Part 2 Physical Layer

Chapter 6

Bandwidth Utilization: Multiplexing

http://www.mhhe.com/forouzan

***Most details of this presentation obtain from**

"Behrouz A. Forouzan. *Data Communications and Networking*, 5th edition" textbook

Outline

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

Introduction

In simplest conditions, a medium can carry only one signal at any moment in time.

For example:

- USB cable that connects a keyboard to a PC carries a single digital signal.
- Category 6 twisted pair wire that connects a PC to a LAN carries only one digital signal at a time.

In network system, we want a medium to carry multiple signals at the same time.

The **technique of transmitting multiple signals** over a single medium is **multiplexing**.

Multiplexing

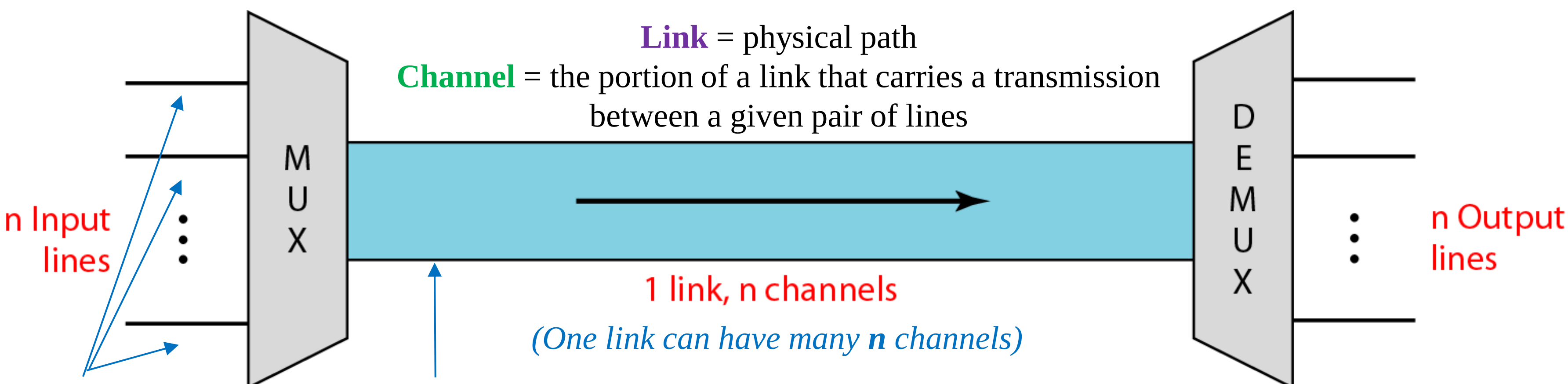
Multiplexing

- Whenever the **bandwidth of a medium** linking two devices is ***greater than*** the **bandwidth needs of the devices**, the ***link can be shared***.
  - If the bandwidth of a link is greater than the bandwidth needs of the devices connected to it, the ***bandwidth is wasted***.
  - An efficient system **maximizes the utilization** of all resources; ***bandwidth*** is one of the most precious resources we have in data communications.
- **Multiplexing** is the set of techniques that allows the ***simultaneous transmission of multiple signals*** *across a* ***single data link***.

Multiplexing *(cont'd)*

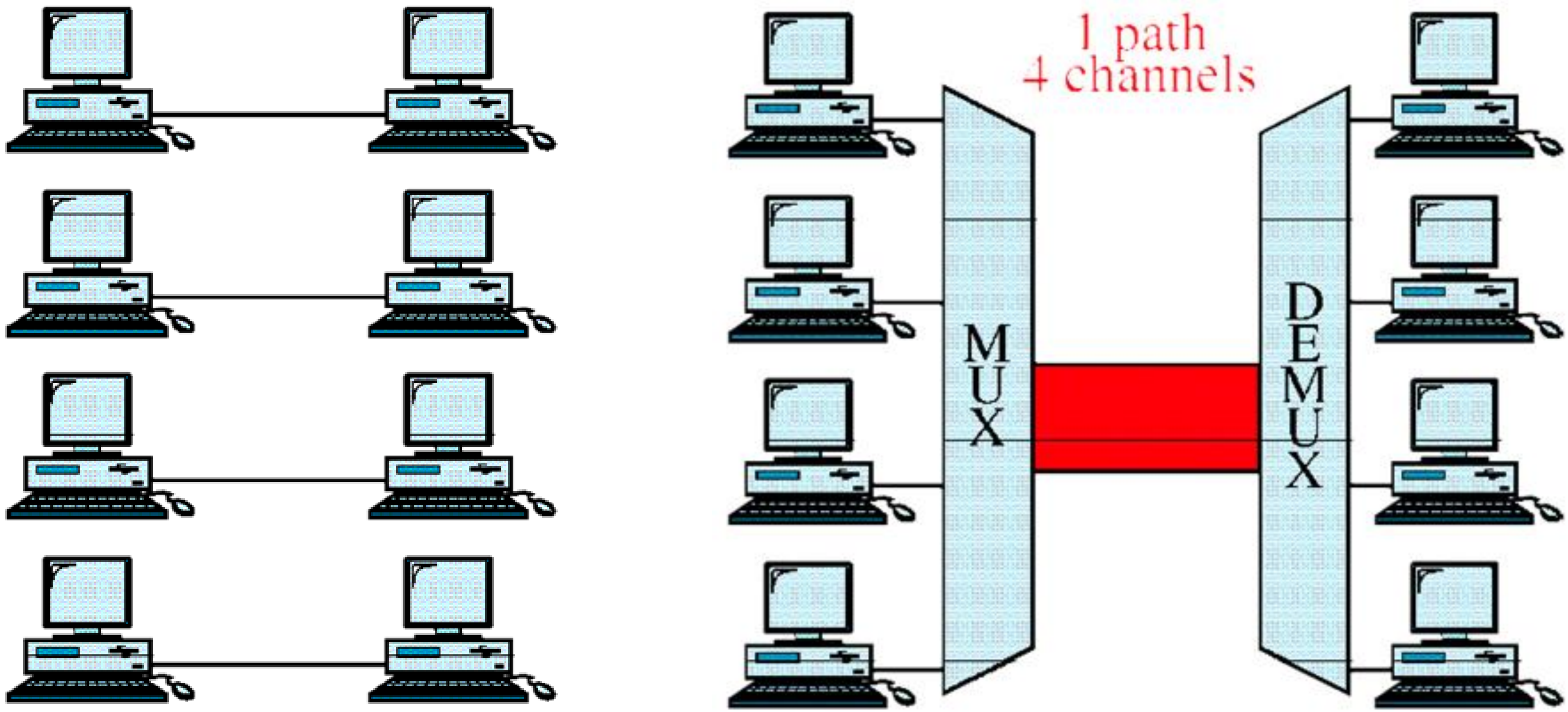
In a multiplexed system, ***n*** lines *share* the bandwidth of one link.

- 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.



N lines share **one** link

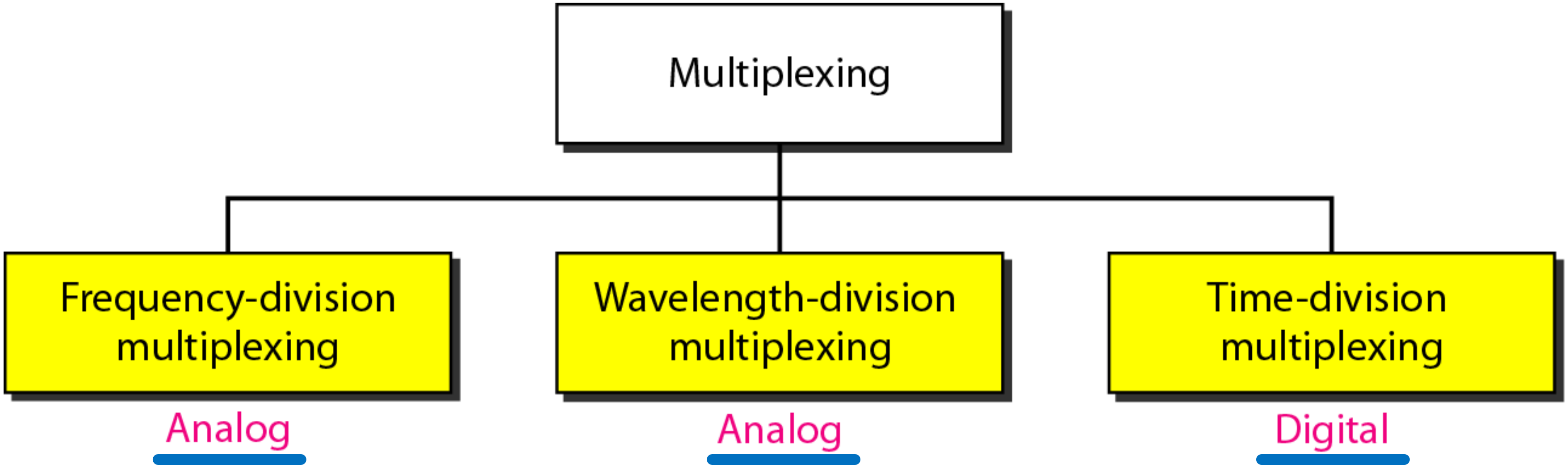
Multiplexing *(cont'd)*



a. No multiplexing b. Multiplexing

Multiplexing *(cont'd)*

- There are **three** basic multiplexing techniques:



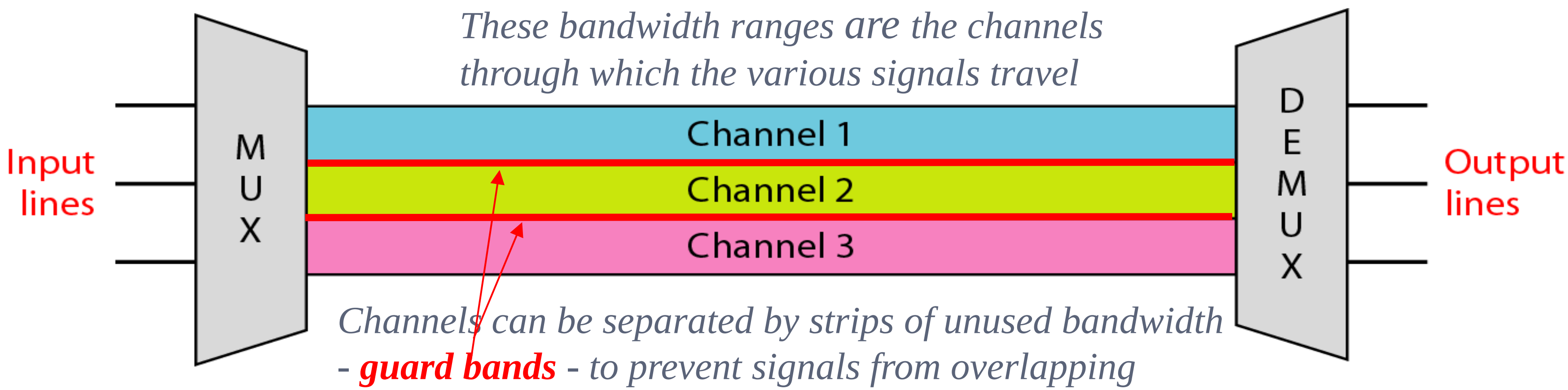
Frequency-Division Multiplexing (FDM)

FDM is the oldest multiplexing technique and is used in many fields of communication, including:

- broadcast television and radio,
- Cable television, and
- cell phones.

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.



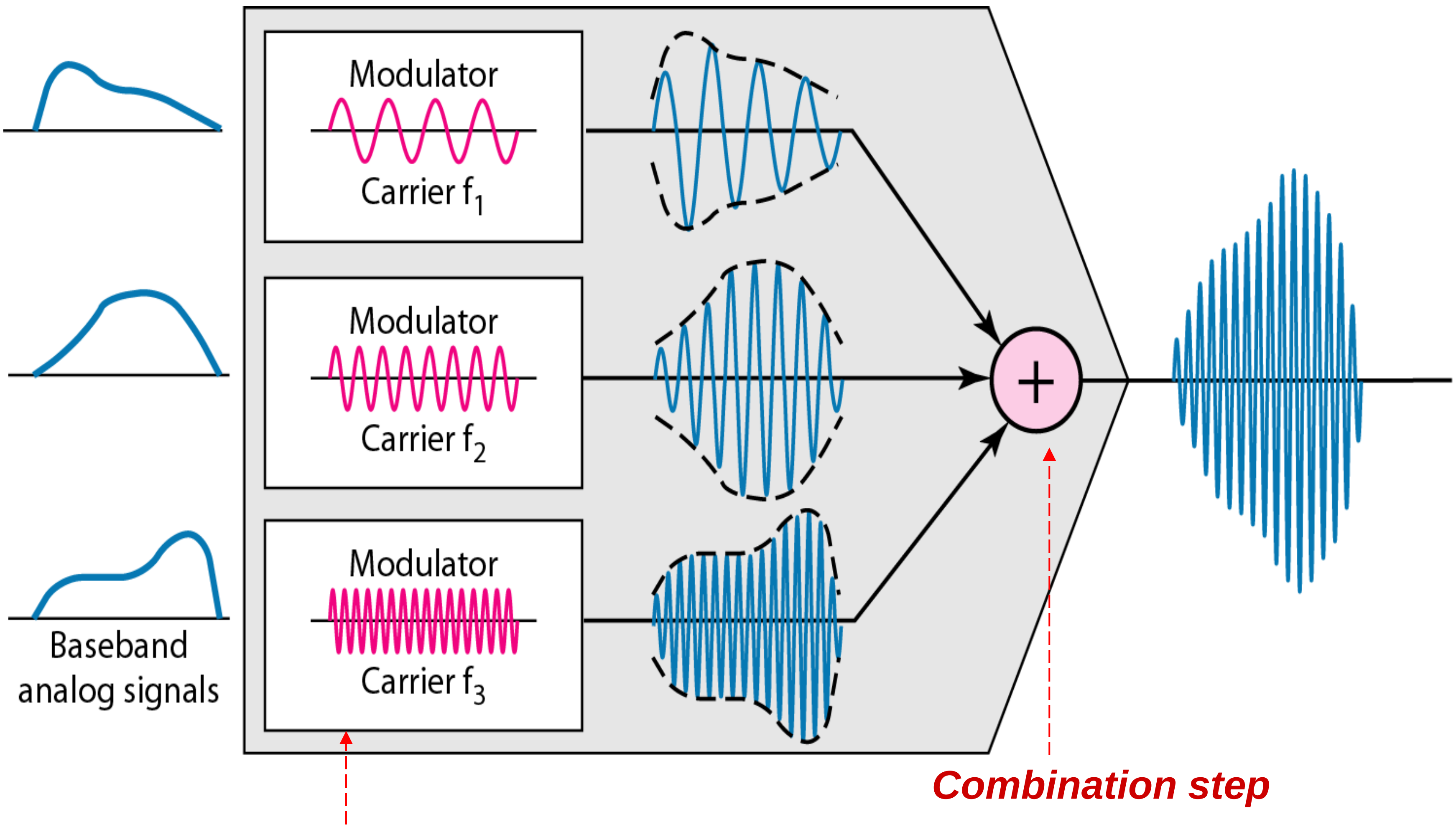
Note

FDM is an **analog multiplexing** technique that combines **analog signals**.

FDM – Multiplexing Process

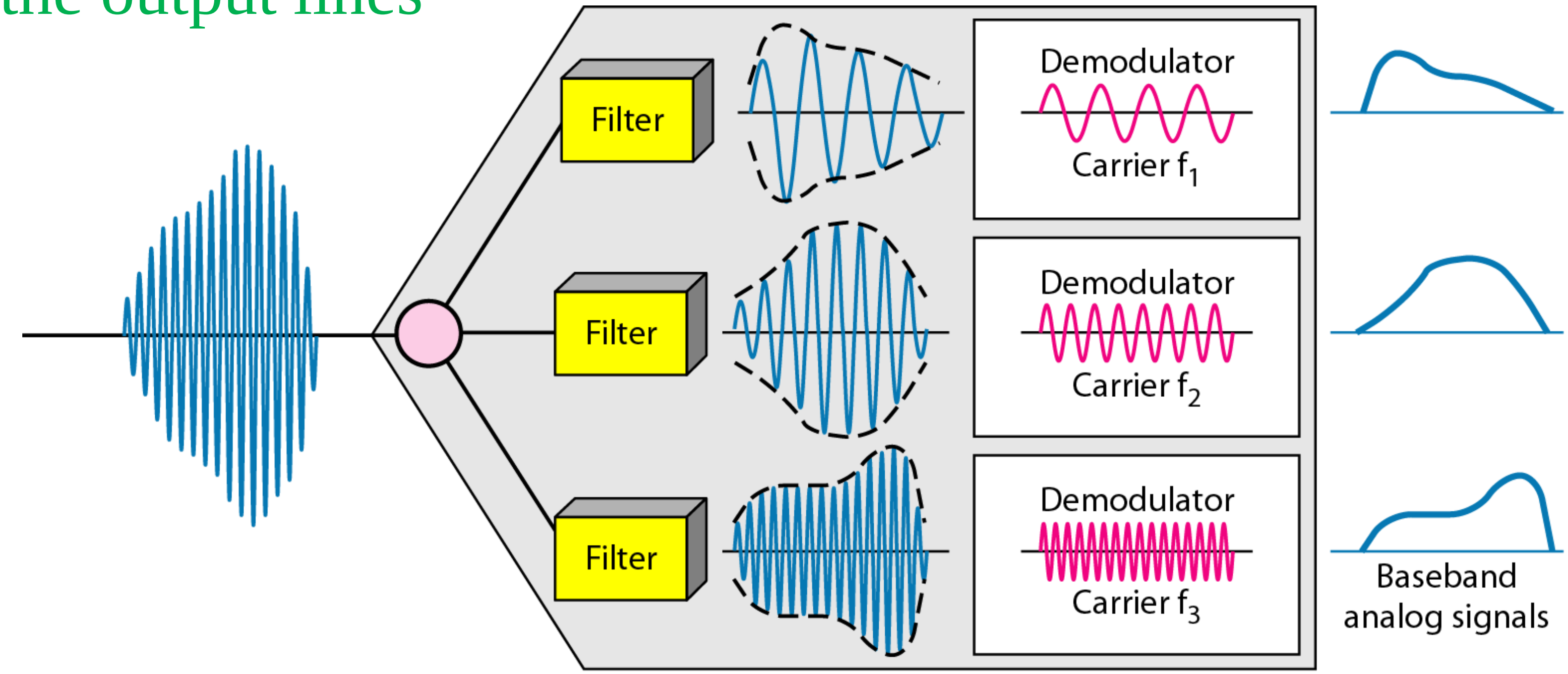
- **Each source** (*each signal generated by each sending device*) generates a signal of a ***similar frequency range***.
- Inside the **multiplexer**, these **similar signals** ***modulates different carrier frequencies*** *(such as f_1, f_2,* and *f_3)*.
- The resulting modulated signals are then ***combined into a single composite signal*** that is sent out over a media link that has enough bandwidth to accommodate it.

FDM – Multiplexing Process *(cont'd)*



FDM – Demultiplexing Process

- The **demultiplexer** 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



Ex. Of FMD

Cable television is still one of the more commonly found applications of FMD.

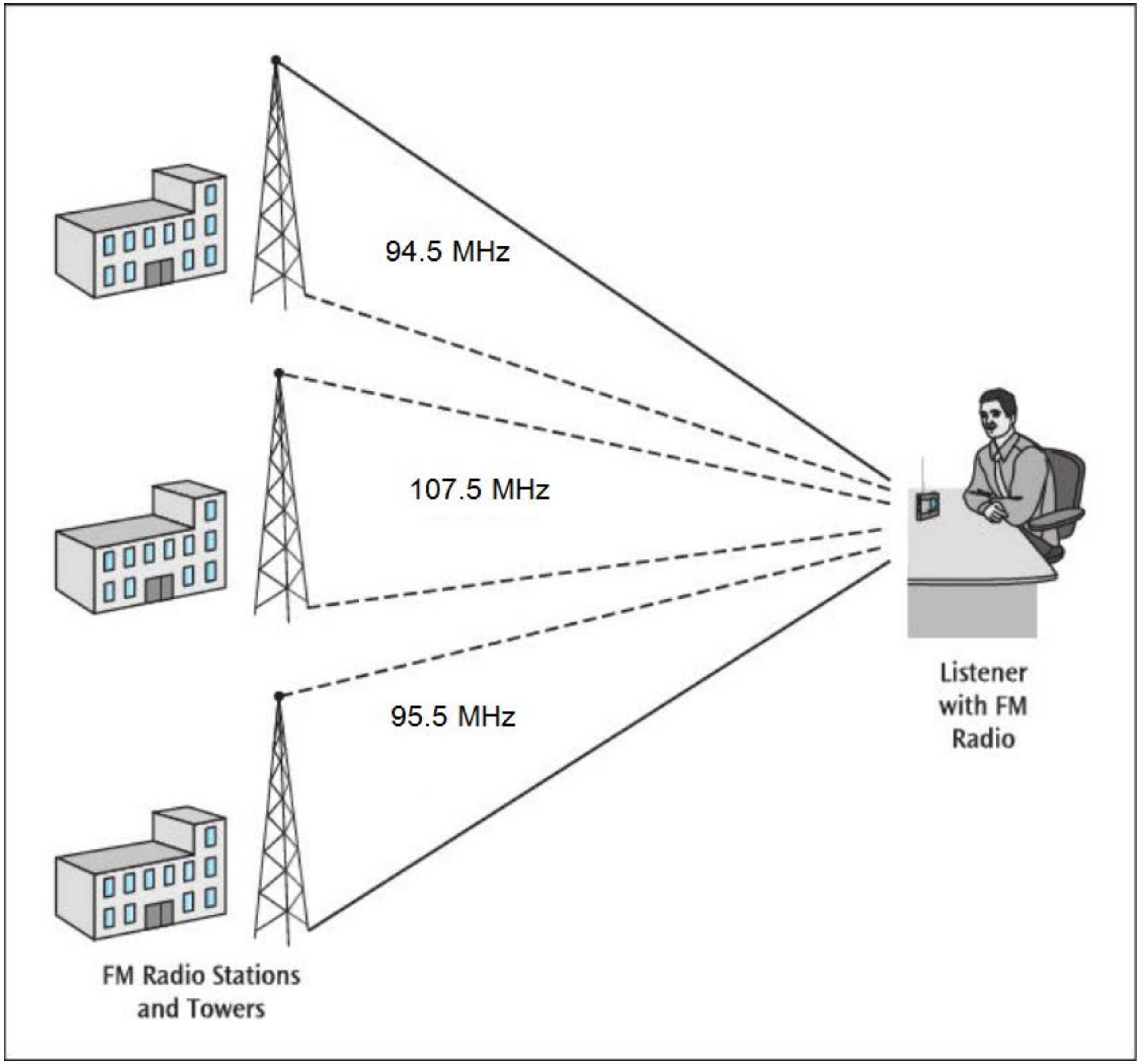
From Table 1:

- Each cable television channel is assigned a unique range of frequencies by the Federal Communications Commission (FCC),
- and these frequency assignments are fixed, or static.
- Note from Table 5-1 that the frequencies of the various channels do not overlap.

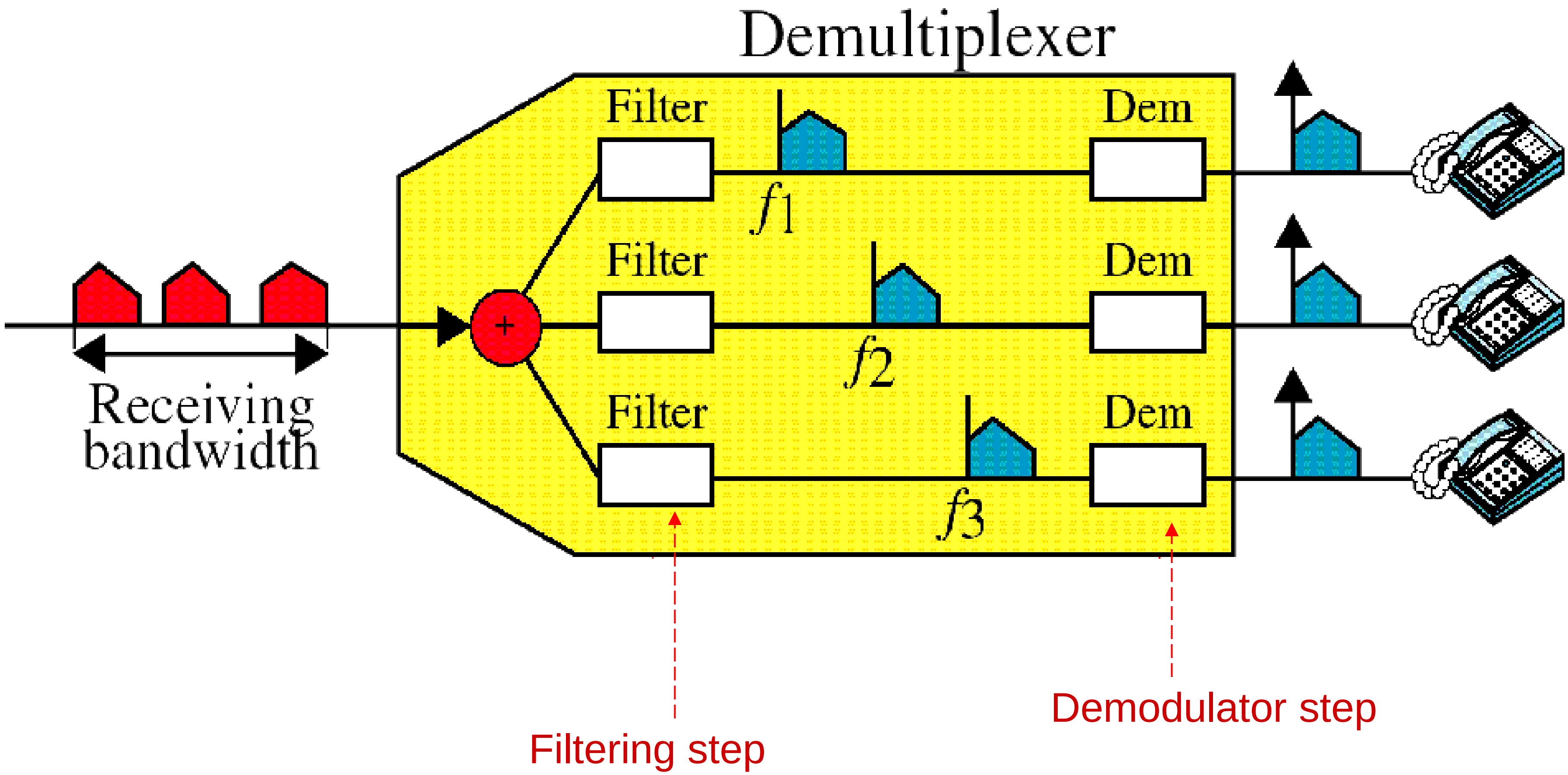
Table 1 Assignment of frequencies for cable television channels

	Channel	Frequency in MHz
Low-Band VHF and Cable	2	55–60
	3	61–66
	4	67–72
	5	77–82
	6	83–88
Mid-Band Cable	95	91–96
	96	97–102
	97	103–108
	98	109–114
	99	115–120
	14	121–126
	15	127–132
	16	133–138
	17	139–144
	18	145–150
	19	151–156
	20	157–162
	21	163–168
	22	169–174
High-Band VHF and Cable	7	175–180
	8	181–186
	9	187–192
	10	193–198
	11	199–204
	12	205–210
	13	211–216

Radio stations have multiplexed their radio signals onto a band of frequencies. Individual radios employ a demultiplexor (a tuner) to separate each radio signal from the others.



FDM – Demultiplexing Process *(cont'd)*

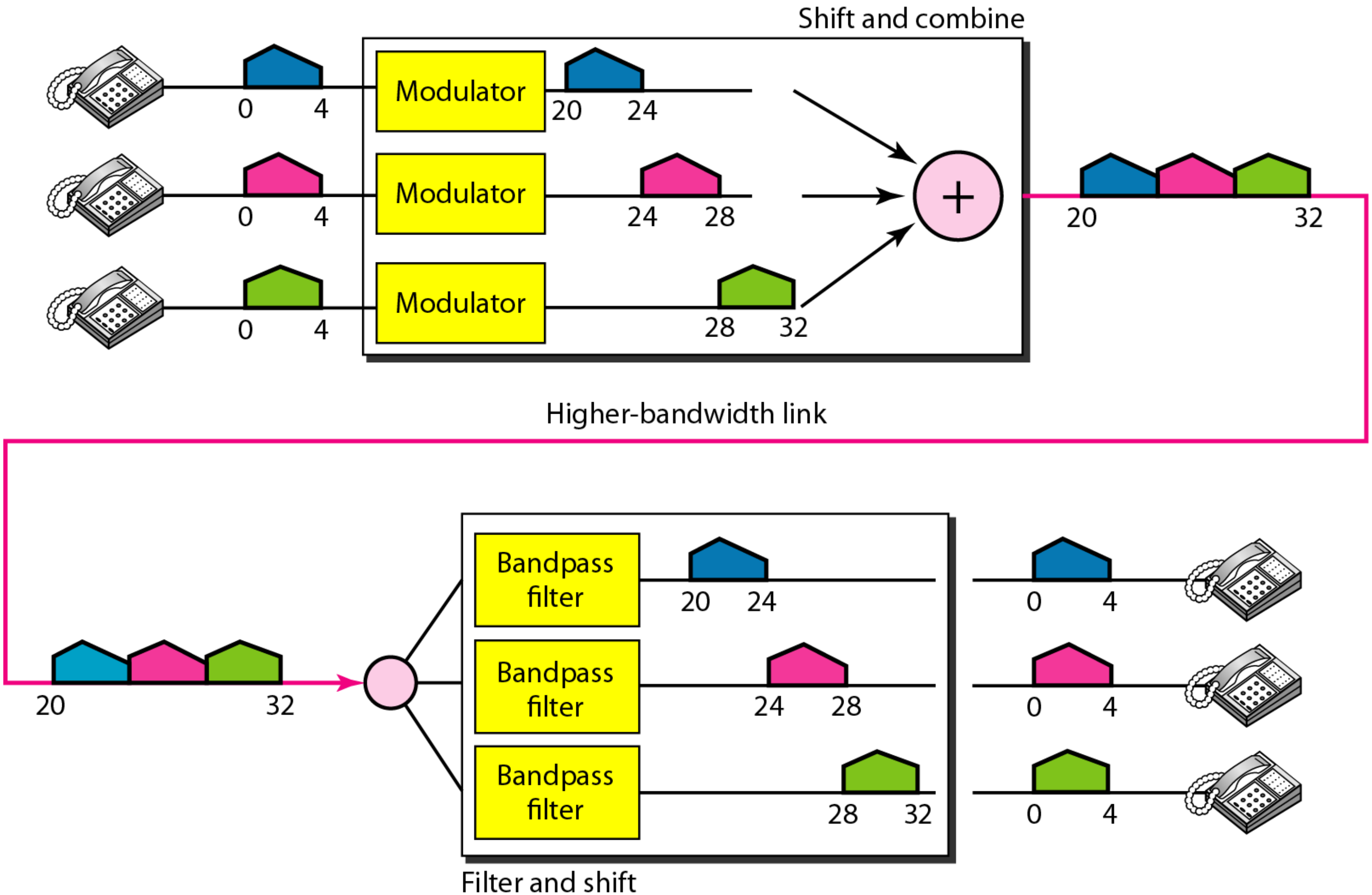


FDM – Example 1

- 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.

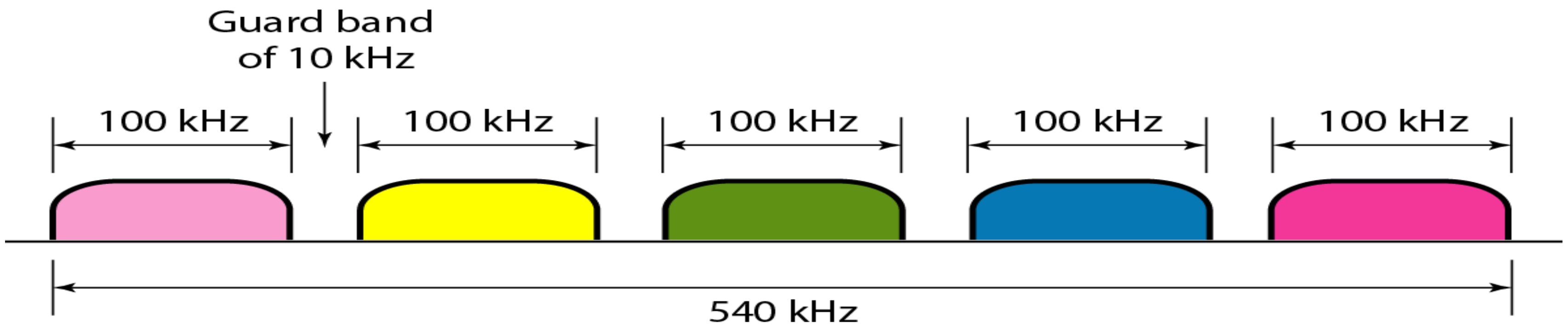
- **Solution**:
  - We shift *(modulate)* each of the three voice channels to a different bandwidth.

FDM – Example 1 *(cont'd)*



FDM – 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 $(5 \times 100) + (4 \times 10) = \mathbf{540\ kHz}$*



Example Applications of FDM

- A very common application of FDM is **AM** and **FM** radio broadcasting.
  - Radio uses the **air** as the transmission medium.
  - A special band from 530 to 1700 kHz is assigned to AM radio. All radio stations need to share this band. Each AM station needs 10 kHz of bandwidth.
  - Each station uses a different carrier frequency, which means it is **shifting its signal and multiplexing**. The signal that goes to the air is a combination of signals.
  - A receiver receives all these signals, but filters (by **tuning**) only the one which is desired.
  - Without multiplexing, only one AM station could broadcast to the common link, the air.

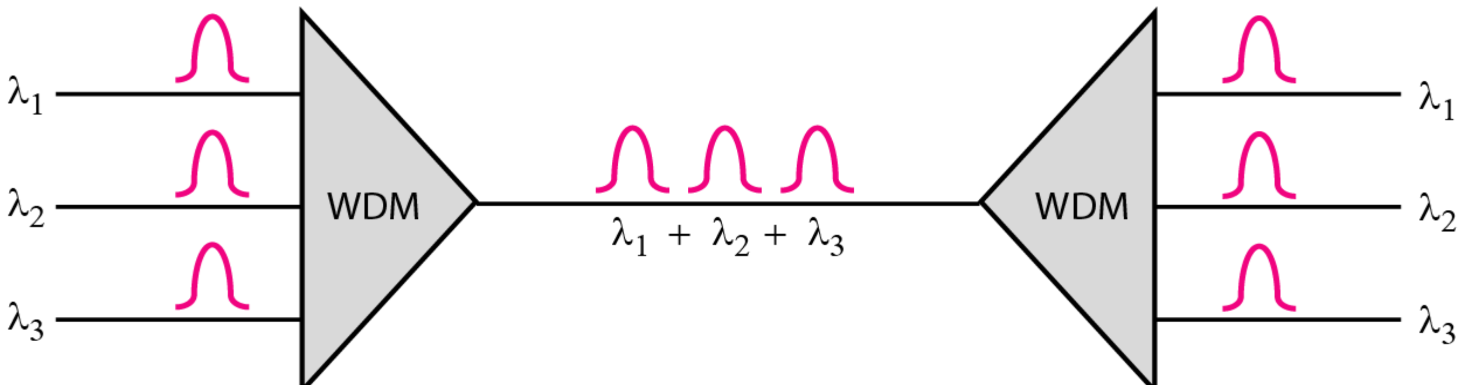
Wavelength-Division Multiplexing

Wavelength-Division Multiplexing

- **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 *(Cont'd)*

- **WDM** is conceptually the same as **FDM**, except that the multiplexing and demultiplexing involve ***optical signals*** transmitted through ***fiber-optic channels***.
  - The idea is the same: We are ***combining different signals of different frequencies***.
  - The difference is that the frequencies are **very high**.



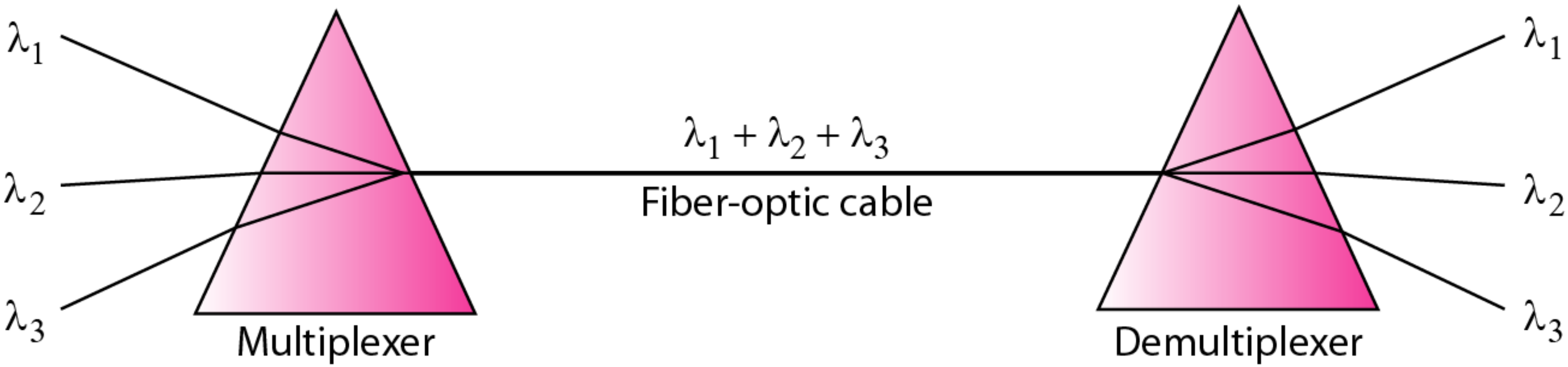
Note

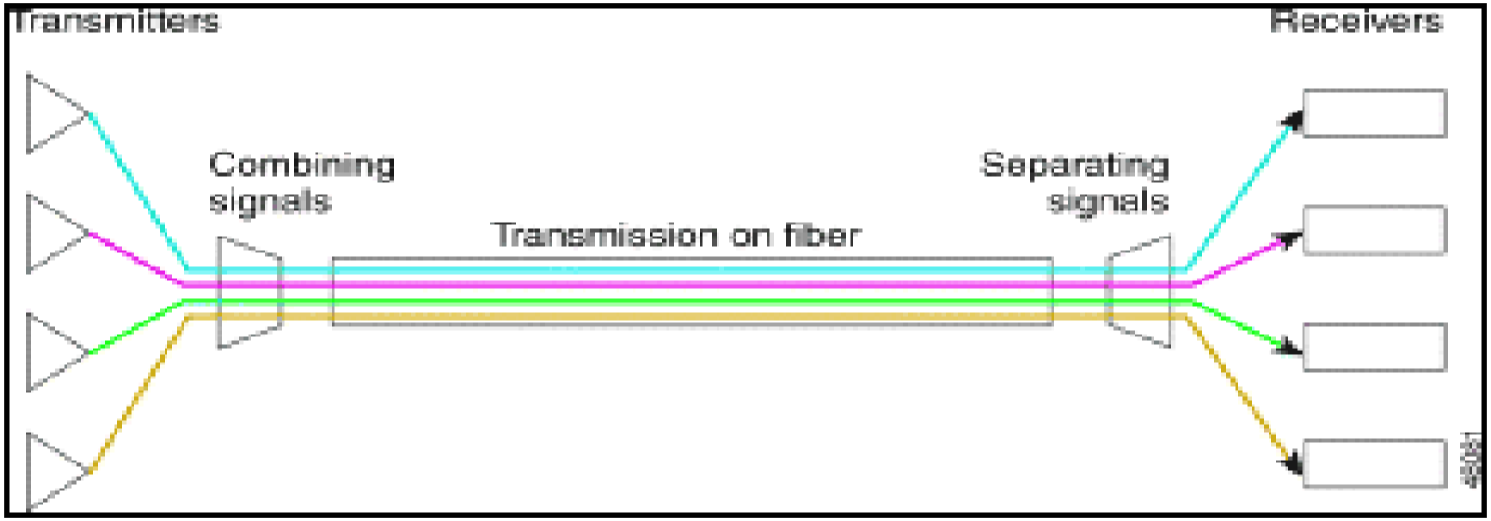
WDM is an analog multiplexing technique to combines optical signals.

WDM *(Cont'd)*

- Although **WDM** technology is very complex, the basic idea is very simple.
  - We want to combine multiple light sources into one single light at the multiplexer and do the reverse at the demultiplexer.
  - 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***.
  - 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 demultiplexer can also be made to reverse the process.

WDM *(Cont'd)*





Wavelength-Division Multiplexing

Time-Division Multiplexing (TDM)

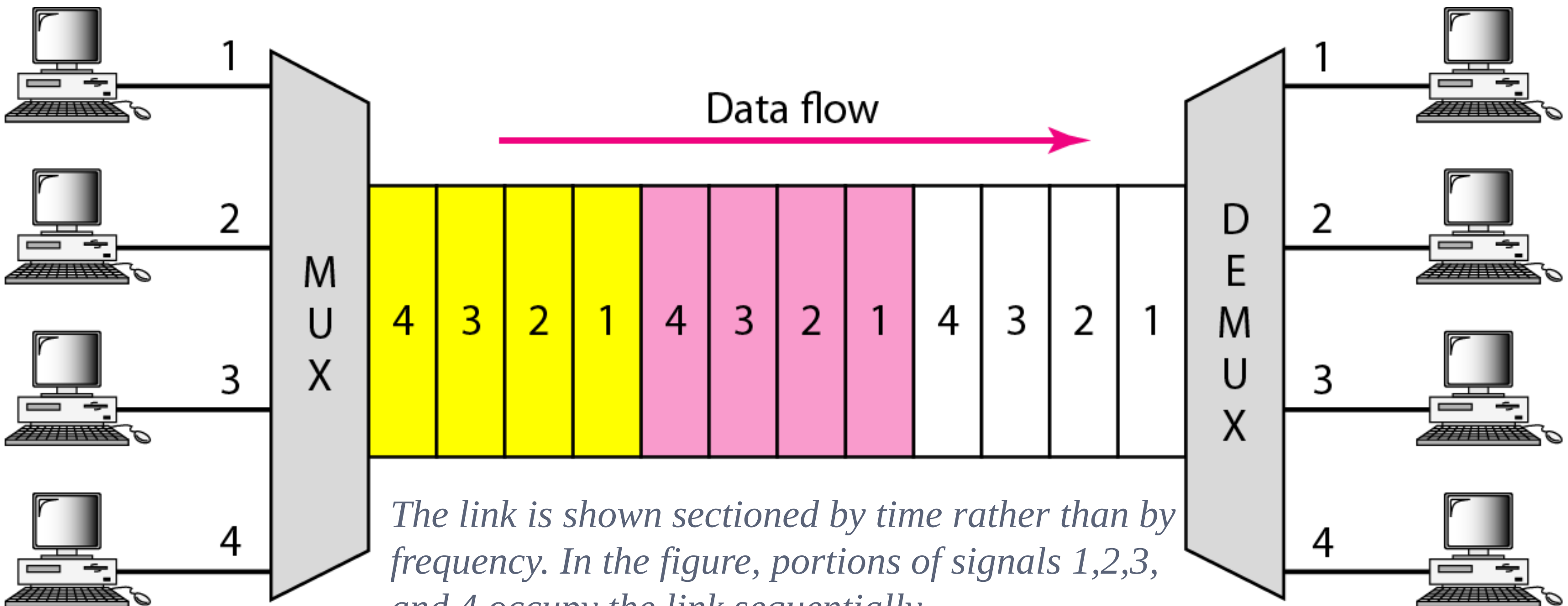
- **TDM** allows only one user at a time to transmit, and
- the sharing of the medium is accomplished by **dividing available transmission *time* among users**.

Time-Division Multiplexing

- **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**.
  - Digital data from different sources are combined into one timeshared link.
  - Each connection occupies a **portion of time** in the link.

TDM *(cont'd)*

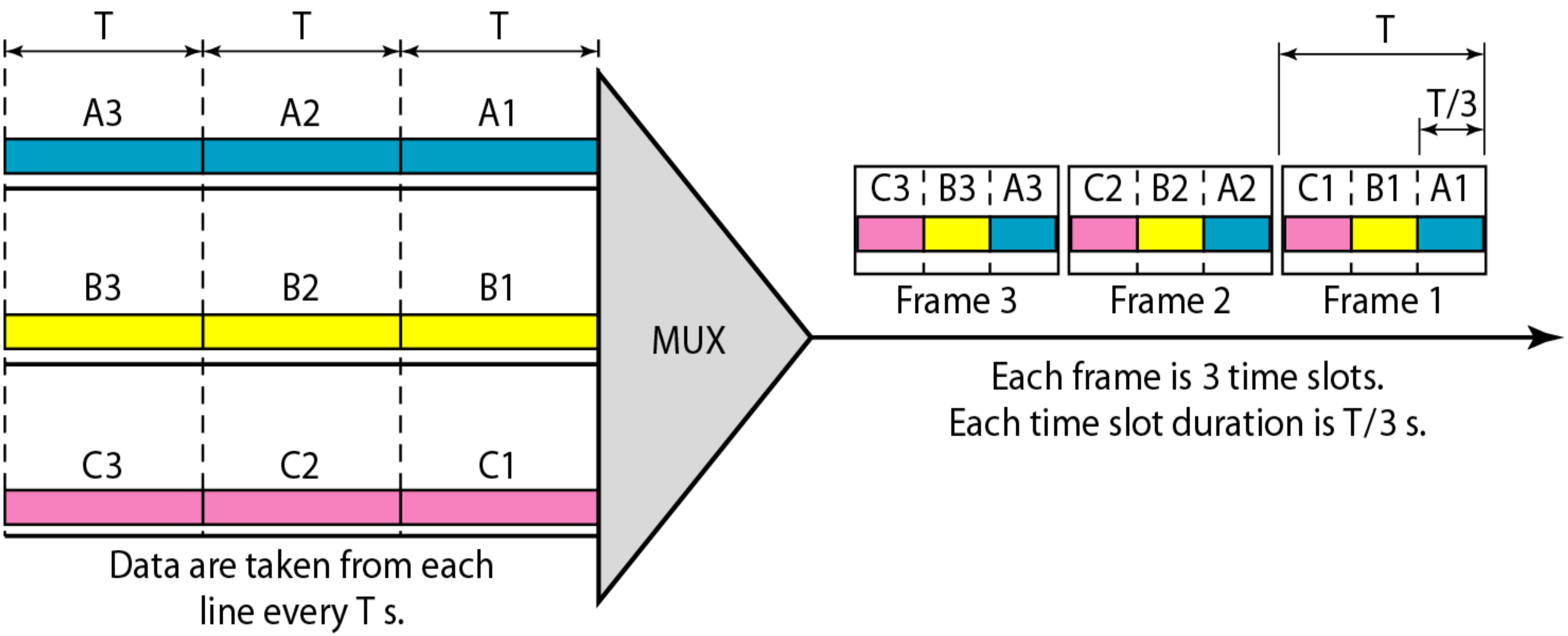


The link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1,2,3, and 4 occupy the link sequentially.

- We can divide TDM into **two** different schemes:
  - Synchronous TDM
  - Statistical TDM

Synchronous TDM

- 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***.

Time Slots and Frames *(cont'd)*

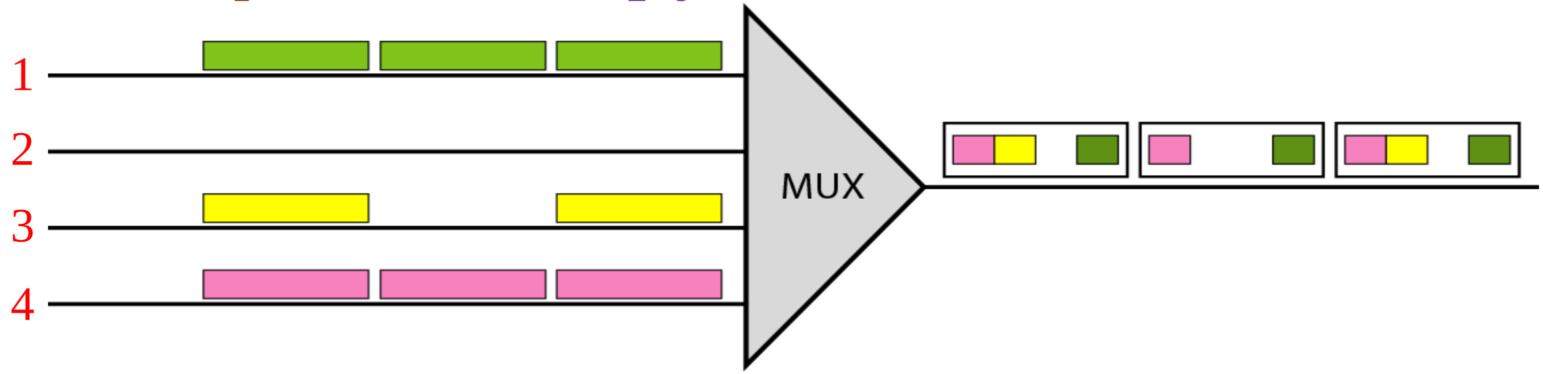
- In synchronous TDM, a round of data units from each input connection is collected into a **frame**.
  - If we have ***n*** connections, a frame is divided into ***n*** time slots and one slot is allocated for each unit, one for each input line.
  - If the duration of the input unit is ***T***, the duration of each slot is ***T/n*** and the duration of each frame is ***T***.
- The data rate of the output link must be ***n* times** the data rate of a connection to guarantee the flow of data.

Time Slots and Frames *(cont'd)*

- Time slots are grouped into frames.
- A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.
- In a system with ***n*** input lines, each frame has ***n*** slots, with each slot allocated to carrying data from a specific input line.

Synchronous TDM – Empty Slots

- One problem of 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***.



  - The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.
  - **Statistical TDM** can improve the efficiency by removing the empty slots from the frame

Statistical TDM

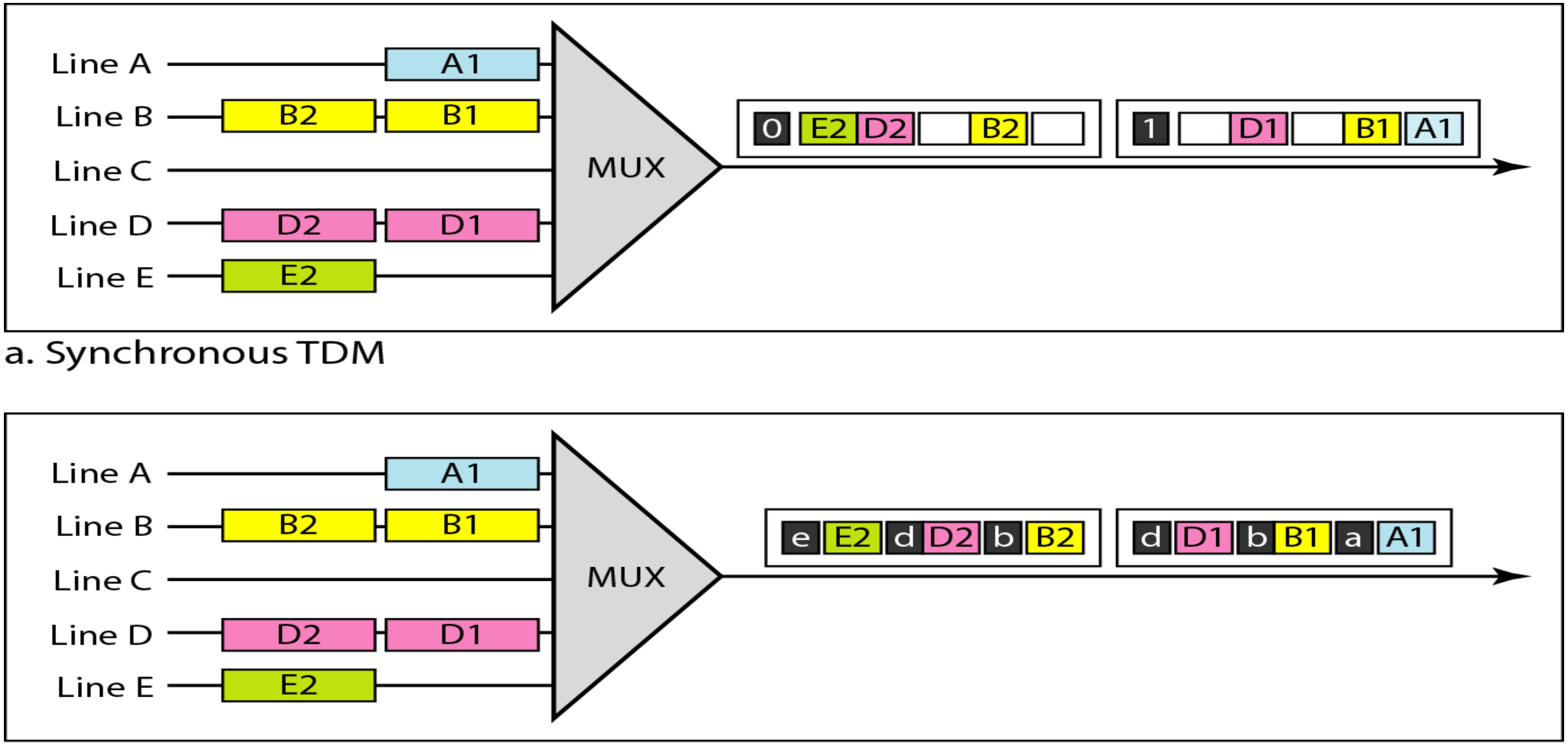
- In **synchronous TDM**, *each input has a **reserved slot** in the output frame*.
  - This can be ***inefficient*** if some input lines have ***no data*** to send.

- In **statistical TDM**, ***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.

Statistical TDM *(cont'd)*

- In **statistical TDM**, 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 TDM *(cont'd)*



a. Synchronous TDM

b. Statistical TDM

- In (**a**), some slots are empty because the corresponding line does not have data to send.
- In (**b**), no slot is left empty as long as there are data to be sent by any input line.

Statistical TDM - Addressing

- In the figure of the previous slide, shows a major difference between slots in synchronous TDM and statistical TDM.
  - 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.
  - If the multiplexer and the demultiplexer are synchronized, this is guaranteed.

Statistical TDM – Addressing *(cont'd)*

- In **statistical TDM**, there is no fixed relationship between the inputs and outputs because there are no preassigned or reserved slots.
  - We need to ***include the address of the receiver*** inside each slot to show where it is to be delivered.
  - The addressing in its simplest form can be ***n*** bits to define ***N*** different output lines with $\boldsymbol{n = \log_2 N}$.
  - For example, for **eight** different output lines, we need a **3-bit** address.

Statistical TDM – 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.
  - This would mean an overhead of 300 percent.
  - In statistical TDM, a block of data is usually many bytes while the address is just a few bytes.

Statistical TDM – No Synchronization Bit

- There is another difference between synchronous and statistical TDM, but this time it is ***at the frame level***.
  - The frames in statistical TDM ***need not*** be synchronized, so we do not need synchronization bits.

Statistical TDM – 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**.

Reference

1. Behrouz A. Forouzan. 2012. ***Data Communications and Networking***. 5th edition. McGraw-Hill Inc.