CSE 365: Communication Engineering

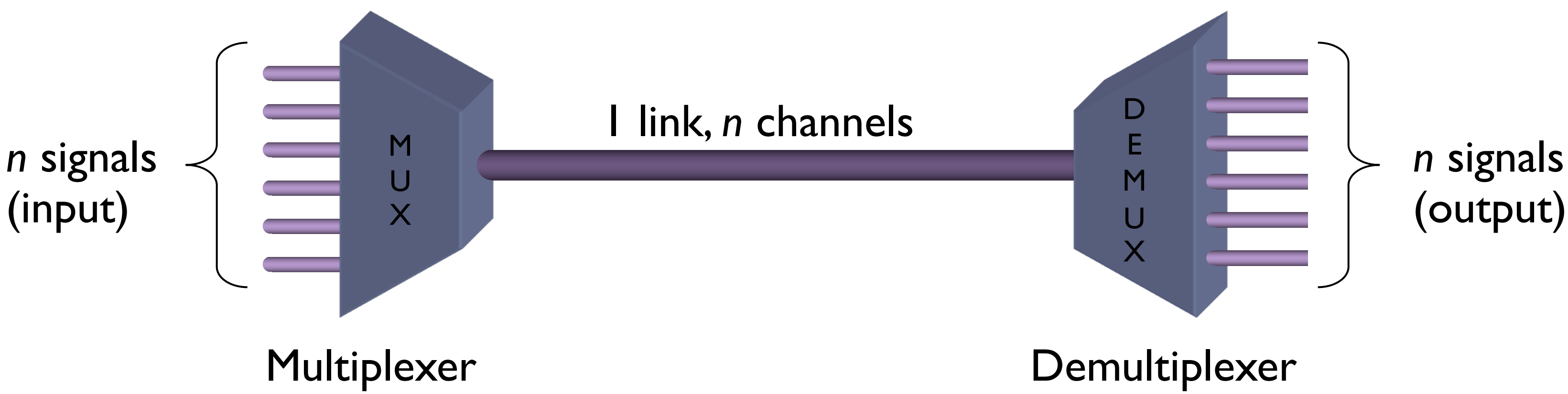
Chapter 6: Bandwidth Utilization: Multiplexing and Spectrum Spreading

Multiplexing

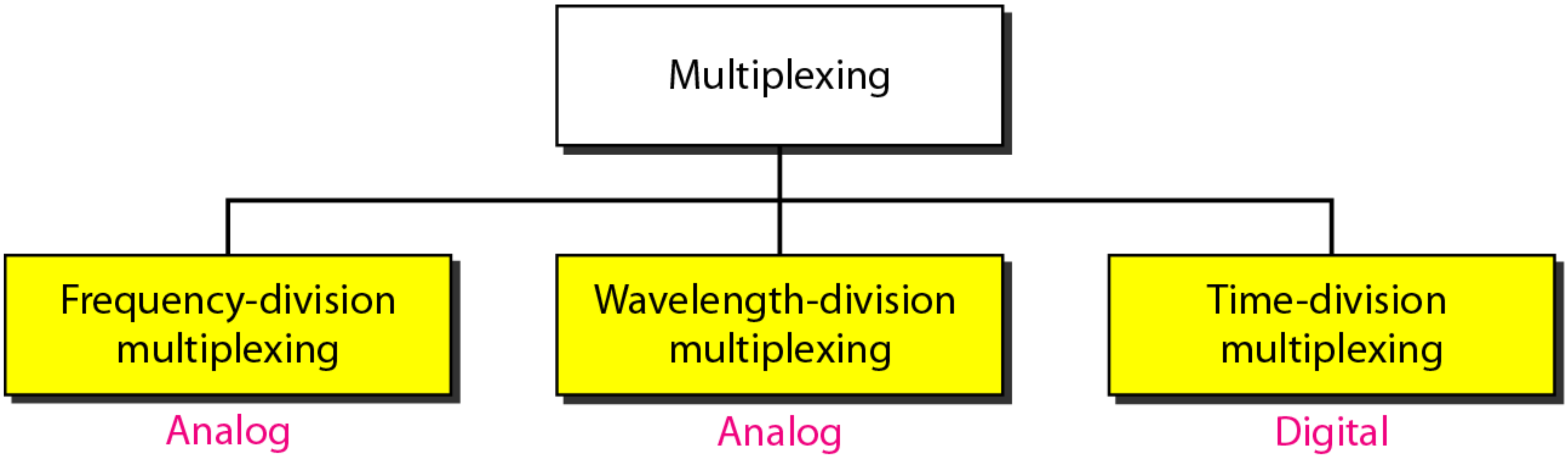
- Multiplexing is a technique in which multiple signals are combined into a composite signal so that these can be transmitted over a common link.
- It is essential to keep the multiple signals apart so that they don't interfere with each other and can be separated easily at the receiving end.

Multiplexing

- Multiplexer (MUX) → many to one
- Demultiplexer (DEMUX) → one-to-many
- A link is divided into channels.
- *Link* refers to the physical path; whereas *channel* refers to the portion of a link that carries a transmission



Categories of Multiplexing

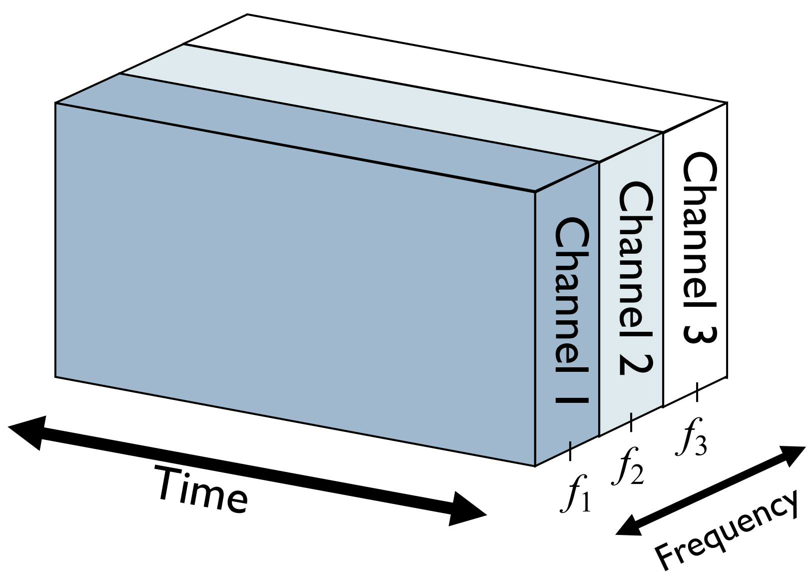


Frequency Division Multiplexing (FDM)

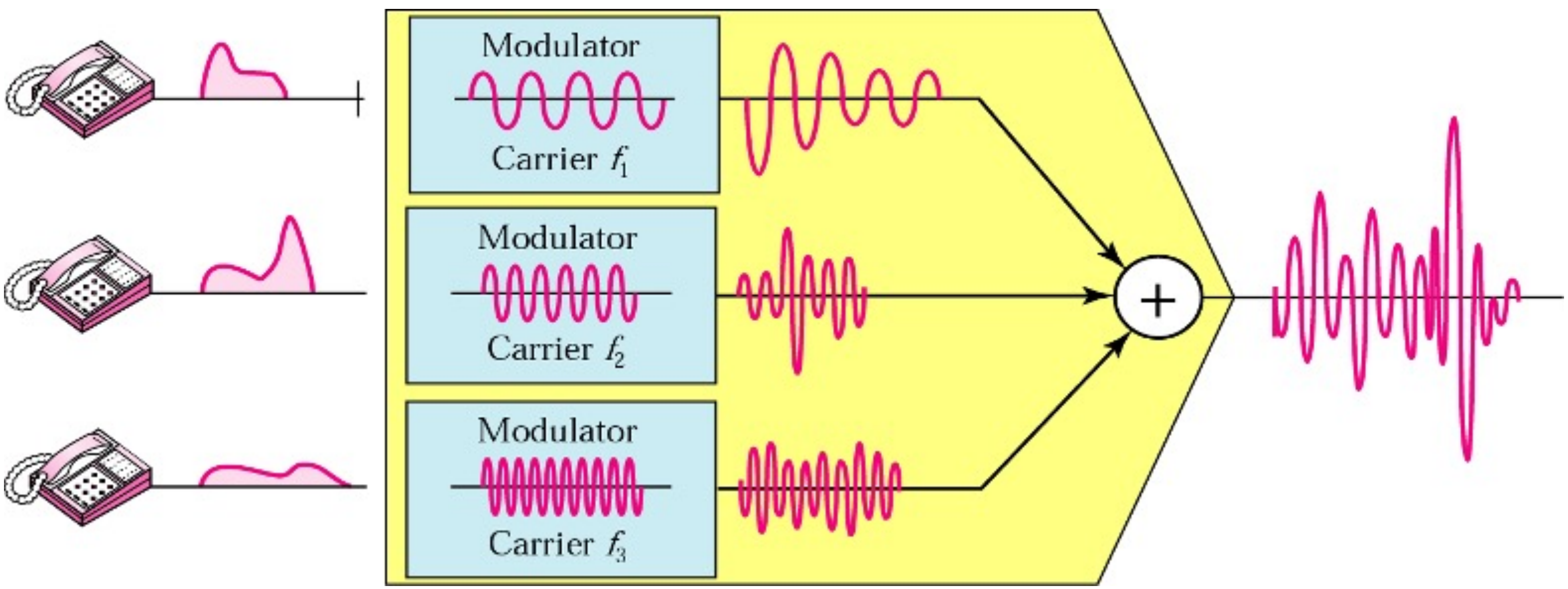
An analog multiplexing technique to combine signals

- In FDM, all users use the same common link at the same time (for full time) but they are allotted different frequencies to prevent any kind of signal interference.
- Medium BW > Channel BW
- The bandwidth is divided among users, not the time.
- Each signal is modulated to a different carrier frequency
- Modulated signals are then combined into a single composite signal that can be transported by the link
- AM and FM radio broadcasting, television broadcasting, the first generation of cellular telephones

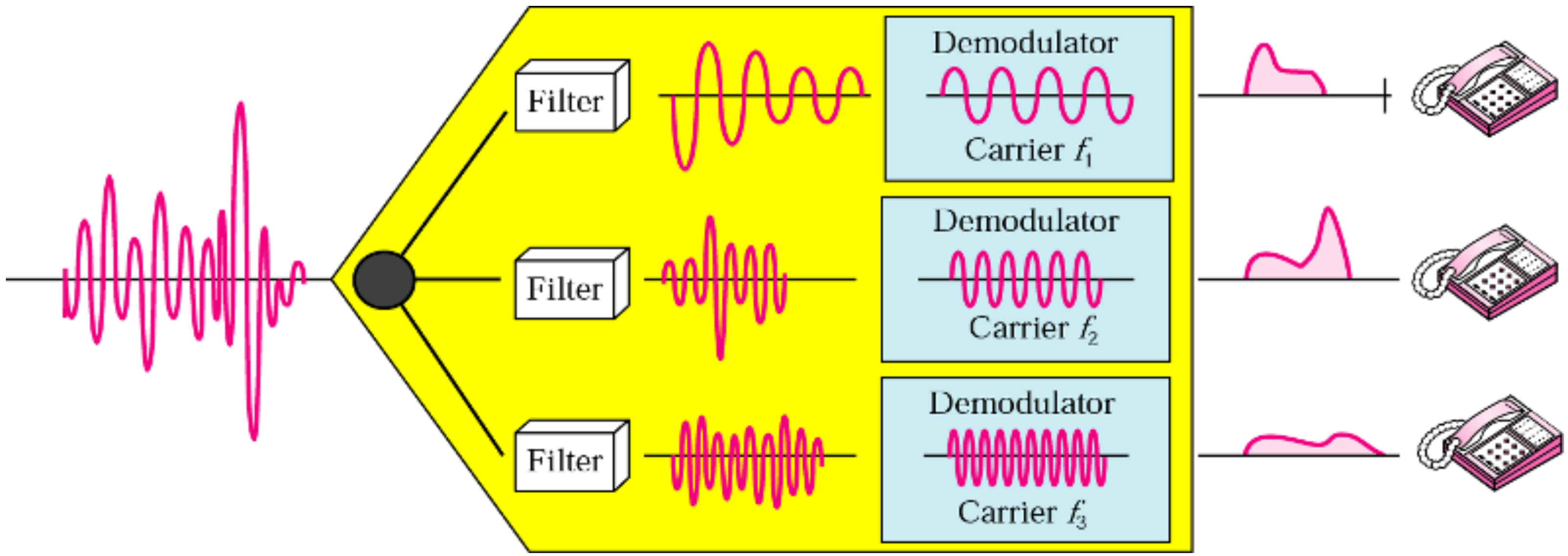
Frequency Division Multiplexing (FDM)



FDM: Multiplexing Process

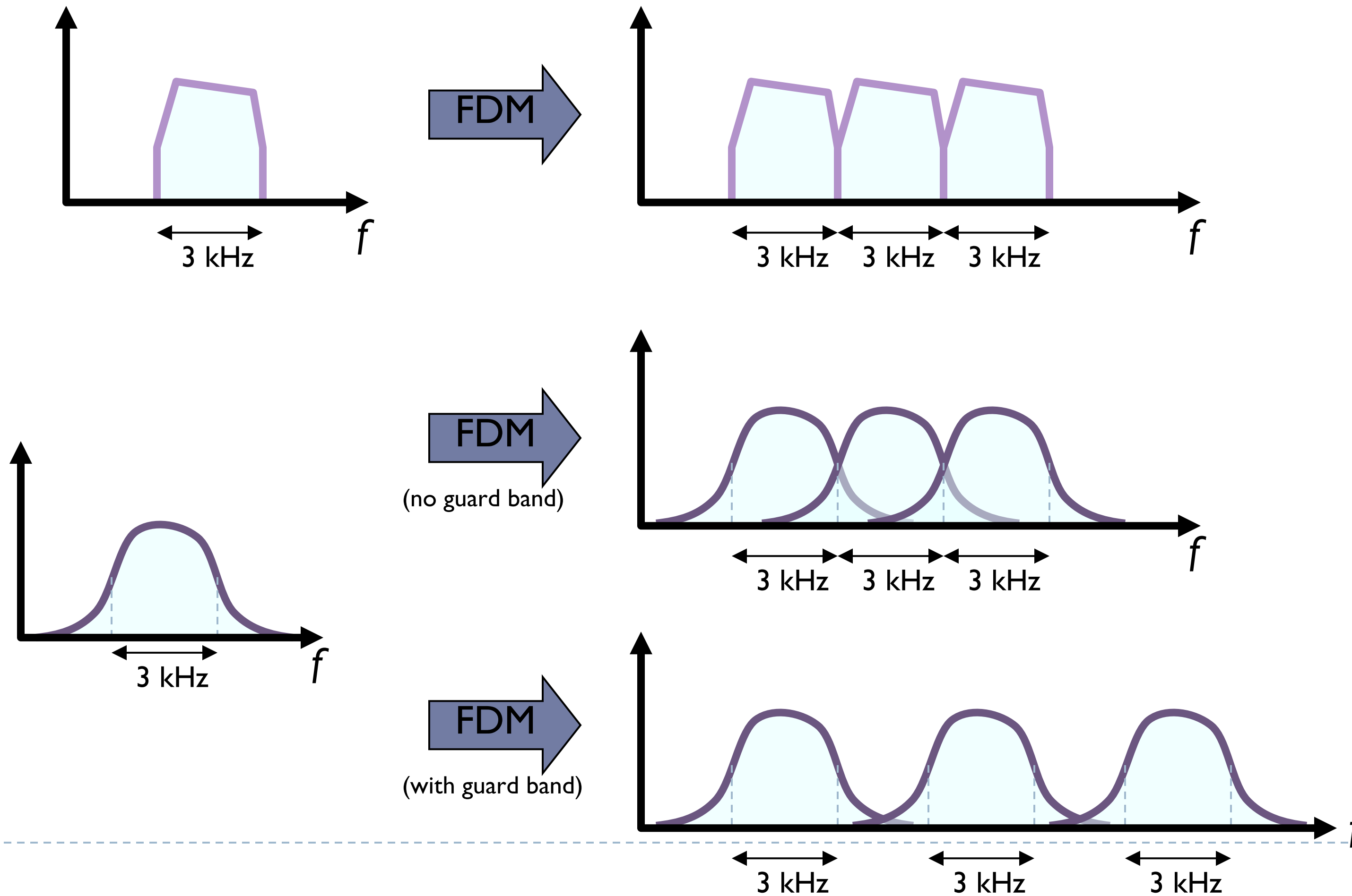


FDM: Demultiplexing Process



Frequency Division Multiplexing (FDM)

- *Guard bands:* Channels can be separated by strips of unused bandwidth to prevent signals from overlapping



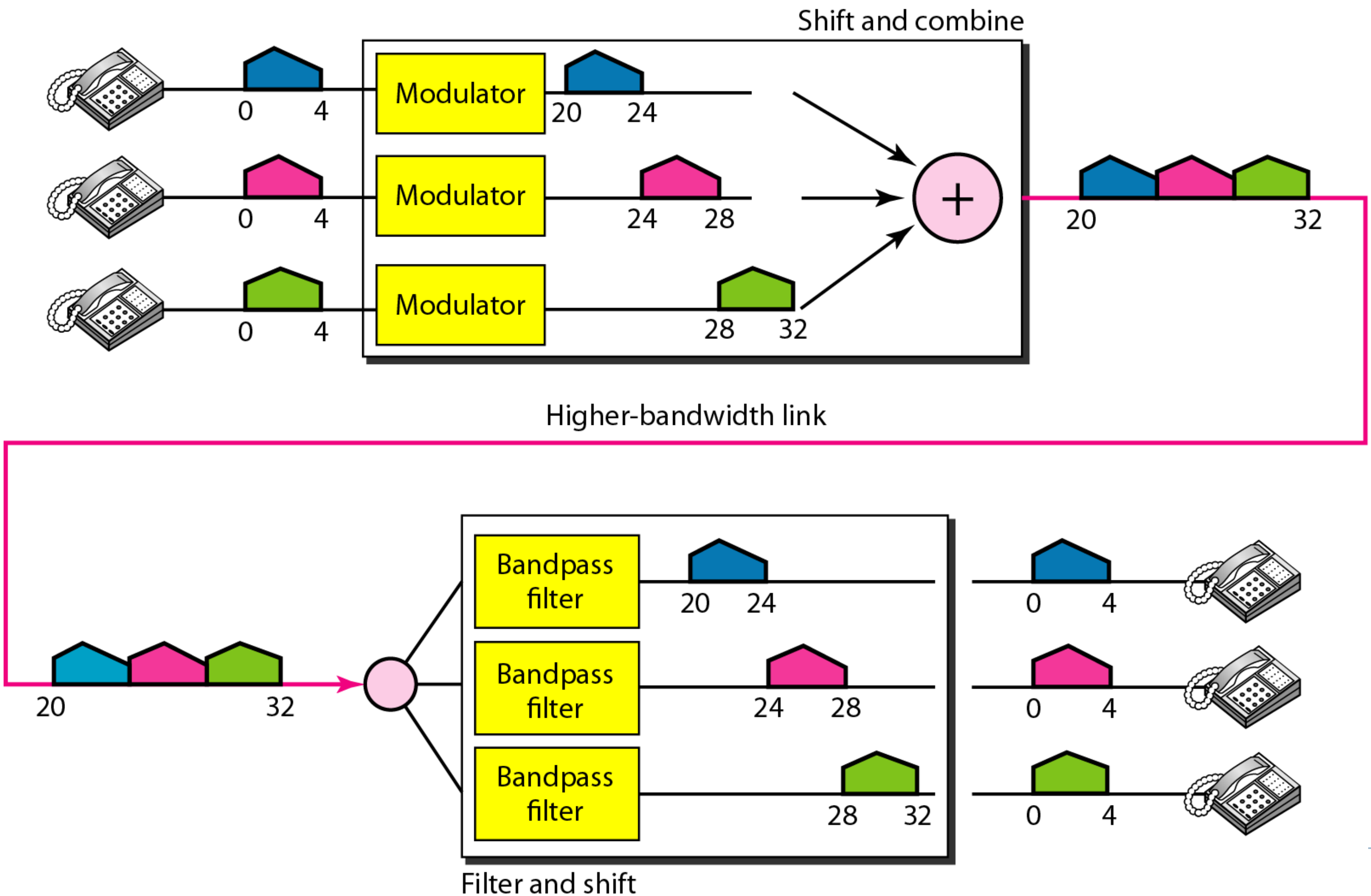
FDM: *Example 6.1*

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

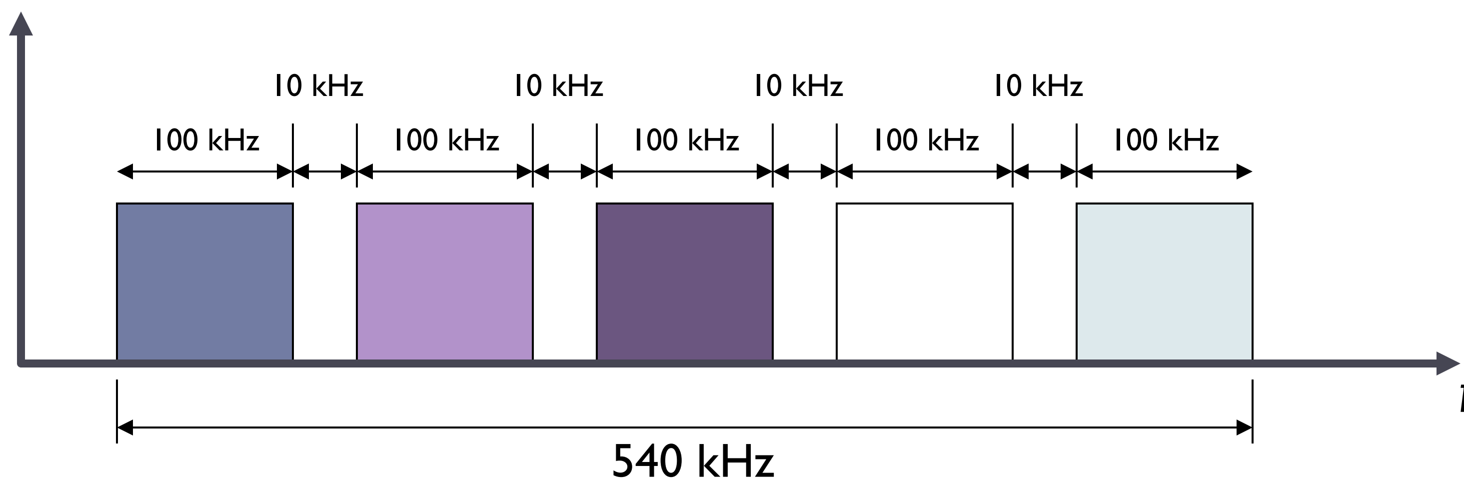
We shift (modulate) each of the three voice channels to a different bandwidth, as shown in the next Figure. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them.

FDM: *Example 6.1*



FDM: *Example 6.2*

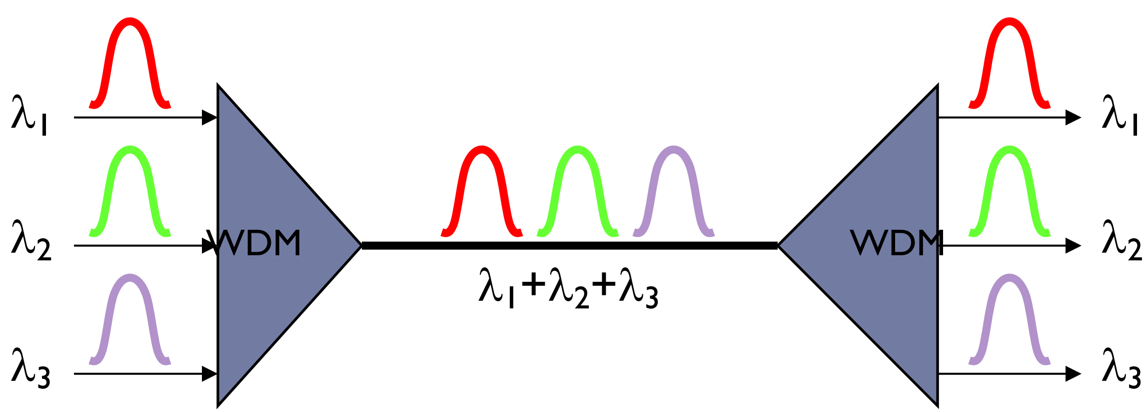
Five voice channels, each with a 100-kHz bandwidth, are to be multiplexed together. If there is a need for a guard band of 10 kHz, what is the minimum bandwidth of the link?



Wavelength Division Multiplexing (WDM)

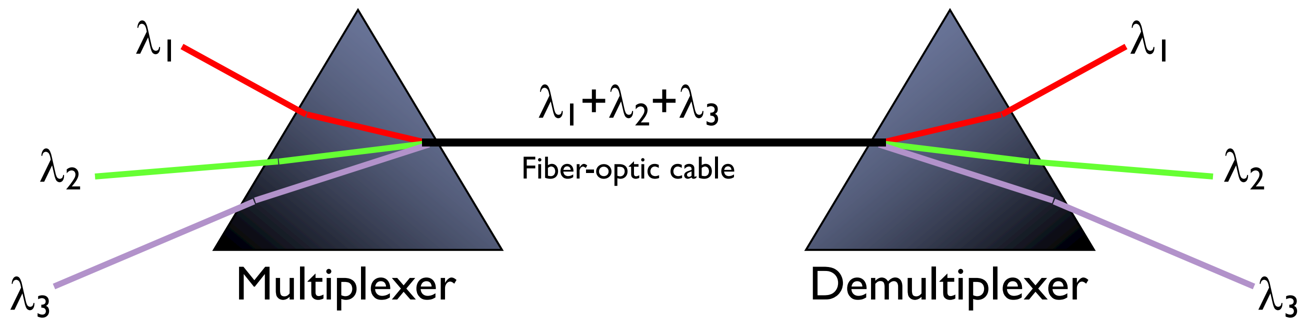
An analog multiplexing technique to combine optical signals

- WDM is a special case of FDM
  - Uses optical signals transmitted through fiber-optic channels
  - Frequencies are very high



Wavelength Division Multiplexing (WDM)

- Prisms are used in WDM.

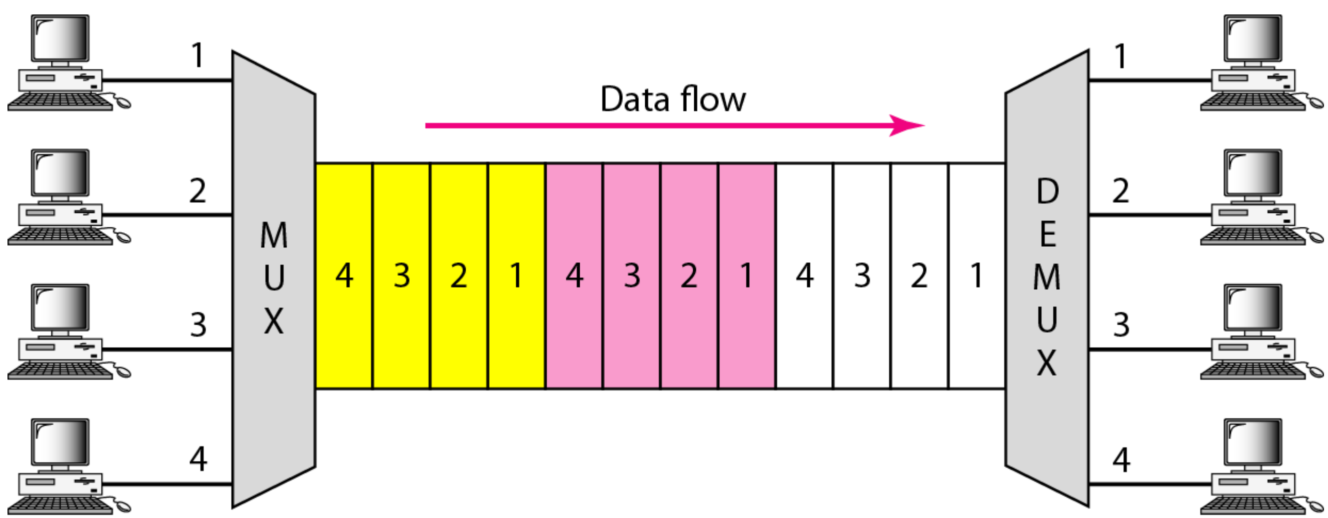


- One application of WDM is the SONET network

Time Division Multiplexing (TDM)

A digital multiplexing technique to combine data

- 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, time is shared.

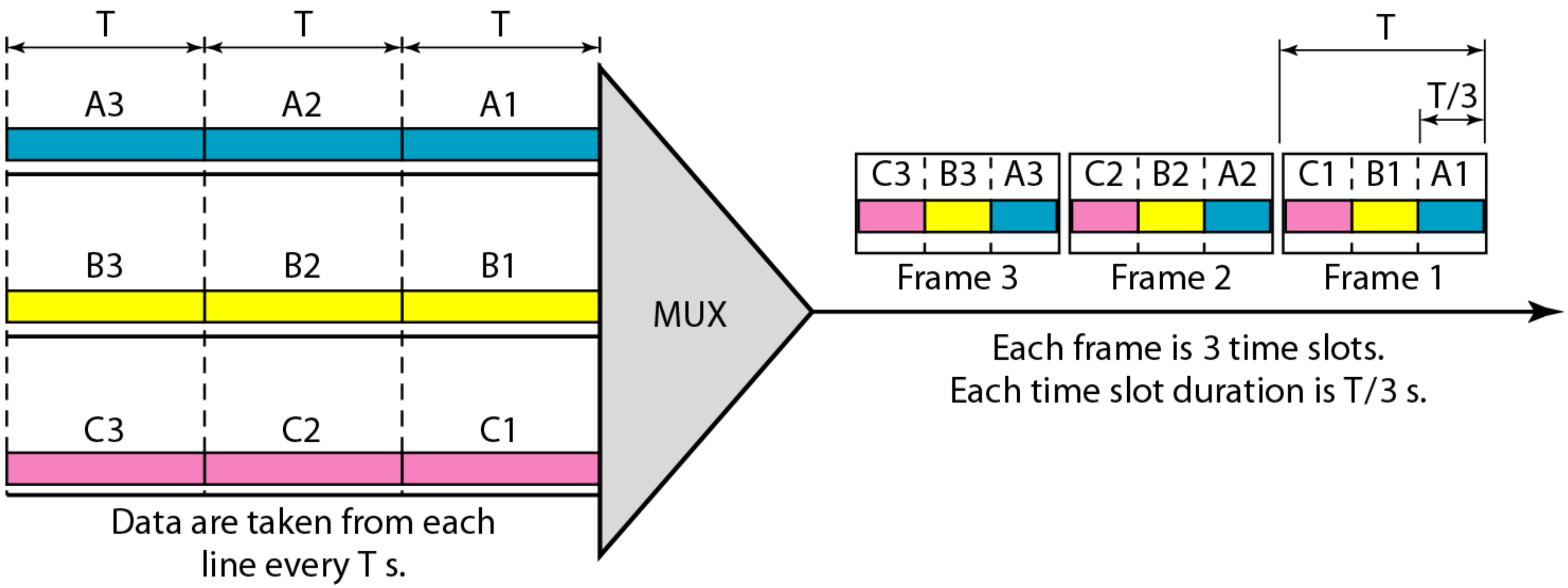


Types of TDM

- Synchronous TDM – each input connection has an allotment in the output even if it is not sending data.
- Statistical TDM – slots are dynamically allocated to improve bandwidth efficiency.

Synchronous TDM

- TDM Frame: A frame consists of one complete cycle of time slots



TDM: *Example 6.5*

In previous figure, the data rate for each one of the 3 input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

(a) each input slot,

(b) each output slot, and

(c) each frame?

Solution

We can answer the questions as follows:

a. The data rate of each input connection is 1 kbps. This means that the bit duration is 1/1000 s or 1ms. The duration of the input time slot is 1 ms (same as bit duration).

TDM: *Example 6.5*

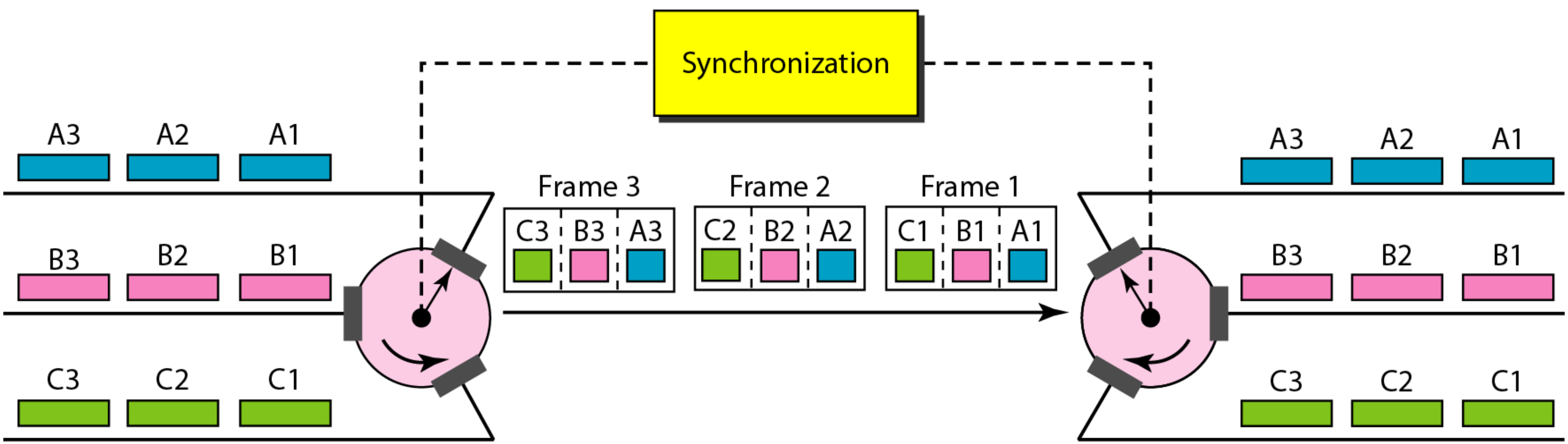
b. The duration of each output time slot is one-third of the input time slot. This means that the duration of the output time slot is 1/3 ms.

c. Each frame carries three output time slots. So the duration of a frame is 3 × 1/3 ms, or 1 ms.

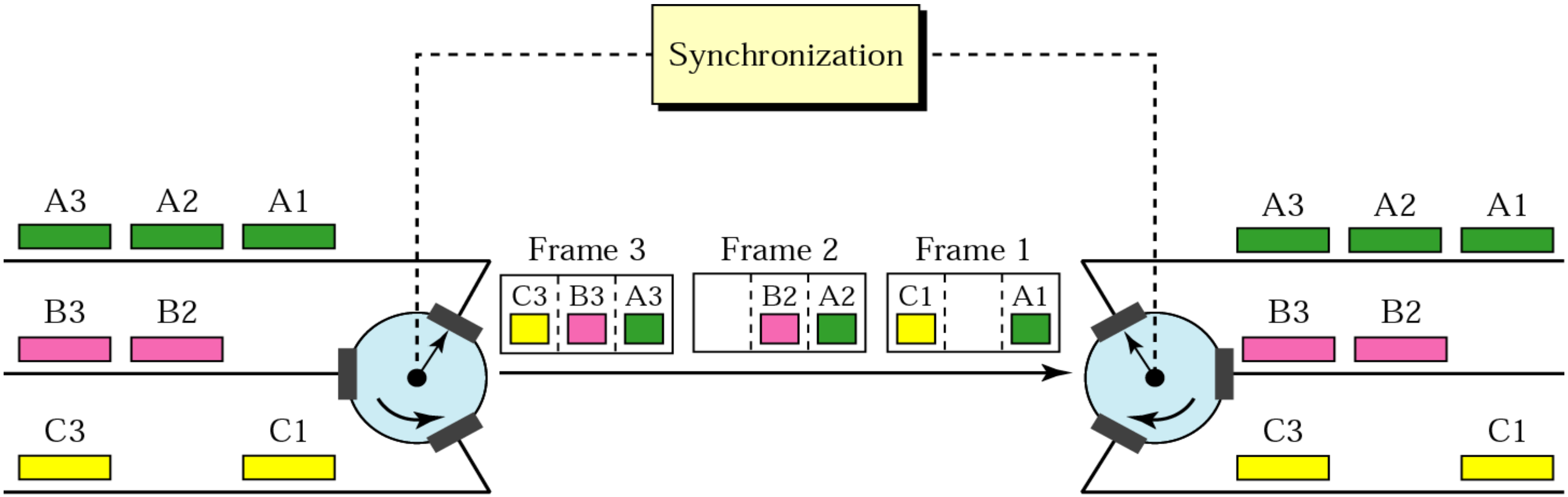
Note: The duration of a frame is the same as the duration of an input unit.

Interleaving

- TDM can be visualized as two fast-rotating switches, one on the MUX side and the other on the DEMUX side.
- The switches are synchronized and rotate at the same speed, but in opposite direction.
- When the switch open in front of a connection, that connection has the opportunity to send/receive a unit onto the path.



Empty Slots



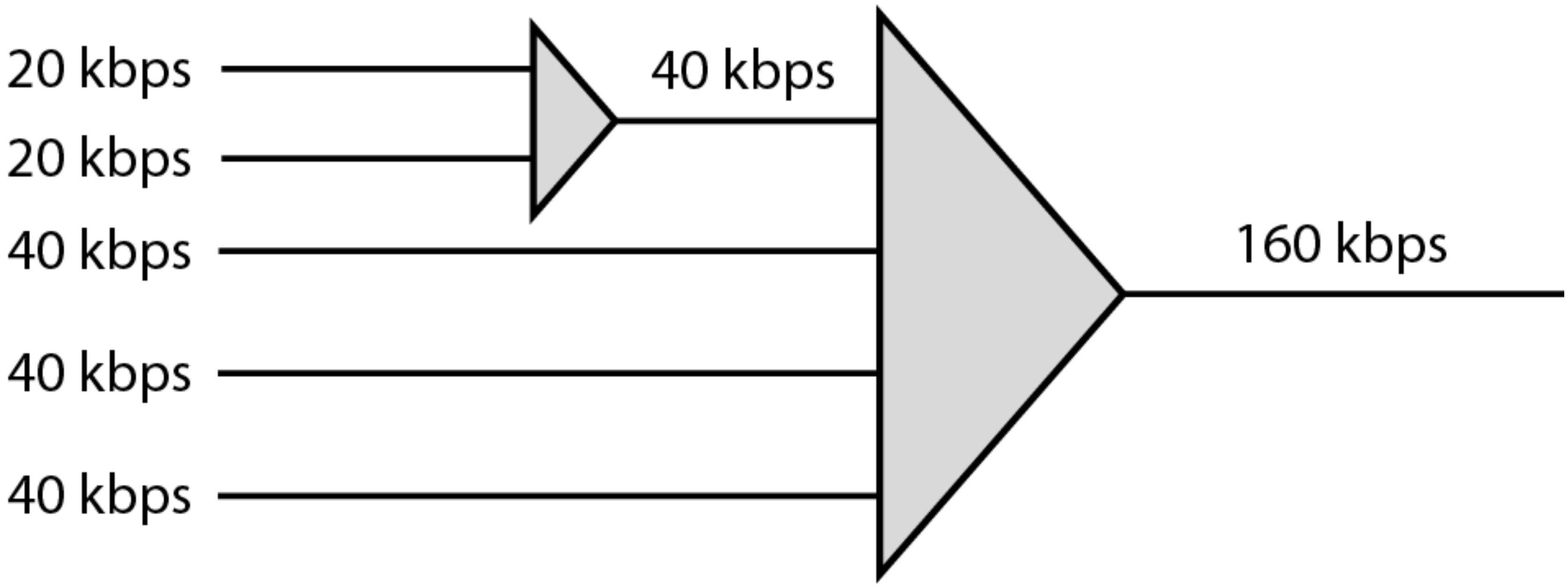
- If a source does not have data to send, the corresponding slot in the output frame is empty.
- That is wasteful of bandwidth.

Data Rate Management

- Not all input links have the same data rate.
- Some links may be slower.
- There maybe several different input link speeds.
- To handle the mismatch in the input data rates in TDM, we have three strategies:
    - 1. Multilevel Multiplexing
    - 2. Multiple Slot Allocation
    - 3. Pulse Stuffing

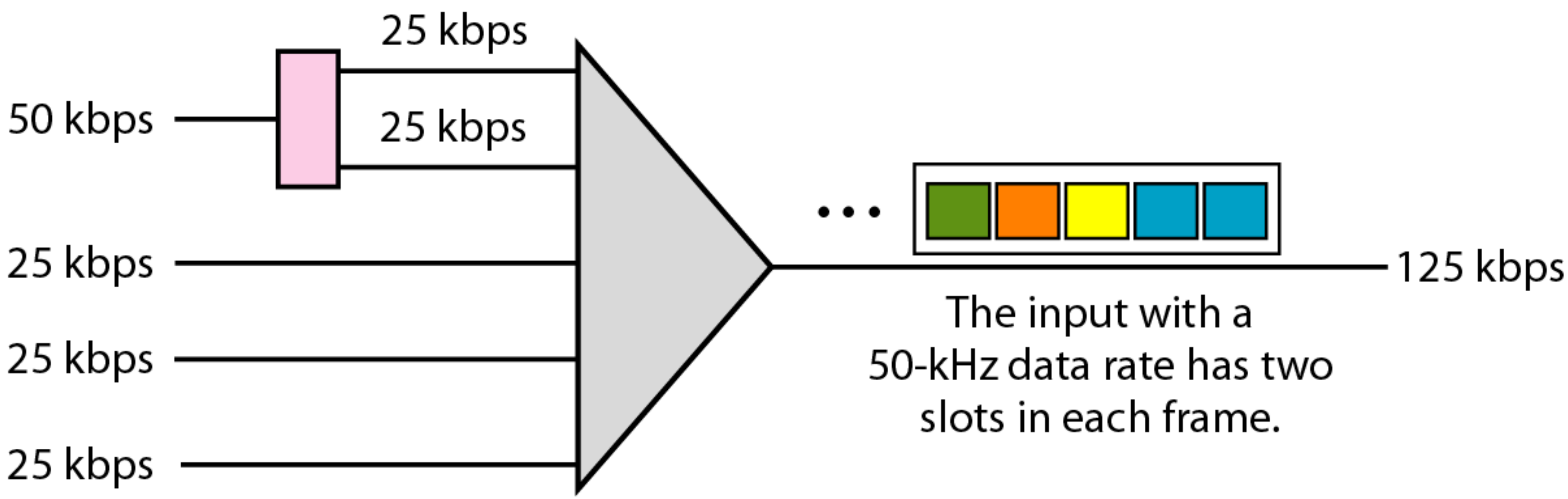
Multi-Level Multiplexing

- Multilevel Multiplexing is used when the data rate of the input links are multiples of each other.



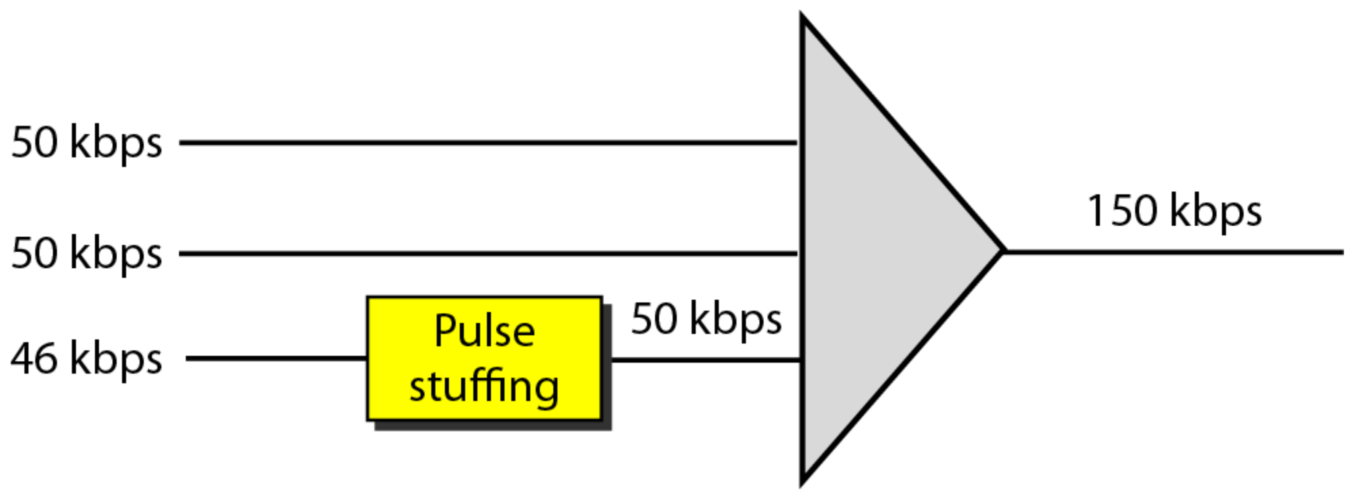
Multiple-Slot Allocation

- Multiple slot allocation is used to allot more than one slot in a frame to a single input line.



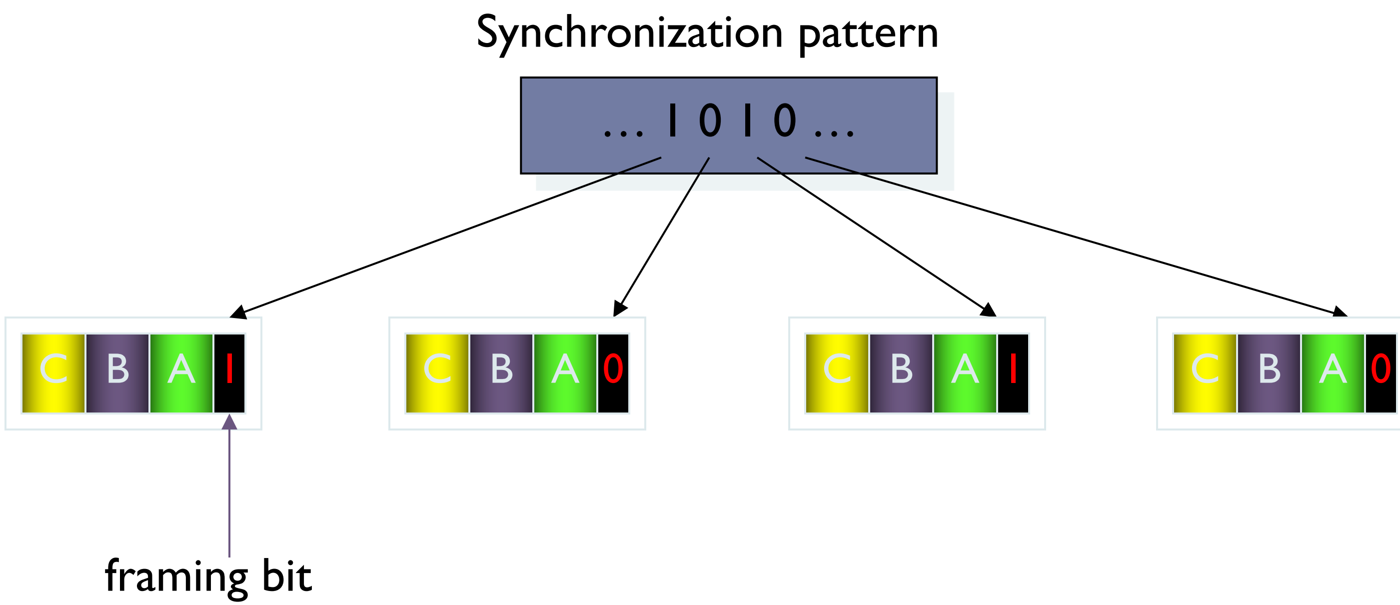
Pulse Stuffing/Bit Stuffing/Bit Padding

- Pulse Stuffing is used to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates.



Frame Synchronization

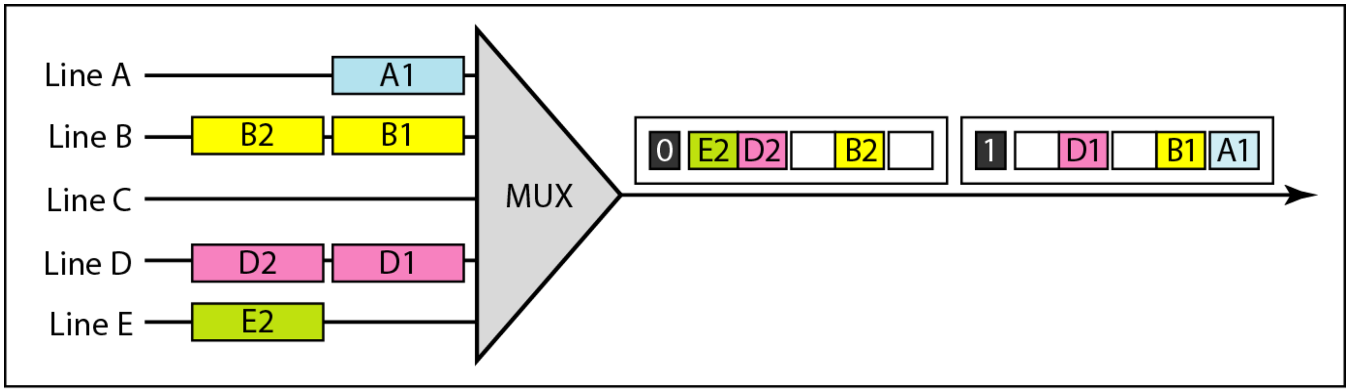
- Multiplexer and demultiplexer must be synchronized
- Framing bits are used to provide synchronization



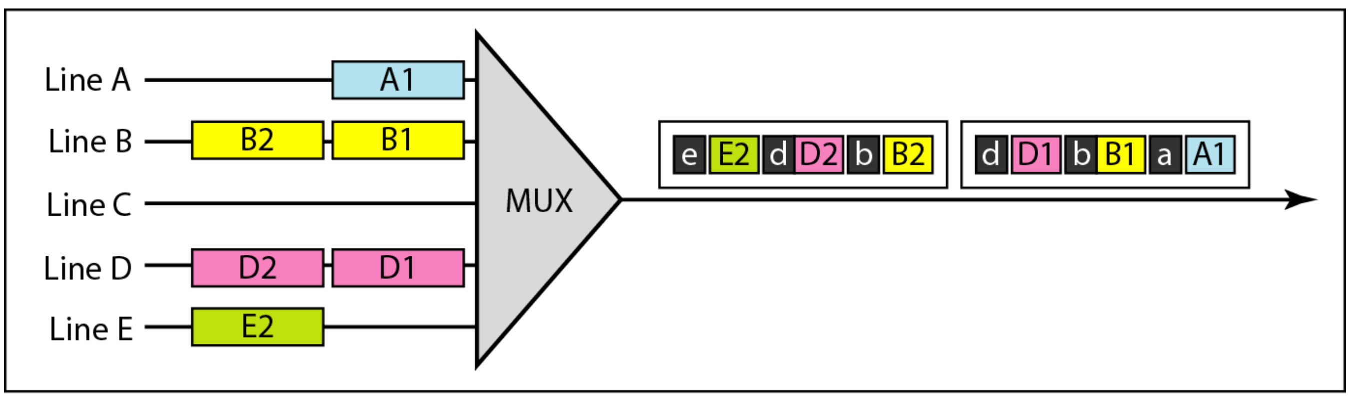
Statistical Time-Division Multiplexing

- Slots are dynamically allocated to improve bandwidth efficiency
- Number of slots in each frame < Number of input lines
- 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 Time-Division Multiplexing



a. Synchronous TDM



b. Statistical TDM

Statistical Time-Division Multiplexing

- Addressing:
  - The output slot carries data and the address of the destination slot
  - Can be n bits to define N different output lines with

$$n = \log_2 N$$

- Slot size:
  - The ratio of the data size to address size must be reasonable to make transmission efficient
- No Synchronization bit
- Bandwidth:
  - The capacity of the link is normally less than the sum of the capacities of each channel

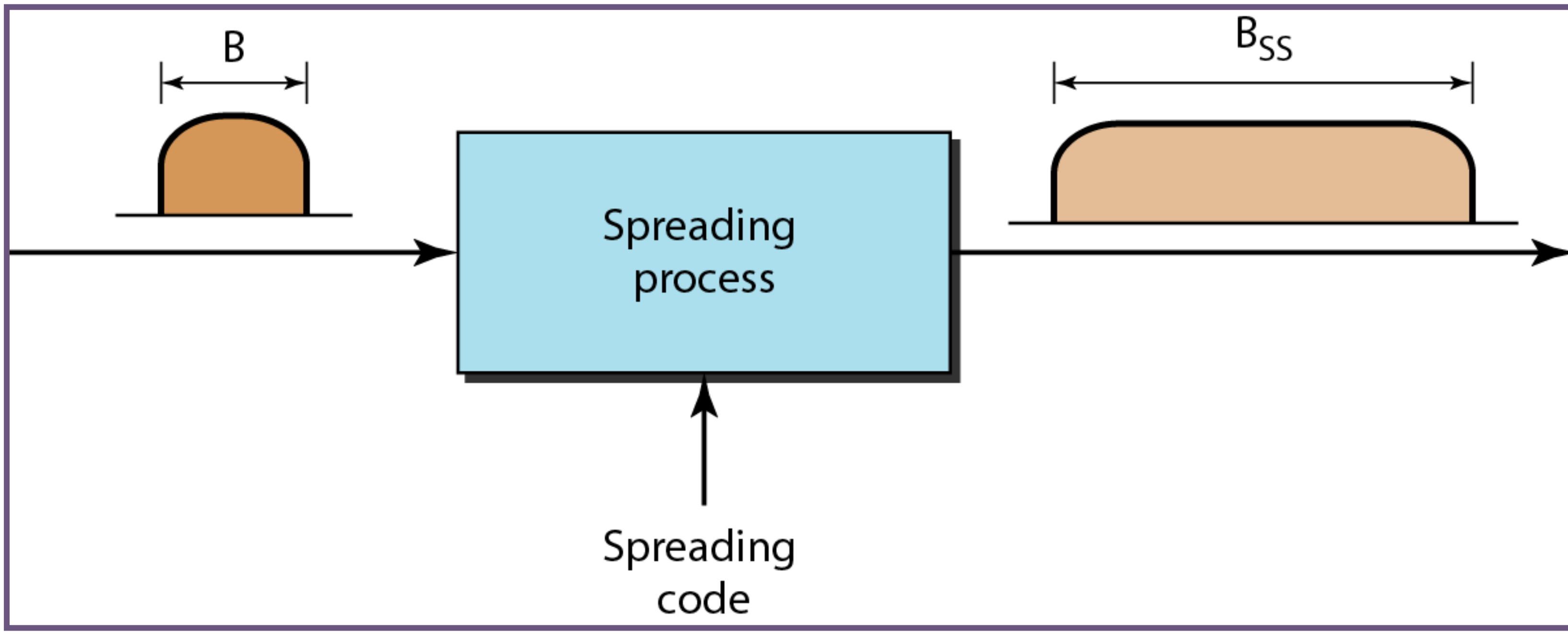
Spread Spectrum

- Spread signal to use larger bandwidth
  - To prevent eavesdropping (privacy)
  - To reduce effect from interference (anti-jamming)
- If the required bandwidth for each station is B, spread spectrum expands it to B_{SS};

$$B_{SS} >> B.$$

- Two principles
  - Redundancy - The bandwidth allocated to each station needs to be larger than what is needed.
  - Independent process - The spreading process occurs after the signal is created by the source.

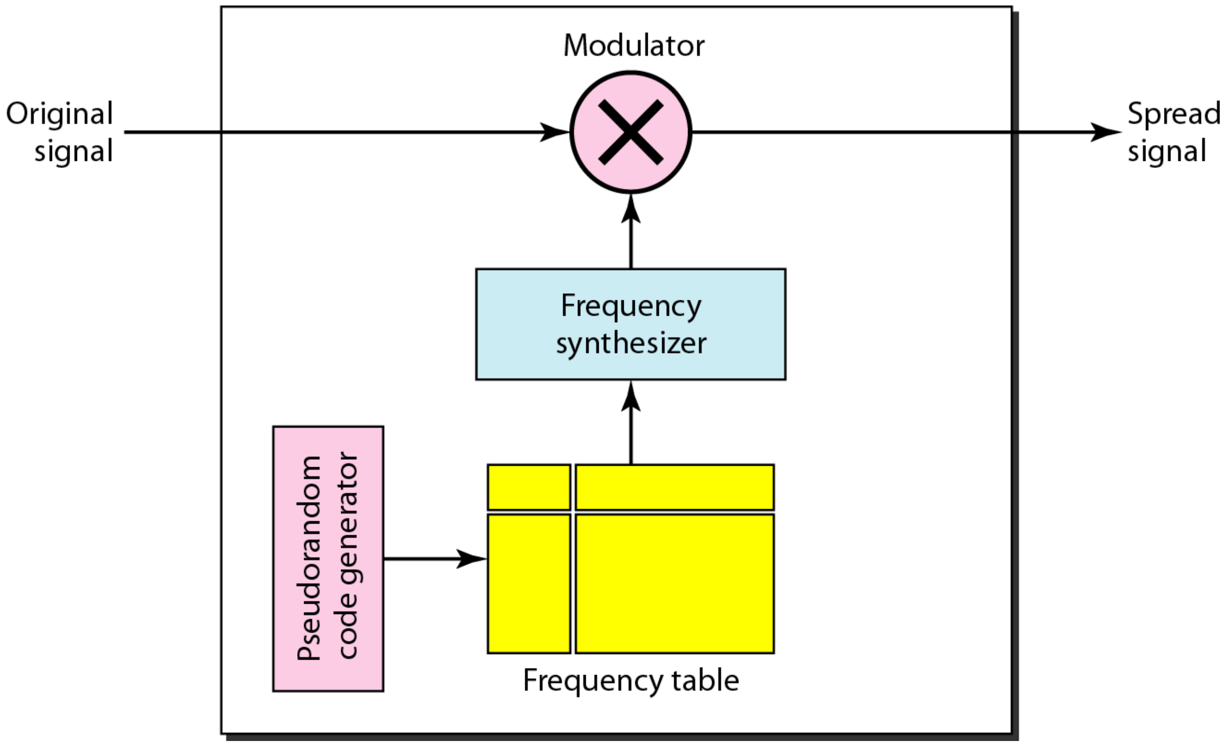
Spread Spectrum

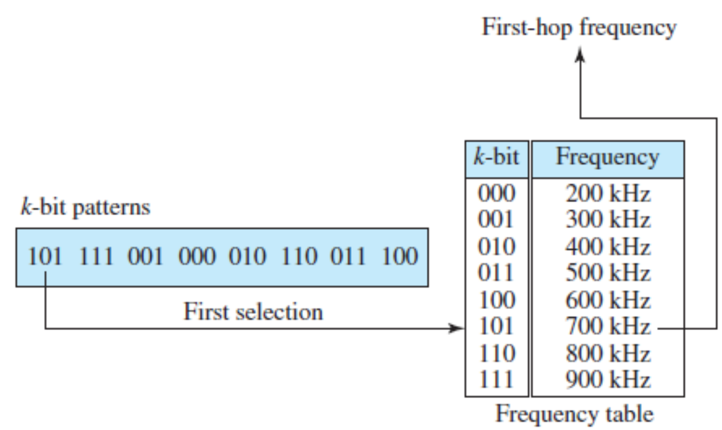


Frequency-Hopping Spread Spectrum (FHSS)

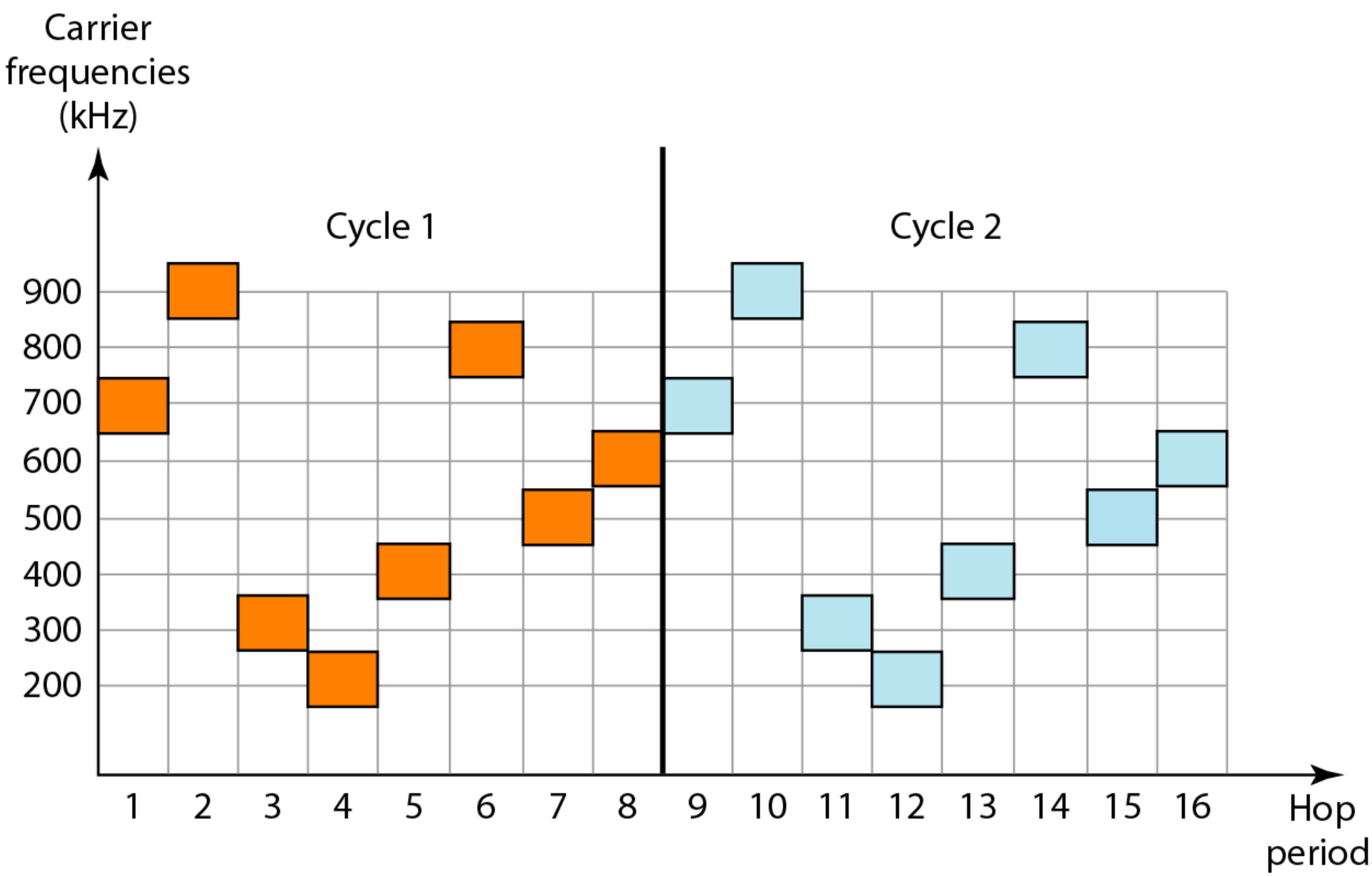
- Uses *M different carrier* frequencies that are modulated by the source signal.
- At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency.
- *The bandwidth occupied by a source after* spreading is $B_{FHSS} >> B$.
- Used in Bluetooth technology.

General Layout for 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

FHSS

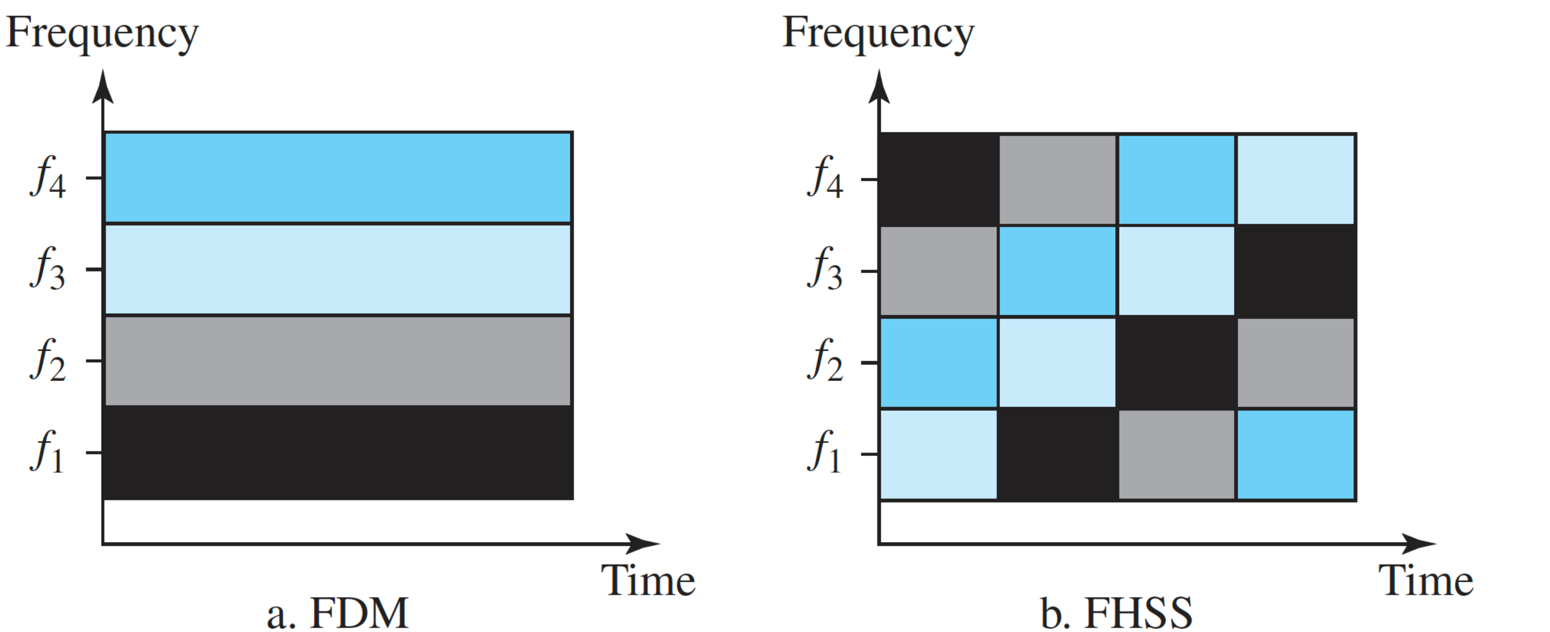
- It can preserve privacy
  - If an intruder tries to intercept the transmitted signal, (s)he can only access a small piece of data because (s)he does not know the spreading sequence to quickly adapt to the next hop.
- Anti-jamming effect
  - A malicious sender may be able to send noise to jam the signal for one hopping period (randomly), but not for the whole period.

Bandwidth Sharing in FHSS

- If the number of hopping frequencies is M, we can multiplex M channels into one by using the same B_{ss} bandwidth.
- This is possible because a station uses just one frequency in each hopping period; M − 1 other frequencies can be used by M − 1 other stations.
- In other words, M different stations can use the same B_{ss} if an appropriate modulation technique such as multiple FSK (MFSK) is used.

Bandwidth Sharing in FHSS

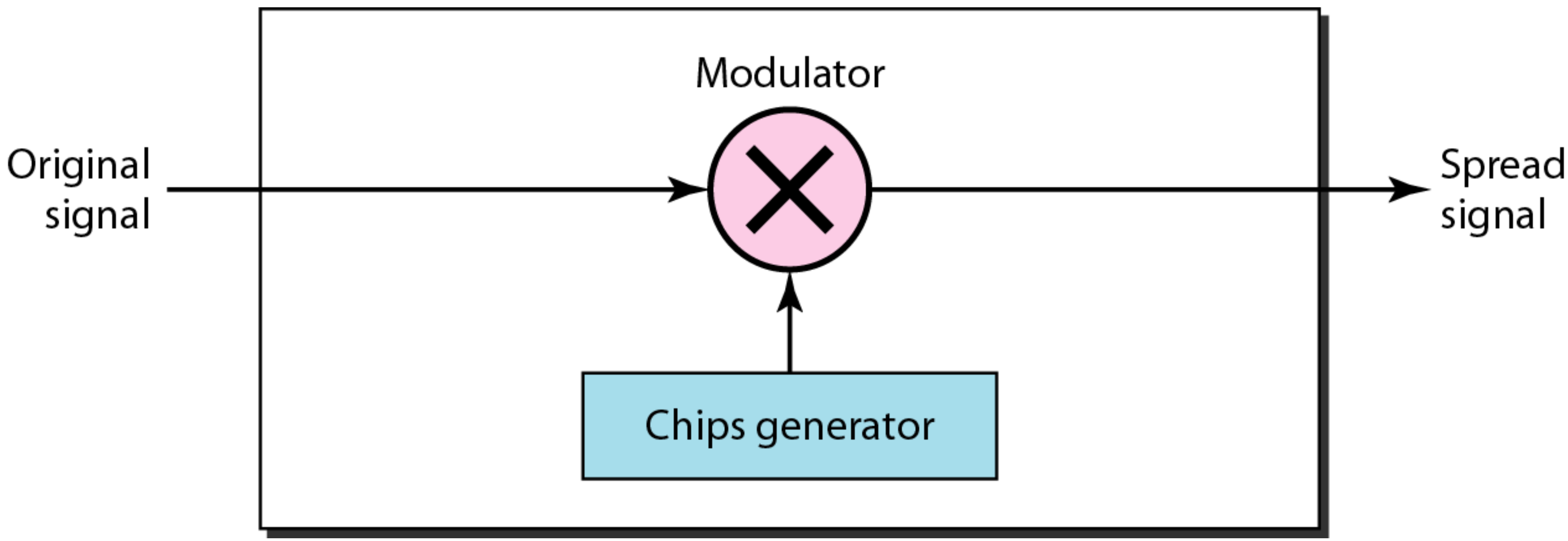
- FHSS is similar to FDM.



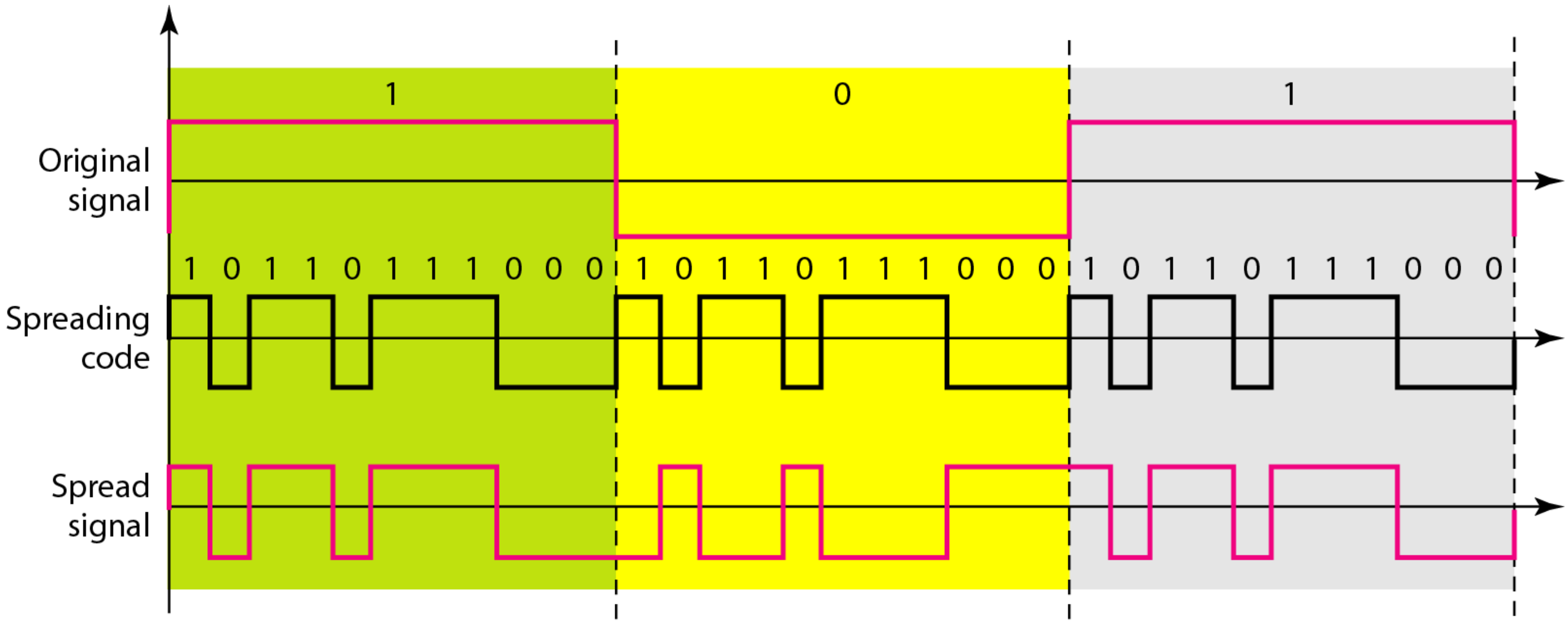
The figure shows an example of four channels using FDM and four channels using FHSS. In FDM, each station uses 1/M of the bandwidth, but the allocation is fixed; in FHSS, each station uses 1/M of the bandwidth, but the allocation changes hop to hop.

Direct-Sequence SS

- "DSSS" – Direct-Sequence Spread Spectrum
  - Used in Wireless LANs



DSSS Example



Bandwidth Sharing in DSSS

- Can we share a bandwidth in DSSS?
- The answer is no and yes.
- If we use a spreading code that spreads signals (from different stations) that cannot be combined and separated, we cannot share a bandwidth.
- By using a special type of sequence code that allows the combining and separating of spread signals, we can share the bandwidth.