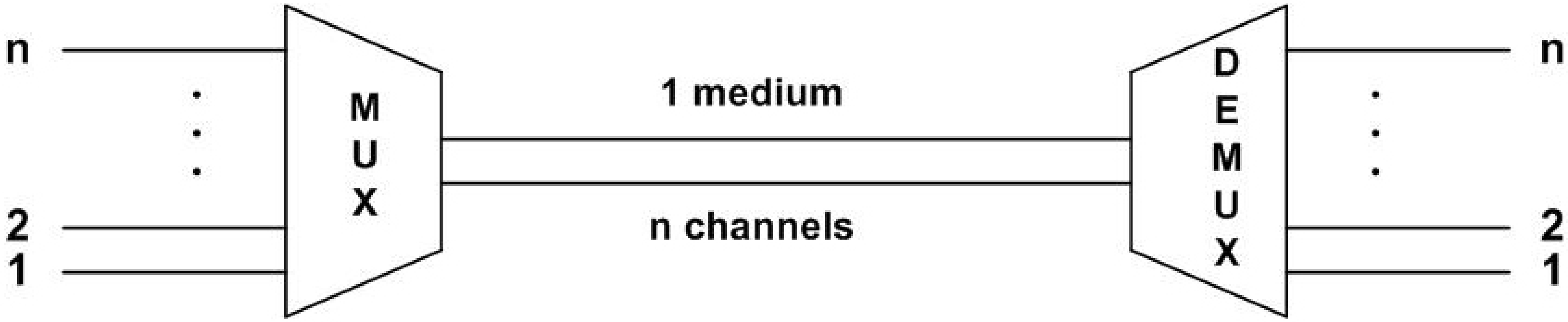
Multiplexing

Introduction

- Under the simplest conditions, a medium can carry only one signal at any moment in time.
- For multiple signals to share one medium, the medium must somehow be divided

Why multiplexing?

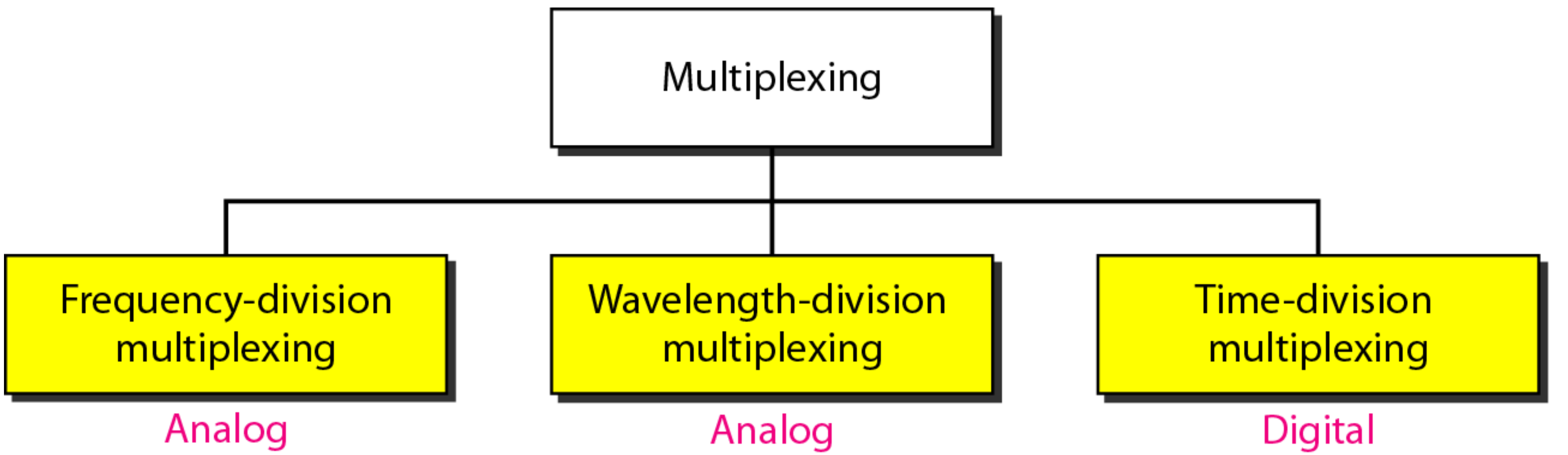
- The communication media usually have much higher bandwidth
- On the other hand individual users have lesser data to send. And as a consequence the two communicating stations do not utilize the full capacity of a data link.


n
2
1
M U X
1 medium
n channels
D E M U X
n
2
1

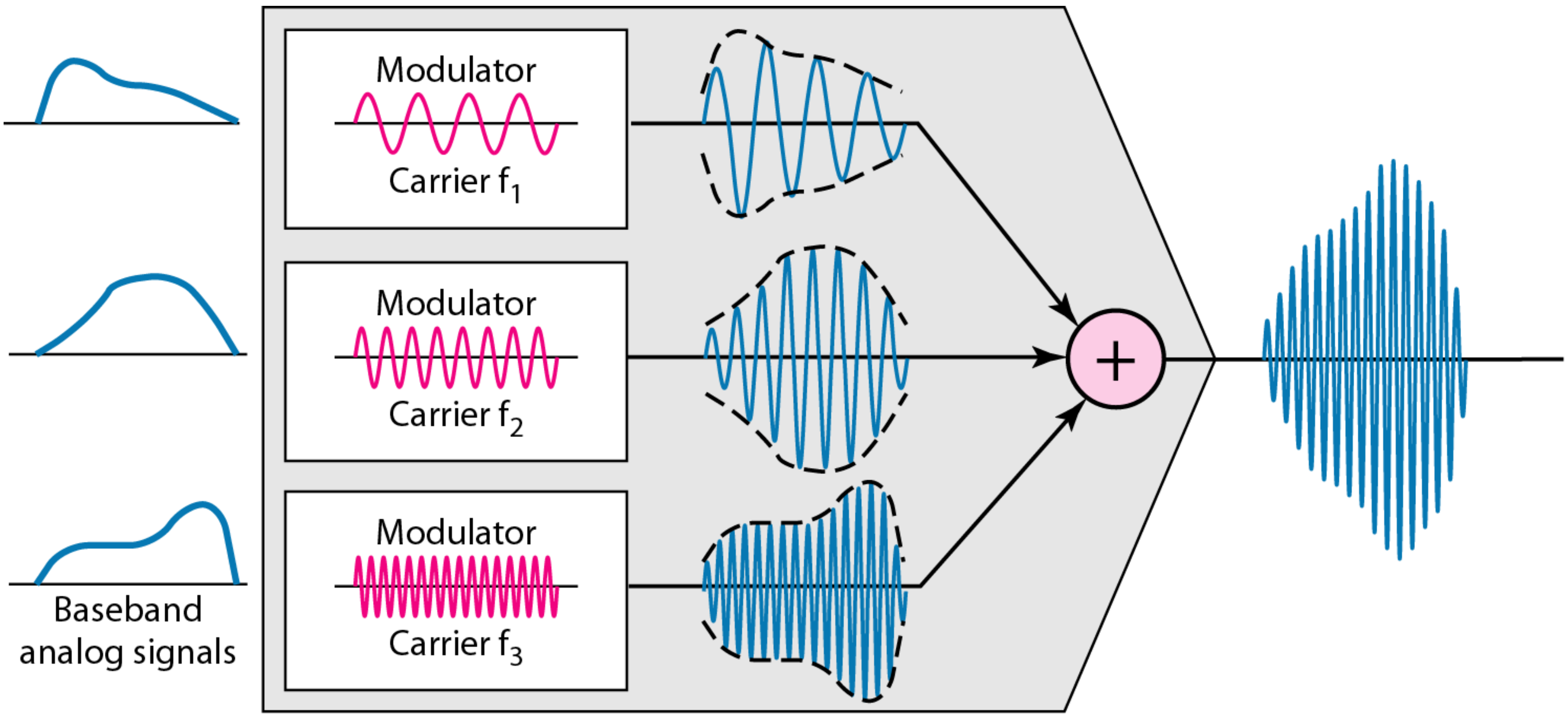
Multiplexing techniques can be categorized into the following three types:

- ***Frequency-division multiplexing (FDM)***: It is most popular and is used extensively in radio and TV transmission. Here the frequency spectrum is divided into several logical channels, giving each user exclusive possession of a particular frequency band.

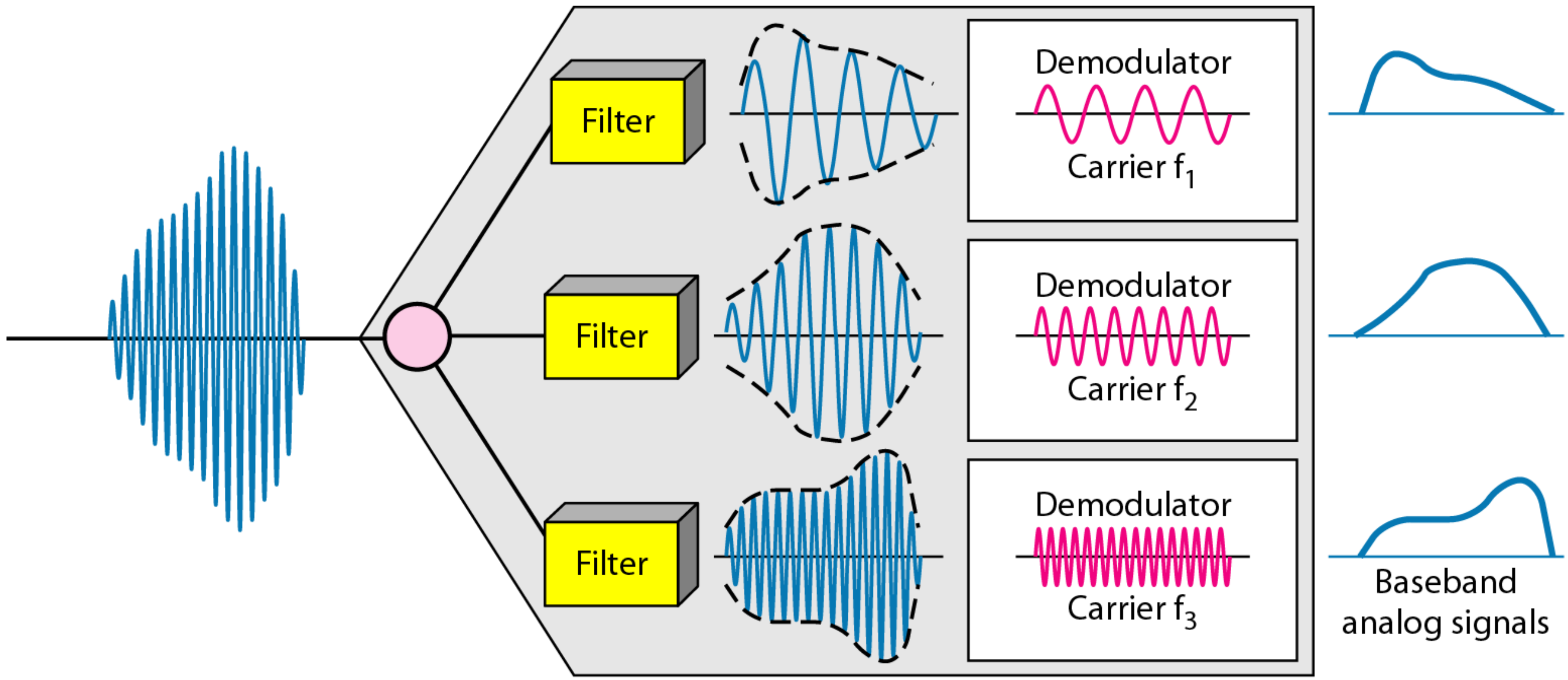
- ***Time-division Multiplexing (TDM):*** It is also called synchronous TDM, which is commonly used for multiplexing digitized voice stream. The users take turns using the entire channel for short burst of time.
- ***Statistical TDM:*** This is also called asynchronous TDM, which simply improves on the efficiency of synchronous TDM.


Multiplexing
Frequency-division multiplexing
Wavelength-division multiplexing
Time-division multiplexing
Analog
Analog
Digital

Frequency-Division Multiplexing

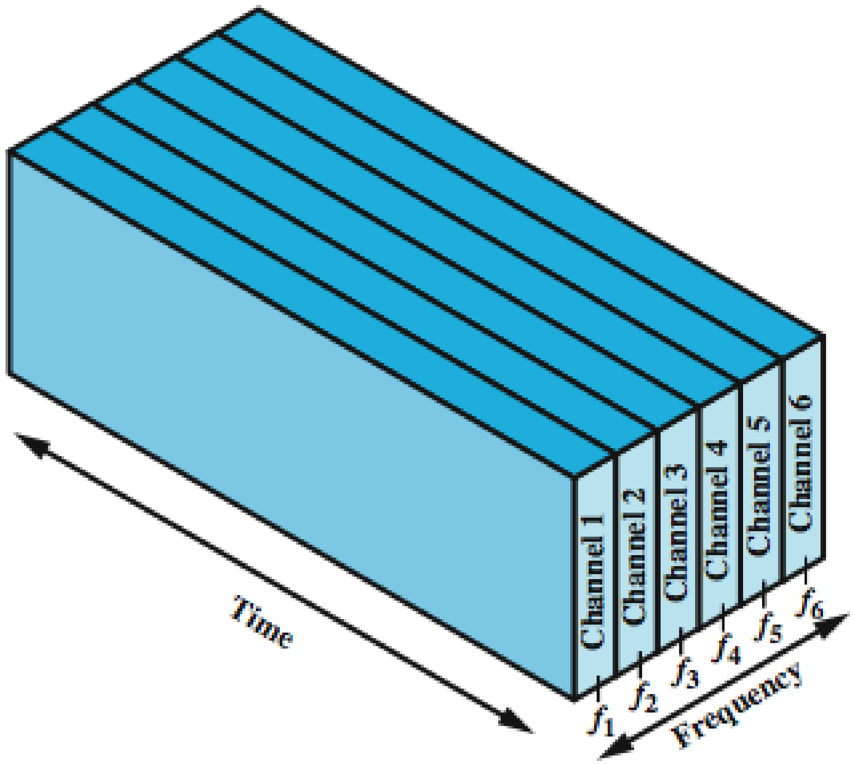


FDM is an analog multiplexing technique that combines analog signals.



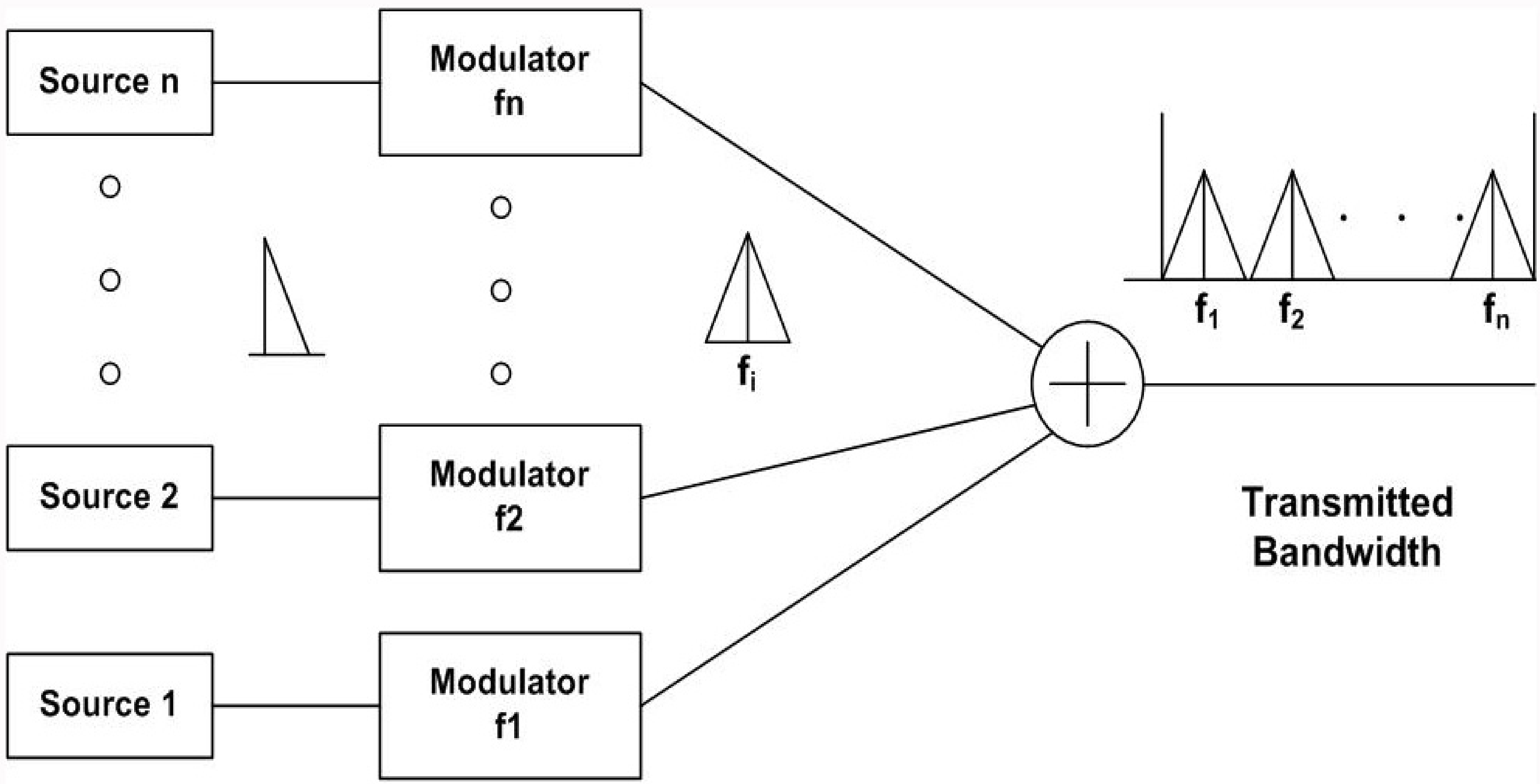
Filter
Filter
Filter
Demodulator
Carrier f_1
Demodulator
Carrier f_2
Demodulator
Carrier f_3
Baseband
analog signals

Frequency Division Multiplexing

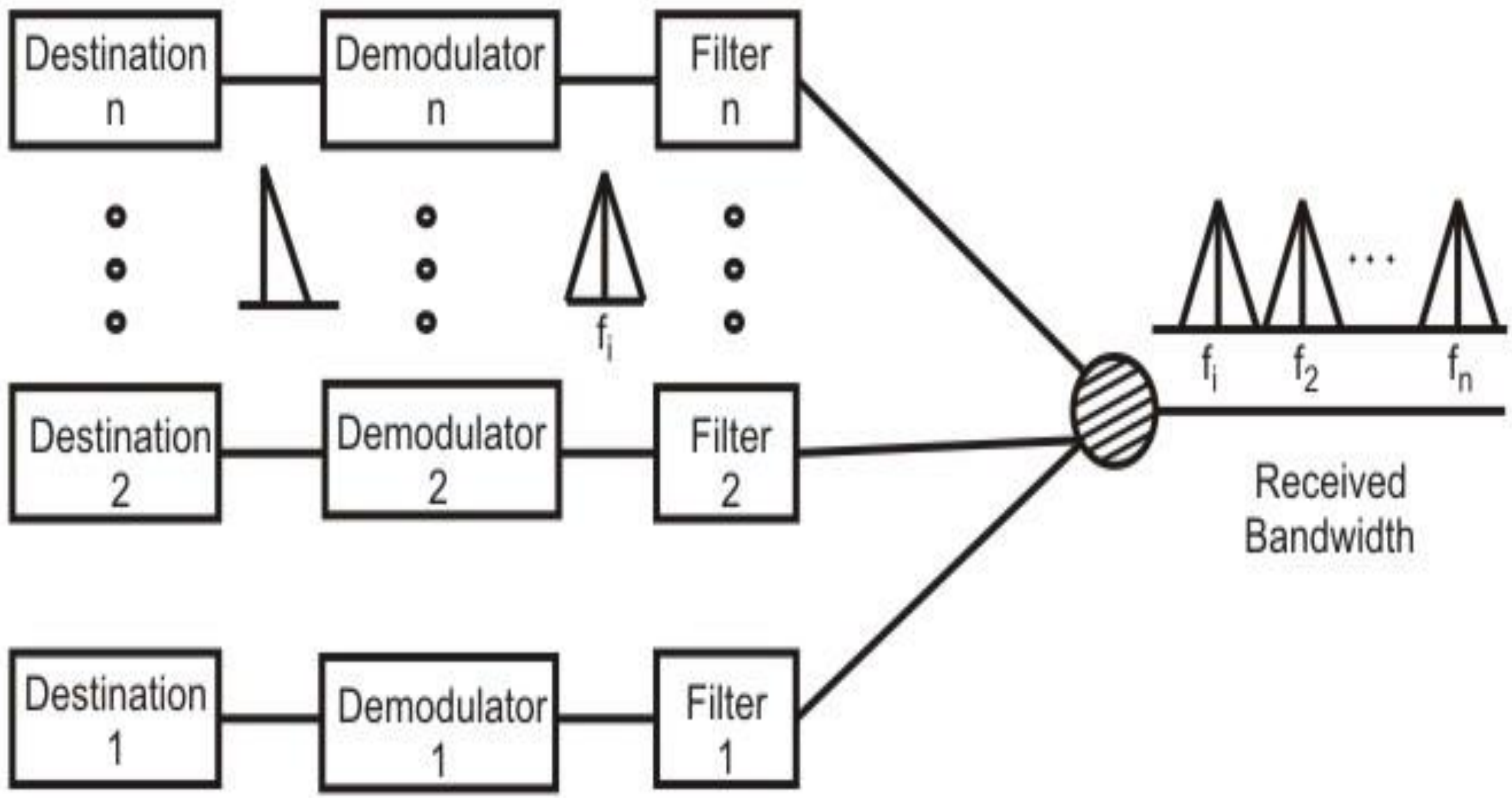


(a) Frequency division multiplexing

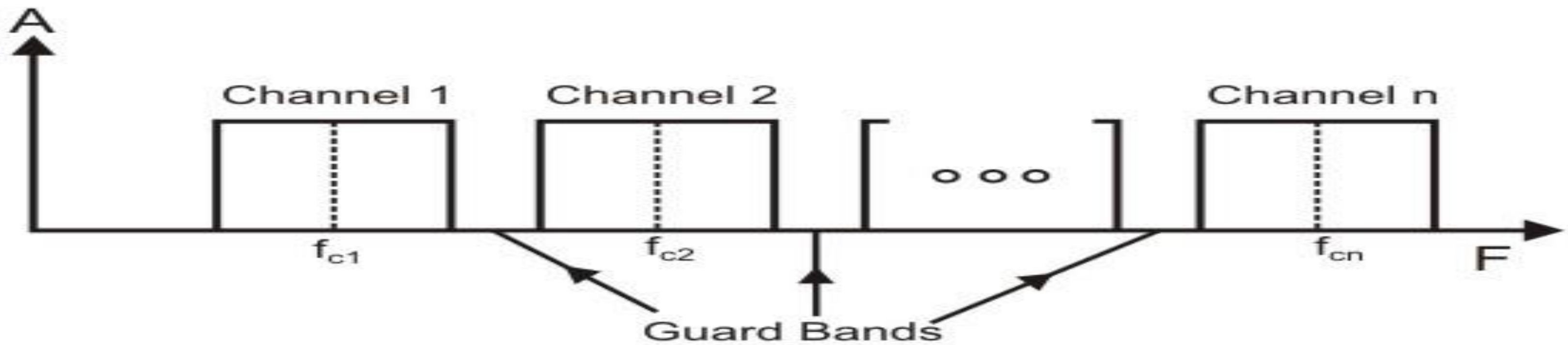
- Basic approach is to divide the available bandwidth of a single physical medium into a number of smaller, independent frequency channels.
- Using modulation, independent message signals are translated into different frequency bands.
- All the modulated signals are combined to form a composite signal for transmission.
- The carriers used to modulate the individual message signals are called *sub-carriers*,



FDM Multiplexing Process



FDM Demultiplexing Process

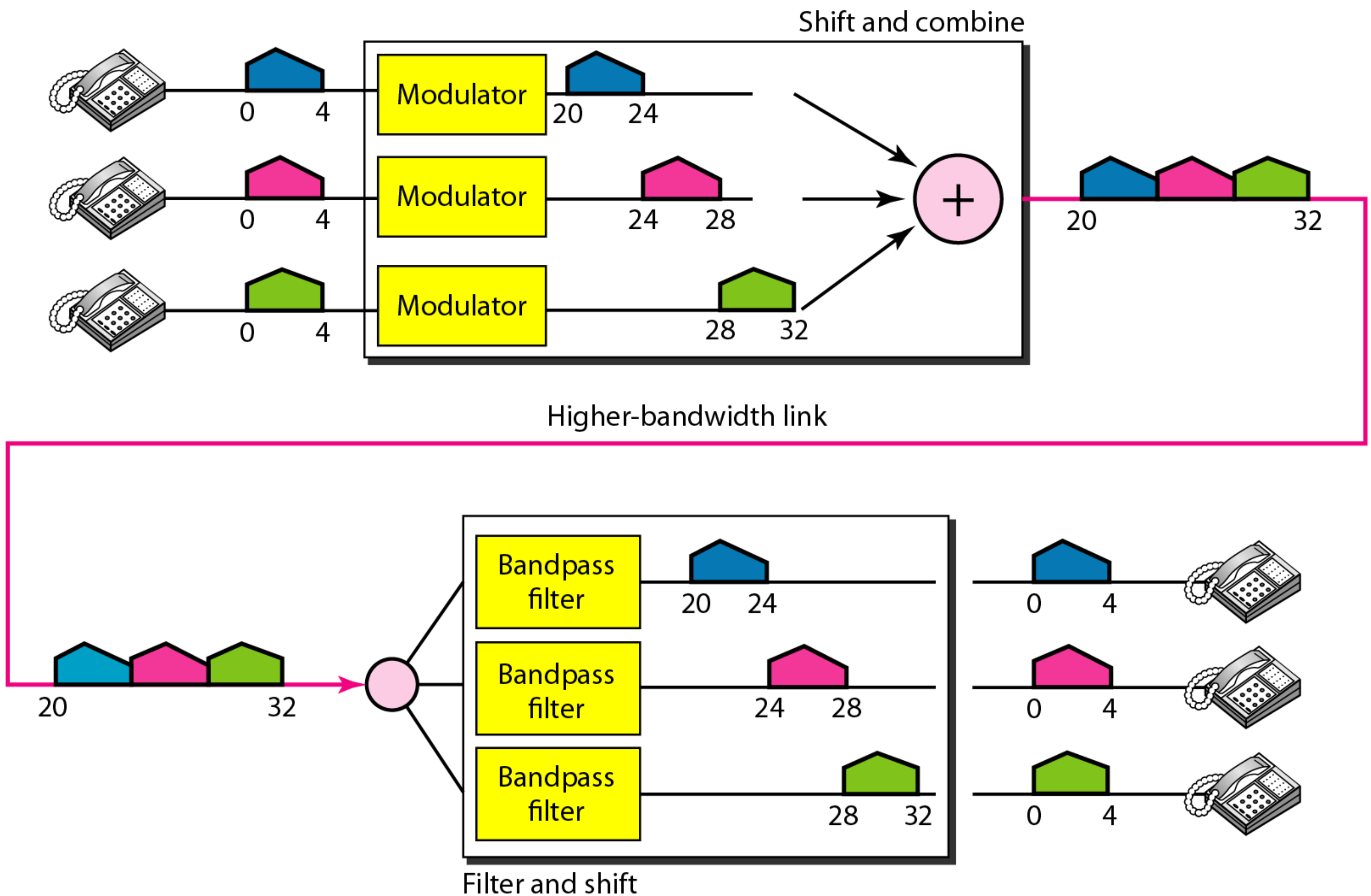


- If the channels are very close to one other, it leads to inter-channel cross talk.
- Channels must be separated by strips of unused bandwidth to prevent inter-channel cross talk.
- These unused channels between each successive channel are known as **guard band**s

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, as shown in Figure. 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 in Figure.

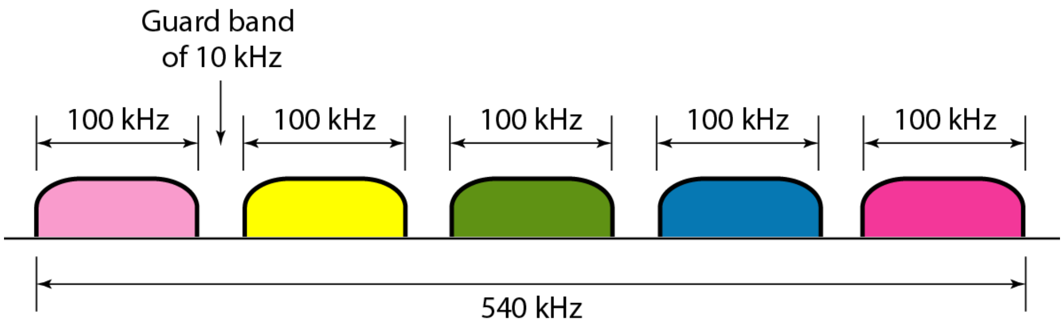

Shift and combine
Modulator
Modulator
Modulator
0
4
0
4
0
4
20
24
24
28
28
32
20
32
Higher-bandwidth link
20
32
Bandpass filter
Bandpass filter
Bandpass filter
20
24
24
28
28
32
0
4
0
4
0
4
Filter and shift

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

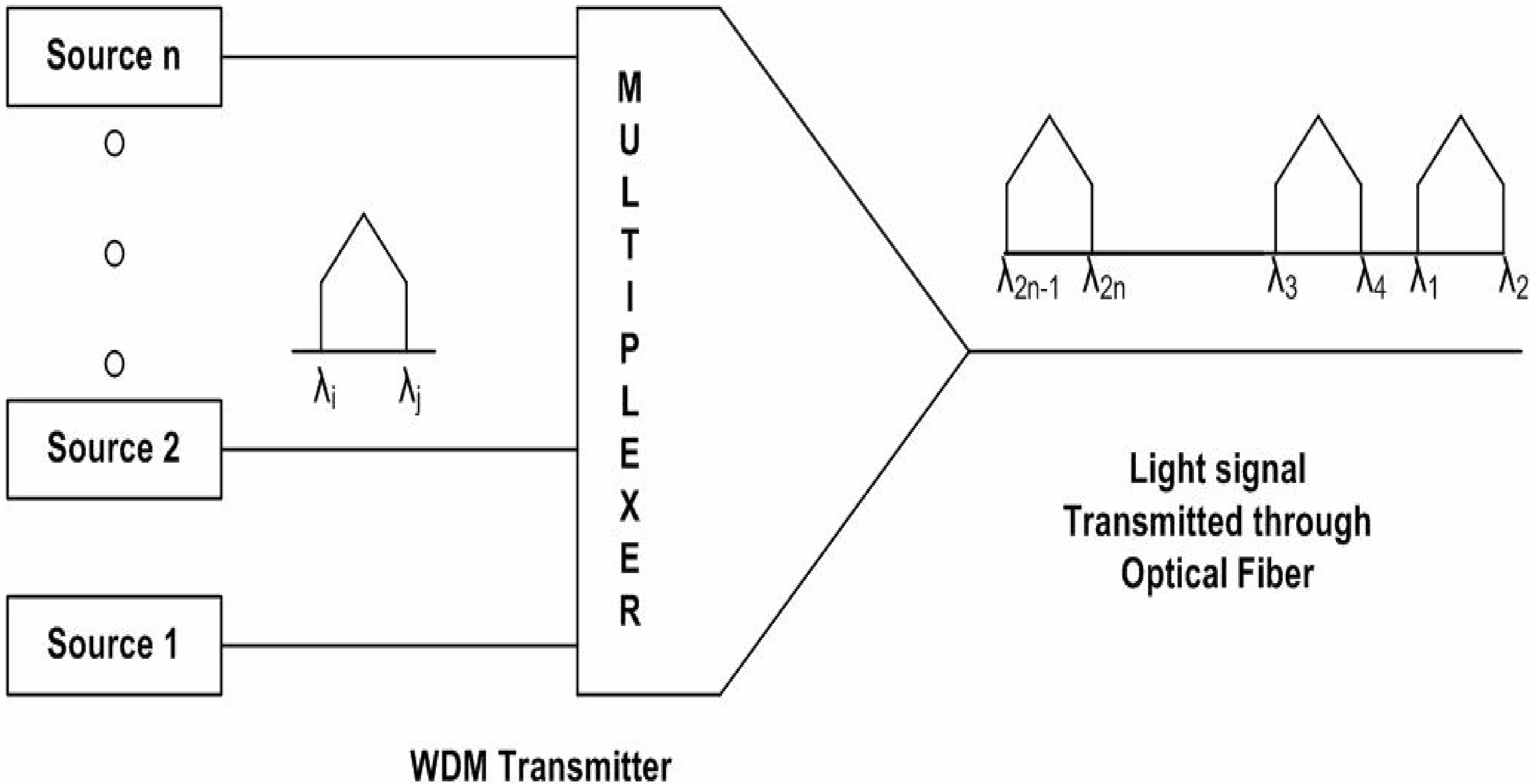
For five channels, we need at least four guard bands. This means that the required bandwidth is at least

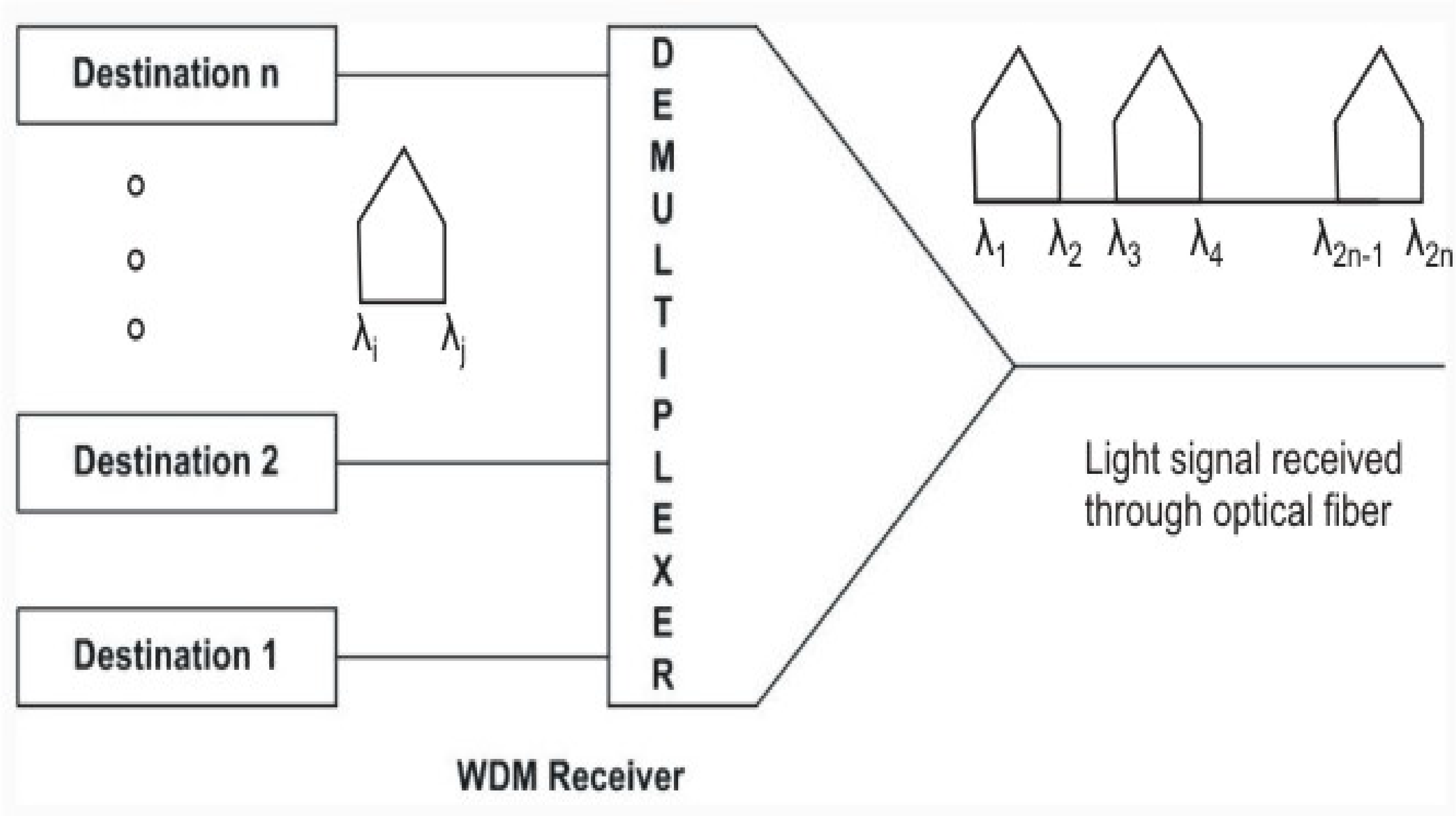
$$5 \times 100 + 4 \times 10 = 540 \text{ kHz},$$

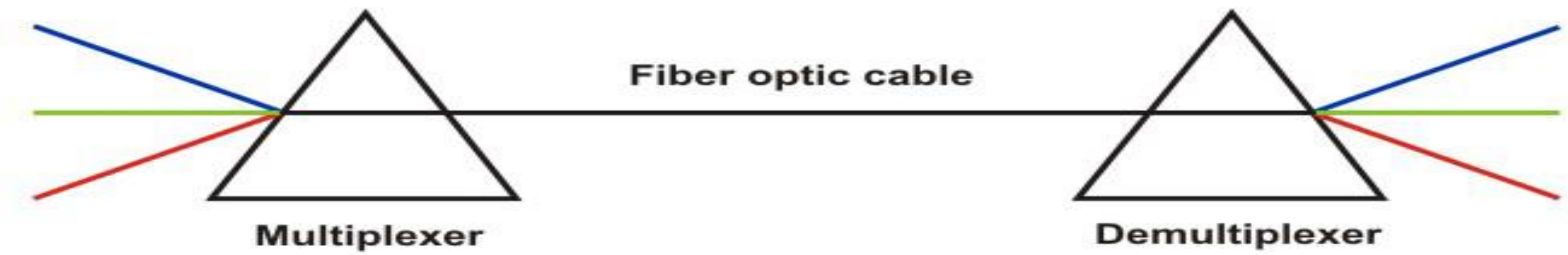


Wavelength-Division Multiplexing

- Wavelength-division multiplexing (WDM) is conceptually same as the FDM, except that the multiplexing and demultiplexing involves light signals transmitted through fibre-optic channels.
- The idea is the same: we are combining different frequency signals.
- However, the difference is that the frequencies are very high.


Source n
Source 2
Source 1
λ_i
λ_j
MULTIPLEXER
λ_{2n-1}
λ_{2n}
λ_3
λ_4
λ_1
λ_2
Light signal
Transmitted through
Optical Fiber
WDM Transmitter


Destination n
Destination 2
Destination 1
λ_i λ_j
DEMULTIPLEXER
λ_1 λ_2 λ_3 λ_4 λ_{2n-1} λ_{2n}
Light signal received through optical fiber
WDM Receiver



- From the basic knowledge of physics we know that light signal is bent by different amount based on the angle of incidence and wavelength of light as shown by different colours in the figure.
- One prism performs the role of a multiplexer by combining lights having different frequencies from different sources.
- The composite signal can be transmitted through an optical fibre cable over long distances, if required.
- At the other end of the optical fibre cable the composite signal is applied to another prism to do the reverse operation, the function of a demultiplexer.

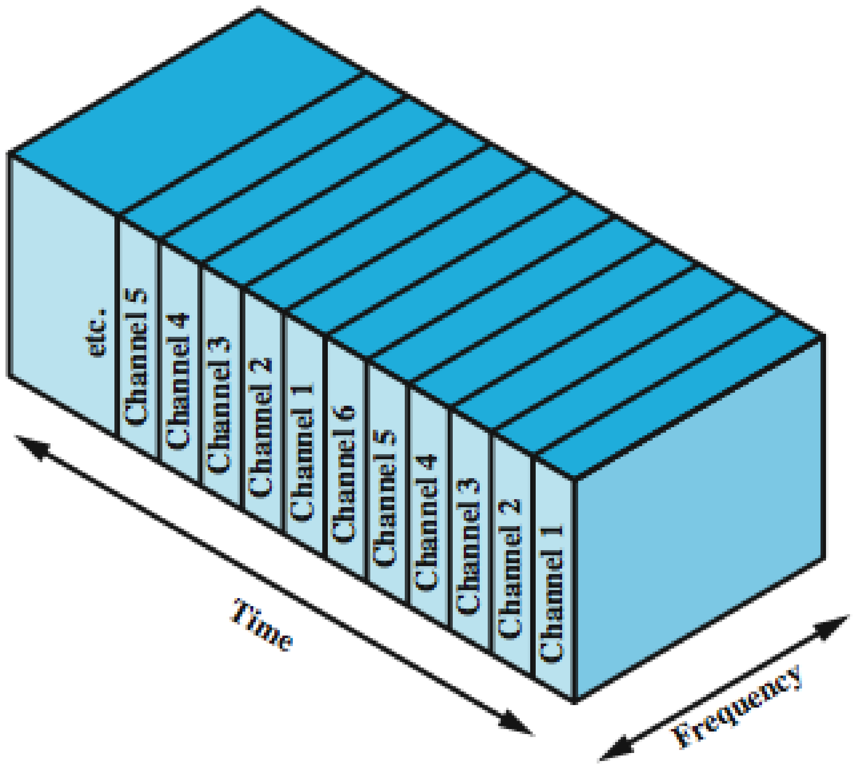
Time-Division Multiplexing

- In frequency division multiplexing, all signals operate at the same time with different frequencies, but in Time-division multiplexing all signals operate with same frequency at different times.

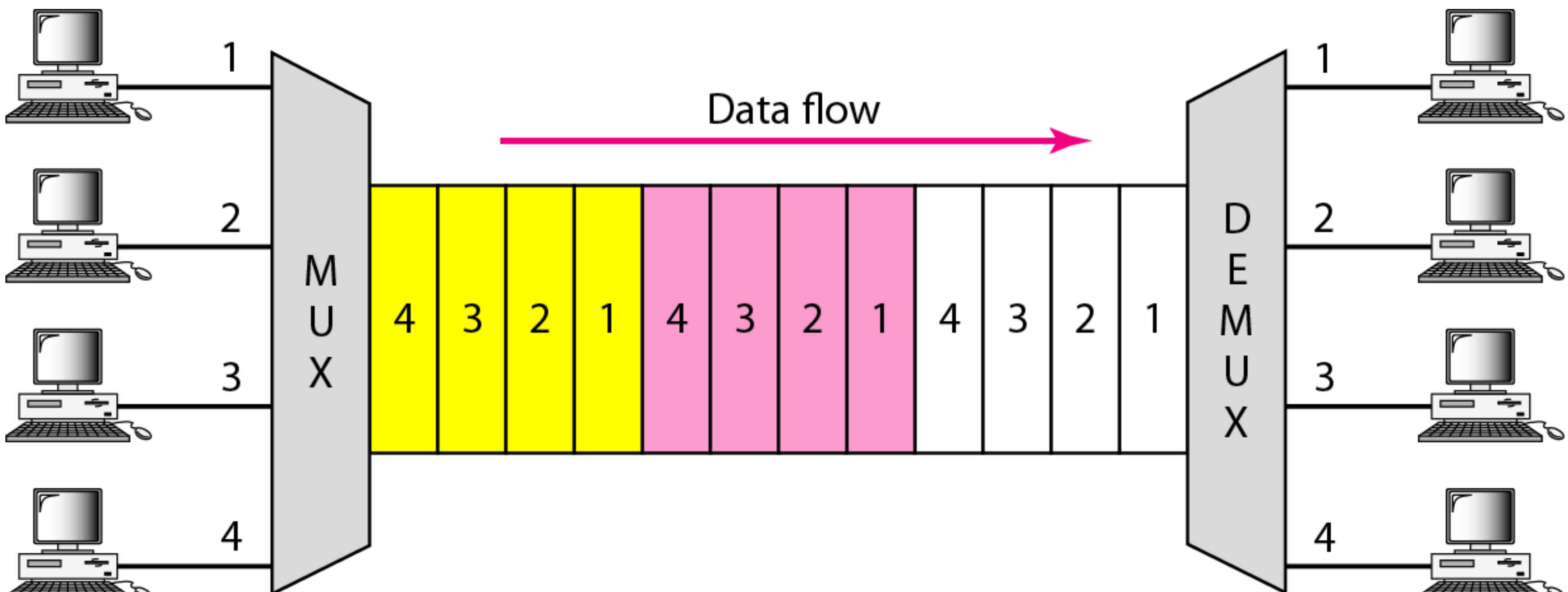
Synchronous Time Division Multiplexing

- The multiplexor accepts input from attached devices in a round-robin fashion and transmit the data in a never ending pattern.
- Synchronous TDM is called synchronous because the time slots are preassigned to sources and fixed.
- The sequence of slots dedicated to one source, from frame to frame, is called a **channel**.
- The slot length equals the transmitter buffer length, typically a bit or a byte (character).
- The time slots for each source are transmitted whether or not the source has data to send
- it is possible for a synchronous TDM device to handle sources of different data rates. For example, the slowest input device could be assigned one slot per cycle, while faster devices are assigned multiple slots per cycle.

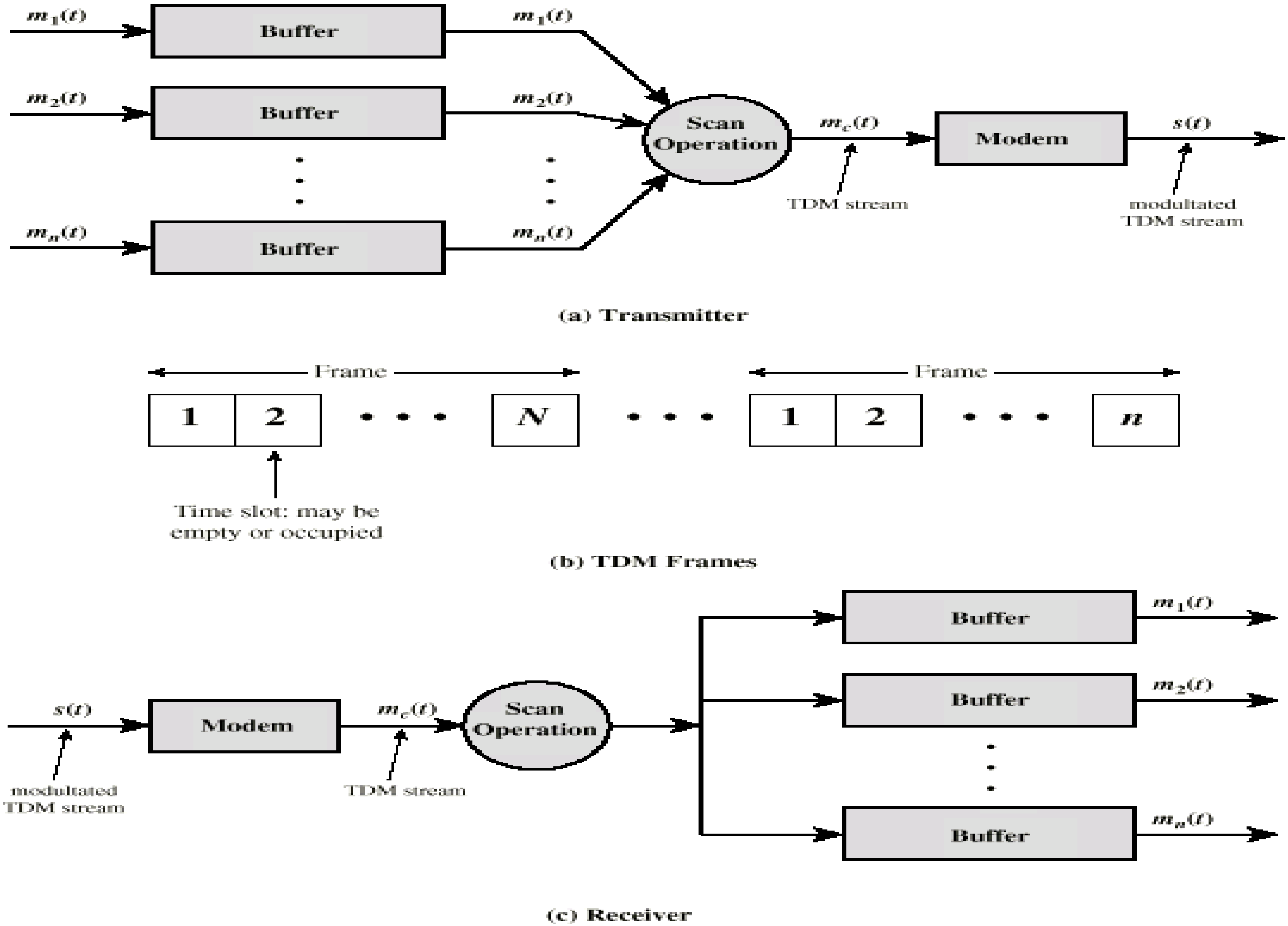
Synchronous Time Division Multiplexing



(b) Time division multiplexing

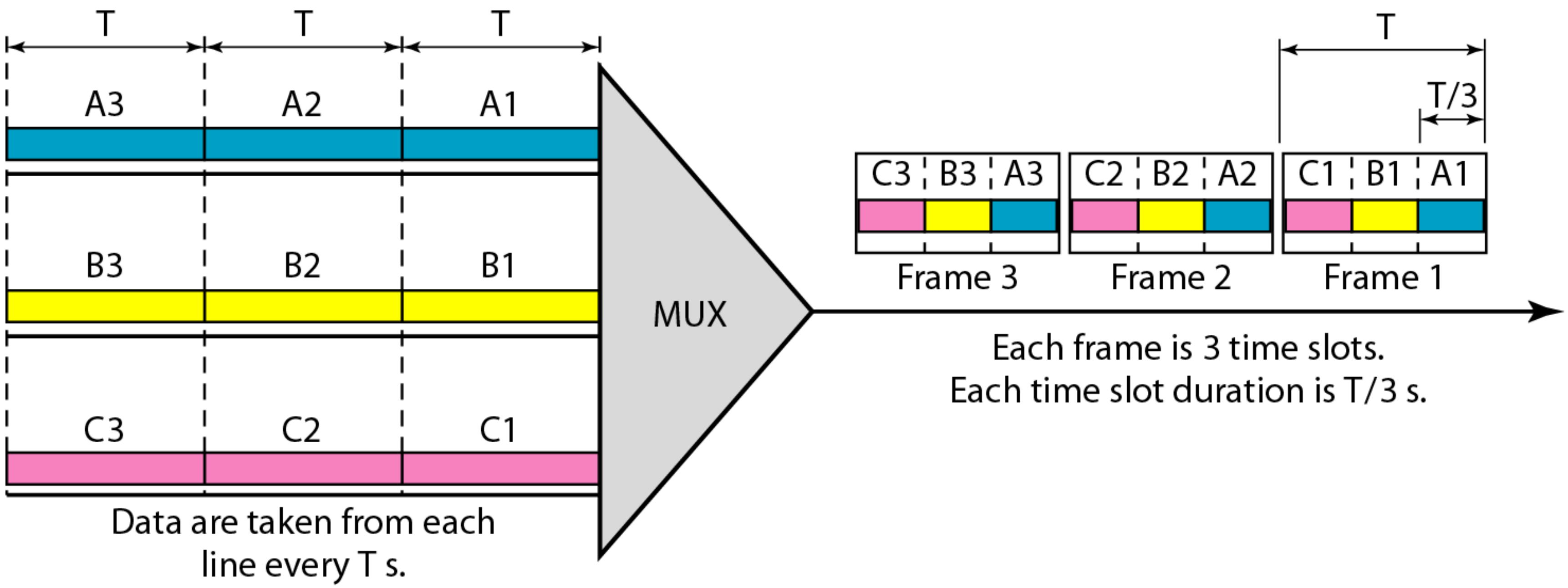


1
2
3
4
MUX
Data flow
4 3 2 1 4 3 2 1 4 3 2 1
DEMUX
1
2
3
4

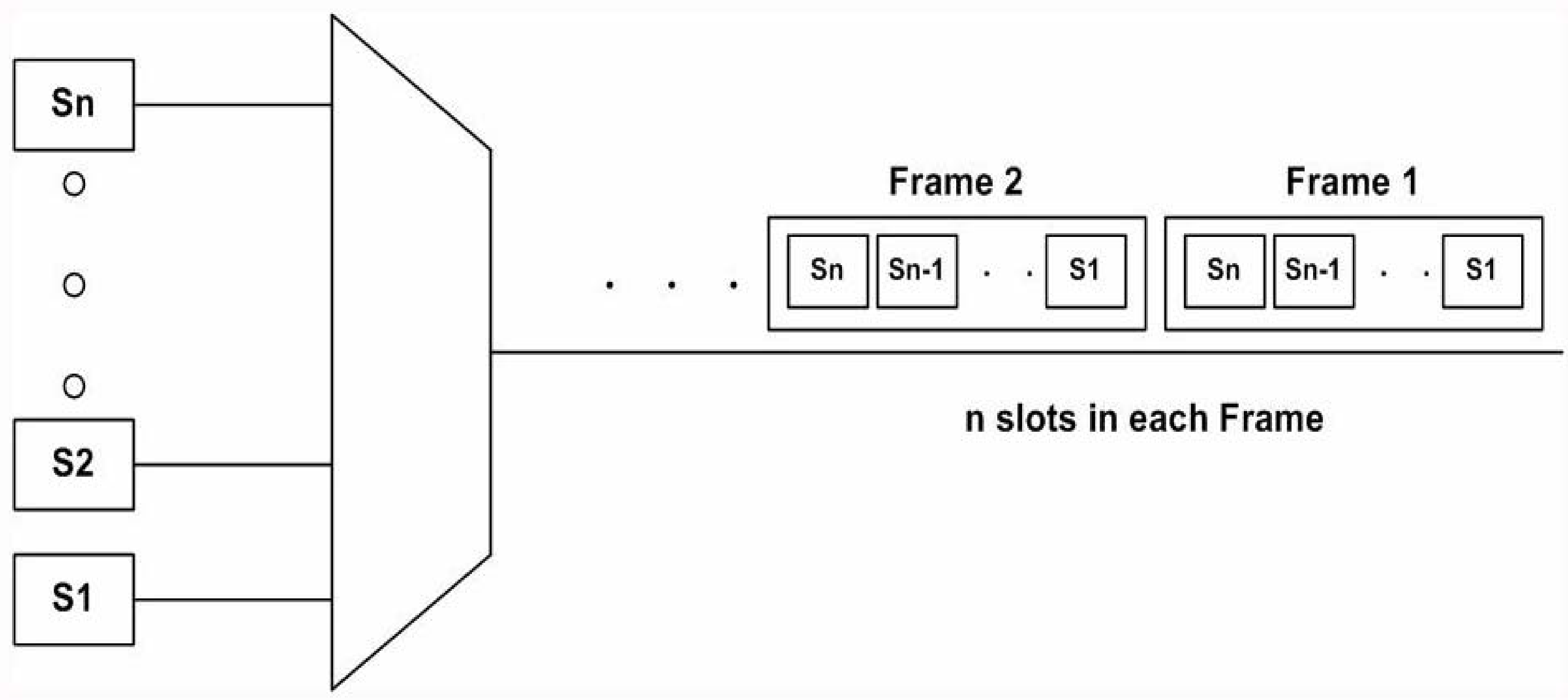


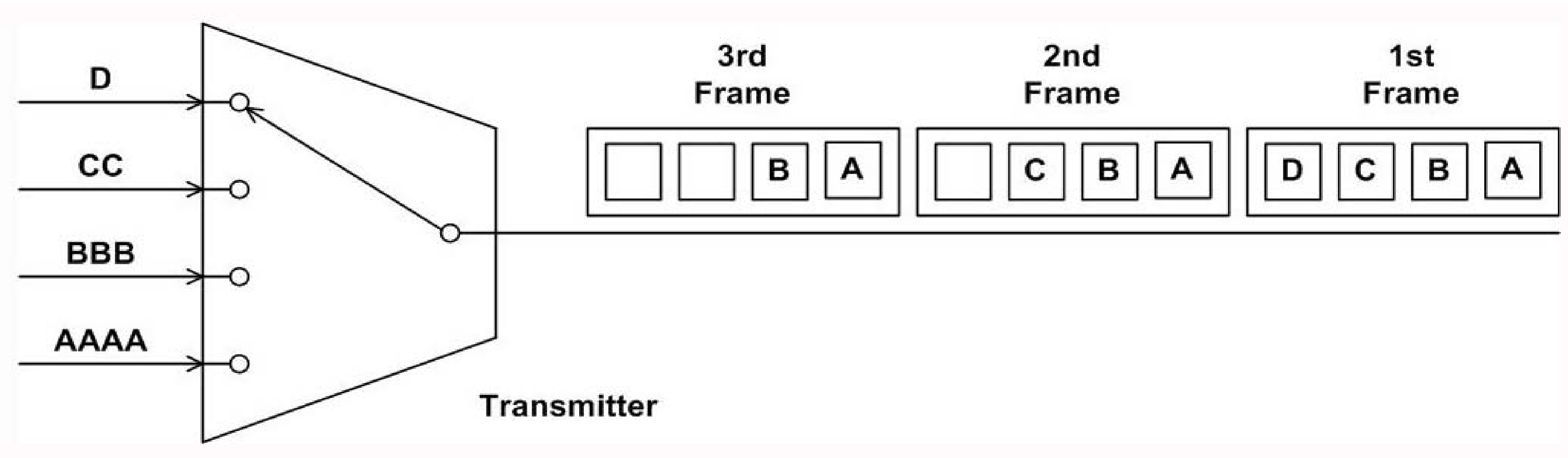
m1(t)
Buffer
m1(t)
m2(t)
Buffer
m2(t)
mn(t)
Buffer
mn(t)
Scan Operation
mc(t)
TDM stream
Modem
s(t)
modulated TDM stream
(a) Transmitter
Frame
Frame
1
2
N
1
2
n
Time slot: may be empty or occupied
(b) TDM Frames
s(t)
modulated TDM stream
Modem
mc(t)
TDM stream
Scan Operation
Buffer
m1(t)
Buffer
m2(t)
Buffer
mn(t)
(c) Receiver

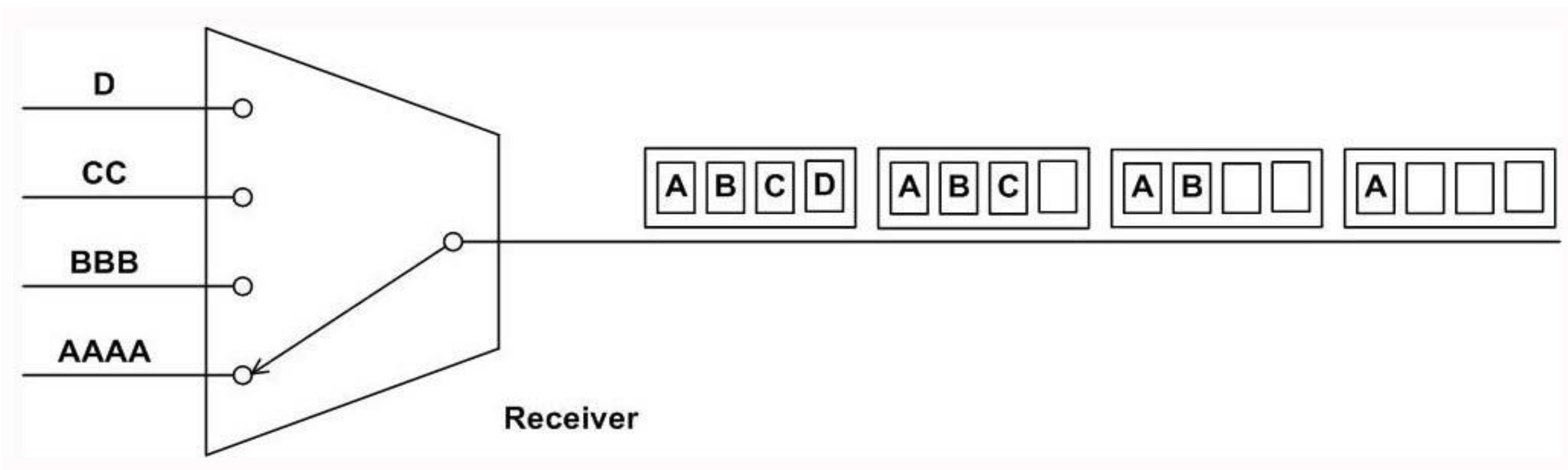
Synchronous time-division multiplexing



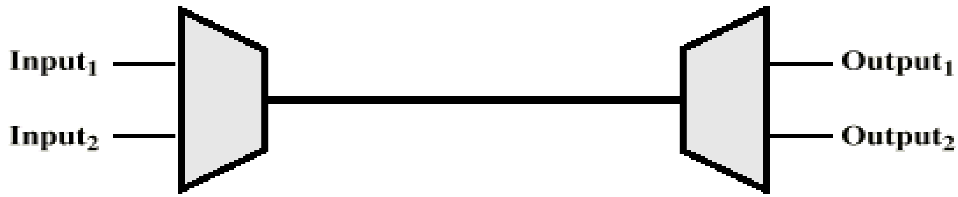
1. In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.
2. In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.


Sn
S2
S1
Frame 2
Frame 1
Sn
Sn-1
S1
Sn
Sn-1
S1
n slots in each Frame


D
CC
BBB
AAAA
3rd Frame
2nd Frame
1st Frame
B A
C B A
D C B A
Transmitter


D
CC
BBB
AAAA
A B C D
A B C
A B
A
Receiver

Data link control on TDM channel



(a) Configuration

Input$_1$ • • • • • • • • • • • F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1

Input$_2$ • • • F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2

(b) Input data streams

• • • f_2 F_1 d_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 C_2 d_1 A_2 C_1 F_2 A_1 f_2 F_1 f_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 d_2 d_1 C_2 C_1 A_2 A_1 F_2 F_1

(c) Multiplexed data stream

Legend: F = flag field; A = address field; C = control field; d = one octet of data field; f = one octet of FCS field

- We assume two data sources, each using HDLC.
- One is transmitting a stream of HDLC frames containing three octets of data each
- the other is transmitting HDLC frames containing four octets of data.
- The octets of the HDLC frames from the two sources are shuffled together for transmission over the multiplexed line.
- The FCS is not in one piece. However, the pieces are reassembled correctly before they are seen by the device on the other end of the HDLC protocol.

Framing

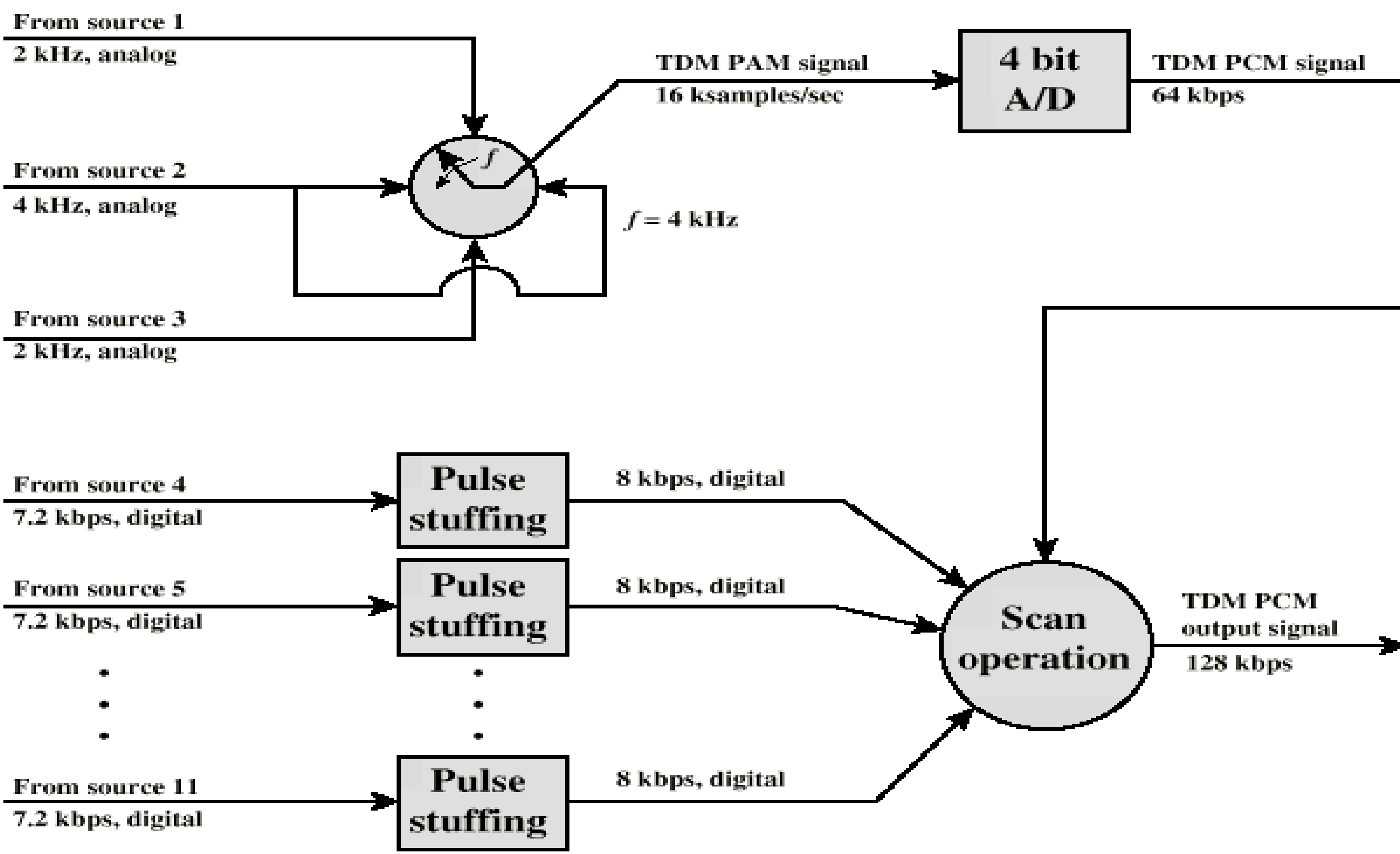
- Some means is needed to assure frame synchronization.
- Important to maintain framing synchronization because, if the source and destination are out of step, data on all channels are lost.
- The most common mechanism for framing is known as added-digit framing.
- In this scheme, typically, one control 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

Pulse Stuffing

- If each source has a separate clock, any variation among clocks could cause loss of synchronization.
- the data rates of the input data streams may vary.
- For both these problems, a technique known as pulse stuffing is an effective remedy
  - Outgoing data rate (excluding framing bits) higher than sum of incoming rates
  - Stuff extra dummy bits or pulses into each incoming signal until it matches local clock
  - Stuffed pulses inserted at fixed locations in frame and removed at demultiplexer

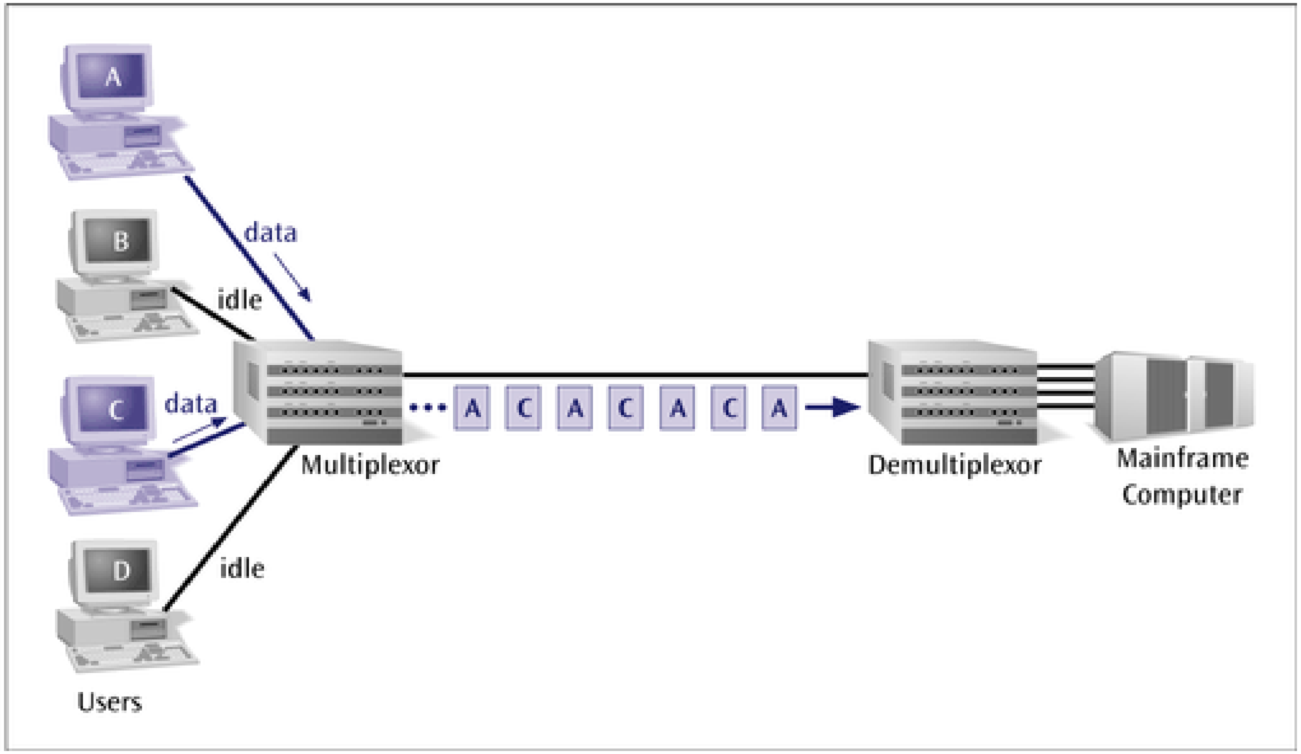
TDM of Analog and Digital Sources



Statistical Time Division Multiplexing

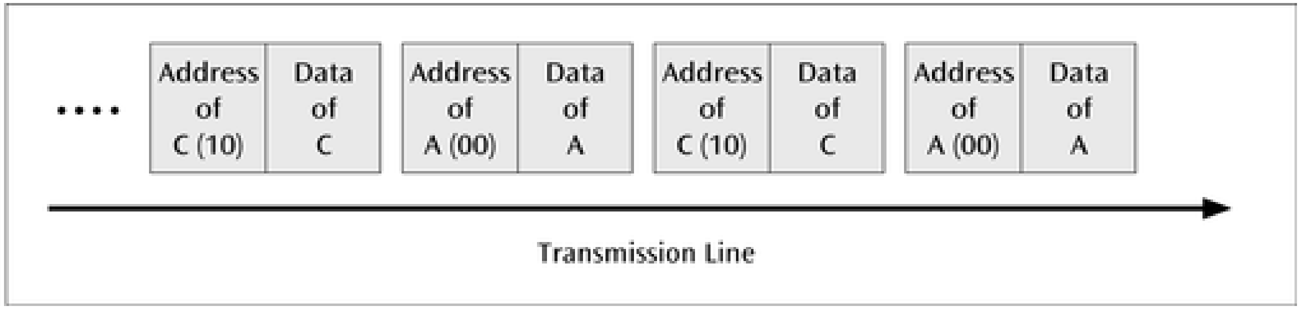
- A statistical multiplexor transmits only the data from active workstations.
- If a workstation is not active, no space is wasted on the multiplexed stream.
- A statistical multiplexor accepts the incoming data streams and creates a frame containing only the data to be transmitted.

Figure 5-9
Two stations out of four transmitting via a statistical multiplexor



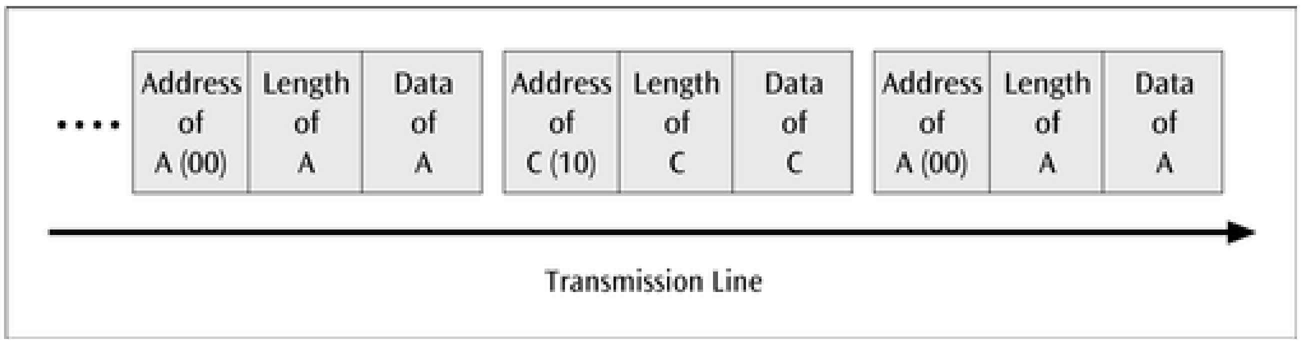
To identify each piece of data, an address is included

Figure 5-10
Sample address and data in a statistical multiplexor output stream



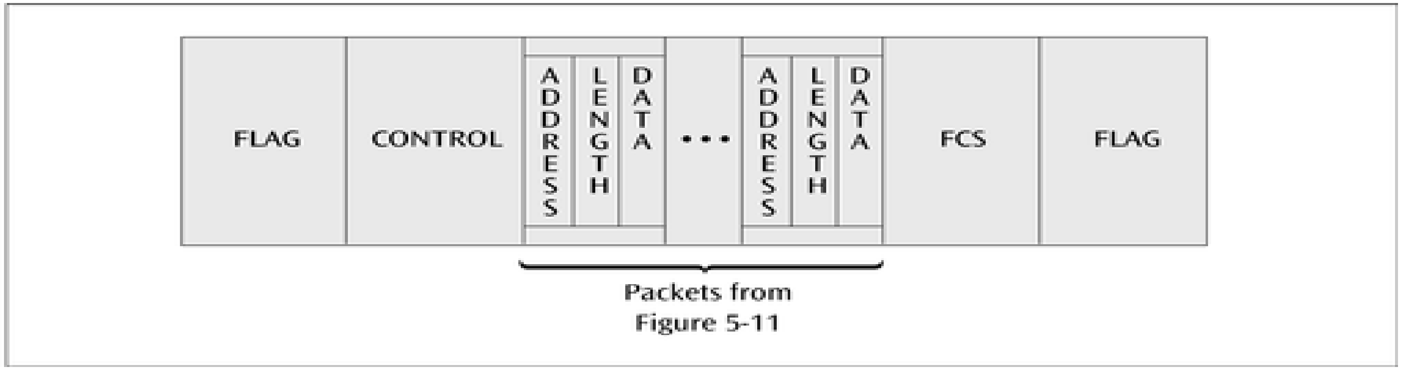
If the data is of variable size, a length is also included

Figure 5-11
Packets of address and data fields in a statistical multiplexor output stream



More precisely, the transmitted frame contains a collection of data groups.

Figure 5-12
Frame layout for the information packet transferred between statistical multiplexors



Example

We need to use synchronous TDM and combine 20 digital sources, each of 100 Kbps. Each output slot carries 2 bit from each digital source, but one extra bit is added to each frame for synchronization. Answer the following questions:

a. What is the size of an output frame in bits?

b. What is the output frame rate?

c. What is the duration of an output frame?

d. What is the output data rate?

e. What is the efficiency of the system (ratio of useful bits to the total bits).

Example

- Ten sources, six with a bit rate of 200 kbps and four with a bit rate of 400 kbps are to be combined using TDM with no synchronizing bits. Answer the following questions about the final stage of the multiplexing:
  a) What is the size of a frame in bits?
  b) What is the frame rate?
  c) What is the duration of a frame?
  d) What is the data rate?

  [Each output slot carries 1 bit from each digital source]

Example

- Show the contents of the five output frames for a synchronous TDM multiplexer that combines four sources sending the following characters. Note that the characters are sent in the same order that they are typed. The third source is silent.
  a) Source 1 message: HELLO
  b) Source 2 message: HI
  c) Source 3 message:
  d) Source 4 message: BYE

Example

- A character-interleaved time division multiplexer is used to combine the data streams of a number of 110-bps asynchronous terminals for data transmission over a 2400-bps digital line. Each terminal sends asynchronous characters consisting of 7 data bits, 1 parity bit, 1 start bit, and 2 stop bits. At least 3% of the line capacity is reserved for pulse stuffing to accommodate speed variations from the various terminals.
  a) Determine the number of bits per character.
  b) Determine the number of terminals that can be accommodated by the multiplexer.

a) $n = 7 + 1 + 1 + 2 = 11$ bits/character

b) Available capacity $= 2400 \times 0.97 = 2328$ bps

If we use 20 terminals sending one character at a time in TDM, the total capacity used is:

20x110 bps=220bps<2328

21×110 bps $= 2310$ bps available capacity

22 x 110bps=2420>2328