Department of Computer science and Information Technology

CHAPTER 6: Bandwidth Utilization: Multiplexing and Spectrum Spreading

MULTIPLEXING

- **Multiplexing** is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.
- In a multiplexed system, *n lines share the bandwidth of one link.*
- The lines on the left direct their transmission.
- Streams to a **multiplexer (MUX)**, which combines them into a single stream (many-to-one). At the receiving end, that stream is fed into a **demultiplexer (DEMUX),** which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.

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- The word **link** refers to the physical path.
- The word **channel** refers to the portion of a link that carries a transmission between a given pair of lines.
- One link can have many (*n) channels.*
- There are three basic multiplexing techniques: **frequency-division multiplexing**, **wavelength-division multiplexing**, and **time-division multiplexing**.

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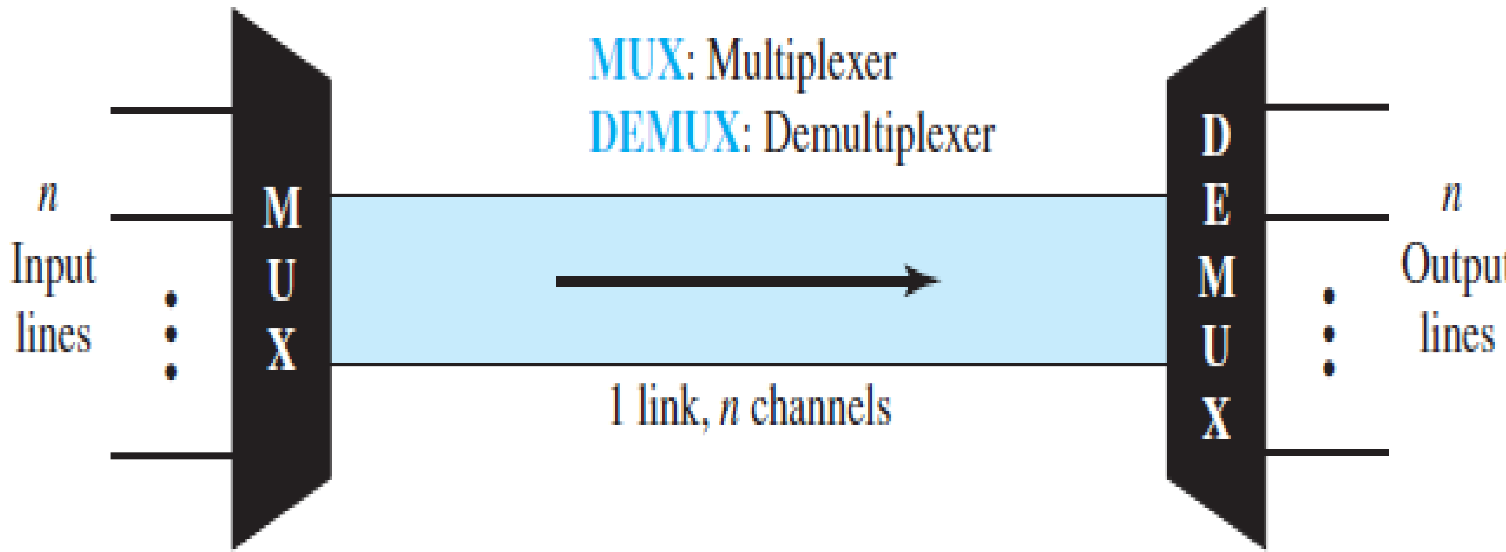
Figure 6.1 *Dividing a link into channels*



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.
- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.

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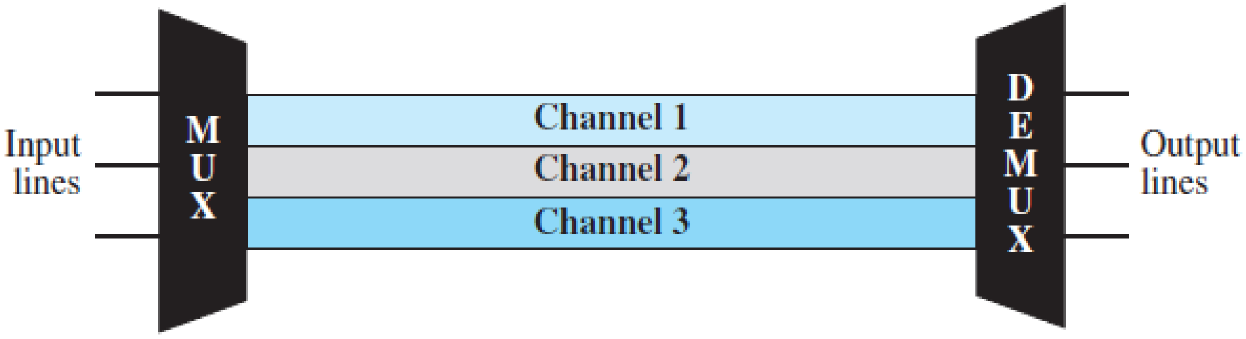
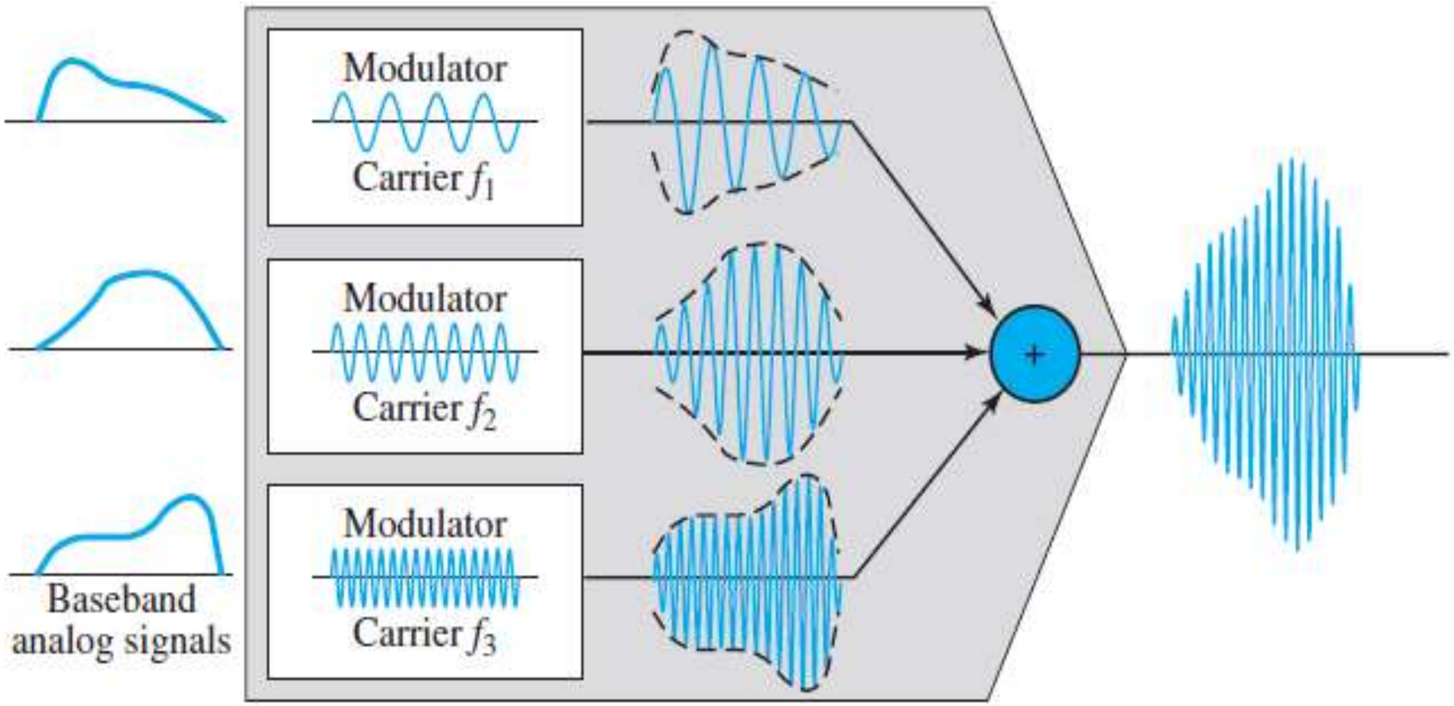
- Channels can be separated by strips of unused bandwidth—**guard bands**—to prevent signals from overlapping.

Figure 6.3 *Frequency-division multiplexing*



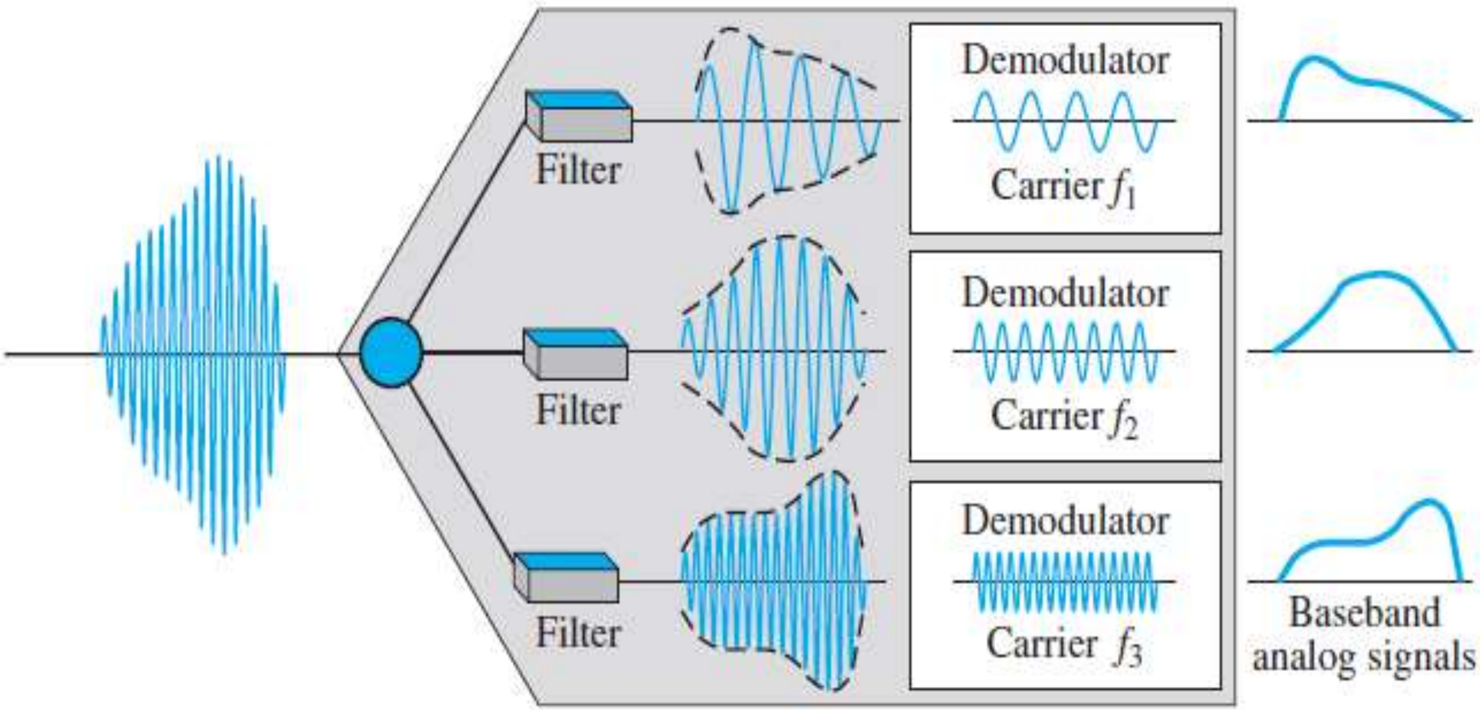
Multiplexing Process

Figure 6.4 *FDM process*



Demultiplexing Process

Figure 6.5 *FDM demultiplexing example*



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- 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?

Ans: 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,

Applications of FDM

- AM and FM radio broadcasting.
- television broadcasting.
- The first generation of cellular telephones also uses FDM.

Wavelength-Division Multiplexing

- **Wavelength-division multiplexing (WDM)** is designed to use the high-data-rate capability of fiber-optic cable.
- The idea is the same: We are combining different signals of different frequencies. The difference is that the frequencies are very high.

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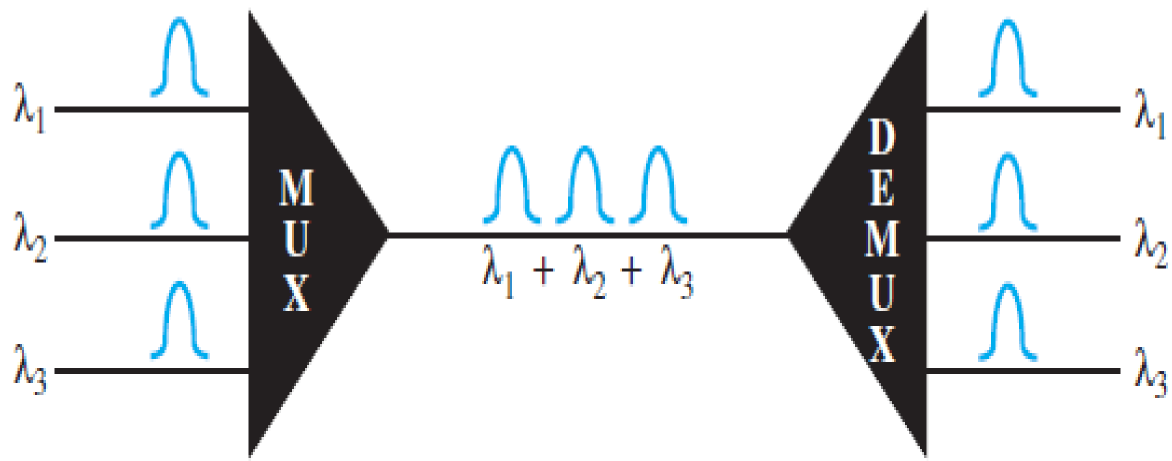
Figure 6.10 *Wavelength-division multiplexing*



WDM is an analog multiplexing technique to combine optical signals.

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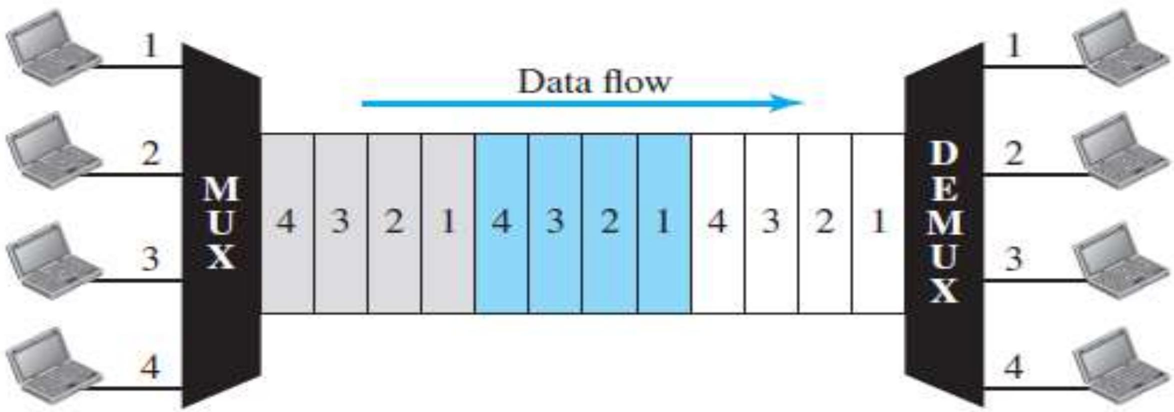
- Very narrow bands of light from different sources are combined to make a wider band of light. At the receiver, the signals are separated by the demultiplexer.
- The combining and splitting of light sources are easily handled by a prism.
- One application of WDM is the SONET network, in which multiple optical fiber lines are multiplexed and demultiplexed.

Time-Division Multiplexing

- Instead of sharing a portion of the bandwidth as in FDM, time is shared.

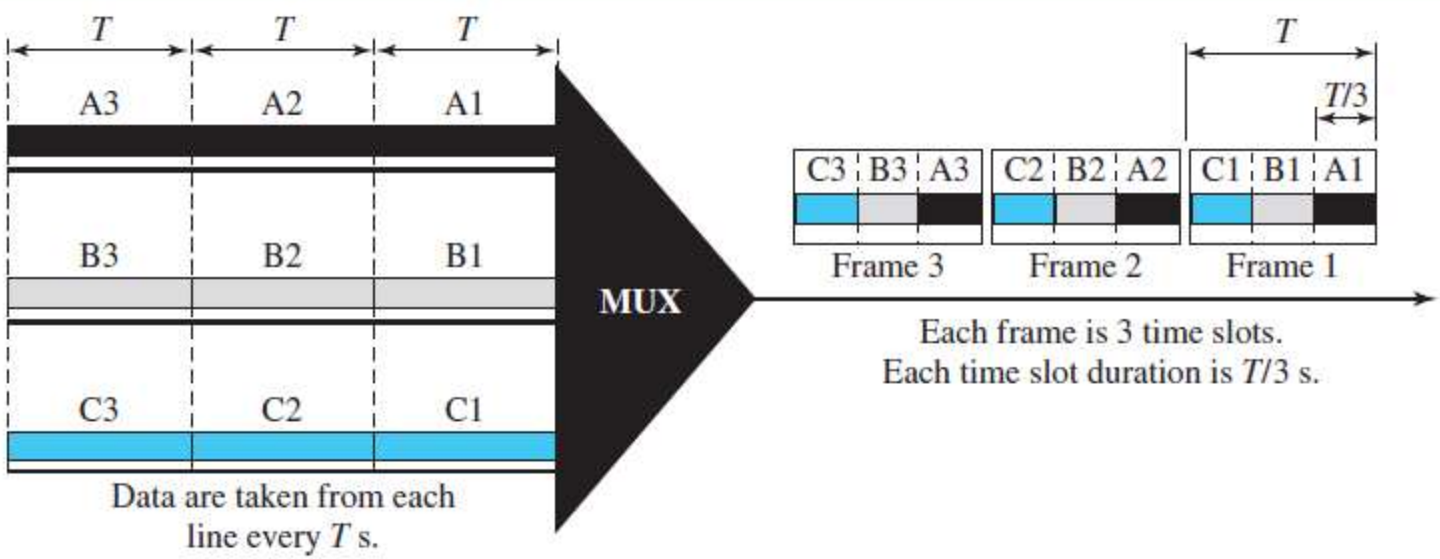
Figure 6.12 *TDM*



Synchronous TDM

- In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

Figure 6.13 *Synchronous time-division multiplexing*



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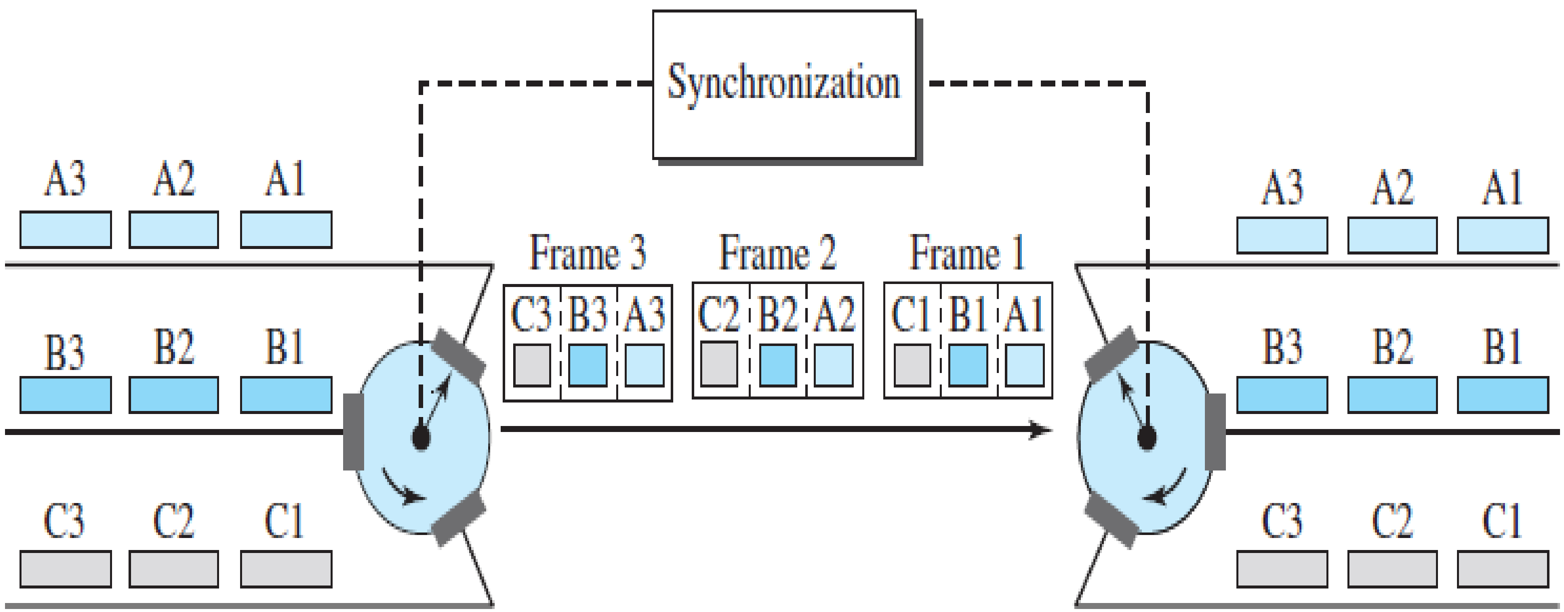
- In synchronous TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.

Interleaving

Figure 6.15 *Interleaving*



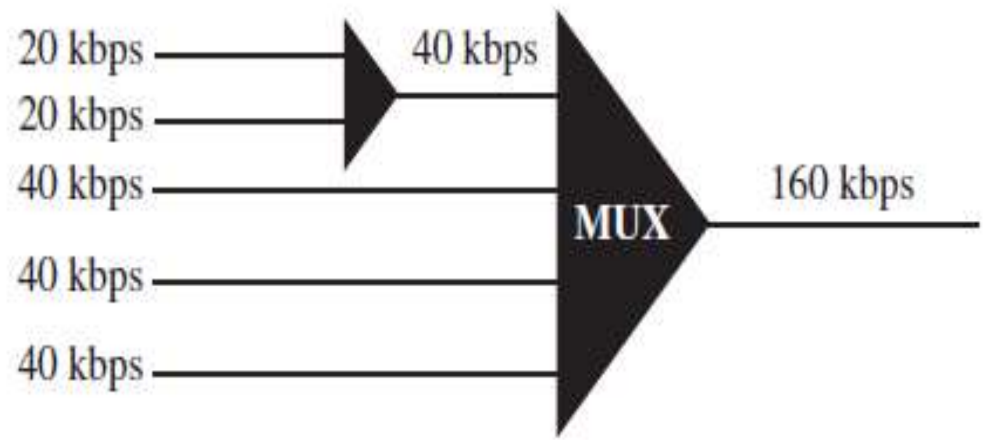
Data Rate Management

- One problem with TDM is how to handle a disparity in the input data rates.
- if data rates are not the same, three strategies, or a combination of them, can be used **multilevel multiplexing, multiple-slot allocation,** and **pulse stuffing.**

Multilevel Multiplexing

- Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others.

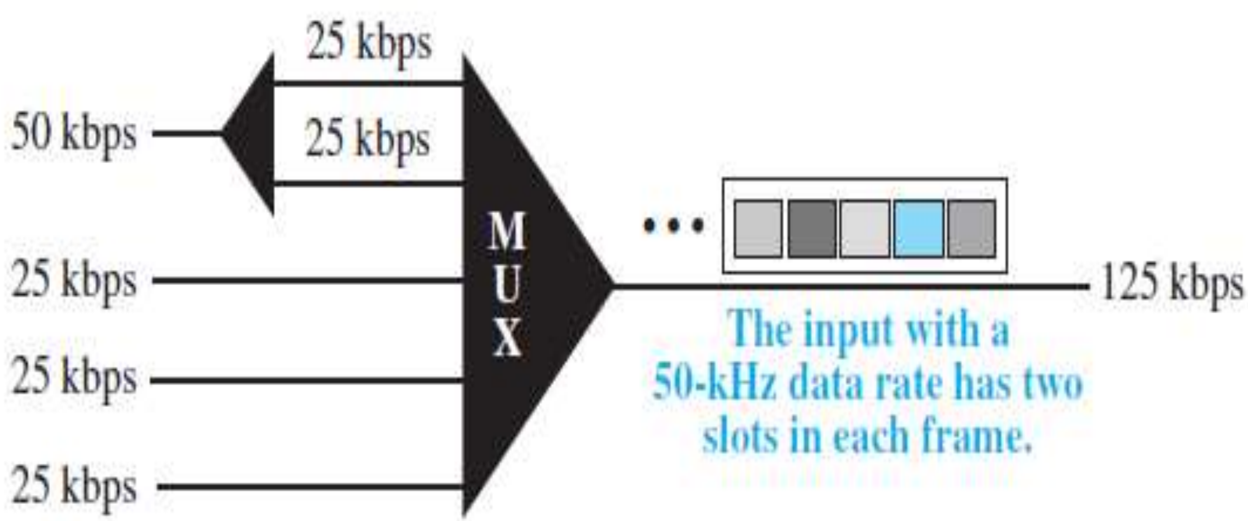
Figure 6.19 *Multilevel multiplexing*



Multiple-Slot Allocation

- Sometimes it is more efficient to allot more than one slot in a frame to a single input line.

Figure 6.20 *Multiple-slot multiplexing*



Pulse Stuffing

- Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied. One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will increase their rates. This technique is called ***pulse stuffing, bit padding, or bit stuffing.***

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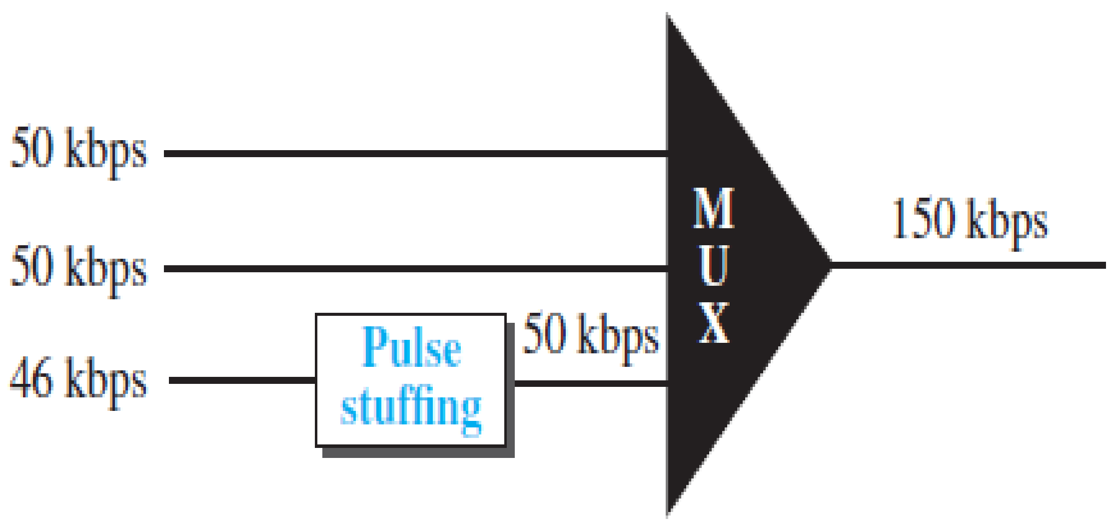
Figure 6.21 *Pulse stuffing*



Frame Synchronizing

- If the multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel. For this reason, one or more synchronization bits are usually added to the beginning of each frame. These bits, called **framing bits,** follow a pattern, frame to frame, that allows the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately.

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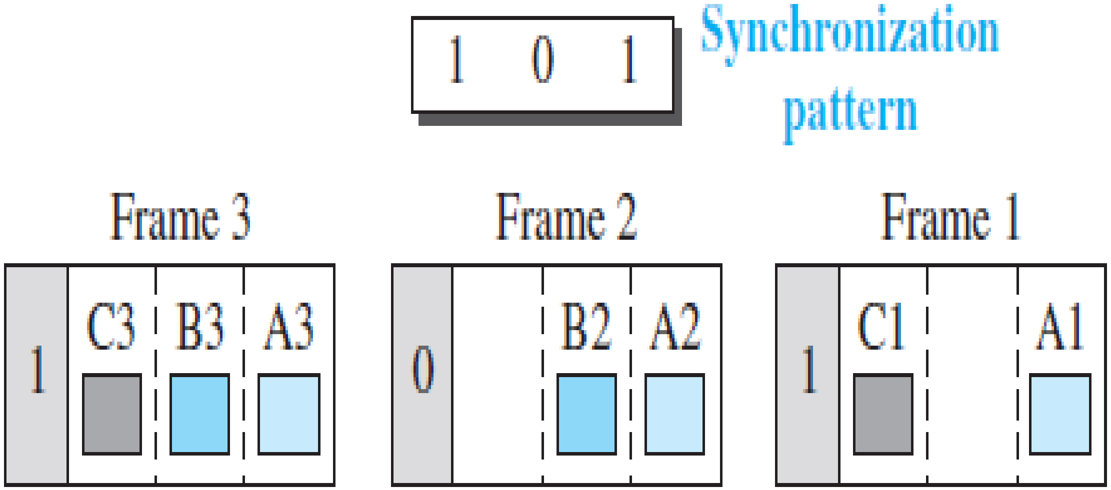
Figure 6.22 *Framing bits*



Reference:

- Data Communications and Networking, Behrouz A. Forouzan, Fifth Edition, TMH, 2013.