Digital Communication
Topic 3- Transmission Impairments

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Ppt 2 Page 65 :- As we increase the period of the Amplitude vs frequency curve, the peaks of different discrete frequencies come closer to each other , How does that help in signal analysis?

There are two (popular ways of looking at frequency of periodic signals.

(i) One is how often a periodic signal repeats the same waveform.

(ii) The second way of looking at frequency is in terms of sinusoidal waves.

Frequency of non periodic signals cannot be expressed in either of the above mentioned ways. However, there is a way to split certain aperiodic signals into infinite sinusoidal signals using a technique called Fourier transform (time-limited and band limited). Using that technique, an aperiodic signal can be represented using a continuous band of frequencies. Some signals can be represented using a finite band of frequencies (called its bandwidth).

Ppt 2 Page 82 :- How does the Media Access Control Help to prevent contention while using baseband transmission?

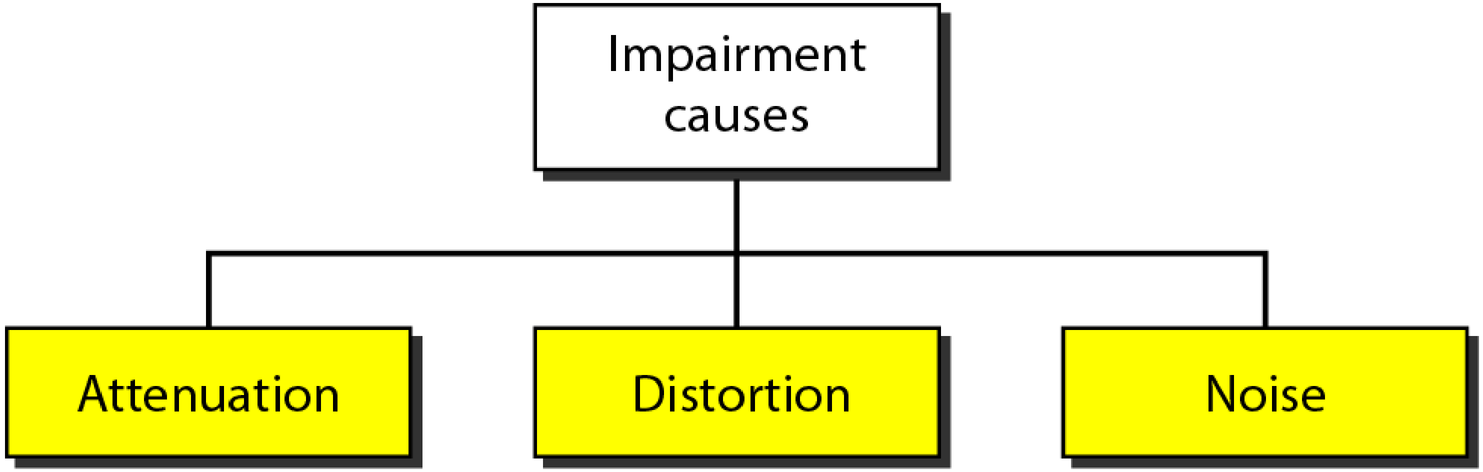
3 Lectures

- Overview of Impairments-1L
- Channel Capacity (Nyquist and Shanon)-1L
- Performance -1L

Impairments

- 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: signal strength falls off with distance.
  - Means loss of energy -> weaker signal
- Depends on medium: When a signal travels through a medium it loses energy overcoming the resistance of the medium
  - For guided media, the attenuation is generally exponential and thus is typically expressed as a constant number of decibels per unit distance.
  - For unguided media, attenuation is a more complex function of distance and the makeup of the atmosphere.

Attenuation Distortion

Three considerations for the transmission engineer:

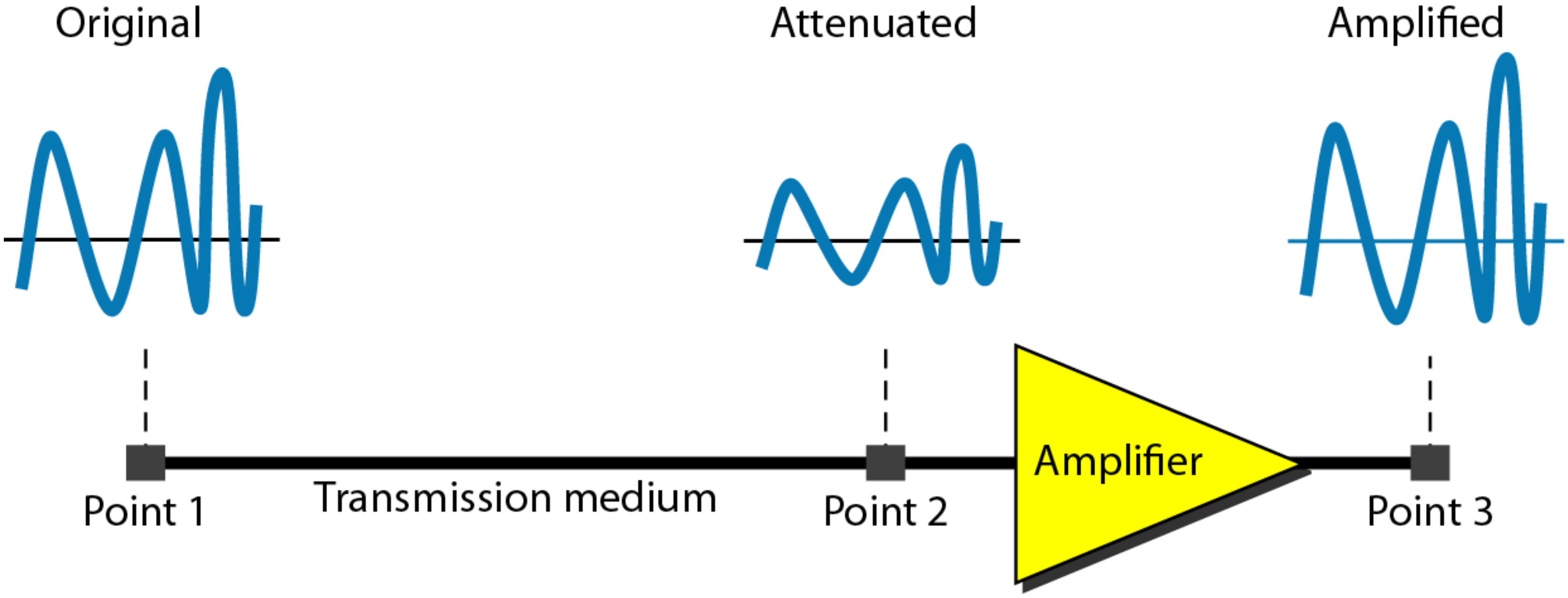
1. A received signal must have **sufficient strength** so that the electronic circuitry in the receiver can detect the signal.
2. The signal must maintain a level **sufficiently higher than noise** to be received without error.

These two problems are dealt with by the use of amplifiers or repeaters.

3. Attenuation is often an increasing function of frequency. This leads to attenuation distortion:
   - some frequency components are attenuated more than other frequency components.

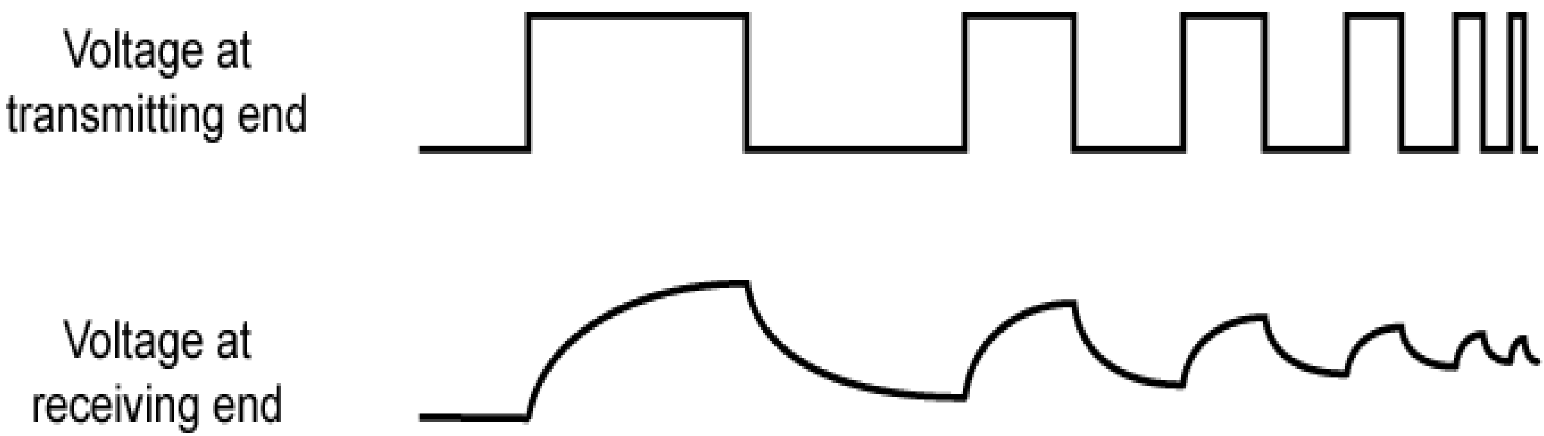
Attenuation distortion is particularly noticeable for analog signals: the attenuation varies as a function of frequency, therefore the received signal is distorted, reducing intelligibility.

Attenuation



Attenuation of Digital Signals

- Digital signal generally cheaper than analog signaling
- Less susceptible to noise
- Suffer more from attenuation!
  - Pulses become rounded and smaller
  - Leads to loss of information



Measurement of Attenuation

- To show the loss or gain of energy the unit "decibel" is used.

$$dB = 10\log_{10}P_2/P_1$$

P_1 - input signal

P_2 - output signal

- 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

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

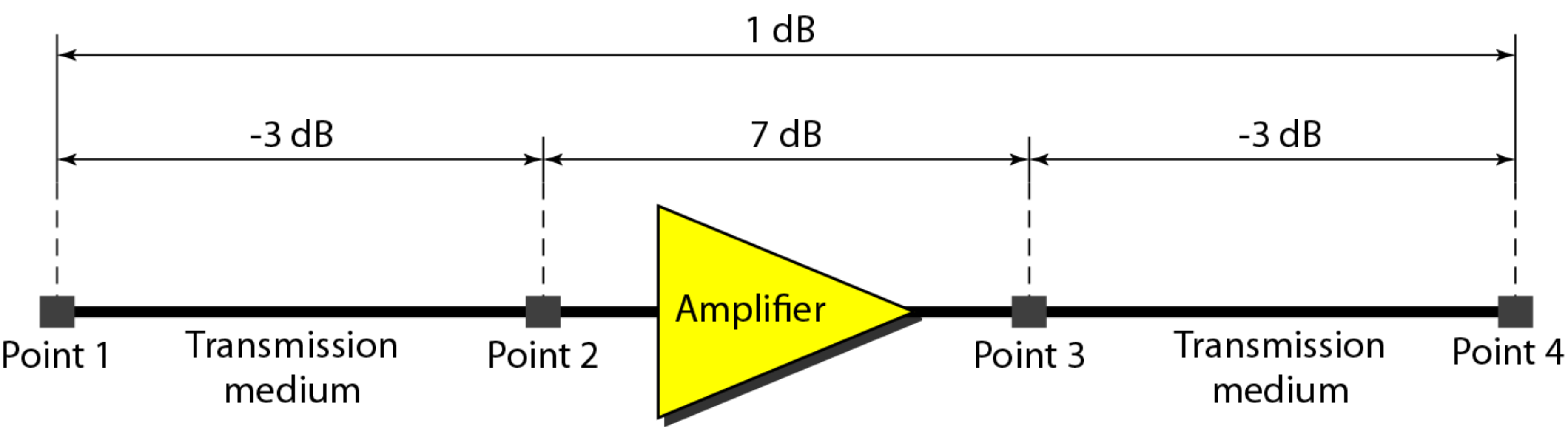
- A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

- 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

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

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

- 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 below a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as $\boxed{dB = -3 + 7 - 3 = +1}$



- Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.
  - We can calculate the power in the signal as

$$\boxed{\begin{array}{c} \mathrm{dB_m} = 10 \log_{10} P_m = -30 \\ \log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW} \end{array}}$$

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

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

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

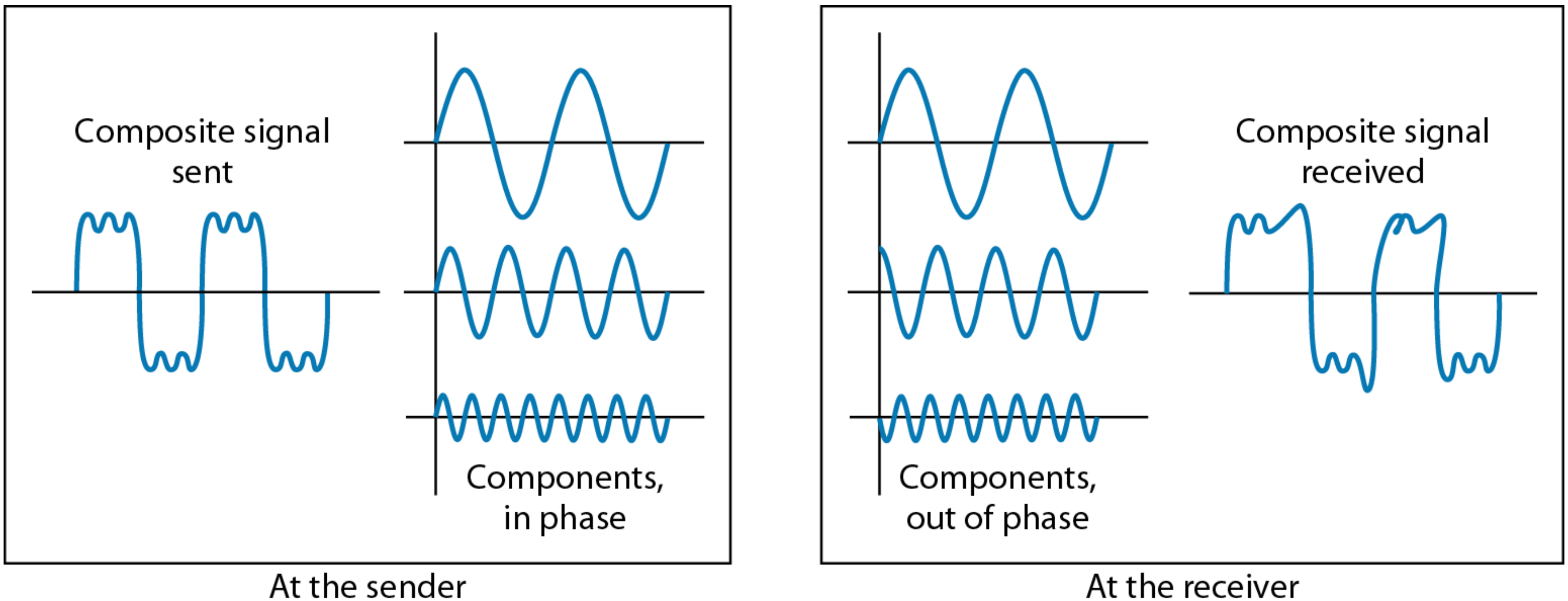
$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4\ \mathrm{mW}$$

Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Delay distortion occurs because the velocity of propagation of a signal through a guided medium varies with frequency.
  - Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
  - Various frequency components of a signal will arrive at the receiver at different times, resulting in phase shifts between the different frequencies.

- That means that the signals have different phases at the receiver than they did at the source.

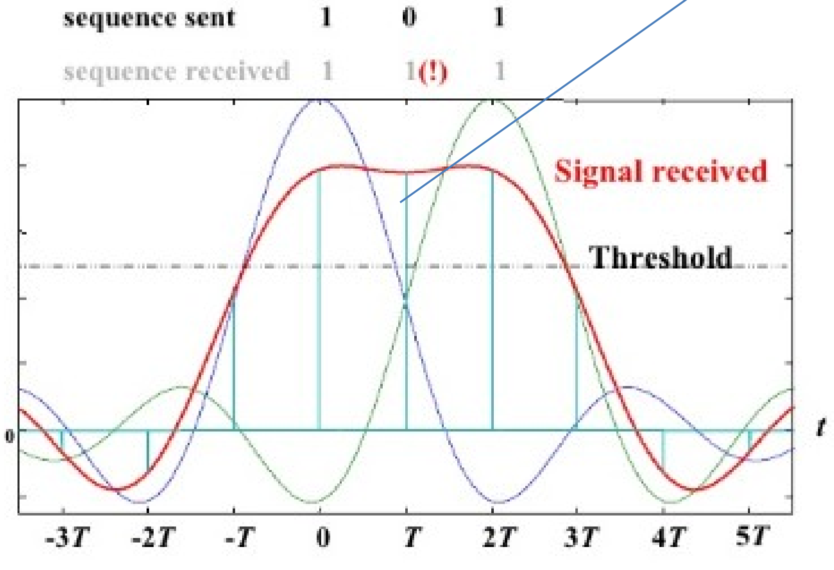
Distortion



Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

Delay Distortion

- Delay distortion is particularly critical for digital data
  - Some of the signal components of one bit position will spill over into other bit positions, causing intersymbol interference, which is a major limitation to maximum bit rate over a transmission channel.



Sequence of three pulses (1, 0, 1)
sent at a rate 1/*T*

Noise

- For any data transmission event, the received signal will consist of
  - the transmitted signal, modified by the various distortions imposed by the transmission system,
  - plus additional unwanted signals that are inserted somewhere between transmission and reception.
- The undesired signals are referred to as noise, which is the major limiting factor in communications system performance.

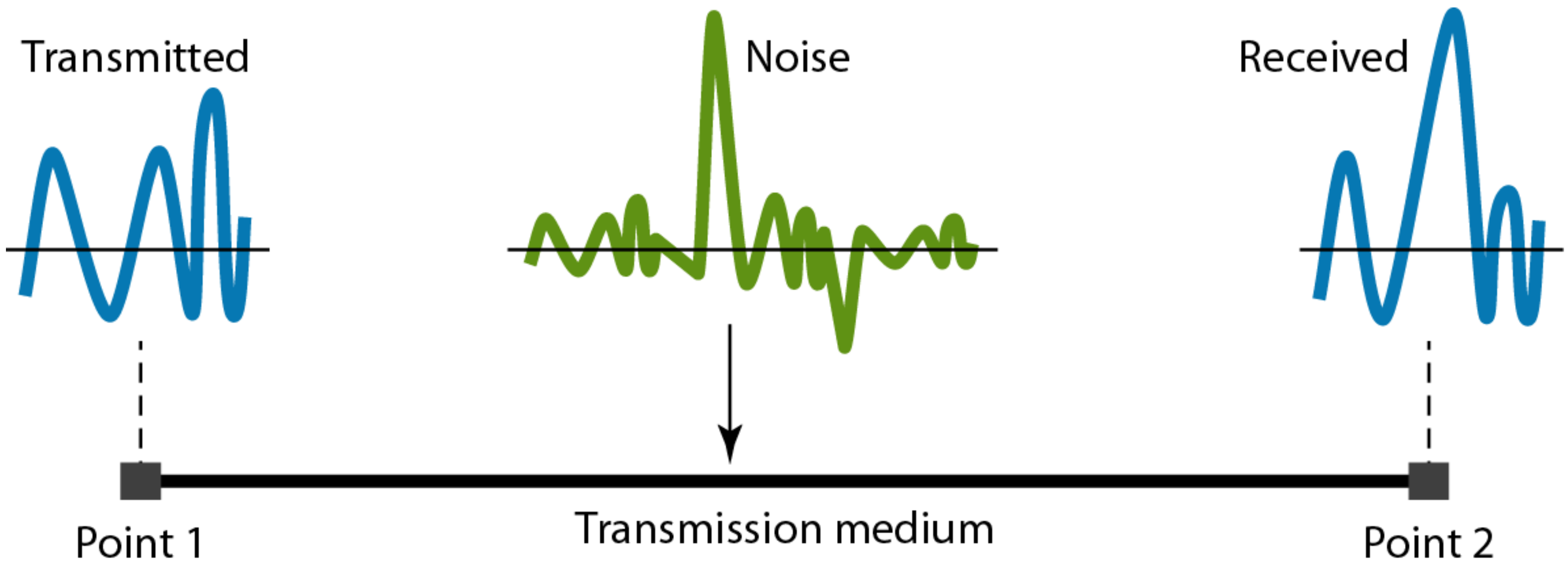
Four Categories of Noise

- Thermal (White Noise)
  - Thermal agitation of electrons in the wire creates an extra signal.
  - It is present in all electronic devices and transmission media, and is a function of temperature.
  - Cannot be eliminated, and therefore places an upper bound on communications system performance.

- Induced (Intermodulation Noise)
  - When signals at different frequencies share the same transmission medium, the result may be intermodulation noise.
  - Signals at a frequency that is the sum or difference of original frequencies or multiples of those frequencies will be produced.
  - E.g., the mixing of signals at f1 and f2 might produce energy at frequency f1 + f2. This derived signal could interfere with an intended signal at the frequency f1 + f2.

- Crosstalk
  - It is an unwanted coupling between signal paths. It can occur by electrical coupling between nearby twisted pairs.
  - Typically, crosstalk is of the same order of magnitude as, or less than, thermal noise.

- Impulse
  - Impulse noise is non-continuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude.
  - It is generated from a variety of cause, e.g., external electromagnetic disturbances such as lightning.
  - It is generally only a minor annoyance for analog data.
  - But it is the primary source of error in digital data communication.


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

Signal to Noise ratio

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as $SNR_{dB.}$

- The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?
  - The values of SNR and SNR_{dB} can be calculated as follows:

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

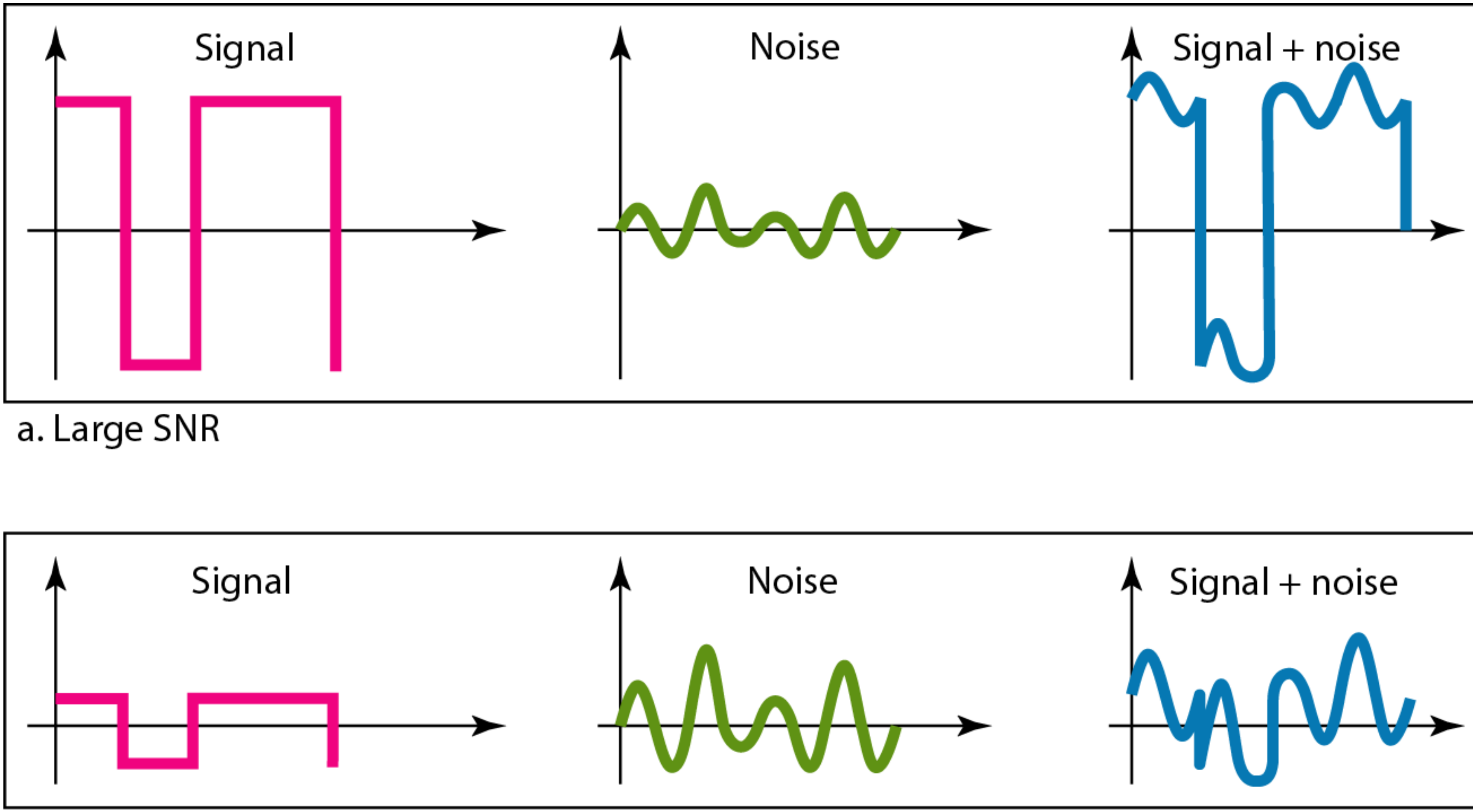
$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

- The values of SNR and SNRdB for a noiseless channel are

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

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

Two cases of SNR: a high SNR and a low SNR



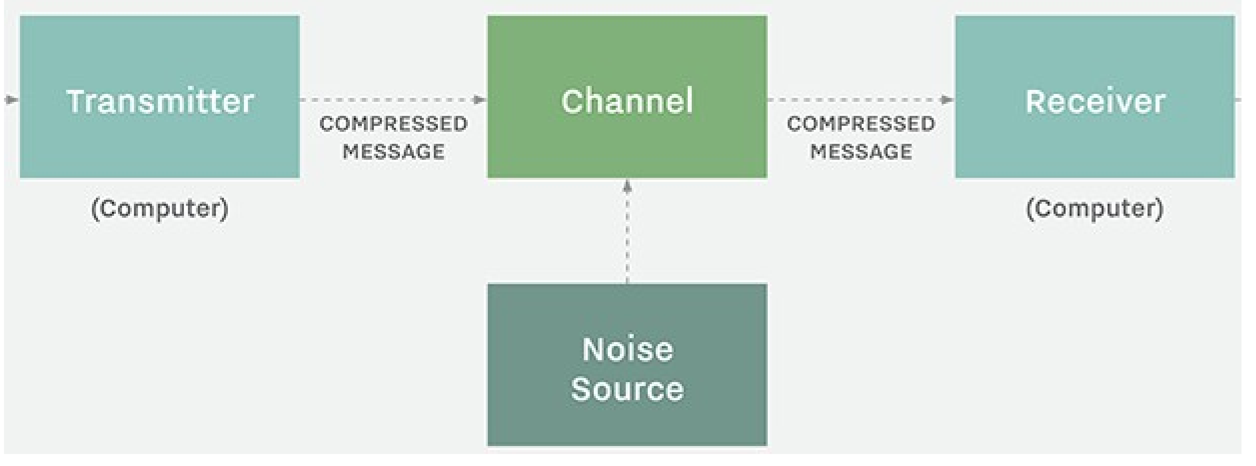
a. Large SNR

b. Small SNR

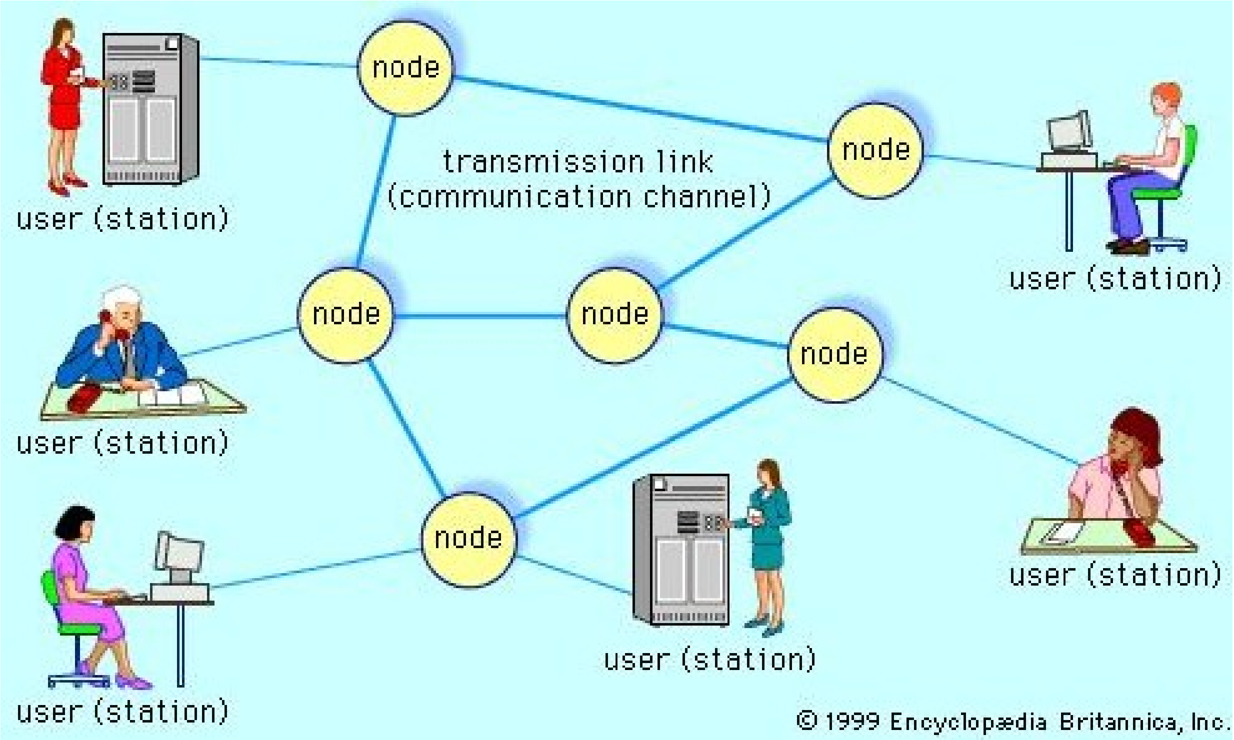
CHANNEL CAPACITY

Communication channel

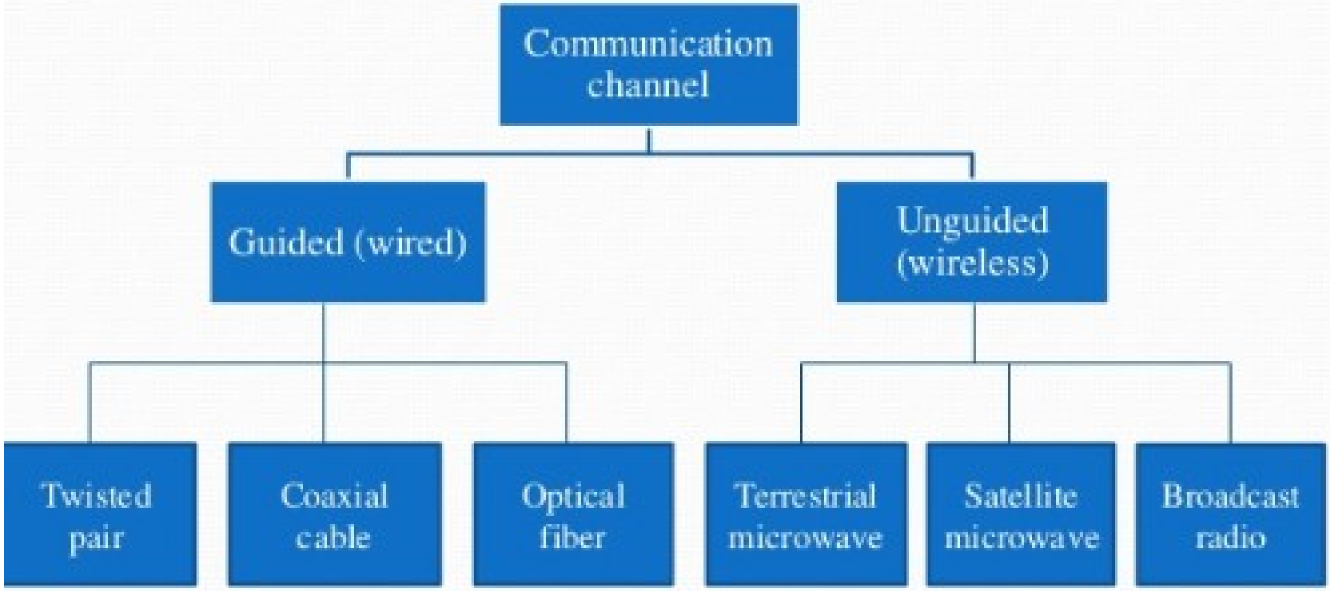
- Communication channel is a connection between transmitter and receiver through which Data can be transmitted.
- Communication channel also called as communication media or transmission media.



Communication Channel



- A path through which information is transmitted from one place to another is called communication channel. It is also referred to as communication medium or link.



- Other types are Under Water Acoustic Channels, Storage Channels like magnetic tapes, magnetic disks etc.

Channel Capacity

- The maximum rate at which data can be transmitted over a given communication channel, under given conditions, is referred to as the channel capacity.
- Data rate
  - The rate in **bits per second** (bps) at which data can be communicated
- Bandwidth
  - In cycles per second, or Hertz
  - Constrained by transmitter and the nature of the medium
- Error rate
  - The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.
- We would like to make as efficient use as possible of a given bandwidth, i.e., *we would like to get as high a data rate as possible at a particular limit of error rate for a given bandwidth*.

Data Rate

- 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)

- Increasing the levels of a signal increases the probability of an error occurring, in other words it reduces the reliability of the system. Why??

Capacity of a system

- The bit rate of a system increases with an increase in the number of signal levels we use to denote a symbol.
- A symbol can consist of a single bit or “n” bits.
- The number of signal levels = 2^n.
- As the number of levels goes up, the spacing between level decreases -> increasing the probability of an error occurring in the presence of transmission impairments.

Two Formulas

- Problem: Given a bandwidth, what data rate can we achieve?

- Nyquist Formula
  - Assume noise free

- Shannon Capacity Formula
  - Assume white noise

Nyquist Theorem

- Nyquist gives the upper bound for the bit rate of a transmission system by calculating the bit rate directly from the number of bits in a symbol (or signal levels) and the bandwidth of the system (assuming 2 symbols/per cycle and first harmonic).
- Nyquist theorem states that for a noiseless channel:

$$C = 2\,B \log_2 2^n$$

C= capacity in bps

B = bandwidth in Hz

Nyquist Theorem

- Does the Nyquist theorem bit rate agree with the intuitive bit rate described in baseband transmission?
  - They match when we have only two levels. We said, in baseband transmission, the bit rate is 2 times the bandwidth if we use only the first harmonic in the worst case. However, the Nyquist formula is more general than what we derived intuitively; it can be applied to baseband transmission and modulation. Also, it can be applied when we have two or more levels of signals.

- 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

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

- 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

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

- We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?
  - We can use the Nyquist formula as shown:

$$\boxed{\begin{array}{c} 265{,}000 = 2 \times 20{,}000 \times \log_2 L \\ \log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels} \end{array}}$$

  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.

Shanon’s Theorem

- Shannon’s theorem gives the capacity of a system in the presence of noise.

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

- 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

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

- 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.

- 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

$$\boxed{\begin{aligned} C &= B \log_2 (1 + \mathrm{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163 \\ &= 3000 \times 11.62 = 34{,}860 \text{ bps} \end{aligned}}$$

- 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.

- 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

- 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

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

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

- 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

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

- 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?
  - First, we use the Shannon formula to find the upper limit.
  - Next, we can use the Nyquist formula to find the number of signal levels.

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

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

  - 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.

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

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

PERFORMANCE

Performance

- One important issue in networking is the performance of the network—how good is it?
  - Bandwidth - capacity of the system
  - Throughput - no. of bits that can be pushed through
  - Latency (Delay) - delay incurred by a bit from start to finish
  - Bandwidth-Delay Product

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 bandwidth of a subscriber line is 4 kHz for voice or data.
- The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link. Often referred to as Capacity.
  - 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

- In data transmission, **network throughput** is the amount of data moved successfully from one place to another in a given time period, and typically measured in bits per second (bps), as in megabits per second (Mbps) or gigabits per second (Gbps).
- 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?

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

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

Propagation & Transmission Delay

- Propagation speed - speed at which a bit travels though the medium from source to destination.
  - Propagation Delay = Distance/Propagation speed
- Transmission speed - the speed at which all the bits in a message arrive at the destination. (difference in arrival time of first and last bit)
  - Transmission Delay = Message size/bandwidth bps

Latency

- Latency = Propagation delay + Transmission delay + Queueing time + Processing time

Problem

- 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.
  - 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.

- 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 × 108 m/s.

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

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

  - 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.

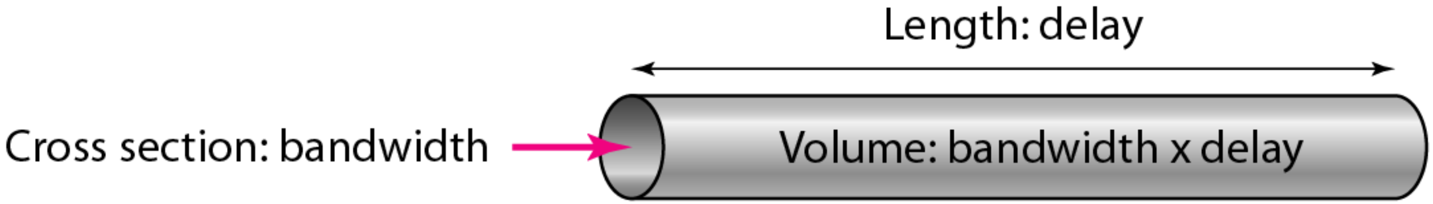
- What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

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

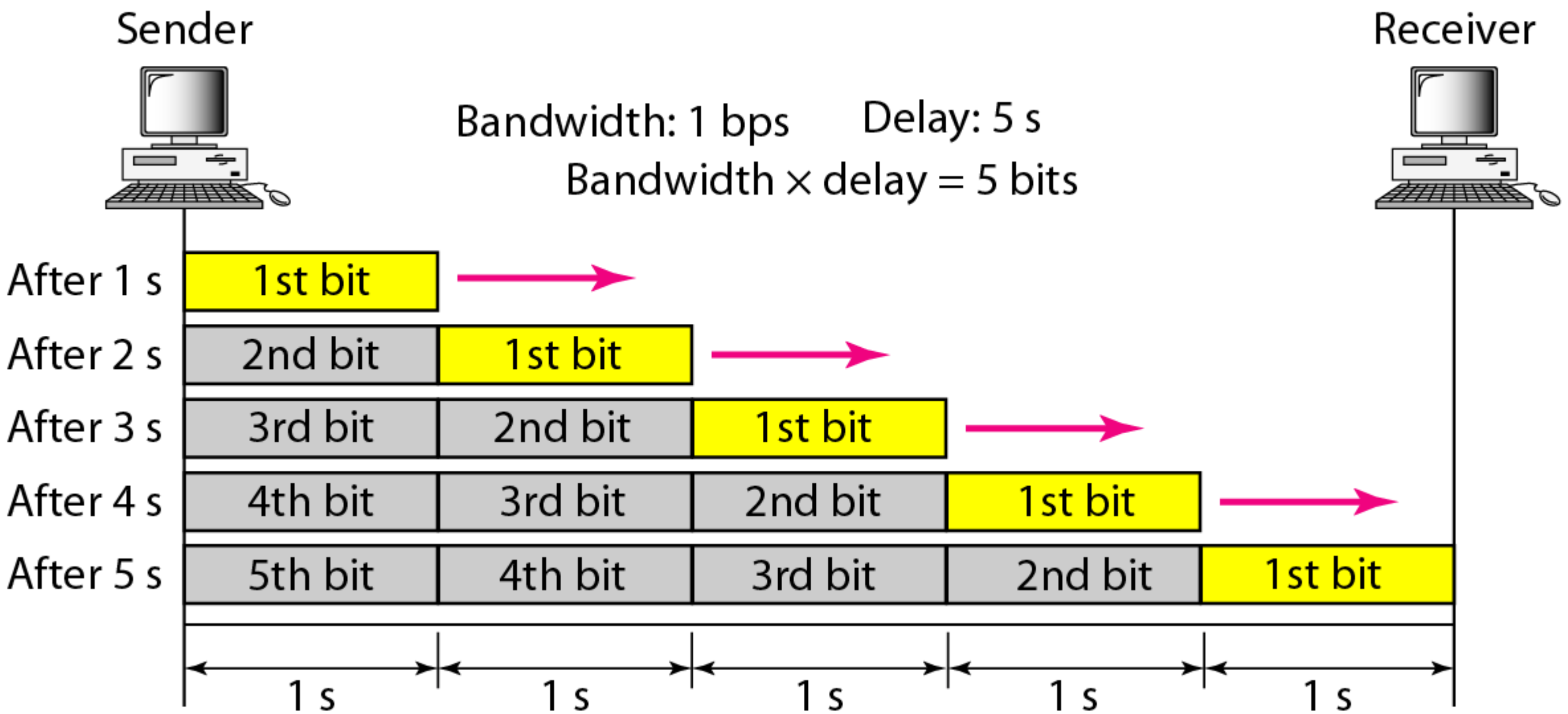
$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

- 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.

- We can think about 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. We can say the volume of the pipe defines the bandwidth-delay product as shown below.



Filling the link with bits



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