CS311: DATA COMMUNICATION

Multiplexing

by

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Outline of the Lecture

- What is Multiplexing and why is it used ?
- Basic concepts of Multiplexing
- Types of Multiplexing:
  - Frequency Division Multiplexing (FDM)
  - Wavelength Division Multiplexing (WDM)
  - Time Division Multiplexing (TDM)
    - Synchronous
    - Asynchronous
  - Inverse TDM

Introduction

- To make efficient use of high-speed telecommunications lines, some form of multiplexing is used.
- Multiplexing allows several transmission sources to share a larger transmission capacity.
- Most individual data communicating devices typically require modest data rate, but the media usually has much higher bandwidth.
- Two communicating stations do not utilize the full capacity of a data link.
- The higher the data rate, the most cost effective is the transmission facility.

Cont…

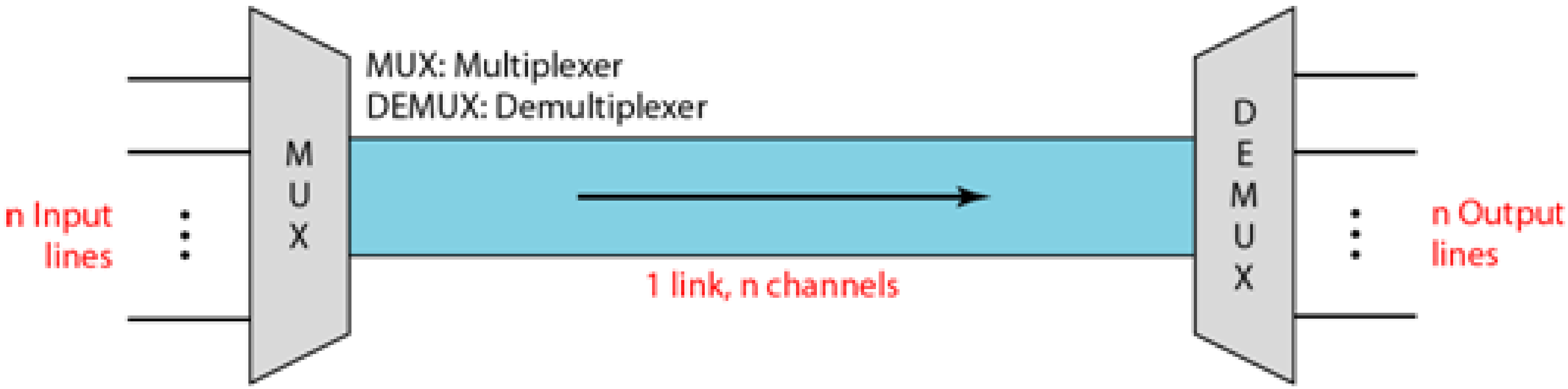
- When the bandwidth of a medium is greater than individual signals to be transmitted through the channel, a medium can be shared by more than one channel of signals by using Multiplexing.

- For efficiency, the channel capacity can be shared among a number of communicating stations.

- Most common use of multiplexing is in long-haul communication using coaxial cable, microwave and optical fibre.

Basic Concept

- A device known as Multiplexer (MUX) combines ‘n’ channels for transmission through a single medium or link.
- At the other end a De-multiplexer (DEMUX) is used to separate out the ‘n’ channels.



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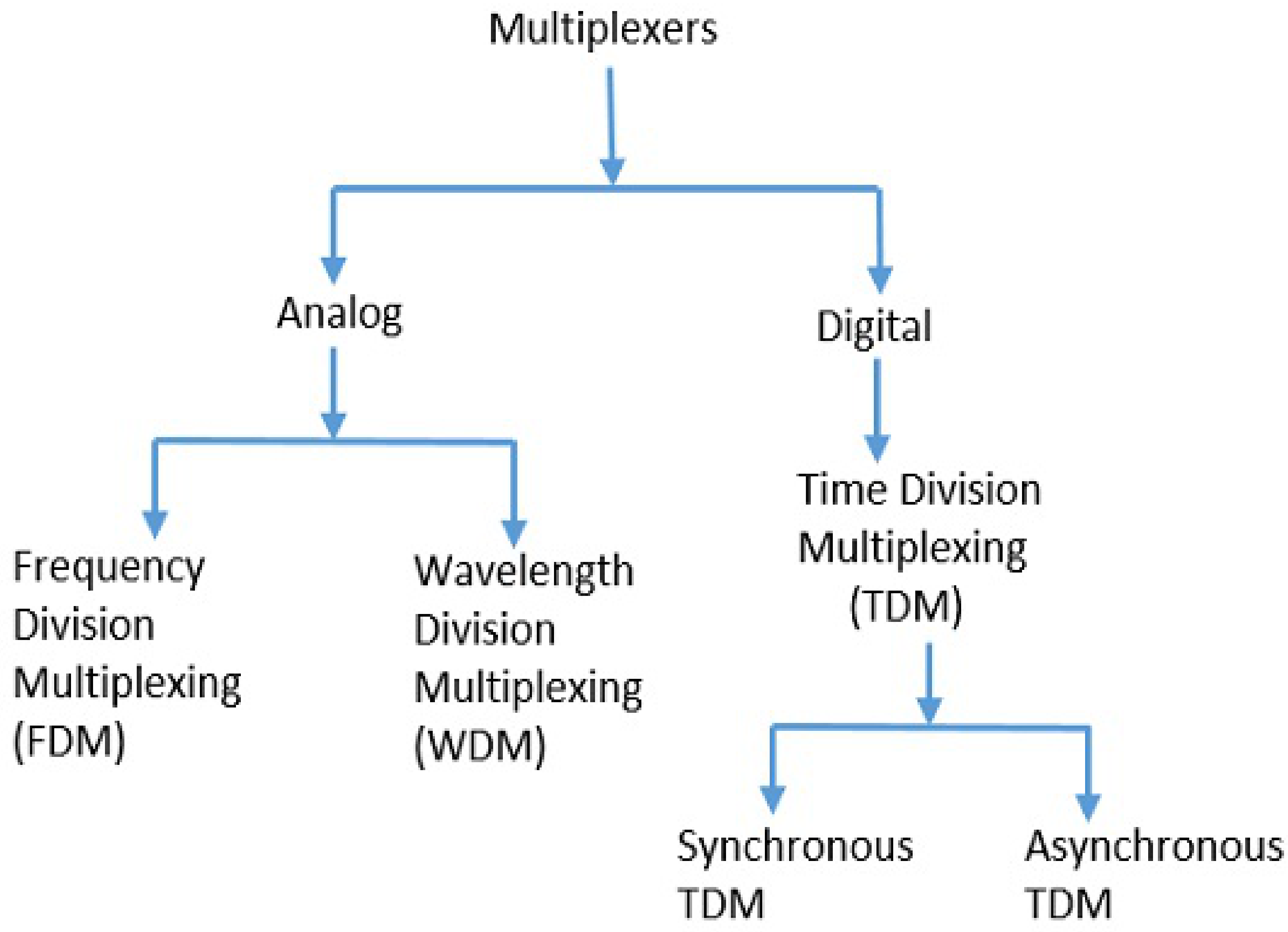

Multiplexers
Analog
Digital
Frequency Division Multiplexing (FDM)
Wavelength Division Multiplexing (WDM)
Time Division Multiplexing (TDM)
Synchronous TDM
Asynchronous TDM

FDM

- **FDM** can be used with analog signals.
- A number of signals are carried simultaneously on the same medium by allocating to each signal a different frequency band.
- FDM is possible when the useful bandwidth of the transmission medium exceeds the required bandwidth of signals to be transmitted.
- A number of signals can be carried simultaneously if each signal is modulated onto a different carrier frequency and the carrier frequencies are sufficiently separated that the bandwidths of the signals do not significantly overlap.

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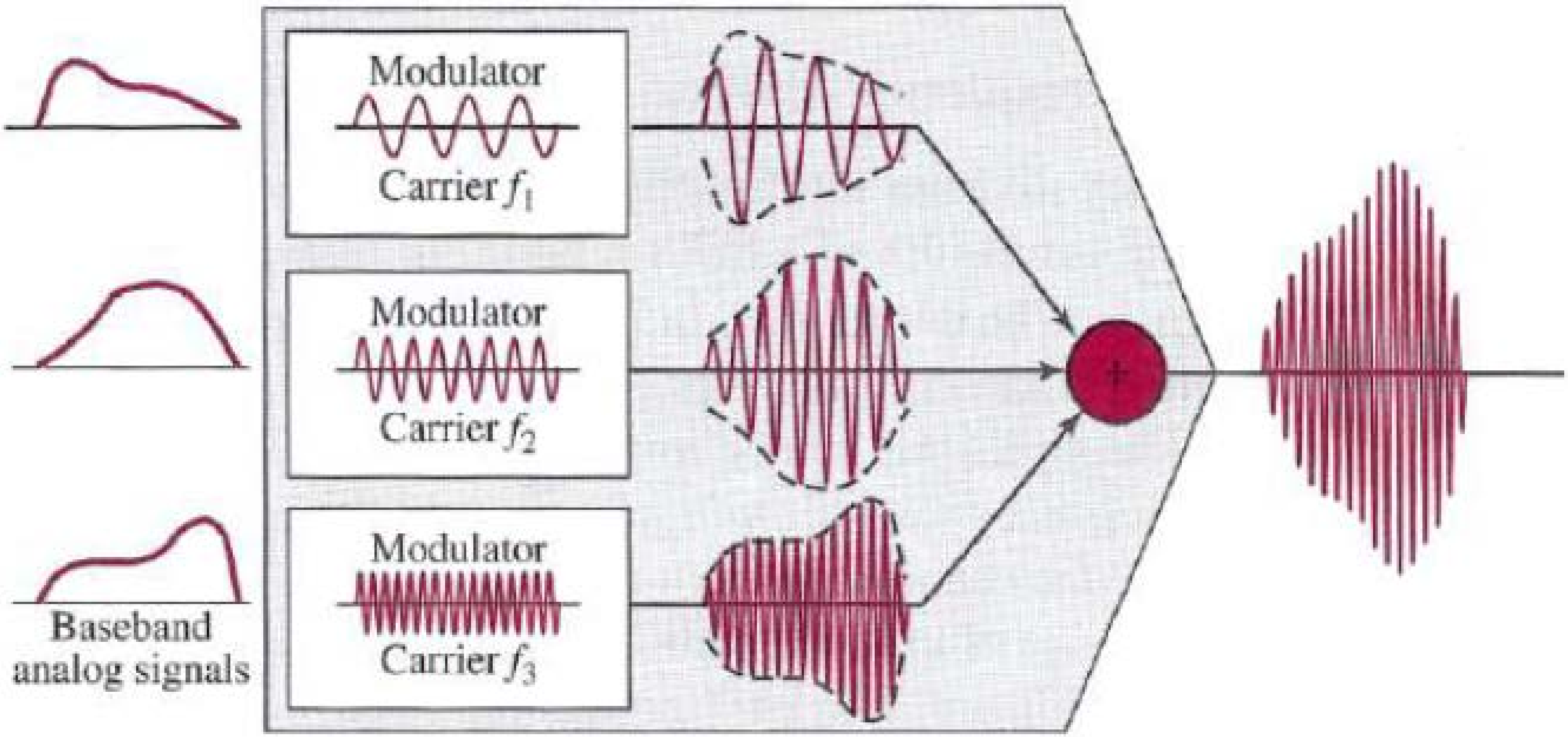

FDM Multiplexing Process

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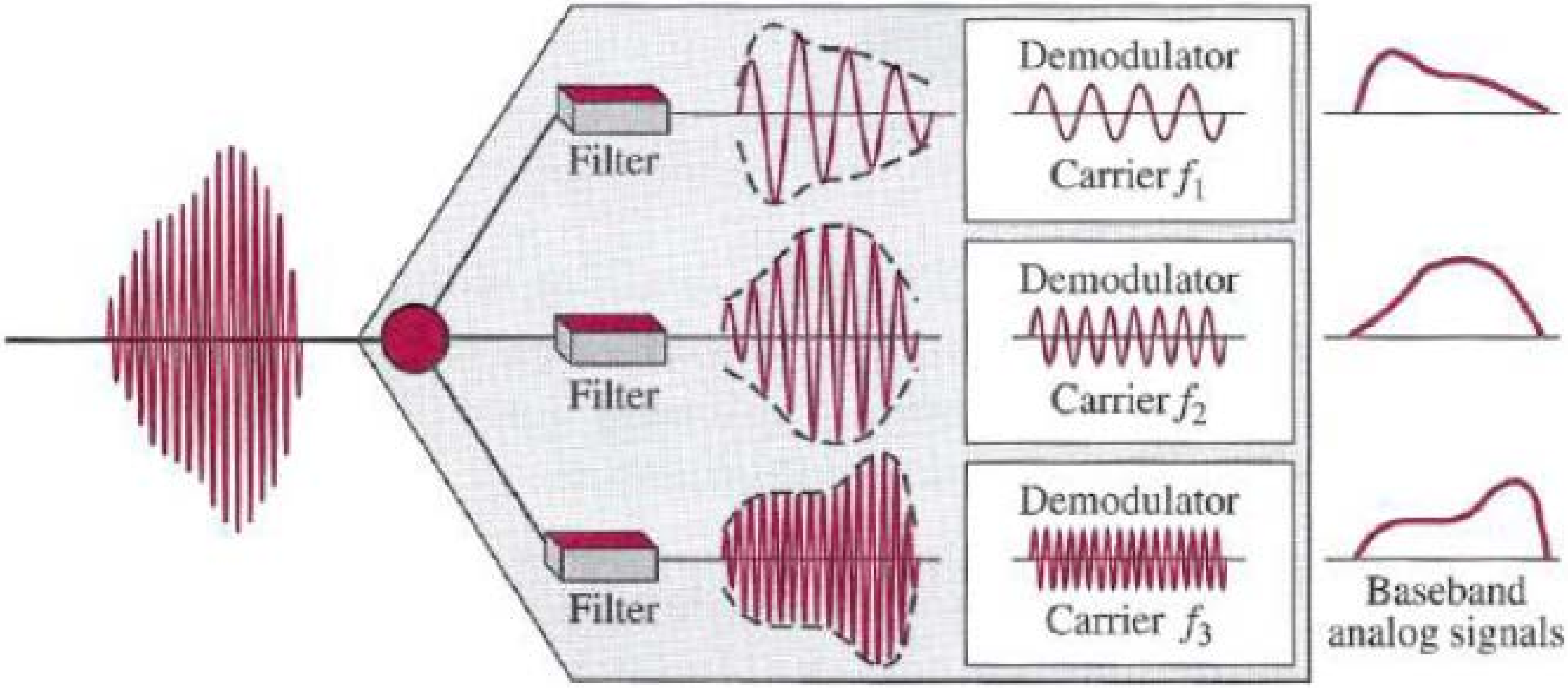
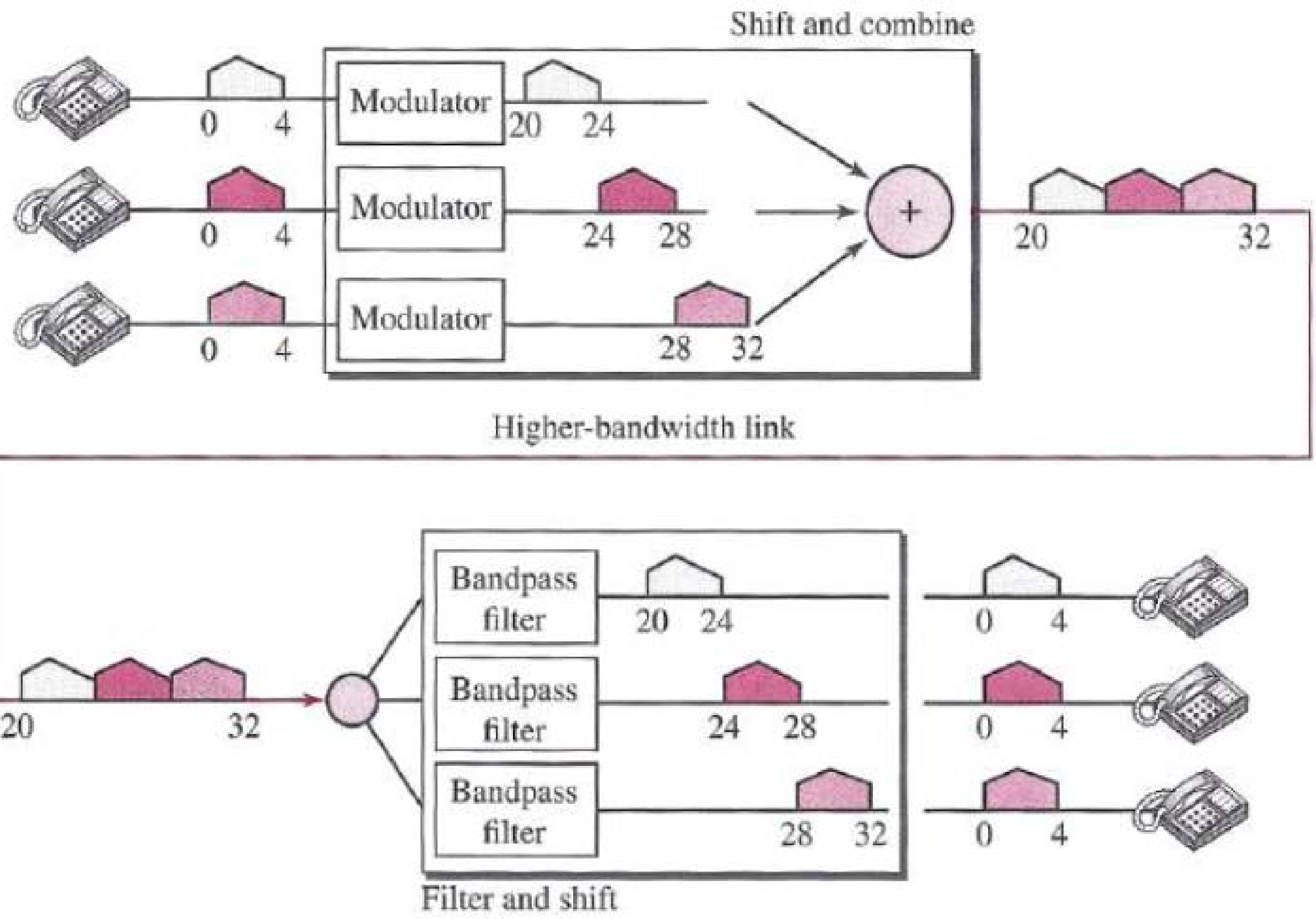


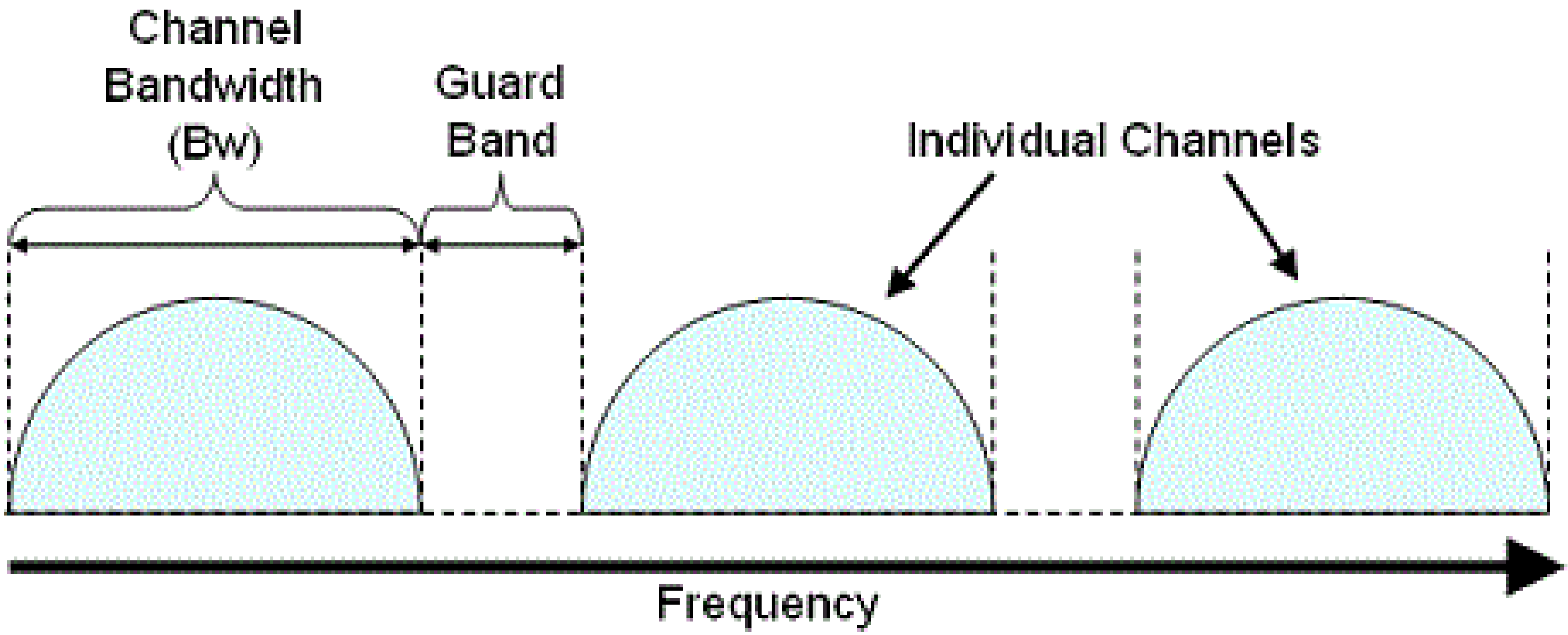
FDM De-Multiplexing Process

Example



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

Guard Band



- A Guard-Band is a narrow frequency range that separates two ranges of wider frequency.
- This ensures that simultaneously used communication channels do not experience interference or cross-talk, which would result in decreased quality for both transmissions.

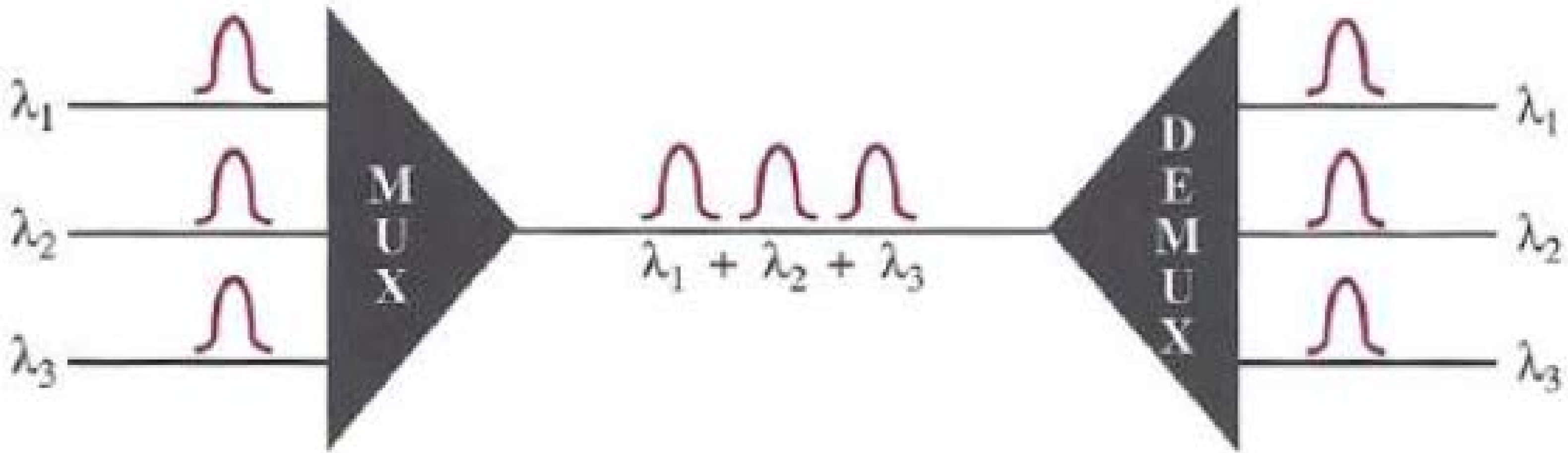
Applications of FDM

- Transmission of AM/FM Radio broadcasting
- TV broadcasting
- Cable television

Wavelength Division Multiplexing

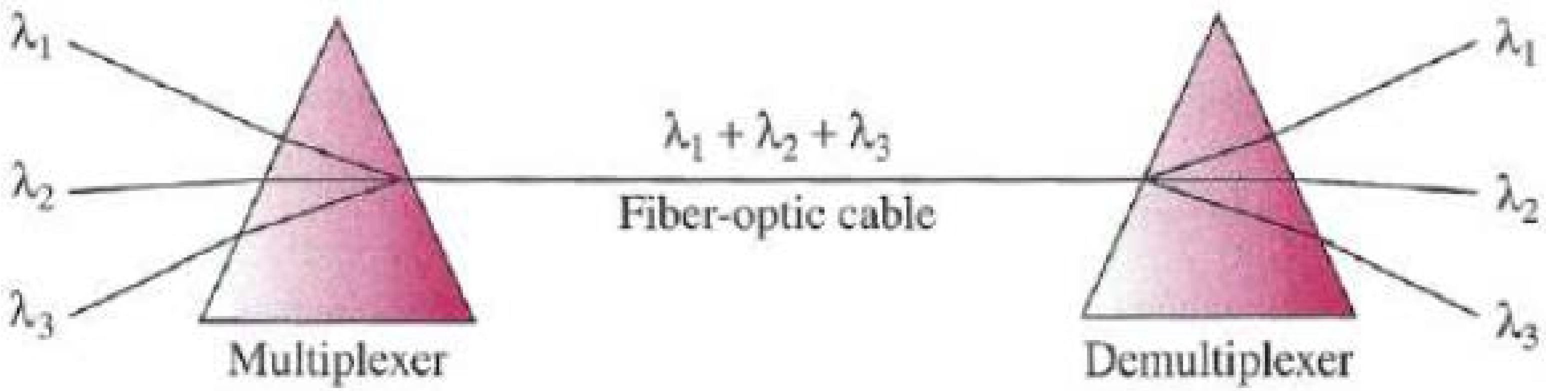
- Optical fiber medium provides enormous bandwidth.
- WDM is the most viable technology that overcomes the huge opto-electronic bandwidth mismatch.
- WDM optical fiber network comprises optical wavelength switches/routers interconnected by point-to-point fiber links.
- End users may communicate with each other through all-optical (WDM) channels known as ***Light-paths***, which may span over more than one fiber links.

WDM



λ_1
λ_2
λ_3
M U X
$\lambda_1 + \lambda_2 + \lambda_3$
D E M U X
λ_1
λ_2
λ_3

Example



λ_1
λ_2
λ_3
$\lambda_1 + \lambda_2 + \lambda_3$
Fiber-optic cable
Multiplexer
Demultiplexer
λ_1
λ_2
λ_3

Time Division Multiplexing

- Possible when the bandwidth of the medium exceeds the data rate of digital signals to be transmitted.
- Multiple digital signals can be carried on a single transmission path by interleaving portions of each signal in time.
- Interleaving can be at the bit level or in blocks of bytes.

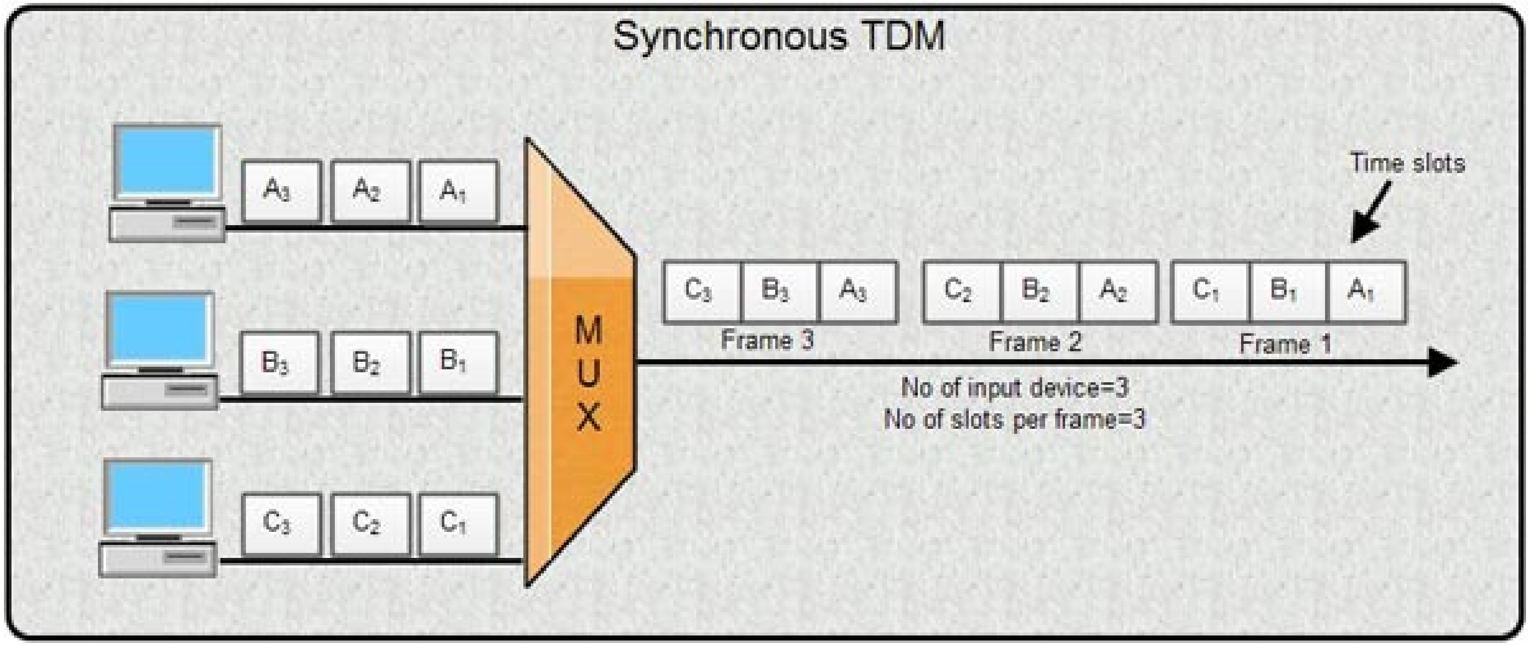
TDM

- The incoming data from each source are briefly buffered.
  - Each buffer is typically one bit or one character in length.
  - The buffers are scanned sequentially to form a composite data stream.
  - The scan operation is sufficiently rapid so that each buffer is emptied before more data can arrive.

Synchronous TDM

- Composite data rate must be at least equal to the sum of the individual data rate.

- The composite signal can be transmitted directly or through a modem.



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Frame Synchronization

- In this scheme, typically, one control bit is added to each TDM frame.
- An identifiable pattern of bits, from frame to frame, is used as a "control channel."

- Thus, to synchronize, a receiver compares the incoming bits of one frame position to the expected pattern.
- If the pattern does not match, successive bit positions are searched until the pattern persists over multiple frames.

- Once frame synchronization is established, the receiver continues to monitor the framing bit channel.
- If the pattern breaks down, the receiver must again enter a framing search mode.

Cont…

Pulse Stuffing

- If each source has a separate clock, any variation among clocks could cause loss of synchronization.

- With pulse stuffing, the outgoing data rate of the multiplexer, excluding framing bits, is higher than the sum of the maximum instantaneous incoming rates.

- The extra capacity is used by stuffing extra dummy bits or pulses into each incoming signal until its rate is raised to that of a locally generated clock signal.
- The stuffed pulses are inserted at fixed locations in the multiplexer frame format so that they may be identified and removed at the de-multiplexer.

Limitations of Synchronous TDM

- In synchronous TDM, many of the time slots in a frame may be wasted.
- The problem is overcame in Statistical / Asynchronous / Intelligent TDM.
- In Statistical TDM, time slots are allocated dynamically on demand.
- It takes the advantage of the fact that not all the attached devices may be transmitting all of the time.

Asynchronous TDM

- As with a synchronous TDM, the statistical multiplexer has a number of I/O lines on one side and a higher-speed multiplexed line on the other. Each I/O line has a buffer associated with it.

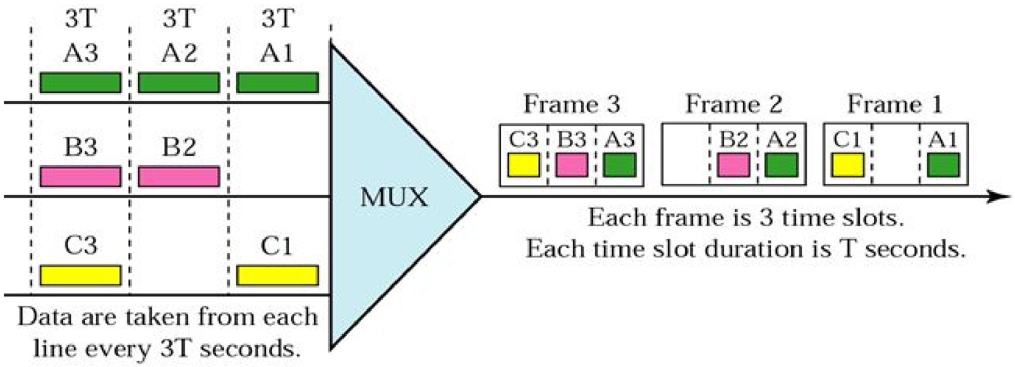
- In the case of the statistical multiplexer, there are ‘n’ I/O lines, but only *k*, where $k < n$, time slots available on the TDM frame.

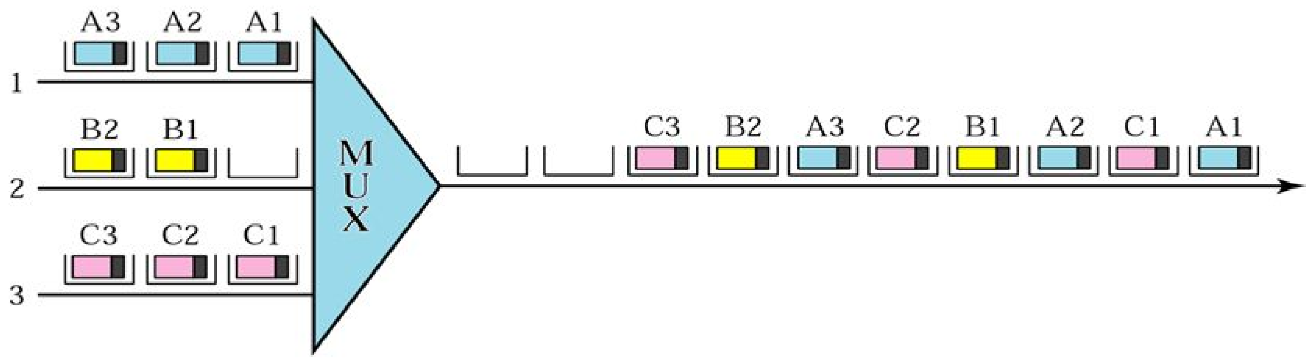
- For input, the function of the multiplexer is to scan the input buffers, collecting data until a frame is filled, and then send the frame.

- On output, the multiplexer receives a frame and distributes the slots of data to the appropriate output buffers.

Synchronous vs Asynchronous

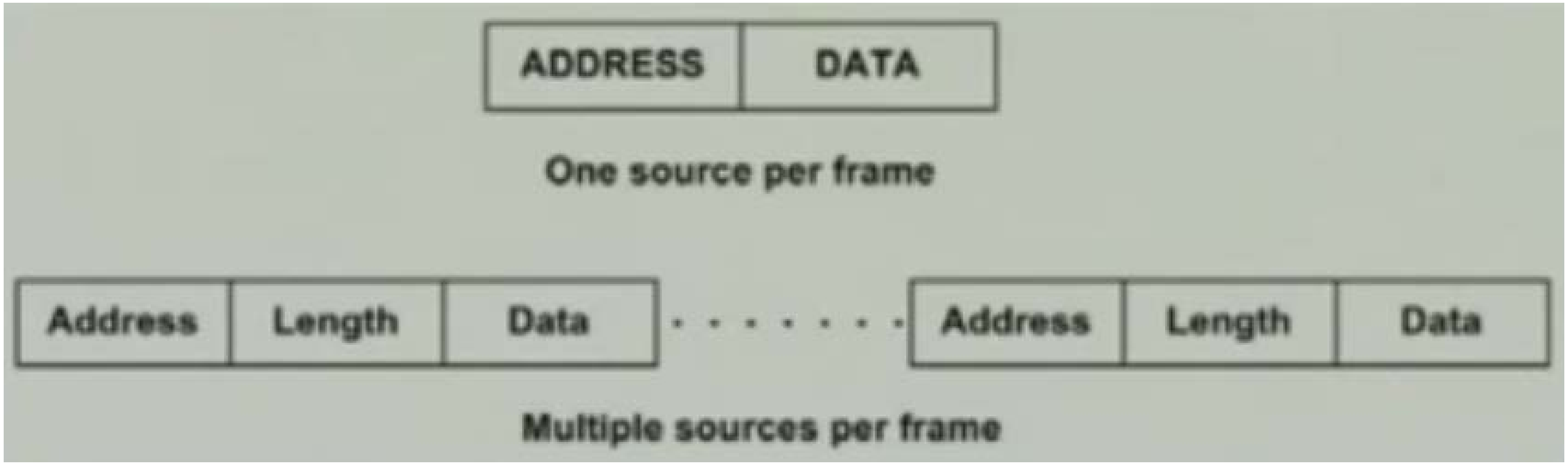
Synchronous vs. Asynchronous TDM





Asynchronous TDM

- Since data arrive from and are distributed to I/O lines unpredictably, *address information* is required to assure proper delivery.
- This leads to more overhead per slot.
- Relative addressing can be used to reduce overhead.



Performance of Asynchronous TDM

- In ATM, the data rate at the output is less than the data rate at the input.
- However, in peak periods the input may exceed capacity.

- Buffers of suitable size may be included to overcome this problem.

- Let 'n' = number of inputs, 'r' = data rate of each source, 'M' = effective capacity of the output, 'α'=mean fraction of time each input is transmitting, $0 < \alpha < 1$.

- Then, a measure of compression is $C = M/(nr)$, bounded by $\alpha < C < 1$.

Inverse Multiplexing

- An inverse multiplexer (IMUX) is a device performing the opposite function of a multiplexer (MUX).

- Instead of allowing one or more low-speed analog or digital input signals (or data streams) to be selected, combined and transmitted at a higher speed on a single shared medium i.e. multiplexing, an inverse multiplexer breaks the combined and related higher speed analog or digital signals into several concurrent lower-speed related signals or data streams.

- Thus, using multiple slower lines, the data stream can be more evenly distributed across all lines.

Cont…

- The difference between de-multiplexing (DEMUX) and inverse multiplexing is that the output streams of de-multiplexing are unrelated but the output streams of inverse multiplexing are related.

- Just as multiplexers are combined with de-multiplexers to create bi-directional data flow, inverse multiplexers may be combined with an inverse DEMUX (i.e. the reverse of an inverse multiplexer).

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2010), Data and Computer Communications
2. NPTL lecture on Data Communication, by Prof. A. K. Pal, IIT Kharagpur
3. B. A. Forouzan, (2013), Data Communication and Networking