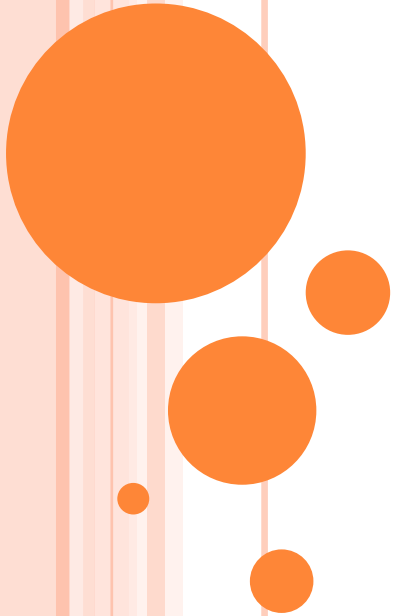


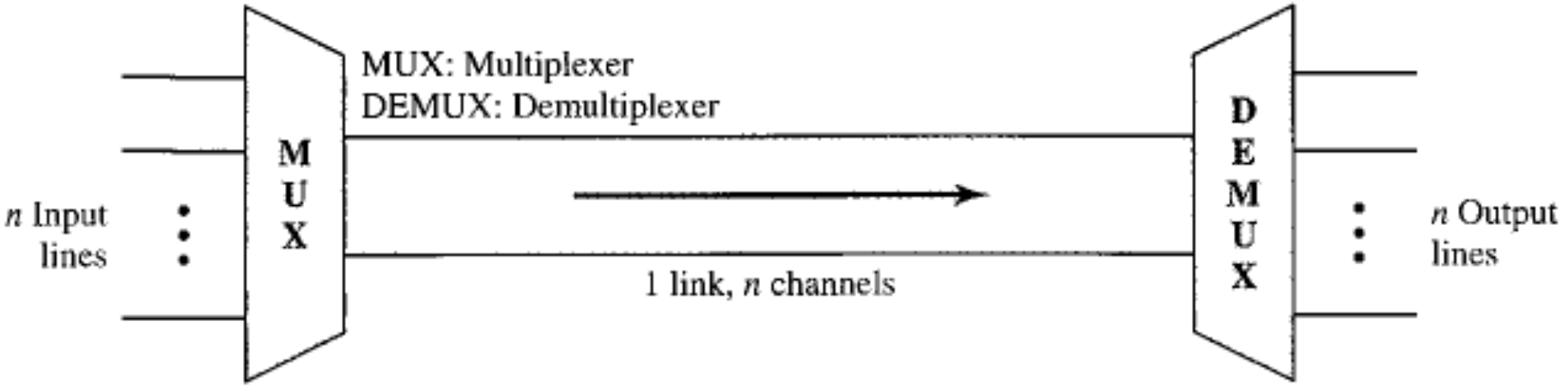
Chapter – 6
Bandwidth utilization: multiplexing and spreading

Key terms of this chapter

- Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.
-
- Efficiency can be achieved by multiplexing.
- Privacy and anti-jamming can be achieved by spreading.

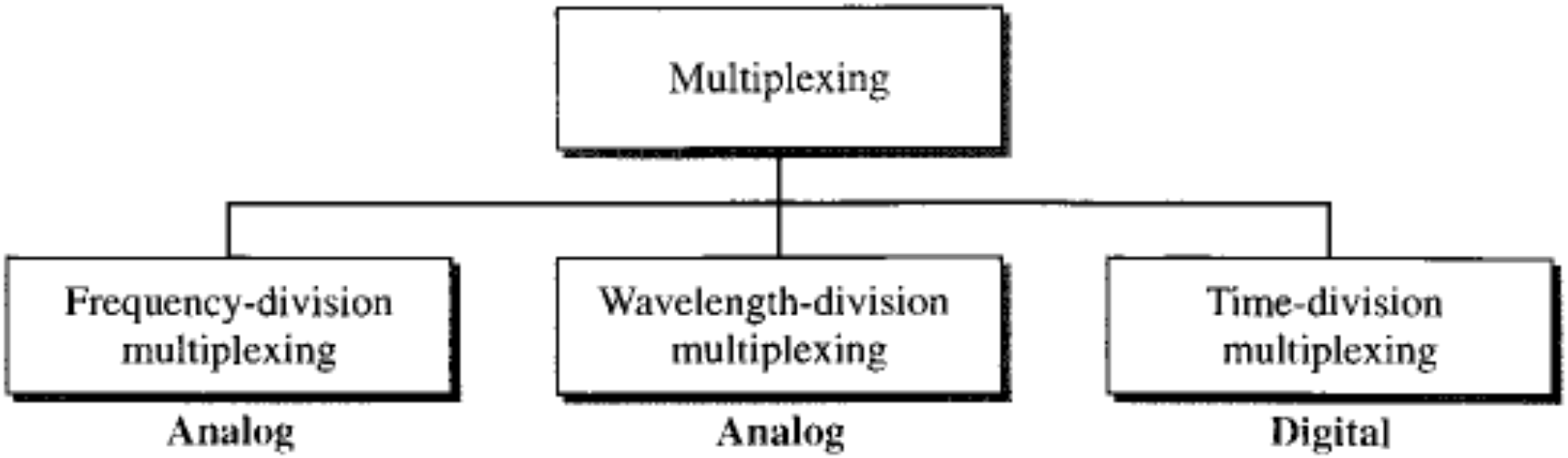
Multiplexing (MUX)

- Multiplexing is the technique to allow simultaneous transmission of multiple signals across a single data link.
- If 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.



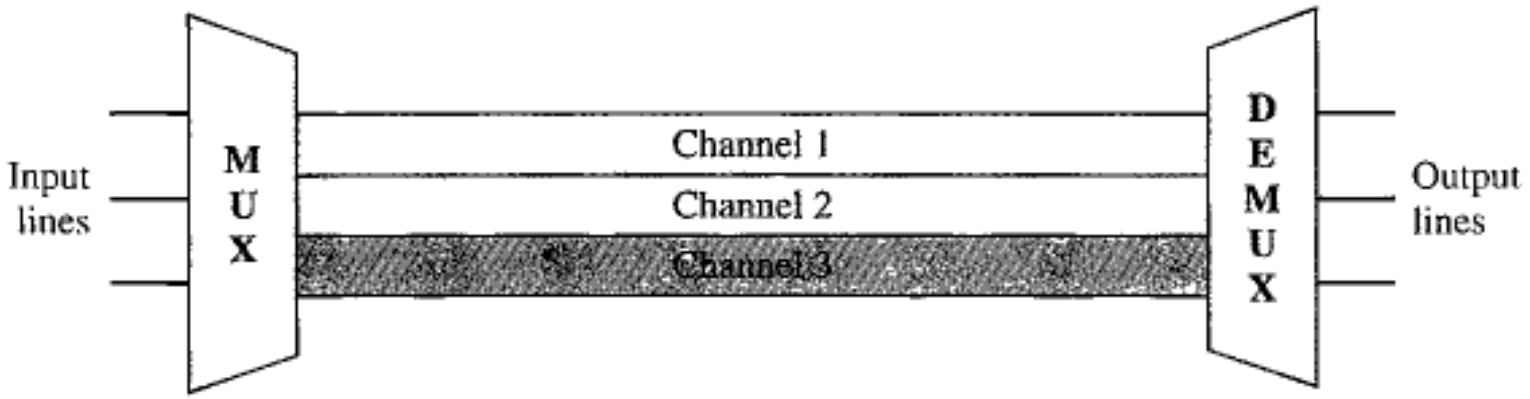
Categories of multiplexing

- Check out which one is analog and which one is digital !

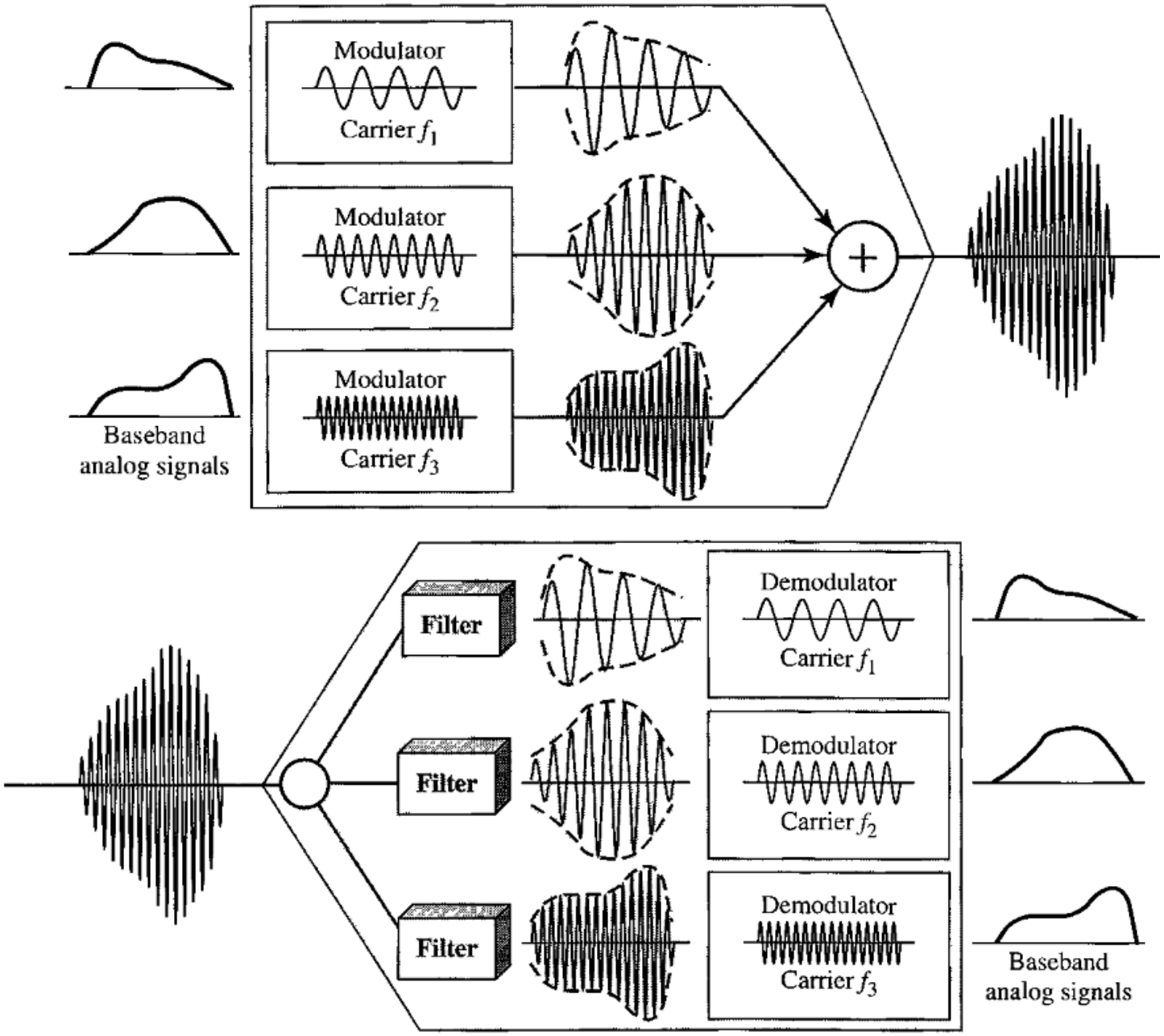


Frequency division multiplexing (FDM)

- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.
- Channels can be separated by guard bands to prevent overlapping

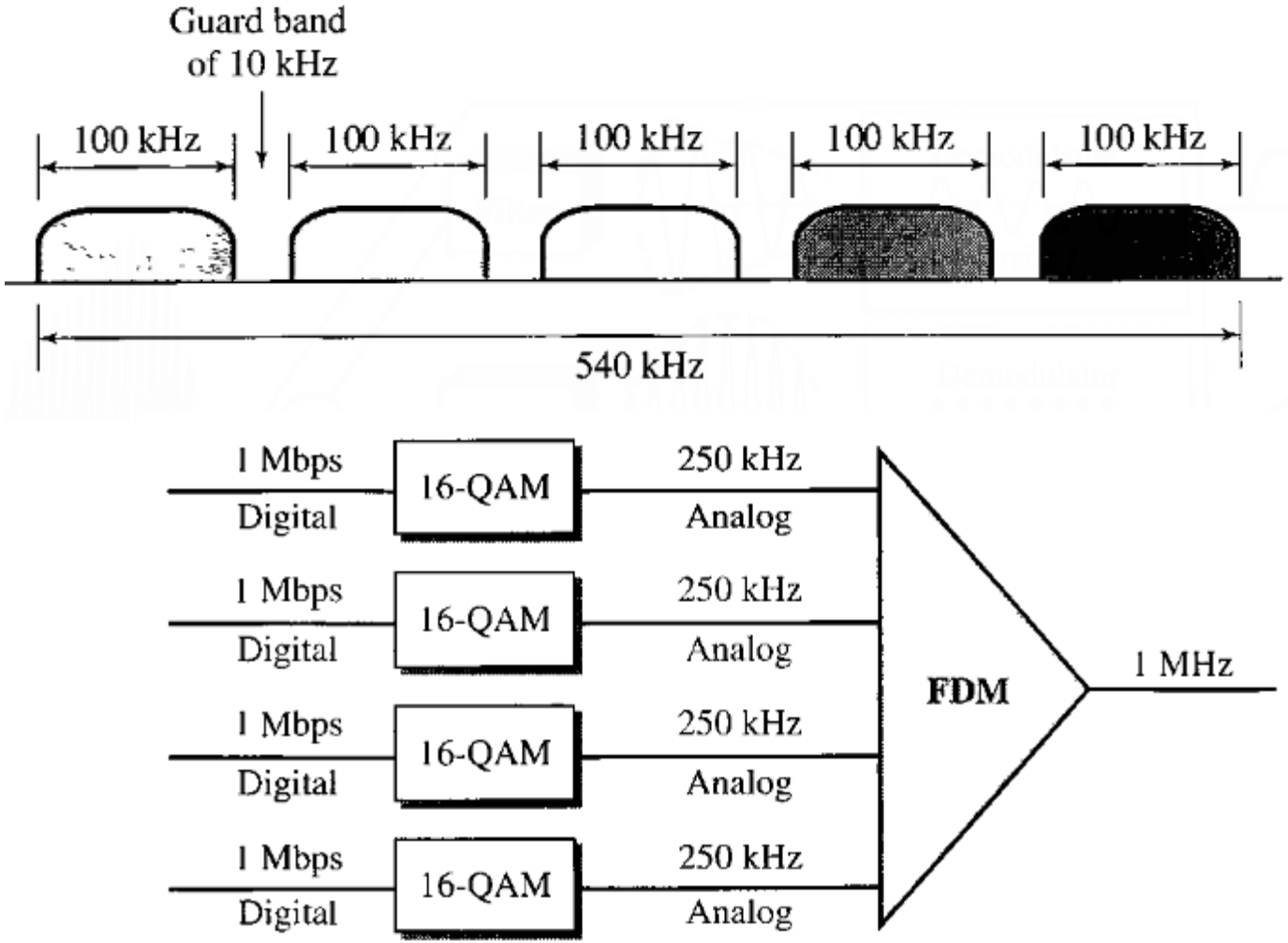


FDM PROCESS


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

FDM…The analog Carrier system

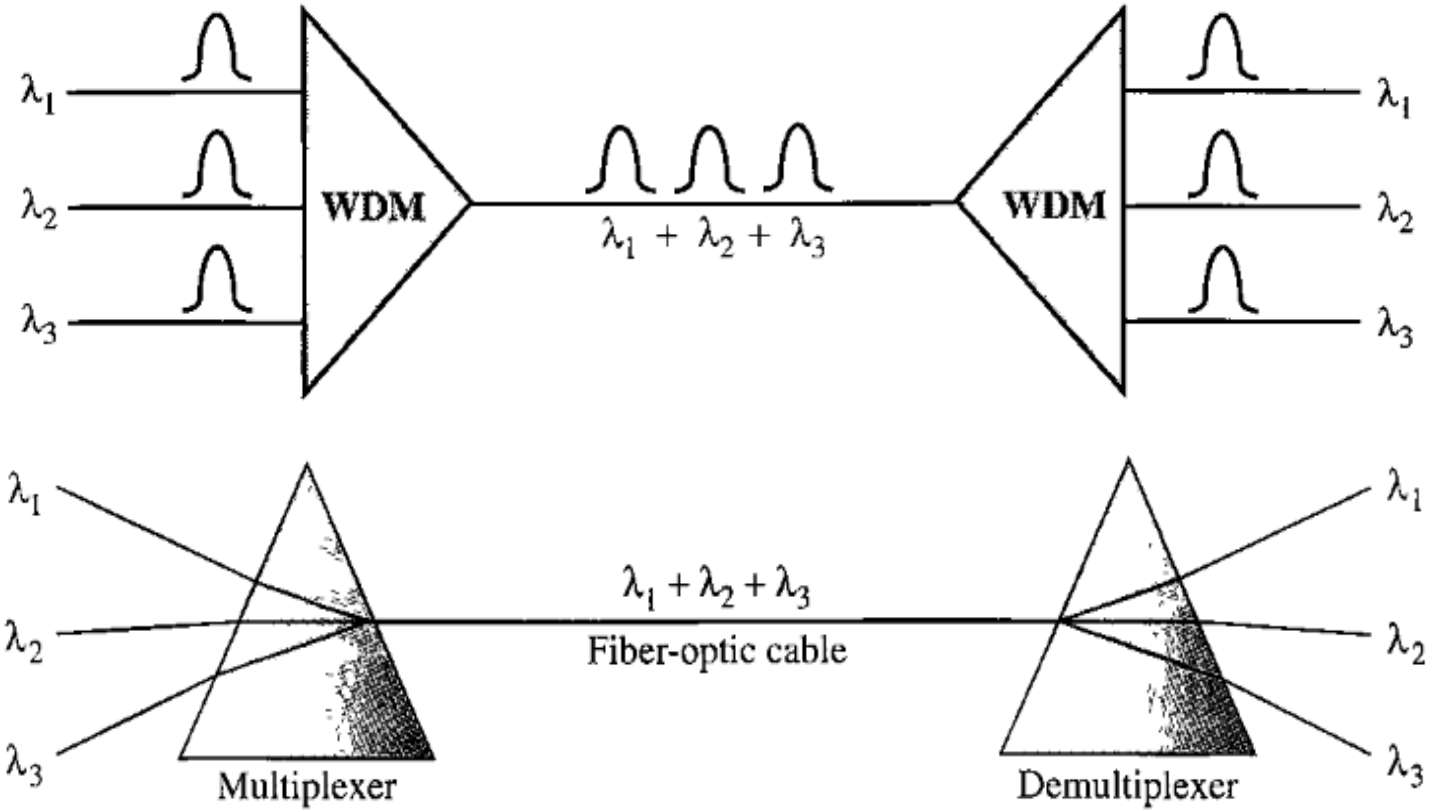
- Greatest example of FDM is AM and FM radio



WDM

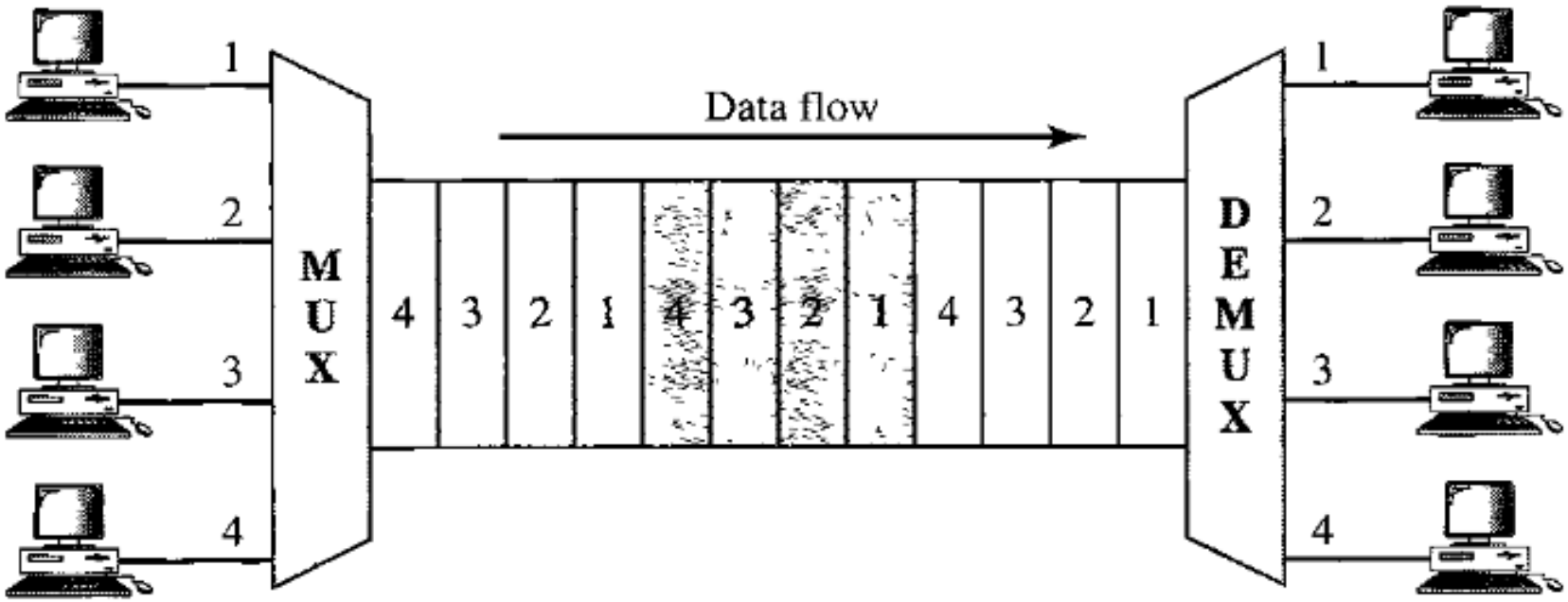
- WDM is just like FDM, but for optical signals.

- Very narrow band of light from different sources are combined to make a wider band of light.



TDM

- In TDM, each connection occupies the total bandwidth a for a certain amount of time, instead of sharing the total bandwidth



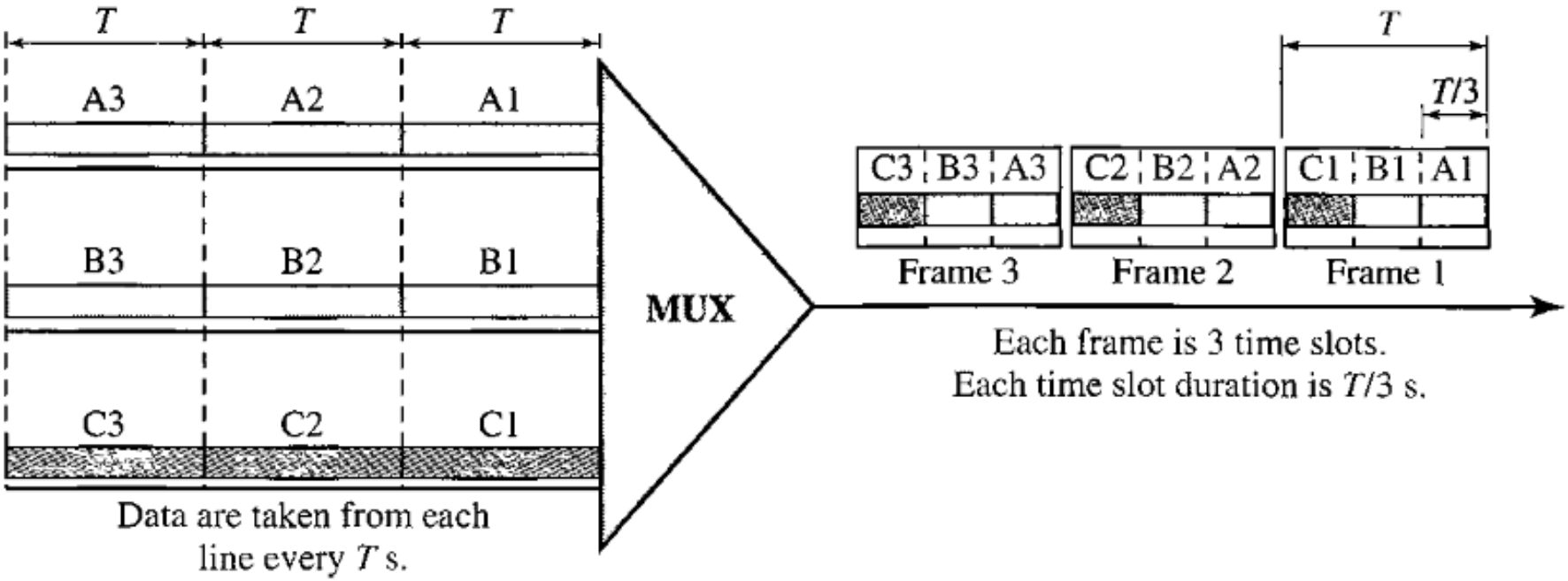
TDM types

- Synchronous
  - Each input connection has one slot in the output even though it is not sending any data.
  - Has synchronization bits
  - No addressing is needed

- Statistical
  - Slots are allocated based on available data
  - No synchronization bits
  - Addressing is needed

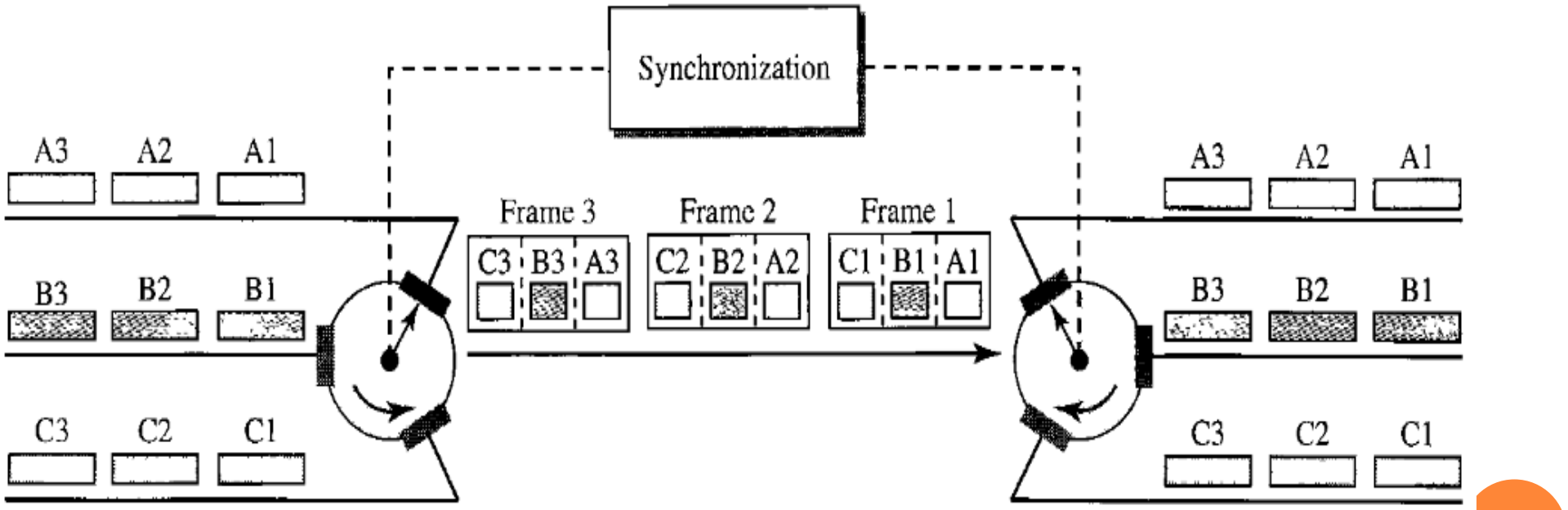
Synchronous TDM…

- Time slots and frames



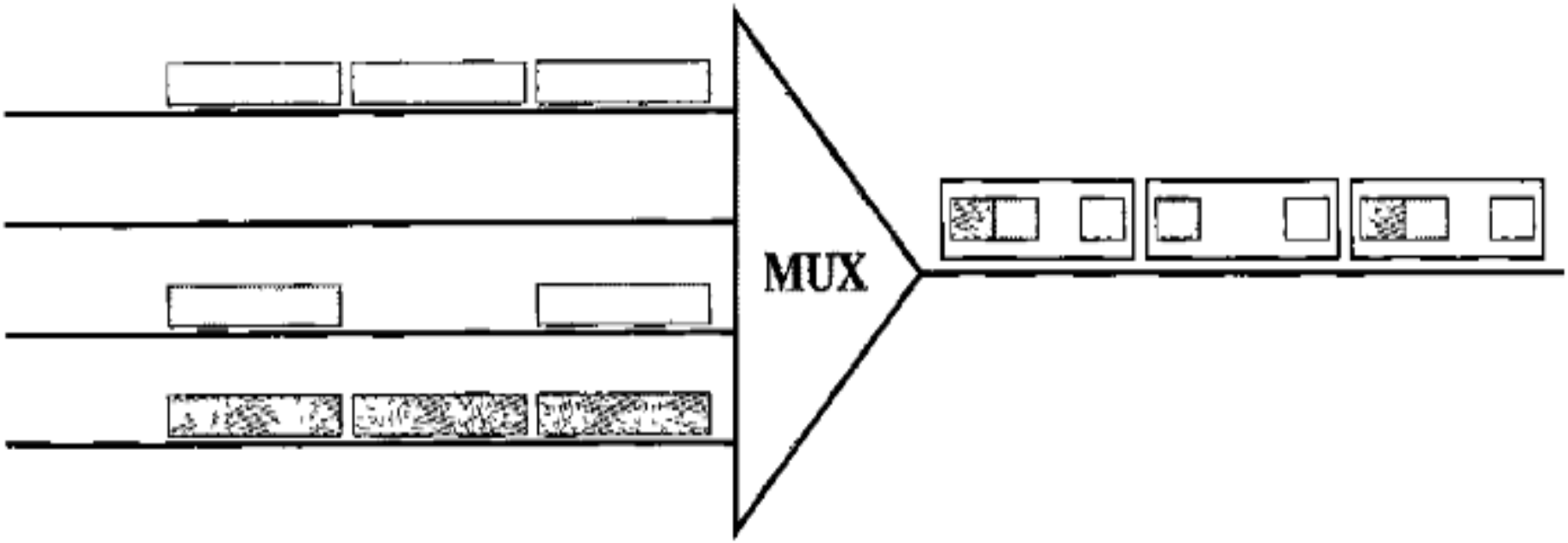
Synchronous TDM…

- Interleaving



Synchronous TDM…

- Empty slots

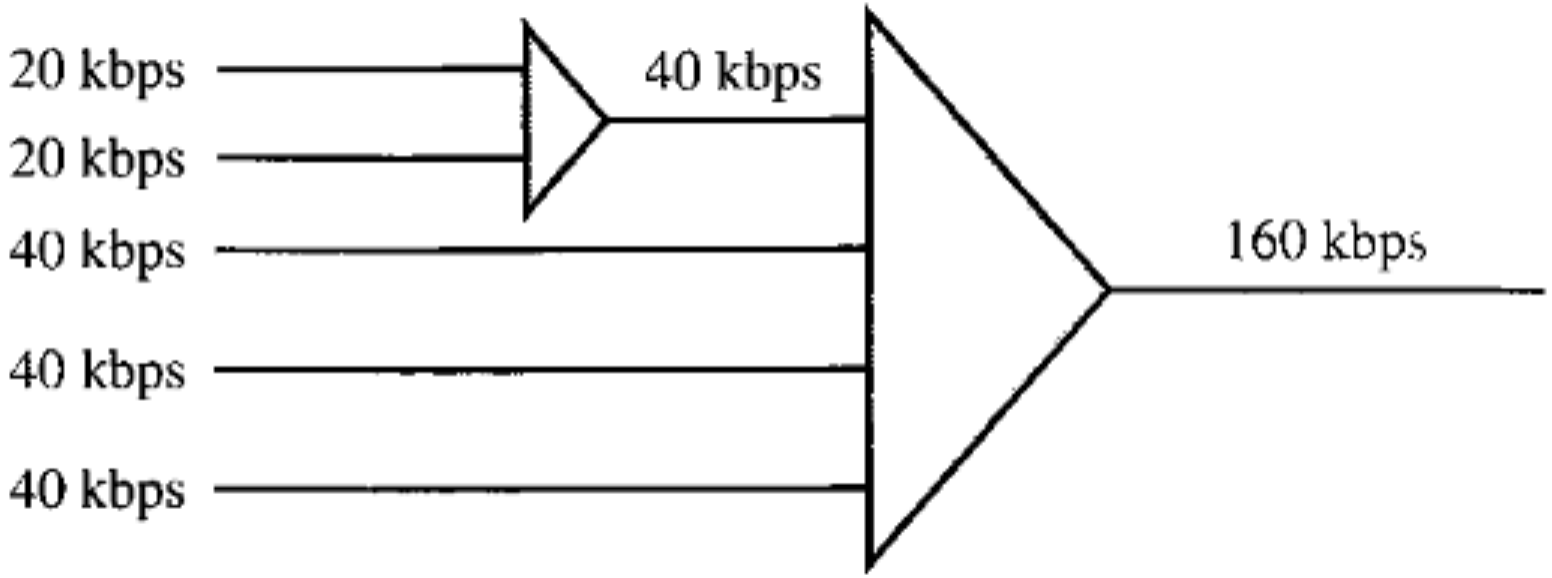


Data rate management

- In all our discussion so far, we assumed that the data rates of all input lines were the same.
- However, if data rates are not the same, then problem can occur with TDM
- Three strategies, or a combination of them, can be used to solve this problem.
  - Multilevel multiplexing
  - Multiple-slot allocation, and
  - Pulse stuffing.

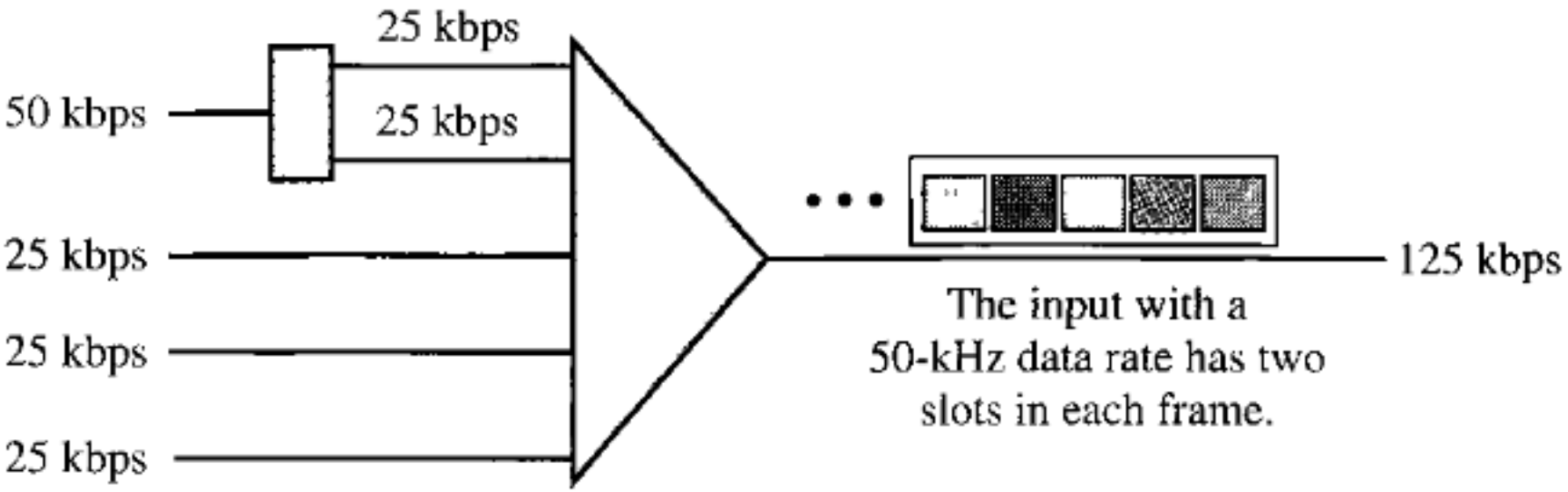
Multilevel multiplexing

- Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others.



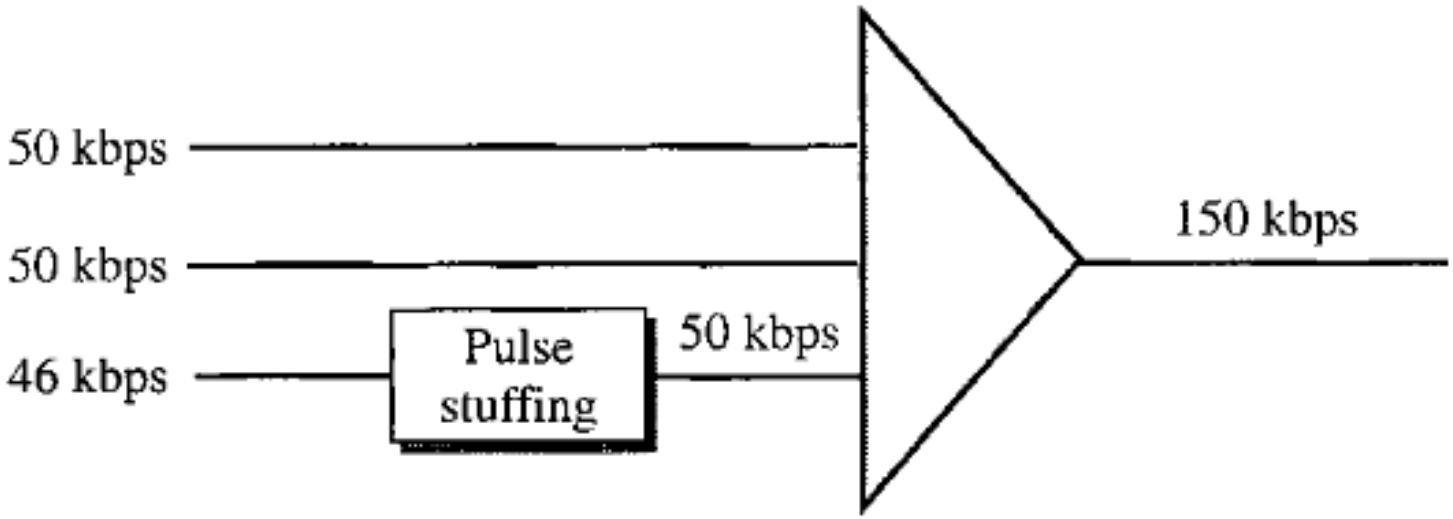
Multiple-slot multiplexing

- Sometimes it is more efficient to allot more than one slot in a frame to a single input line.
- We insert a serial-to-parallel converter in the line to make two inputs out of one.



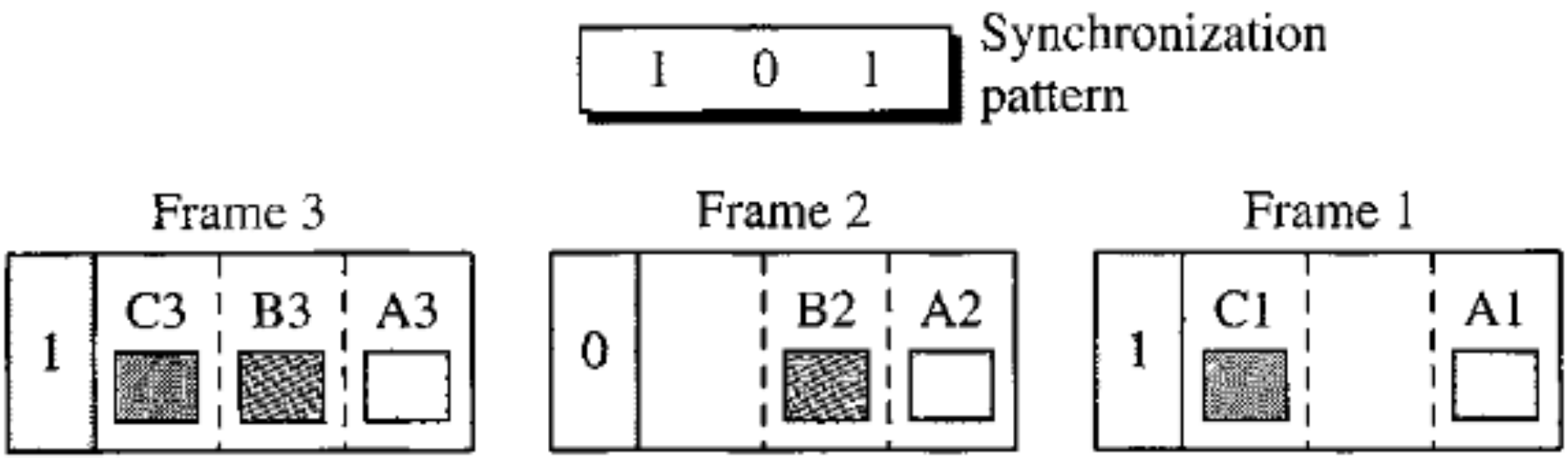
Pulse stuffing

- Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied.
- One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will increase their rates. This technique is called pulse stuffing, bit padding, or bit stuffing.



Synchronous TDM…

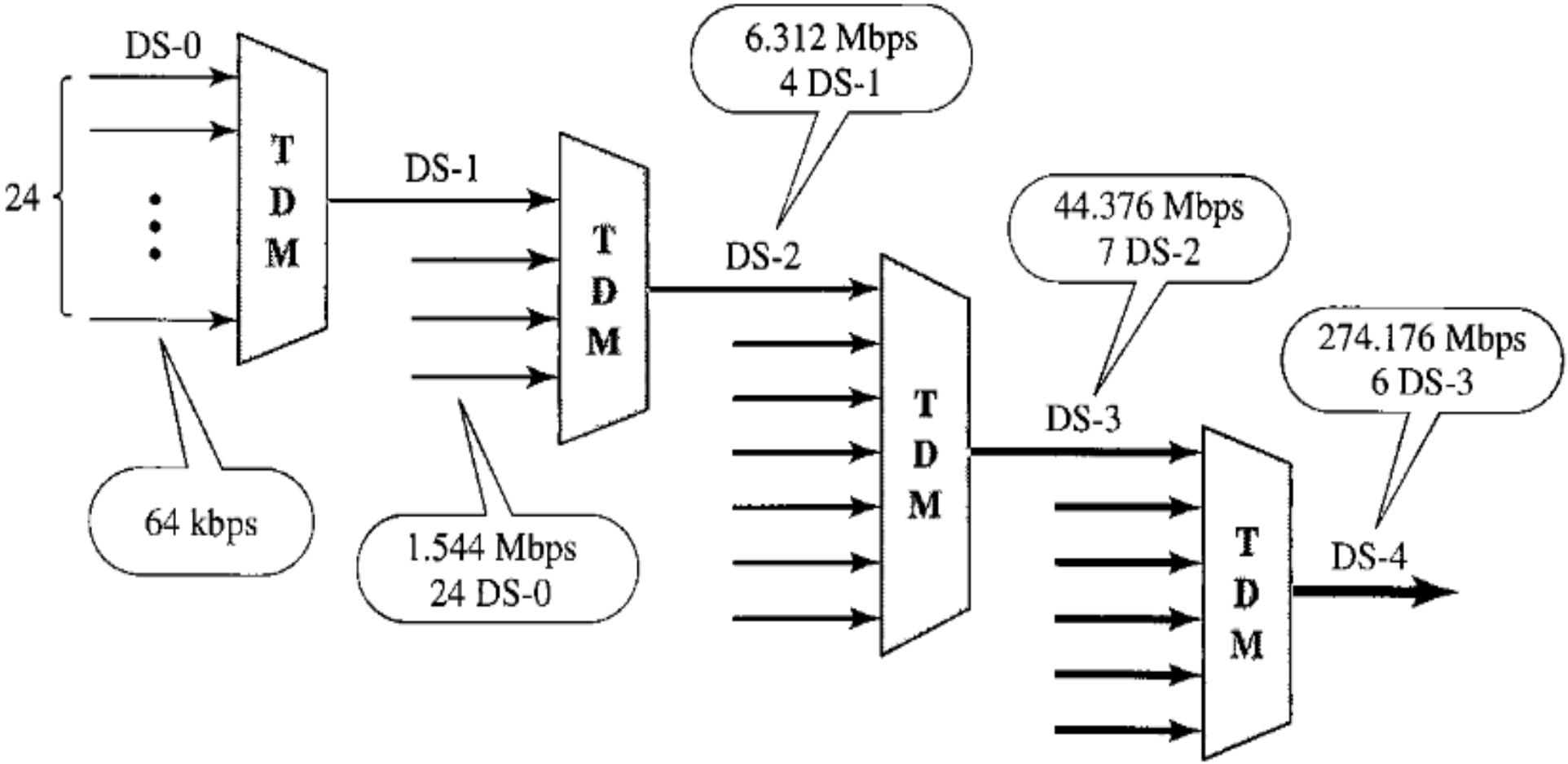
- Frame Synchronization
  - with synchronization bits, known as framing bits.



Digital signal (DS) service

- Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy.
- Few DS services: DS-0, DS-1, DS-2, DS-3, DS-4.
- A DS-0 service is a single digital channel of 64 kbps.
- DS-1 is a 1.544-Mbps service; 1.544 Mbps is 24 times 64 kbps plus 8 kbps of overhead. It can be used as a single service for 1.544-Mbps transmissions, or it can be used to multiplex 24 DS-0 channels.
- DS-2 is a 6.312-Mbps service; 6.312 Mbps is 96 times 64 kbps plus 168 kbps of overhead.

DS SERVICE

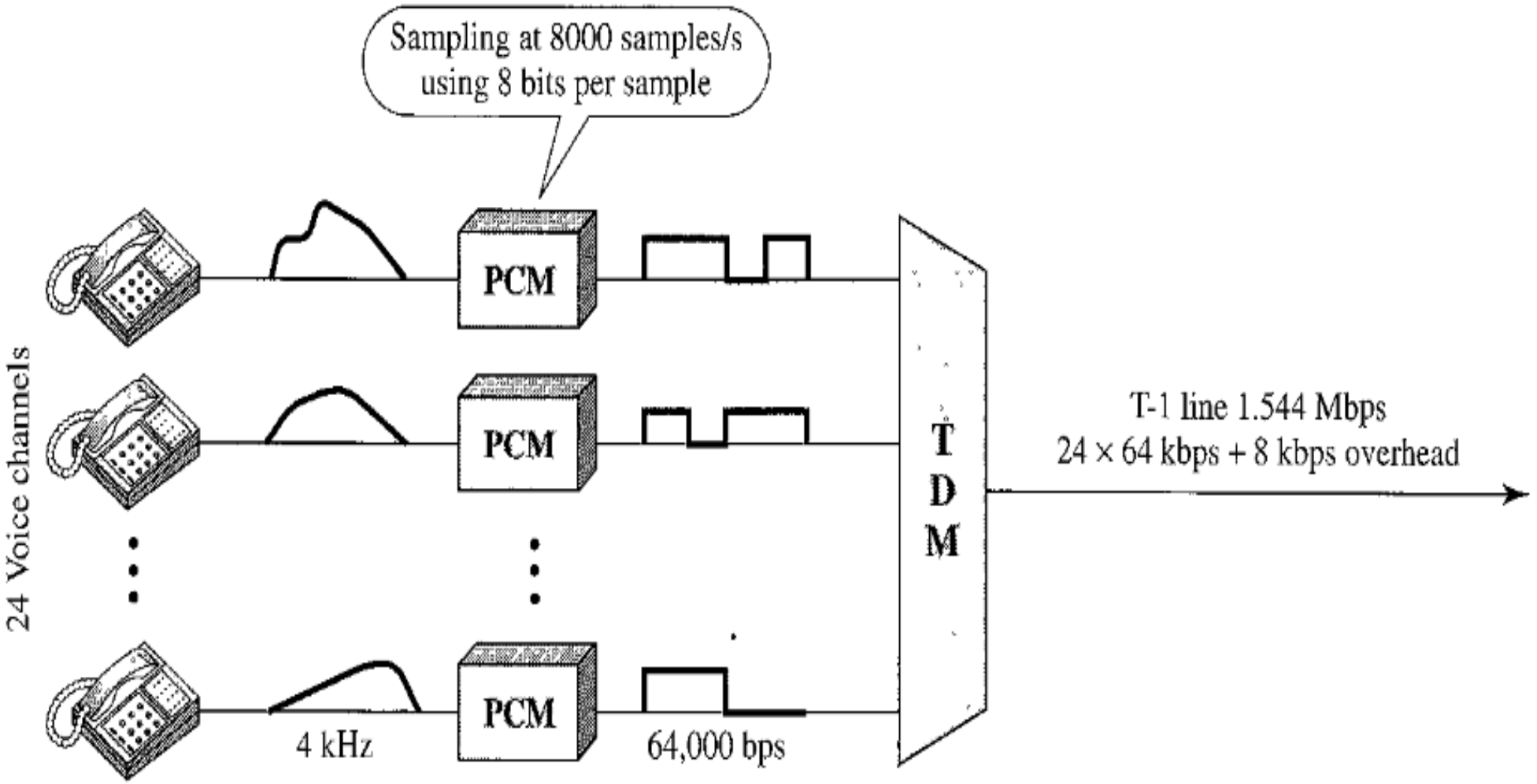

DS-0
24
T
D
M
64 kbps
DS-1
1.544 Mbps
24 DS-0
T
D
M
6.312 Mbps
4 DS-1
DS-2
T
D
M
44.376 Mbps
7 DS-2
DS-3
T
D
M
274.176 Mbps
6 DS-3
DS-4

T-LINES

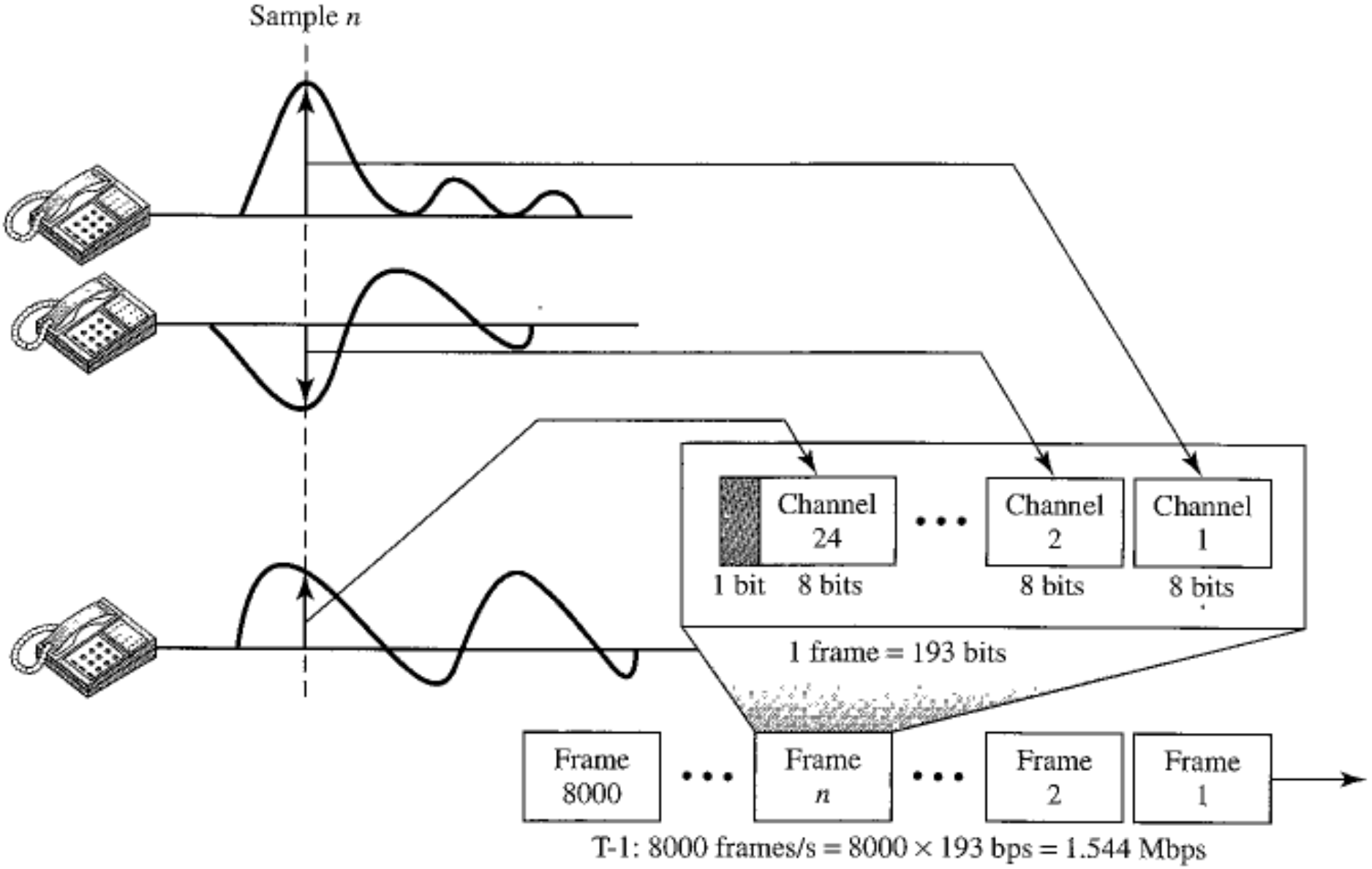
- DS-0, DS- 1, and so on are the names of services.
- To implement those services, telephone companies use T lines (T-1 to T-4). These are lines with capacities precisely matched to the data rates of the DS-1 to DS-4 services
- So far only T-1 and T-3 lines are commercially available.

Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

T-1 LINE FOR MULTIPLEXING TELEPHONE LINES



T-1 FRAME STRUCTURE



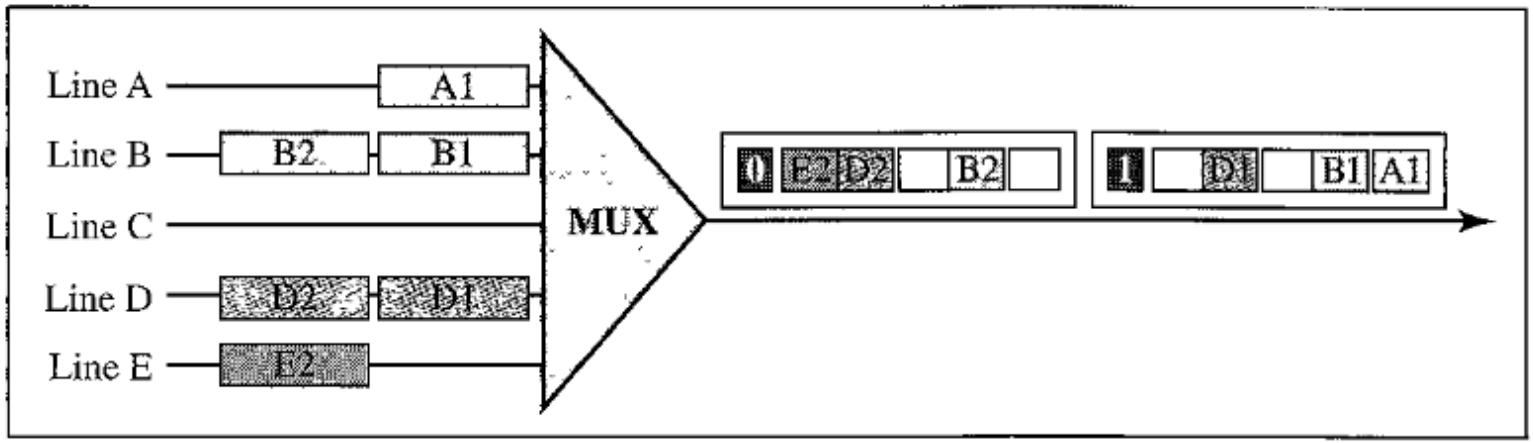
E LINES

- Europeans use a version of T lines called E lines. The two systems are conceptually identical, but their capacities differ.
- Table below shows the E lines and their capacities.

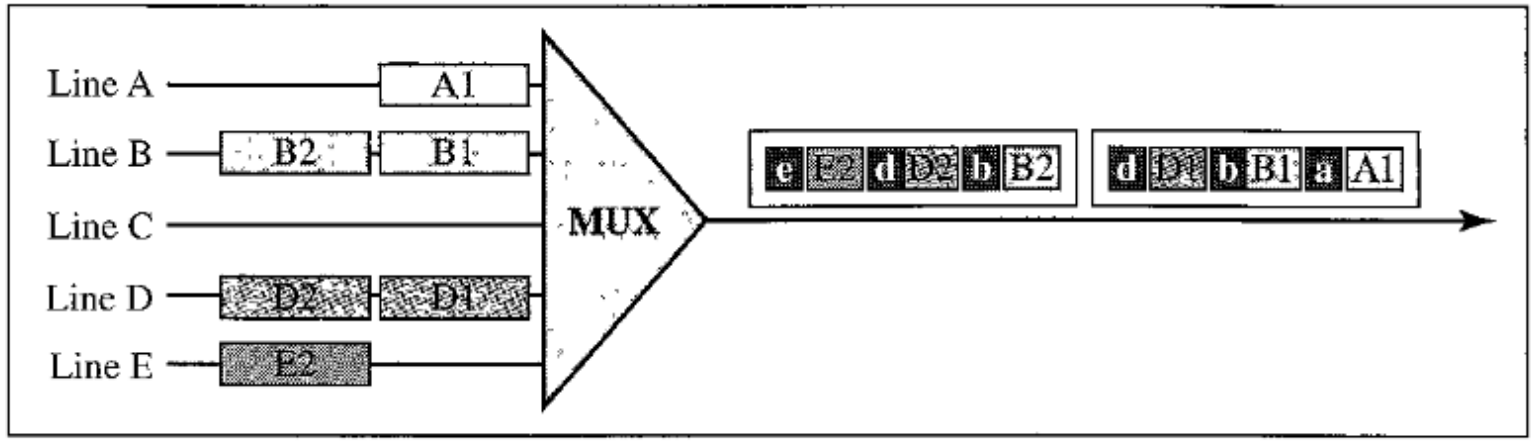
Line	*Rate (Mbps)*	*Voice Channels*
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Statistical TDM

- Slots are dynamically allocated to improve BW efficiency.



a. Synchronous TDM



b. Statistical TDM

Spread spectrum

- Multiplexing combines signals from several sources to achieve bandwidth efficiency; the available bandwidth of a link is divided between the sources.
- In spread spectrum (SS), we also combine signals from different sources to fit into a larger bandwidth, but our goals are somewhat different.
- Spread spectrum is designed to be used in wireless applications (LANs and WANs) where all stations use air as the medium for communication.
- Stations must be able to share this medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder

Spread spectrum (2)

- To achieve these goals, spread spectrum techniques add redundancy; they spread the original spectrum needed for each station.
- If the required bandwidth for each station is B, spread spectrum expands it to B_{ss}, such that $B_{ss} >> B$.
- The expanded bandwidth allows the source to wrap its message in a protective envelope for a more secure transmission.

Difference between SS and Multiplexing

- In Multiplexing, the total bandwidth is divided among the sources.
- It combines signals from different sources in order to achieve bandwidth efficiency.
- However, SS requires additional bandwidth in order to ensure security.

Spread spectrum

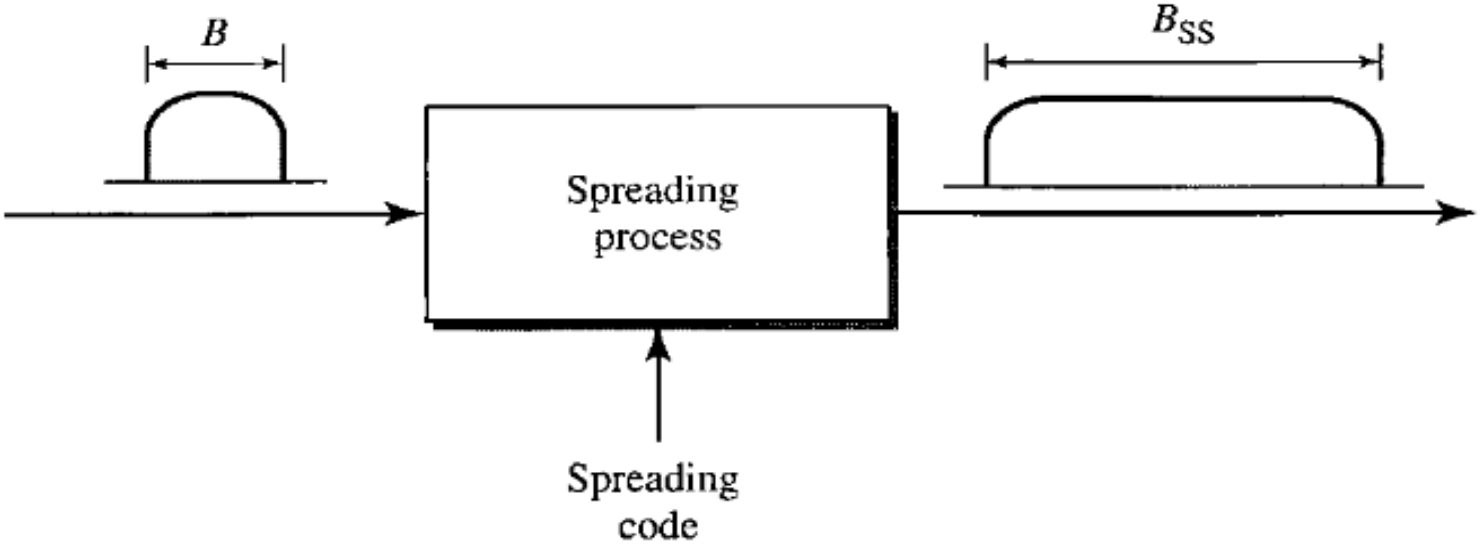
- Spread spectrum achieves its goals through two principles:

- The bandwidth allocated to each station needs to be, by far, larger than what is needed. This allows redundancy.

- The expanding of the original bandwidth B to the bandwidth B_{ss} must be done by a process that is independent of the original signal. In other words, the spreading process occurs after the signal is created by the source.

SPREAD SPECTRUM

- The figure shows original bandwidth B and spreaded bandwidth B_{ss}. The spreading code is a series of numbers
- Spreading is accomplished by means of a pseudo-random spreading code that look random, but are actually a pattern.
- It is also independent of the data and this same code is also used for de-spreading



Techniques for spread spectrum

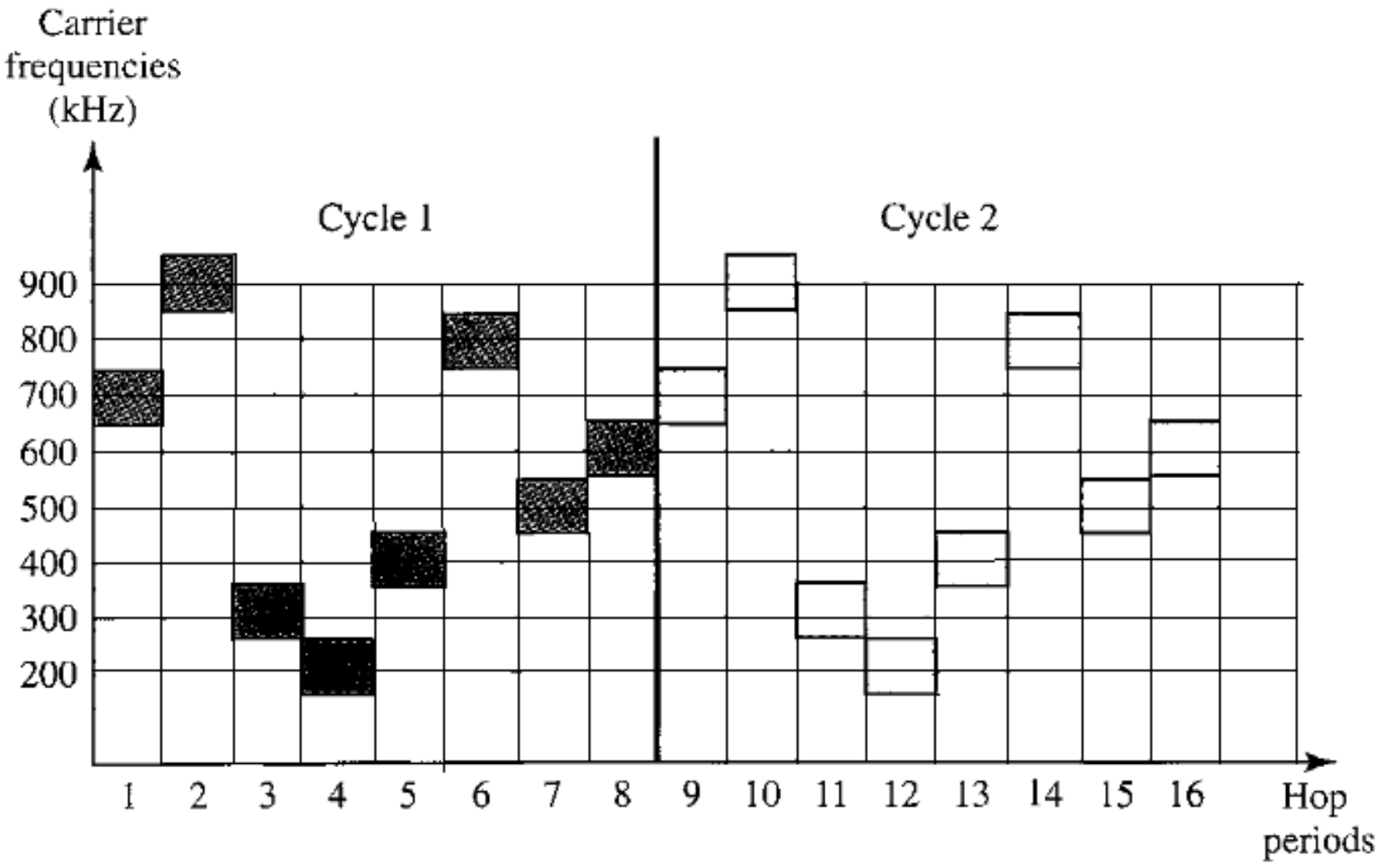
- There are two techniques to spread the bandwidth:
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS).

Frequency Hopping Spread Spectrum (FHSS)

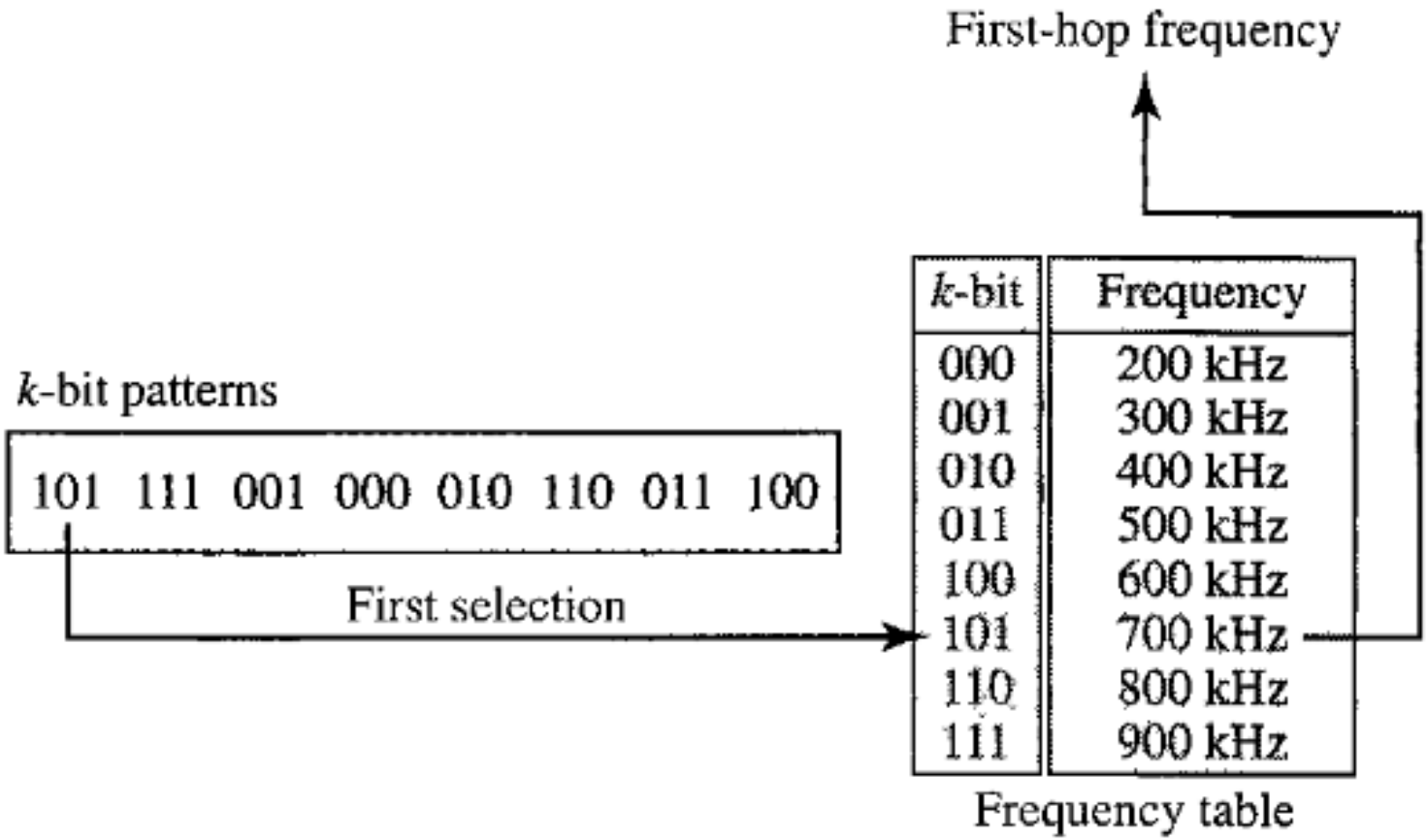
- The frequency hopping spread spectrum (FHSS) technique uses a number of different carrier frequencies that are modulated by the source signal.

- At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency

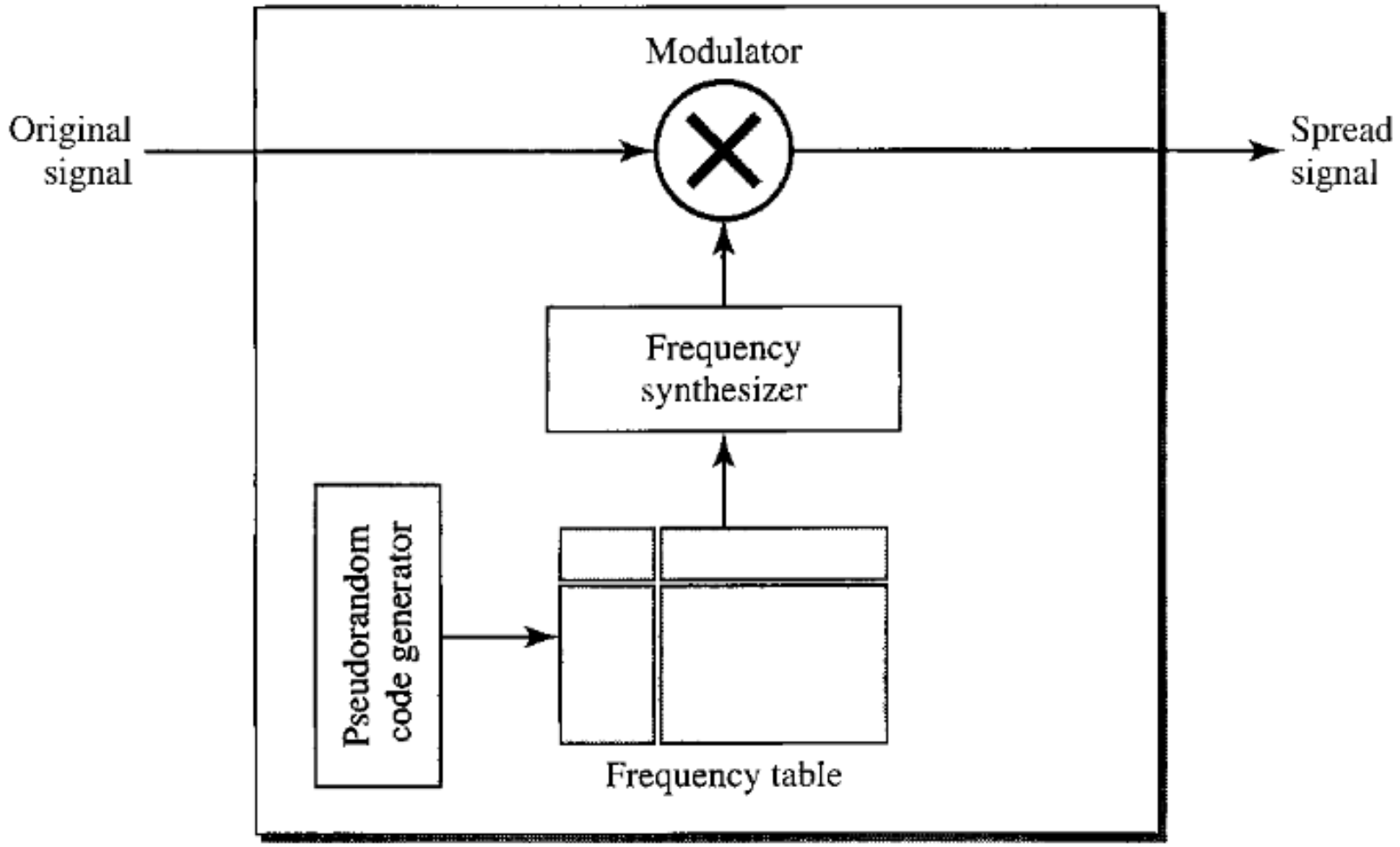
FHSS Cycles


Carrier frequencies (kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop periods

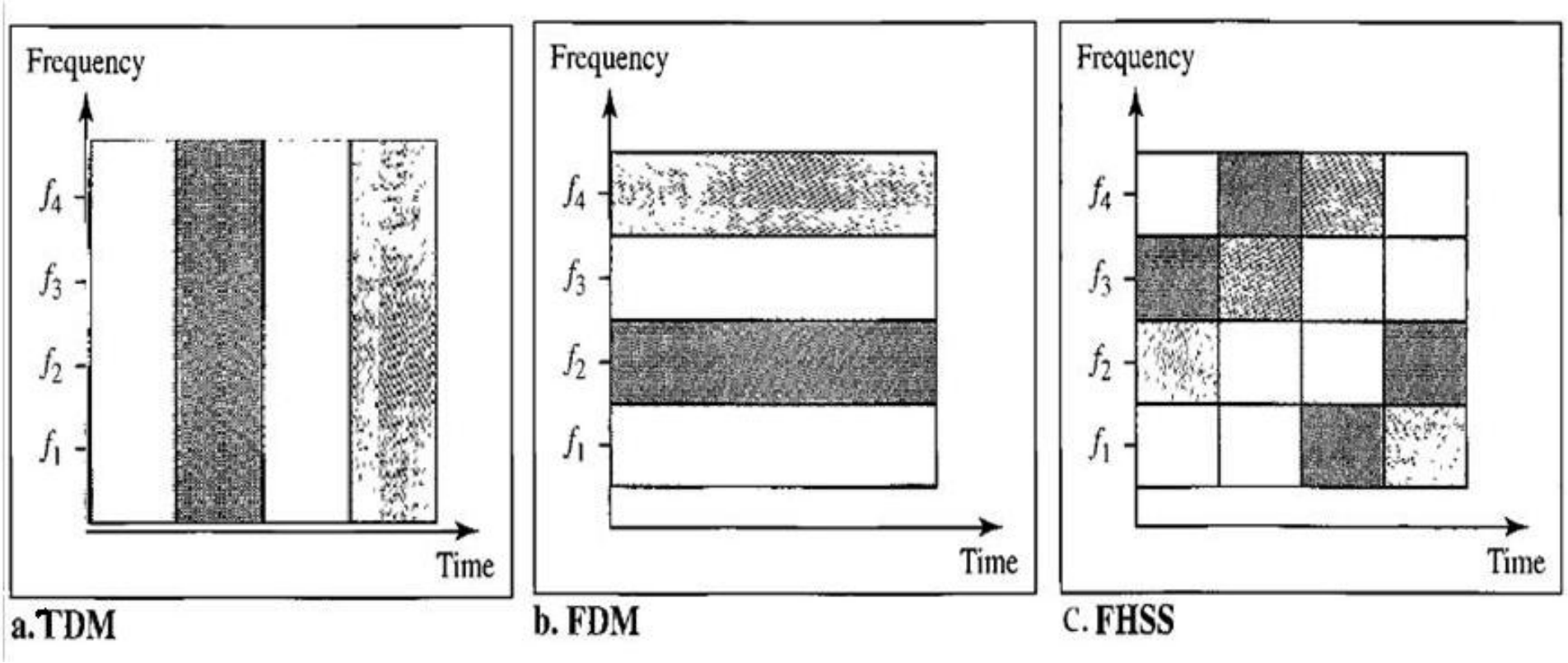
Frequency Selection



FHSS Technique



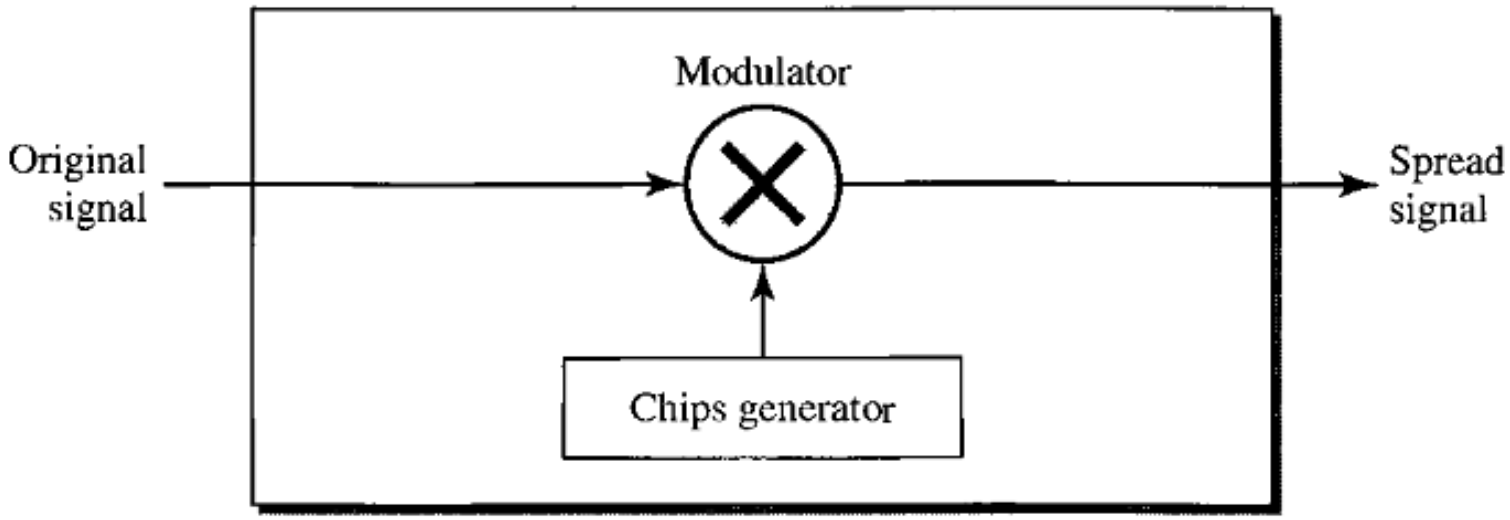
Bandwidth Sharing



Direct Sequence Spread Spectrum

- DSSS also expands the bandwidth of the signal in a different process.

- DSSS represents each data bit with *n* bits using a spreading code.



DSSS Example