MULTIPLEXING

Multiplexing

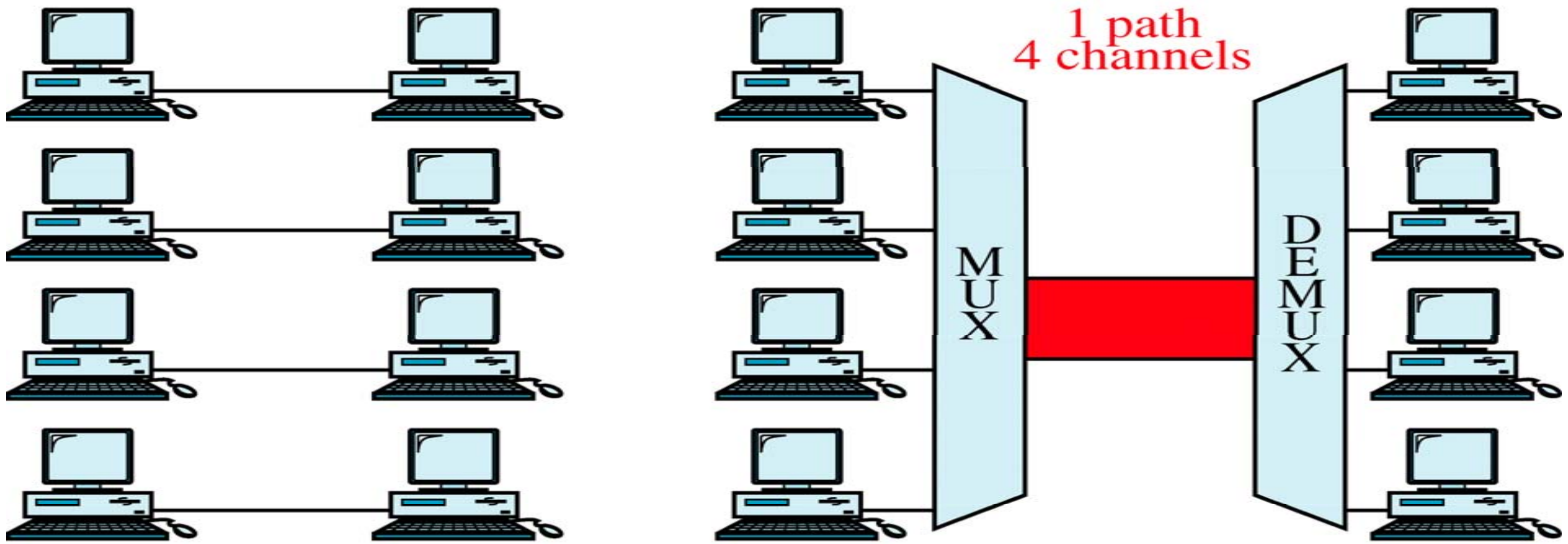
- Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

- 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.

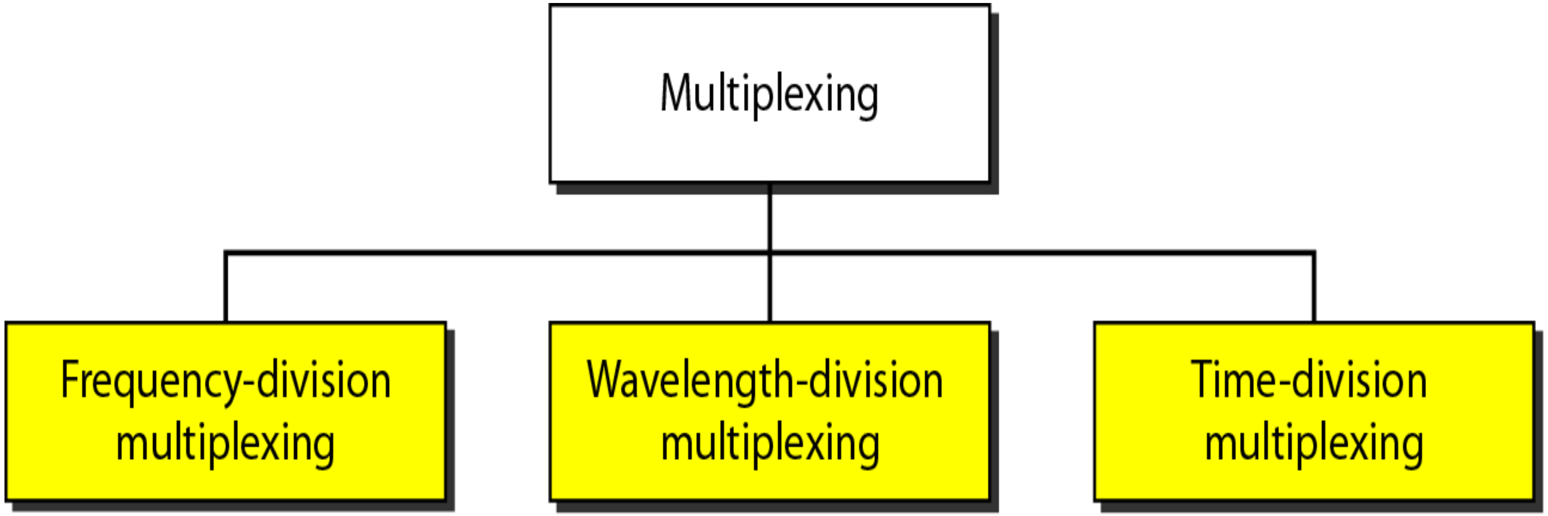
- Time-Division Multiplexing
- Frequency-Division Multiplexing
- Wavelength-Division Multiplexing

Multiplexing vs. No Multiplexing



a. No multiplexing b. Multiplexing

Multiplexing



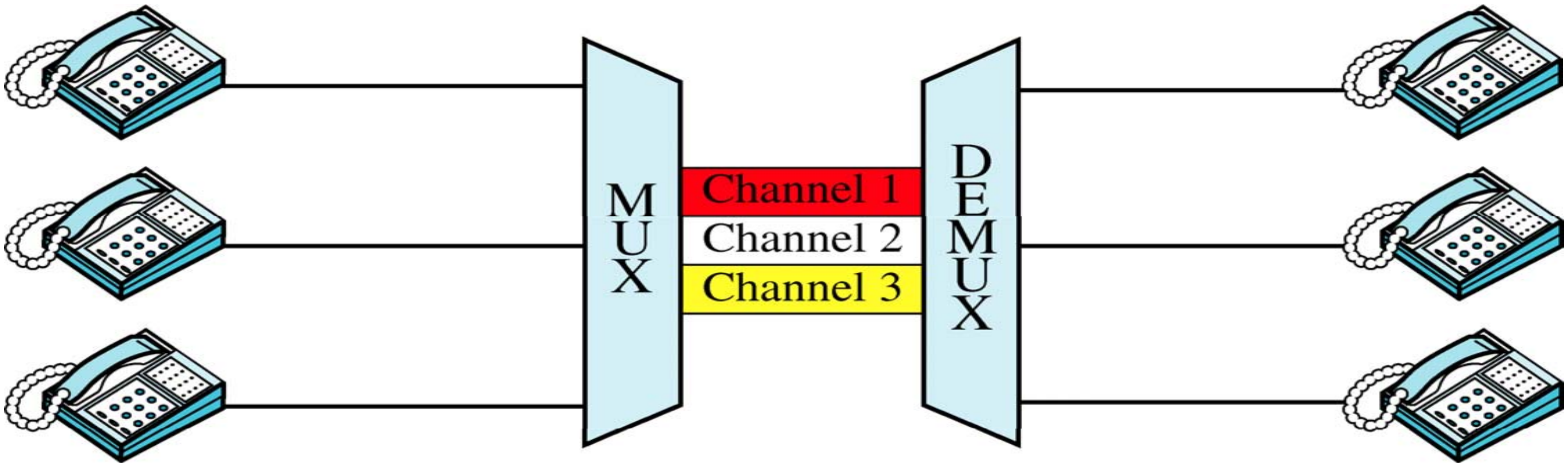
Frequency Division Multiplexing (FDM)

- Oldest multiplexing technique.
- Usually, FDM is an analog multiplexing technique that combines analog signals.
- Used in radio, cable TV
- Carry multiple video channel on a single cable
- Each signal is modulated onto a different carrier frequency, that are separated by guard bands.

Frequency Division Multiplexing (FDM)

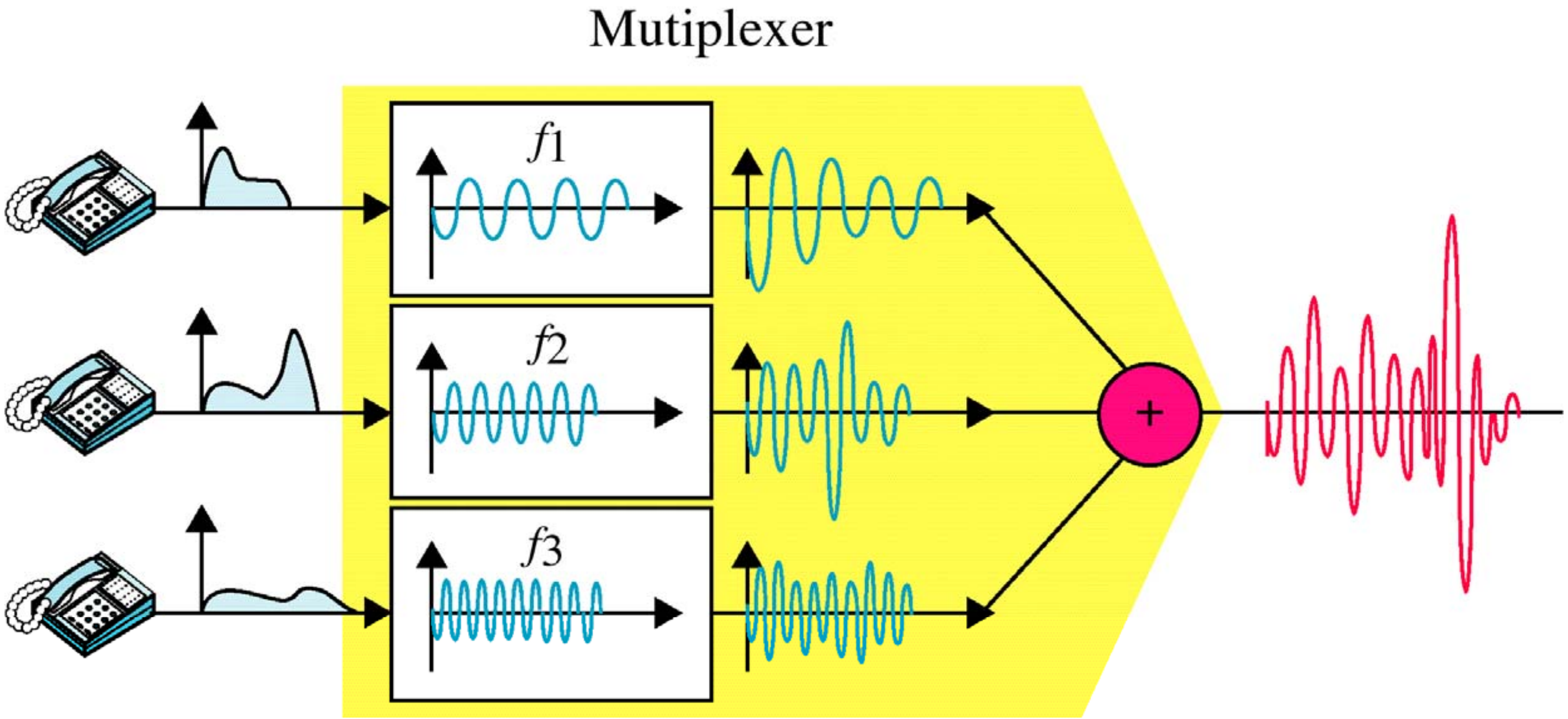
- The multiplexer is attached to a high-speed communication line
- A corresponding demultiplexer is on the other end of the high-speed line, which separates the multiplexed signals.

Frequency Division Multiplexing (FDM)

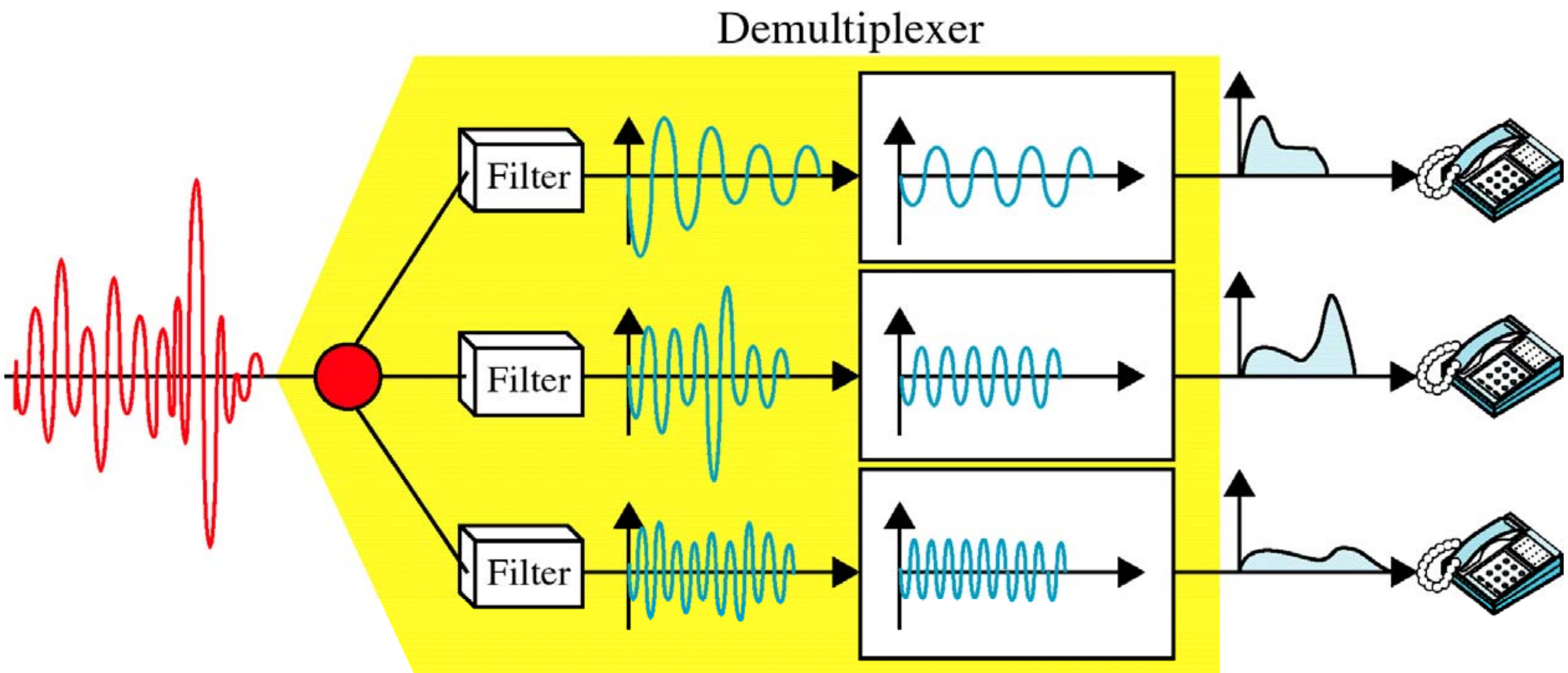


- User-1 can use channel-1 for the entire time. That is, channel-1 is entirely dedicated to user-1.
- Similarly for channel-2, which is at different frequency can be used by user-2

FDM



De-multiplexing



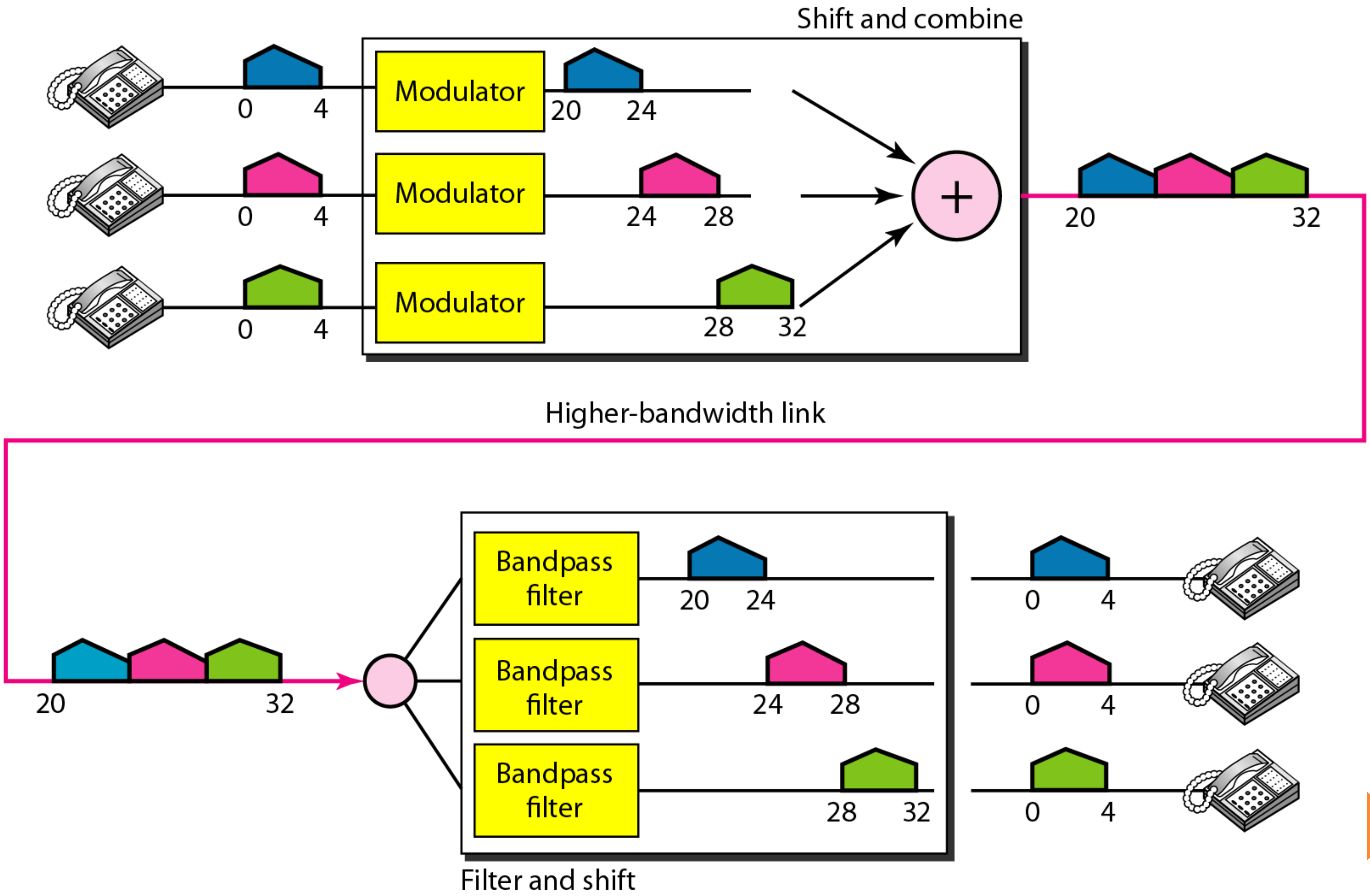
FDM (EXAMPLE)

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. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown below...

FDM (Example)



Shift and combine
Modulator
Modulator
Modulator
0
4
0
4
0
4
20
24
24
28
28
32
+
20
32
Higher-bandwidth link
20
32
Bandpass filter
Bandpass filter
Bandpass filter
20
24
24
28
28
32
0
4
0
4
0
4
Filter and shift

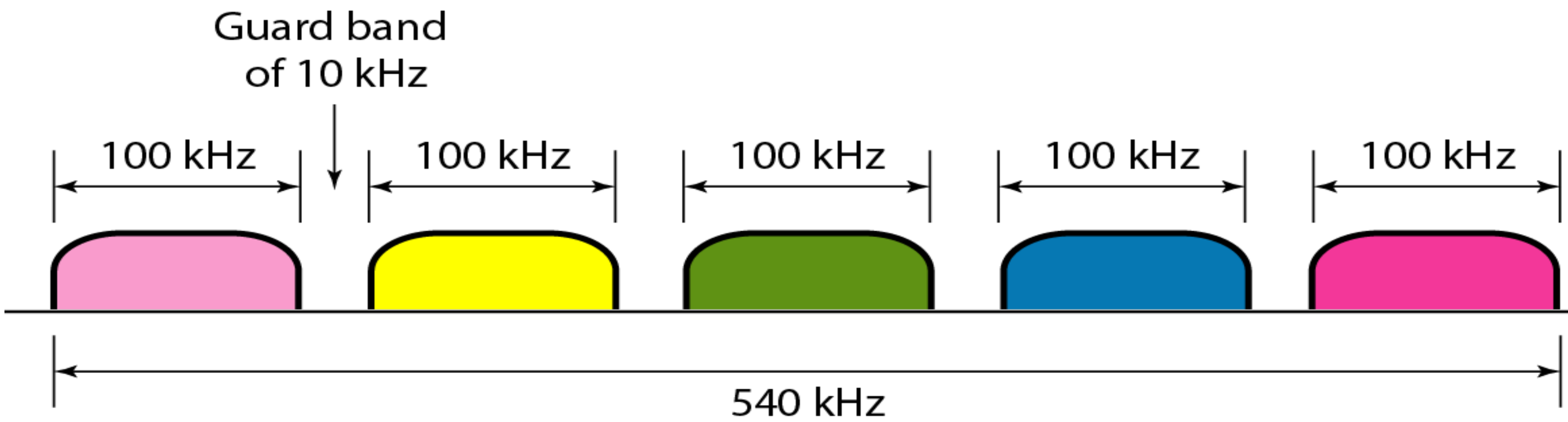
FDM (Example)

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

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



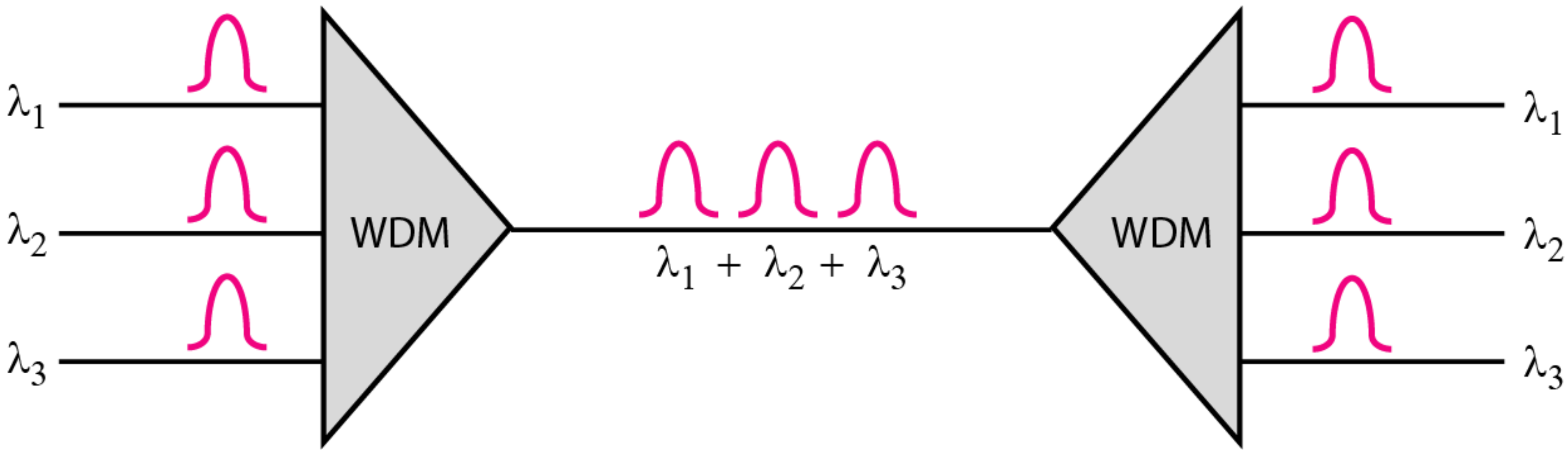
Frequency Division Multiplexing (FDM)

- FDM cannot utilize the full capacity of the cable.
- It is imp that the frequency bands do not overlap. So there must be a considerable gap between the frequency bands to ensure that signals do not interfere with each other.
- FDM is usually used to carry analog signals, although modulated digital signals can also be used.

Wavelength-division multiplexing (WDM)

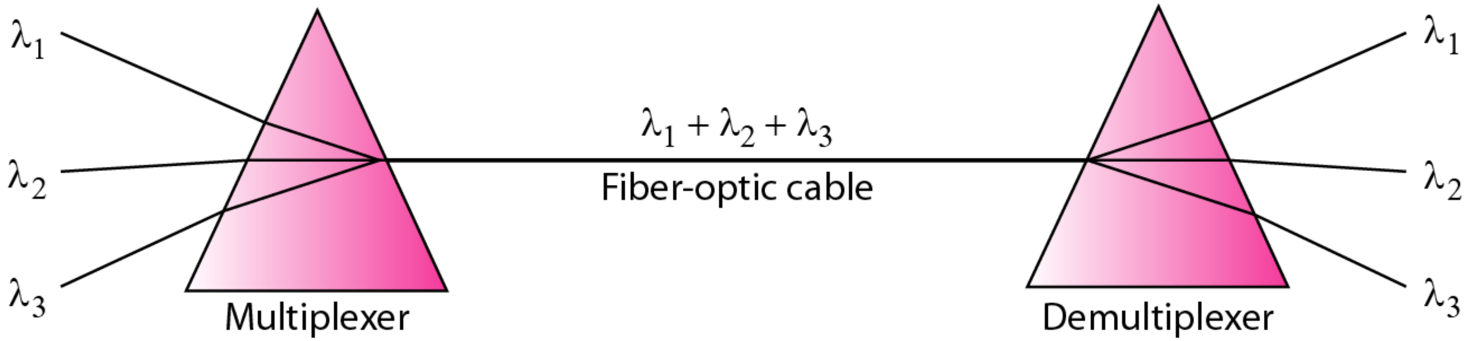
- WDM is same as FDM, but applied to fibers.
- WDM multiplexes multiple data streams onto a single fiber optic line.
- Different wavelength lasers transmit multiple signals
- It provides high reliability and very high capacity

Wavelength-division multiplexing (WDM)



PRISMS IN WAVELENGTH-DIVISION MULTIPLEXING AND DEMULTIPLEXING

- Prisms form the basis of optical multiplexing and demultiplexing
  - Multiplexor accepts beams of light of various wavelengths and uses a prism to combine them into a single beam
  - Demultiplexor uses a prism to separate the wavelengths.



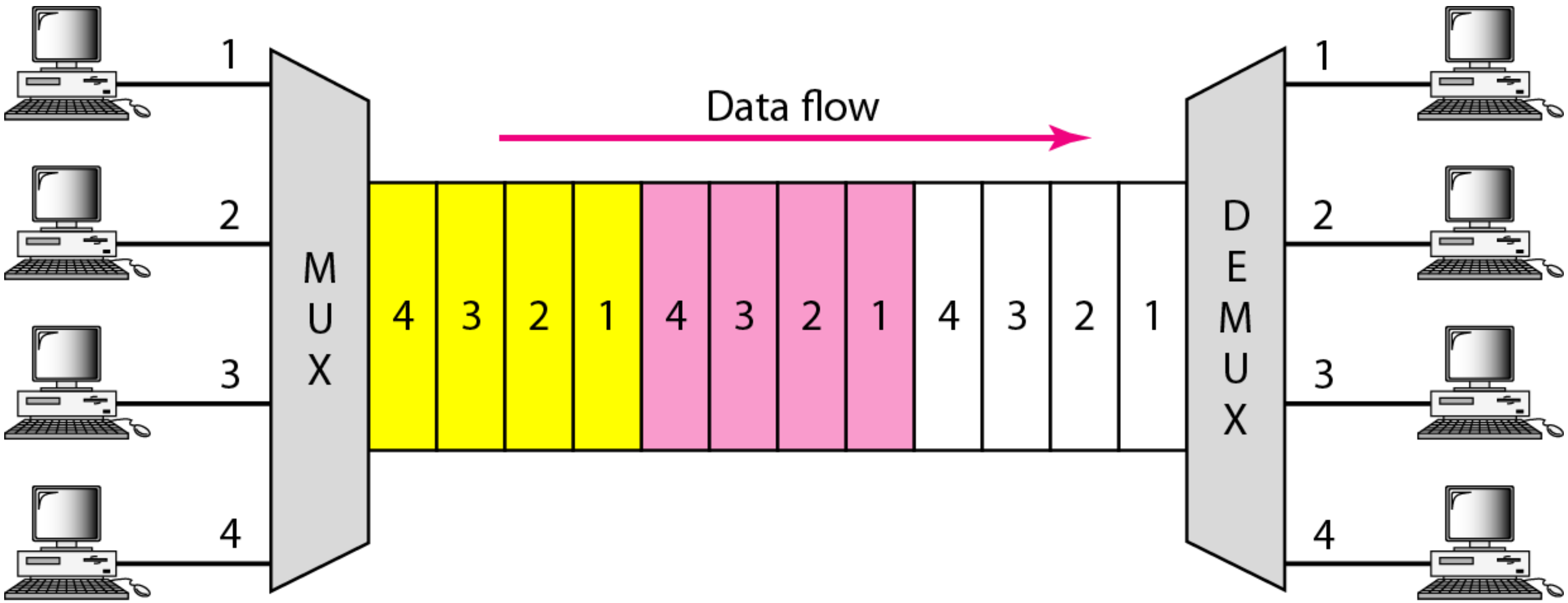
Time Division Multiplexing (TDM)

- Sharing of signal is accomplished by dividing available transmission time on a medium among users.

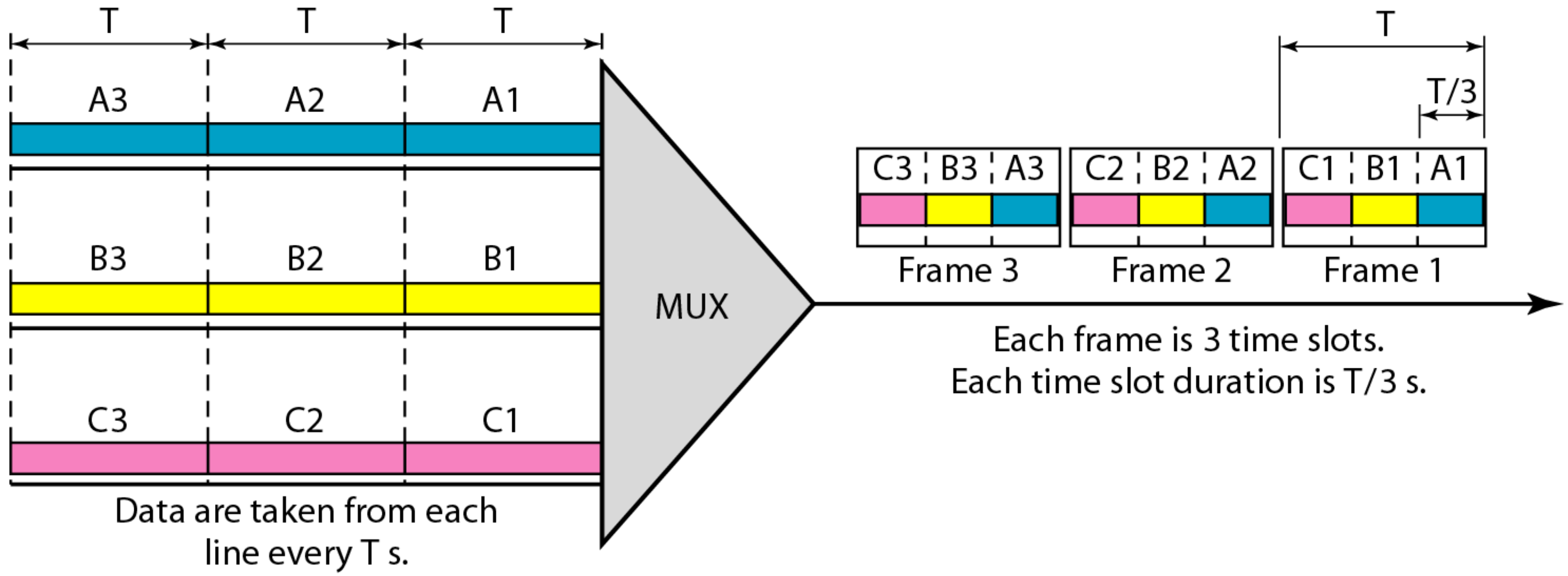
- TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.

- Two basic variations of TDM:
  - Synchronous time-division multiplexing
  - Statistical or asynchronous time-division multiplexing

Time Division Multiplexing (TDM)

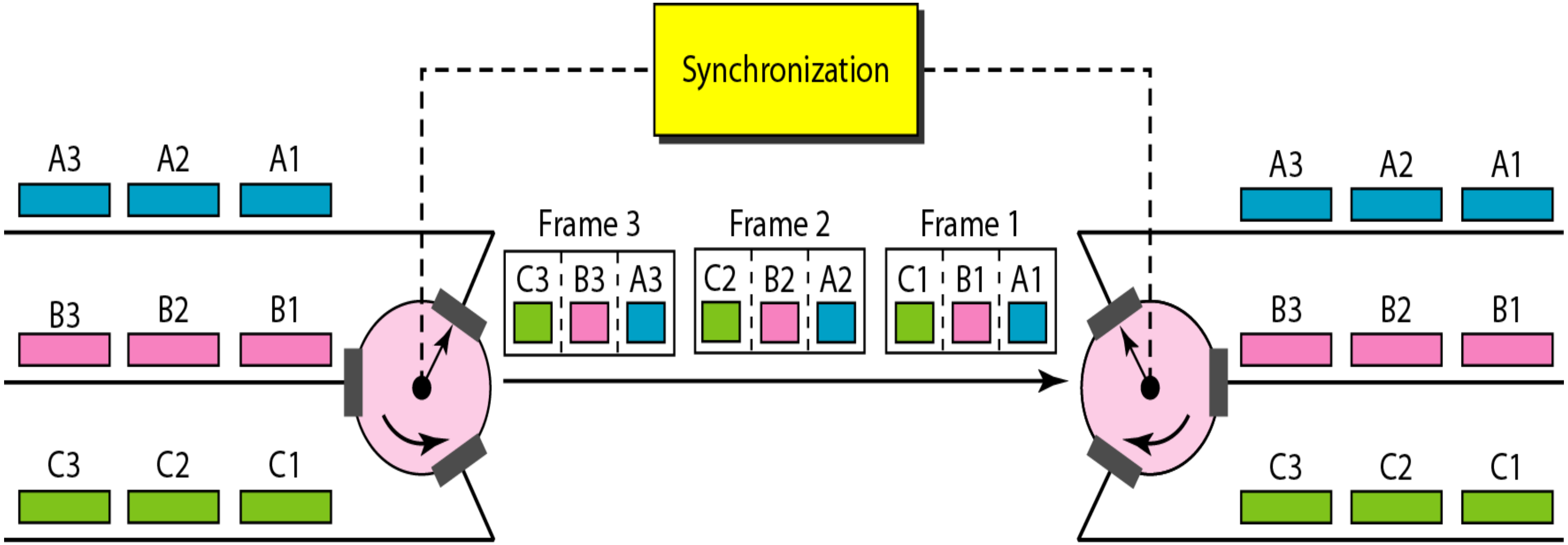


Synchronous TDM

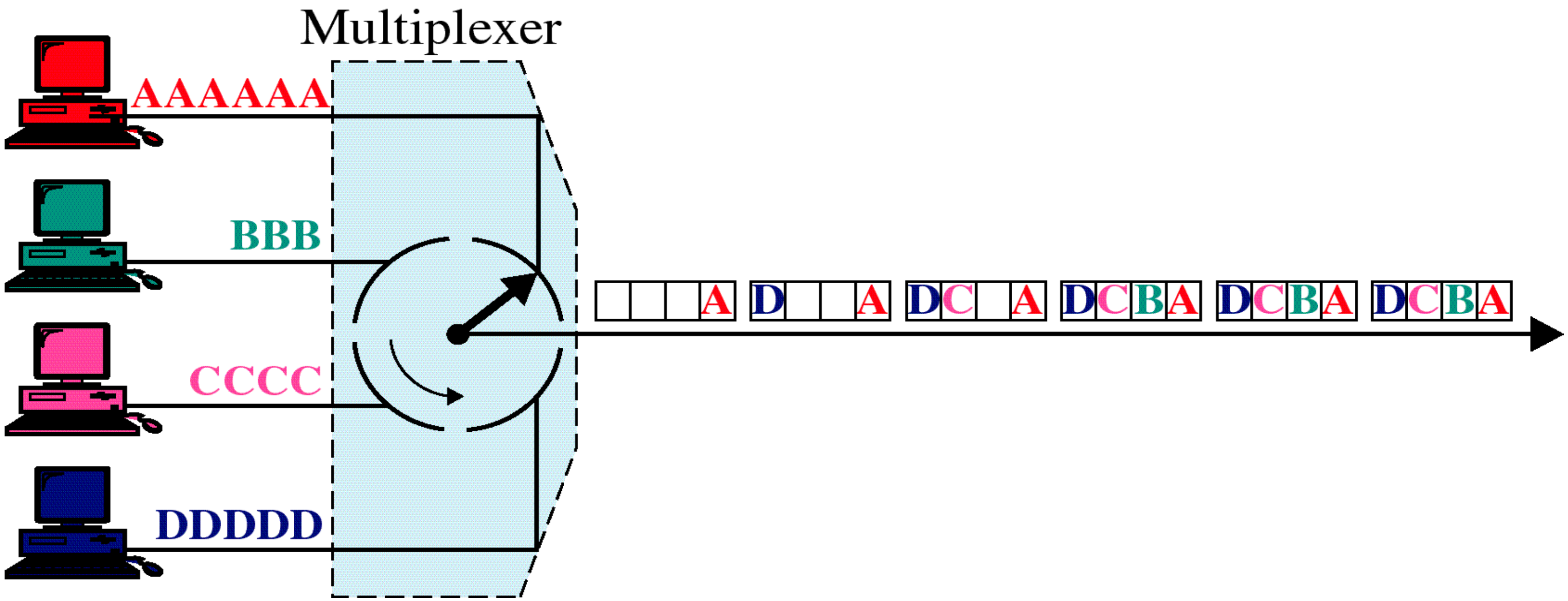


- The multiplexer accepts input from attached devices in a round robin fashion.
- The process of taking a group of bits from each input line for multiplexing is called interleaving.
- We interleave bits from each input onto one output.

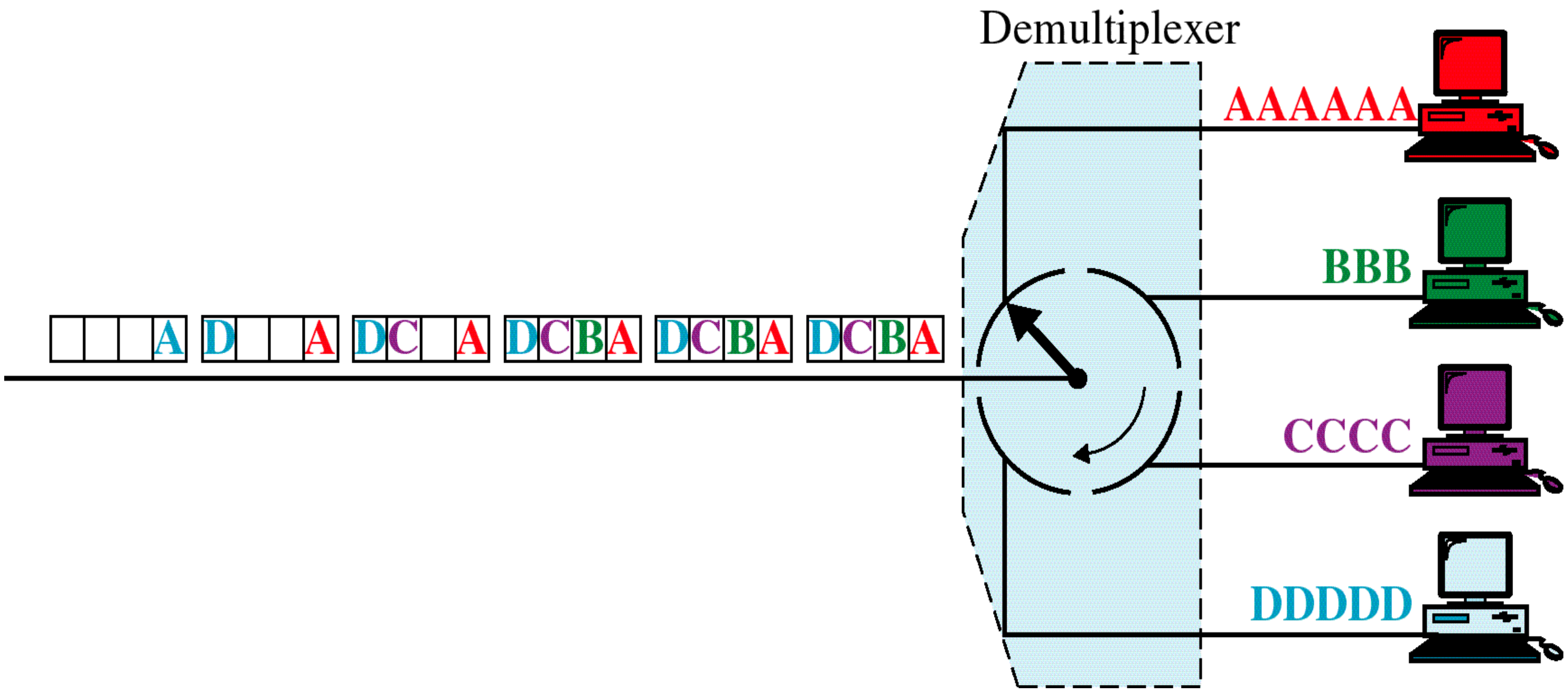
Interleaving



TDM, Multiplexing



TDM, Demultiplexing



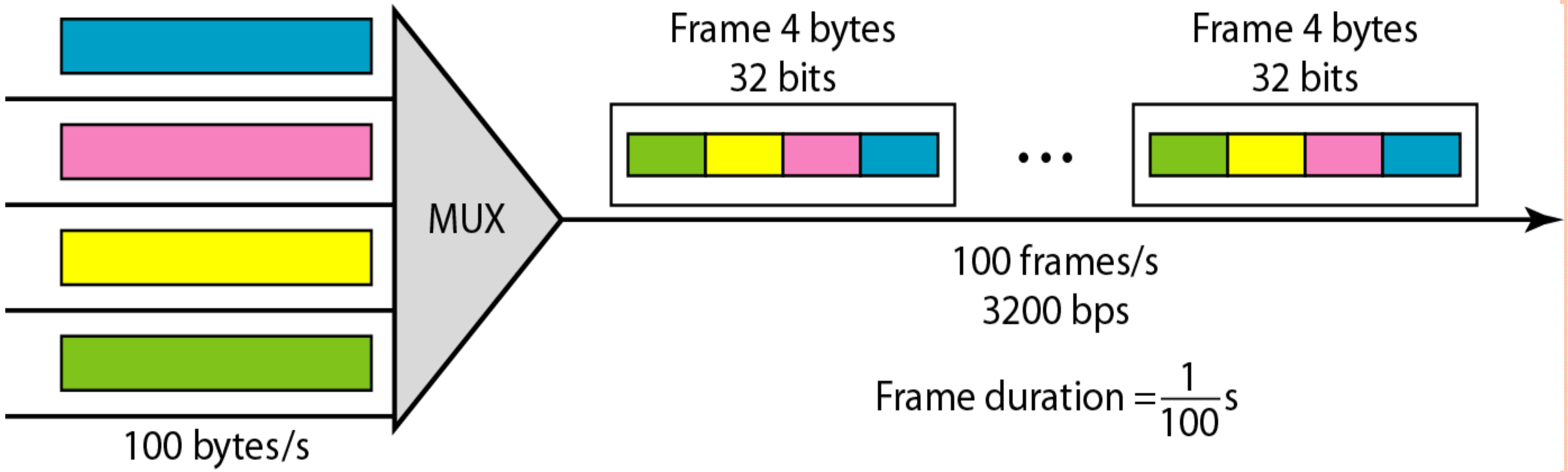
Example

Four channels are multiplexed using TDM. If each channel sends 100 bytes/sec 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

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

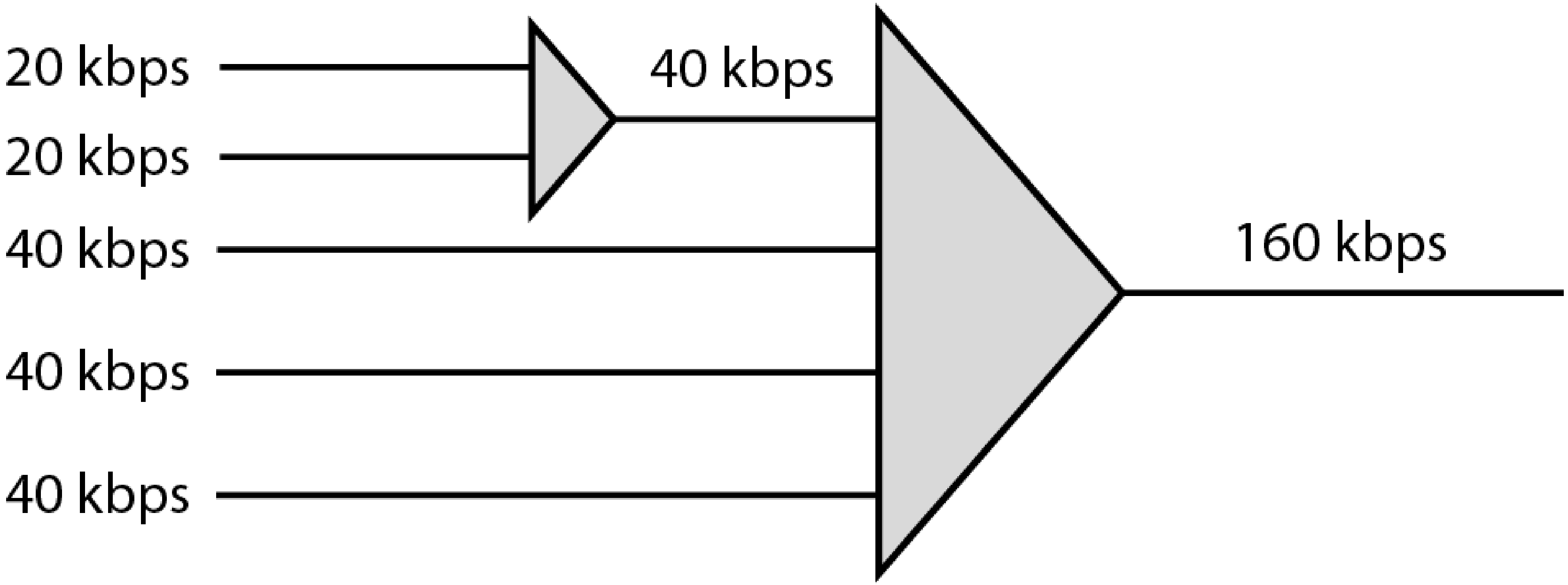


Frame 4 bytes
32 bits
Frame 4 bytes
32 bits
MUX
100 frames/s
3200 bps
Frame duration = $\frac{1}{100}$ s
100 bytes/s

Data Rate Management

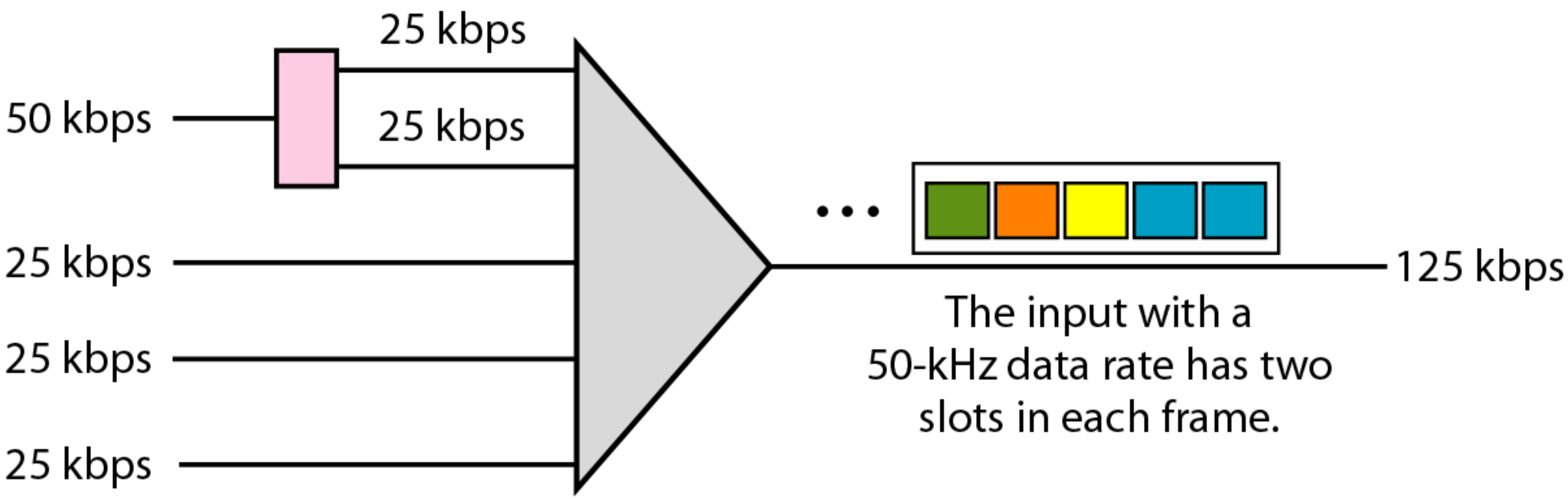
- Not all input links maybe have the same data rate.
- Some links maybe slower. There maybe several different input link speeds
- There are three strategies that can be used to overcome the data rate mismatch: multilevel, multislot and pulse stuffing

Multilevel multiplexing



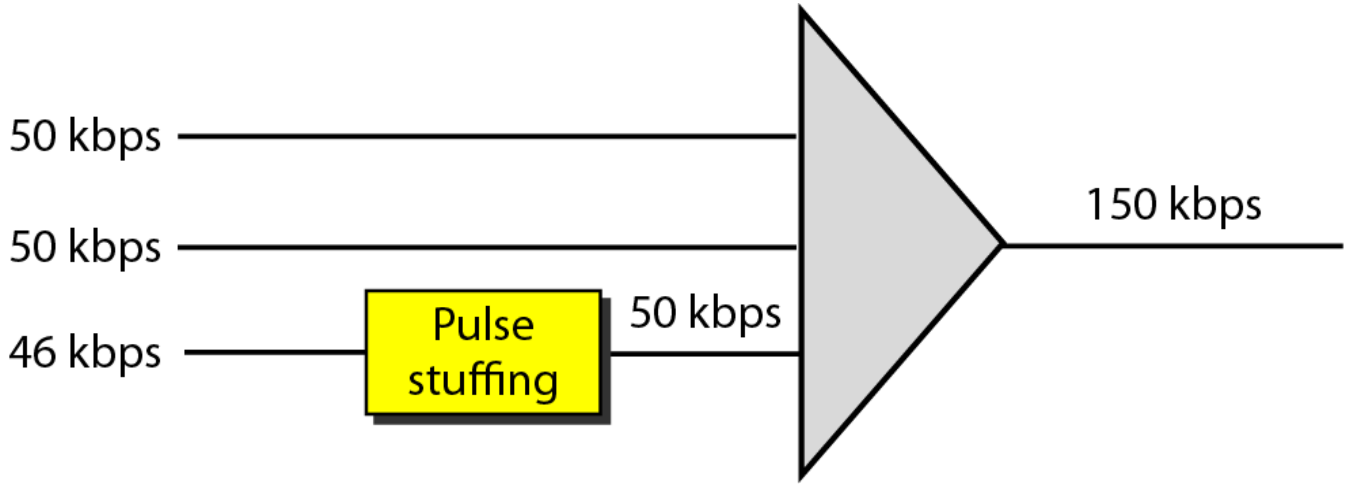
- Multilevel: used when the data rate of the input links are multiples of each other.

Multiple-slot multiplexing



- Multislot: we can allot more than one slot in a frame to a single input line.
- Higher bit rate channels are allocated more slots per frame, and the output frame rate is a multiple of each input link.

Pulse stuffing

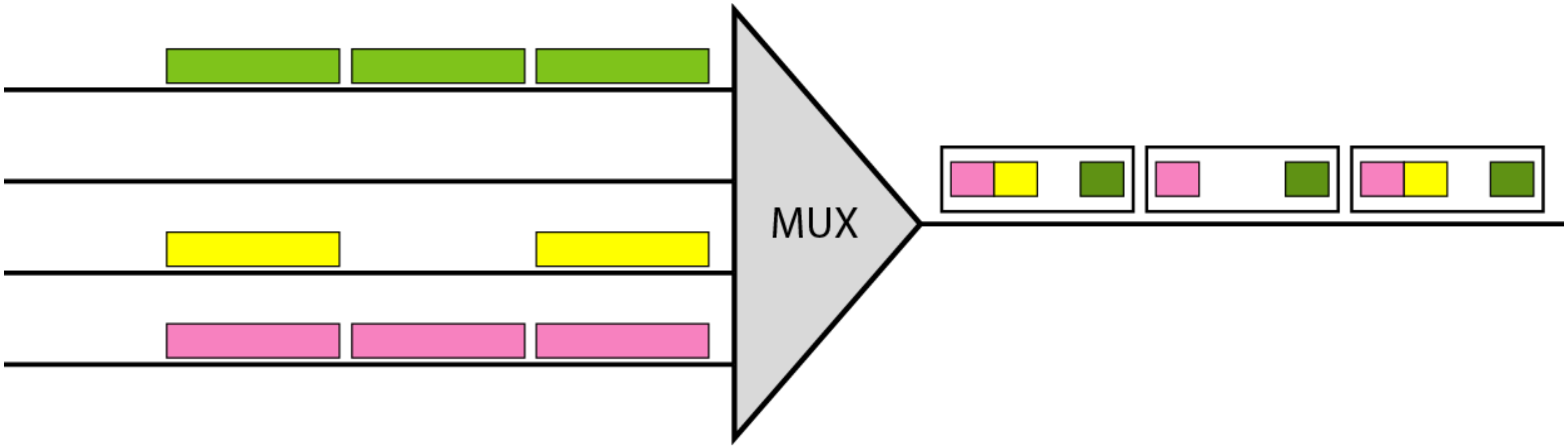


- Pulse Stuffing: The slowest speed link will be brought up to the speed of the other links by bit insertion, this is called pulse stuffing.
- Generally used if the bit rate of a source is not an integral multiple of the others.

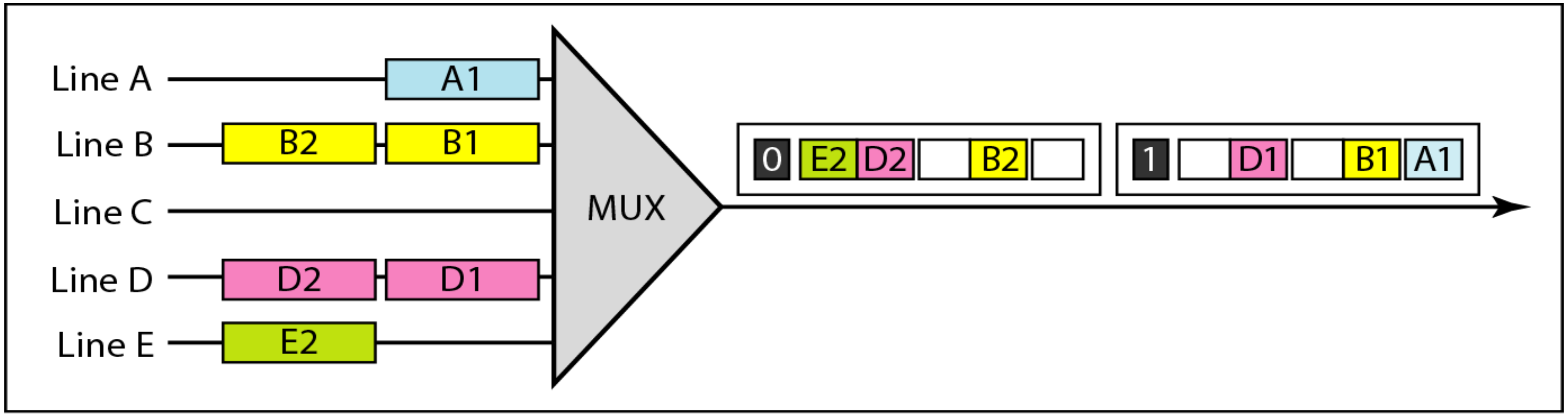
Inefficient use of Bandwidth

- Sometimes an input link may have no data to transmit.
- When that happens, one or more slots on the output link will go unused.
- That is wasteful of bandwidth.

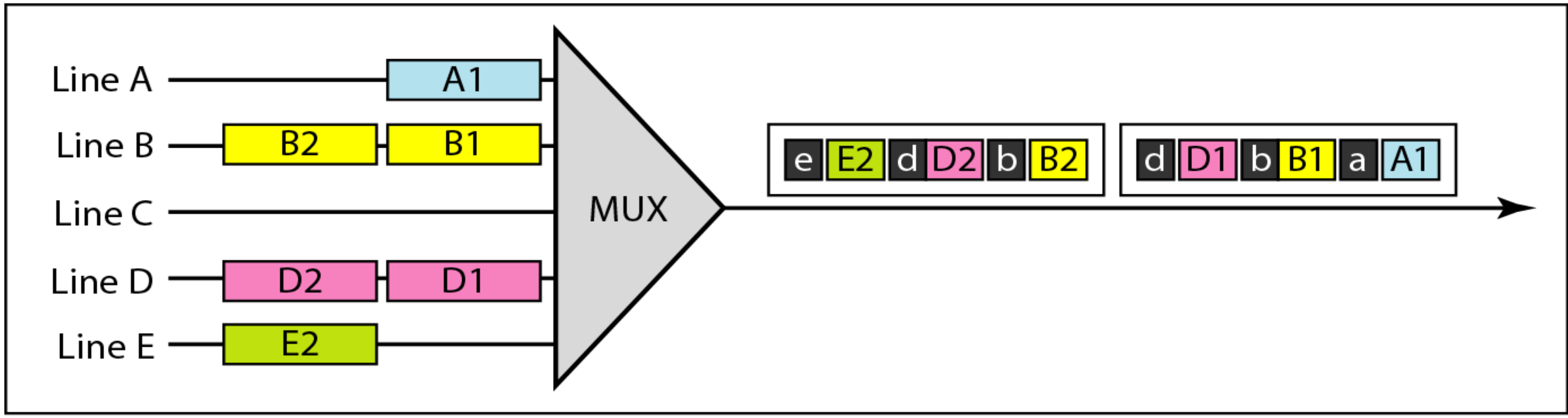
Empty slots



TDM slot comparison



a. Synchronous TDM

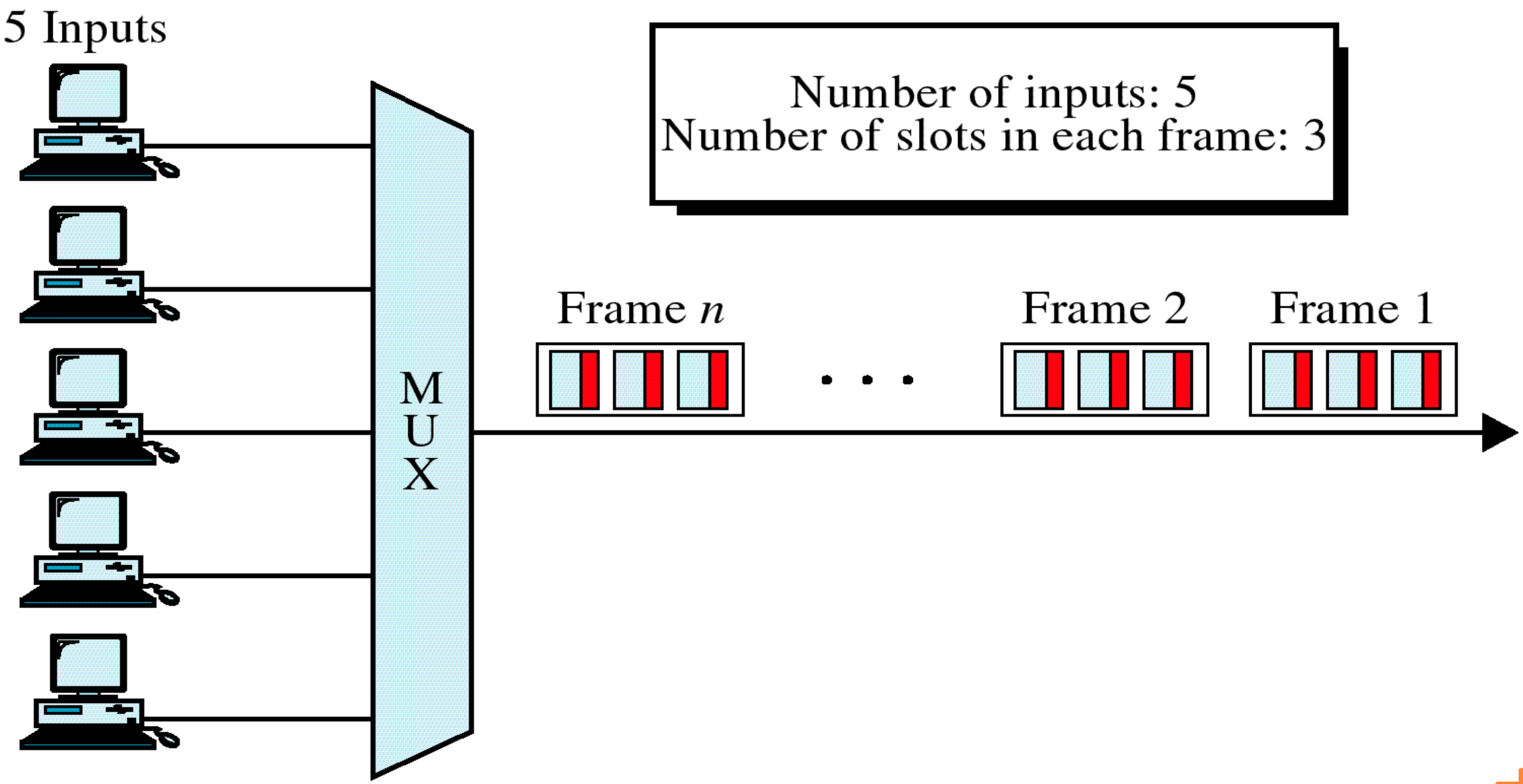


b. Statistical TDM

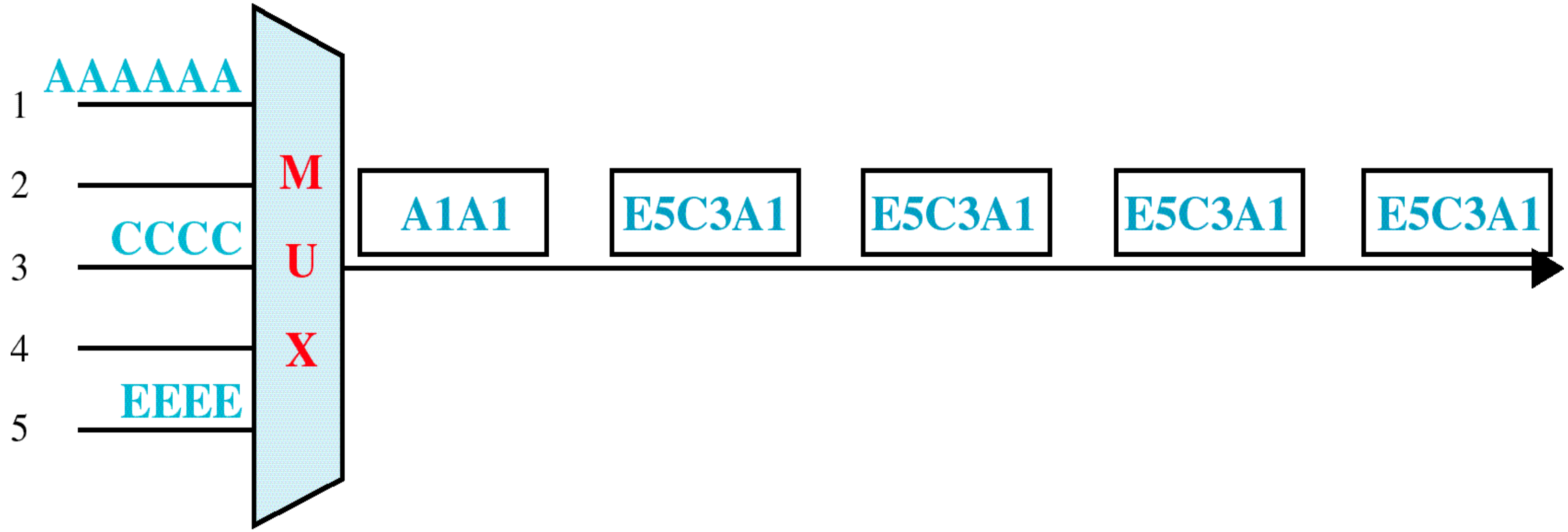
Asynchronous TDM

- Asynchronous TDM avoids bandwidth wastage.
- Unlike synchronous TDM, in asynchronous TDM the total speed of the input lines can be greater than the capacity of the path.
- In asynchronous TDM, if we have n input lines, the frames contain no more than m slots, with m < n.
  - Number of slots (m) is based on a statistical analysis of the number of input lines that are likely to be transmitting at any given time.
- For a given link, asynchronous TDM can support more devices tan synchronous TDM.

Asynchronous TDM



Frames and Addresses

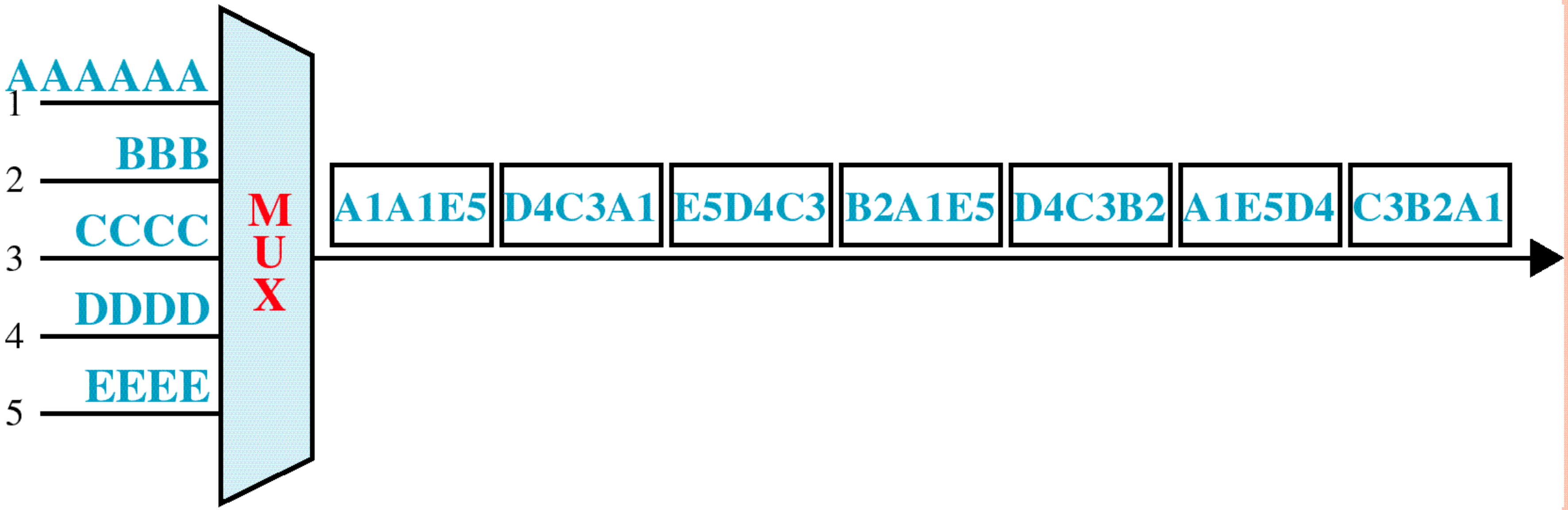


a. Only three lines sending data

Frames and Addresses

Only four lines sending data

Frames and Addresses



All five lines sending data

ADDRESSING AND OVERHEAD

- In asynchronous TDM, each time slot must carry an address telling the demultiplexer how to direct the data.
- This increases overhead
  - We can reduce this overhead…
- It makes asynchronous TDM inefficient for bit or byte interleaving.
- asynchronous TDM is efficient only when the size of the time slot is relatively high.

Variable Length Time Slots

- Stations transmitting at a faster data rate can be given a longer slot.

- To manage variable length fields, we need to add control bits to the beginning of each time slot to indicate the length of the incoming data.