Chapter 3

Data and Signals

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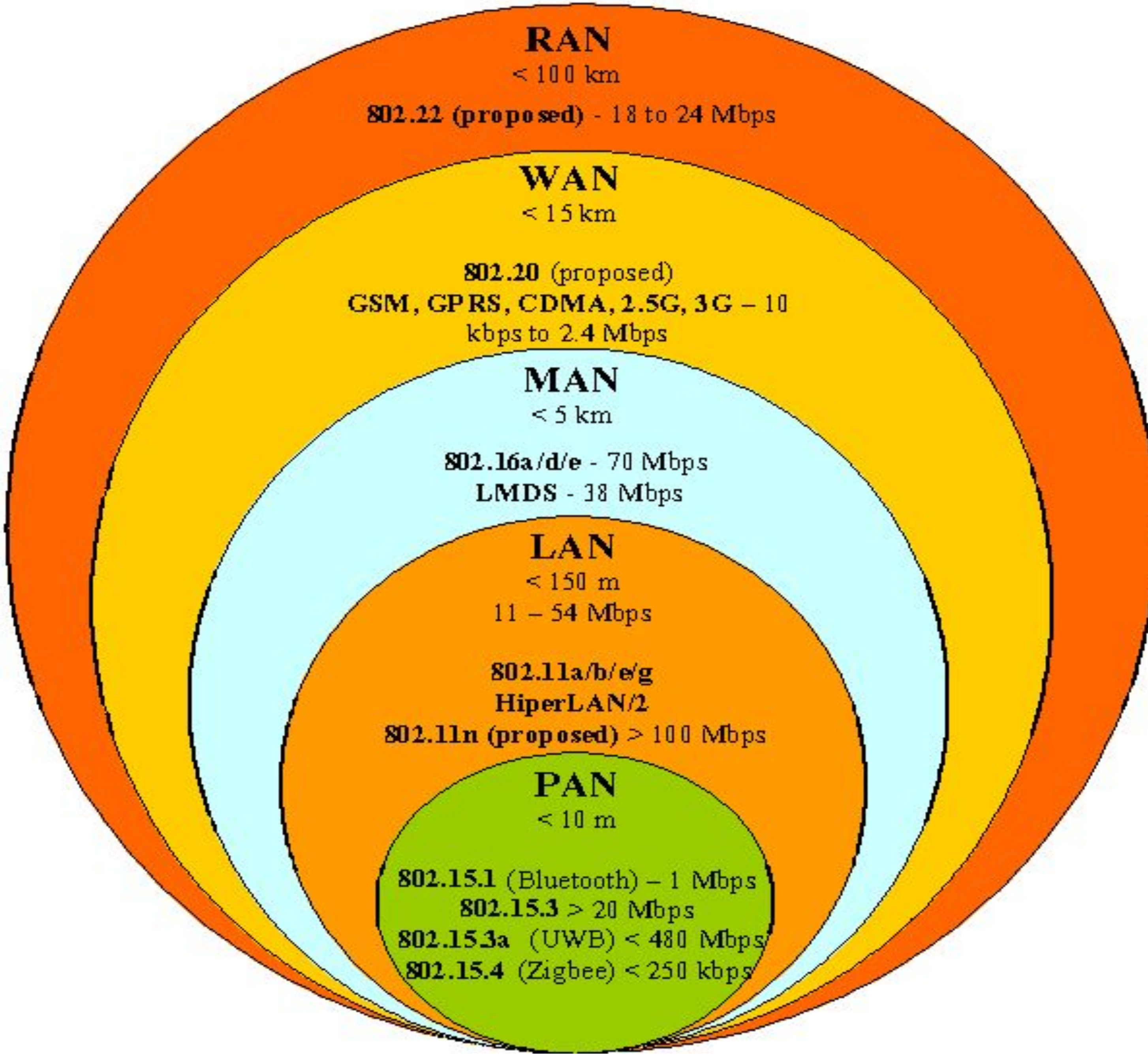
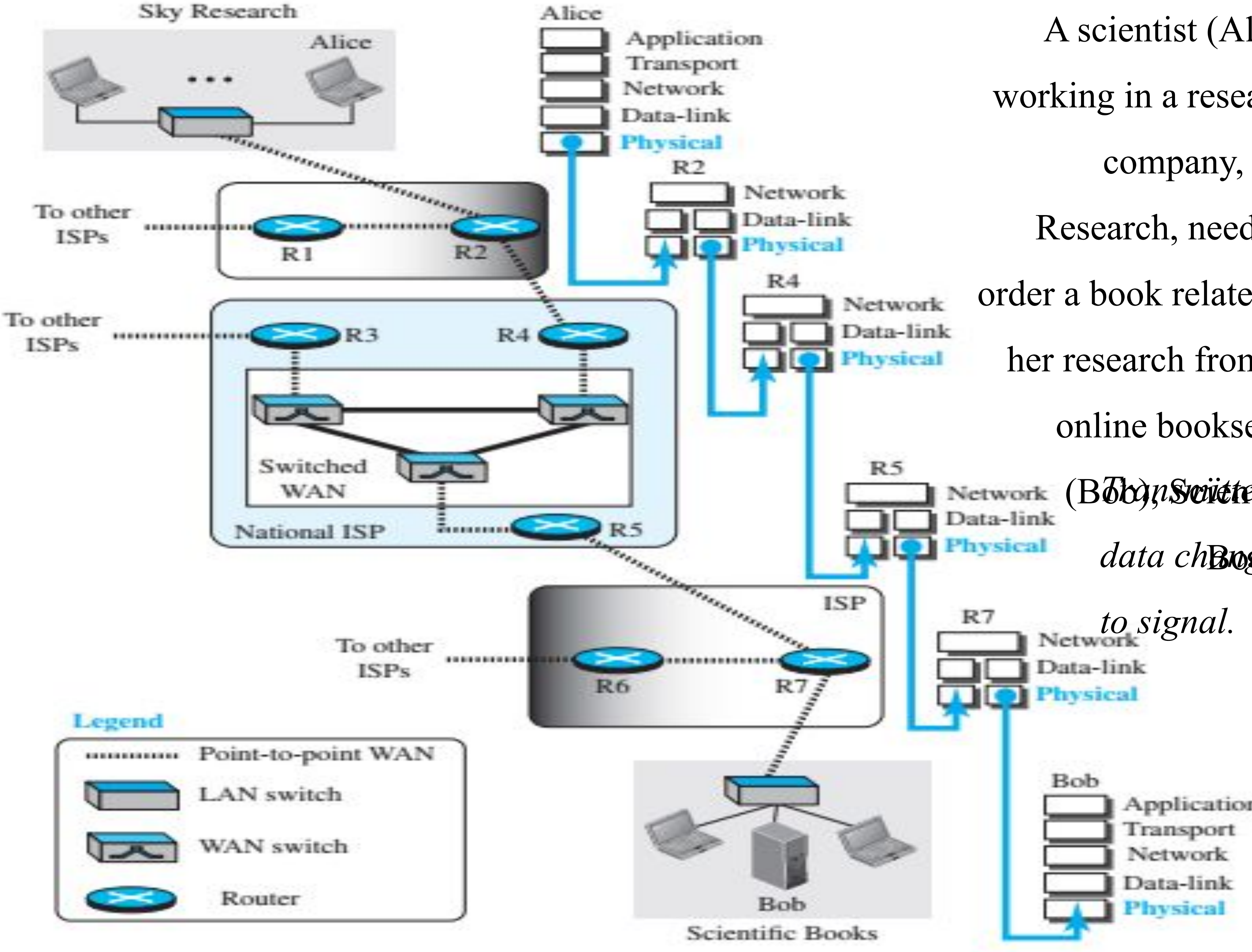
gure 1 – Exemplary 802.22 deployment configuration



3.2

BASIS OF COMPARISON	LAN	MAN	WAN
Expands to	Local Area Network	Metropolitan Area Network	Wide Area Network
Meaning	A network that connects a group of computers in a small geographical area.	It covers relatively large region such as cities, towns.	It spans large locality and connects countries together. Example Internet.
Ownership of Network	Private	Private or Public	Private or Public
Design and maintenance	Easy	Difficult	Difficult
Propagation Delay	Short	Moderate	Long
Speed	High	Moderate	Low
Fault Tolerance	More Tolerant	Less Tolerant	Less Tolerant
Congestion	Less	More	More
Used for	College, School, Hospital.	Small towns, City.	Country/Continent.



A scientist (Alice) working in a research company, Sky Research, needs to order a book related to her research from an online bookseller (Bob), Scientific Books.

Transmitted data changes to signal.

3.4

Note

To be transmitted, data must be transformed to electromagnetic signals.

3-1 ANALOG AND DIGITAL

Data can be analog or digital. The term analog data refers to information that is continuous; digital data refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.

Topics discussed in this section:

Analog and Digital Data
Analog and Digital Signals
Periodic and Nonperiodic Signals

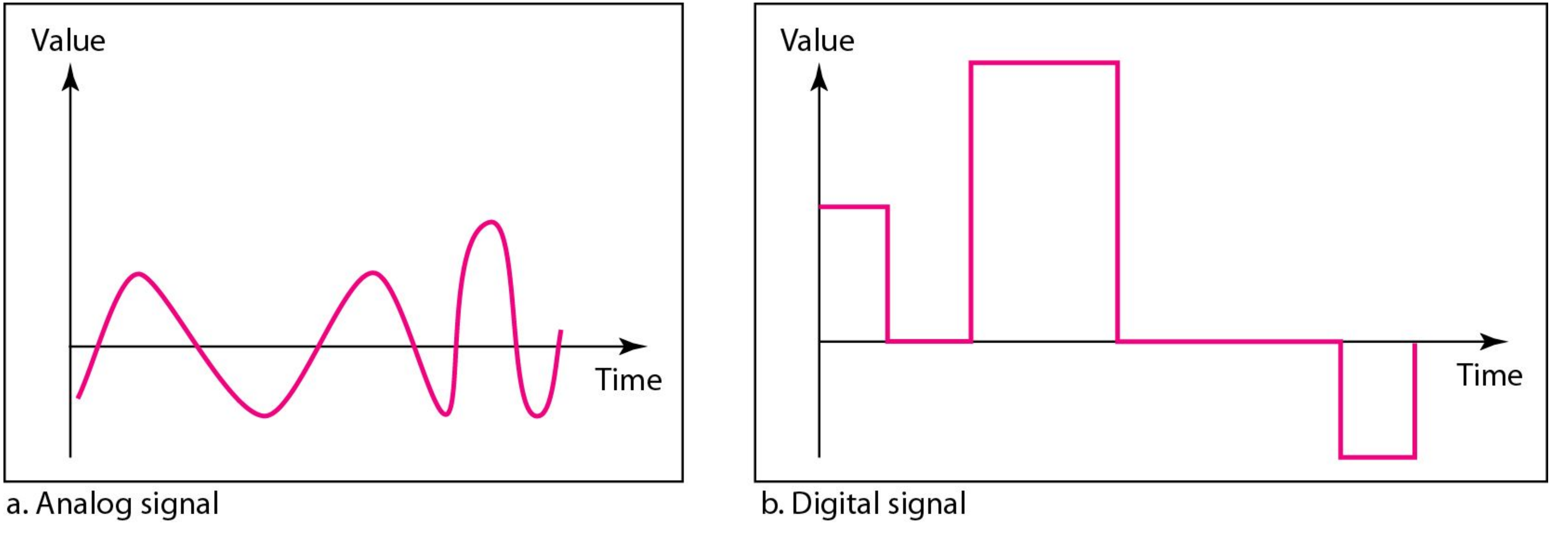
Note

Data can be analog or digital. Analog data are continuous and take continuous values. Digital data have discrete states and take discrete values.

Note

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

Figure 3.1 *Comparison of analog and digital signals*



Analog v/s Digital

Analog

- Used to transmit video and audio signals.
- Used when we don’t have large bandwidth.
- Higher error rate due to sine property.
- Continuous by nature.
- Uses curved wave forms.
- Can travel short distance.
- Amplifiers are used which gives strength to signal but can’t correct the signals.
- Analog signals can be used for digital transmission. Eg; Modem sends digital data over analog telephone lines.

Digital

- Used to transfer (0,1) bits generally for file transfer.
- Used when we have large bandwidth.
- Low error rate.
- Discrete by nature.
- Square wave forms.
- Can travel long distance.
- Repeaters are used to give strength to signal which can also correct signals.
- Digital signals can be used for analog transmission. Eg. You tube, Skype transmitting audio video signals using digital signals.

Note

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

3-2 PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.

Out of Syllabus

Topics discussed in this section:

Sine Wave
Wavelength
Time and Frequency Domain
Composite Signals
Bandwidth

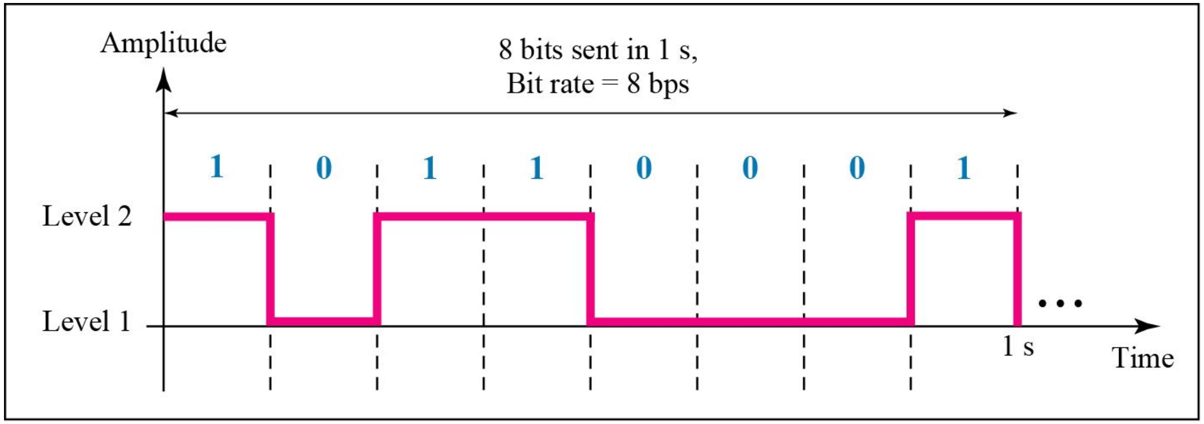
3-3 DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

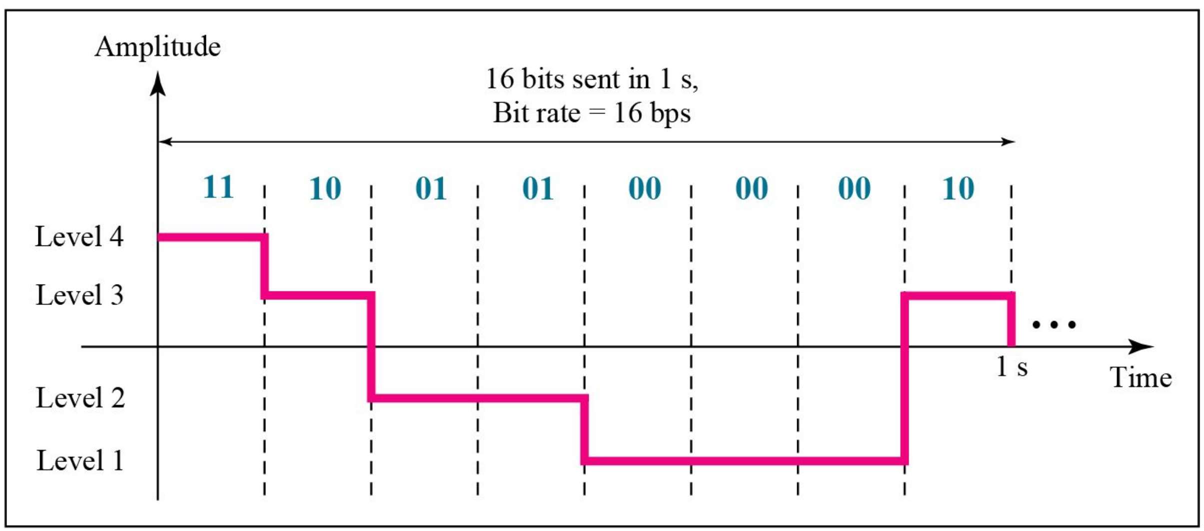
Topics discussed in this section:

Bit Rate
Bit Length
Digital Signal as a Composite Analog Signal
Application Layer

Figure 3.16 *Two digital signals: one with two signal levels and the other with four signal levels*



a. A digital signal with two levels



b. A digital signal with four levels

Example 3.16

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

Example 3.17

A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Example 3.18

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$\boxed{100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}}$$

Example 3.19

A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$\boxed{2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}}$$

Example 3.20

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$1920 \times 1080 \times 30 \times 24 = 1{,}492{,}992{,}000 \text{ or } 1.5 \text{ Gbps}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.

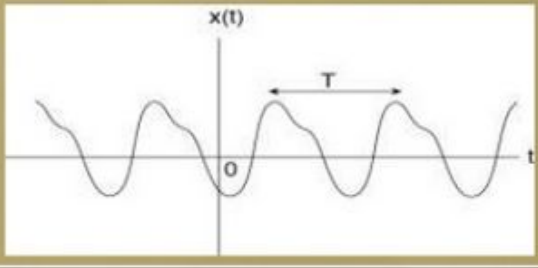
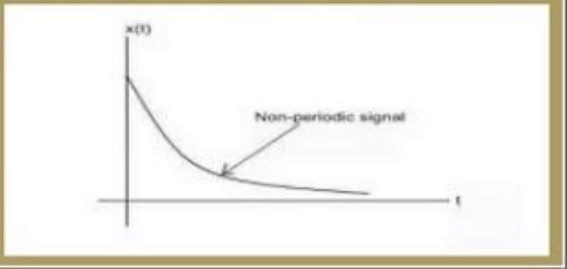
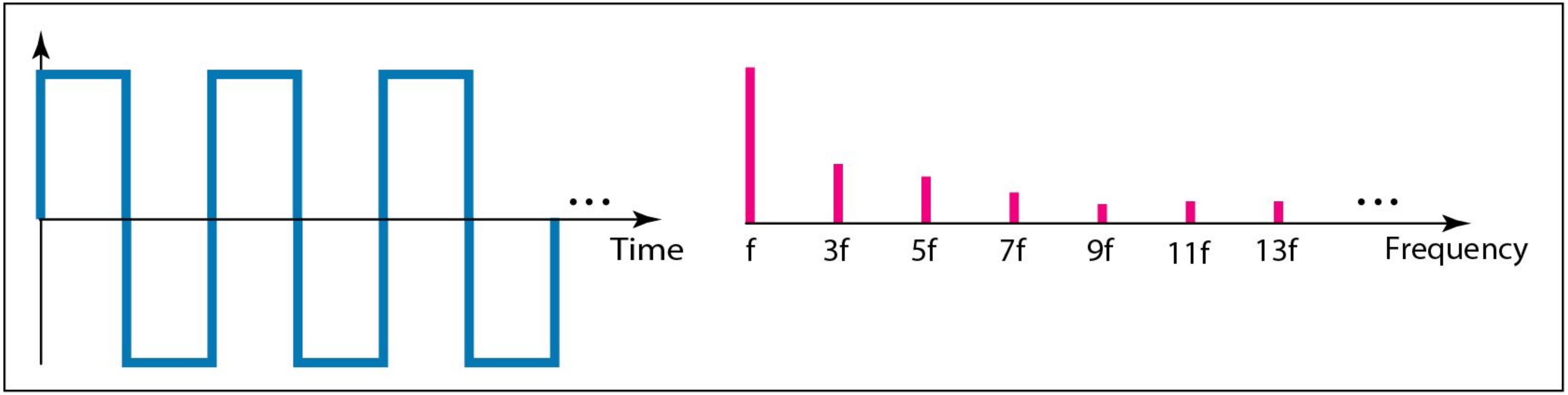
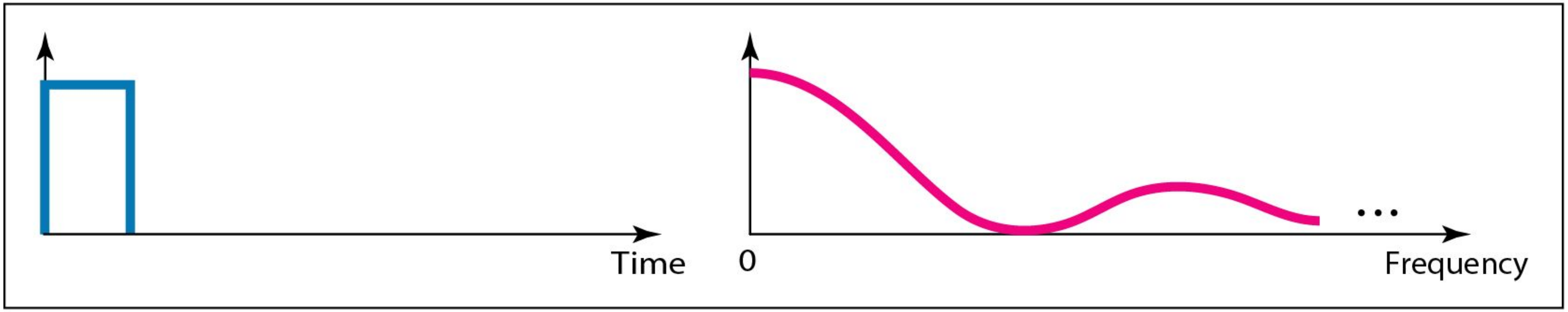
Periodic Signal	Aperiodic Signal
❑ A signal which repeats itself after a specific interval of time is called periodic signal.	❑ A signal which does not repeat itself after a specific interval of time is called aperiodic signal.
❑ A signal that repeats its pattern over a period is called periodic signal	❑ A signal that does not repeats its pattern over a period is called aperiodic signal or non periodic.
❑ They can be represented by a mathematical equation	❑ They cannot be represented by any mathematical equation
❑ Their value can be determined at any point of time	❑ Their value cannot be determined with certainty at any given point of time
❑ They are deterministic signals	❑ They are random signals
❑ Example: sine cosine square sawtooth etc	❑ Example: sound signals from radio , all types of noise signals
❑ Figure: 	❑ Figure: 

Figure 3.17 ***The time and frequency domains of periodic and nonperiodic digital signals***



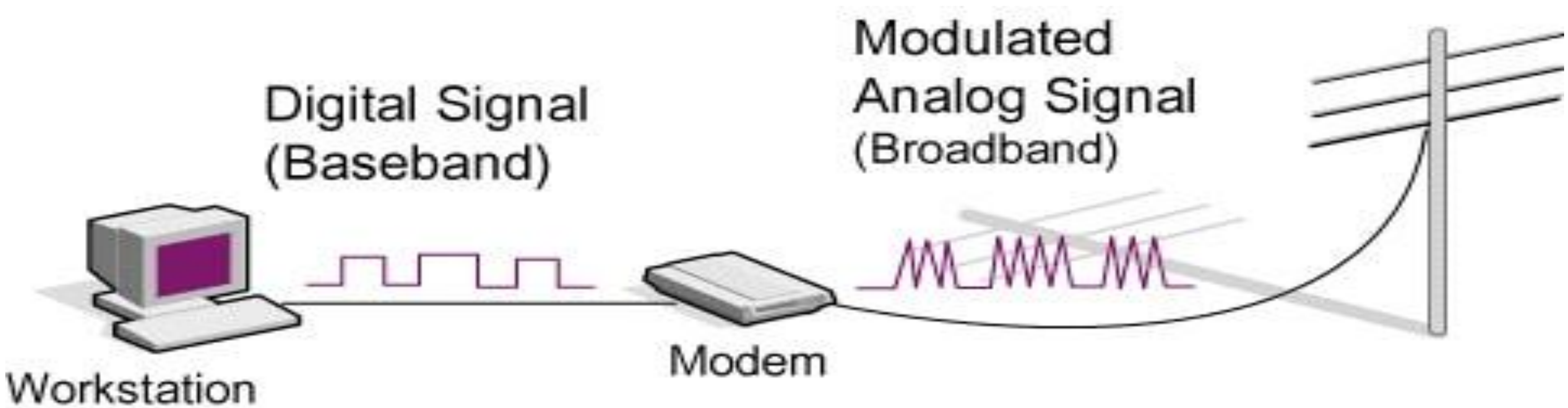
a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

Baseband v/s Broadband

- In the **baseband** transmission the whole bandwidth of the cable is utilized by a single signal.
- Conversely, in the **broadband** transmission, multiple signals are sent on multiple frequencies simultaneously using a single channel.



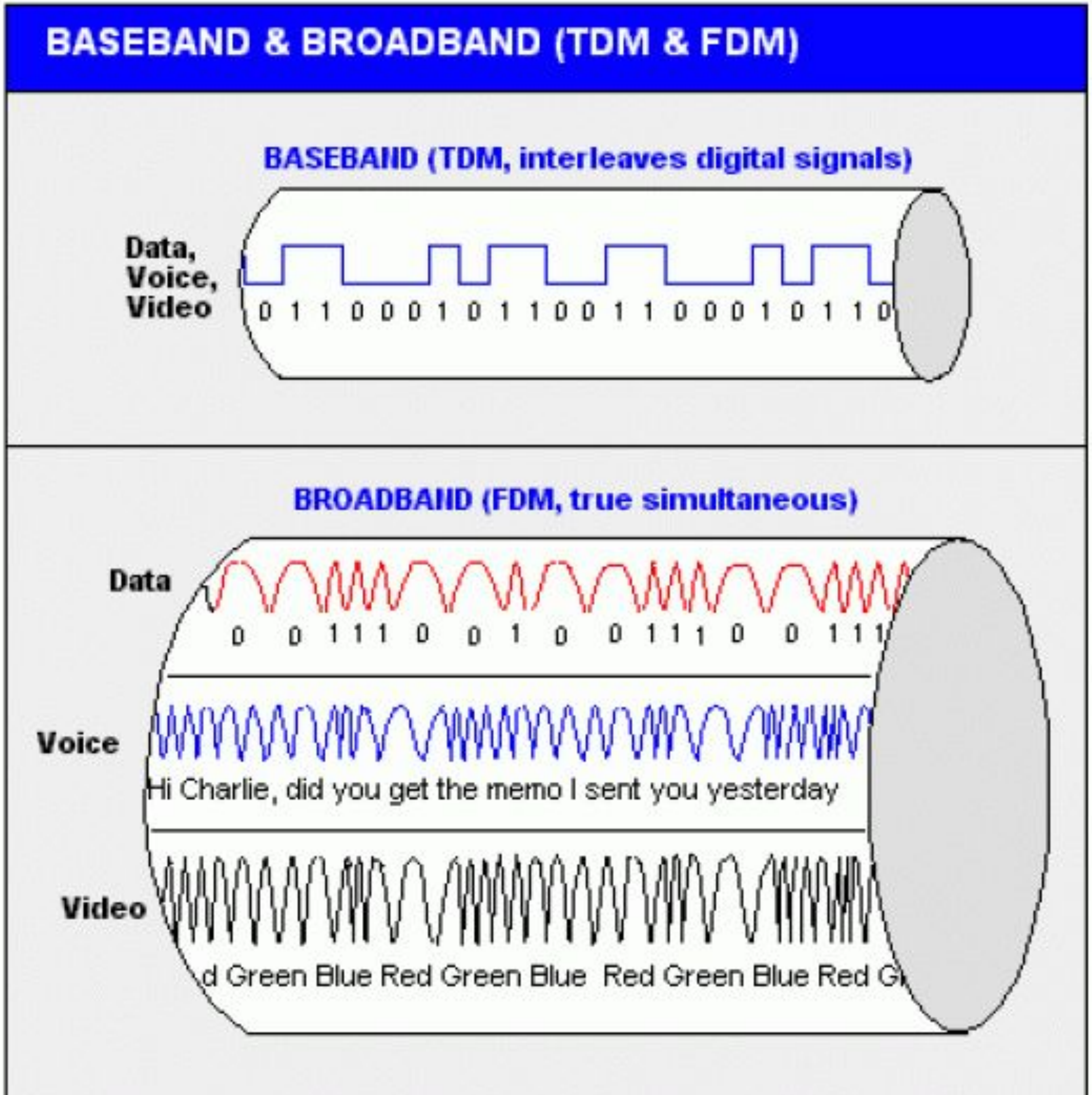

BASEBAND & BROADBAND (TDM & FDM)
BASEBAND (TDM, interleaves digital signals)
Data,
Voice,
Video
0 1 1 0 0 0 1 0 1 1 0 0 1 1 0 0 0 1 0 1 1 0
BROADBAND (FDM, true simultaneous)
Data
0 0 1 1 1 0 0 1 0 0 1 1 1 0 0 1 1 1
Voice
Hi Charlie, did you get the memo I sent you yesterday
Video
d Green Blue Red Green Blue Red Green Blue Red G

Figure 3.18 *Baseband transmission*

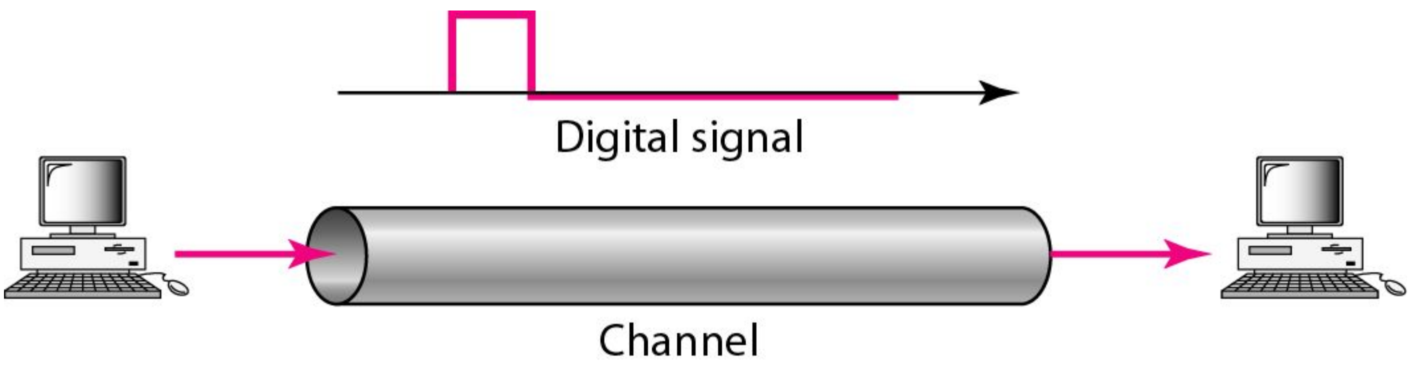
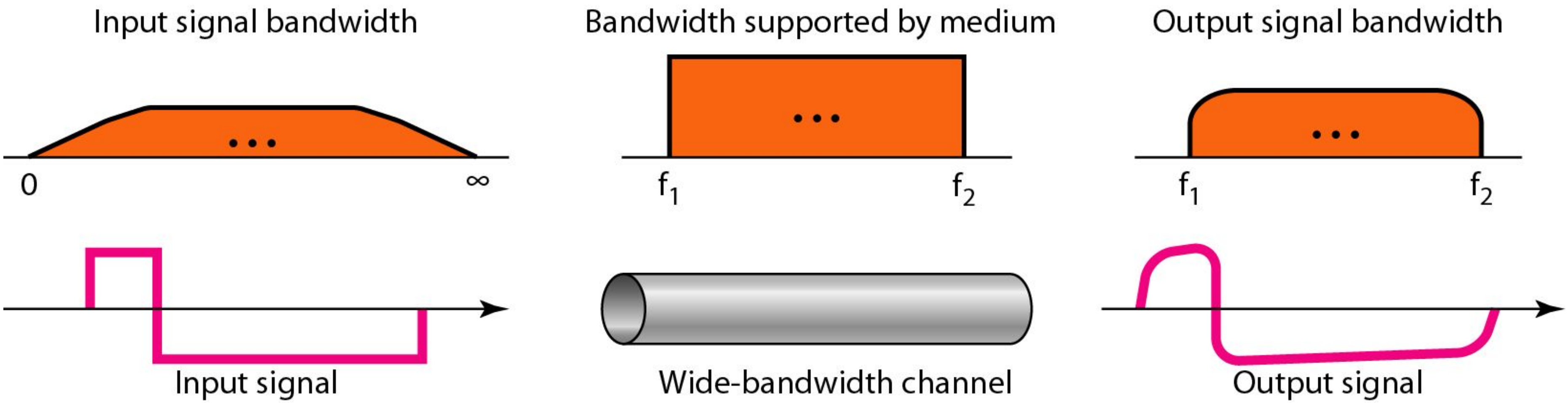
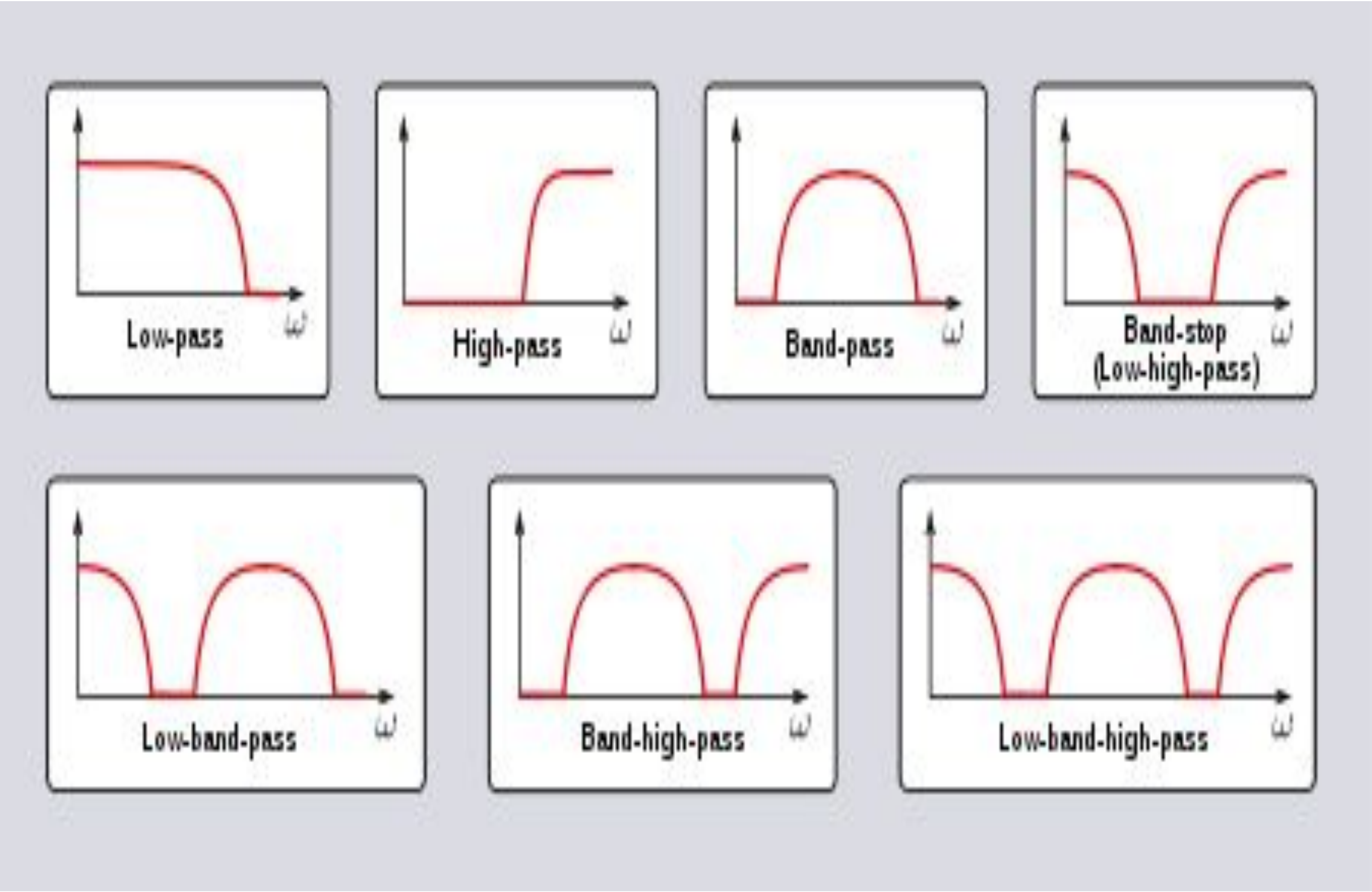


Figure 3.20 *Baseband transmission using a dedicated medium*



Low pass, Band pass & High pass filters



Note

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

Note

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth.

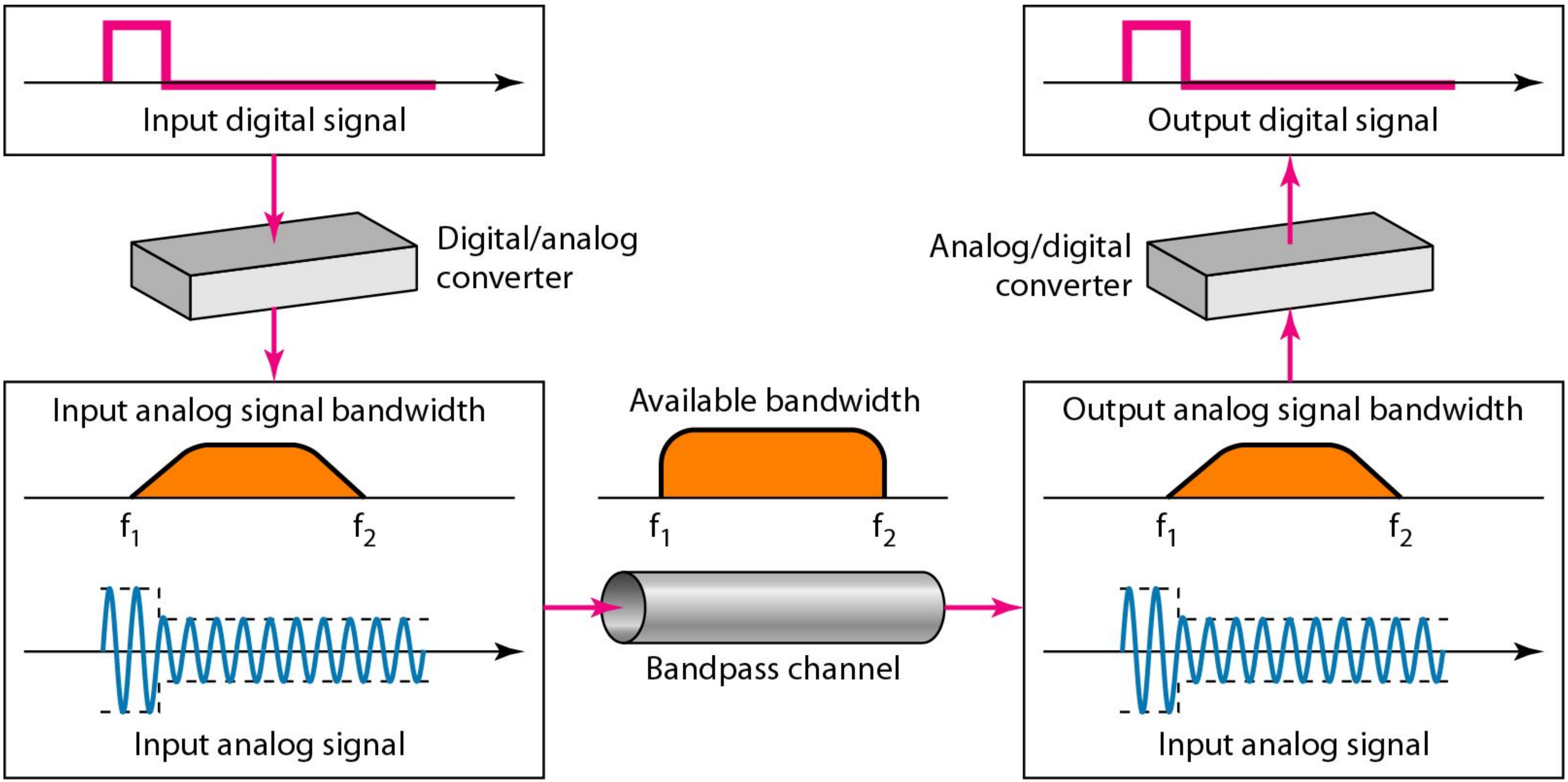
Table 3.2 ***Bandwidth requirements***

Bit Rate	*Harmonic 1*	*Harmonics 1, 3*	*Harmonics 1, 3, 5*
$n = 1$ kbps	$B = 500$ Hz	$B = 1.5$ kHz	$B = 2.5$ kHz
$n = 10$ kbps	$B = 5$ kHz	$B = 15$ kHz	$B = 25$ kHz
$n = 100$ kbps	$B = 50$ kHz	$B = 150$ kHz	$B = 250$ kHz

Note

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Figure 3.24 ***Modulation of a digital signal for transmission on a bandpass channel***



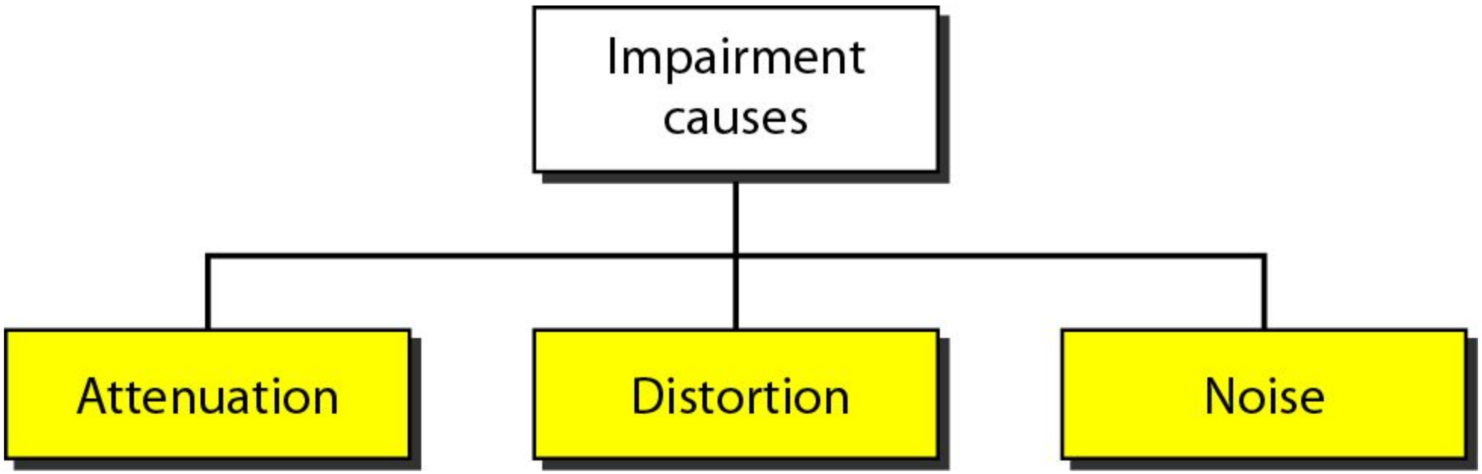
3-4 TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

Topics discussed in this section:

Attenuation
Distortion
Noise

Figure 3.25 *Causes of impairment*



Attenuation

- Attenuation means a loss of energy.
- When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
- To show that a signal has lost or gained strength, engineers use the unit of the decibel.
- The decibel (dB) measures the relative strengths of two signals or one signal at two different points.

Distortion

- Distortion means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies.
- As a result, signal components at the receiver have phases different from what they had at the sender.
- The shape of the composite signal is therefore not the same.

Noise

- Noise is another cause of impairment.
- Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.
- **Thermal noise** is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter.
- **Induced noise** comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.
- **Crosstalk** is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.
- **Impulse noise** is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

Figure 3.26 ***Attenuation***

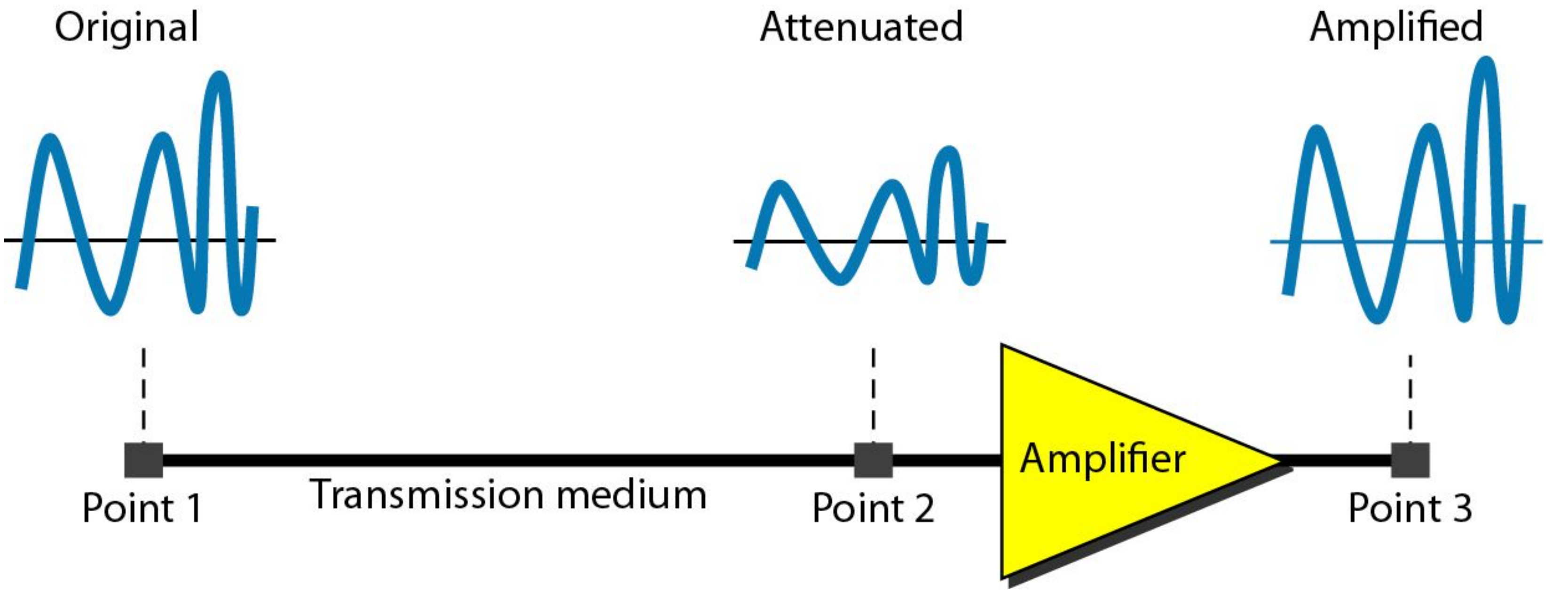


Figure 3.28 ***Distortion***

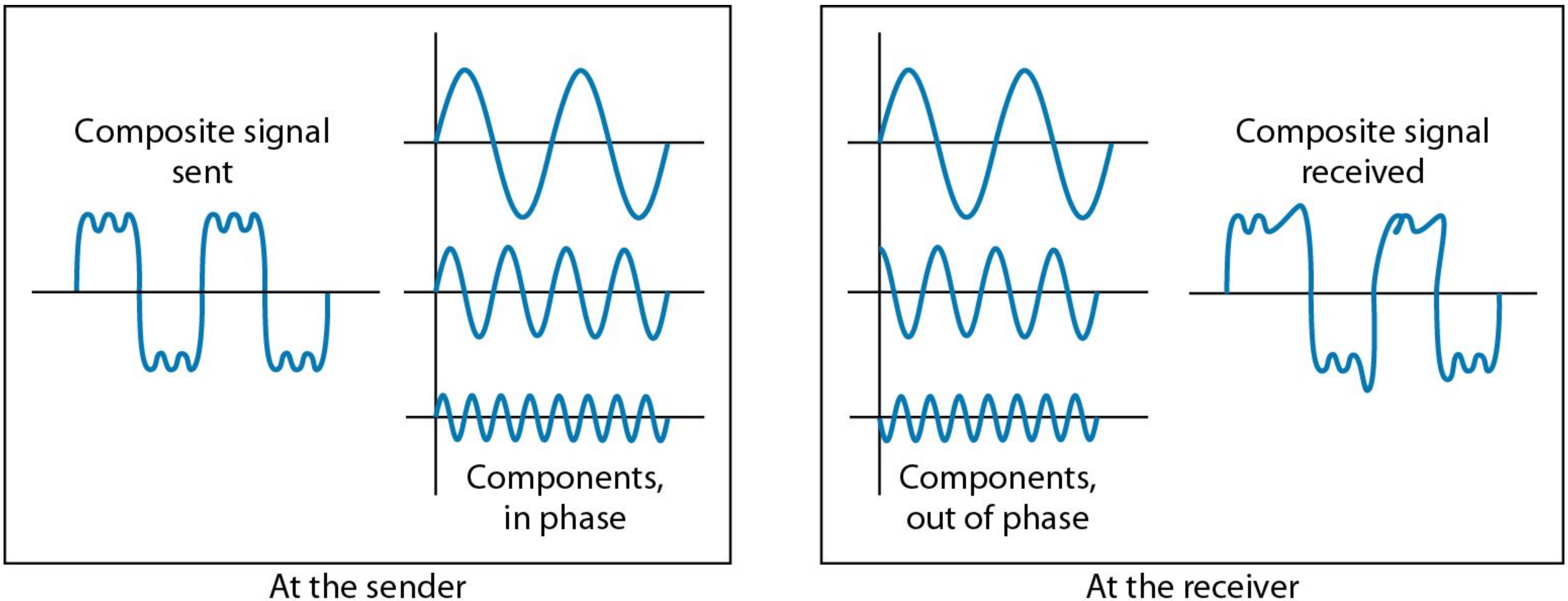


Figure 3.29 *Noise*

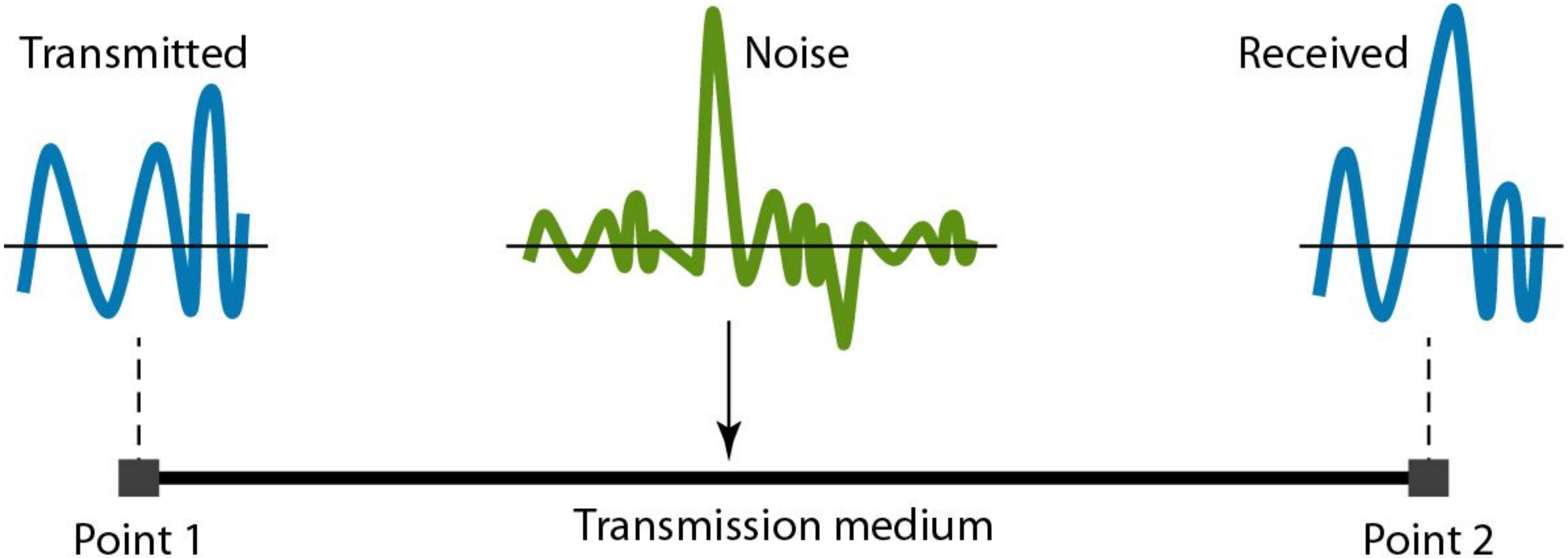
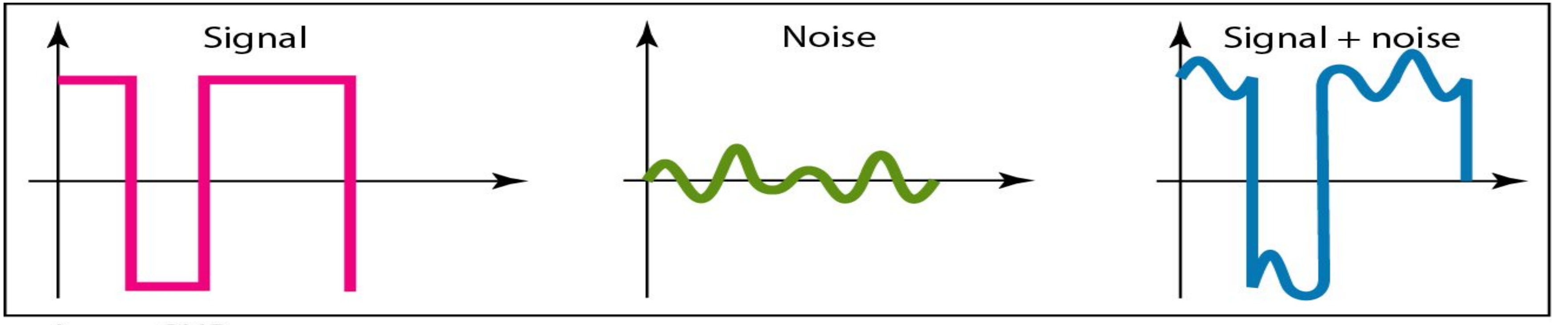
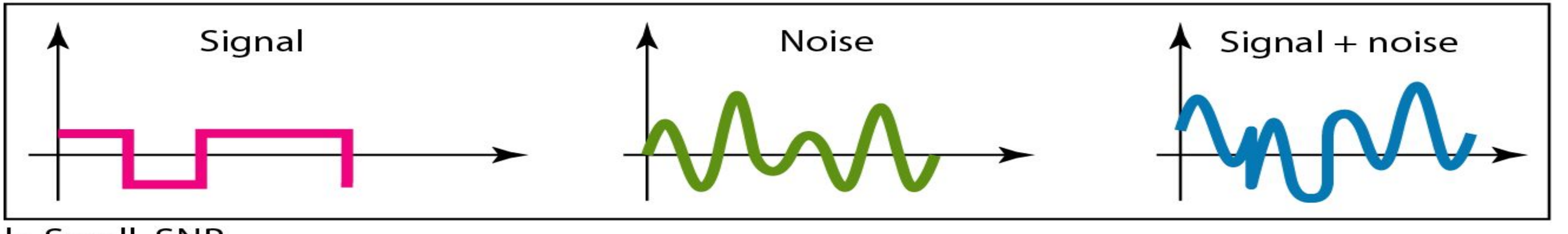


Figure 3.30 *Two cases of Signal to Noise Ratio: a high SNR and a low SNR*

$$\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$



a. Large SNR



b. Small SNR

3-5 DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. ***The bandwidth available***
2. ***The level of the signals we use***
3. ***The quality of the channel (the level of noise)***

Topics discussed in this section:

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity
Using Both Limits

Note

Increasing the levels of a signal may reduce the reliability of the system.

Note

Increasing the levels of a signal may reduce the reliability of the system.

Two theoretical formulas were developed to calculate the data rate: one by <u>Nyquist</u> for a noiseless channel, another by <u>Shannon</u> for a noisy channel.

Data Rate Calculation

Nyquist

Noiseless Channel

L = signal levels

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

Shannon

Noisy Channel

SNR = signal to noise ratio

$$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})$$

Example 3.34

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example 3.35

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example 3.37

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example 3.38

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2(1 + \text{SNR}) = 3000 \log_2(1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Example 3.40

For practical purposes, when the SNR is very high, we can assume that SNR + 1 is almost the same as SNR. In these cases, the theoretical channel capacity can be simplified to

$$\boxed{C = B \times \frac{\mathrm{SNR_{dB}}}{3}}$$

For example, we can calculate the theoretical capacity of the previous example as

$$\boxed{C = 2\ \mathrm{MHz} \times \frac{36}{3} = 24\ \mathrm{Mbps}}$$

Example 3.41

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

Example 3.41 (continued)

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$\boxed{4\ \text{Mbps} = 2 \times 1\ \text{MHz} \times \log_2 L \quad \longrightarrow \quad L = 4}$$

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

3-6 PERFORMANCE

One important issue in networking is the performance of the network—how good is it? We discuss quality of service, an overall measurement of network performance, in greater detail in Chapter 24. In this section, we introduce terms that we need for future chapters.

Topics discussed in this section:

Bandwidth
Throughput
Latency (Delay)
Bandwidth-Delay Product

Performance

- Bandwidth: a range of frequencies within a given band, in particular that used for transmitting a signal.
- Throughput: the amount of bits passing through a system or process at given time.
- Latency (Delay): the total time it takes a data packet to travel from one node to another.
- Bandwidth-Delay Product: the product of a data link's capacity (in bits per second) and its round-trip delay time (in seconds).

Note

In networking, we use the term bandwidth in two contexts.

- **The first, bandwidth in hertz, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.**
- **The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.**

Figure 3.31 *Filling the link with bits for case 1 Frequency Based. FDM*

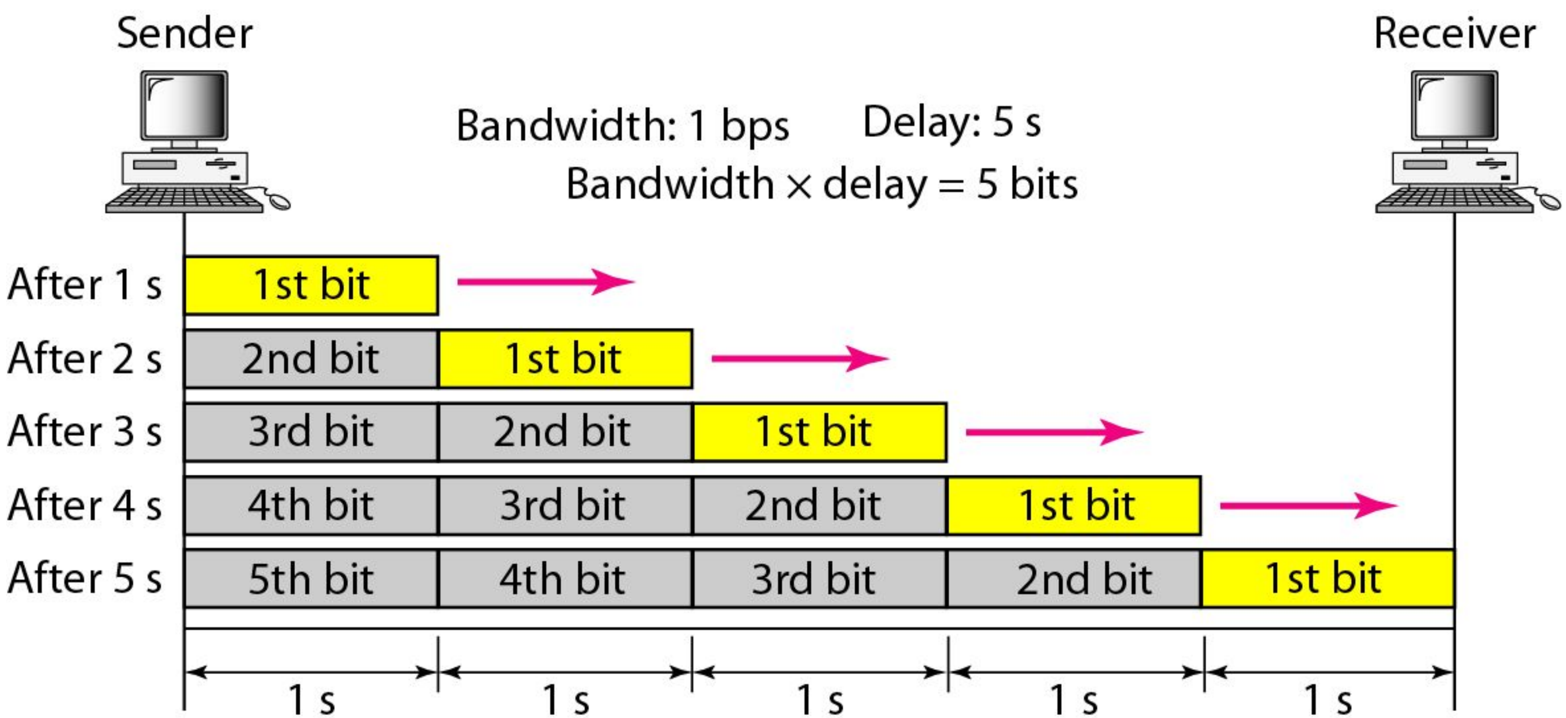
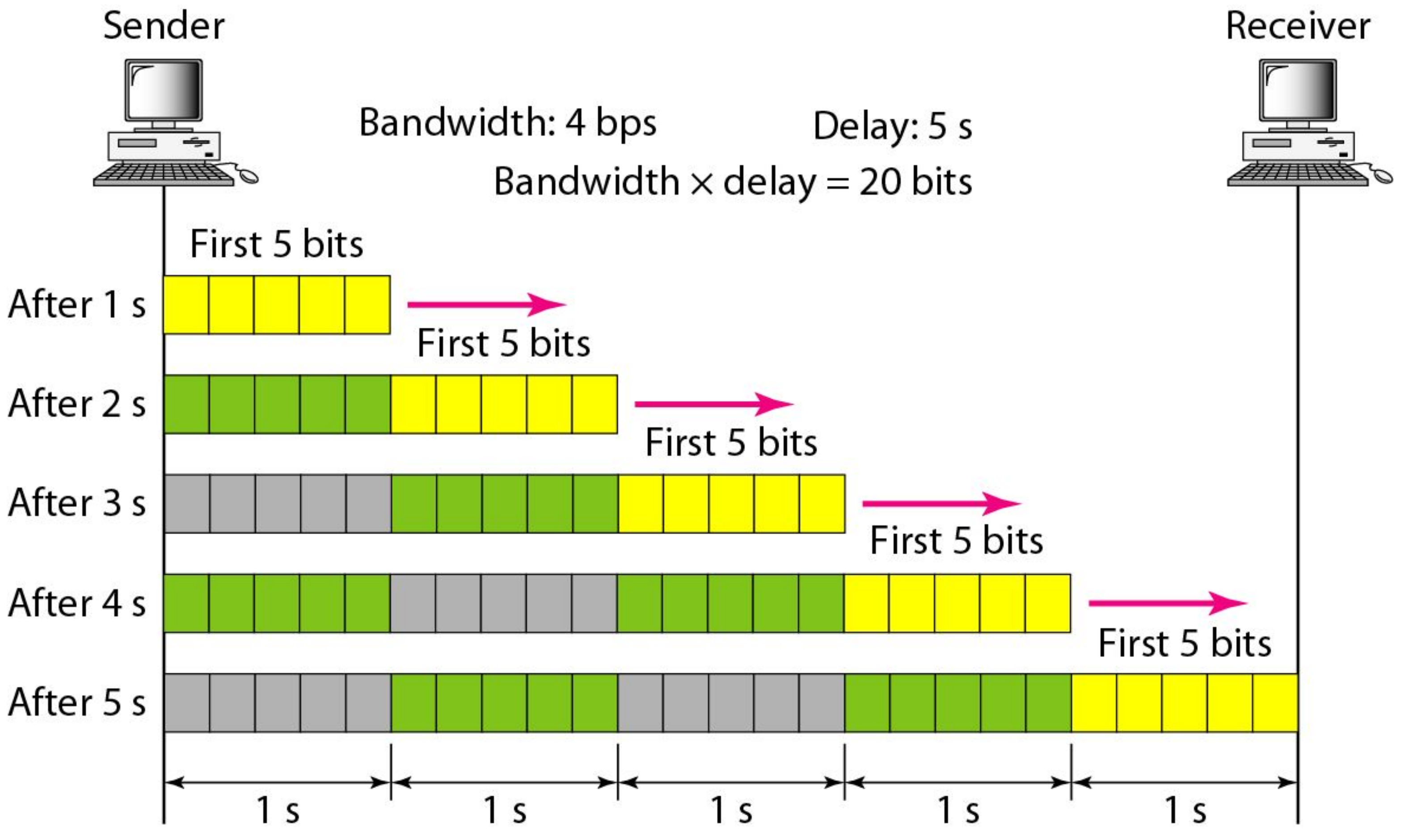


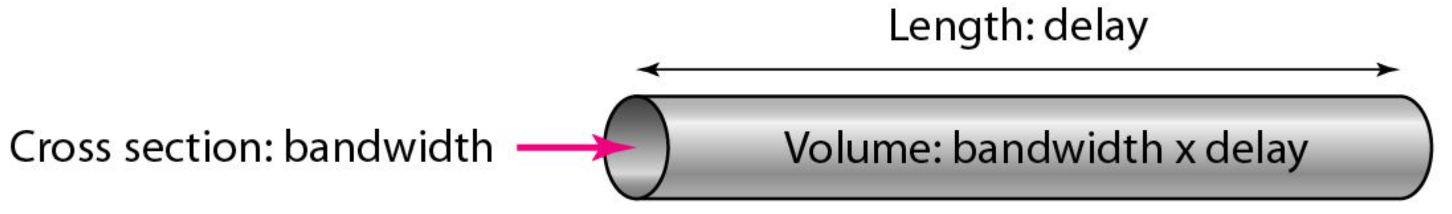
Figure 3.32 *Filling the link with bits in case 2 Time Based. TDM*



Note

The bandwidth-delay product defines the number of bits that can fill the link.

Figure 3.33 ***Concept of bandwidth-delay product***



Develop your skills in designing networks

THANK YOU