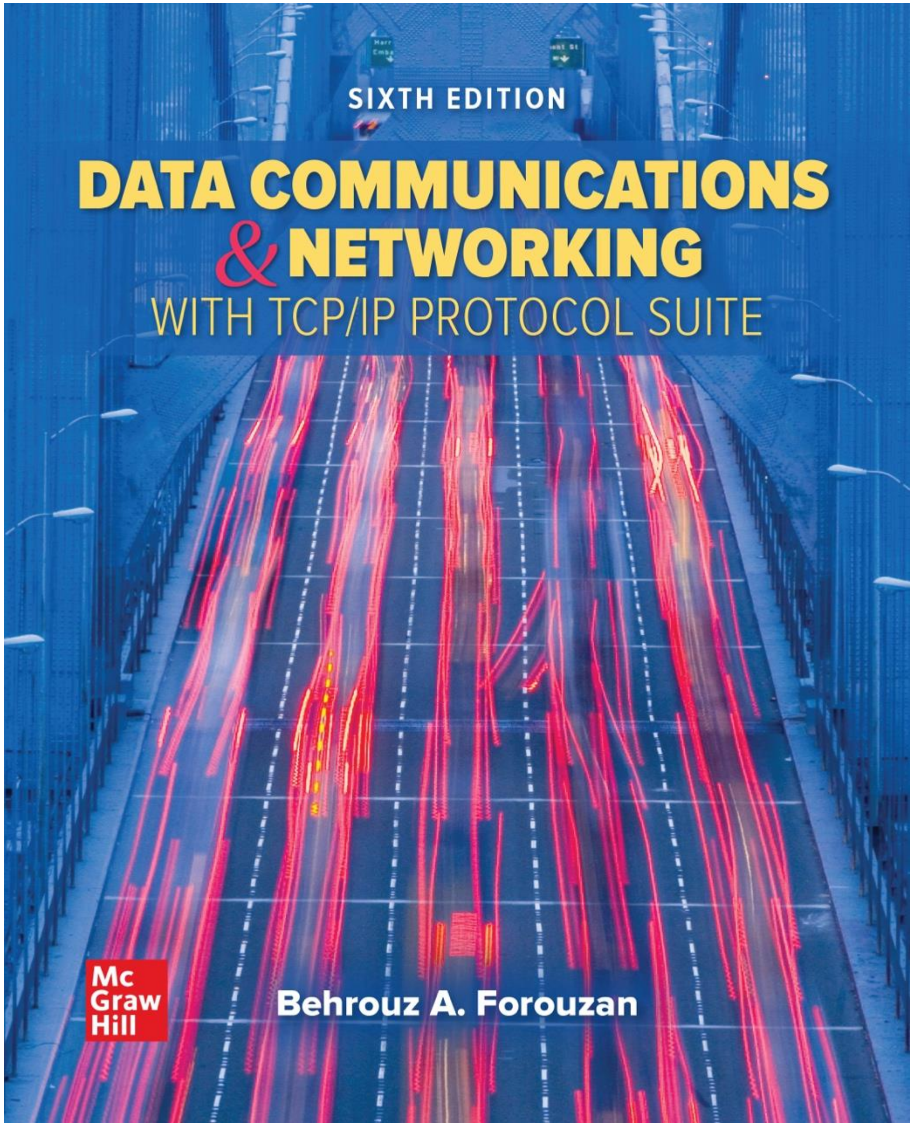
Chapter 02

Physical Layer

- Data Communications and Networking, With TCP/IP protocol suite Sixth Edition
- Behrouz A. Forouzan



Chapter 2: Outline

- 2.1 SIGNALS
- 2.2 SIGNAL IMPAIRMENT
- 2.3 DIGITAL TRANSMISSION
- 2.4 ANALOG TRANSMISSION
- 2.5 MULTIPLEXING
- 2.6 TRANSMISSION MEDIA

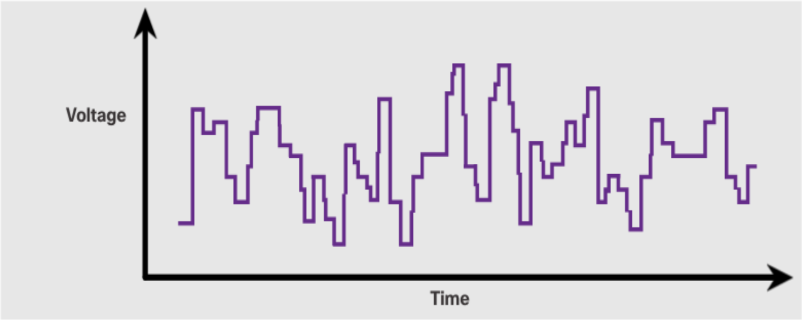
Physical Layer

- Deals with **the actual communication media**
  - Defines the **<u>physical characteristics</u>** of **interfaces** and **transmission media**
    - the way devices are connected to each other and to the link (topology)
    - Shape, size and number of pins of connectors
    - What voltages and currents are used
    - The type of transmission media
    - Transmission mode (duplex type)

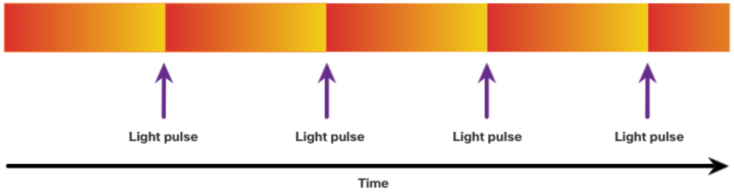
  - **Representation of bits** – encoding into Electrical or Optical signals
  - **Data Rate** = transmission rate = bandwidth (**number of bits sent per second**)
  - **Synchronization of bits** (sender and receiver clocks must be synchronized)
  - Devices that operates at this level: **Network card, hub, repeater**

Note

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



Electrical Signals Over Copper Cable



Light Pulses Over Fiber-Optic Cable

A Transmission System

Transmission: Communication of data by propagation and processing of signals through a **communication channel**

Signal: **Electromagnetic energy** that moves through the transmission medium and carries some information.

Transmitter

- Converts information into *signal* suitable for transmission
- **Injects energy** into communications medium or channel
  - Telephone converts voice into *electric current*
  - **NIC** converts bits into *electric current or pulses of light*

Receiver

- **Receives energy** from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into *voice*
  - NIC converts *electric current or pulses of light* into *bits*

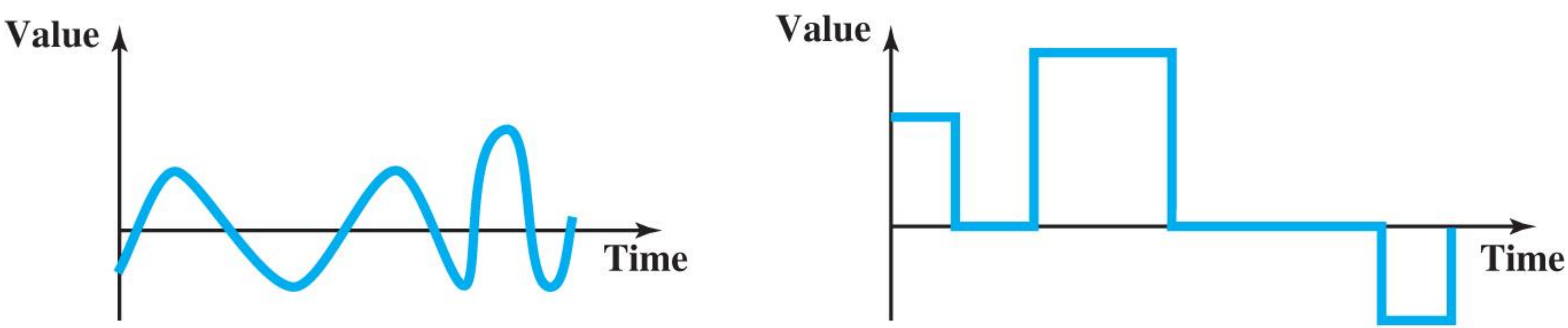
Analog and Digital

- Analog Data: **Continuous** value data (sound, light, temperature)
- Digital Data: **Discrete** value (text, integers, symbols)
- Analog Signals: **Continuously** varying **electromagnetic wave**
  - have an **<u>infinite number</u>** of values over a **<u>period of time</u>**
- Digital Signals: Series of voltage pulses (square wave)
  - have only a **<u>limited number</u>** of values over a **period of time**.
  - Maintains a constant level then changes to another constant level
- Signals are classified into:
  - Periodic Signals: Consists of **<u>repeated patterns</u>** over **identical** period of times (**cycles**)
  - Aperiodic Signals: change **without a pattern** that repeats over time

Figure 2.2 Comparison of analog and digital signals

Left: `∿∿∿∿∿∿` → **Analog = Continuous**

Right: `‾‾__‾‾‾__` → **Digital = Discrete**



a. Analog signal   b. Digital signal

In data communication, we commonly use periodic analog signals and aperiodic digital signals.

Note:

In data communication, we commonly use periodic analog signals and aperiodic digital signals.

Note

Frequency is the rate of change with respect to time.

Change in a short span of time means high frequency.

_/¯_/¯_/¯_/¯_

Change over a long span of time means low frequency.

_____/¯¯¯¯_____/¯¯¯¯_____

Note

Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Example

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$\boxed{T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^3\ \text{ms} = 16.6\ \text{ms}}$$

1 second = 1000 ms

Example

The period of a signal is 100 ms. What is its frequency in kilohertz?

$$T = 100 \text{ ms}$$

Step 1: Convert milliseconds to seconds

$$100 \text{ ms} = \frac{100}{1000} = 0.1 \text{ s}$$

Step 2: Calculate frequency

$$f = \frac{1}{T}$$

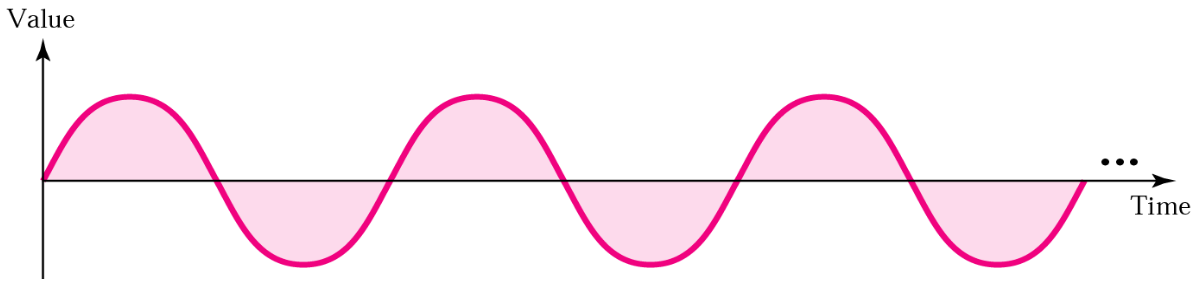
$$f = \frac{1}{0.1} = 10 \text{ Hz}$$

Step 3: Convert Hz to kHz

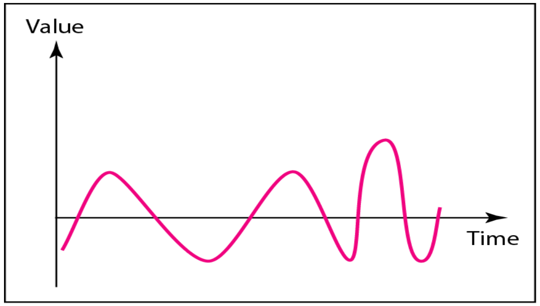
$$10 \text{ Hz} = \frac{10}{1000} = \boxed{0.01 \text{ kHz}}$$

Signals that have just one frequency are called simple signals, for example, the sine signal is simple signal

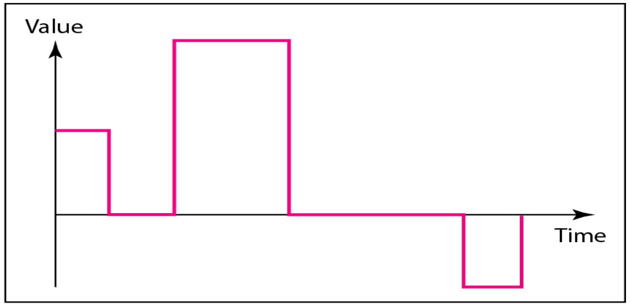
(each cycle takes the same time)



Signals that are composed of multiple frequencies are called composite signals (each cycle takes different time)



a. Analog signal

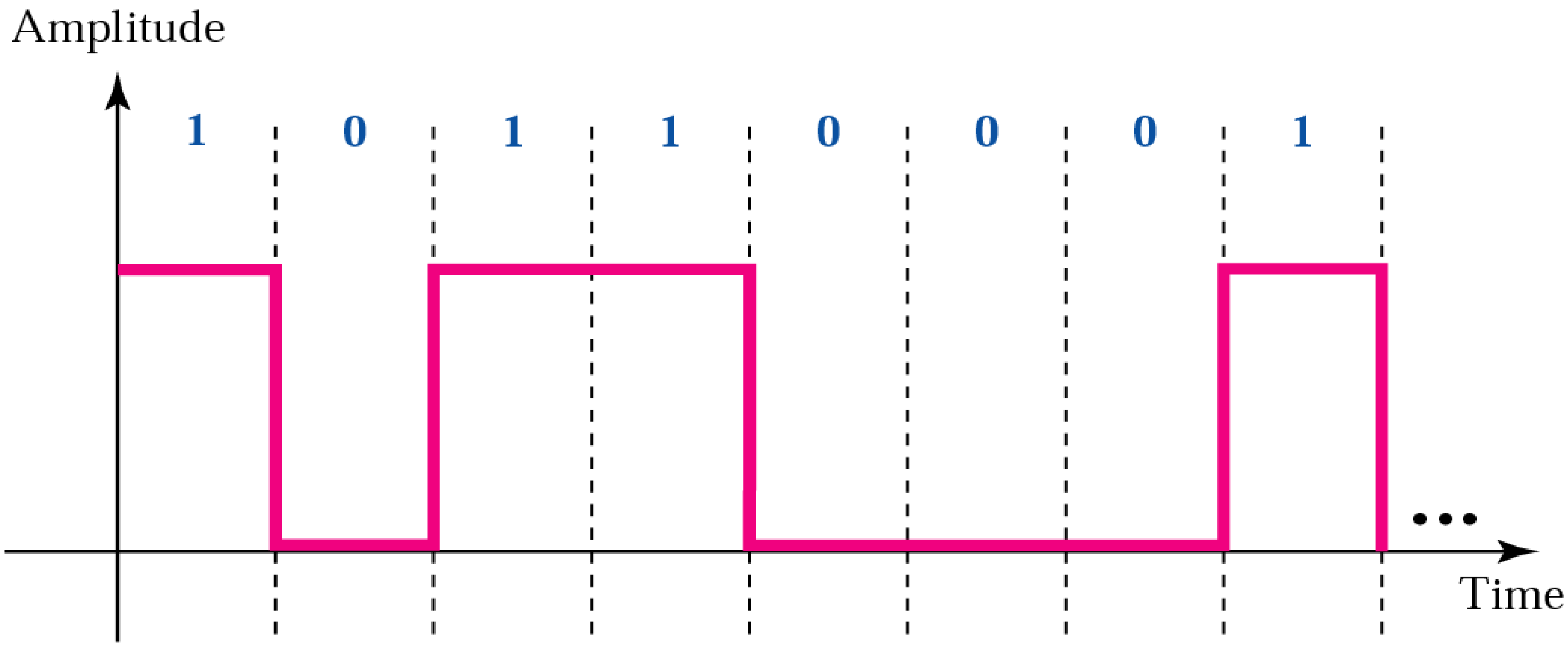


b. Digital signal

Digital Signals

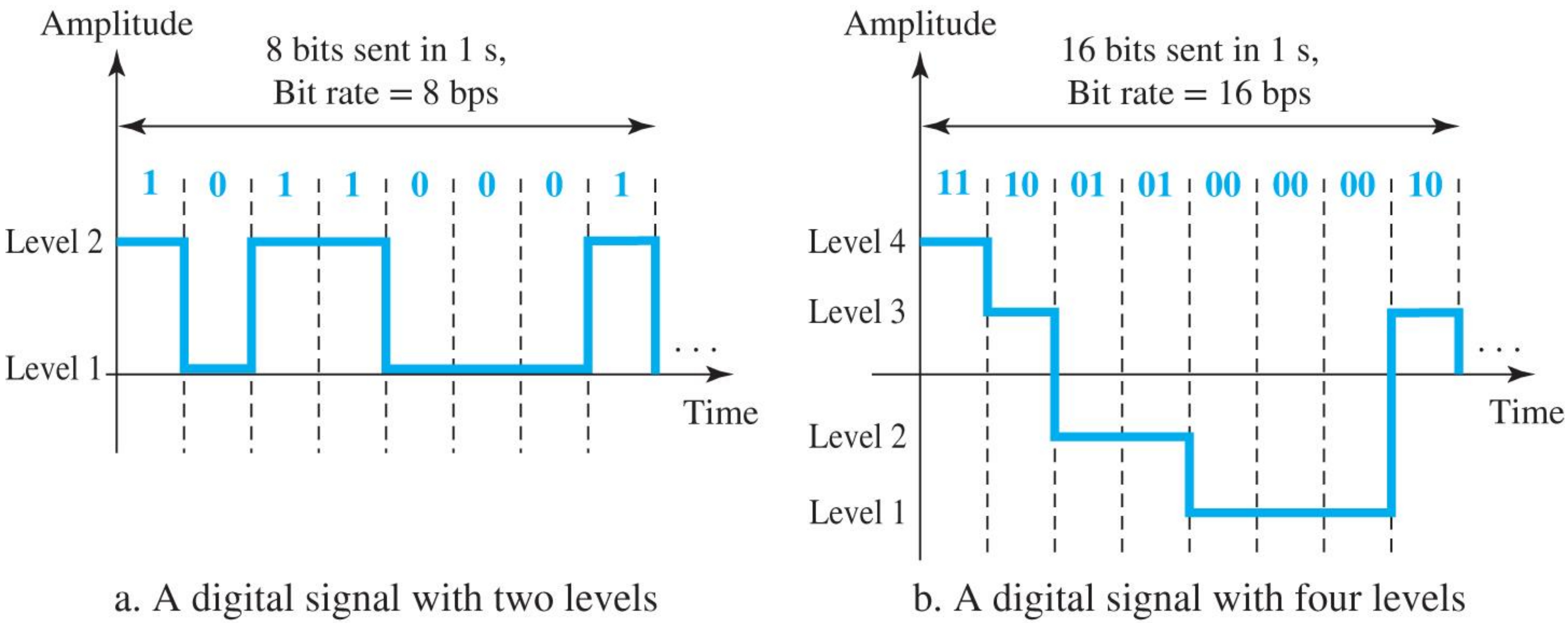
1 = Positive voltage > 0

0 = Zero voltage



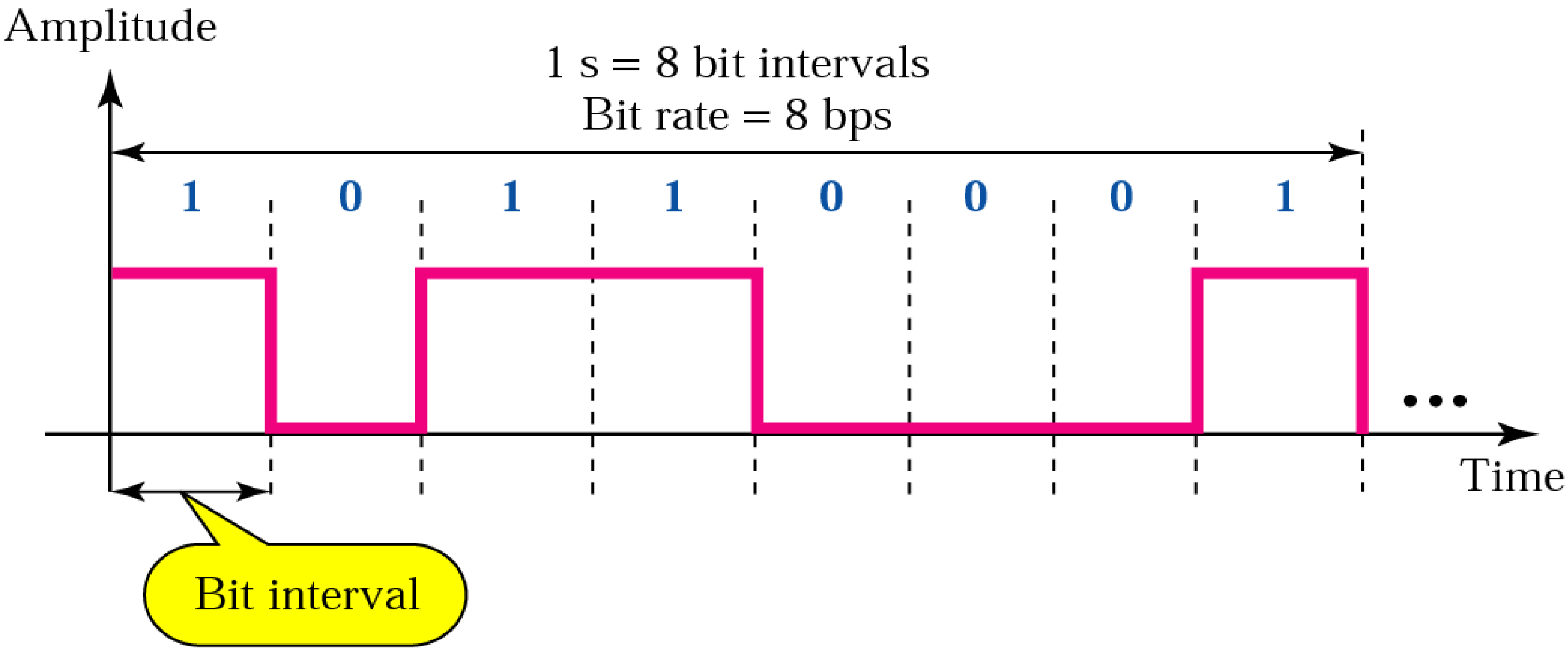
Most Digital Signals are <u>Aperiodic</u> ➔ Frequency is not appropriate

Two digital signals, one with two and one with four bit-levels



- Access the text alternative for slide images.

Figure ***Bit rate and bit interval***



<u>Bit Interval</u> (digital signal period): **<u>The time</u> required to <u>send</u> (represent) one single bit (time units)**

Bit Rate (digital bandwidth) = Transmission speed = Link Capacity: **<u>Number</u> of bits sent per second (bps)**

Example

A digital signal has a bit rate of 2000 bps. What is the duration of each bit (bit interval)

Solution

The bit interval is the inverse of the bit rate.

Bit interval = 1/ 2000 s = 0.000500 s
= 0.000500 x 10^6 μs = 500 μs (microsecond)

Advantages of Digital Transmission

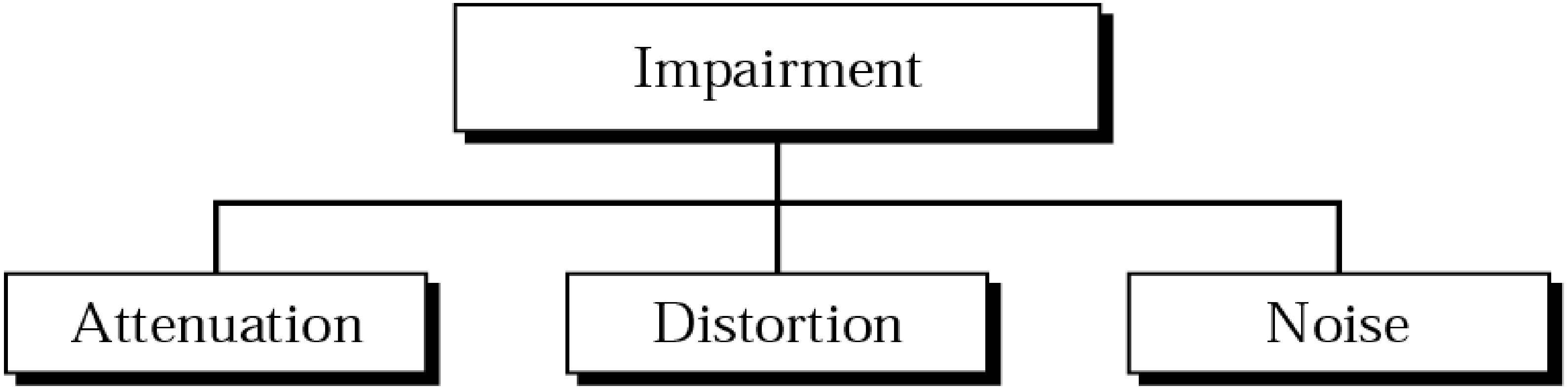
Low cost	Digital technology can be inexpensive
Longer distances	Repeaters regenerate the signal
Security & privacy	Digital information can be protected
Encryption	Converts data into a protected/unreadable form
Noise removal	Digital signals can be regenerated accurately
Digital multiplexing	Multiple data sources share one link
Analog + digital processing	Computers can process converted voice, video, etc.

Signal corruption

- No transmission medium can pass all the signal frequencies safely
- A medium may
  - Pass some frequencies
  - Block others
  - Weaken others

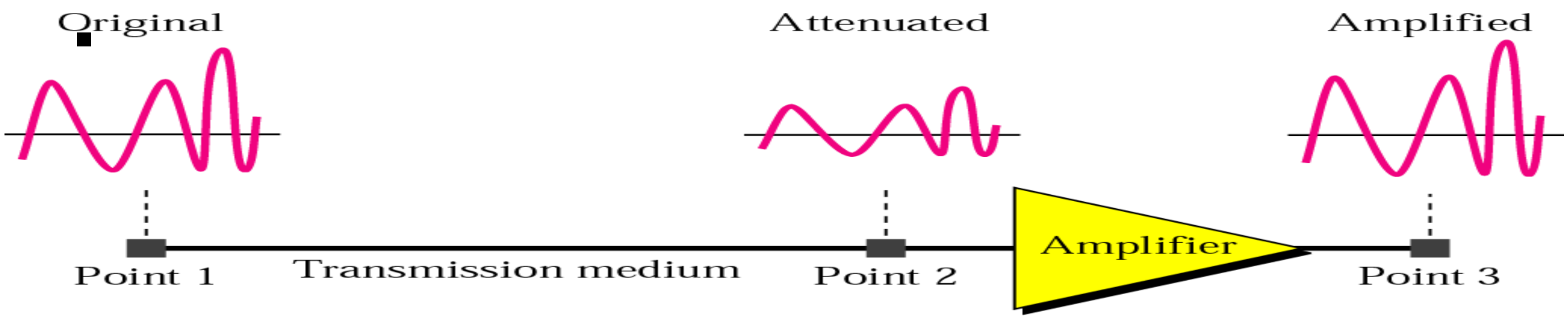
Transmission Impairments

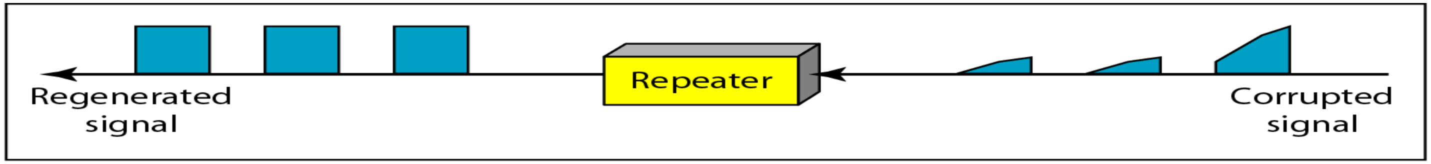
Impairments: Factors that make the received signal
<u>different</u> from the transmitted one



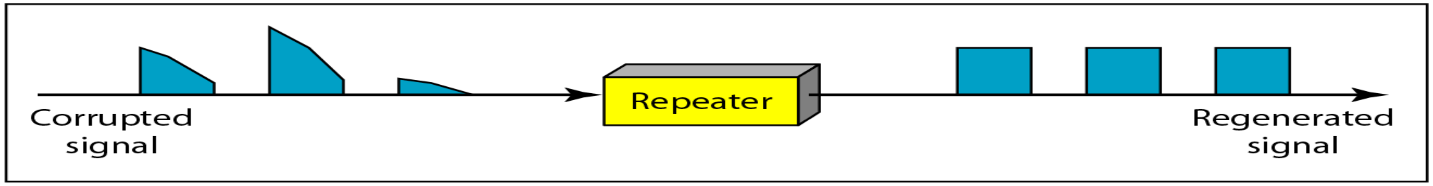
Attenuation

- Attenuation: **Loss of energy** due to **resisting the medium** (Signal strength falls off with distance)
- Increases with signal frequency
- Ex. A wire carrying electrical signal becomes warm after some time
- Amplifiers (analog signals) and repeaters (digital signals) are used to handle attenuation





a. Right-to-left transmission.



b. Left-to-right transmission.

Distortion

- Distortion : **Signal changes in shape**
- **Example:** In a video call, distorted images or audio delays may result from signal distortion during transmission.
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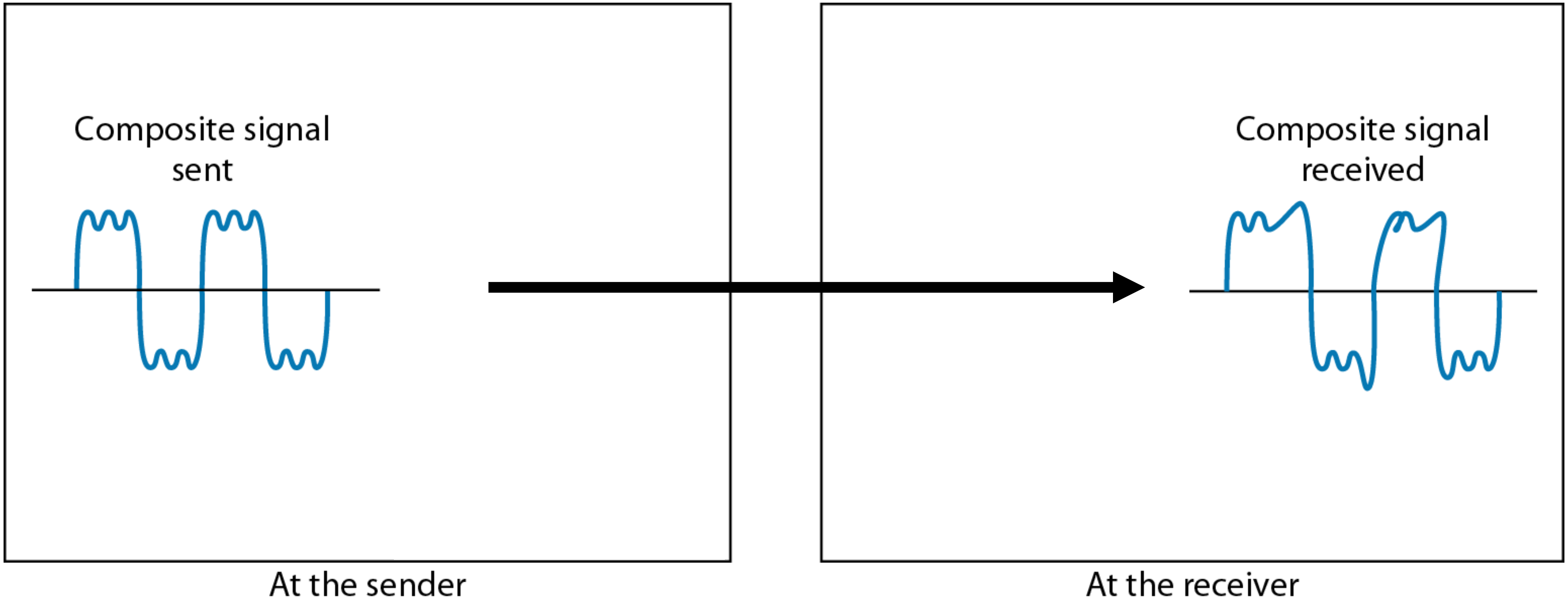
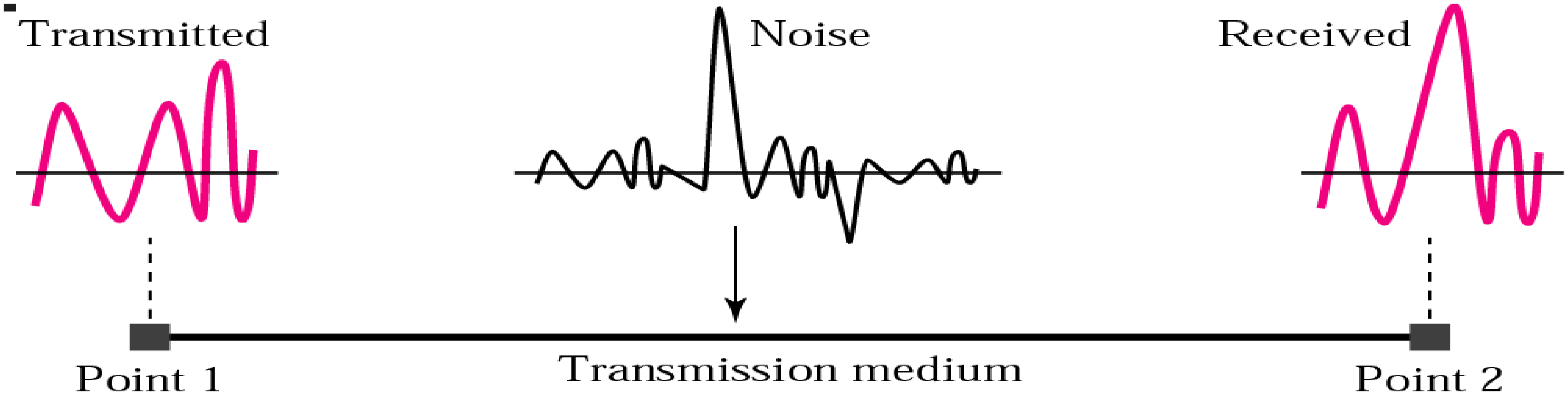


Noise



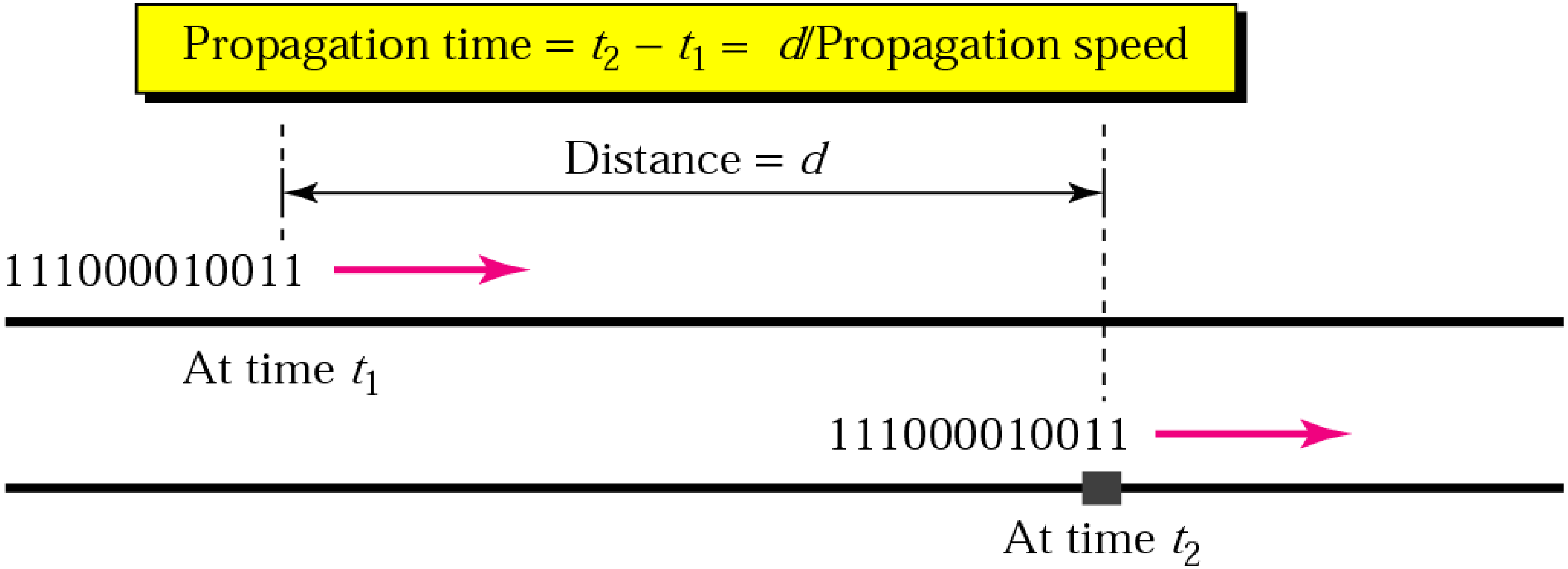
- **<u>Thermal Noise</u>** due to **random motion of electrons** in a wire which will create an **<u>extra signal</u>**
- **<u>Induced Noise:</u>** caused by motors and electrical equipments.
- **<u>crosstalk noise</u>** : Two wires beside each others (hearing another conversation in the background while talking with the phone)
- **<u>Impulse noise</u>:** irregular pulses or noise spikes of short duration and high amplitude
    - caused by **power lines or lightning**
    - **Very critical** in case of **digital signals** (primary source of error in digital data communication)

PERFORMANCE

Other Physical layer definitions:

- **Propagation time**= time required for a bit to move between two nodes.
  - Propagation time = **distance of the link (between the two nodes) / Propagation speed**
- **Propagation speed**: Speed of light in the medium.
- Depends on the medium
  - Light travels at $3x10^8$ m/s Vacuum (free space), lower in the air and much lower in a cable (2/3 in vacuum)

Propagation Time



Other Physical layer definitions – Transmission Time

- **Transmission time** = The time it takes the sender to transmit (put) all the bits of a frame into the link (from NIC to Medium)

  - $Transmission\ Time(\text{seconds}) = \frac{\textbf{Length of frame (message) in bits}}{\textbf{bandwidth}\ \text{(bit rate) (bps)}}$

  - **Queuing Time** = Time needed for each **intermediate device** to hold the message before it can be processed.

- **Latency (delay): Total message delivery time = Transmission time + Propagation time + processing time+ queuing time**

Example

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission time as shown on the next slide:

Example (continued)

Propagation time=Distance/Propagation speed

Transmission time=Message size in bits/Bandwidth

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^{8}} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^{9}} = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

Example

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission times as shown on the next slide.

Example (continued)

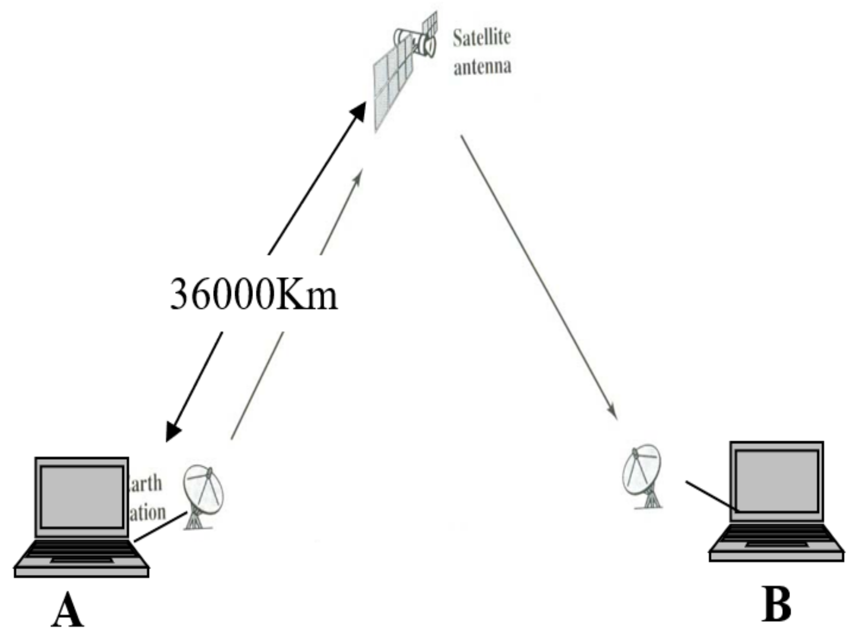
Propagation time=Distance/Propagation speed

Transmission time=Message size in bits/Bandwidth

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time. The propagation time can be ignored.



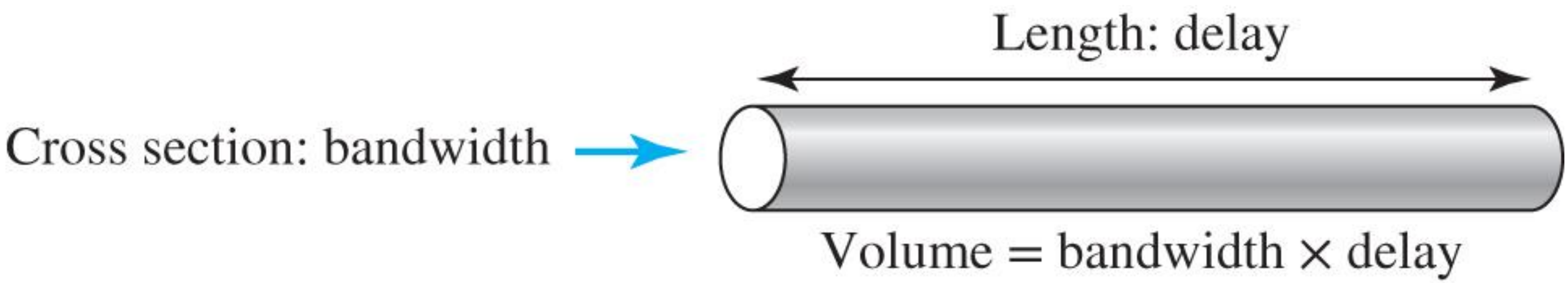
Suppose that two computers (A , and B) are connected by satellite link. Assume that the bandwidth of the satellite link is **1Gbps** and the frame length is **2000 bytes,** and the distance between the satellite and the ground station is **36000Km** and the speed of light is **3 x 10^8 m/s.**

Propagation time=Distance/Propagation speed

Transmission time=Message size in bits/Bandwidth

Figure 2.7 Bandwidth-delay product

We can think about the link between two points as a pipe. The <u>cross section of the pipe represents the bandwidth</u>, and the <u>length of the pipe represents the delay</u>. We can say the <u>volume</u> of the pipe defines the <u>bandwidth-delay</u> product



bandwidth-delay product = Length of the link in bits

- **Bandwidth** = how wide the pipe is → how many bits can enter per second.
- **Delay** = how long the pipe is → how long a bit takes to travel from one end to the other.
- **Bandwidth-delay product** = how many bits fit inside the pipe.

Figure *Filling the link with bits for case 1*

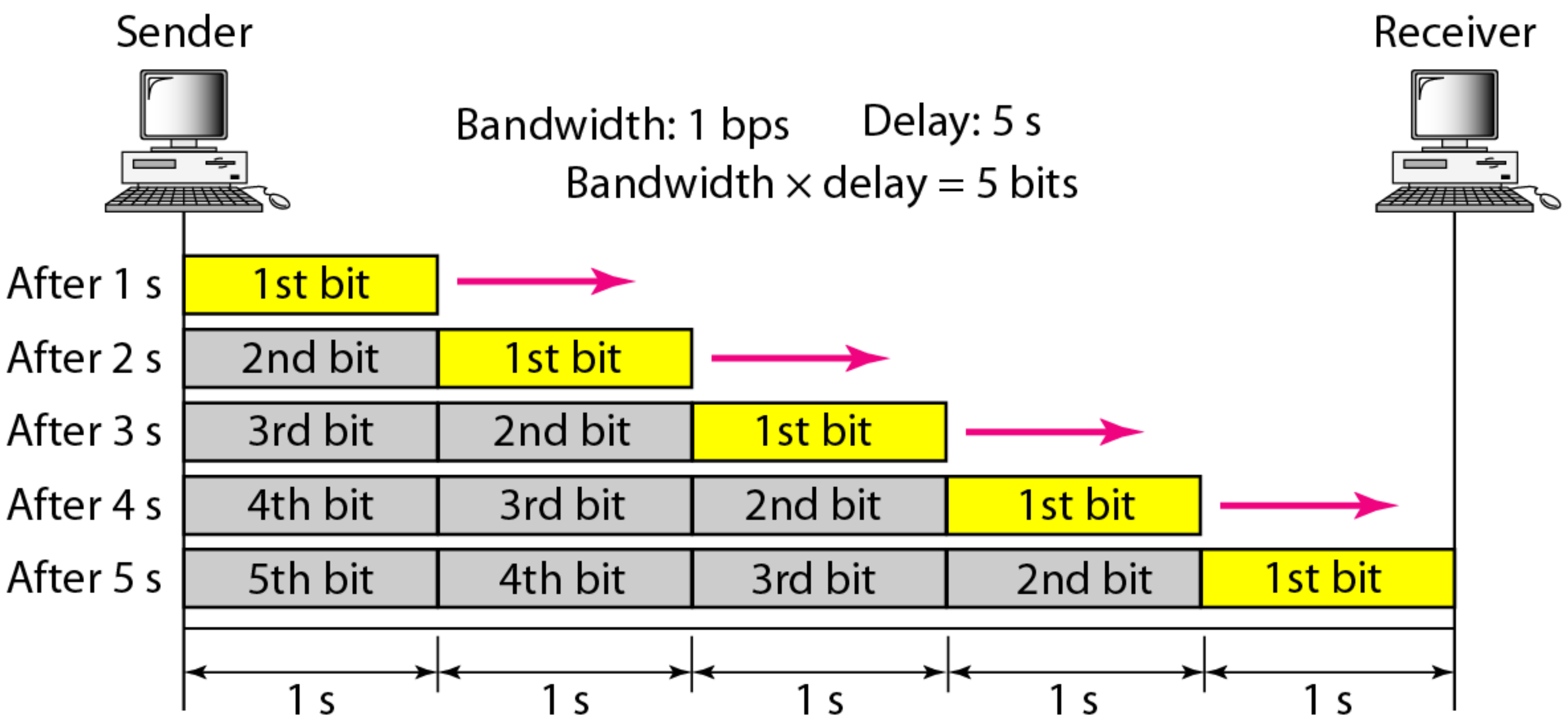
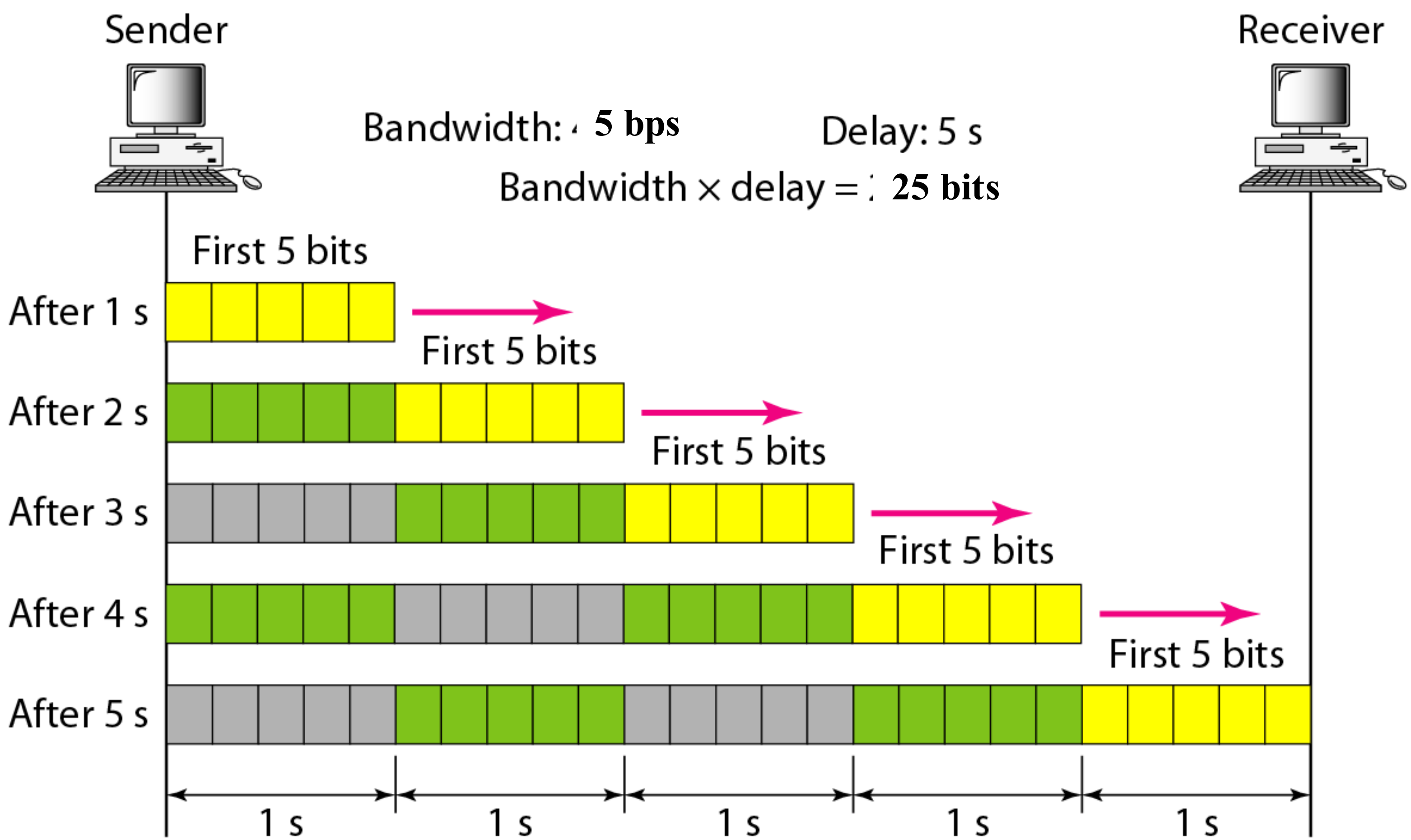
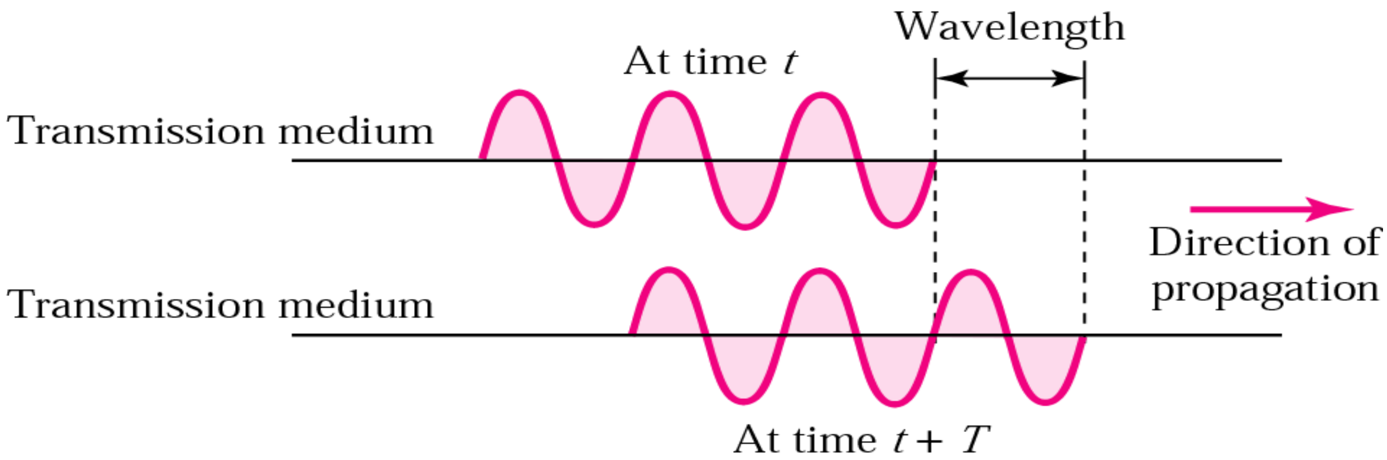


Figure *Filling the link with bits in case 2*



Other Physical layer definitions - Wavelength

- **Wavelength:** the distance a **simple** signal can travel in one period (or the distance occupied by one cycle)



- Depends on both the signal frequency and the medium
- Wavelength = Propagation speed x Period
  = Propagation speed / frequency