Faculty of Applied Sciences
B.Sc. in Computing

Academic Year 2022/2023 2nd Semester

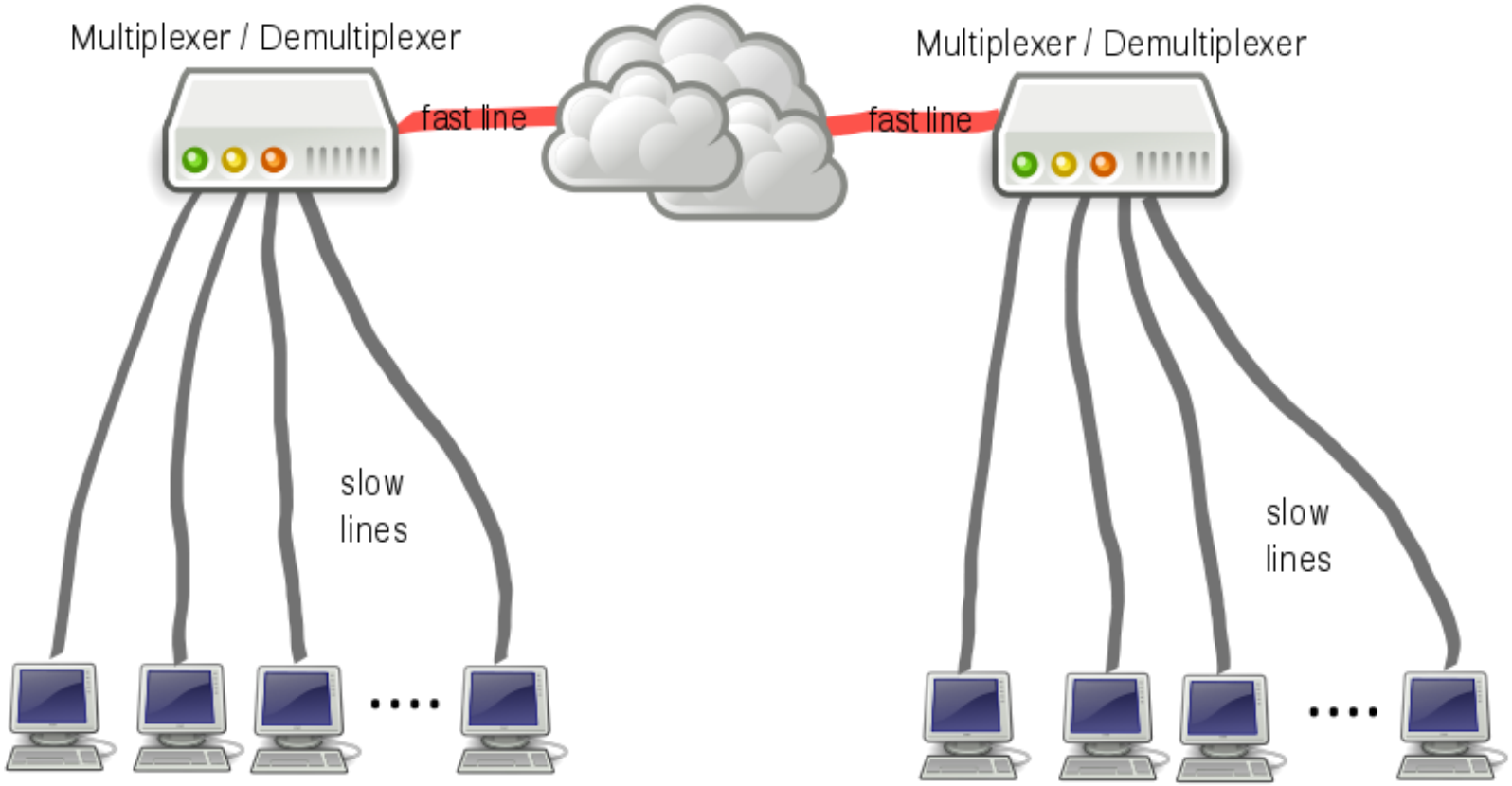
COMP123 – 121/122

Data Communications

Multiplexing

General Multiplex Scheme

- Discussion: how do we share a fast line?



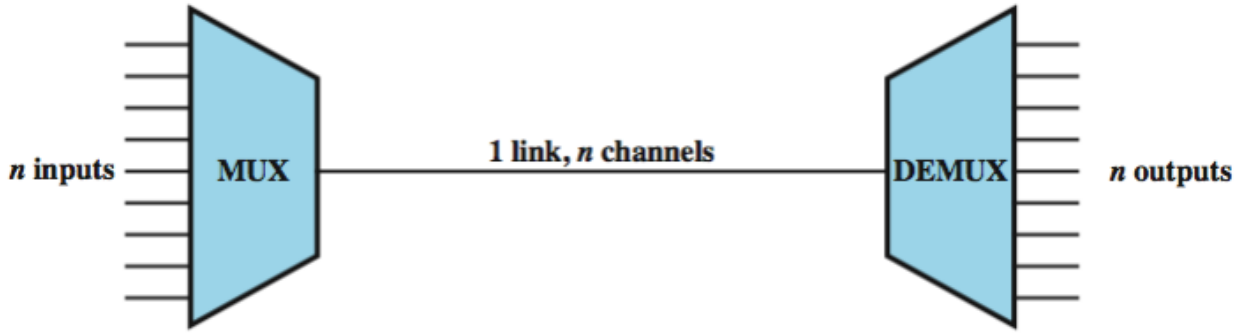
Source: http://en.wikipedia.org/wiki/Multiplexing

Multiplexing

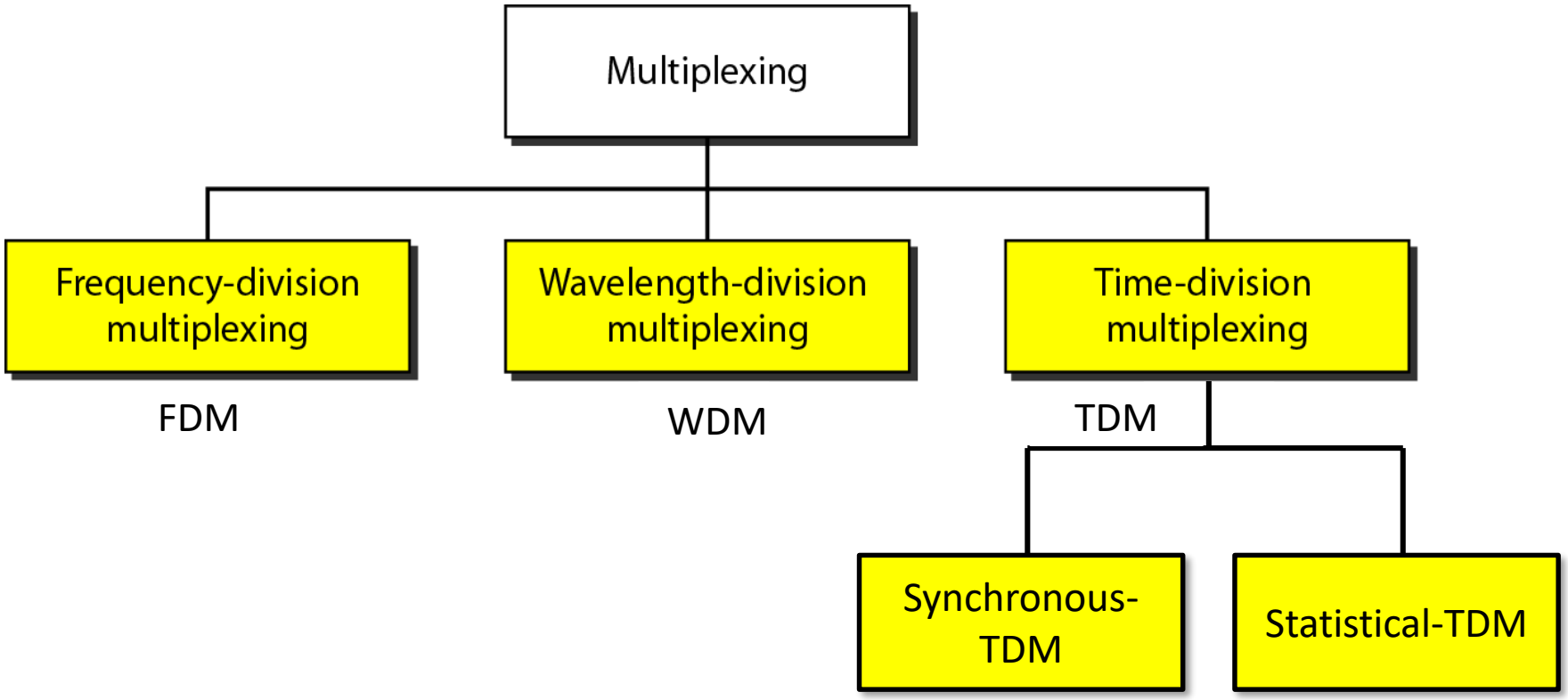
- To make efficient use of high-speed telecommunications lines → minimizing circuit costs
- several transmission sources to share a larger transmission capacity (multiple links on 1 physical line)
- A common application of multiplexing is in long distance communications.
- Connections on networks are usually high-capacity fiber, coaxial, or microwave links.
- These links can carry large number of voice and data transmissions simultaneously using multiplexing.

Multiplexer/Demultiplexer

- A multiplexer (**MUX**) selects one of several analog or digital input signals and forwards the selected input into a single line.
- A demultiplexer (**DEMUX**) takes a single input signal and selects one of many data-output-lines, which is connected to the single input.
- Sometimes just called a **Multiplexer**



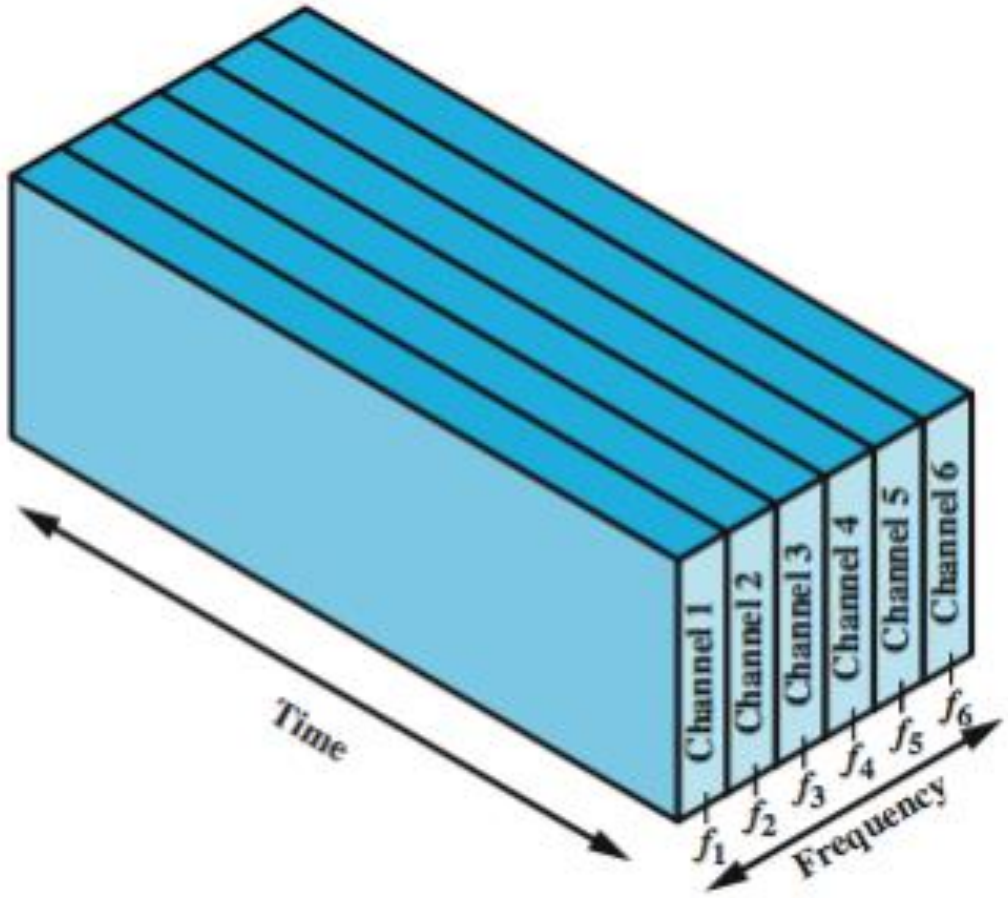
Categories of Multiplexing



Frequency Division Multiplexing (FDM)

- Multiple messages are transmitted simultaneously over a wideband channel
- Each signal is modulated onto a different carrier frequency
- The FDM signal has a total bandwidth that is larger than the sum of the bandwidth of the analog or digital signals
- Each component is then demodulated to recover the original signal

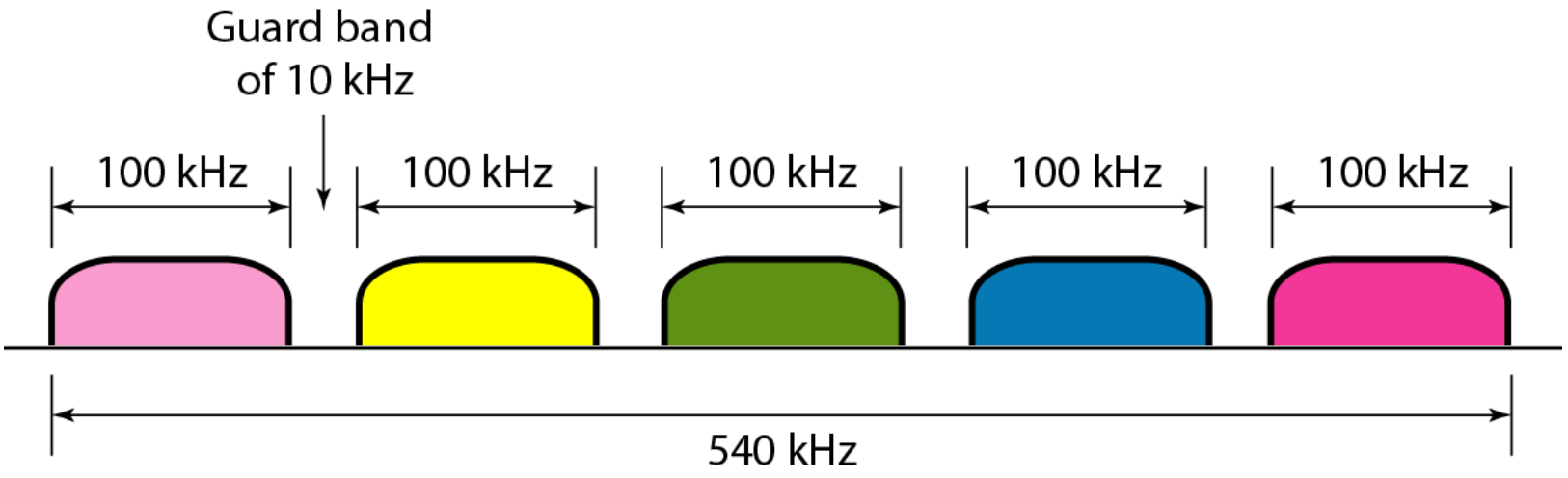
Frequency Division Multiplexing (FDM)



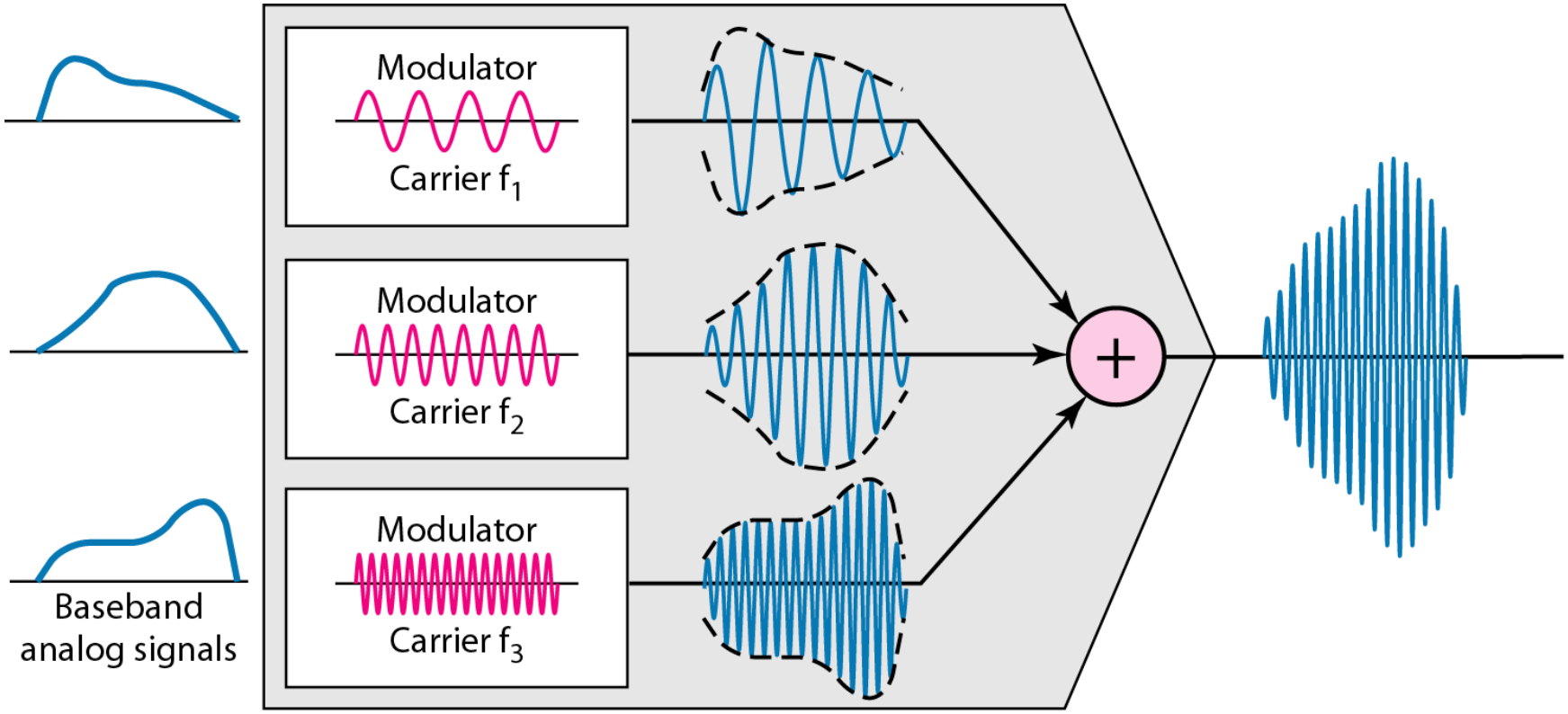
Frequency Division Multiplexing (FDM)

FDM – Guard Band

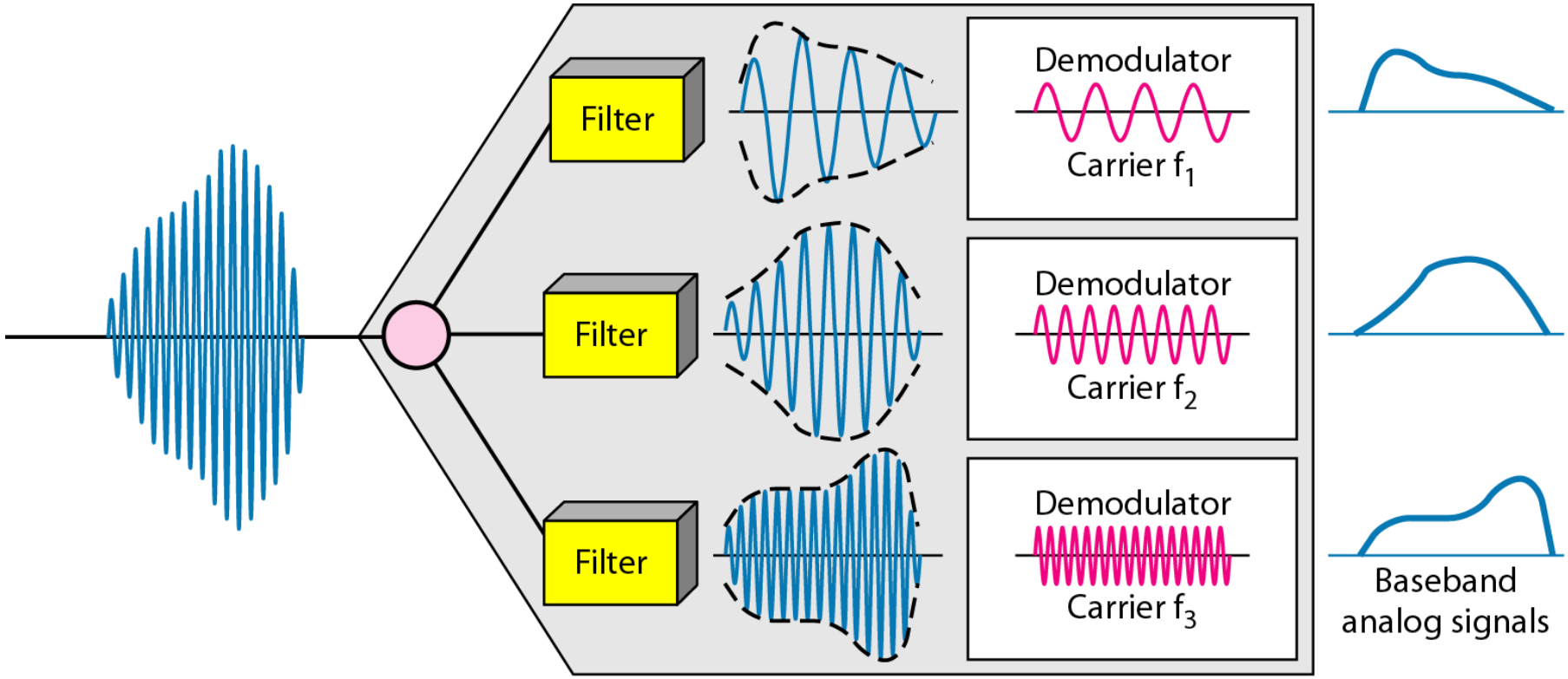
- Additional bandwidth between adjacent channels is needed to prevent interference
- This additional bandwidth is called Guard Band



FDM Process (Multiplexing)



FDM Process (De-multiplexing)



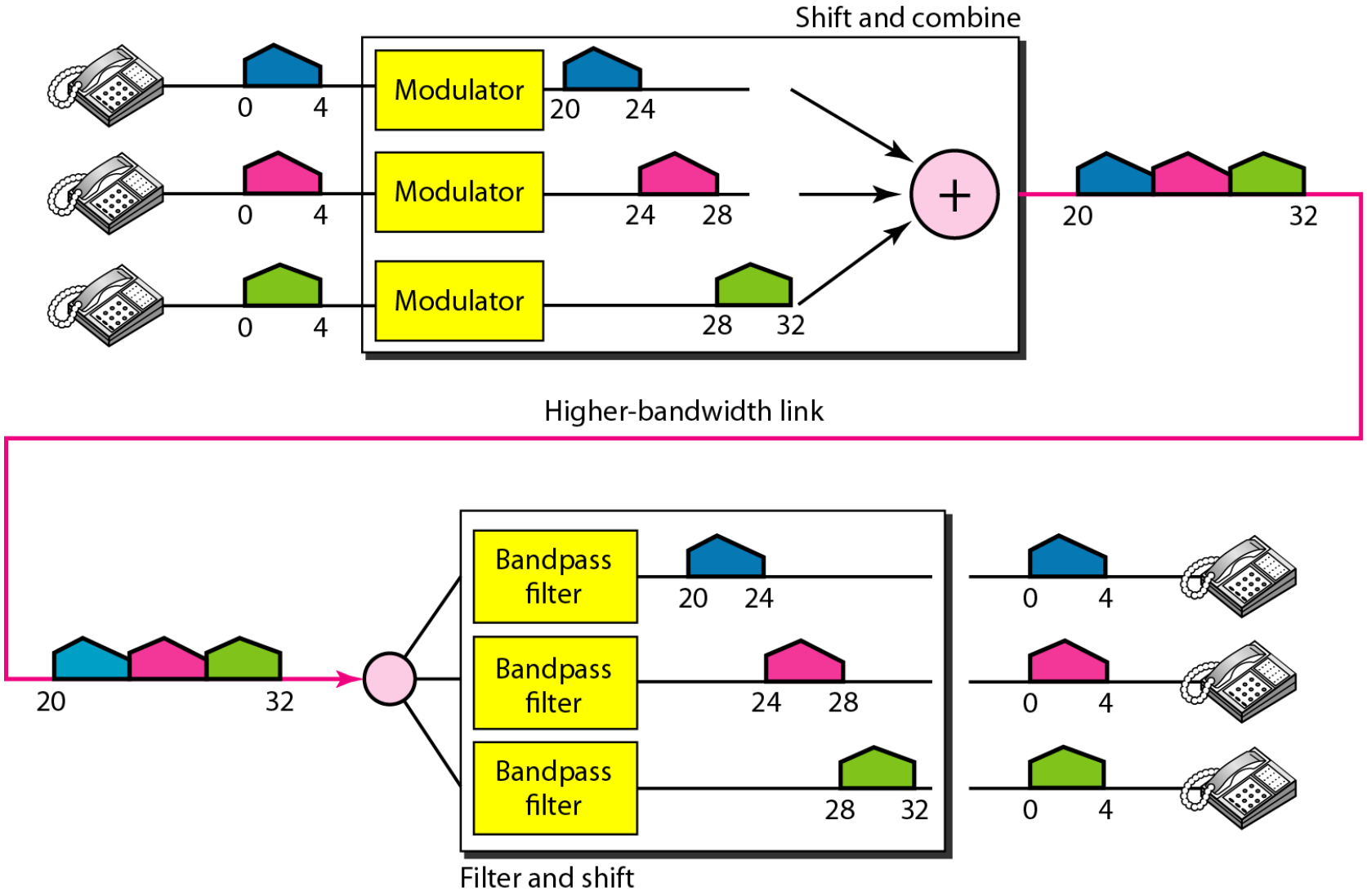
Example of FDM (1/2)

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.

Example of FDM (2/2)



Analog Carrier Systems

- Long-distance links use an FDM hierarchy
- AT&T (USA) and ITU-T (International) variants

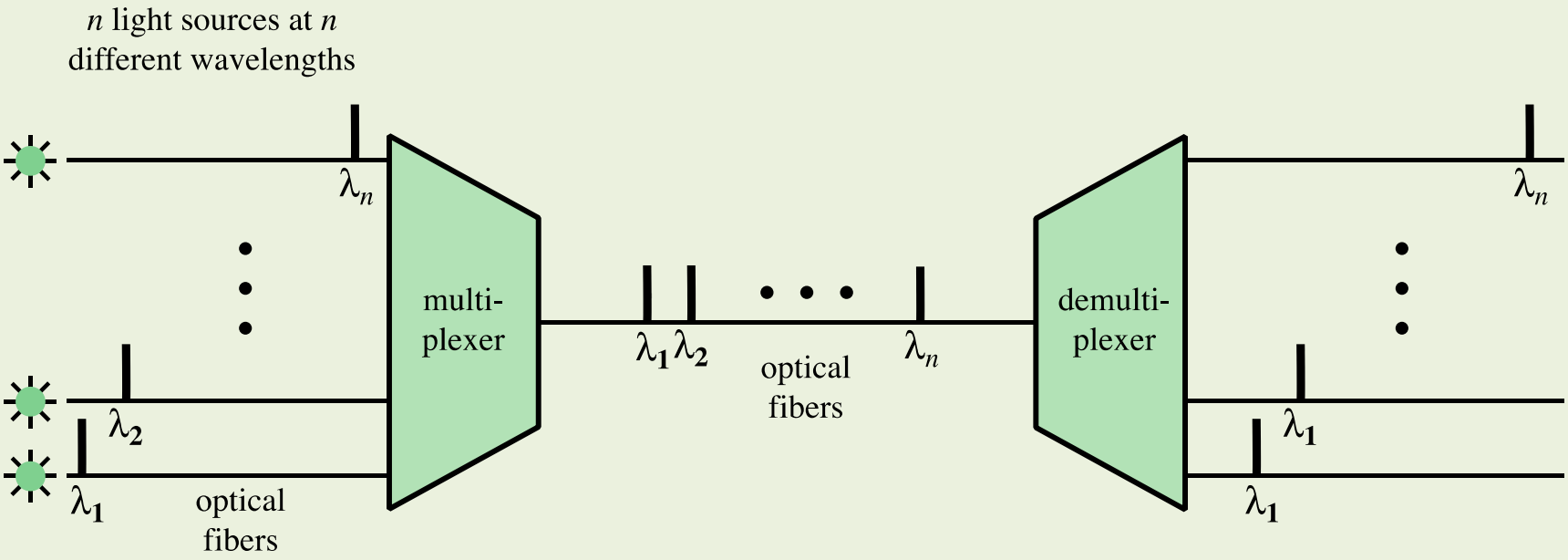
Group	Supergroup	Mastergroup
• 12 voice channels (4kHz each) = 48kHz • Range 60kHz to 108kHz	• FDM of 5 group signals supports 60 channels • Carriers between 420kHz and 612 kHz	• FDM of 10 supergroups supports 600 channels

- Original signal can be modulated many times

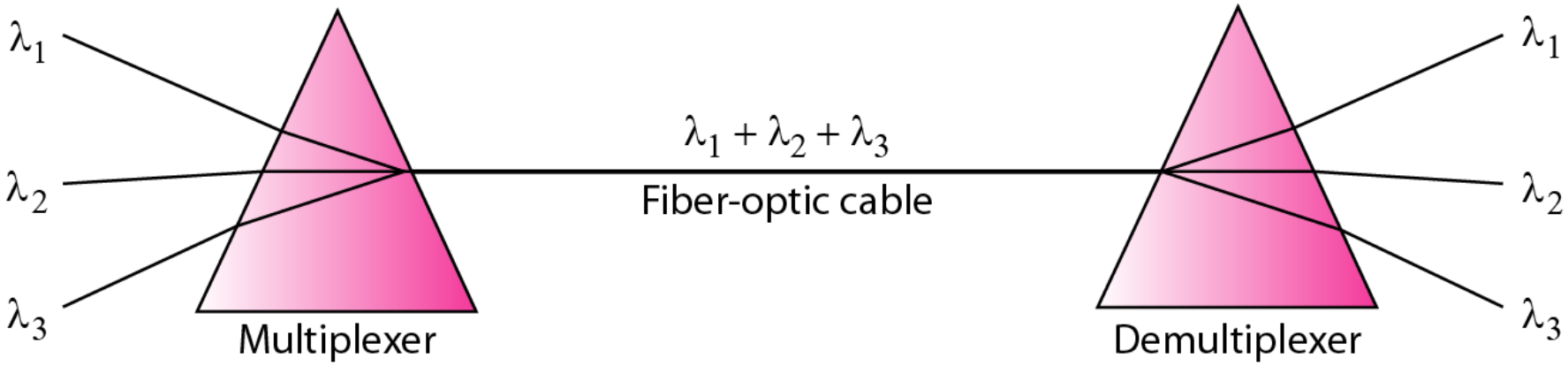
Wavelength Division Multiplexing (WDM)

- FDM with multiple beams of light at different freq.
- Carried over optical fiber links
  - commercial systems with 160 channels of 10 Gbps
  - lab demo of 256 channels 39.8 Gbps
- Architecture similar to other FDM systems
  - Multiplexer consolidates laser sources (1550nm) for transmission over single fiber
  - Optical amplifiers amplify all wavelengths
  - Demux separates channels at the destination

Wavelength Division Multiplexing (WDM)

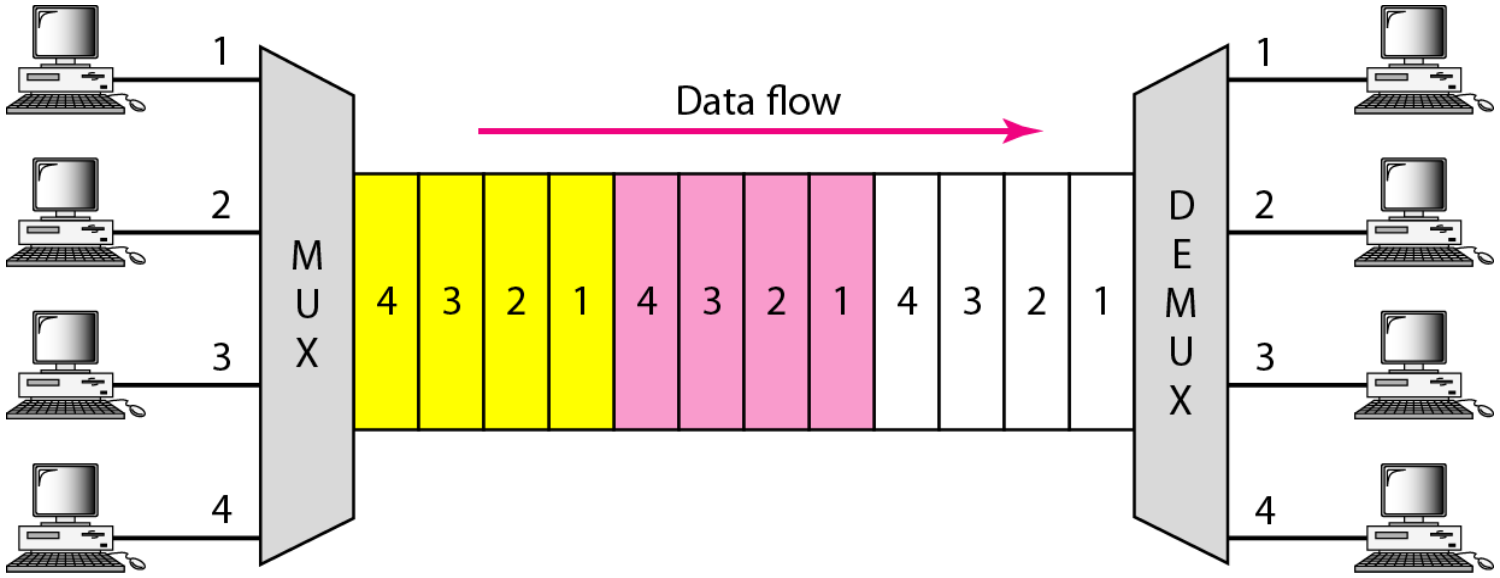


Prisms in WDM Multiplexing and De-multiplexing

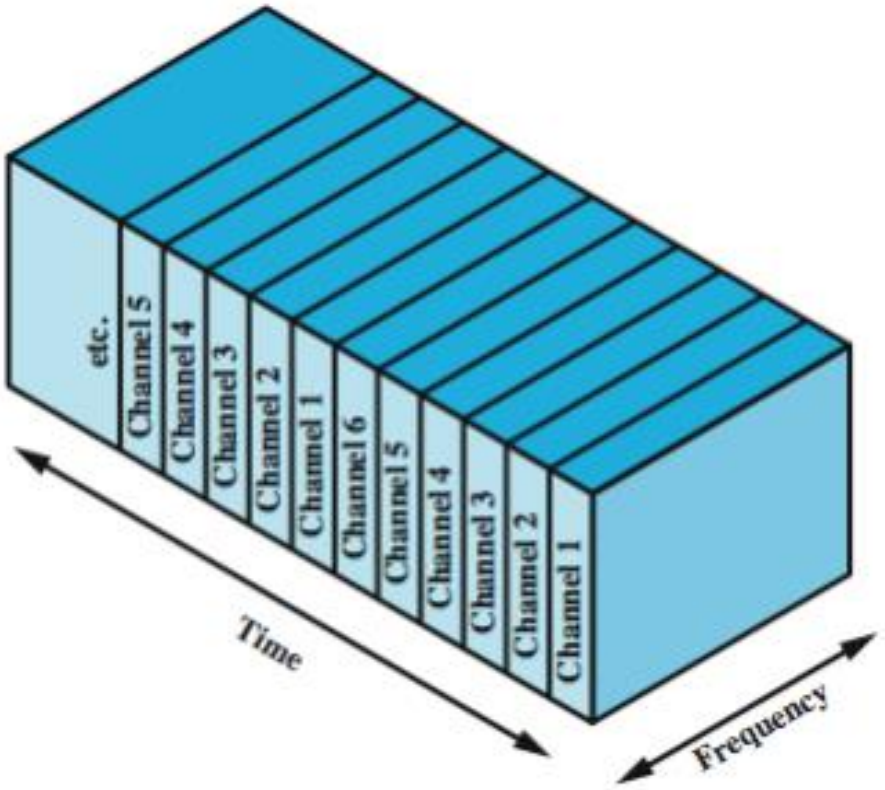


Time-division Multiplexing (TDM)

- A digital process that allows several connections to share, in time, the high bandwidth of a link
- Each connection occupies a portion of time in the link
- Two different schemes: **synchronous** and **statistical**



Time-division Multiplexing (TDM)



Synchronous-TDM System Overview (1/2)

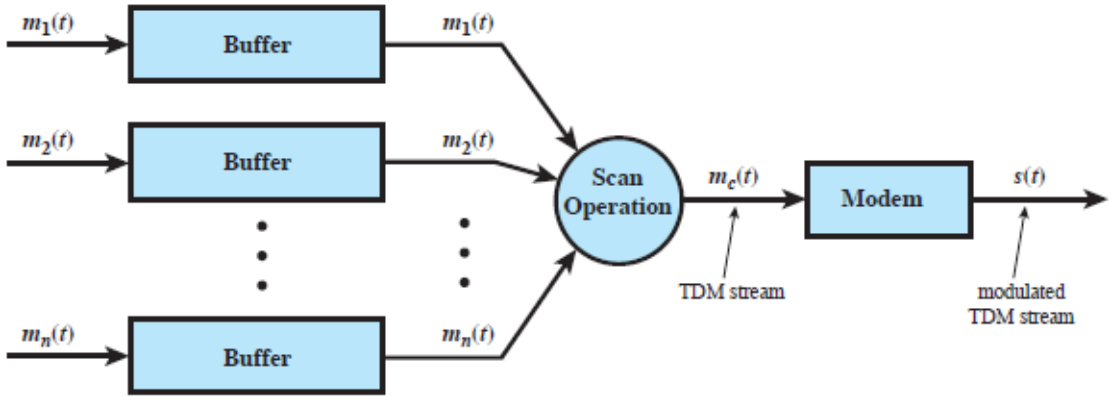
- A number of analog or digital signals are to be multiplexed onto the same transmission medium
- The incoming data from each source are briefly **buffered**.
- The buffers are scanned sequentially to form a composite digital data stream
- The data are organized into **frames**. Each frame contains a cycle of **time slots** and each source is assigned one or more time slots per frame

Synchronous-TDM System Overview (2/2)

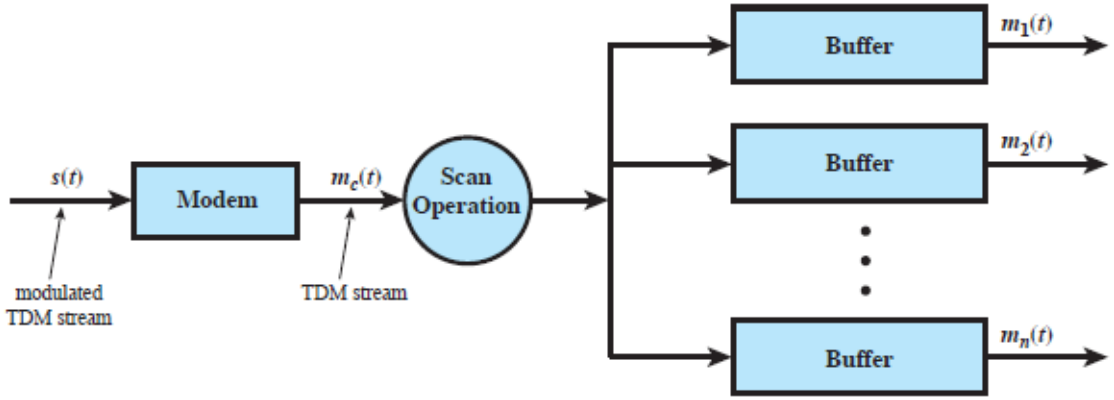
- The time slots are **pre-assigned** to sources and fixed, which are transmitted whether or not the source has data to send

- At the receiver, the interleaved data are de-multiplexed and routed to the appropriate destination buffer.

Synchronous-TDM System Overview



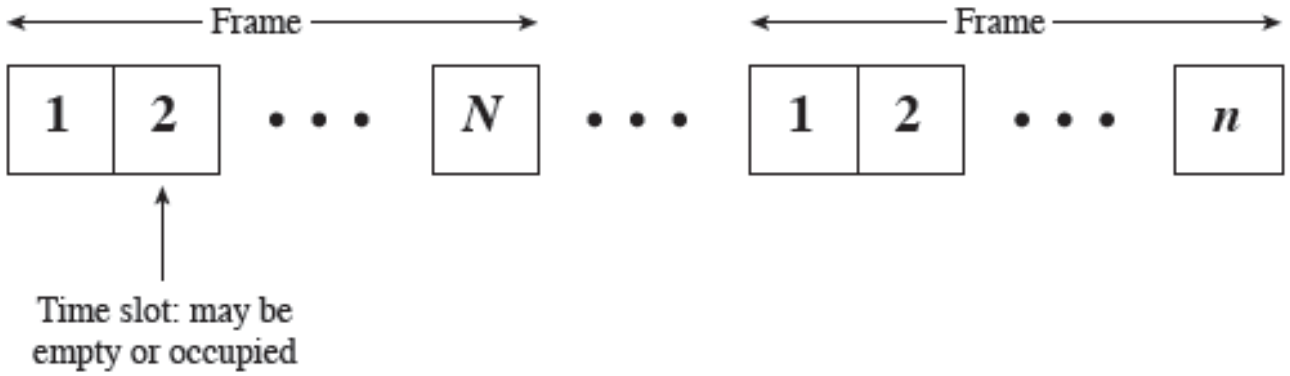
Transmitter



Receiver

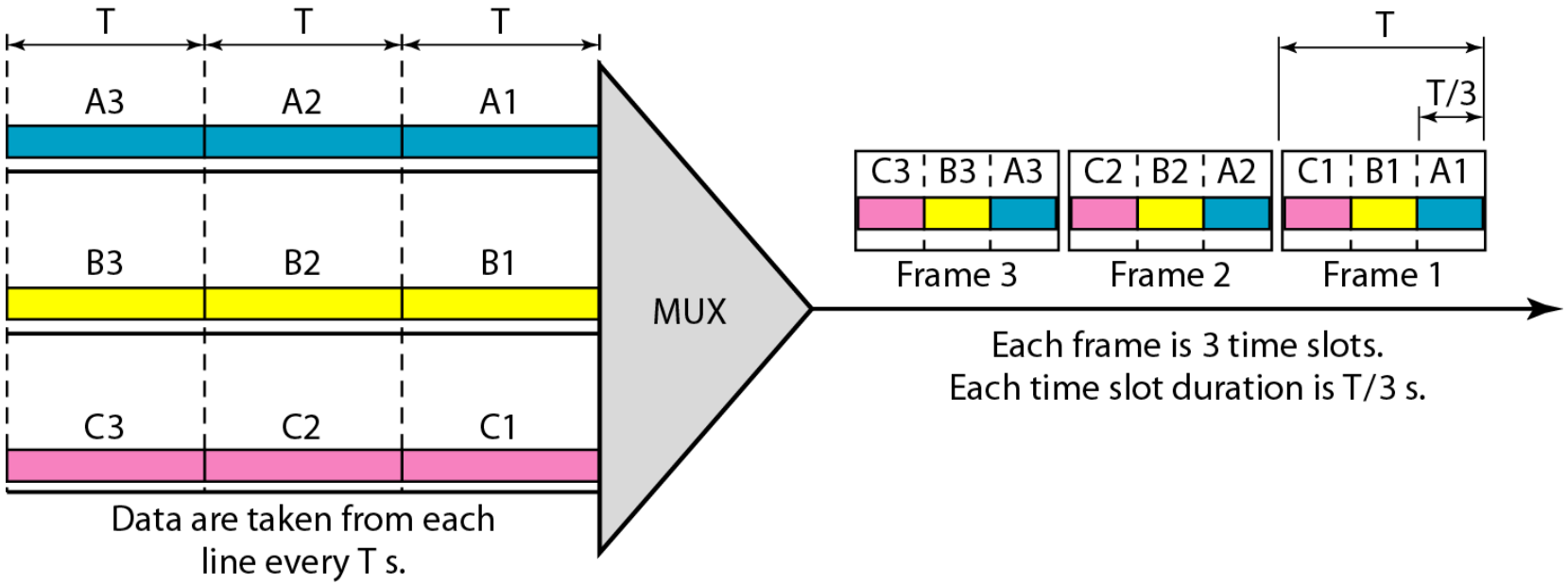
Time Slots and Frames

- Each input occupies one input time slot, which can be 1 bit, one character, or one block of data
- Each input unit becomes one output unit and occupies one output time slot
- The duration of an output time slot is *n* times shorter than the duration of an input time slot



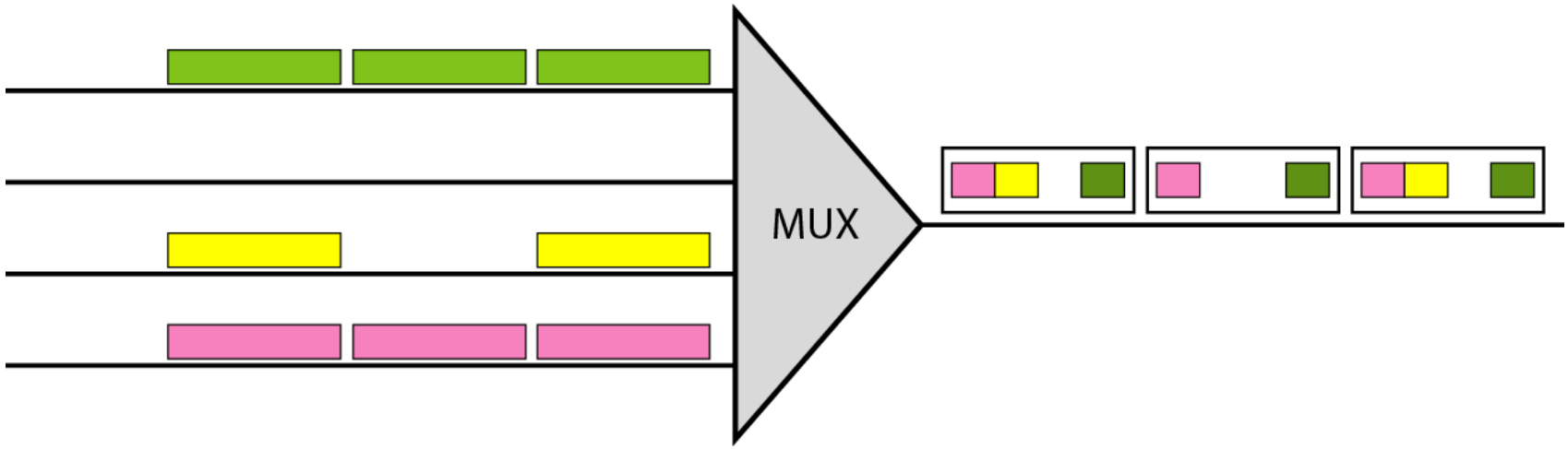
Relation of Input and Output Slot Duration

- Data are taken from each line every T seconds ➔ input time slot duration = T seconds
- Each frame has 3 time slots
- Output time slot duration is T/3 seconds



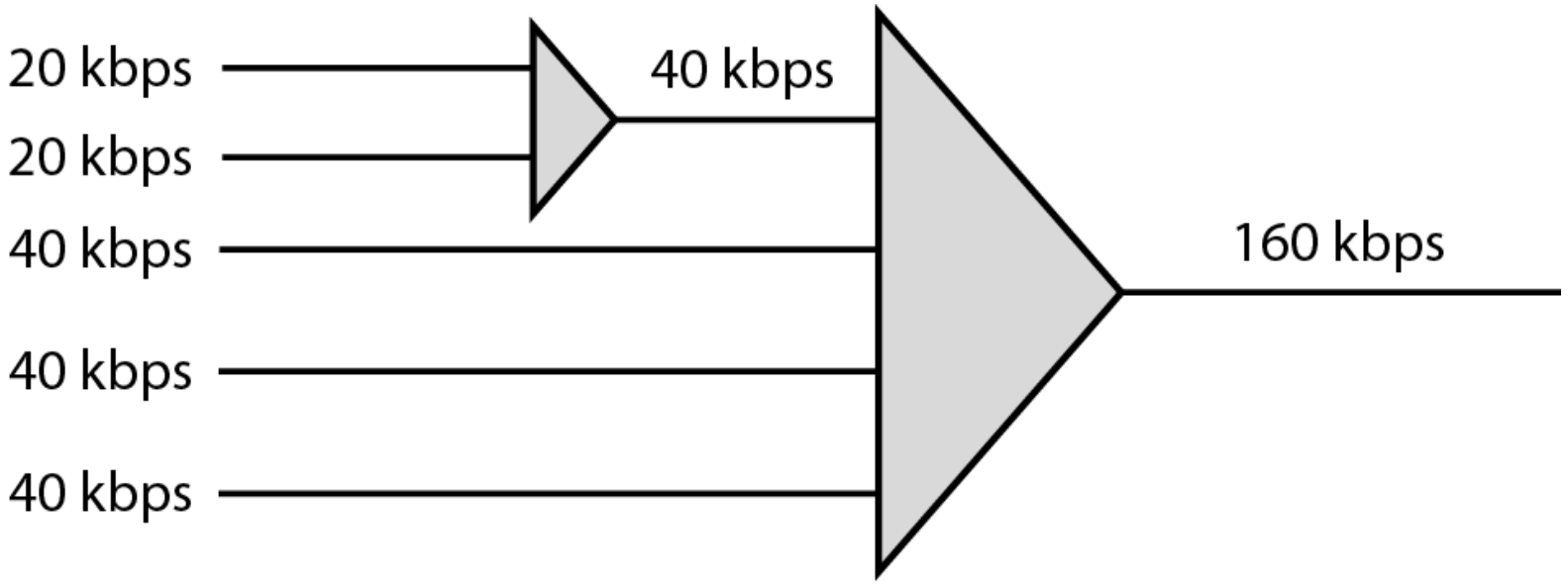
Empty Slots

- Empty slots are generated if there are no data to send
- Time slots are wasted
- Statistical TDM can improve the efficiency



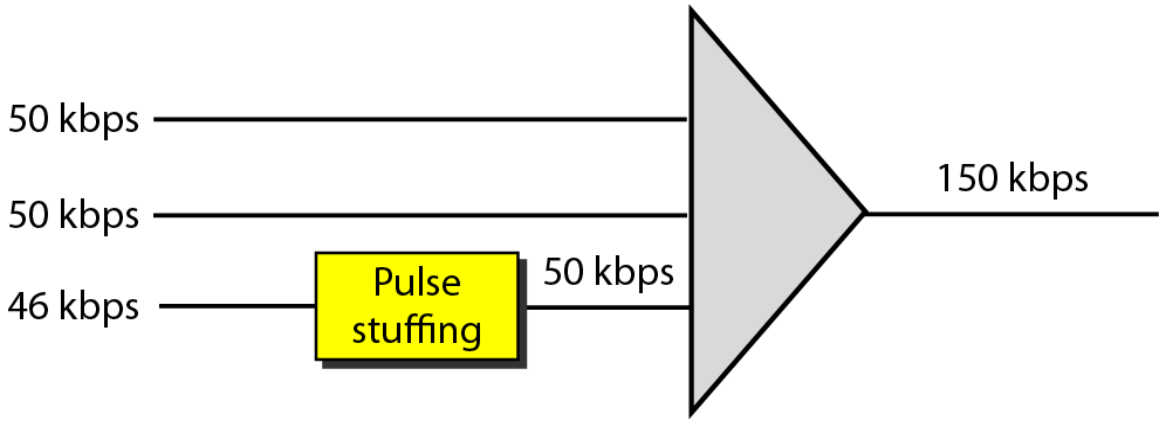
Multilevel Multiplexing

- A technique used when the data rate of an input rate is a multiple of others



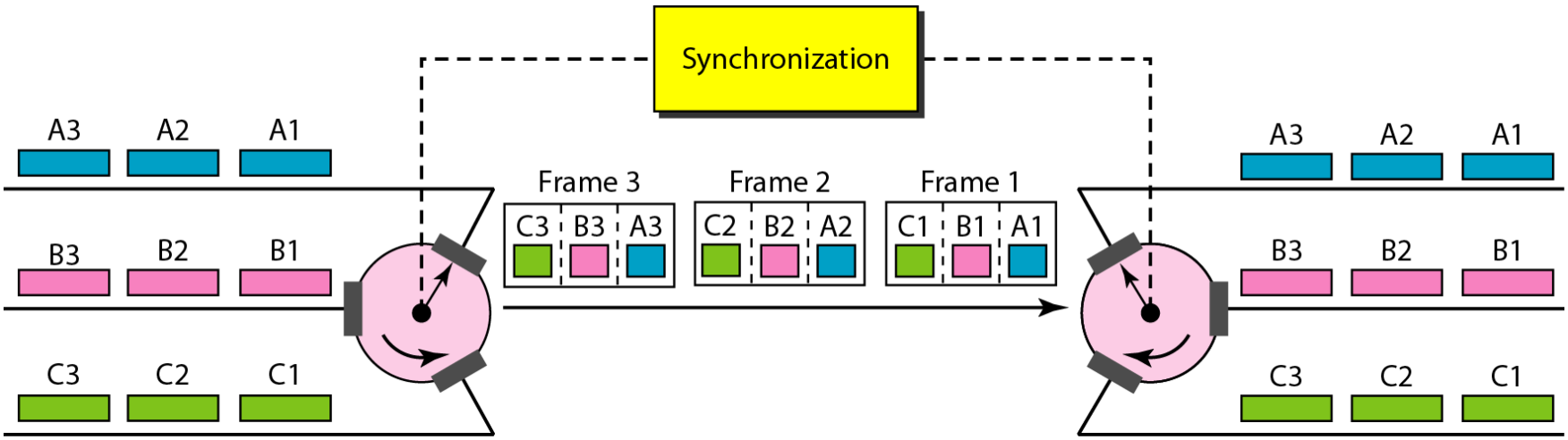
Pulse Stuffing

- Issue of data rates from different sources not related by simple rational number
- One solution is to make the highest input data rate the dominant data rate
- Add dummy bits to the input lines with lower rates to increase their rates to match the dominant data rate.
- This technique is called pulse stuffing, bit padding or bit stuffing.



Interleaving

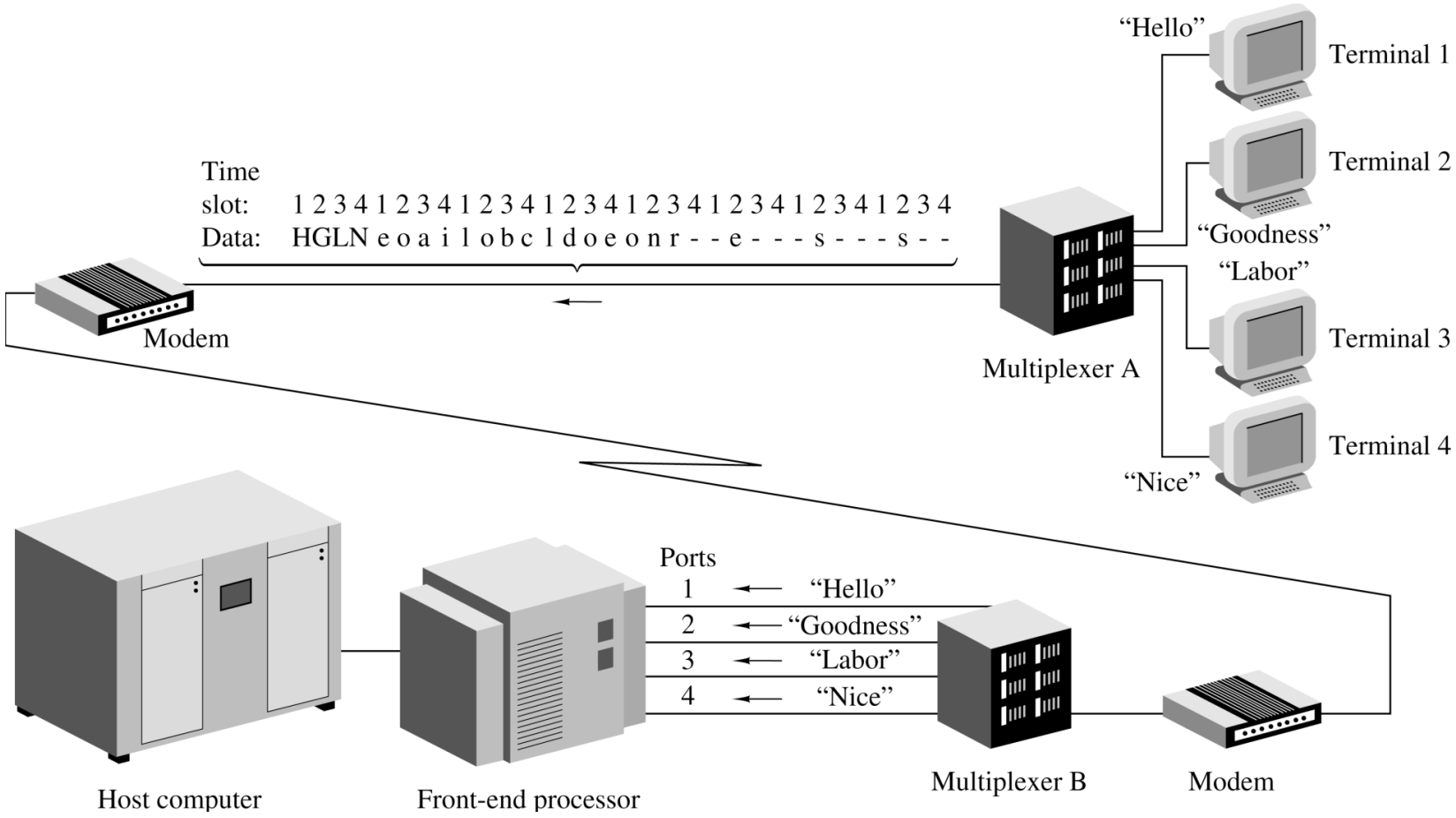
- The switches are synchronized and rotate at the same speed, but in opposite direction
- On the multiplexing side, different data sources take turn to send data
- This process is called interleaving



Character Interleaving

- Also called **Byte Interleaving**
- Each device is given a **time slot**.
- During each time slot, takes **one character** from each device and send it

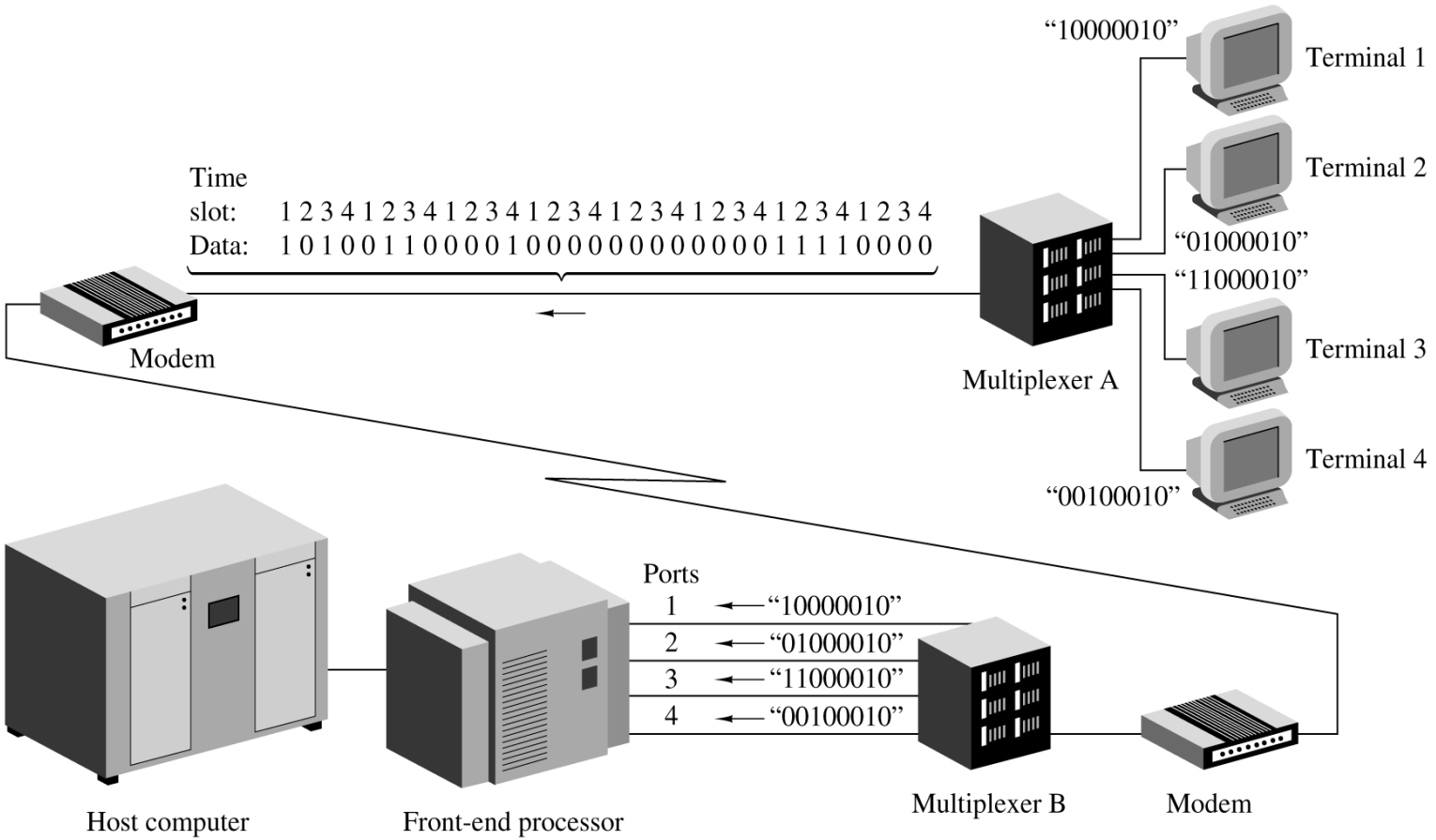
Character Interleaving



Bit Interleaving

- Each device is given a time slot.
- During each **time slot**, takes **one bit** from each device and send it
- The **time slot is shorter**, containing only one bit instead of an entire character.
- Advantage and disadvantage
  - Bit-Interleaving TDM is simple and efficient and requires little or no buffering of I/O data.
  - Unfortunately, Bit-Interleaving TDM does not fit in well with today's microprocessor-driven, byte-based environment.

Bit Interleaving



Statistical TDM

- in synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- multiplexer scans input lines and collects data until frame full
- line data rate lower than aggregate input line rates
- may have problems during peak periods
  - must buffer inputs

Statistical Time-Division Multiplexing (STDM)

- STDM assumes that not all of the devices will transmit all the time, which is a very reasonable assumption.
- Allocating bandwidth to each device **on the basis of demands and needs**. Devices get time slot only when they need to send data.

Statistical Time-Division Multiplexing (STDM)

- "**Statistical**" refers to the method by which time slots are allocated.
- A statistical multiplexer decides how many time slots to allocate in the **next second** is based on the amount of data sent by a given device in the **last second**.
- **Complicated formulas** are calculated constantly, so the time-slot utilization is changing forever based on the user's **most recent demands** and **probable future needs**.

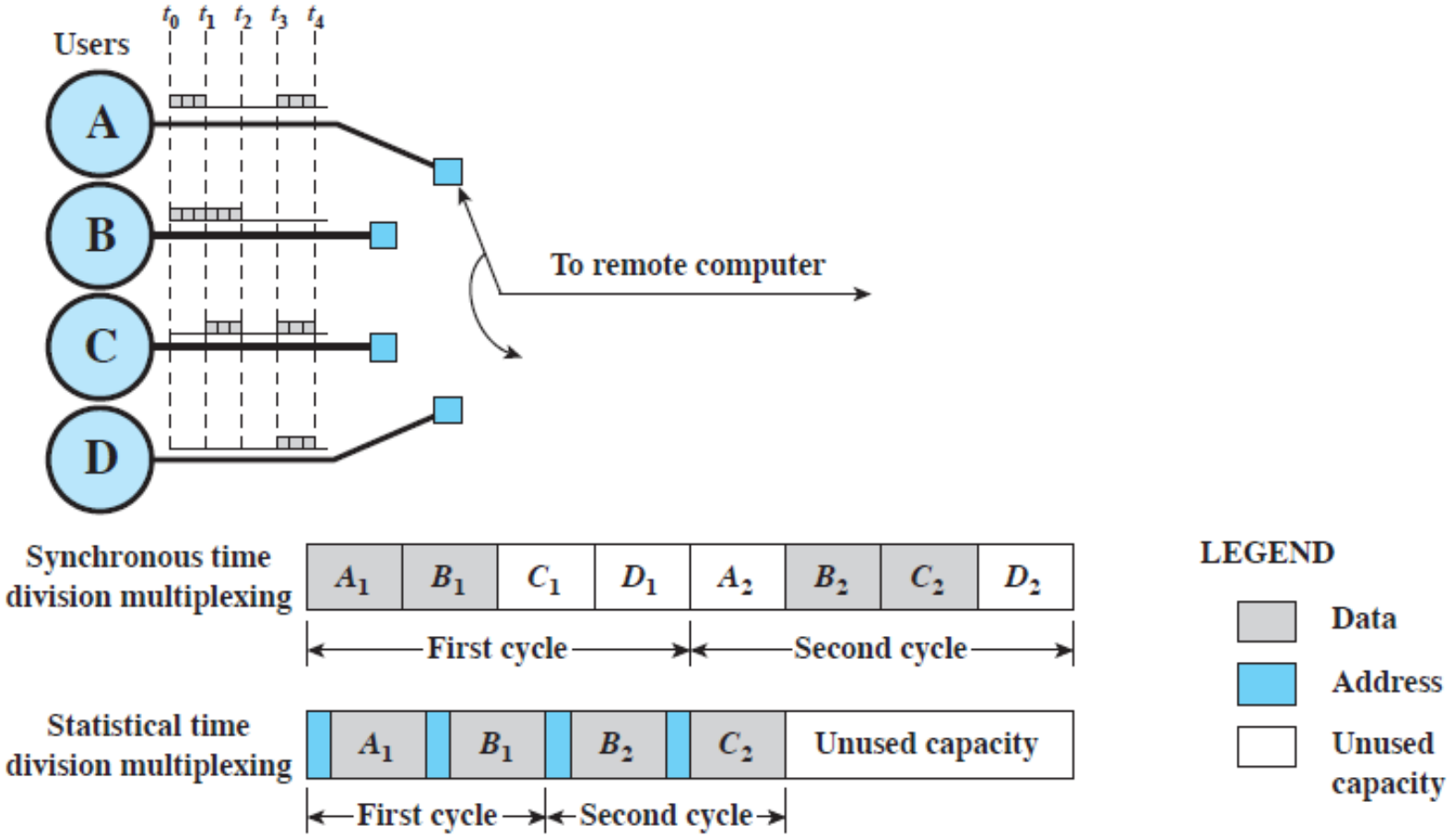
Statistical Time-Division Multiplexing (STDM)

- How does multiplexer B know which data goes to which port?
- Typically, a STDM multiplexer sends not only the data, but also an **address**, which indicates the **destination port**.
  - *Ex. 8 destination ports,*
    3-bit address is used (from 000 to 111)
- STDM needs to use some of the time slots for sending destination address.

Statistical Time-Division Multiplexing (STDM)

- User data are buffered and transmitted as rapidly as possible using available time slots.
- STDM makes **better use of the bandwidth**, but may cause **transmission delay.**

Synchronous TDM Compared with Statistical TDM



FDM and TDM

- FDM was the **first** multiplexing technology, and it is still in use today. However, **TDM is the preferred technology today.**
- By the end of the 20th Century, FDM voice circuits had become rare. Modern telephone systems employ digital transmission, in which TDM is used instead of FDM.

Summary

- Multiplexing multiple channels on single link
- FDM
  - analog carrier systems
  - wavelength division multiplexing
- WDM
- synchronous TDM
  - Empty slots, Pulse stuffing
  - Multilevel multiplexing
- statistical TDM