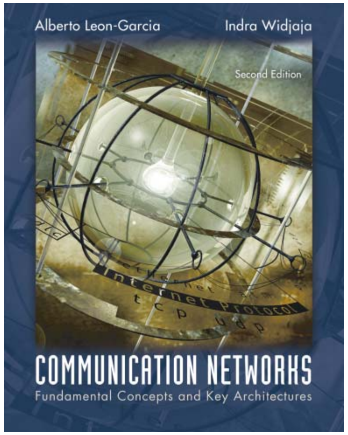
Chapter 3
Digital Transmission Fundamentals



Why Digital Communications?

CSE 3213, Winter 2010

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A Transmission System

Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communications medium or channel
  - Telephone converts voice into electric current
  - Modem converts bits into tones

Receiver

- Receives energy from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into voice
  - Modem converts tones into bits

Transmission Impairments

Communication Channel

- Pair of copper wires
- Coaxial cable
- Radio
- Light in optical fiber
- Light in air
- Infrared

Transmission Impairments

- Signal attenuation
- Signal distortion
- Spurious noise
- Interference from other signals

Transmission Impairments: Attenuation

Attenuation: reduction / loss in signal power

- when a signal travels through a medium it loses some of its energy so that it can overcome the resistance of the medium

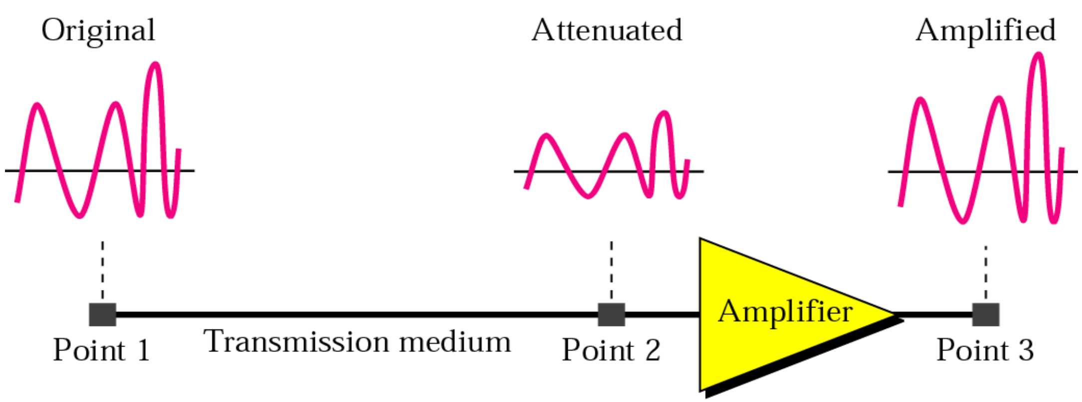
Main challenges in combating attenuation:

Less of a problem for digital signal !!!

(1) received signal must have sufficient strength so that receiver can detect signal, but not too strong to overload transmitter/ receiver circuitry

(2) signal must maintain a level sufficiently higher than noise, at all times, be received without error

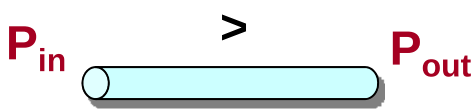
To compensate for loss, analog amplifiers / digital repeaters are used to boost the signal at regular intervals



Attenuation (cont.)

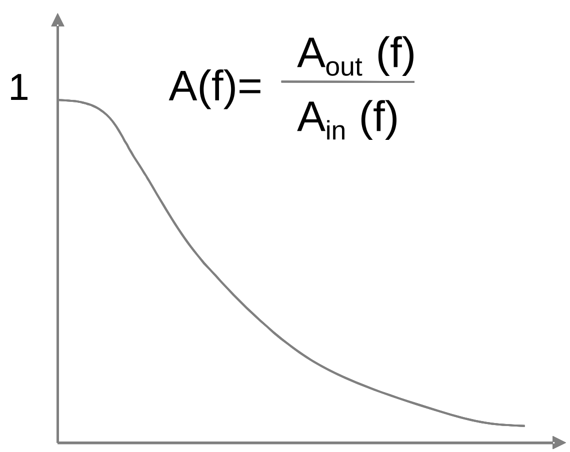
Attenuation : <u>Loss in signal power</u> as it is transferred across a system (medium)

- typically determined for <u>each individual frequency</u>
- apply sinwave of frequency f and power P_{in} to channel input and observe signal power P_{out} at channel output



$$\text{Attenuation}(f) = L(f) = 10 \cdot \log_{10} \frac{P_{in}(f)}{P_{out}(f)} \text{ [dB]}$$

Amplitude Response



$$A(f) = \frac{A_{out}(f)}{A_{in}(f)}$$

See Garcia pp. 125. *f*

- aka 'magnitude of frequency response'

$$L(f) = \frac{P_{in}(f)}{P_{out}(f)} = \frac{A_{in}(f)^2}{A_{out}(f)^2} = \frac{1}{A(f)^2}$$

$$\text{Atten.}(f) = L(f) = 20 \cdot \log_{10} \frac{1}{A(f)} \text{ [dB]}$$

channel's amplitude response function A(f)

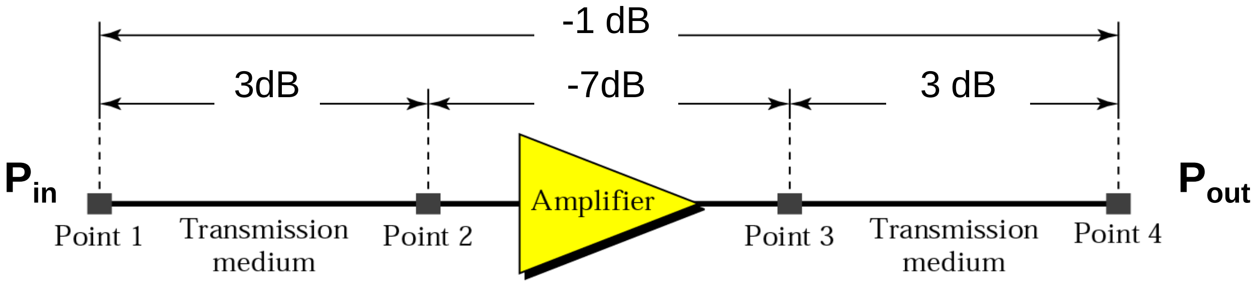
Attenuation (cont.)

Why decibel (log function)?

1. Signal strength often falls off exponentially, so loss is easily expressed in terms of decibels – linear function in log-plot.

2. The net gain or loss in a cascaded transmission path can be calculated with simple addition and subtraction.

   In figure below, a signal travels a long distance from point 1 to point 4. The signal is attenuated by the time it reaches point 2. Between points 2 and 3, the signal is amplified. Again, between points 3 and 4, the signal is attenuated. We can find the resultant attenuation for the signal just by adding the decibel measurements between each set of points.



In this case, the attenuation can be calculated as: 3-7+3 = -1, which means that the signal has gained power.

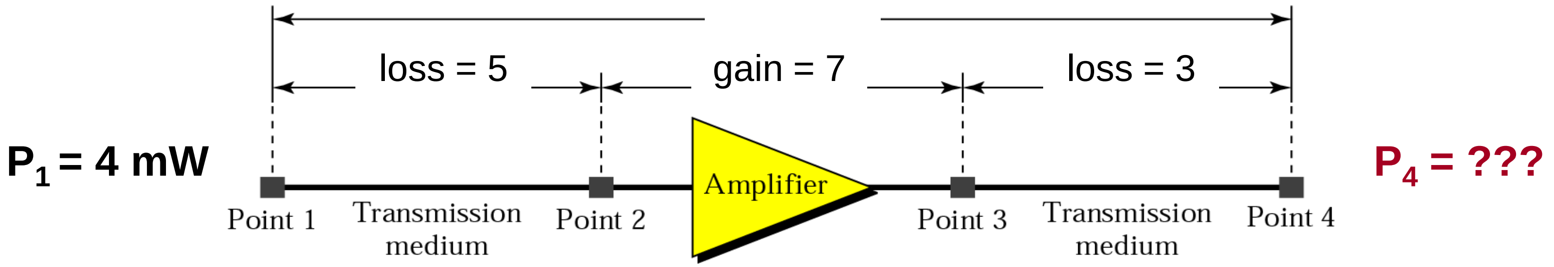
Attenuation (cont.)

Example [attenuation]

Consider a series of transmission elements as shown in the figure below.

The input signal has the power of P_1 = 4 mW. The 1st element is a transmission line with a loss of **5 (x)**, the 2nd element is an amplifier with a gain of **7 (x)**, and the 3rd element is a transmission line with a loss of **3 (x)**.

Calculate the output power P_4.

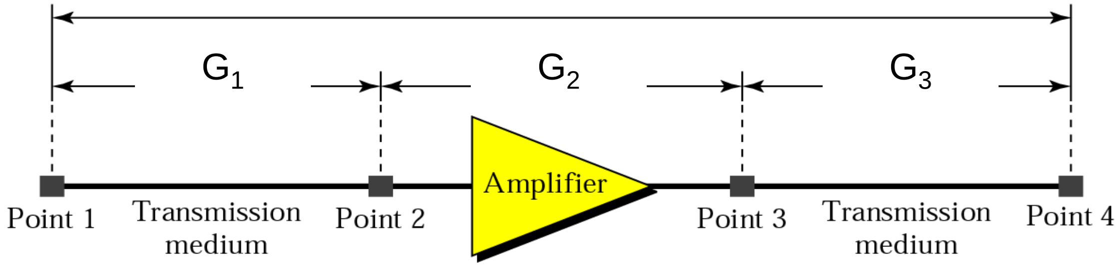


$$\frac{P_4}{P_1} = \frac{P_4}{P_3} \cdot \frac{P_3}{P_2} \cdot \frac{P_2}{P_1} = \frac{1}{5} \cdot \frac{7}{1} \cdot \frac{1}{3} = 0.47$$

$$P_4 = 0.47 \cdot 4 \text{ [mW]} = 1.88 \text{ [mW]}$$

Attenuation (cont.)

$P_1 = 4$ mW



$P_4 = ???$

$$\frac{P_4}{P_1} = \frac{P_4}{P_3} \cdot \frac{P_3}{P_2} \cdot \frac{P_2}{P_1} = G_1 \cdot G_2 \cdot G_3 = \frac{1}{L_1} \cdot \frac{1}{L_2} \cdot \frac{1}{L_3}$$

$$10 \cdot \log \frac{P_4}{P_1} [\text{dB}] = 10 \cdot \log(G_1 \cdot G_2 \cdot G_3) = 10 \cdot \log(G_1) + 10 \cdot \log(G_2) + 10 \cdot \log(G_3)$$

$$10 \cdot \log \frac{P_4}{P_1} [\text{dB}] = G_1[\text{dB}] + G_2[\text{dB}] + G_3[\text{dB}]$$

Transmission Impairments: Delay Distortion

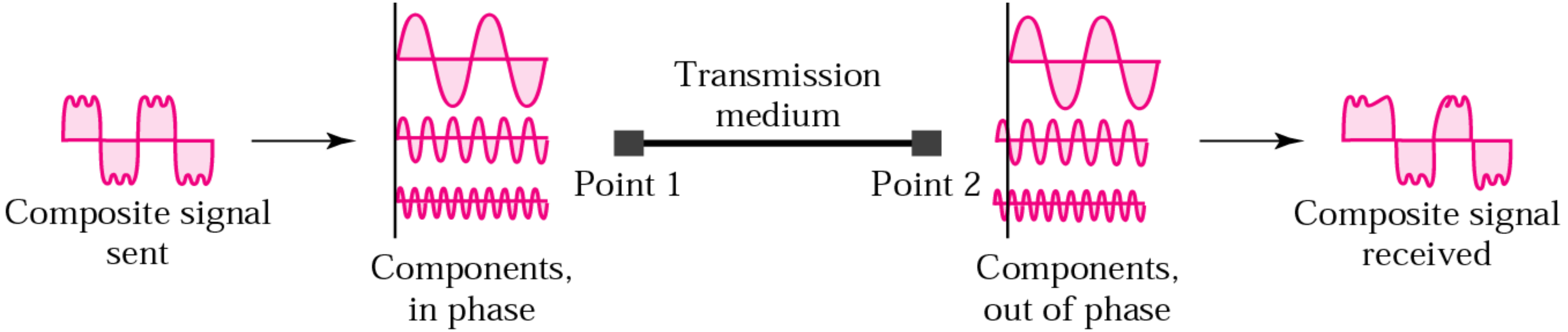
Delay Distortion: change in signal's form / shape

- each signal component has its own propagation speed through a medium, and therefore, its own delay in arriving at the final destination

- critical for composite-analog and digital signals – some of the signal components of one bit position will spill over into other bit position, causing 'intersymbol interference'

Major limitation to achieving high bit rates

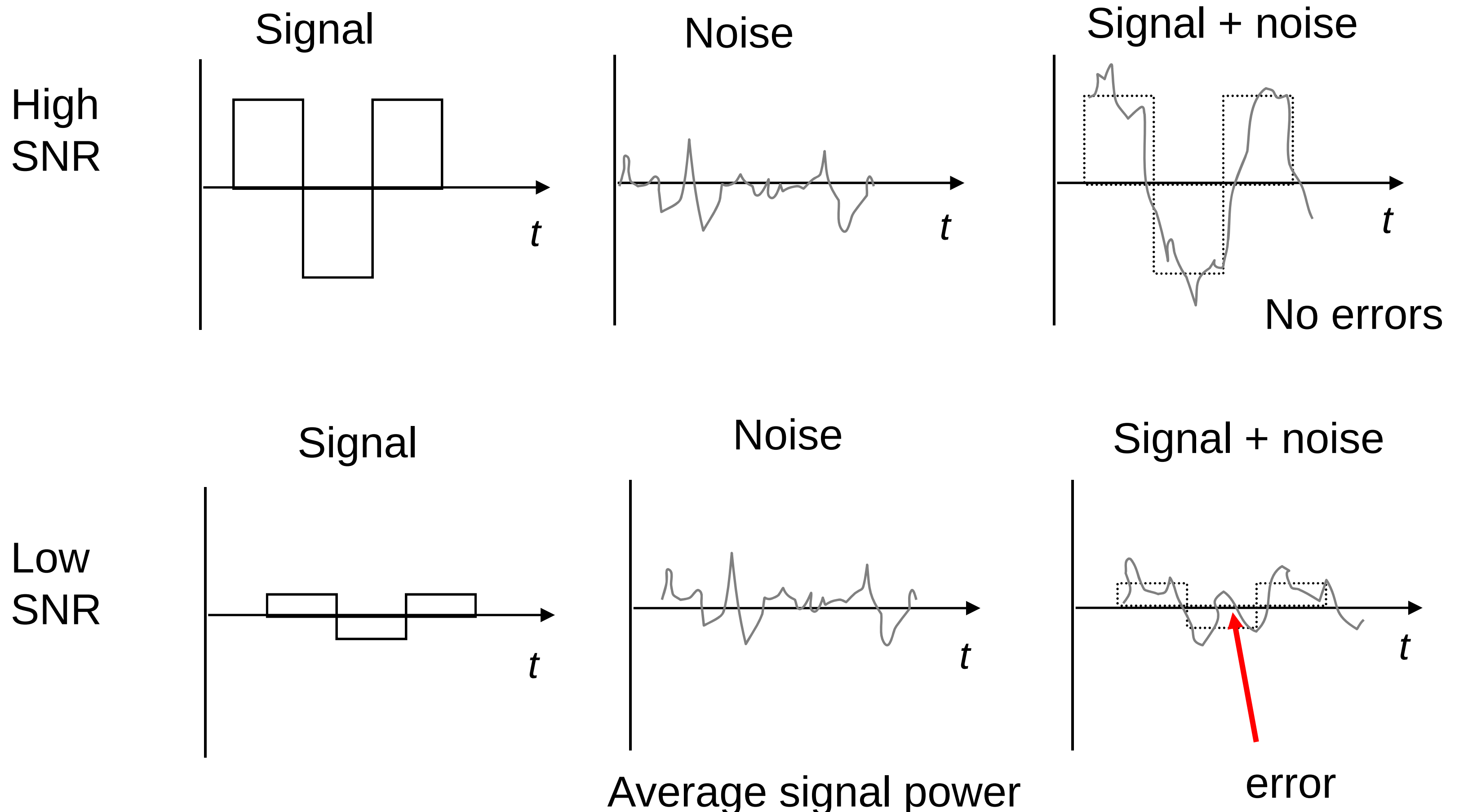
- in bandlimited channels, velocity tends to be highest near the center frequency and fall off towards the edges of the band



Transmission Impairments: Noise

- All physical systems have noise
  - Electrons always vibrate at non-zero temperature
  - Motion of electrons induces noise
- Presence of noise limits accuracy of measurement of received signal amplitude
- Errors occur if signal separation is comparable to noise level
- Bit Error Rate (BER) increases with decreasing signal-to-noise ratio
- Noise places a limit on how many amplitude levels can be used in pulse transmission

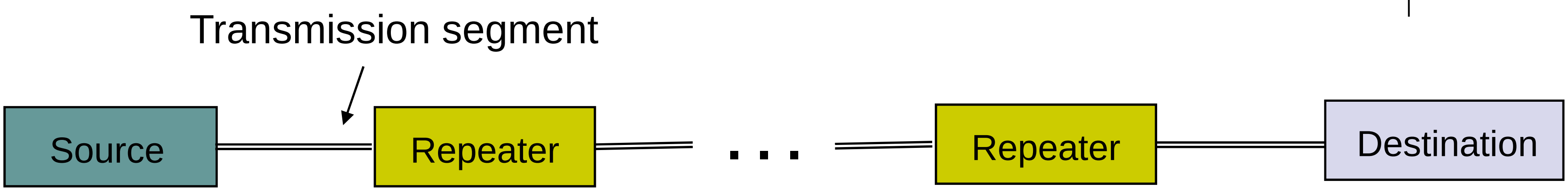
Signal-to-Noise Ratio



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

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

Analog Long-Distance Communications



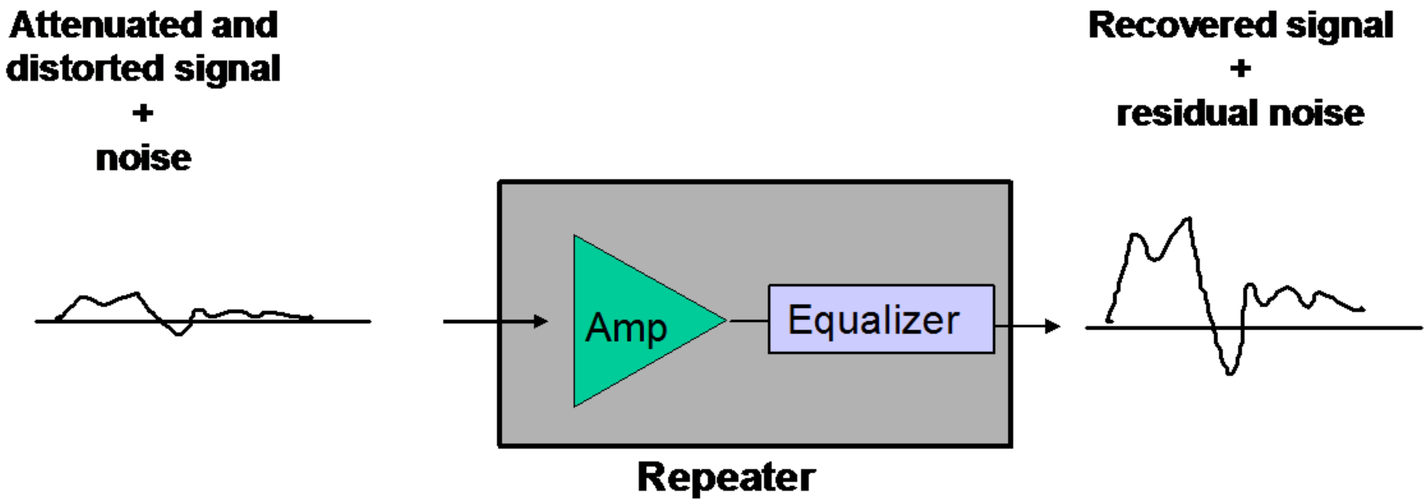
- Each repeater attempts to restore analog signal to its original form

Goals:
1) restore amplitude
2) remove delay distortion
3) remove noise

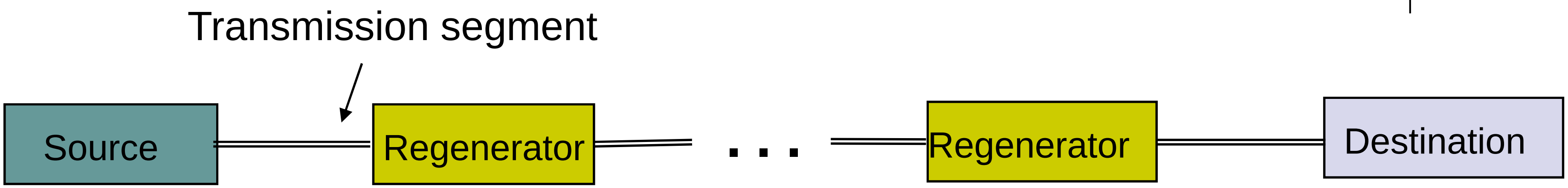
- Restoration is imperfect
  - Distortion is not completely eliminated
  - Noise & interference is only partially removed

Analog Long-Distance Communications (cont.)

- Signal quality decreases with # of repeaters
- Communications is distance-limited
- Still used in analog cable TV systems
- Analogy: Copy a song using a cassette recorder



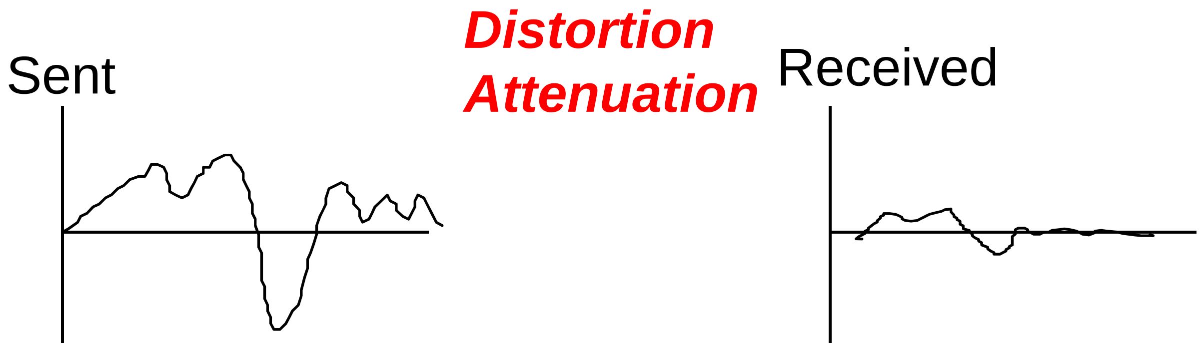
Digital Long-Distance Communications



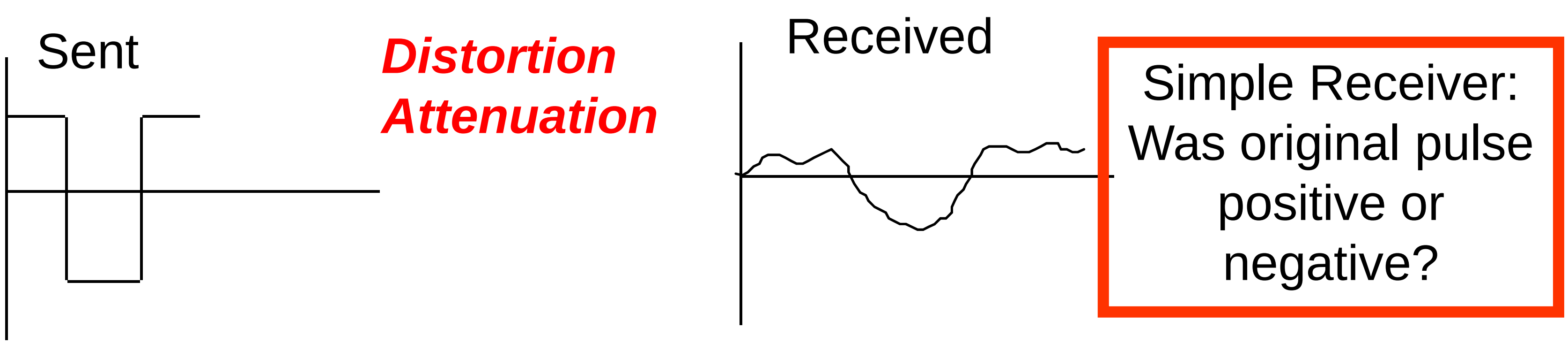
- Regenerator recovers original data sequence and retransmits on next segment
- Then each regeneration is like the first time!
- Analogy: copy an MP3 file
- Communications is possible over very long distances

Analog vs. Digital Transmission

Analog transmission: all details must be reproduced accurately



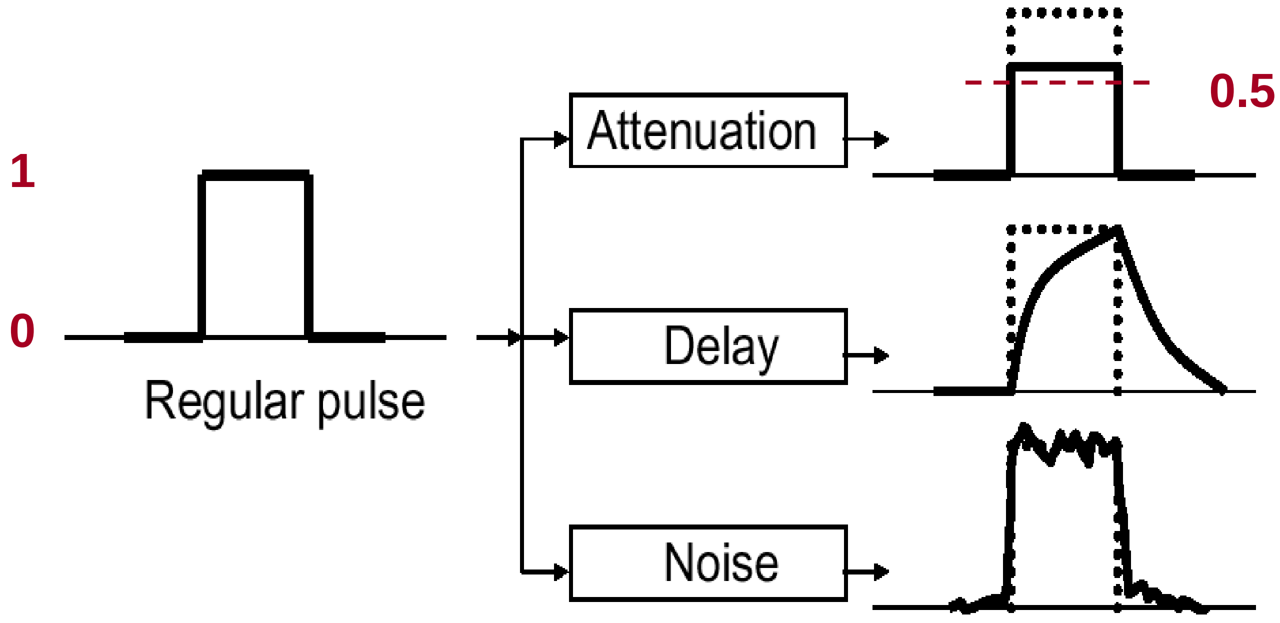
Digital transmission: only discrete levels need to be reproduced



Analog vs. Digital Transmission

Example [transmission impairments in digital transmission]

Digital transmission can easily recover from various types of channel impairments.



So, is digital transmission the ultimate winner?!

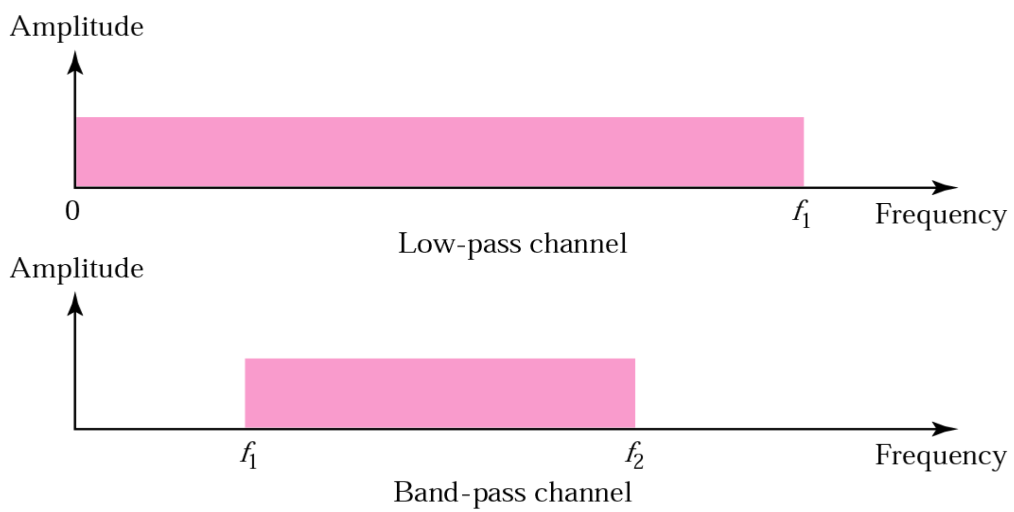
Analog vs. Digital Transmission

Low-pass Channel – bandwidth = $[0, f_1)$

- entire medium (bandwidth) is dedicated to two devices
- devices alternate in transmission

Band-pass Channel – bandwidth = $[f_1, f_2)$

- medium is shared among multiple users
- each pair of users gets a portion of overall bandwidth



Analog vs. Digital Transmission

Digital Transmission Advantages

- signal can be transmitted over long-distance without loosing any quality
- can operate with lower signal levels $\Rightarrow$ lower system cost
- easier to apply encryption
- easier integration of voice, video and data

Digital Transmission Disadvantages

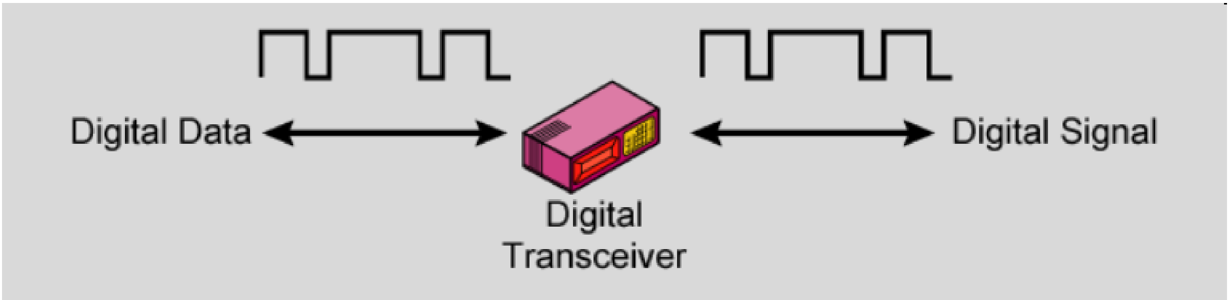
- digital signal theoretically needs a bandwidth $[0, \infty)$ – upper limit can be relaxed if we decide to work with a limited number of harmonics $\Rightarrow$ digital transmission needs a low-pass channel
- analog transmission can use a band-pass channel

Both analog and digital data may be transmitted on suitable transmission media using either digital coding or analog modulation.

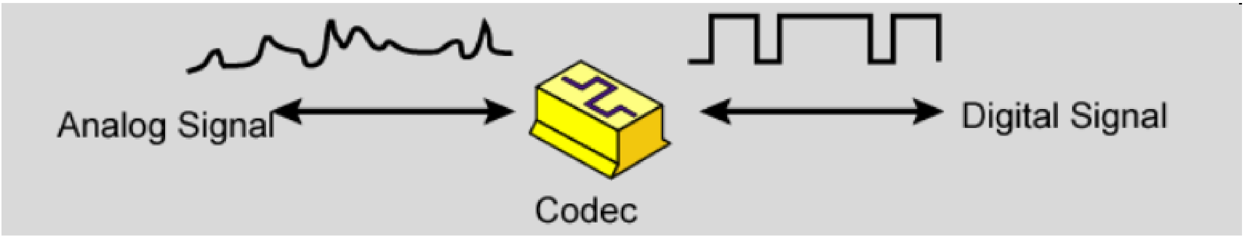
Analog vs. Digital Transmission

Example [digital transmission of digital and analog data]

Digital Data → Digital Signal: Line Coding



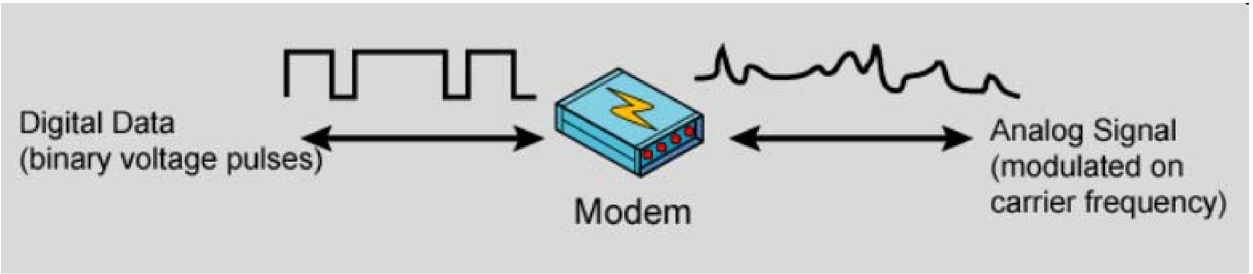
Analog Data → Digital Signal: PCM (Pulse Code Modul.) or Delta Modulation



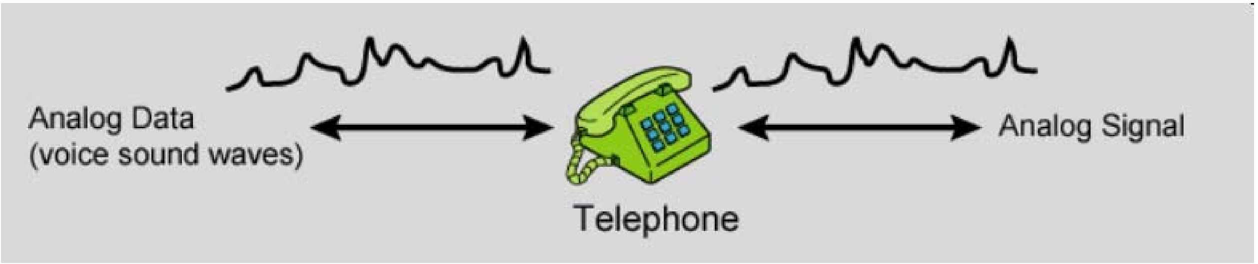
Analog vs. Digital Transmission (cont.)

Example **[analog transmission of digital and analog data]**

Digital data → Analog Signal: Digital Modulation



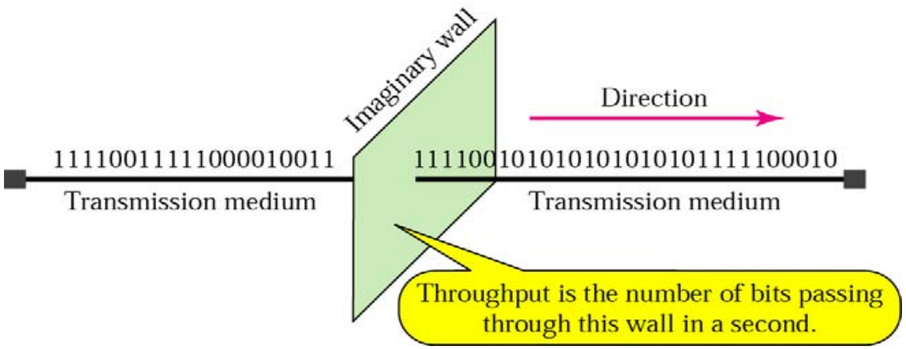
Analog data → Analog Signal: Analog Modulation



More About Digital Transmission

Throughput – measurement of how fast data can pass through an entity in the network (computer, router, channel, etc.)

- if we consider this entity as a wall through which bits pass, throughput is the number of bits that can pass this wall in one second



e.g. R=56 kbps

Example [throughput]

If the throughput at the connection between a device and the transmission medium is 56 kbps, how long does it take to send 100,000 bits out of this device?

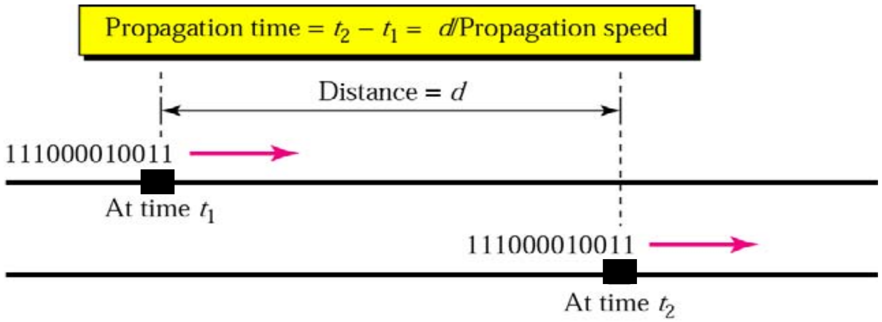
$$t = \frac{N[bits]}{R[bps]} = \frac{100000\ [\text{bit}]}{56000\ [\text{bps}]} = 1{,}786\ [\text{sec}]$$

Throughput and Delay

Propagation Time – measures the time required for a signal (or a bit) to travel from one point of the transmission medium to another

$$p = \frac{d}{c}\,[\text{sec}]$$

- d – length of physical link [m]
- c – signal propagation speed in medium ~ $2*10^8$ [m/s]



Example [propagation time]

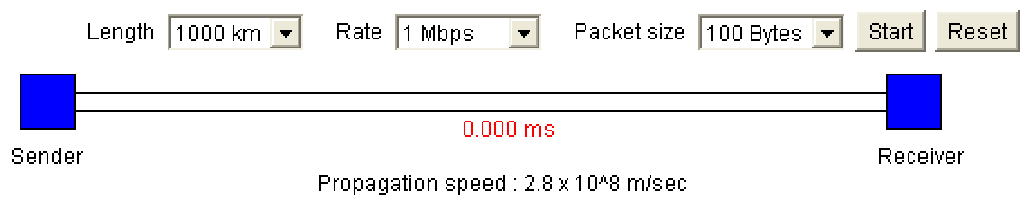
The light of the Sun takes approximately 8 minutes to reach the Earth? What is the distance between the Sun and the Earth?

$$d = p\,[\text{sec}]\cdot c\,[\frac{m}{\text{sec}}] = 8*60\,[\text{sec}]\cdot 3\cdot 10^8[\frac{m}{\text{sec}}] = 144\cdot 10^9[m] = 144\cdot 10^6[km]$$

Throughput and Delay

Overall Delay

- *L* [bits] number of bits in message
- *R* [bps] speed of digital transmission system
- *d* [m] distance in meters
- *c* [m/s] speed of light (3×10^8 m/s in vacuum)



Time to deliver a block of L bits:

$$Delay = t_{propagation} + t_{transmission} = d/c + L/R \text{ seconds}$$

Use data compression to reduce L.

Use higher speed modem/cable to increase R.

Place server closer to reduce d.

http://media.pearsoncmg.com/aw/aw_kurose_network_2/applets/transmission/delay.html