# DATA COMMUNICATION

## CSE 225/233

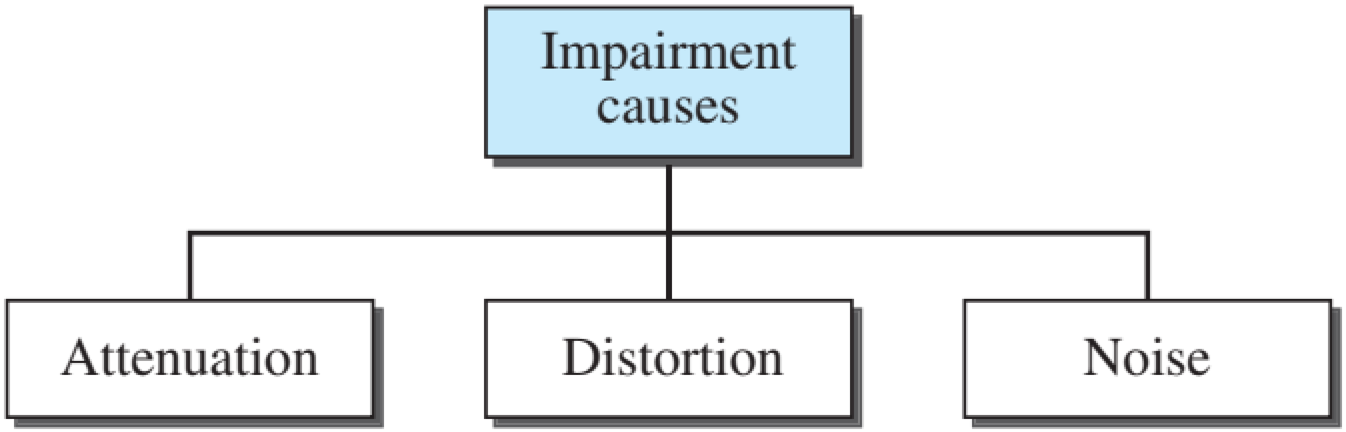
### WEEK-3, LESSON-2

### DATA AND SIGNAL

# Transmission Impairment

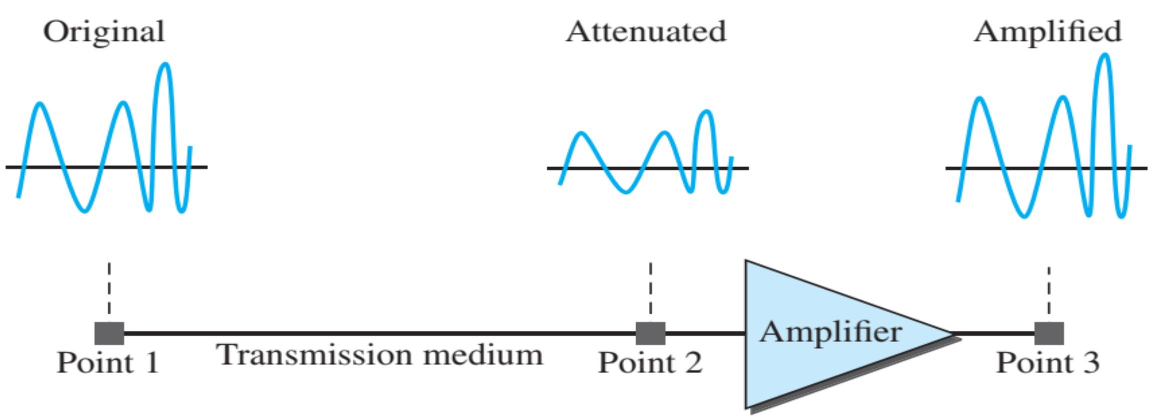
Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are ***attenuation***,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

# 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. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal. Following figure shows the effect of attenuation and amplification.



# Decibel

- To show that a signal has lost or gained strength, we use the concept of the decibel (dB).
- The decibel measures the relative strengths of two signals or a signal at two different points.
- The decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

- where P1 and P2 are the powers of a signal at points 1 and 2, respectively

# Example (1)

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

# Example (2)

A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1 . In this case, the amplification (gain of power) can be calculated as

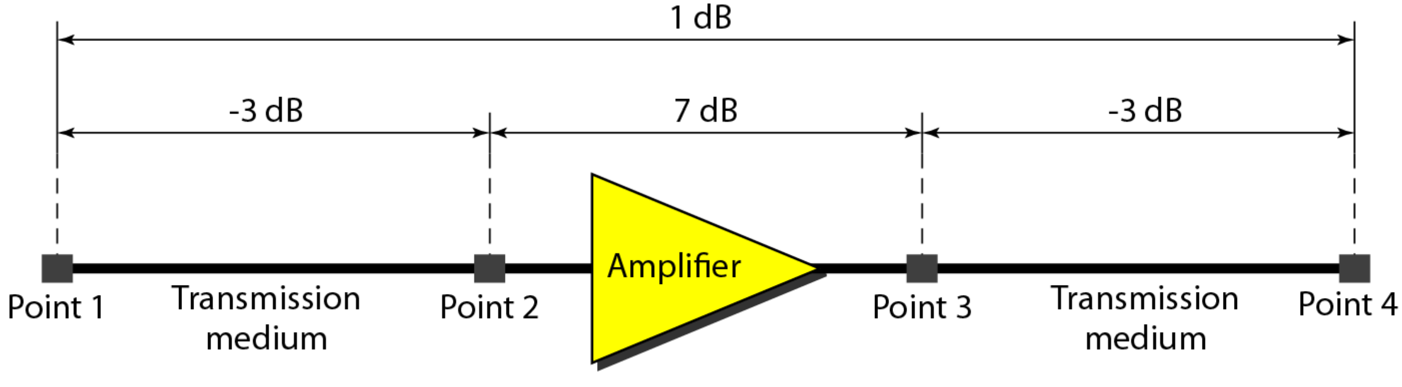
$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

# Example (3)

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.27 a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as

$$dB = -3 + 7 - 3 = +1$$



# Example (4)

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dBm and is calculated as dBm = 10 log10 Pm , where Pm is the power in milliwatts. Calculate the power of a signal with dBm = −30.

**We can calculate the power in the signal as**

$$\mathrm{dB_m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW}$$

# Example (5)

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

**Solution**

**The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as**

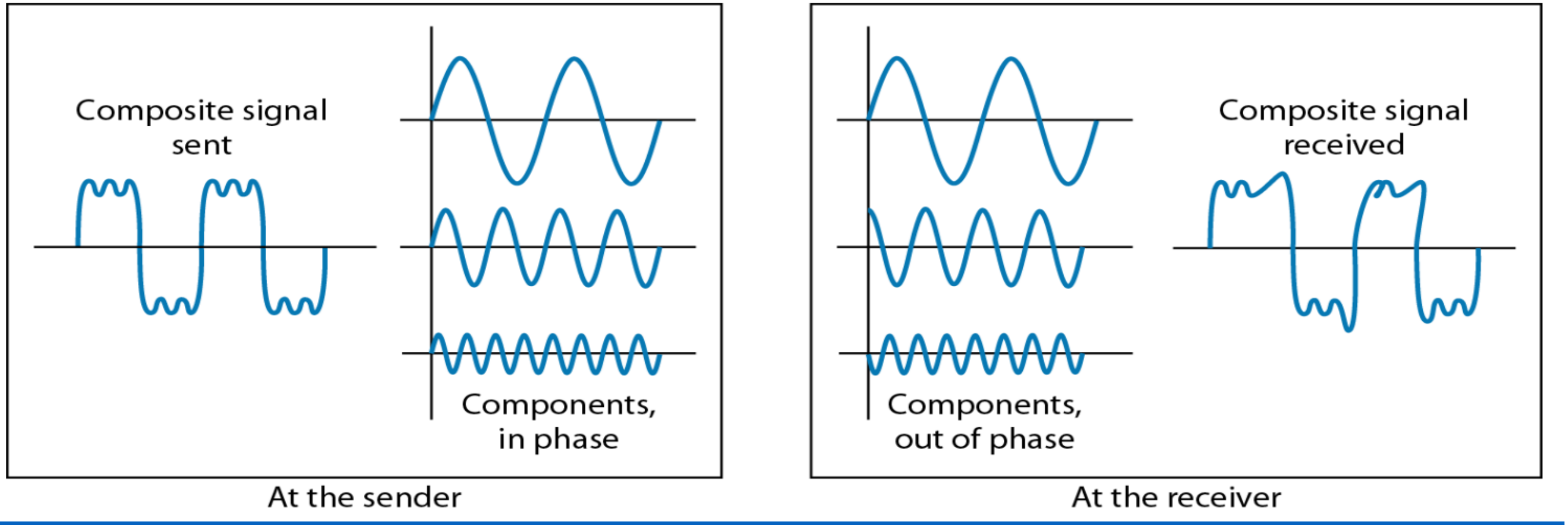
$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

# Distortion

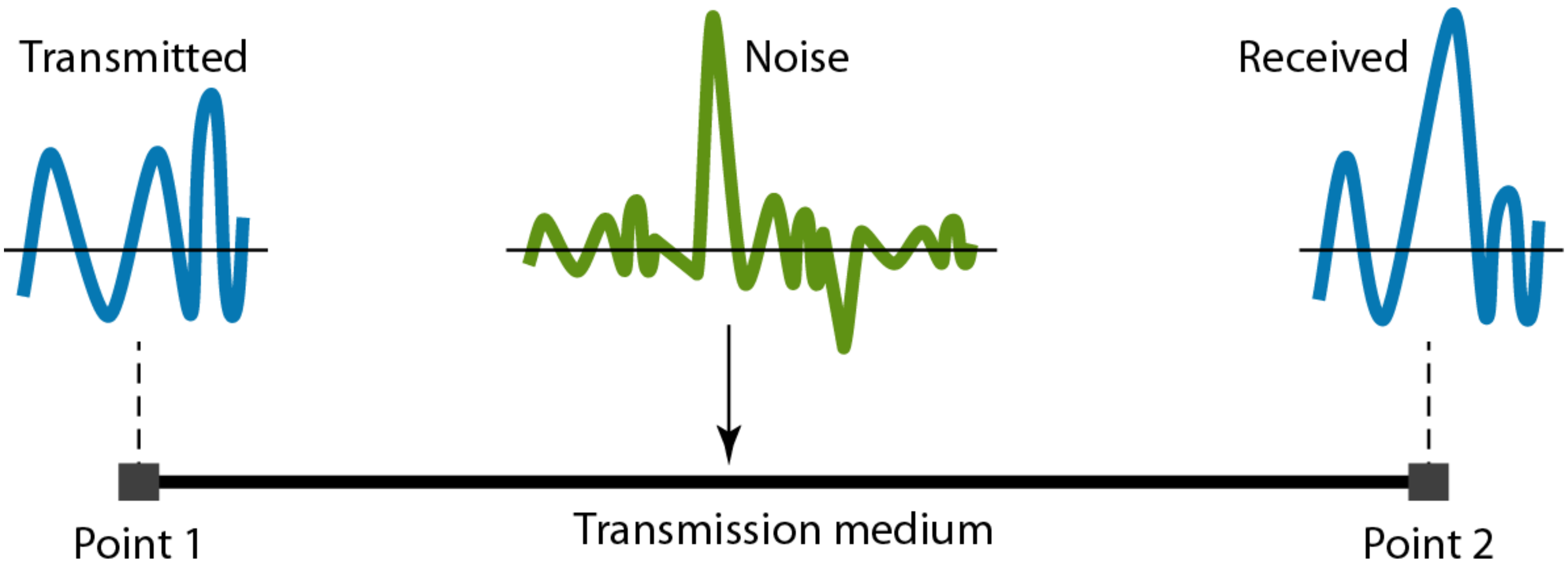
- Distortion means that the signal changes its form or shape.
- Distortion occurs in a composite signal made of different frequencies.
- Each signal component has its own propagation speed through a medium and therefore its own delay in arriving at the final destination.



# 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 appliancses. 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.

# Noise



Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

# Signal to Noise Ratio

- SNR is the statistical ratio of power of the signal to the power of the noise
- In decibels it can be expressed as follows:

$$SNR_{dB} = 10 \log_{10} SNR$$

# Example (1)

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNRdB ?

**Solution**

The values of SNR and SNRdB can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

# Example (2)

The values of SNR and SNRdB for a noiseless channel are

**Solution:**

$$\text{SNR} = \frac{\text{signal power}}{0} = \infty$$

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \infty = \infty$$

**We can never achieve this ratio in real life; it is an ideal.**

# 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)

Two theoretical formulas were developed to calculate the data rate:

Nyquist for a noiseless channel

Shannon for a noisy channel

# Noiseless channel: Nyquist bit rate

For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$C = 2\,B \log_2 L$$

Where,

C is the channel capacity or bit rate in bps
B is the bandwidth in Hz
L is the number of signal levels used to represent data

# Example (1)

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

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

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 (2)

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

**Solution**

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

# Noisy channel: Shannon capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- In this case, the Shannon capacity formula is used to determine the theoretical highest data rate for a noisy channel:

$$C = B \log_2 (1+SNR)$$

Where,

C is the capacity of the channel in bps
B is the bandwidth in Hz
SNR is the signal to noise ratio

# Example (1)

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 (2)

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

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

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)

The signal-to-noise ratio is often given in decibels. Assume that SNRdB = 36 and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

# Example (4)

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.

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

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.

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

# Performance

One important issue in networking is the performance of the network—how good is it? In this section, we introduce the following terms to measure the performance.

**Bandwidth**
**Throughput**
**Latency (Delay)**

# Bandwidth

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.

# Example

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog.

If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz, we can send 112,000 bps by using the same technology.

# Throughput

The throughput is the measurement of how fast data can pass through a network in one second.

Throughput is calculated as follows:

> Throughput = frames per second x bits per frame

# Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

**Solution**

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

# Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source. We can say that latency is made of four components: propagation time, transmission time, queuing time and processing delay.

$$\text{Latency} = \text{propagation time} + \text{transmission time} + \text{queuing time} + \text{processing delay}$$

# Propagation time and transmission time

Propagation time measures the time required for a signal (or a bit) to travel from one point of the transmission medium to another.
Propagation time is calculated as follows:

**Propagation time [s] = Distance [m] / Propagation speed [m/s]**

**Transmission time** measures the time required for a signal to be transmitted from the sending device to the medium.
Transmission time is calculated as follows:

**Transmission time [s] = Data [bits] / Bandwidth [bps]**

# Example (1)

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×108 m/s in cable.

**Solution**

We can calculate the propagation time as

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

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

# Example (2)

What are the propagation time and the transmission time for a 2.5kbyte 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 2.4×108 m/s

**Solution**

We can calculate the propagation and transmission time as follows:

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

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

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 (3)

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 × 108 m/s.

**Solution**

We can calculate the propagation and transmission time as follows:

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

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

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.

# Example (3)

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 × 108 m/s.

**Solution**

We can calculate the propagation and transmission time as follows:

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

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

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.


THANK
YOU