Physical Layer

Basic Terminologies

- Transmission media work by conducting energy along a physical path. For transmission, data needs to be changed to **signals.**
- **Analog data** refers to information that is continuous; **digital data** refers to information that has discrete states
- An **analog signal** has infinitely many levels of intensity over a period of time; A **digital signal,** on the other hand, can have only a limited number of defined values.
- A **periodic signal** completes a pattern within a measurable time frame, called a **period,** and repeats that pattern over subsequent identical periods.
- The completion of one full pattern is called a **cycle.**
- A **nonperiodic signal** changes without exhibiting a pattern or cycle that repeats over time.

Basic Terminologies

- The **peak amplitude** of a signal is the absolute value of its highest intensity
- **Period** refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- **Frequency** refers to the number of periods in 1 s.
- The term **phase**, or phase shift, describes the position of the waveform relative to time 0.
- Phase is measured in degrees or radians [360º is 2π rad; 1º is 2π/360 rad, and 1 rad
- is 360/(2π)].

Basic Terminologies

Wavelength binds the period or the frequency of a simple sine wave to the **propagation speed** of the medium

$$\text{Wavelength} = (\text{propagation speed}) \times \text{period} = \frac{\text{propagation speed}}{\text{frequency}}$$

$$\lambda = \frac{c}{f}$$

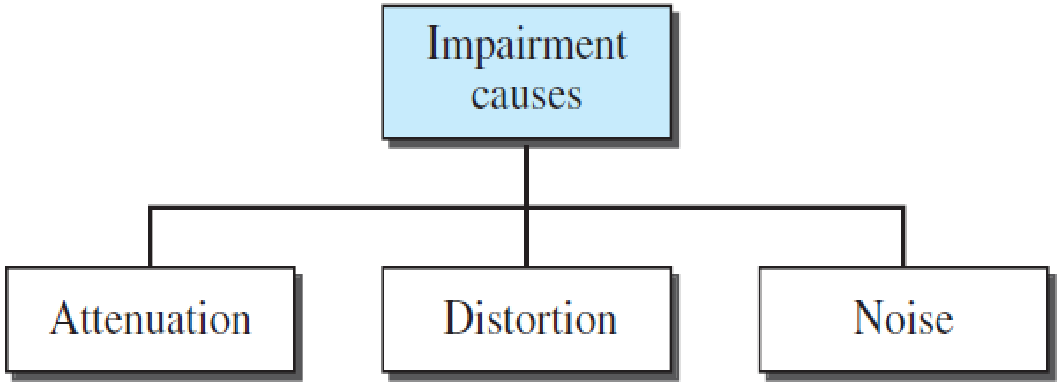
A composite signal is made of many simple sine waves.

Basic Terminologies

- The range of frequencies contained in a composite signal is its **bandwidth**
- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.
- The **bit rate** is the number of bits sent in 1s, expressed in **bits per second (bps)**
- 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.

Signal Impairment

- **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.
- The **decibel (dB)** measures the relative strengths of two signals or one signal at two different points.
- **Distortion** means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies



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.
- **signal-to-noise ratio**
- SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).
- A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

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

DATA RATE LIMITS

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)

Noiseless Channel: Nyquist bit rate : $\textit{BitRate} = 2 \times \textit{bandwidth} \times \log_2 L$

Noisy Channel: Shannon Capacity: $\textit{Capacity} \times \textit{bandwidth} \times \log_2(1 + SNR)$

Performance

Bandwidth

- Bandwidth in hertz and bandwidth in bits per second.
- Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass

Bandwidth in Bits per Seconds

- The term bandwidth can also refer to the number of bits per second that a channel, a link, or even a network can transmit.
- An increase in bandwidth in hertz means an increase in bandwidth in bits per second.
- Ex: 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

Performance

Throughput

- The throughput is a measure of how fast we can actually send data through a network
- Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different.
- A link may have a bandwidth of *B* bps, but we can only send *T* bps
- through this link with *T* always less than *B*.
- In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data.

Performance

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

$$\textbf{Throughput} = (12{,}000 \times 10{,}000) / 60 = 2 \text{ Mbps}$$

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.
- Latency is made of four components: ***propagation time, transmission time,***

queuing time and processing delay.

Latency = propagation time + transmission time + queuing time + processing delay

Propagation Time

- Measures the time required for a bit to travel from the source to the Destination

Propagation time = Distance / (Propagation Speed)

Latency : *Propagation Time*

- The propagation speed of electromagnetic signals depends on the ***medium and on the frequency of the signal.***
- For example, in a vacuum, light is propagated with a speed of 3 × 108 m/s. It is lower in air; it is much lower in cable.

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

Solution

We can calculate the propagation time as

$$\textbf{Propagation time} = (12{,}000 \times 10{,}000) / (2.4 \times 2^8) = 50 \text{ ms}$$

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.

Transmission Time

- **Transmission time** of a message depends on the size of the message and the bandwidth of the channel

Transmission time = (Message size) / Bandwidth

What are the propagation time and the transmission time for a 2.5-KB (kilobyte) 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

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

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.

Transmission Time

What are the propagation time and the transmission time for a 5-MB (megabyte) 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

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

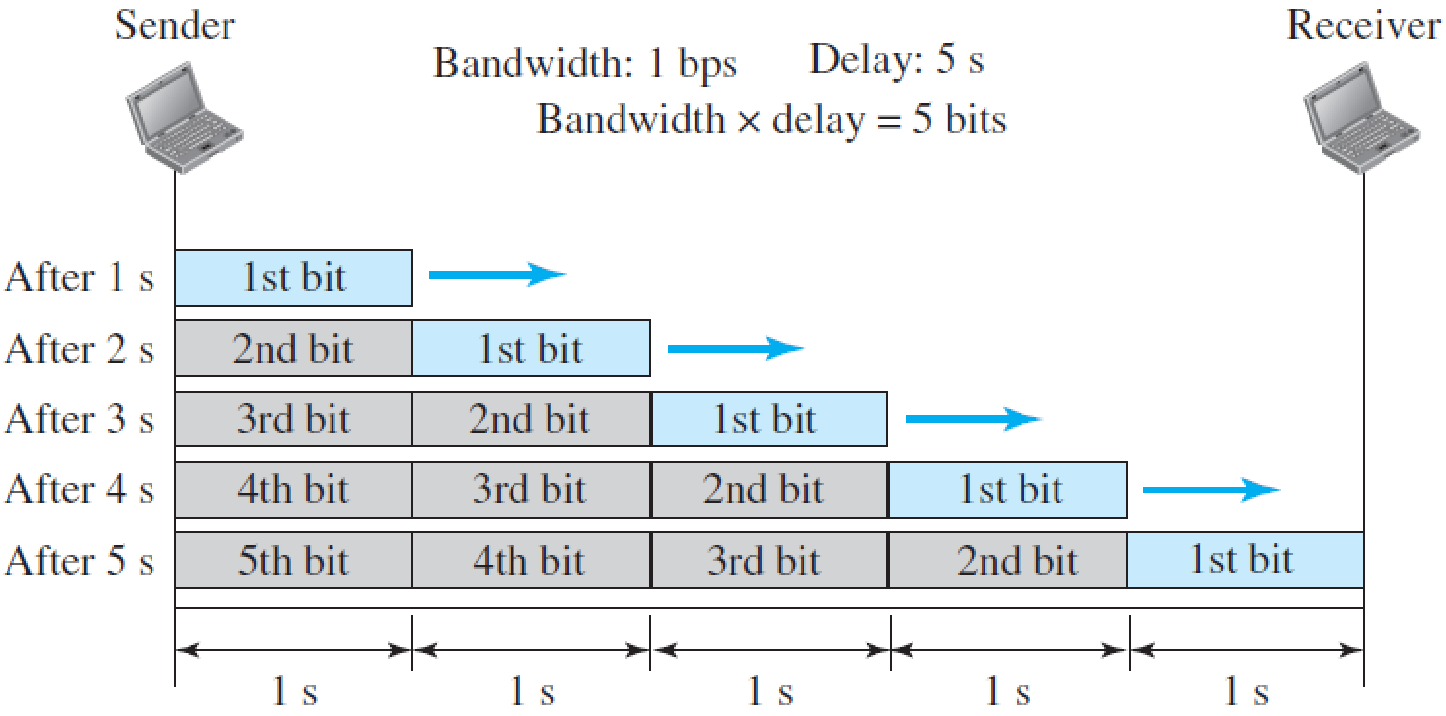
$$\textbf{Transmission time} = (5{,}000{,}000 \times 8) / 10^6 = 40 \text{ s}$$

Queuing Time

- The time needed for each intermediate or end device to hold the message before it can be processed.
- The queuing time is not a fixed factor; it changes with the load imposed on the network.
- When there is heavy traffic on the network, the queuing time increases.
- An intermediate device, such as a router, queues the arrived messages and processes them one by one.
- If there are many messages, each message will have to wait.

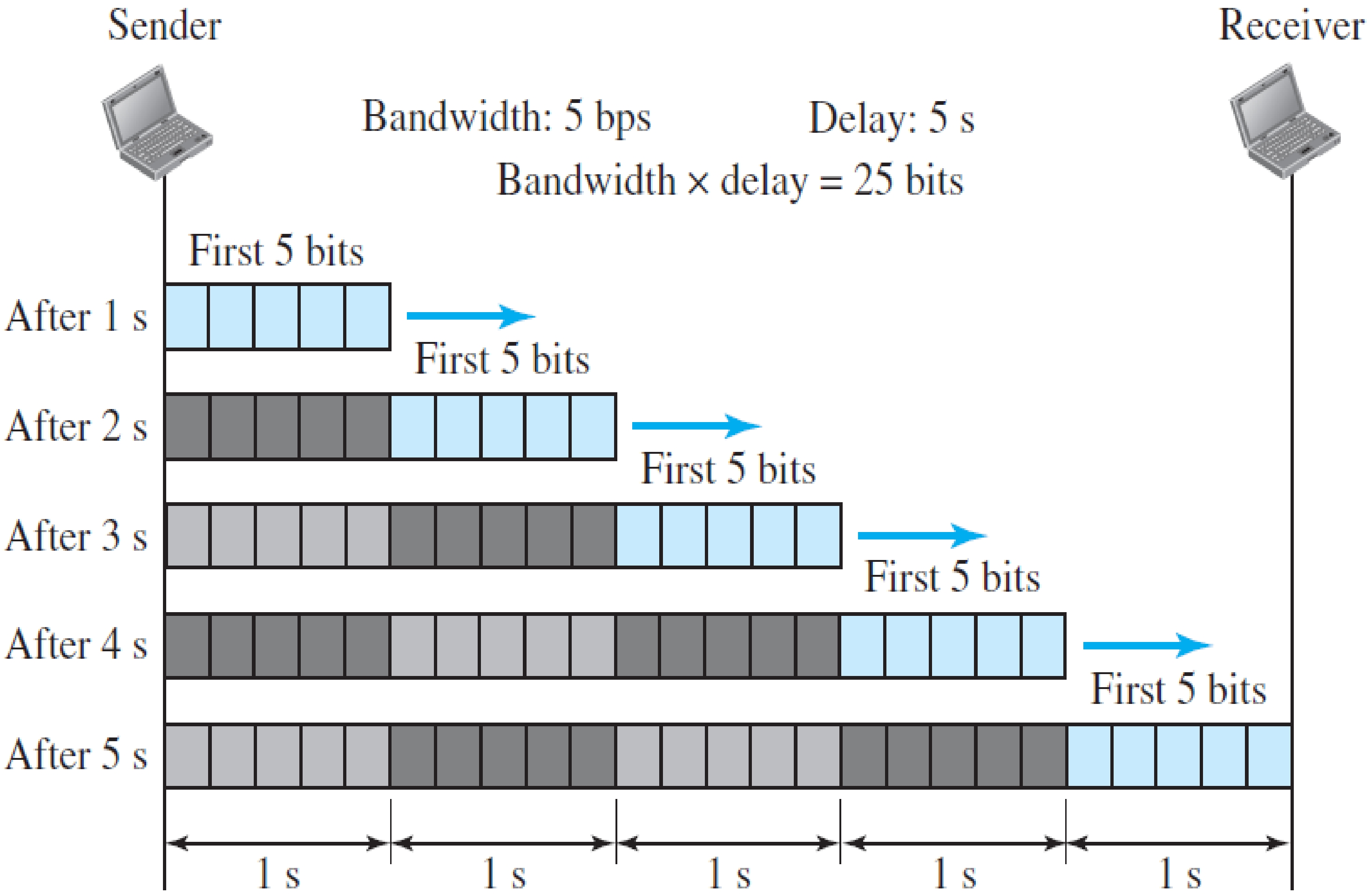
Bandwidth-Delay Product

- Bandwidth and delay are two performance metrics of a link.
- The bandwidth-delay product defines the number of bits that can fill the link.



- Let us assume that we have a link with a bandwidth of 1 bps and the delay of the link is 5 s
- The product 1 × 5 is the maximum number of bits that can fill the link.
- There can be no more than 5 bits at any time on the link

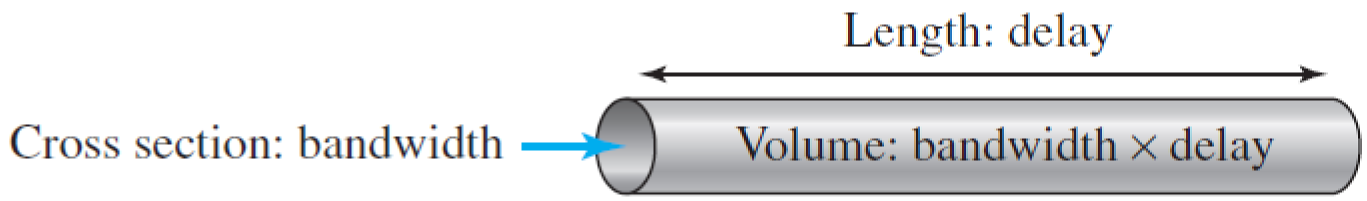
Bandwidth-Delav Product



- Assume we have a bandwidth of 5 bps
- then there can be maximum 5 × 5 = 25 bits on the line.

Concept of bandwidth-delay product

- To fill up the full-duplex channel (two directions), the sender should send a burst of data of (2 × bandwidth × delay) bits.
- The sender then waits for receiver acknowledgment for part of the burst before sending another burst.
- The amount 2 × bandwidth × delay is the number of bits that can be in transition at any time.
- Assume the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay.



Jitter

- Another performance issue that is related to delay is **jitter.**
- It is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for
- example).
- If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

Summary

- Basic terminologies
- Nyquist bit rate,
- Shannon capacity
- Attenuation, distortion, and noise can impair a signal
- Bandwidth delay product

Test your understanding

1. What is the relationship between period and frequency?
2. Name three types of transmission impairment.
3. What is the bit rate for each of the following signals?

   a. A signal in which 1 bit lasts 0.001 s
4. A device is sending out data at the rate of 1000 bps.

   a. How long does it take to send out 10 bits?
5. If the bandwidth of the channel is 5 Kbps, how long does it take to send a frame of 100,000 bits out of this device?
6. How many bits can fit on a link with a 2 ms delay if the bandwidth of the link

Is **a.** 1 Mbps? **b.** 10 Mbps? **c.** 100 Mbps?