Data Communication and Networking

Chapter 6 : Multiplexing

Many to One

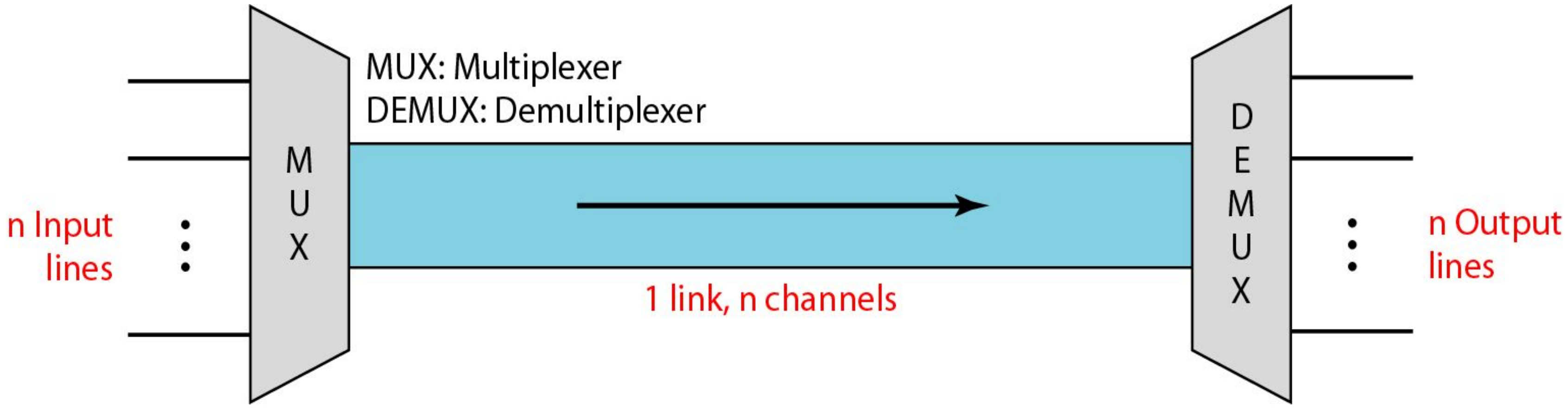
Transmission streams combine into a single stream

One to Many

Stream separates into its component transmission and directs them to their intended receiving devices

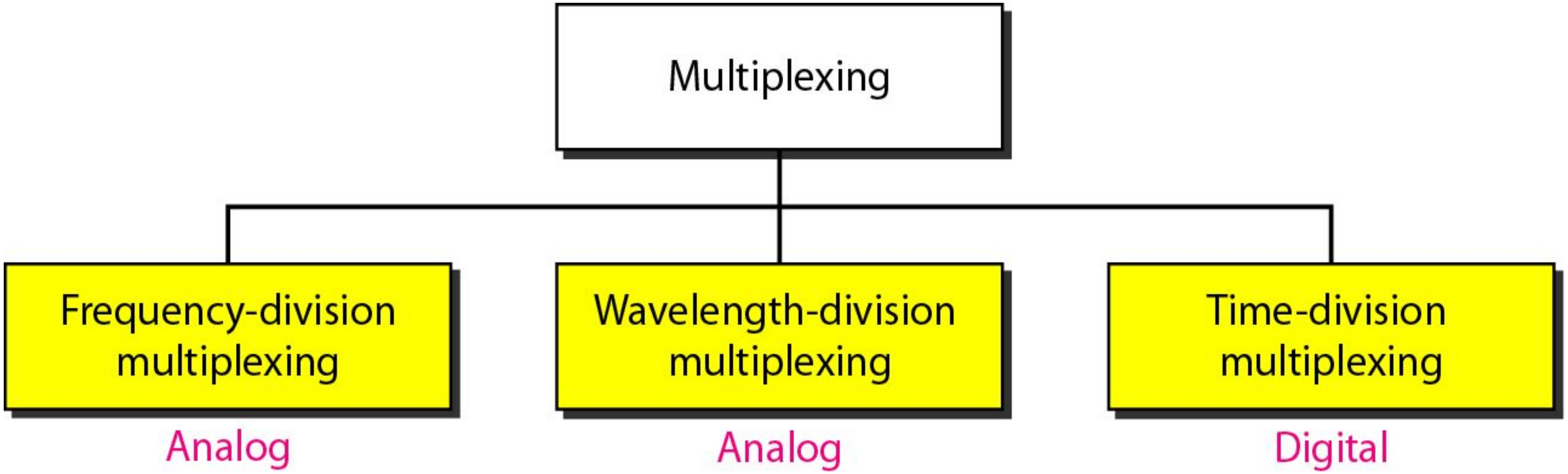
Multiplexing

Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic. In real life, we have links with limited bandwidths. Bandwidth utilization is the wise use of available bandwidth to achieve specific goals. Efficiency can be achieved by multiplexing.



Multiplexing

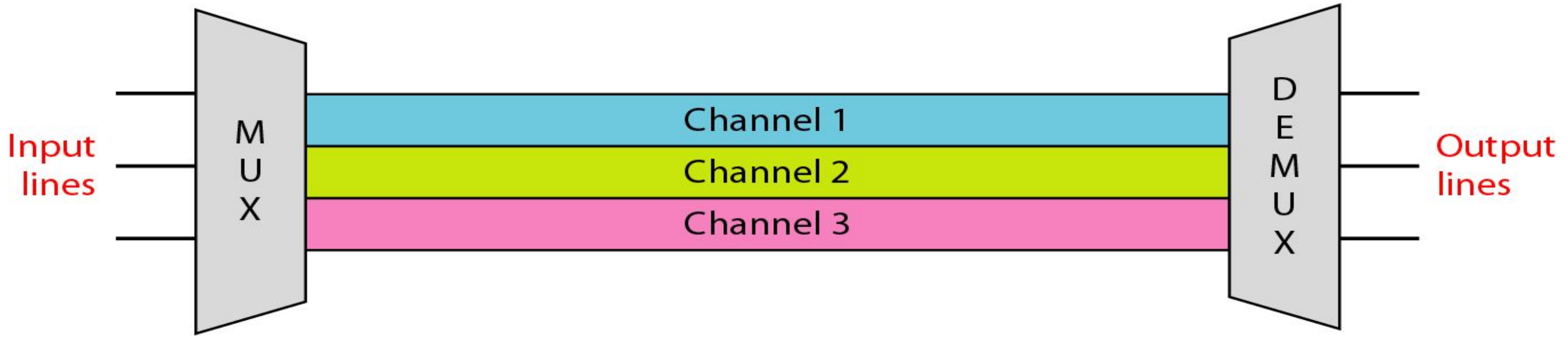
There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing. The first two are techniques designed for analog signals, the third, for digital signals.



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.

In the figure, 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.

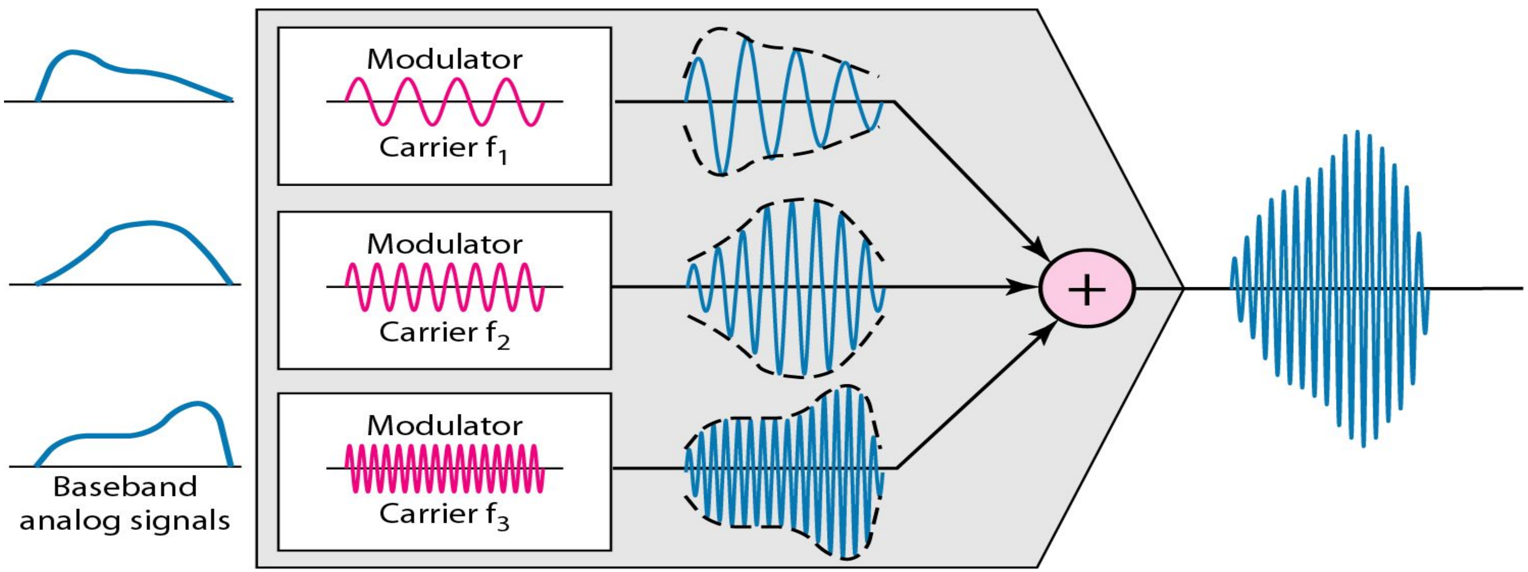


Frequency-division multiplexing (FDM)

- **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 carder frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel.
- Channels can be separated by strips of unused bandwidth **guard bands** to prevent signals from overlapping.
- In addition, carrier frequencies must not interfere with the original data frequencies.

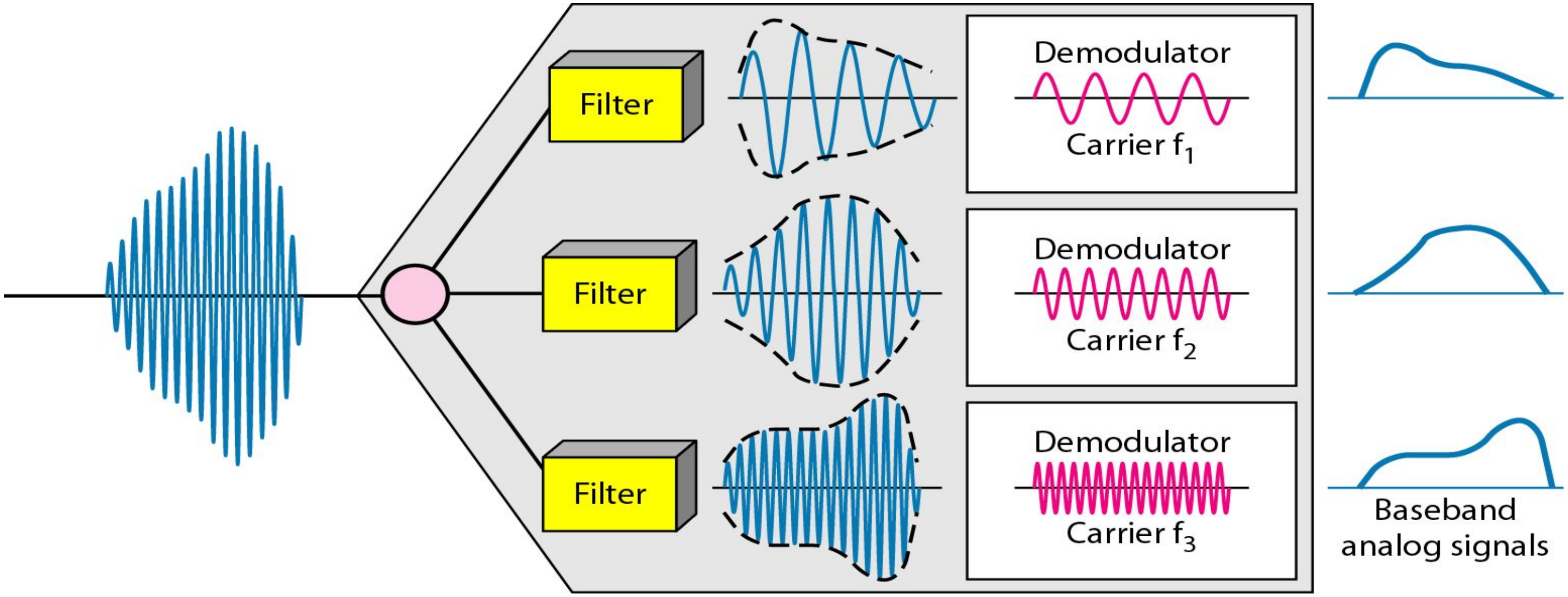
Frequency-division multiplexing (FDM)

The multiplexer uses a series of filters to compose the its constituent component signals into multiplexed signal. The individual signals are then passed to a modulator that combined them.



Frequency-division multiplexing (FDM)

The de-multiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.



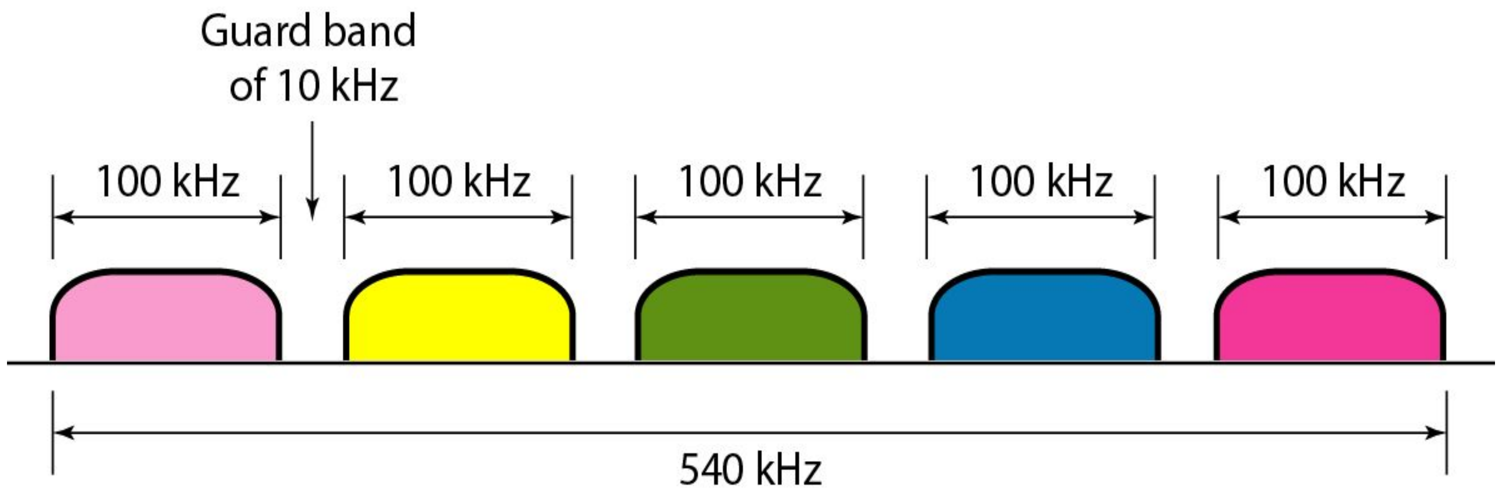
Frequency-division multiplexing (FDM)

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

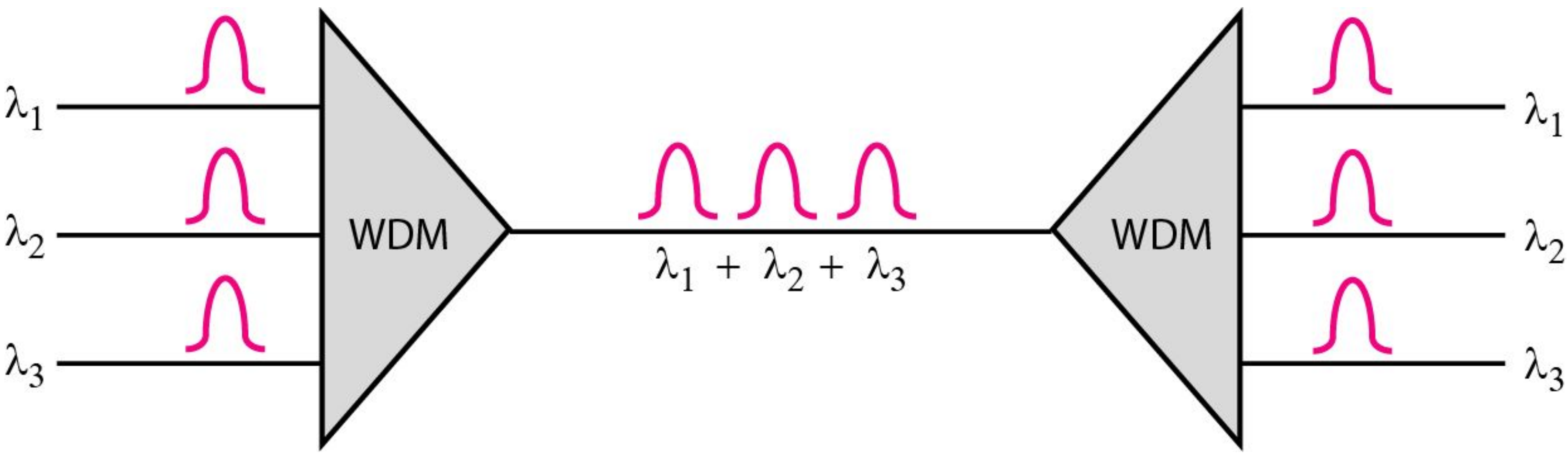
For five channels, we need at least four guard bands. This means that the required bandwidth is at least

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



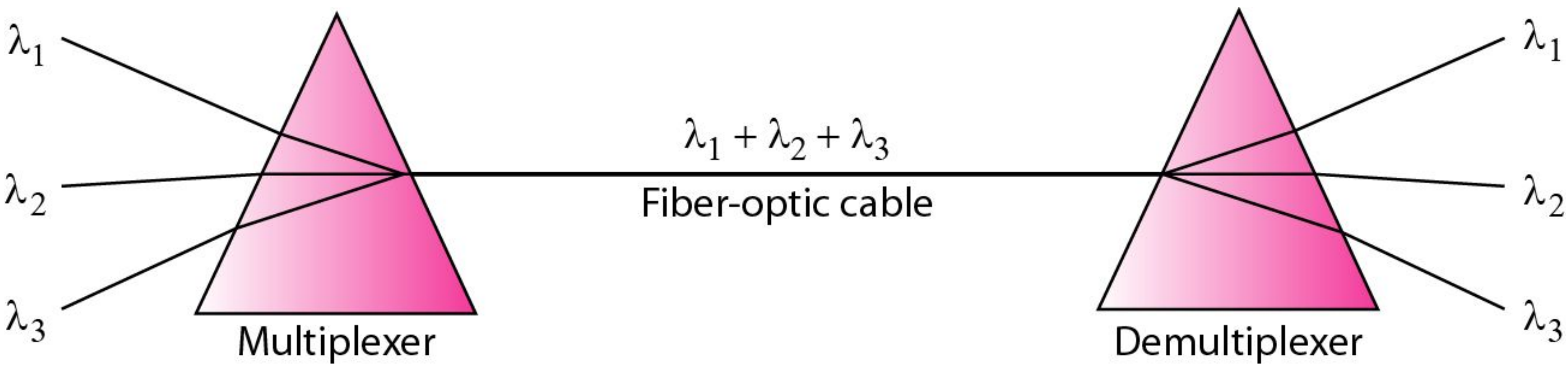
Wavelength-division multiplexing (WDM)

Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable. The optical fiber data rate is higher than the data rate of metallic transmission cable. Using a fiber-optic cable for one single line wastes the available bandwidth. Multiplexing allows us to combine several lines into one. WDM is an analog multiplexing technique to combine optical signals. The combining and splitting of light sources are easily handled by a prism. Recall from basic physics that a prism bends a beam of light based on the angle of incidence and the frequency.



Wavelength-division multiplexing (WDM)

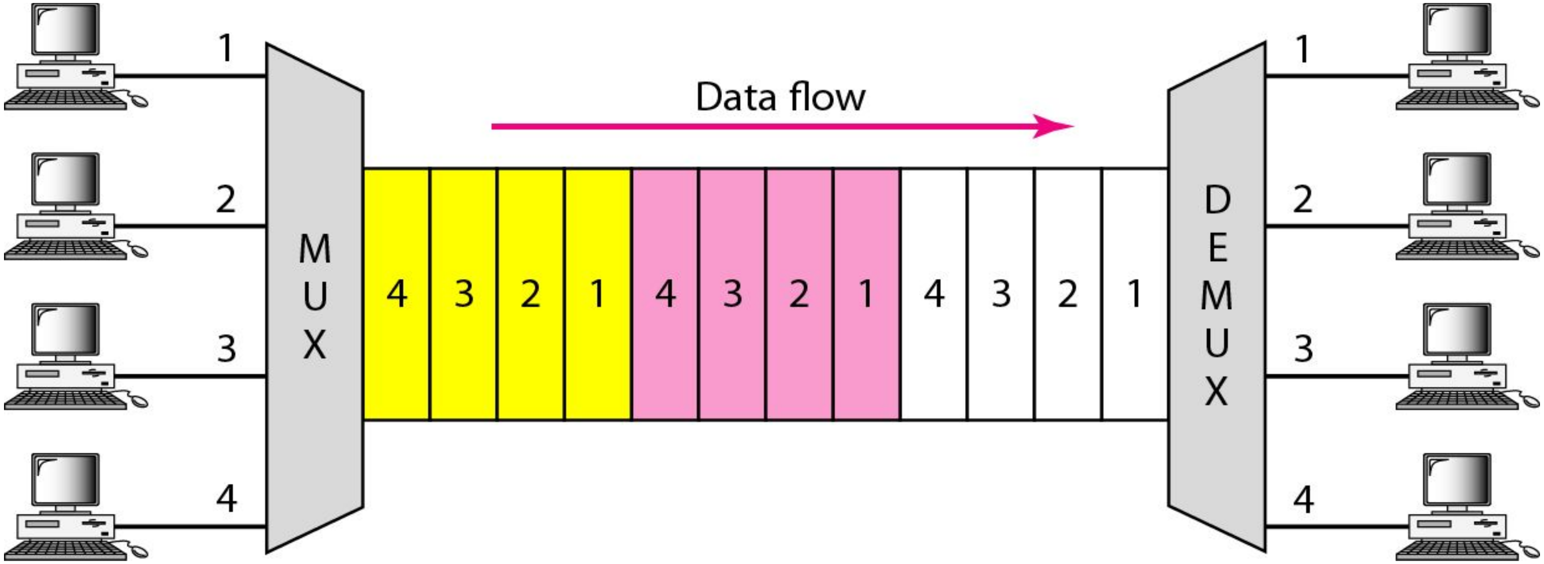
Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies. A de-multiplexer can also be made to reverse the process.



One application of WDM is the SONET network in which multiple optical
fiber lines are multiplexed and de-multiplexed. A new method, called dense WDM (DWDM), can multiplex a very large number of channels by spacing channels very close to one another. It achieves even greater efficiency.

Time-division multiplexing (TDM)

Time-division multiplexing (TDM) is a digital process that 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. Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially. TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

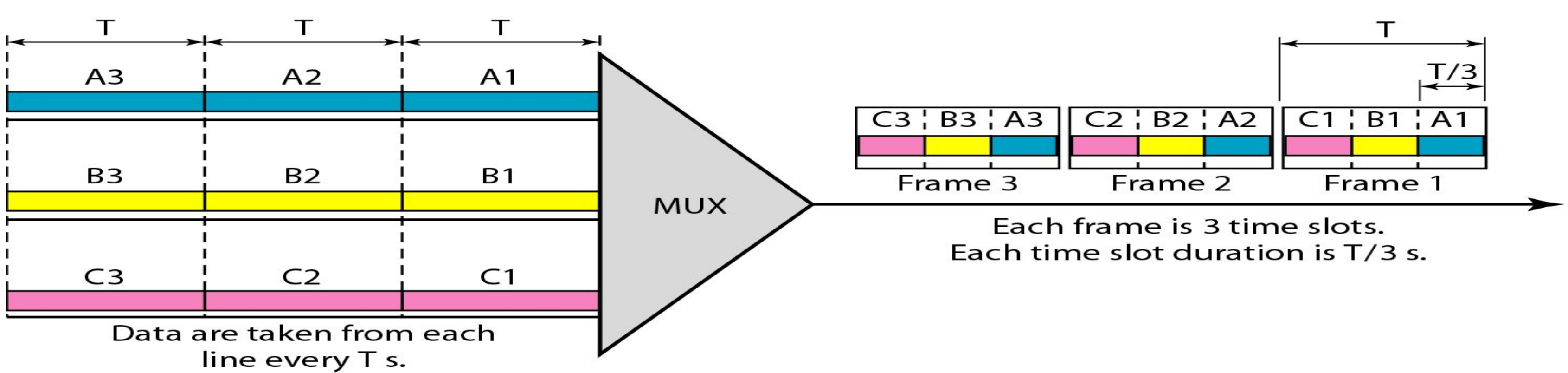


Time-division multiplexing (TDM)

We can divide TDM into two different schemes: synchronous and statistical.

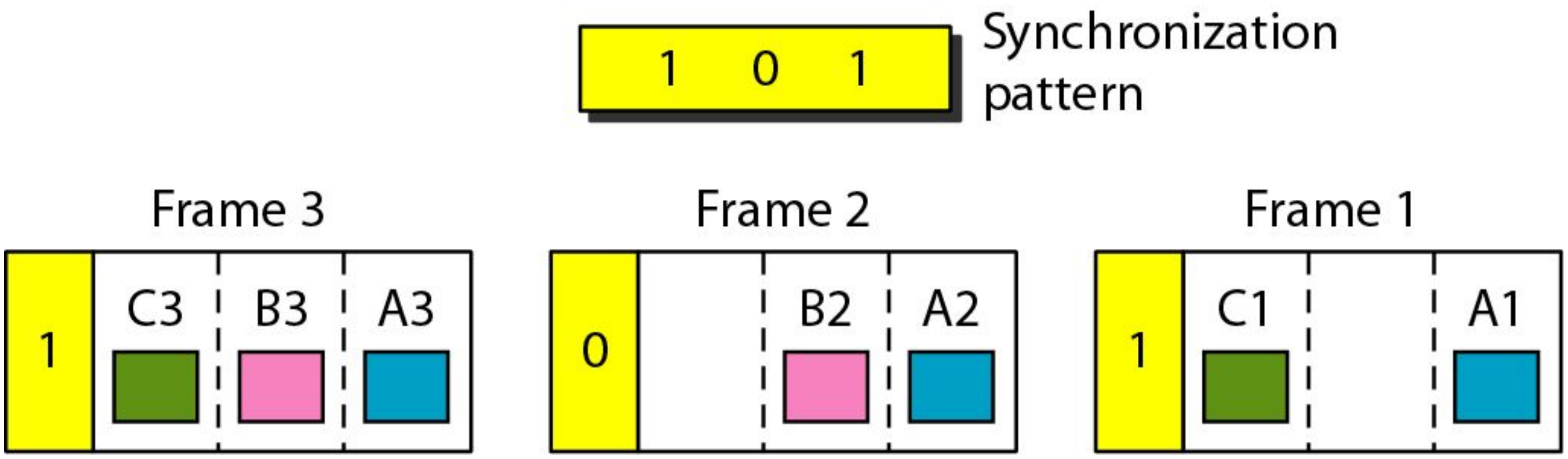
In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

Time Slots and Frames: In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot. A unit can be 1 bit, one character, or one block of data. Each input unit becomes one output unit and occupies one output time slot. However, the duration of an output time slot is n times shorter than the duration of an input time slot. If an input time slot is T s, the output time slot is T/n s, where n is the number of connections. In other words, a unit in the output connection has a shorter duration; it travels faster. In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.



Time-division multiplexing (TDM)

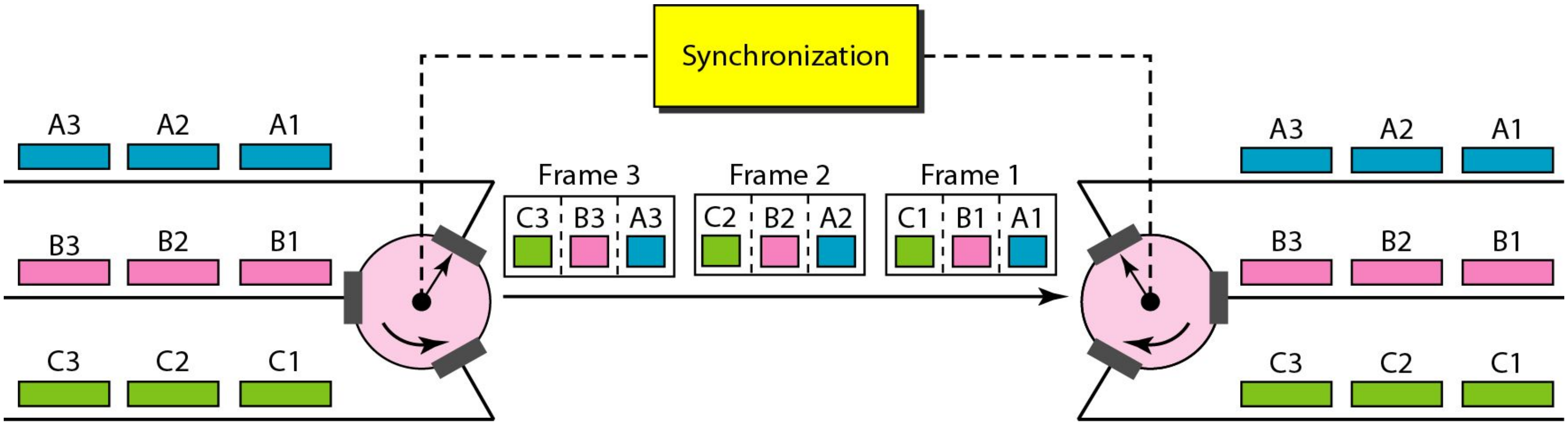
Frame Synchronizing : Synchronization between the multiplexer and demultiplexer is a major issue. If the. multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel. For this reason, one or more synchronization bits are usually added to 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. In most cases, this synchronization information consists of 1 bit per frame, alternating between 0 and 1.



Time-division multiplexing (TDM)

Interleaving

TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called interleaving.



Empty Slots

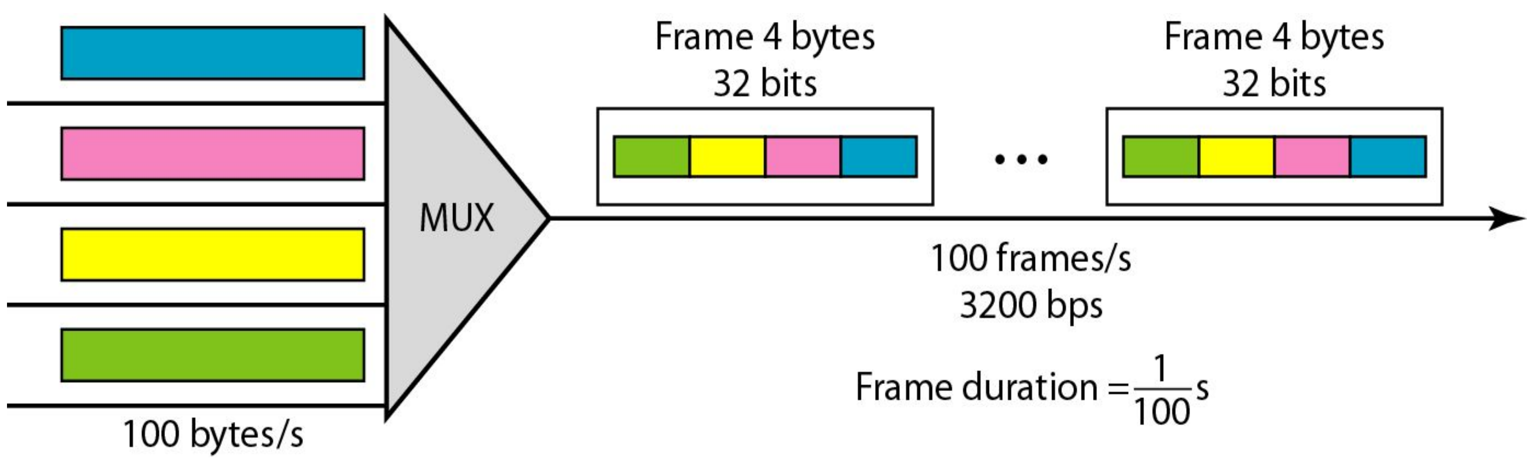
Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty.

Example 6.8

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 6.16. Each frame carries 1 byte from each channel; the size of each frame, therefore, is 4 bytes, or 32 bits. Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, the frame rate must be 100 frames per second. The bit rate is 100 × 32, or 3200 bps.

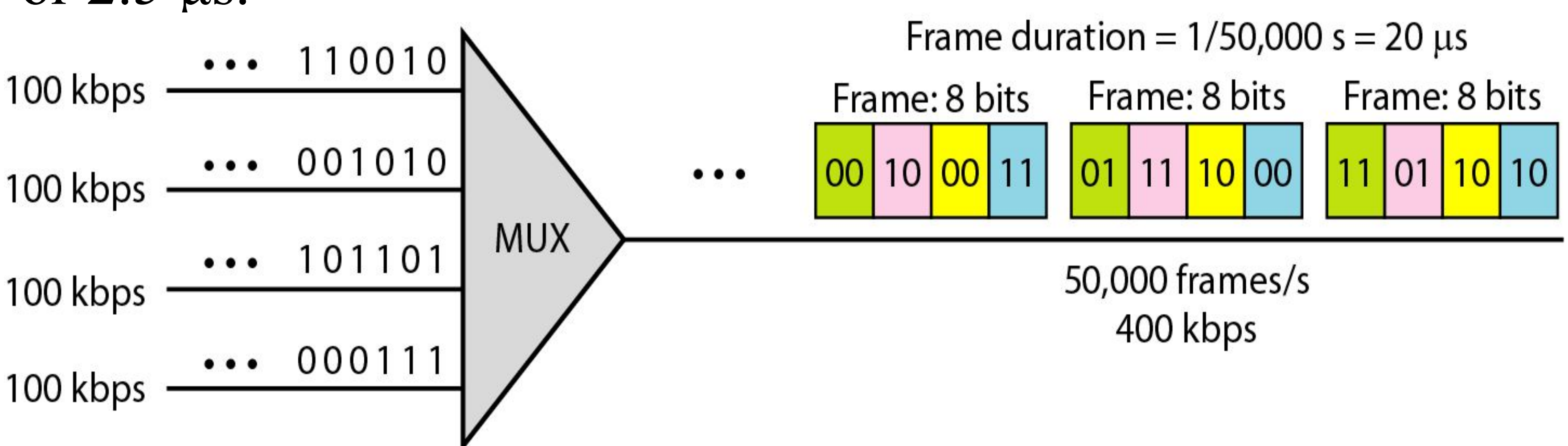


Example 6.9

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

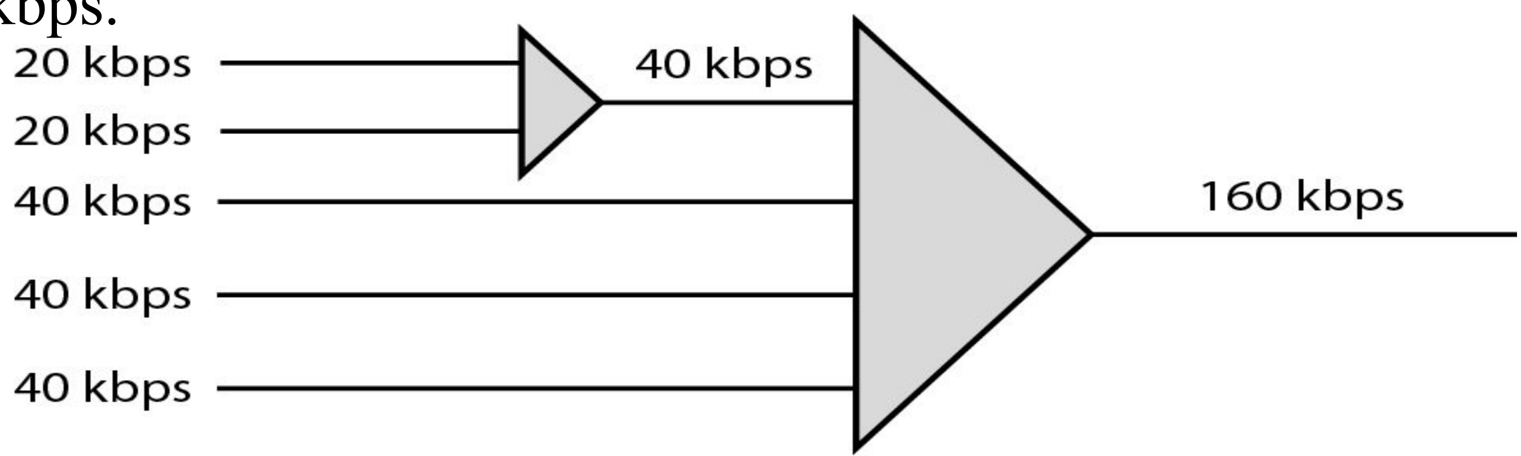
Figure 6.17 shows the output for four arbitrary inputs. The link carries 50,000 frames per second. The frame duration is therefore 1/50,000 s or 20 μs. The frame rate is 50,000 frames per second, and each frame carries 8 bits; the bit rate is 50,000 × 8 = 400,000 bits or 400 kbps. The bit duration is 1/400,000 s, or 2.5 μs.



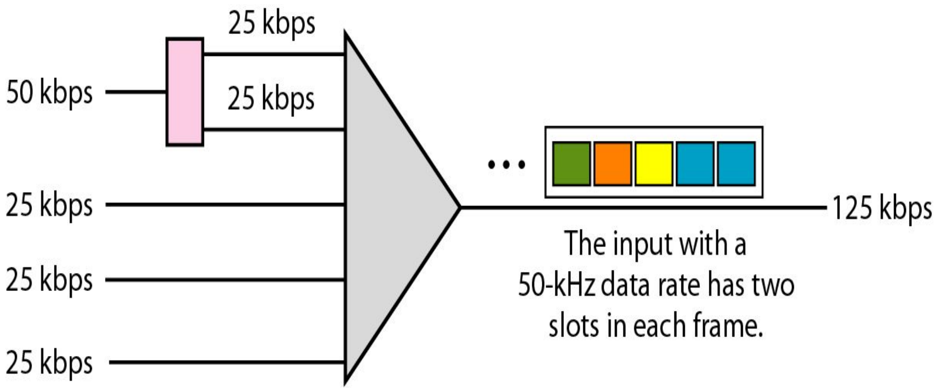
Data Rate Management

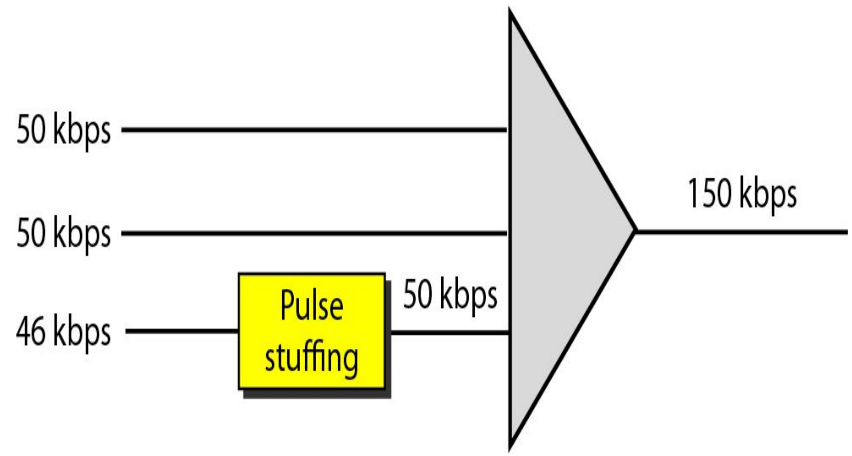
One problem with TDM is how to handle a disparity in the input data rates. In all our discussion so far, we assumed that the data rates of all input lines were the same. However, if data rates are not the same, three strategies, or a combination of them, can be used. We call these three strategies multilevel multiplexing, multiple-slot allocation, and pulse stuffing.

1. Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others. For example, in Figure, we have two inputs of 20 kbps and three inputs of 40 kbps. The first two input lines can be multiplexed together to provide a data rate equal to the last three. A second level of multiplexing can create an output of 160 kbps.



2. Multiple-Slot Allocation Sometimes it is more efficient to allot more than one slot in a frame to a single input line. For example, we might have an input line that has a data rate that is a multiple of another input. In Figure, the input line with a 50-kbps data rate can be given two slots in the output. We insert a serial-to-parallel converter in the line to make two inputs out of one.





3. 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. The input with a data rate of 46 is pulse-stuffed to increase the rate to 50 kbps. Now multiplexing can take place.

Statistical Time-Division Multiplexing

- In synchronous TDM, each input has a reserved slot in the output frame. This can be inefficient if some input lines have no data to send.
- In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.
- Only when an input line has a slot's worth of data to send is it given a slot in the output frame. In statistical multiplexing, the number of slots in each frame is less than the number of input lines.
- The multiplexer checks each input line in round- robin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

Statistical Time-Division Multiplexing

- **Addressing**

  An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination. In synchronous TDM, there is no need for addressing; synchronization and preassigned relationships between the inputs and outputs serve as an address. In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no preassigned or reserved slots.

- **Slot Size**

  Since a slot carries both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient. For example, it would be inefficient to send 1 bit per slot as data when the address is 3 bits. In statistical TDM, a block of data is usually many bytes while the address is just a few bytes.

Statistical Time-Division Multiplexing

- **No Synchronization Bit**

  The frames in statistical TDM need not be synchronized, so we do not need synchronization bits.

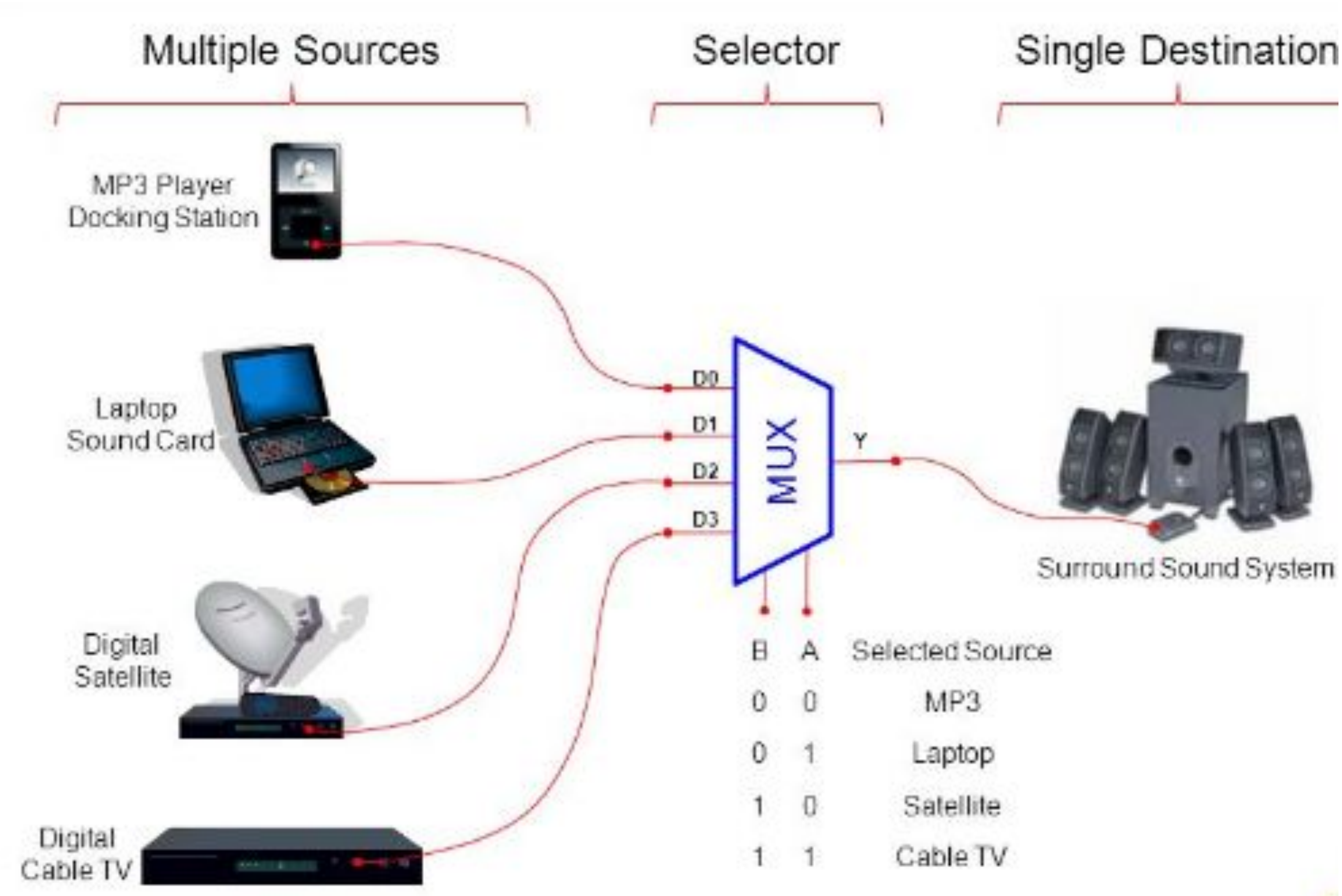
- **Bandwidth**

  In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel. The designers of statistical TDM define the capacity of the link based on the statistics of the load for each channel. If on average only x percent of the input slots are filled, the capacity of the link reflects this. Of course, during peak times, some slots need to wait.

Applications

- Multiplexer are used in various fields where multiple data need to be transmitted using a single line. Following are some of applications of multiplexers
  - Communication system
    - By using multiplexing, the efficiency of the communication system can be increased by allowing the transmission of data, such as audio and video data from different channels through single lines or cables
  - Telephone network
    - In telephone networks, multiple audio signals are integrated on a single line of transmission with the help of a multiplexer
  - Computer memory
    - Huge amount of memory in the computes and multiplexing reduce the number of copper lines required to connect the memory to other parts of the computer
  - Satellite communication
    - Multiplexer is used to transmit the data signals from the computer system of a spacecraft or a satellite to the ground system by using a GSM satellite

Applications



THANK YOU