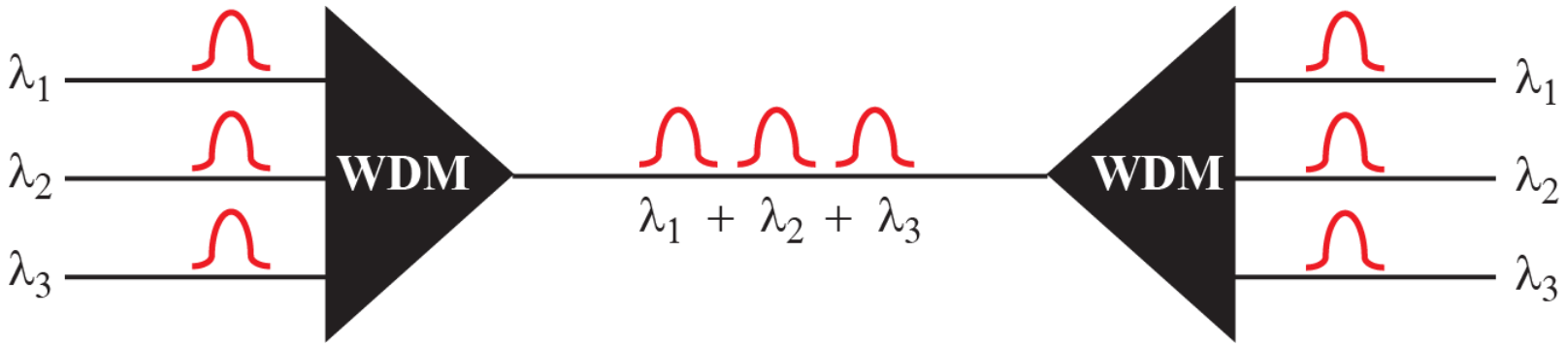

Guard band
of 10 kHz
100 kHz
100 kHz
100 kHz
100 kHz
100 kHz
540 kHz

Wavelength-Division Multiplexing

- ***is designed to use the high-data-rate capability of fiber-optic cable.***

- ***Multiplexing allows us to combine several lines into one.***

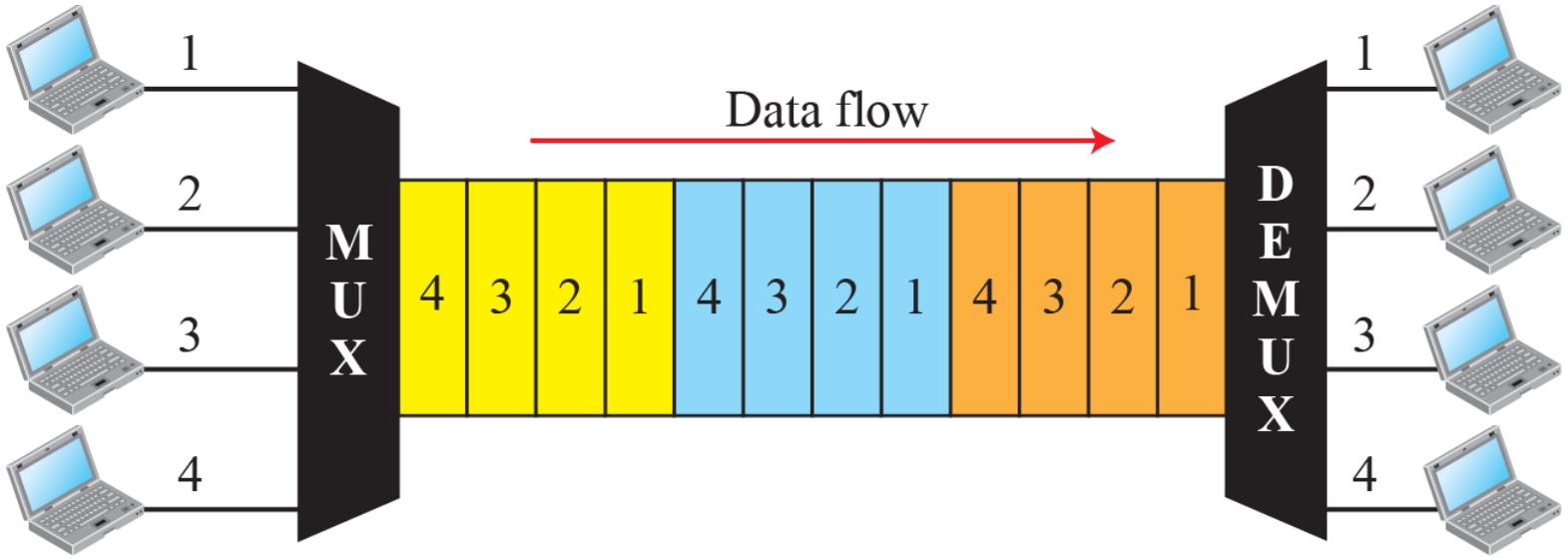
Wavelength-division multiplexing



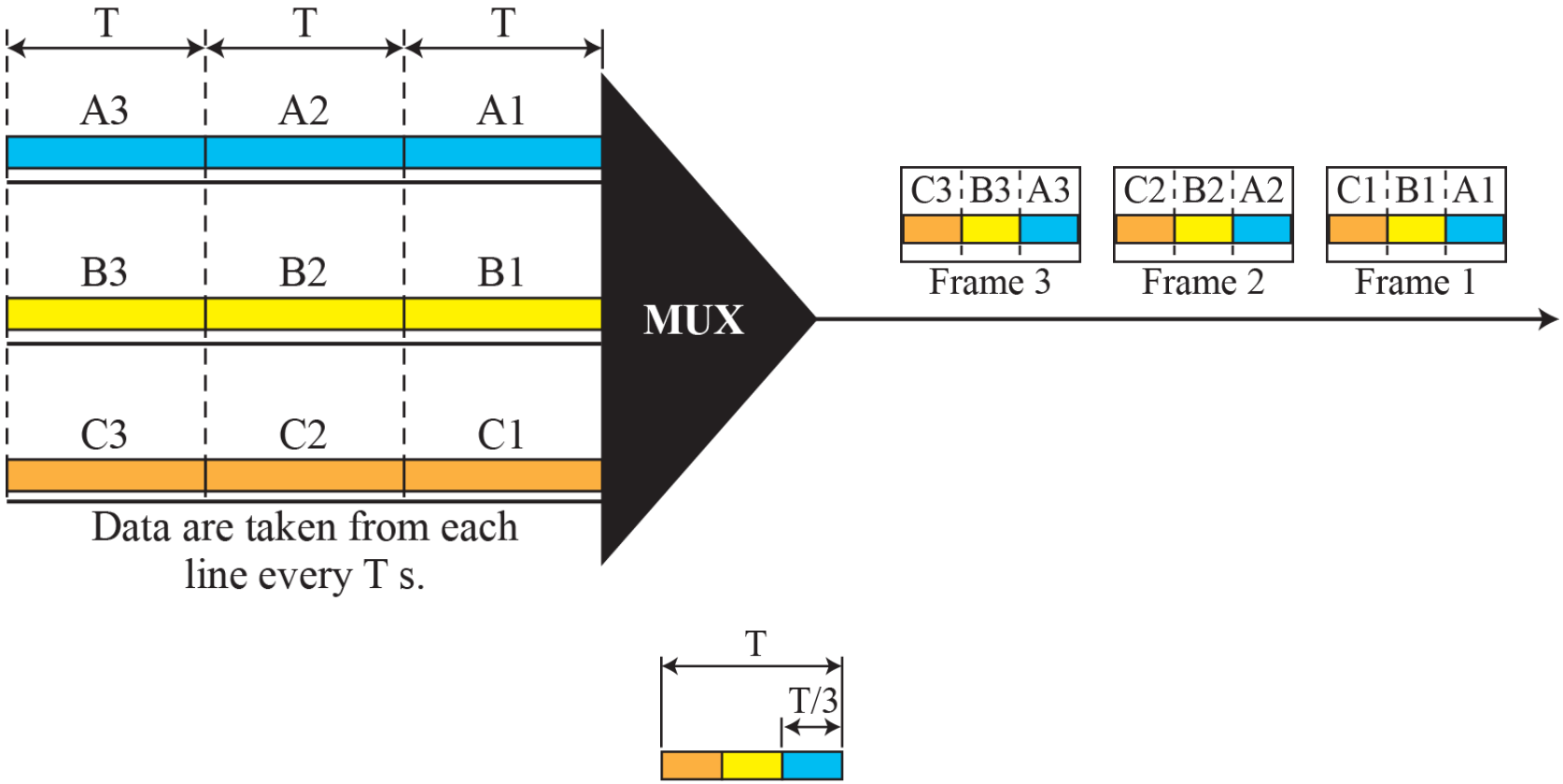
Time-Division Multiplexing

- ***allows several connections to share the high bandwidth of a link.***
- ***instead of sharing a portion of the bandwidth as in FDM, time is shared.***
- ***each connection occupies a portion of time in the link.***
- ***in the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially.***

TDM



Synchronous time-division multiplexing



Example

In the previous picture, 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

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

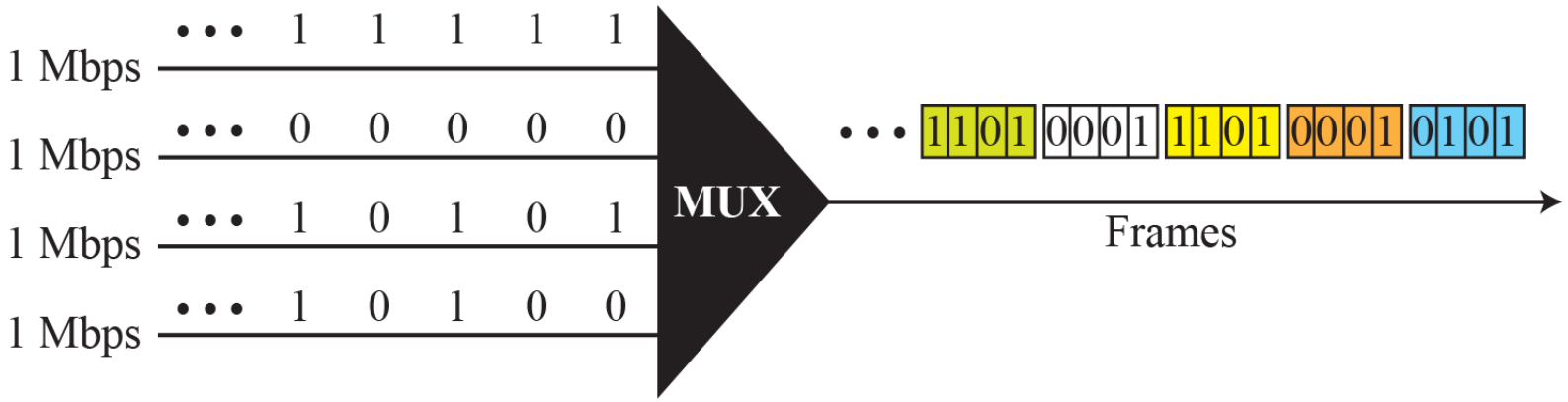
Solution

1. 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.

Example



Example

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 before multiplexing is 1/1 kbps, or 0.001 s (1 ms).
2. The rate of the link is 4 times the rate of a connection, or 4 kbps.
3. The duration of each time slot is one-fourth of the duration of each bit before multiplexing, or 1/4 ms or 250 μs. Note that we can also calculate this from the data rate of the link, 4 kbps. The bit duration is the inverse of the data rate, or 1/4 kbps or 250 μs.
4. The duration of a frame is always the same as the duration of a unit before multiplexing, or 1 ms. We can also calculate this in another way. Each frame in this case has four time slots. So the duration of a frame is 4 times 250 μs, or 1 ms.

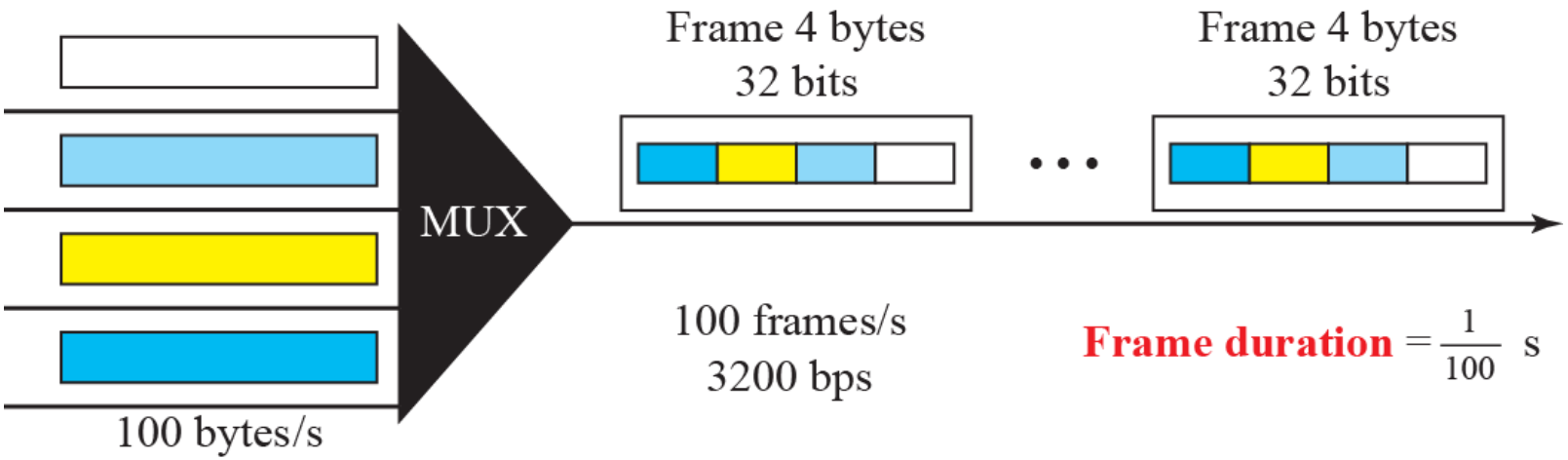
Example

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 on next page. Each frame carries 1 byte from each channel; the size of each frame, therefore, is 4 bytes, or 32 bits. The frame rate is 100 frames per second. The duration of a frame is therefore 1/100 s. The link is carrying 100 frames per second, and since each frame contains 32 bits, the bit rate is 100 × 32, or 3200 bps.

Example


Frame 4 bytes
32 bits
Frame 4 bytes
32 bits
MUX
100 frames/s
3200 bps
Frame duration = 1/100 s
100 bytes/s

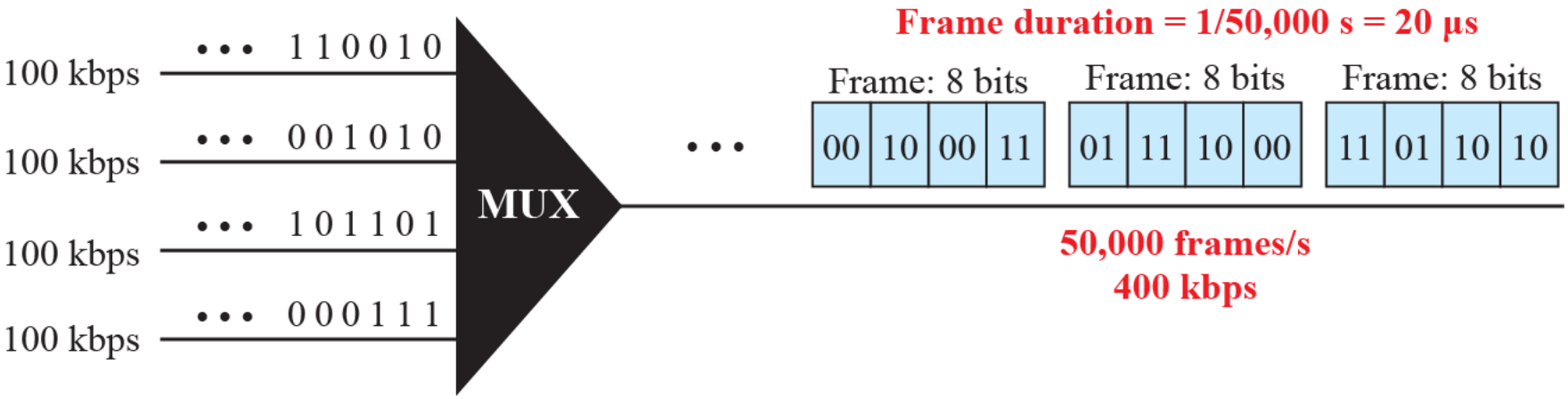
Example 6.9

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?

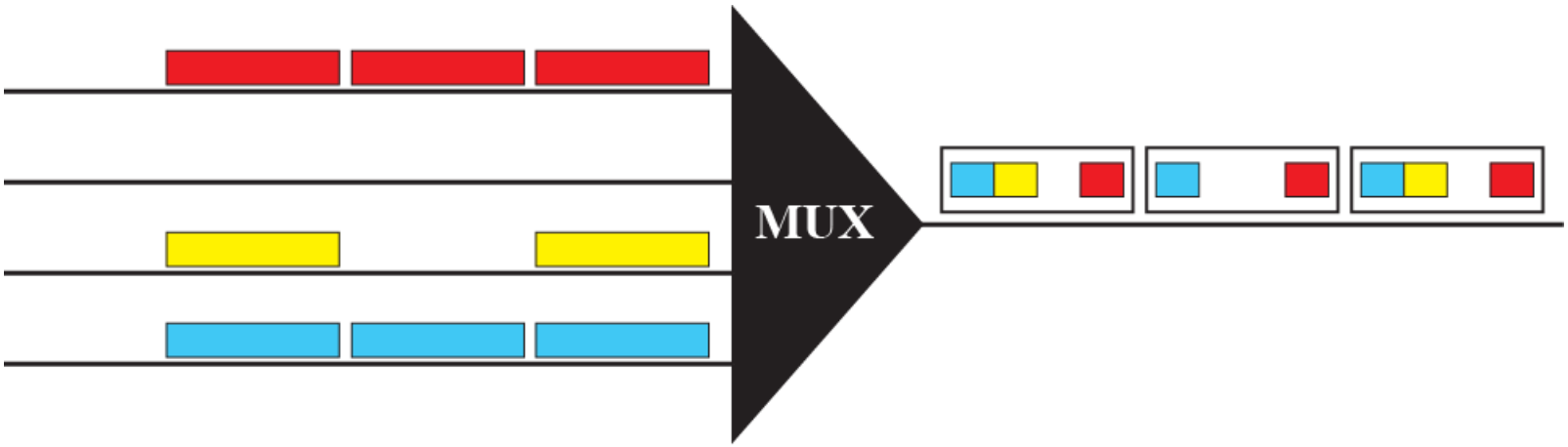
Solution

Figure on next page shows the output for four arbitrary inputs. The link carries 50,000 frames per second since each frame contains 2 bits per channel. The frame duration is therefore 1/50,000 s or 20 μs. The frame rate is 50,000 frames per second, and each frame carries 8 bits; the bit rate is 50,000 × 8 = 400,000 bits or 400 kbps. The bit duration is 1/400,000 s, or 2.5 μs.

Example


100 kbps
100 kbps
100 kbps
100 kbps
• • • 1 1 0 0 1 0
• • • 0 0 1 0 1 0
• • • 1 0 1 1 0 1
• • • 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

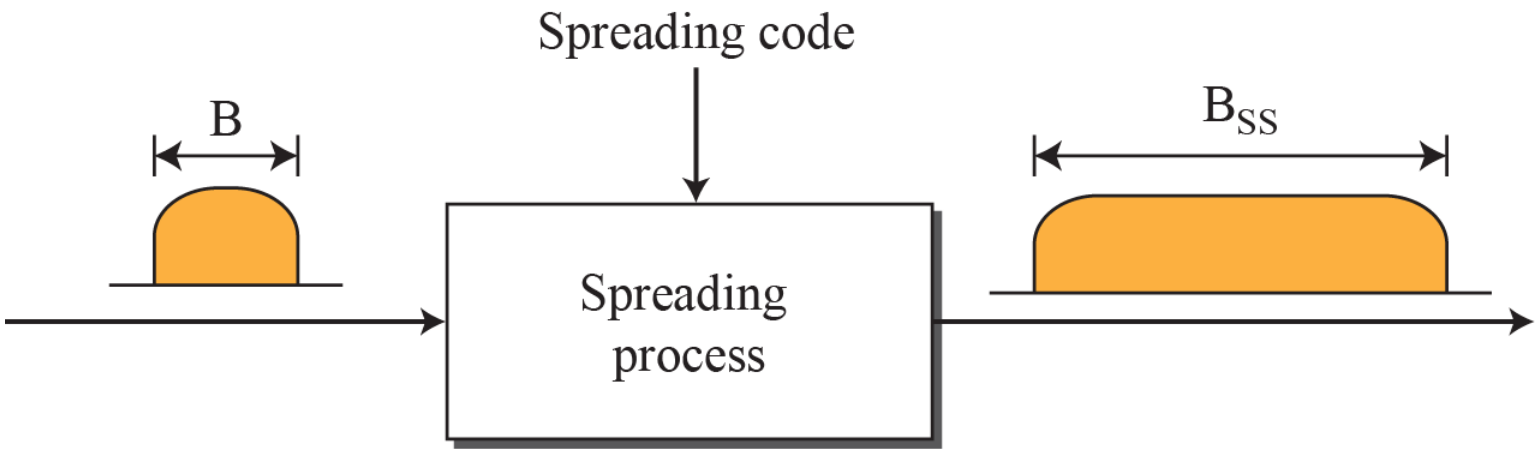
Empty slots



SPREAD SPECTRUM

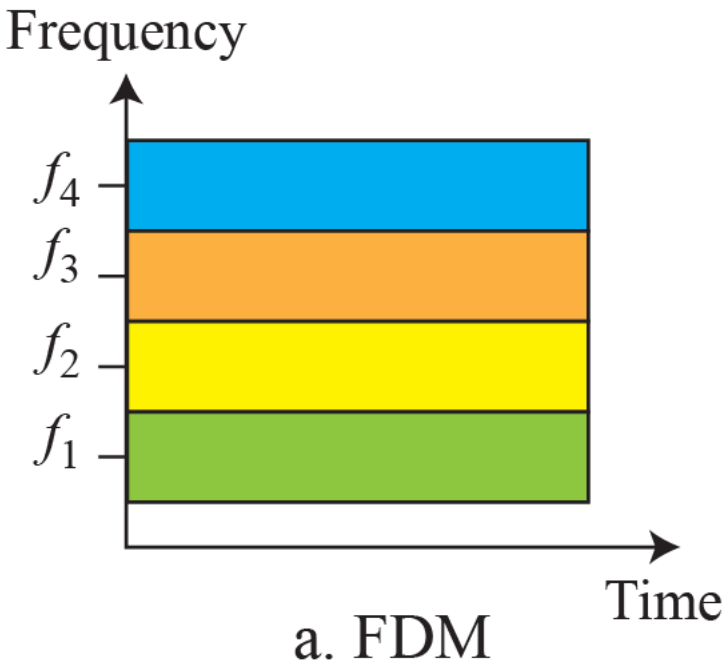
In wireless applications, stations must be able to share the medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder To achieve these goals, spread spectrum techniques add redundancy;

Spread spectrum

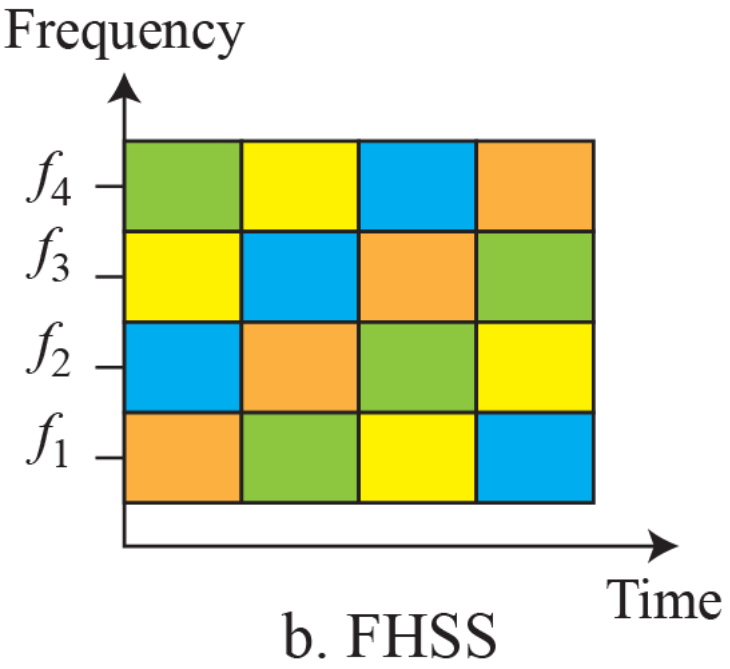


FHHS

Bandwidth sharing



a. FDM



b. FHSS

DSSS

- *The direct sequence spread spectrum (DSSS) technique also expands the bandwidth of the original signal, but the process is different.*
- *In DSSS, we replace each data bit with n bits using a spreading code. In other words, each bit is assigned a code of n bits, called chips, where the chip rate is n times that of the data bit.*

DSSS example