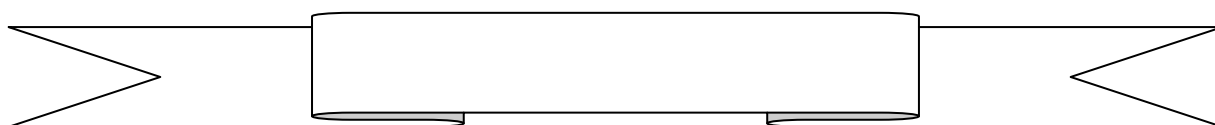




CHAPTER 8

MULTIPLEXING



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

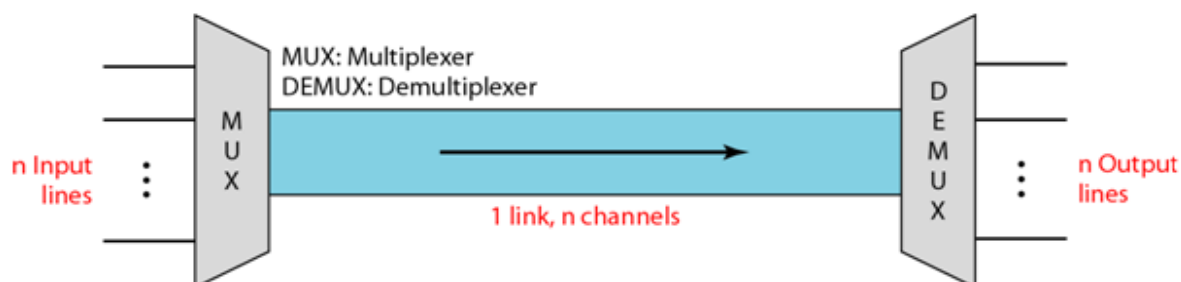


Figure 8.1 Dividing a link into channels

Categories of Multiplexing

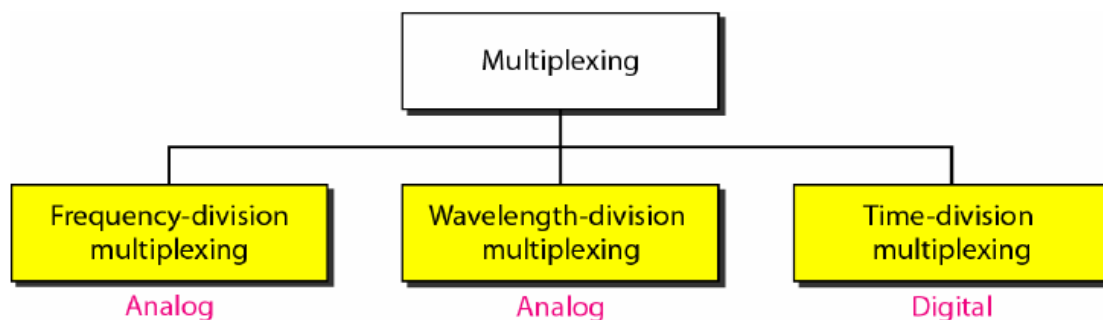


Figure 8.2 Categories of multiplexing

✓ **Frequency-division multiplexing:**

FDM is an analog multiplexing technique that combines analog signals.

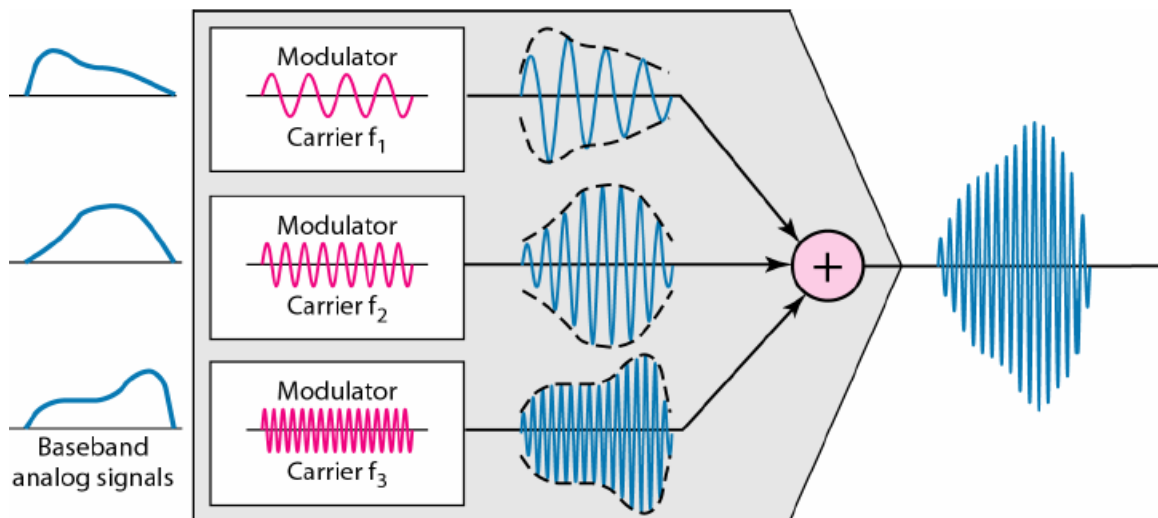


Figure 8.3 Multiplexing Process

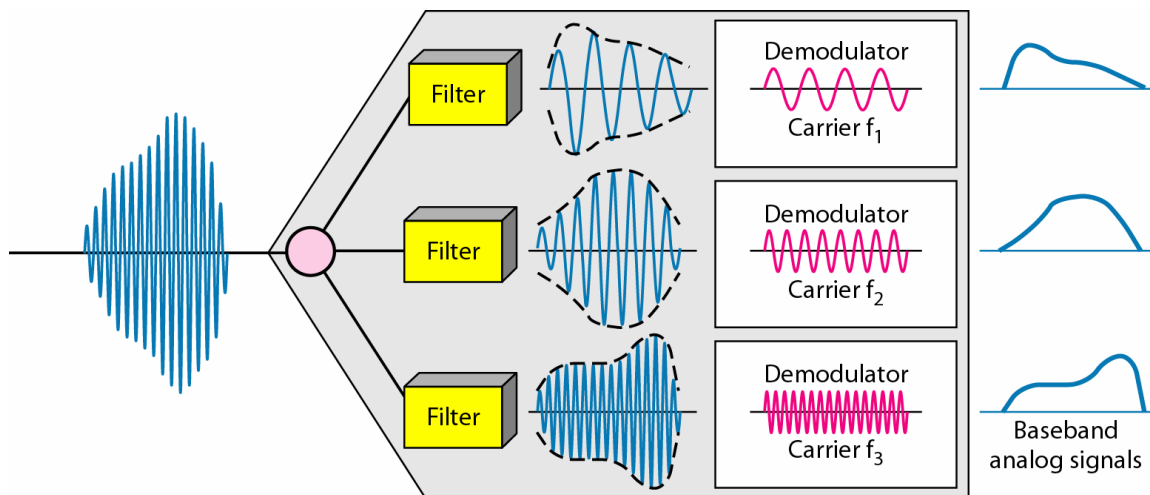


Figure 8.4 Demultiplexing Process

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. Assume there are no guard bands.

Solution:

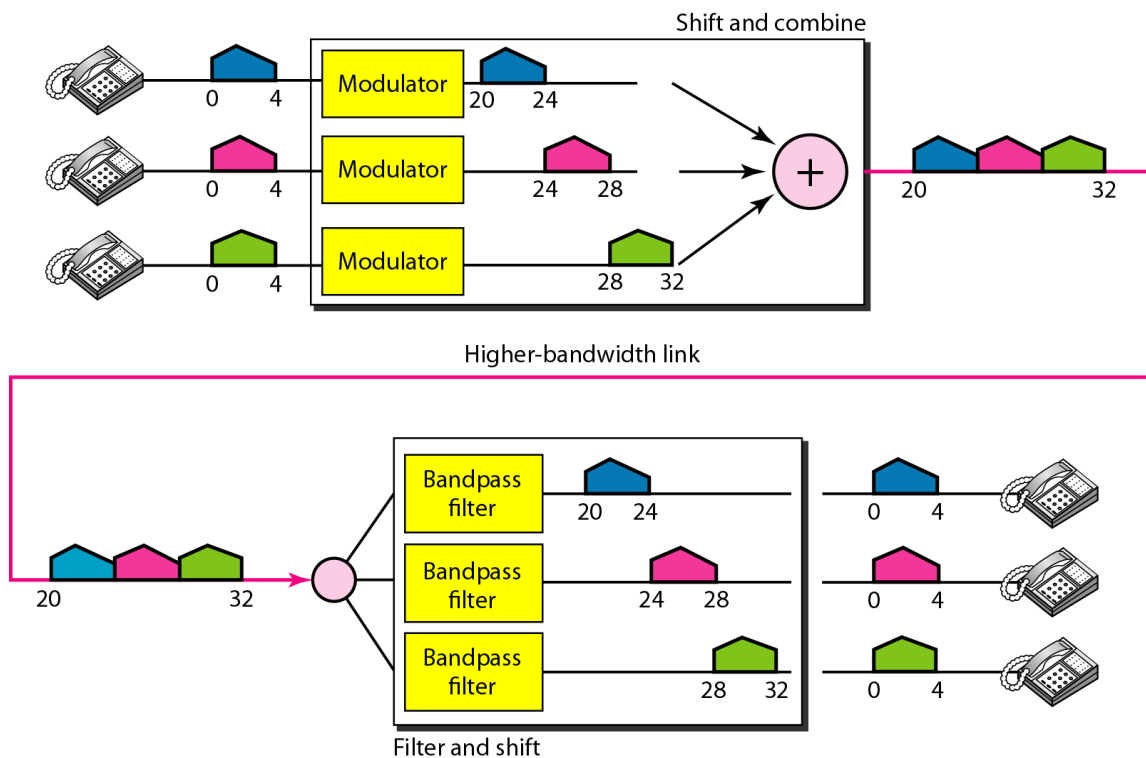


Figure 8.5 Example1

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

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

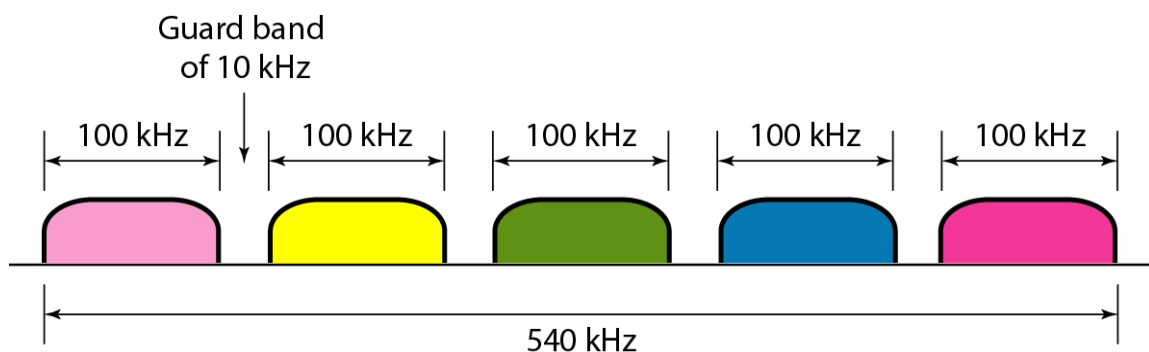


Figure 8.6 Example2

✓ Wavelength-division multiplexing

WDM is an analog multiplexing technique to combine optical signals (high data-rate and minimum wave length)

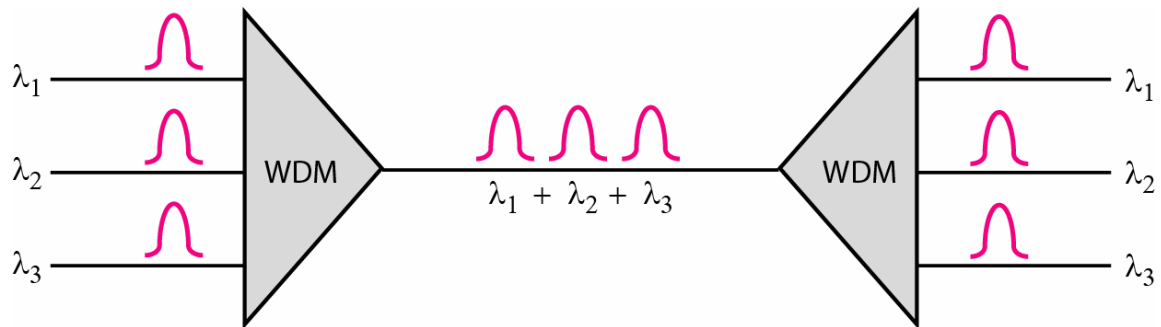


Figure 8.7 Wavelength-division multiplexing

✓ Time Division Multiplexing

TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.

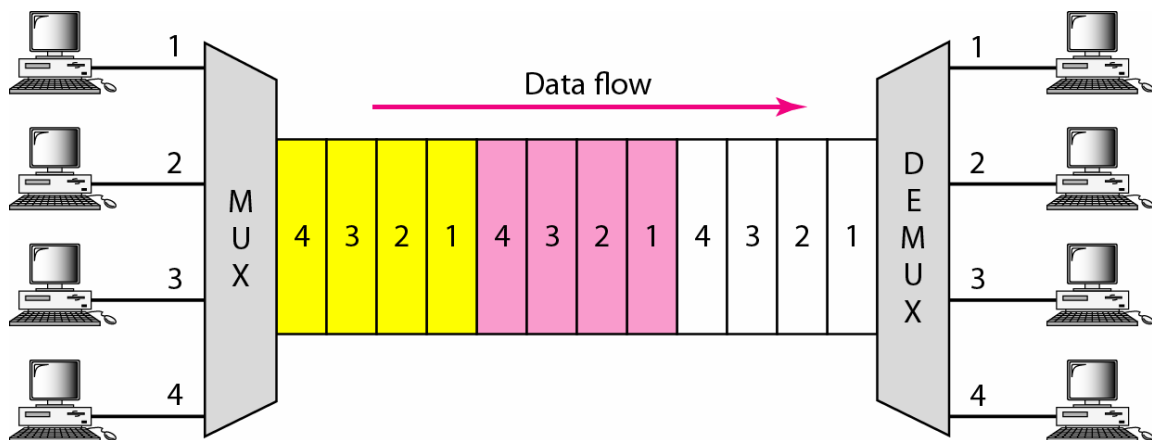


Figure 8.8 Time Division Multiplexing

- TDM has two different schemes: **Synchronous and Statistical**.

Synchronous TDM:

Both transmitter and receiver must be synchronized. The data flow of each input connection is divided into units, where each input occupies one input time slot.

A unit can be one bit, one character or one block.

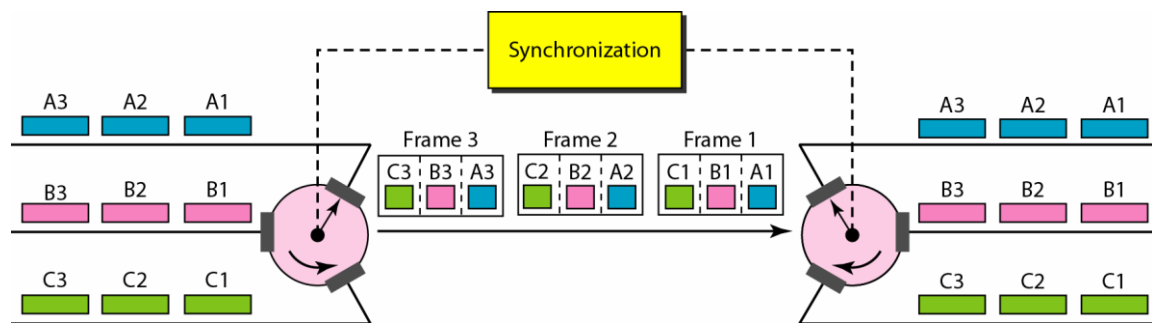
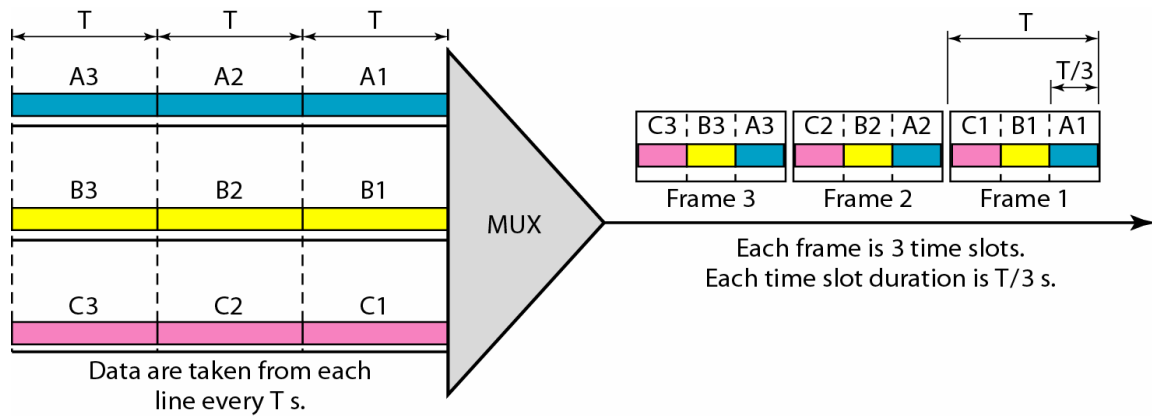


Figure 8.9 Synchronous TDM

Example 3

Figure 8.10 shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is **1 bit**. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.

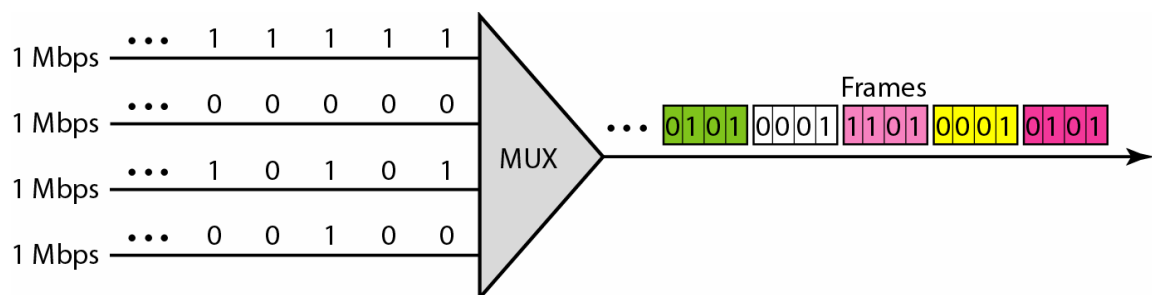


Figure 8.10 Example 3

Solution:

a.) The input bit duration is the inverse of the bit rate:

$$1 / (1 \text{ Mbps}) = 1 \mu\text{s.}$$

b.) The output bit duration is one-fourth of the input bit duration, or $\frac{1}{4}\mu\text{s}$.

c.) The output bit rate is the inverse of the output bit duration or

$$1 / (0.25\mu\text{s}) = 4 \text{ Mbps.}$$

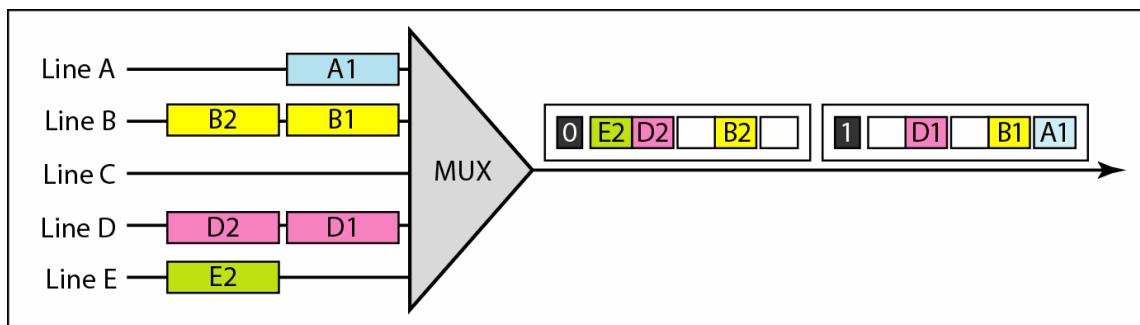
This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the

$$\text{Output rate} = 4 \times 1 \text{ Mbps} = 4 \text{ Mbps.}$$

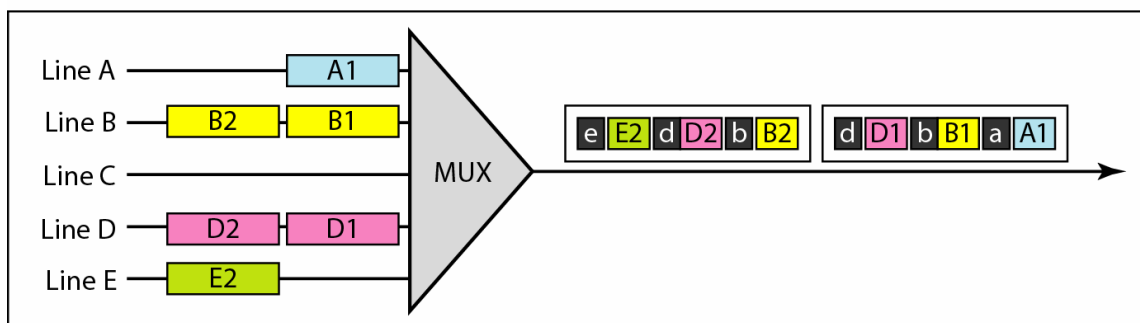
d.) The frame rate is always the same as any input rate. So the frame rate is 1,000,000 frames per second. Because we are sending 4 bits in each frame, we can verify the result of the previous question by multiplying the frame rate by the number of bits per frame

Statistical Time-Division Multiplexing

Time slots are allocated on demand instead of fixed cycle. Requires destination address and hence a control field to identify the owners of each slot and permit reassembly.



a. Synchronous TDM



b. Statistical TDM

Figure 8.11 TDM slot comparison

Frame Synchronization

Synchronization between multiplexer and demultiplexer is a major issue. One or more synchronization bits are usually added to the beginning of each frame.

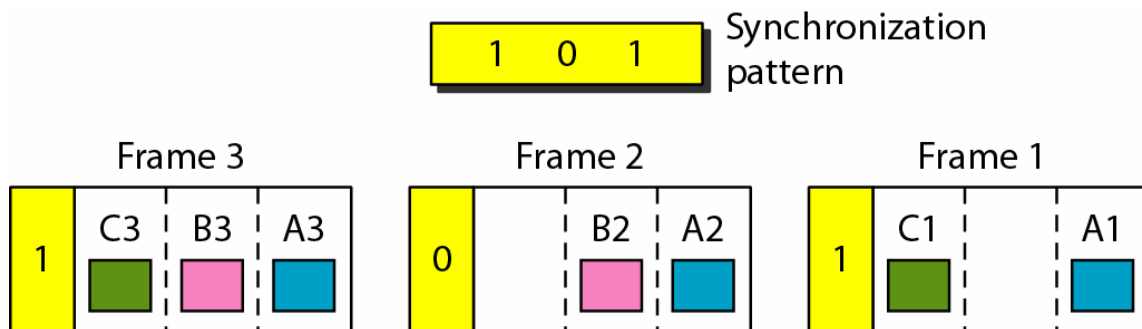


Figure 8.12 Frame Synchronization

Data Rate Management

One problem with TDM is how to handle a disparity in the input data rates. In all our discussion so far, we assumed that the data rates of all input lines were the same. However, if data rates are not the same, three strategies, or a combination of them, can be used.

We call these three strategies **multilevel multiplexing**, **multiple-slot allocation**, and **pulse stuffing**.

- **Multilevel:** used when the data rate of the input links are multiples of each other.

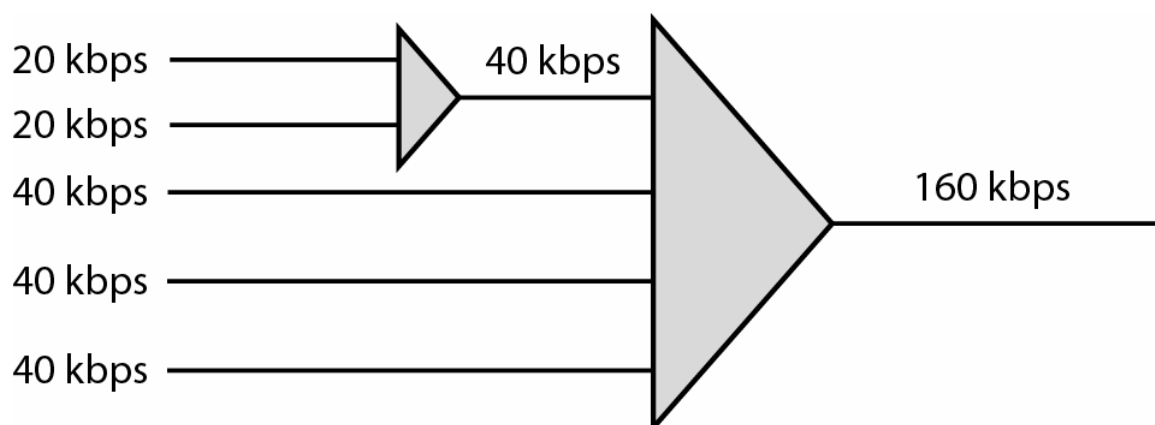


Figure 8.13 Multilevel multiplexing

- **Multislot:** used when there is a GCD between the data rates. The higher bit rate channels are allocated more slots per frame, and the output frame rate is a multiple of each input link.

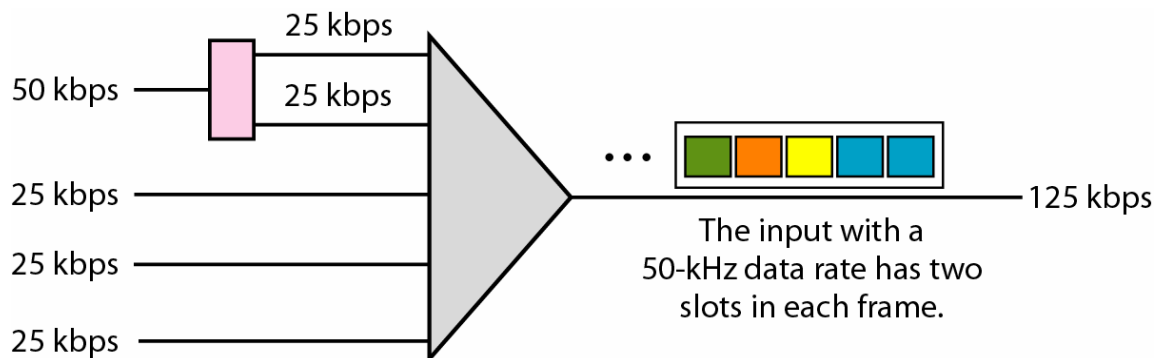


Figure 8.14 Multislot multiplexing

- **Pulse Stuffing:** used when there is no GCD between the links. The slowest speed link will be brought up to the speed of the other links by bit insertion, this is called pulse stuffing.

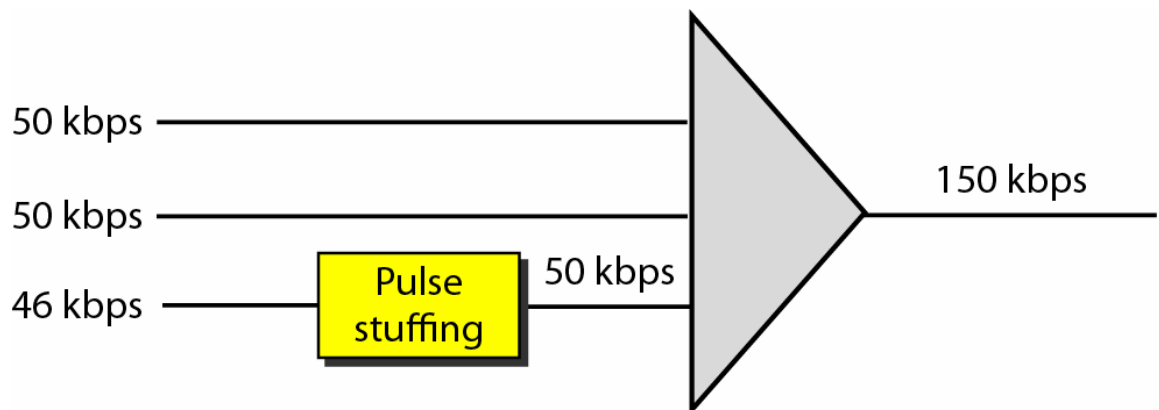


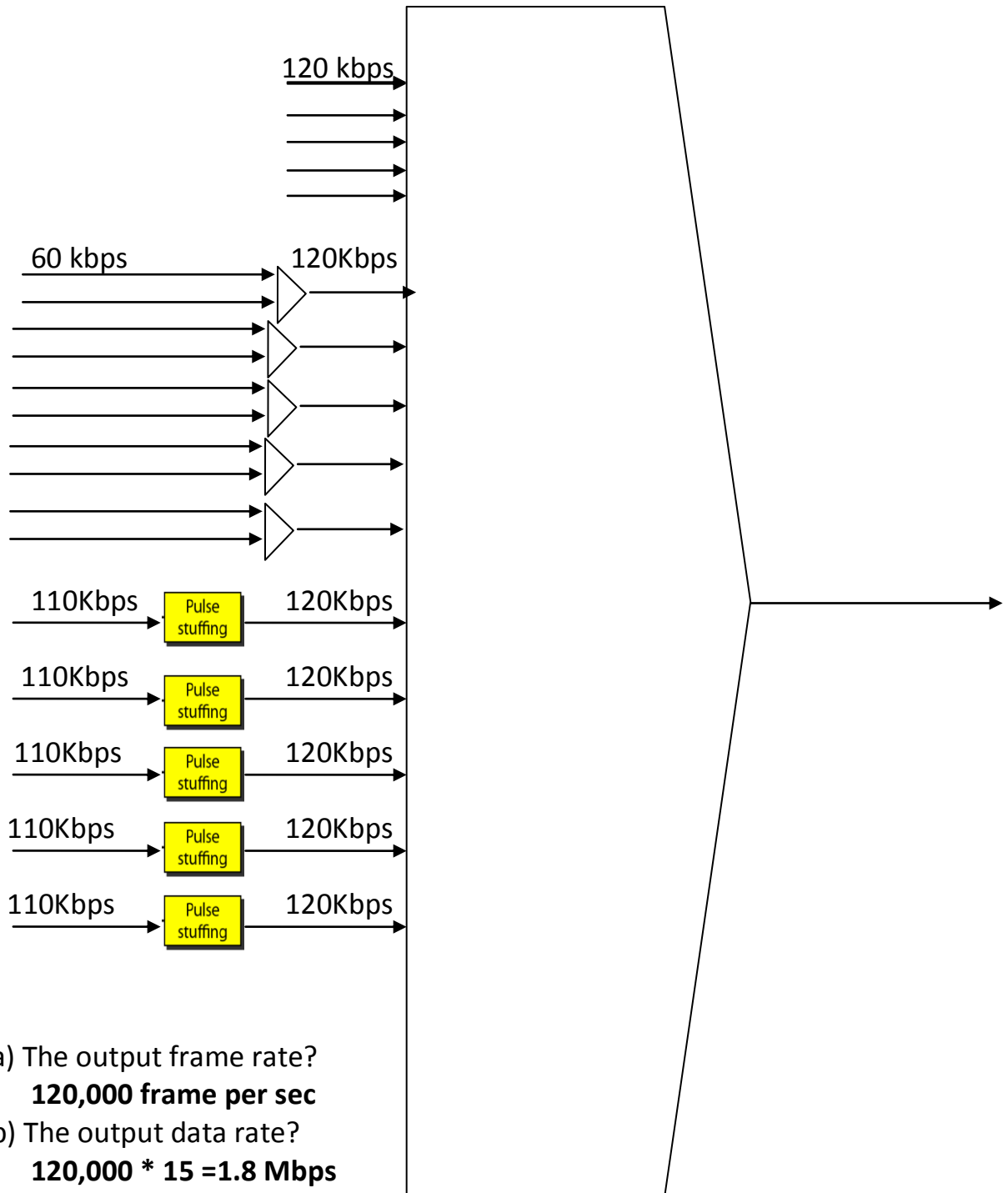
Figure 8.15 Pulse Stuffing

Problems:

1) We need to use synchronous TDM and combine 20 digital sources; 5 with a bit rate of 120 kbps, 10 with a bit rate 60 kbps, and the last 5 with a bit rate of 110 kbps. Design a synchronous TDM for these sources (The unit of data is 1 bit), and then determine the following:

- The output frame rate?
- The output data rate?
- Efficiency of the system?

Solution:



a) The output frame rate?

120,000 frame per sec

b) The output data rate?

120,000 * 15 = 1.8 Mbps

c) Efficiency of the system?

$(5 \times 120 + 10 \times 60 + 5 \times 110) / (15 \times 120) = 0.972$

Or **97.2%**

2) Figure 8.16 shows a multiplexer in a synchronous TDM system. Each output slot is only 10 bits long (3 bits taken from each input plus 1 framing bit). What is the output stream? The bits arrive at the multiplexer as shown by the arrows.

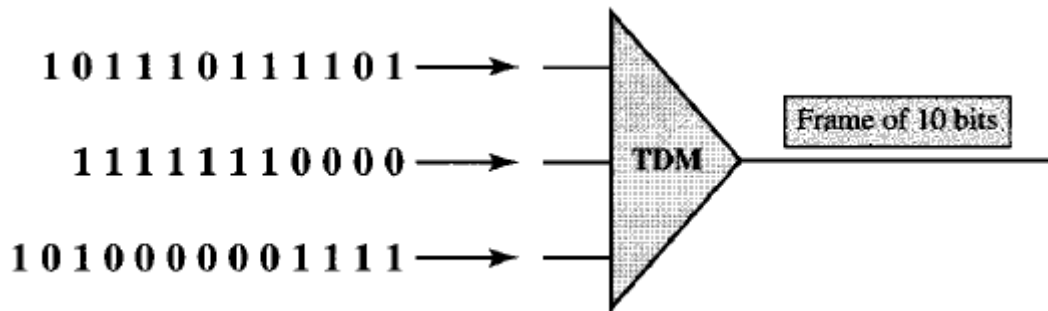
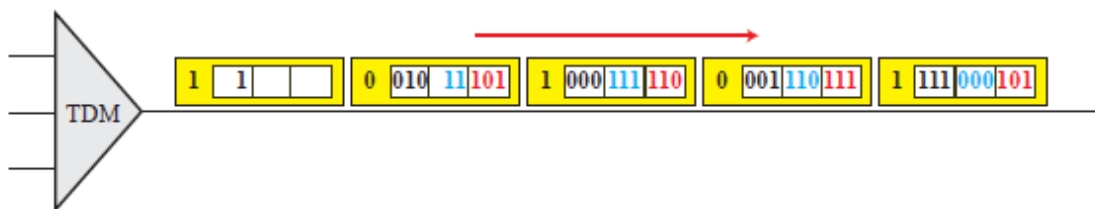


Figure 8.16

Solution:



3) Figure 8.17 shows a demultiplexer in a synchronous TDM. If the input slot is 16 bits long (no framing bits), what is the bit stream in each output? The bits arrive at the demultiplexer as shown by the arrows.

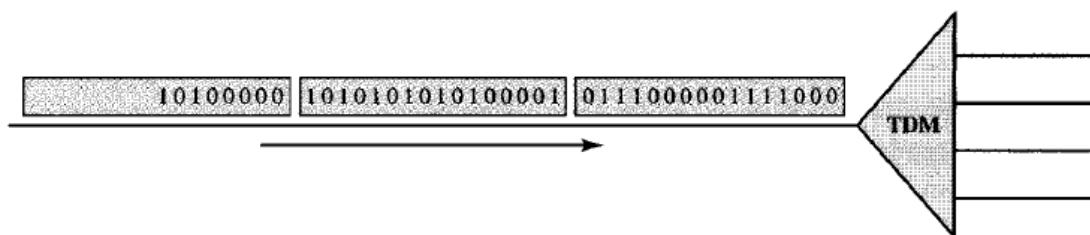


Figure 8.17

Solution:

