Open system Interconnection (OSI)

Physical Layer Transmission Impairment & Performance Metrics

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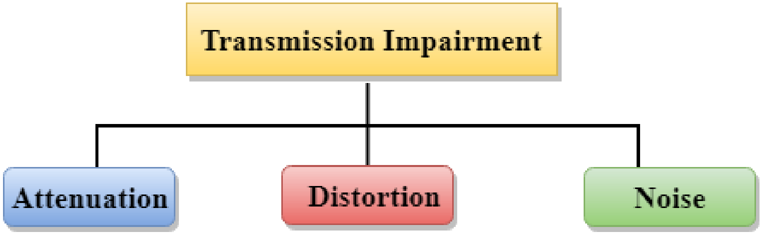
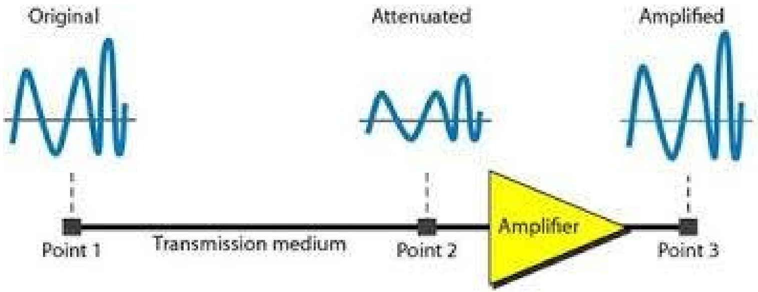
Transmission Impairment

- Signals travel through transmission media, which are not perfect.
- This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium
- Three causes of impairment are:
    - **Attenuation**
    - **Distortion**
    - **Noise**



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 compensate for this loss, amplifiers are used to amplify the signal



Signal Strength in Decibel

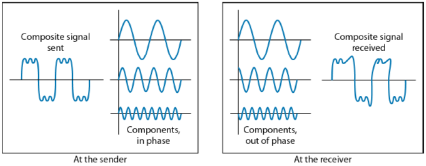
- To show that a signal has lost or gained strength, engineers use the unit of the decibel
- Note that the **decibel is negative if a signal** is **attenuated and positive if a signal is amplified**.
- Variables P_1 and P_2 are the powers of a signal at points 1 and 2, respectively

$$Voltage\ Ratio\ (dB) = 20 \log_{10}^{V_2/V_1}$$

$$Power\ Ratio\ (dB) = 10 \log_{10}^{P_2/P_1}$$

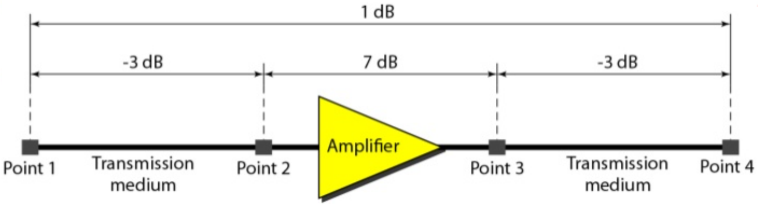
$$Voltage\ Level\ (dB\mu V) = 10 \log_{10}^{V/1\mu V}$$

$$Power\ Level\ (dBm) = 10 \log_{10}^{P/1mW}$$



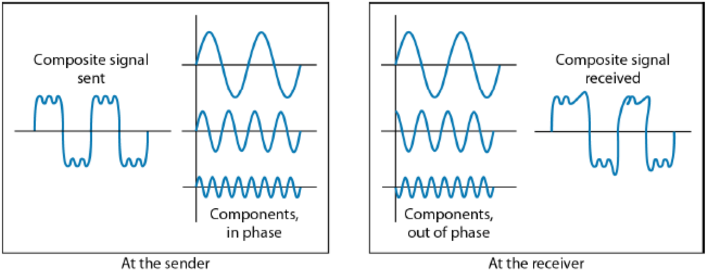
Problems on Attenuation

1. Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that $P_2 = \frac{1}{2}P_1$ In this case, what is attenuation (loss of power) can be calculated as
2. A signal travels through an amplifier, and its power is increased **10 times**. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as
3. 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 dBIkm has a power of 2 mW, what is the power of the signal at 5 km?



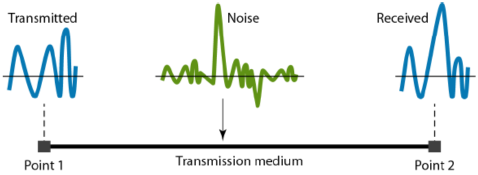
Distortion

- Distortion means that the signal changes its form or shape.
- Distortion can occur 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.



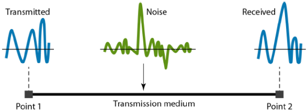
Noise

- Noise is another cause of impairment
- Several types of noise 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.



Signal-to-Noise Ratio (SNR)

- We need to consider the average signal power and the average noise power because these may change with time.
- 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.**



- **SNR is a ratio of signal power, S to noise power, N.**

$$SNR = 10\log\frac{S}{N}\, dB$$

- **Noise Figure, F**

$$\boxed{F = \frac{S_i/N_i}{S_o/N_o}\quad \textbf{dB}}$$

- **Noise factor, NF**

$$NF = 10\log F = 10\log\frac{S_i/N_i}{S_o/N_o}\, dB$$

Problems on Noise

1. The power of a signal is 10 mW and the power of the noise is $1\mu W$; what are the values of SNR and SNR_{dB}?
2. The values of SNR and SNRdB for a noiseless channel are

Calculation of SNR in db

- *The signal to noise ratio is often given in decibels also.*
  - $SNR_{db} = 10 \log_{10} SNR$

    or
  - $SNR_{db} = 10 \log_{10} S/N$

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$$\boxed{\begin{aligned} \mathrm{SNR} &= \frac{\text{signal power}}{0} = \infty \\ \mathrm{SNR_{dB}} &= 10 \log_{10} \infty = \infty \end{aligned}}$$

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:
  - **The bandwidth available**
  - **The level of the signals we use**
  - **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
  BitRate (bps) = 2 x bandwidth (channel) x $1og_2$ **L(signal level)**
- Increasing the levels of a signal may reduce the reliability of the system.
- **Problems**
  1. 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
  2. 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
  3. We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy
- Claude Shannon introduced a formula to determine the theoretical highest data rate for a noisy channel:
  Capacity =bandwidth X log2 (1 +SNR)
- For practical purposes, when the **SNR** is very high, we can assume that **SNR + 1** is almost the same as **SNR.**
- The **Shannon capacity** gives us the upper limit; the **Nyquist formula** tells us how many signal levels we need.
  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
  2. The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} = 36 and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

Performace

- **Bandwidth:** One characteristic that measures network performance is bandwidth.
  - **bandwidth in hertz:** range of frequencies a channel can pass in a composite signal
  - **bandwidth in bits per second :** refer to the number of bits per second that a channel, a link, or even a network can transmit.

Throughput

- The throughput is a measure of how fast we can actually send data through a network.
- The bandwidth is a potential measurement of a link
- The throughput is an actual measurement of how fast we can send data.
- **Example:**
  - We may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps
  - 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?

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

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**
  - **processing delay**
- **Propagation Time:** measures the time required for a bit to travel from the source to the destination.

$$\text{Propagation time} = \frac{\textit{Distance}}{\textit{Propagation speed}}$$

- What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 x 108 mls in cable

Latency (Delay) Cont...

- **Transmission Time**
  - The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time
- The time required for transmission of a message depends on the **size of the message** and the **bandwidth of the channel**

$$\text{Transmission time} = \frac{Messagesize}{Bandwidth}$$

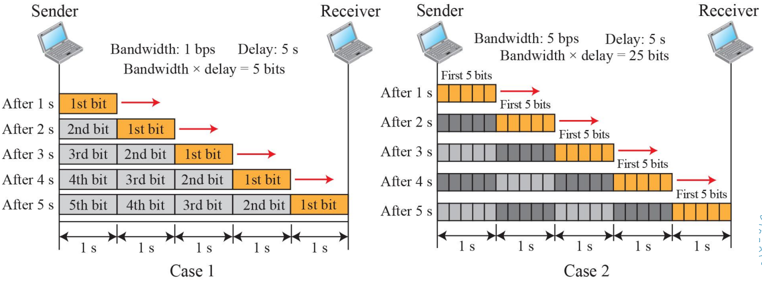
  - What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at $2.4x10^8$ m/s.

$$\textbf{Propagation time} = \frac{12000x1000}{2.4x10^8}, \textbf{Throughput} = \frac{2500x8}{10^9}$$

    - 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 $2.4x10^8$ m/s

Queuing Time

- The third component in latency is the 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.
- Another performance issue that is related to delay is **jitter.**
- **Bandwidth-Delay Product:**



Thank You