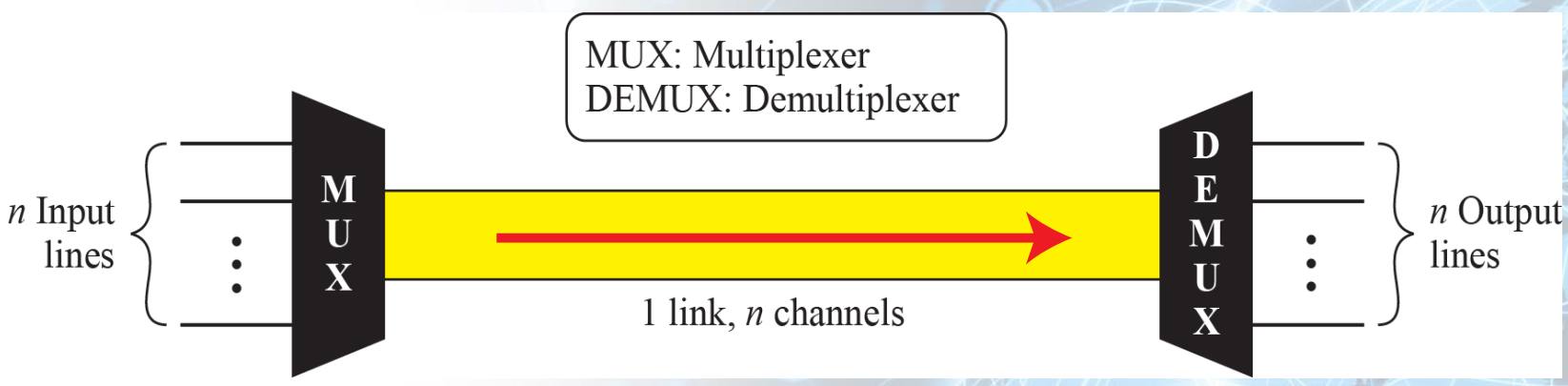
Multiplexing

- Simultaneous transmission of multiple signals across a single data link
- As data & telecomm use increases, so does traffic
  - ✓ Add individual links each time a new channel is needed
  - ✓ Install higher-bandwidth links and use each to carry multiple signals

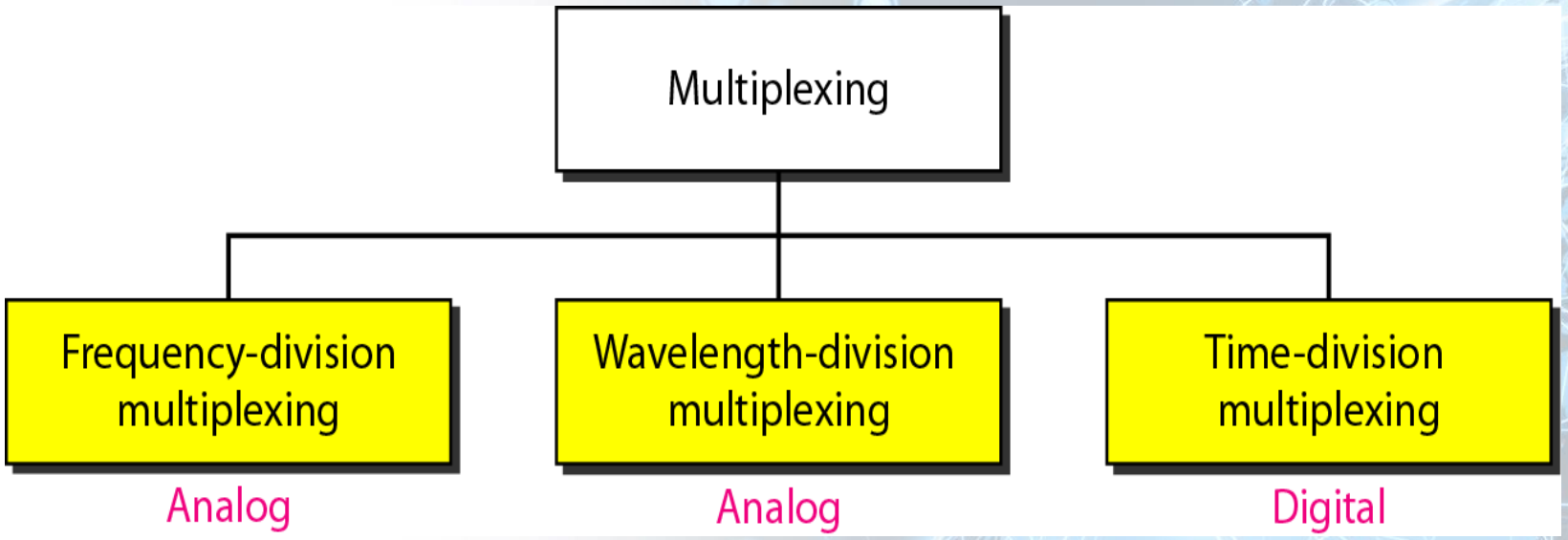
Dividing a Link into Channels



Multiplexing

- Simultaneous transmission of multiple signals across a single data link

Categories of Multiplexing



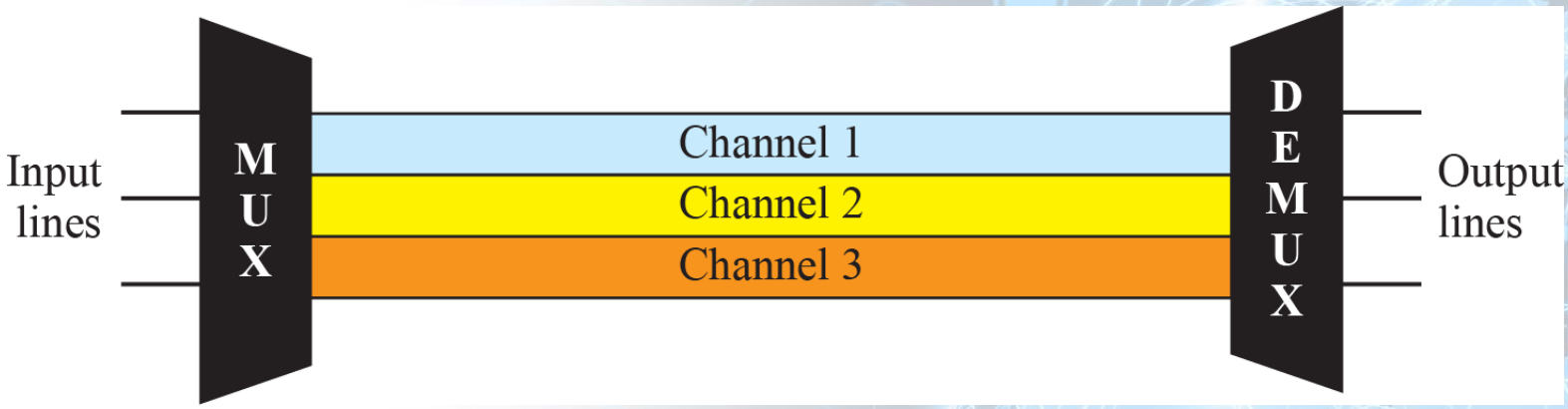
Frequency-Division Multiplexing

- 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
- Signals generated by each sending device modulate different carrier frequencies

Frequency-Division Multiplexing

These modulated signals are then combined into a single composite signal that can be transported by the link

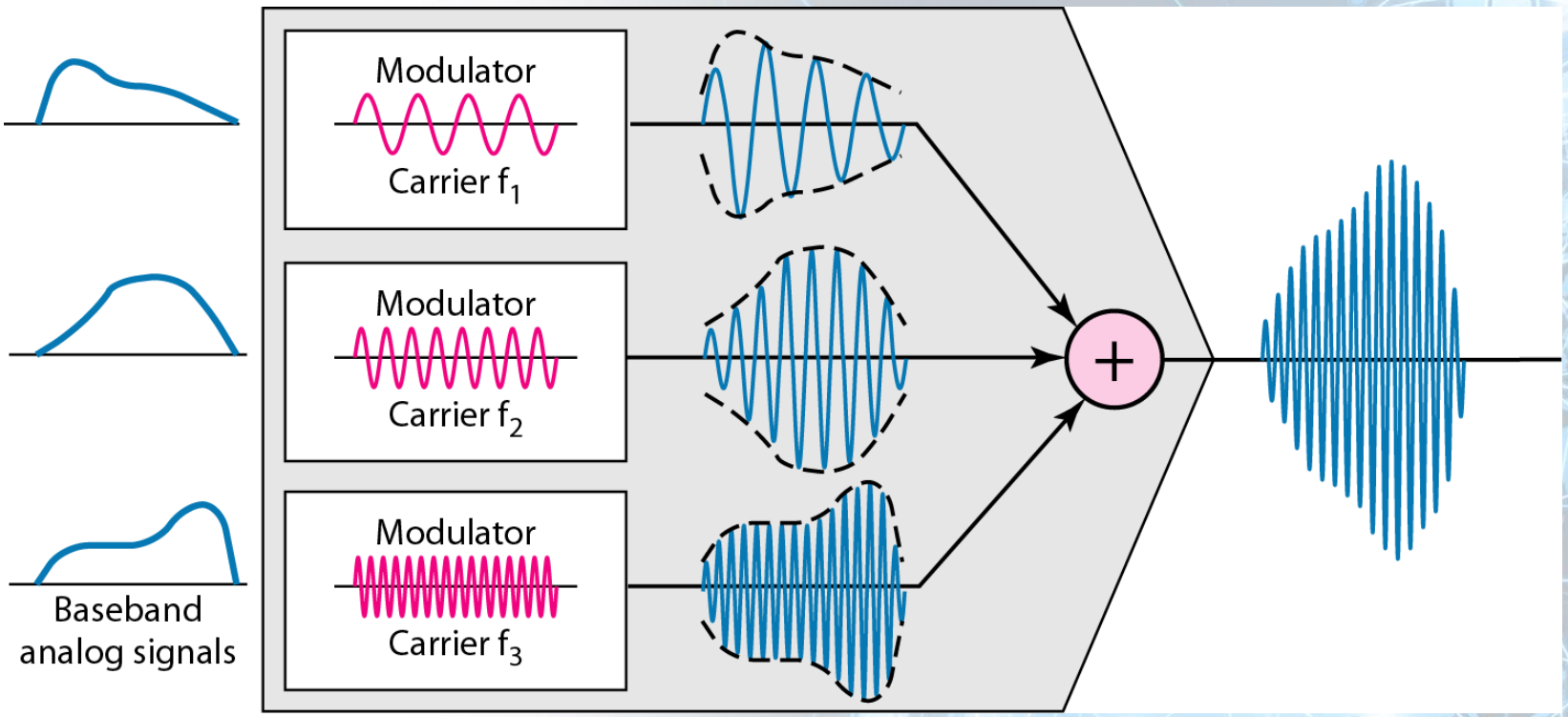
Frequency-Division multiplexing



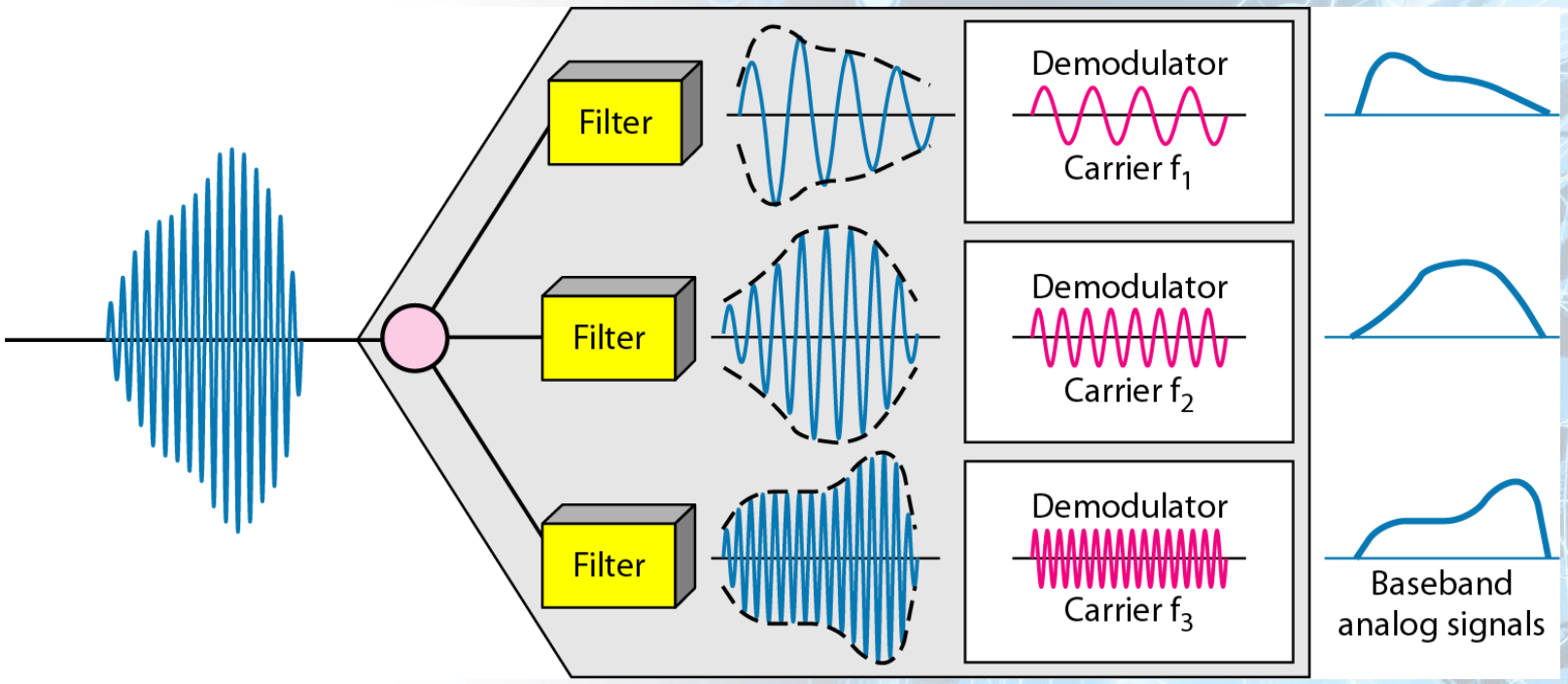
Frequency-Division Multiplexing

- 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

FDM Multiplexing

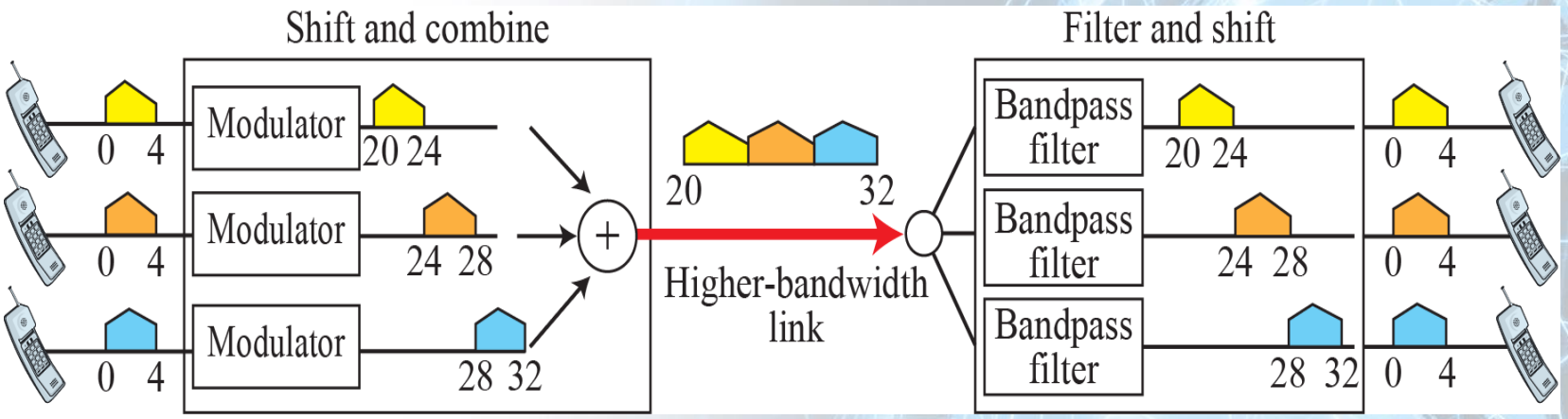


FDM De-Multiplexing



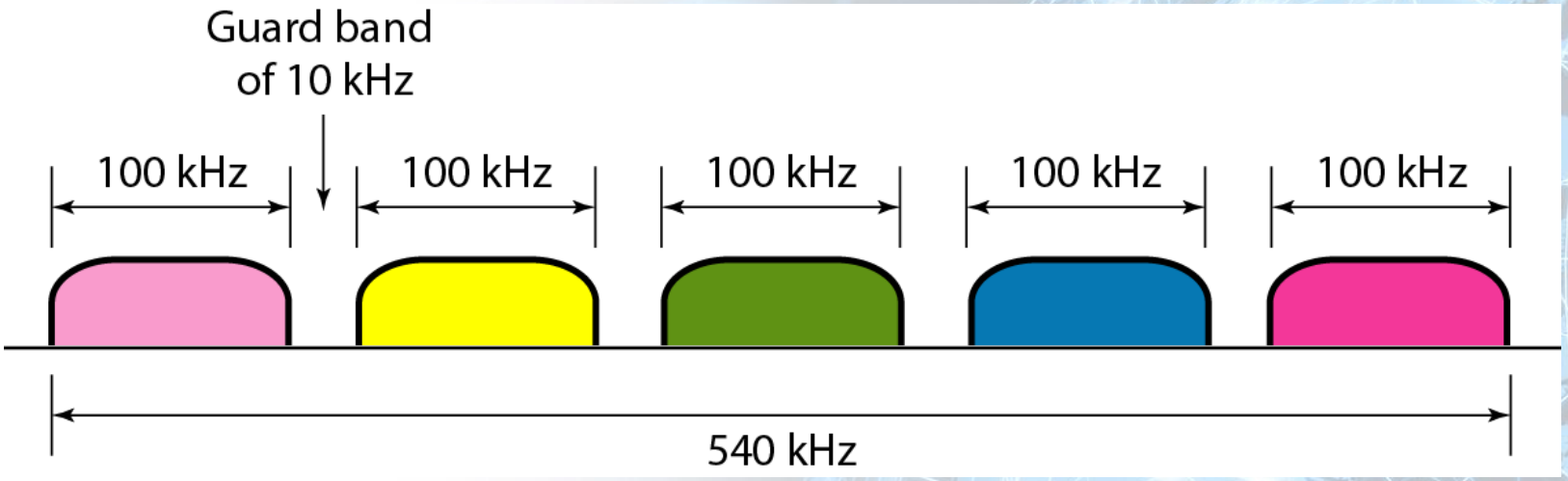
Example

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.



Example

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?

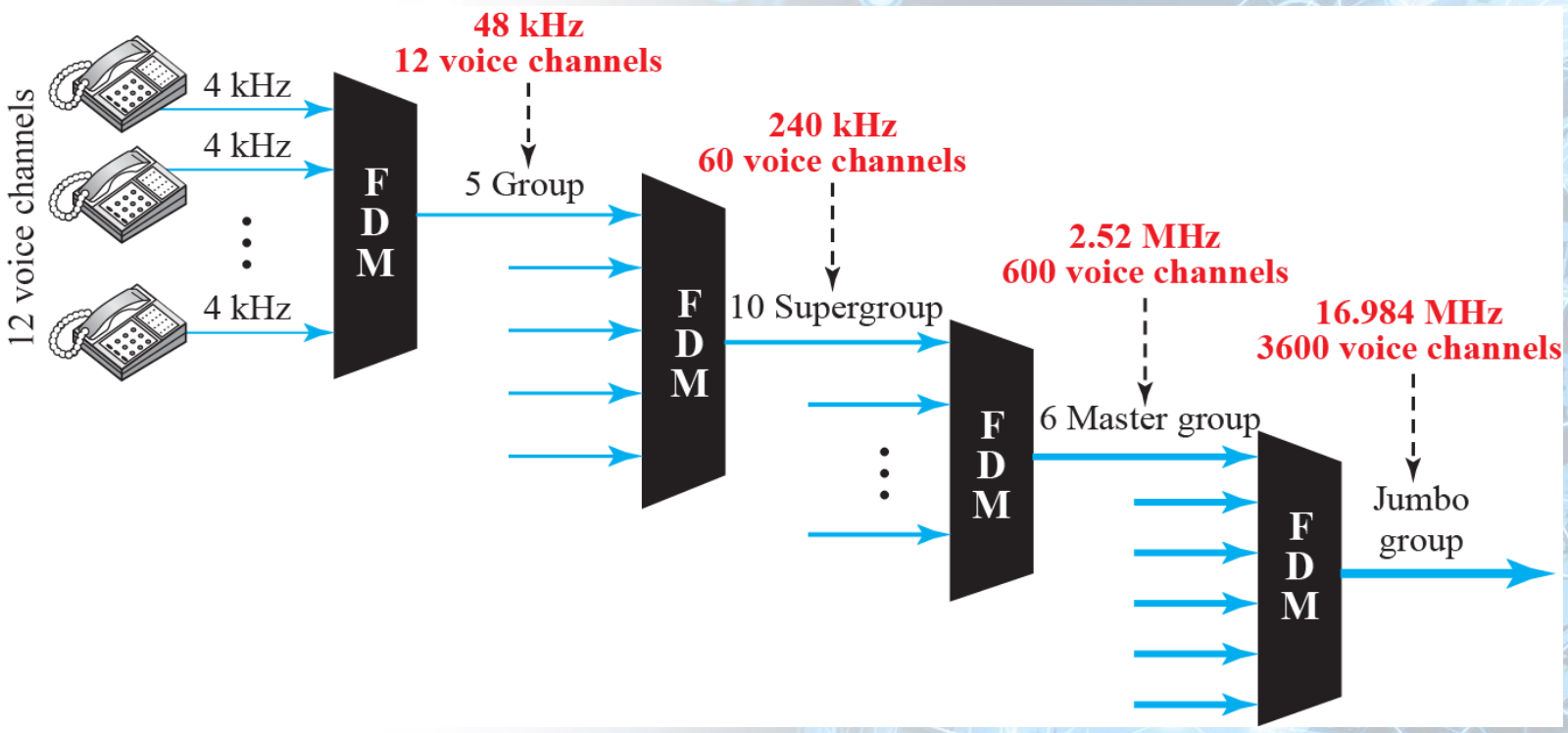


= 540 KHZ

The Analog Carrier System

- Telephone companies multiplex signals from lower-bandwidth lines on to higher-bandwidth lines
- For Analog, FDM is used

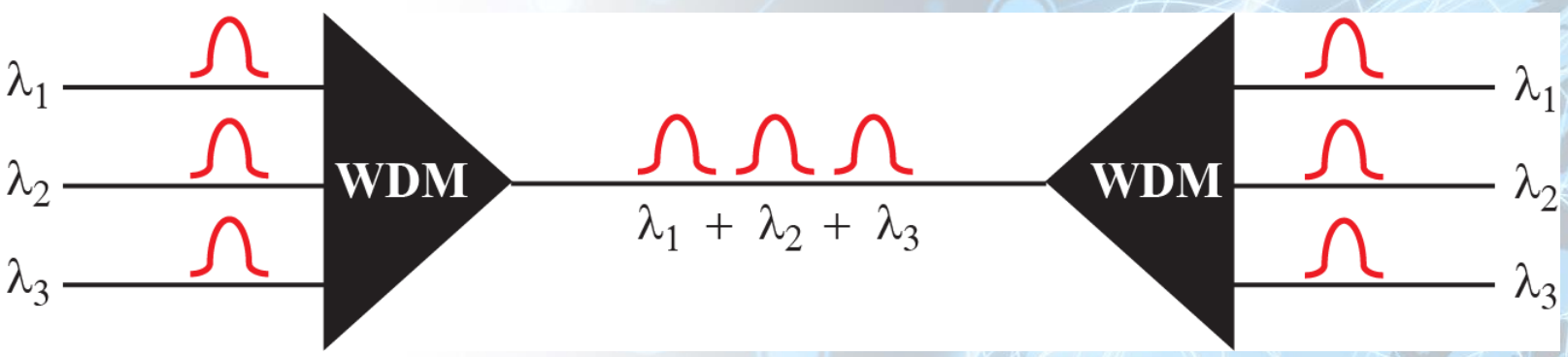
Analog Hierarchy



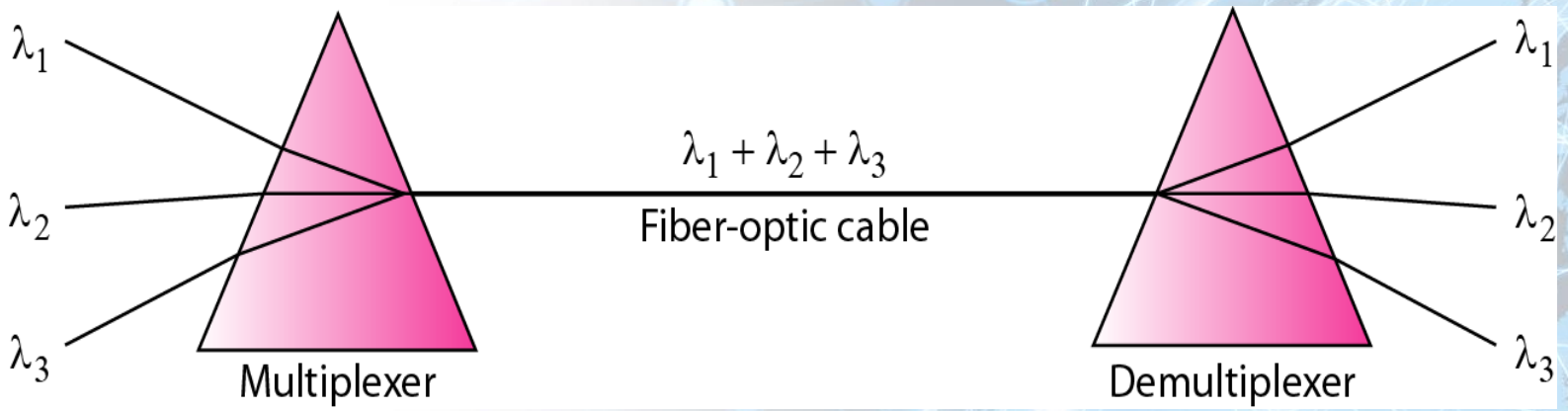
Wavelength-Division Multiplexing

- Designed to use the high-data-rate capability of fiber-optic cable
- Fiber data rate is higher than the data rate of metallic transmission cable
- Using a fiber-optic cable for a single line wastes the available bandwidth
- Multiplexing allows us to combine several lines into one

Wavelength-Division Multiplexing (WDM)



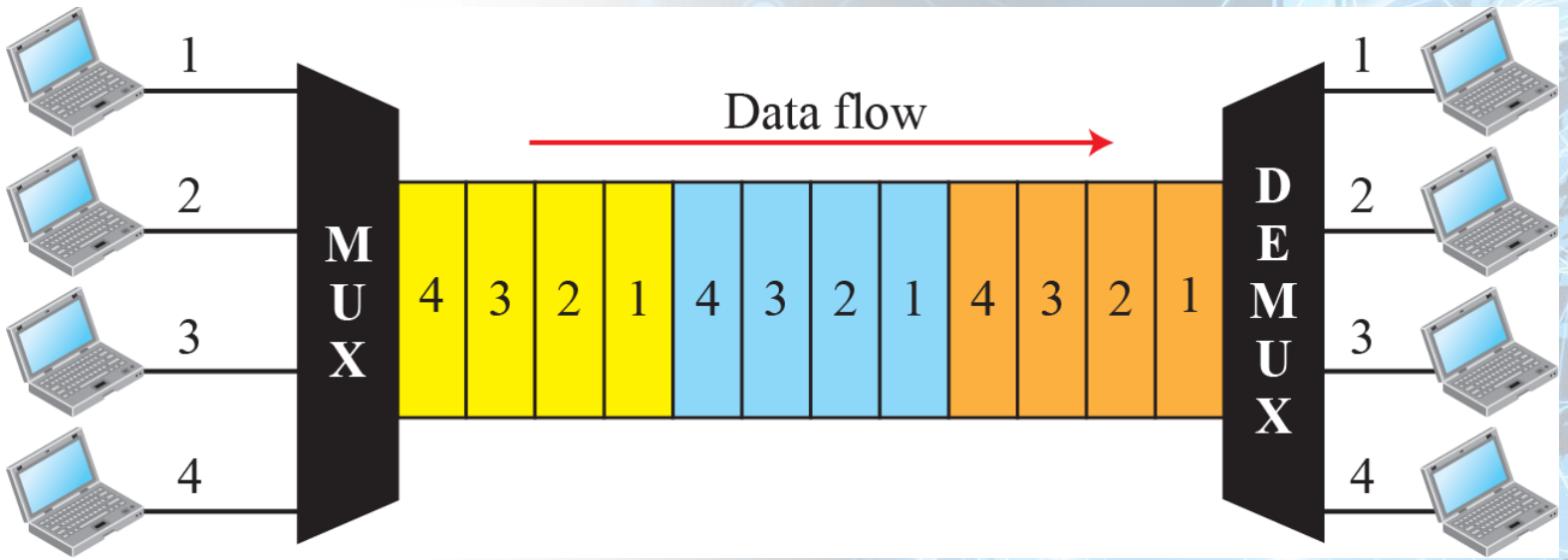
Prisms in Wave-Length Division Multiplexing



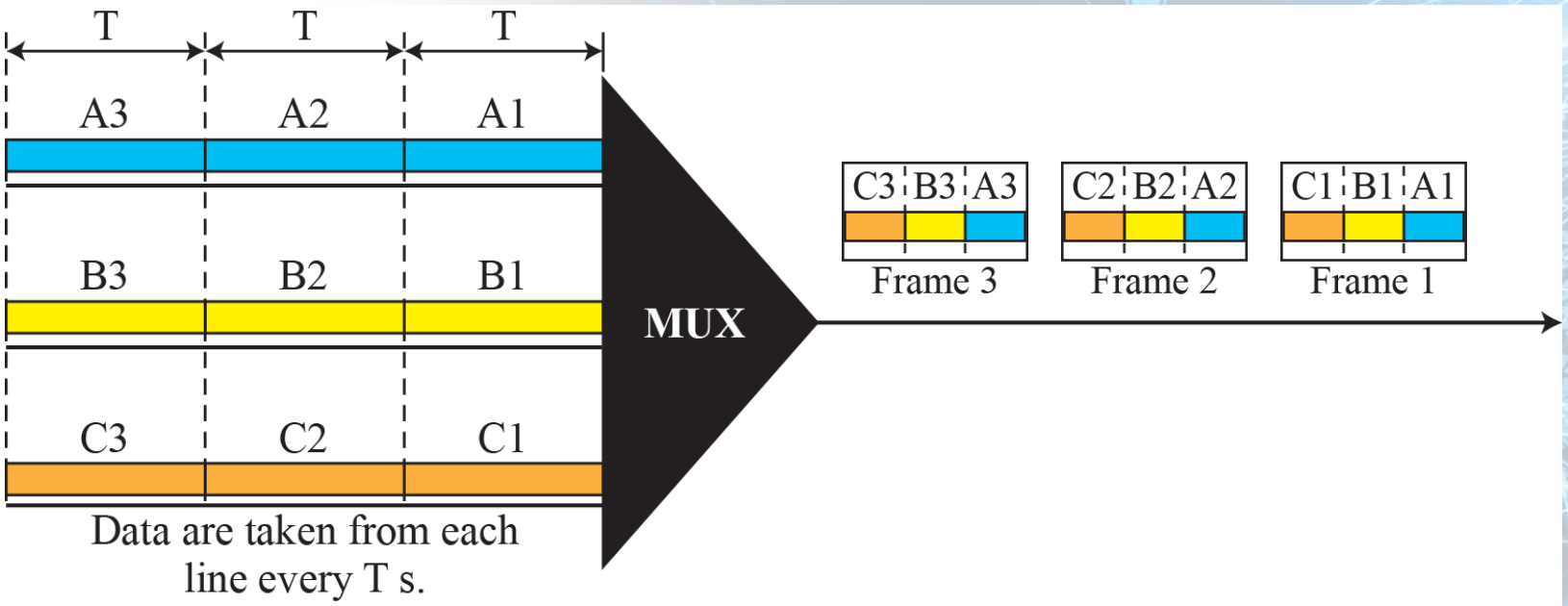
Time-Division Multiplexing

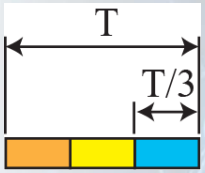
- Digital process that allows several connections to share the high bandwidth of a link
- Time is shared i.e. each connection occupies a portion of time in the link

TDM



Synchronous Time-Division Multiplexing





Each frame is 3 time slots.
Each time slot duration is T/3 s.

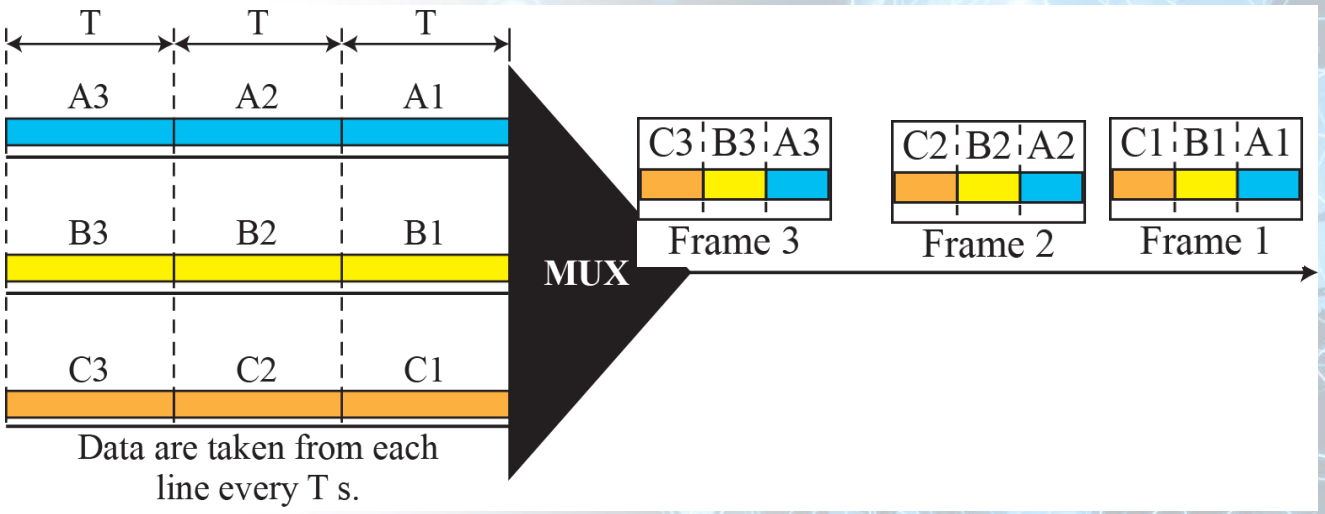
Time-Division Multiplexing

- Digital process that allows several connections to share the high bandwidth of a link
- Time is shared i.e. each connection occupies a portion of time in the link

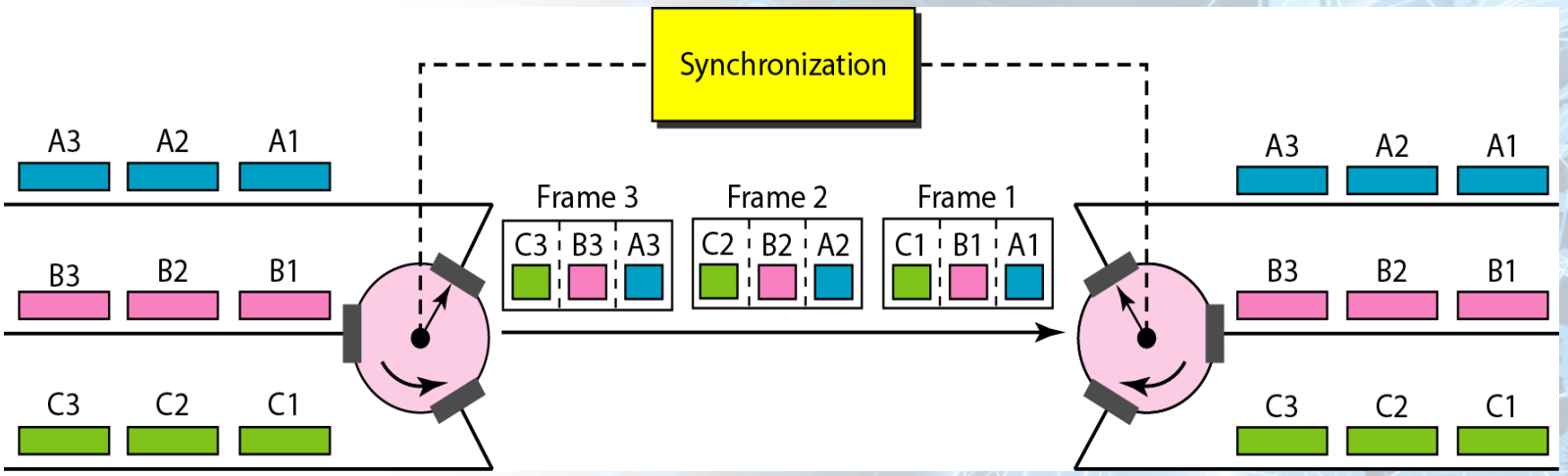
Example

In Figure the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

- **each input slot,**
- **each output slot, and**
- **each frame?**



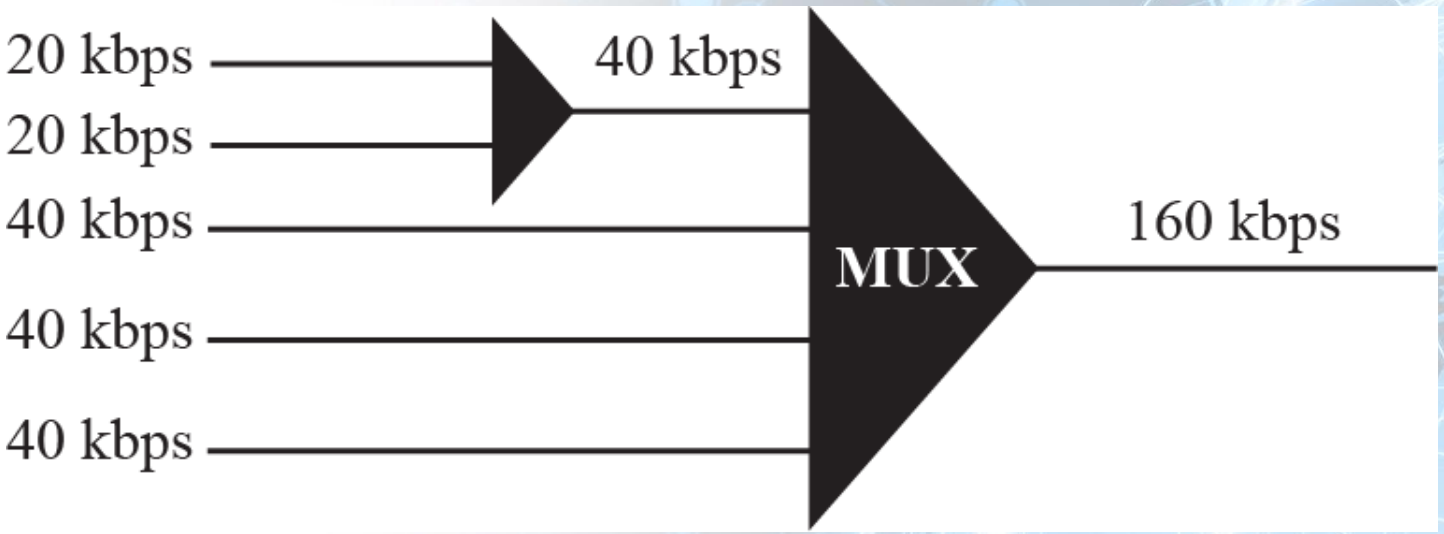
Interleaving



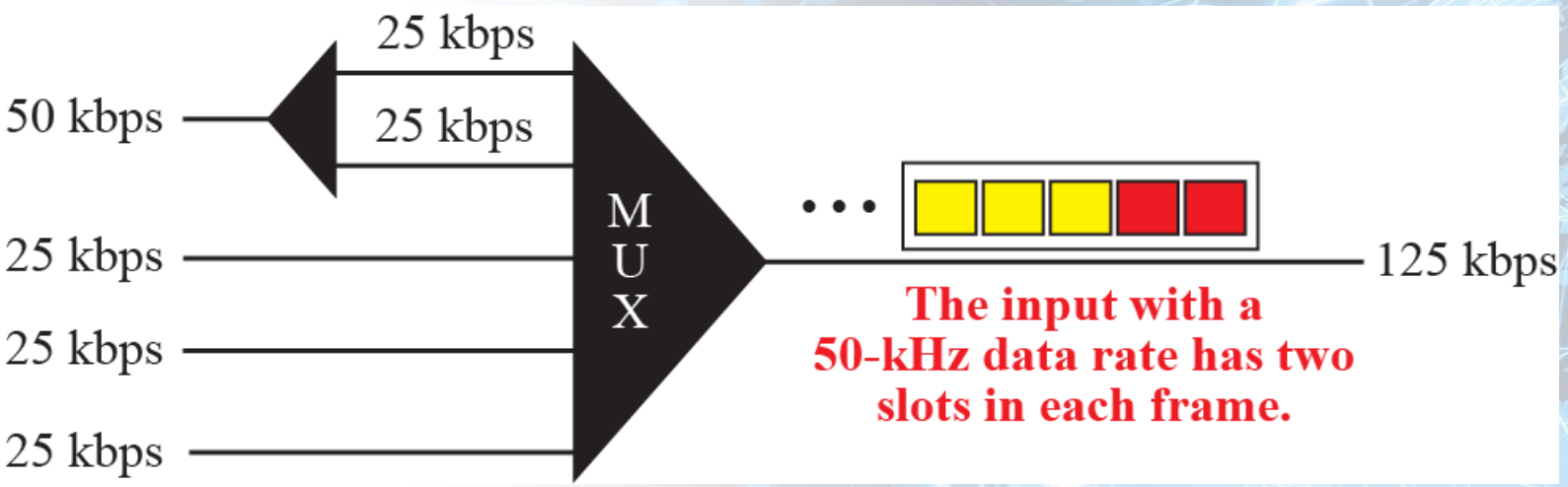
Time-Division Multiplexing

- Digital process that allows several connections to share the high bandwidth of a link
- Time is shared i.e. each connection occupies a portion of time in the link

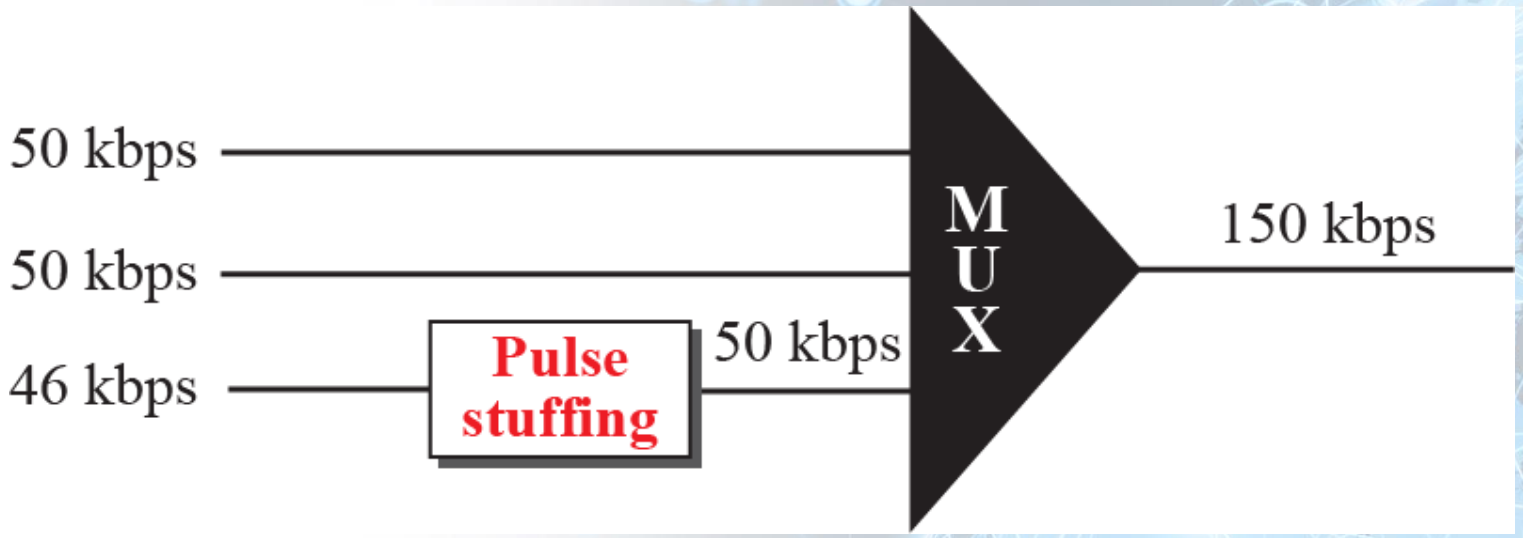
Multilevel Multiplexing



Multiple-SLot Multiplexing



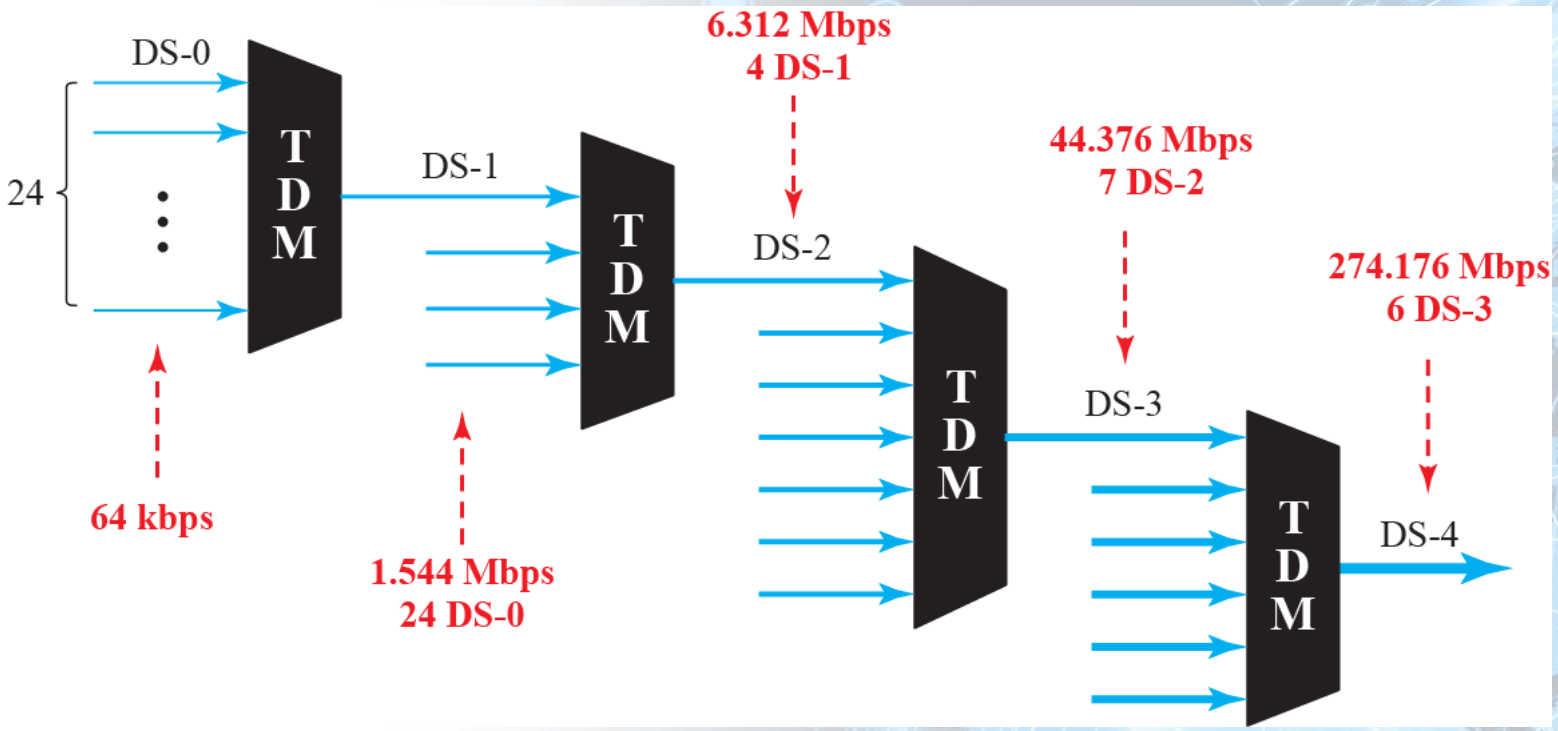
Pulse Stuffing



Time-Division Multiplexing

- Digital process that allows several connections to share the high bandwidth of a link
- Time is shared i.e. each connection occupies a portion of time in the link

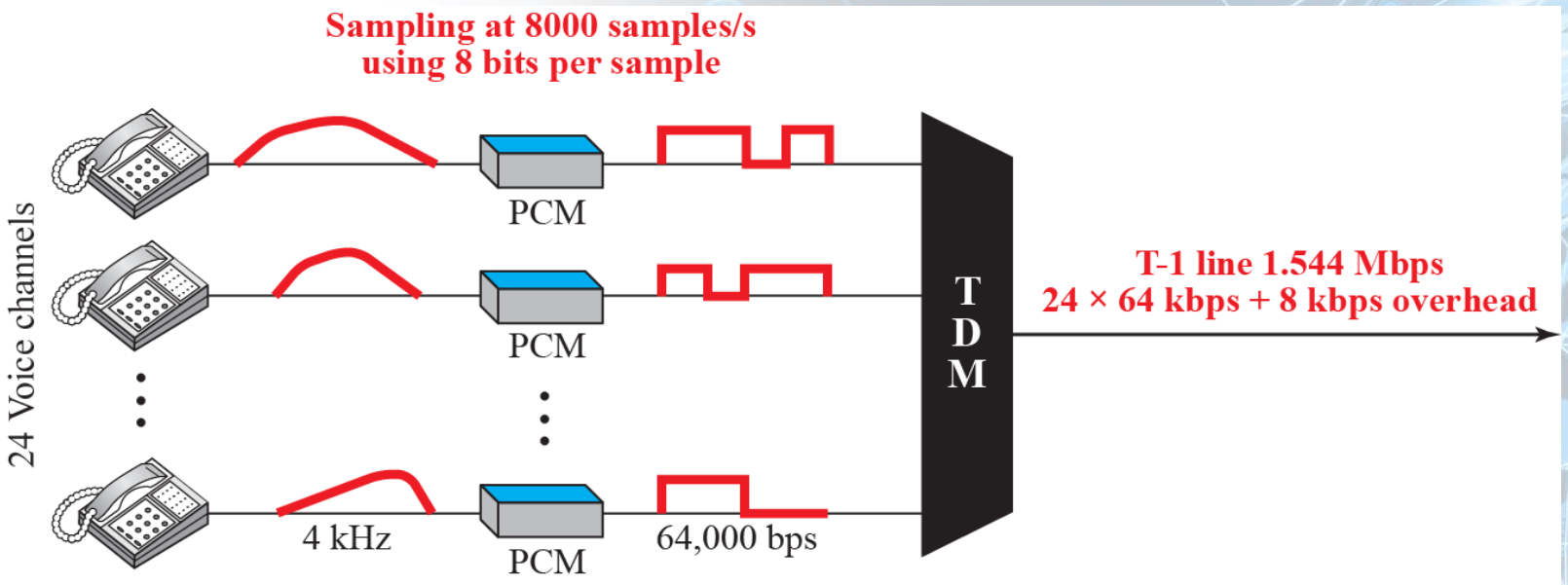
Digital Hierarchy



DS and T Line Rates

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


Sampling at 8000 samples/s
using 8 bits per sample
24 Voice channels
PCM
PCM
PCM
4 kHz
64,000 bps
T
D
M
T-1 line 1.544 Mbps
24 × 64 kbps + 8 kbps overhead

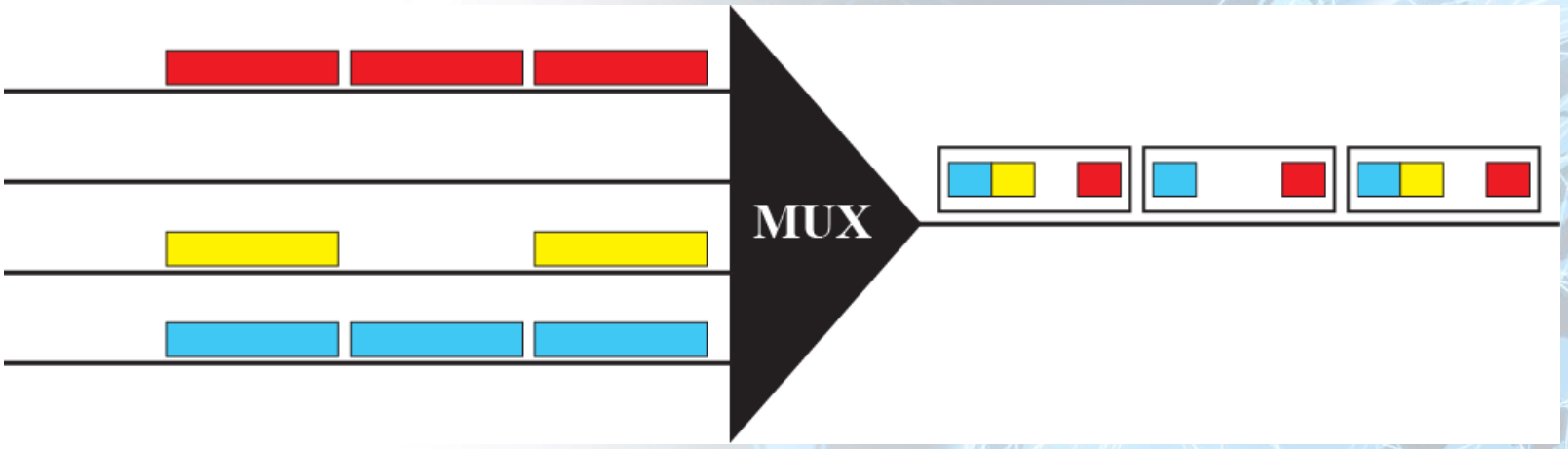
E Line Rates

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

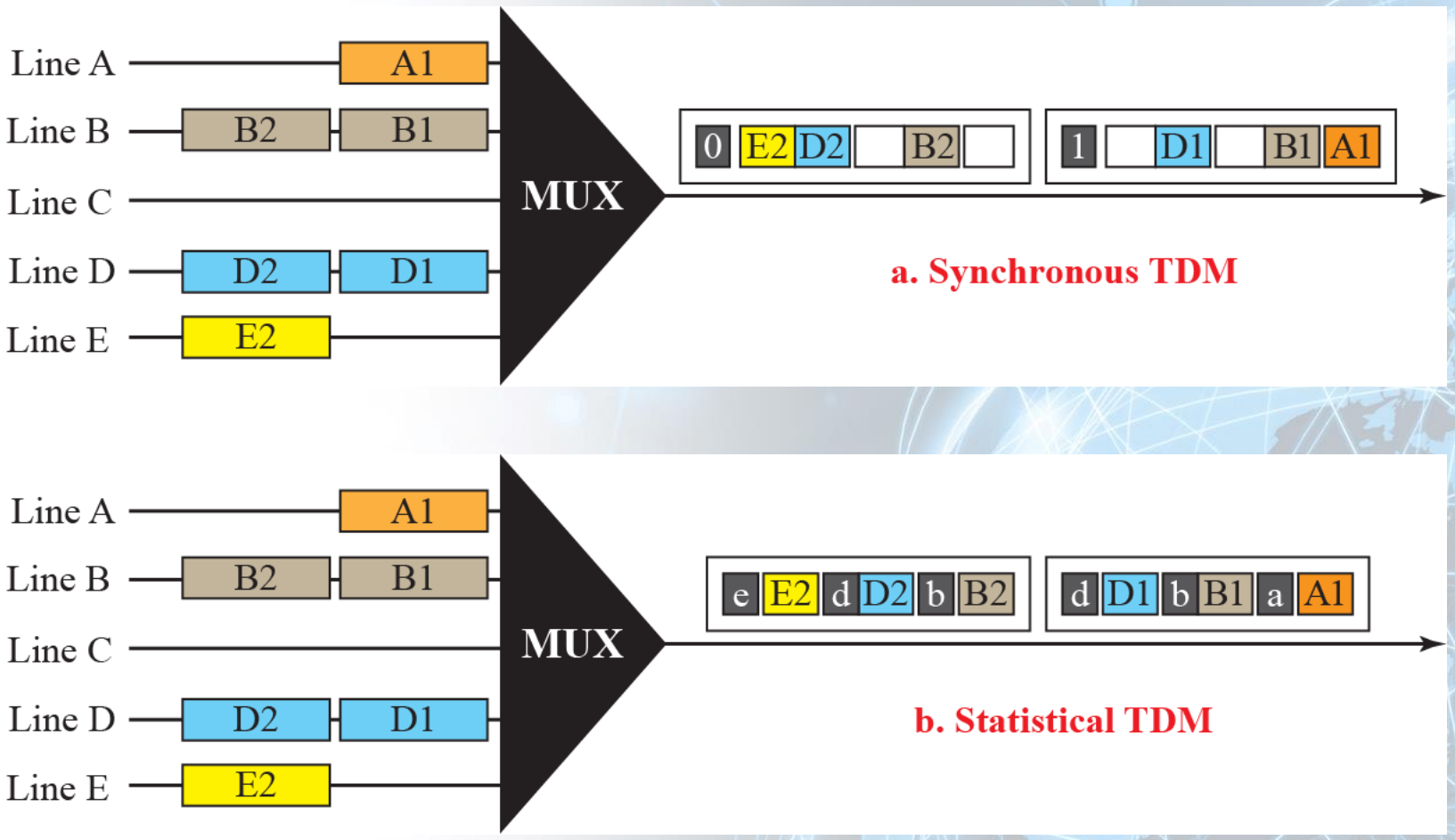
Time-Division Multiplexing

- Synchronous TDM
- Statistical TDM

Empty slots



Statistical TDM



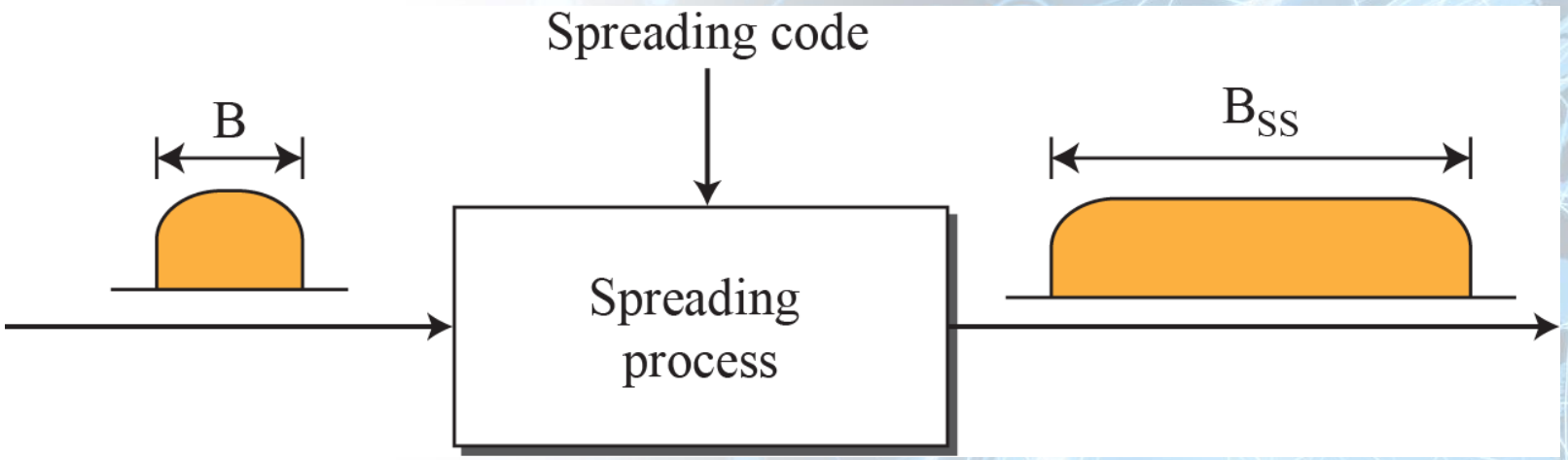
SPREAD SPECTRUM

- In wireless applications, stations must be able to share the medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder
- To achieve these goals, spread spectrum adds redundancy and spread original spectrum needed for each station

SPREAD SPECTRUM - Principles

- Bandwidth allocated to each station needs to be larger than what is needed to allow Redundancy
- Spreading process should be independent of the original signal

Spread Spectrum



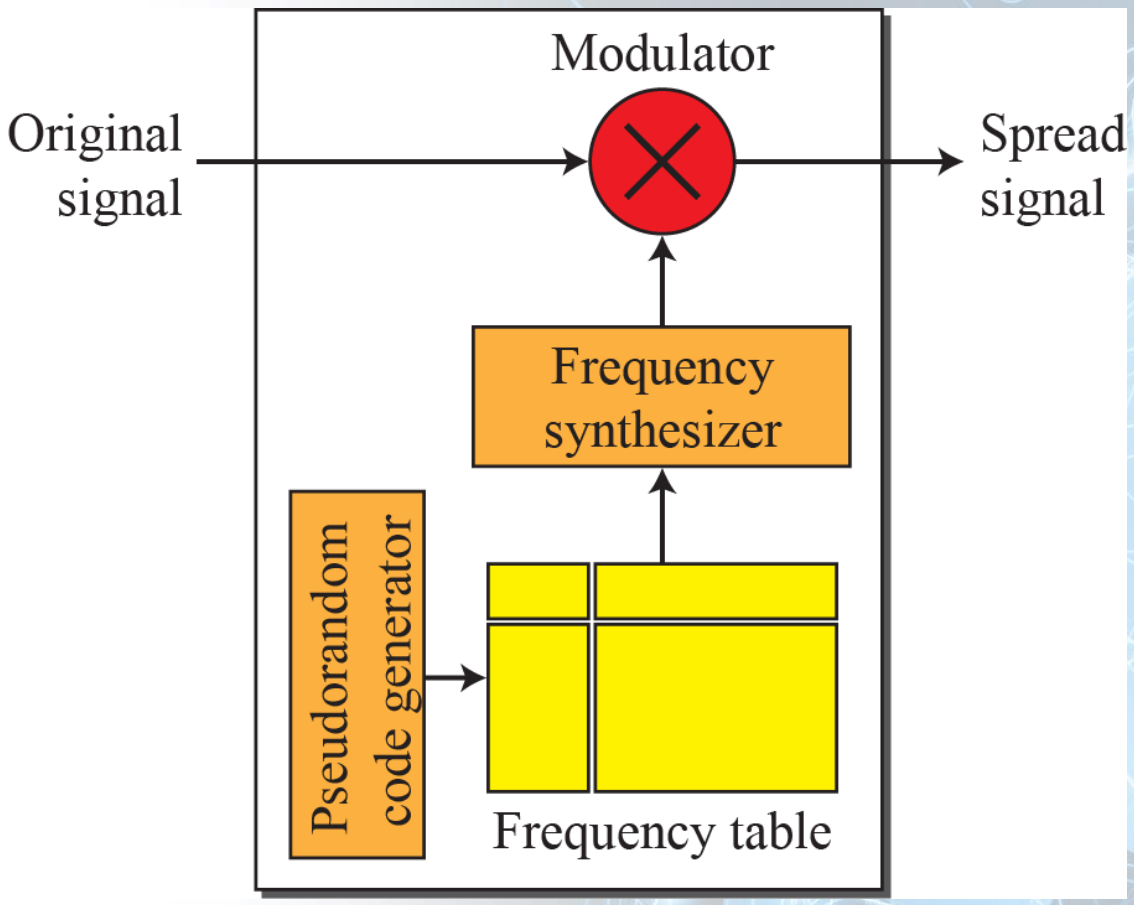
SPREAD SPECTRUM TECHNIQUES

- **Frequency Hopping Spread Spectrum (FHSS)**
- **Direct Sequence Spread Spectrum (DSSS)**

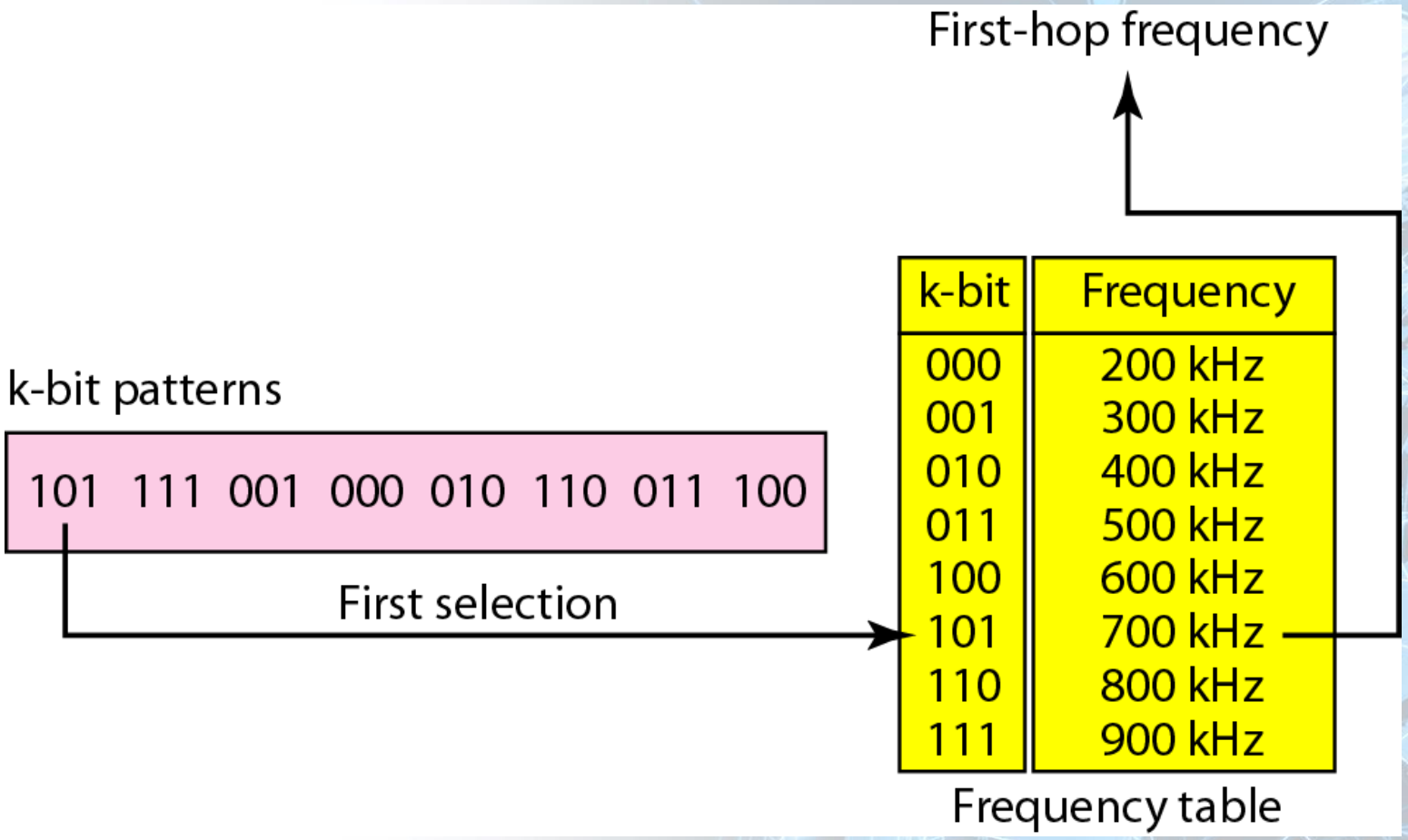
Frequency Hopping Spread Spectrum (FHSS)

- **‘M’ different carrier frequencies that are modulated by the source signal**
- **At one moment, signal modulates one carrier frequency and at next moment, it modulates another**

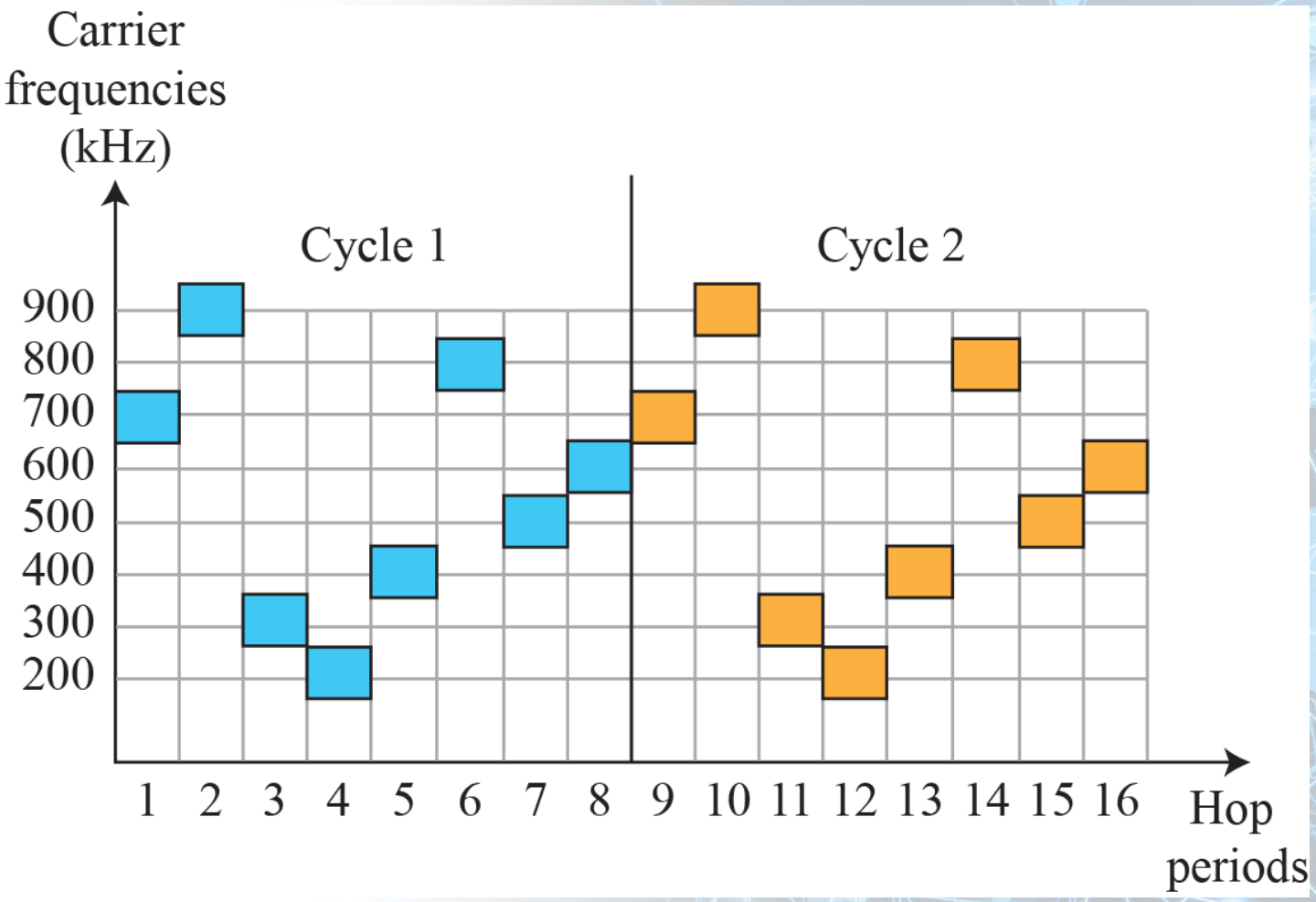
Frequency Hopping Spread Spectrum (FHSS)



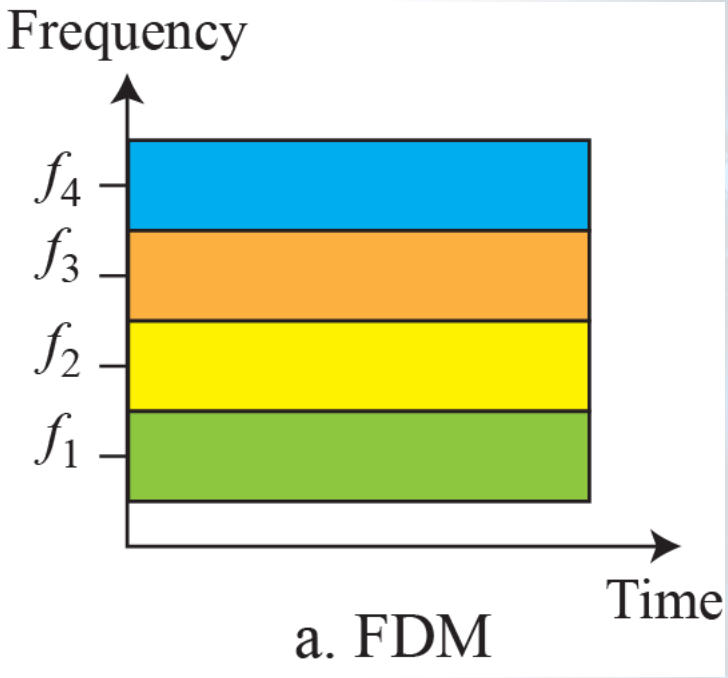
Frequency Selection in FHSS



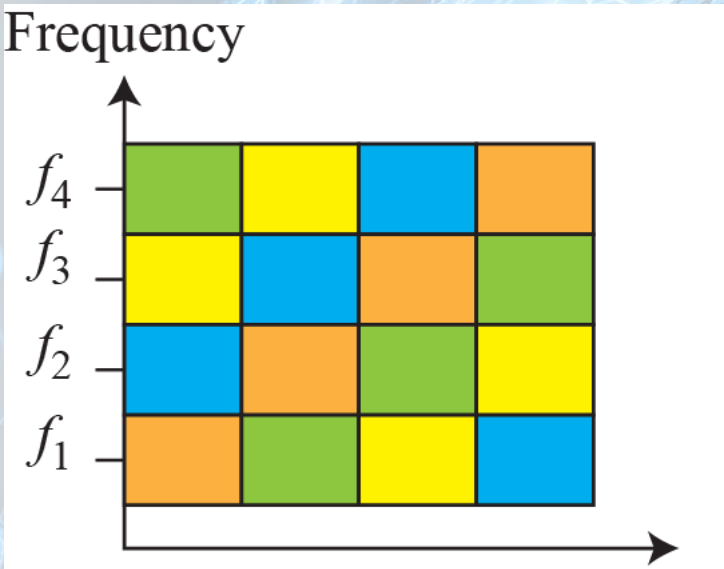
FHSS Cycles


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

Bandwidth Sharing



a. FDM



b. FHSS

DSSS

- DSSS also expands the bandwidth of the original signal, but the process is different
- We replace each data bit with ‘n’ bits using a spreading code
- Each bit is assigned a code of ’n’ bits, called chips, where the chip rate is ‘n’ times that of the data bit

DSSS