Transmission Impairments

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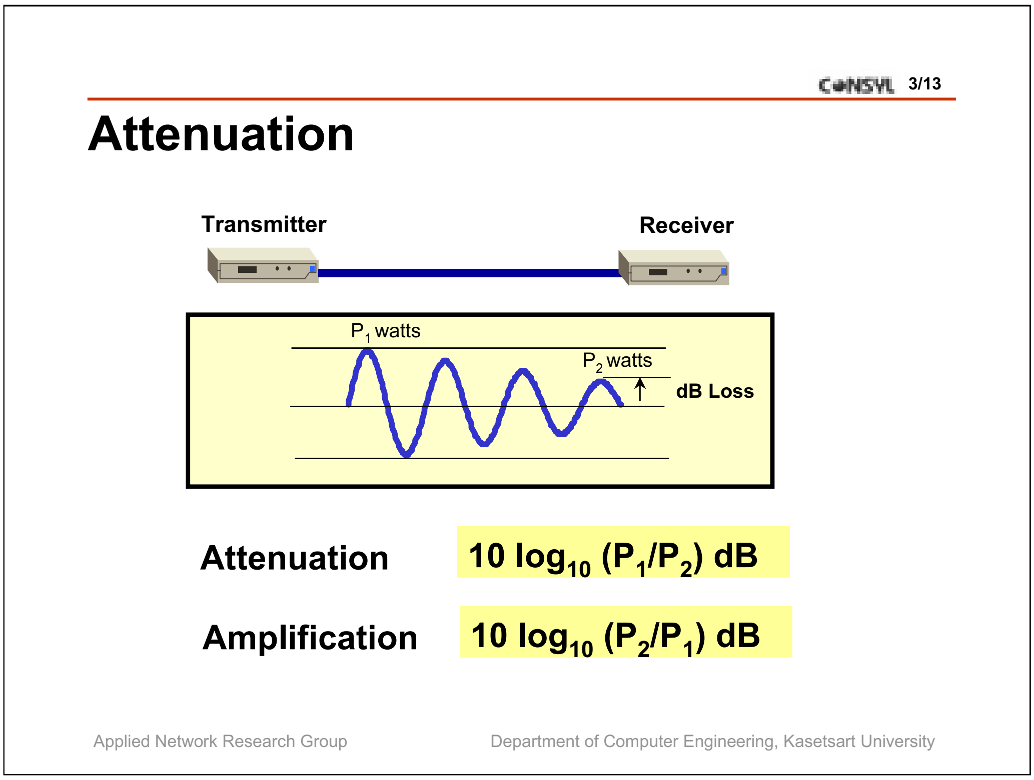
Type of impairments

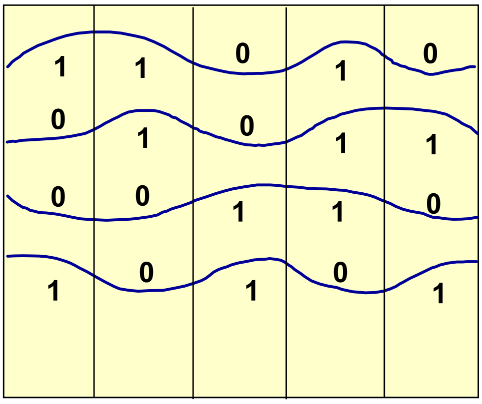
- Attenuation
- Delay distortion
- Noise

The signal is received will differ from the signal that is transmitted due to various transmission impairments. For analog signal, these impairments cause various modifications that degrade the signal quality. For digital signal, A binary 1 may be changed into a binary 0 and vice versa due to bit error.



Signal amplitude decrease along a transmission medium. This is known as *signal attenuation*. Amplifiers or repeaters are inserted at intervals along the medium to improve the received signal as closed as to its original level. Attenuation and amplification are measured in decibel (dB), which is expressed as a constant number of decibels per unit distance.

Delay distortion



- **Velocity of propagation of a signal through a guided medium varies with frequency**
- **Signal components of one bit position will spill over into other bit position**
- **Results : limit max, bit rate transmission**
- **Solving : equalizing**

The various frequency components in digital signal arrive at the receiver with varying delays, resulting in *delay distortion*.

As bit rate increase, some of the frequency components associated with each bit transition are delayed and start to interfere with frequency components associated with a later bit, causing *intersymbol interference*, which is a major limitation to maximum bit rate.

CoNSYL 5/13

Noise

- **Effect**
  - **distorted a transmitted signal**
  - **attenuated a transmitted signal**
- **signal-to-noise ratio to quantify noise**

$$S/N_{db} = 10 \log_{10} \frac{S}{N}$$

S = average signal power
N = noise power

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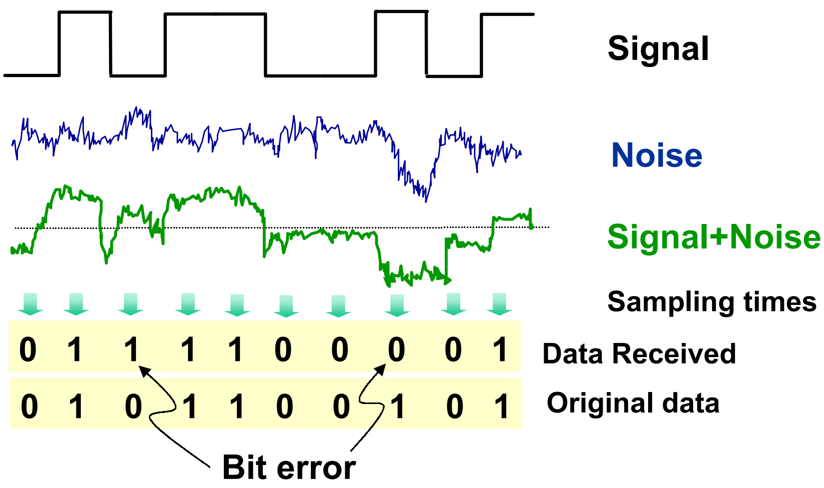
Signal-to-noise ratio (S/N) is a parameter used to quantify how much noise there is in a signal. A high SNR means a high power signal relative to noise level, resulting in a good-quality signal.

Effect of noise



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Impulse noise is the primary source of error for digital data. A sharp spike of energy of 0.01 seconds duration would not destroy any voice data, but would wash out many bits of digital data.

Bit Error Rate

- The BER (Bit Error Rate) is the probability of a single bit being corrupted in a define time interval
- BER of 10^{-5} means on average 1 bit in 10^{-5} will be corrupted
  - A BER of 10^{-5} over voice-graded line is typical.
  - BERs of less than 10^{-6} over digital communication is common.

A Bit Error Rate (BER) is a significant measure of system performance in terms of noise. A BER of 10-6, for example, means that one bit of every million may be destroyed during transmission. Several factors effect the BER:

- Bandwidth
- S/N
- Transmission medium
- Transmission distance
- Environment
- Performance of transmitter and receiver

Effect of noise in practice

- E_b/N_0 = signal energy to noise energy ratio

$$\frac{E_b}{N_0} = \frac{S*W}{R*N} = \frac{S*W}{N*R}$$

$$= S/N + 10\log W - 10\log R \quad (dB)$$

S= signal power in watts
R= data rate
W= bandwidth
N= noise power in received signal

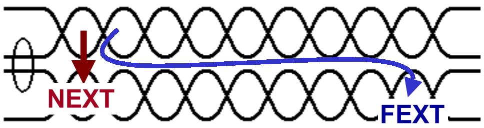
When considering the effect of noise in practice, it is important to determine the minimum signal level that must be used, relative to the noise level, to achieve a specific minimum bit error rate ratio. This can be computed using the expression defined by the ratio of signal power level and noise power level.

Noise types

- **Atmospheric Noise**
  - Lightning : static discharge of clouds
  - Solar noise : sun's ionized gases
  - Cosmic noise : distant stars radiate high frequency signal
- **Gaussian Noise**
  - Thermal noise : generated by random motion of free electrons
- **Crosstalk**
  - NEXT
  - FEXT
- **Impulse Noise :** sudden bursts of irregularly pulses

There are several type of noises categorized from their sources. These noises degrade the performance of the communication system.

Crosstalk



- **NEXT (near-end crosstalk)**
  - interference in a wire at the transmitting end of a signal sent on a different wire
- **FEXT (far-end crosstalk)**
  - interference in a wire at the receiving end of a signal sent on a different wire

Crosstalk is interference generated when magnetic fields or current nearby wires interrupt electrical current in a wire. As electrical current travels through a wire, the current generates a magnetic field. Magnetic field from wires that are closed together can interfere each other.

Shielding the wire and twisting wire pairs around each other help decrease crosstalk.

Nyquist formula

$$C = 2W \log_2 M$$

W = bandwidth in Hz
M = number of discrete signal

Theoretical capacity for Noiseless transmission channel

Example: A noiseless 3KHz channel cannot transmit binary (two-level) signal at a rate exceeding 6000 bps

Channel capacity calculation for voice bandwidth (3000 Hz)

M	Max data rate (C)
2	**6000 bps**
4	**12000 bps**
8	**18000 bps**
16	**24000 bps**

Nyquist derived an equation expressing the maximum data rate for a finite bandwidth noiseless channel. The theoretical maximum information (data) rate of a transmission channel is referred to as *channel capacity.*

Shannon's Law

The maximum data rate of a noisy channal whose bandwidth W Hz, and whose signal-to-noise ration is S/N, is given by

$$C = W \log_2 (1 + \frac{S}{N})$$

W = bandwidth in Hz
S = average signal power in watts
N = random noise power in watts

Let W = 3300-300 Hz = 3000 Hz
Assume a typical decibel ration of 30 dB, thus S/N=1000

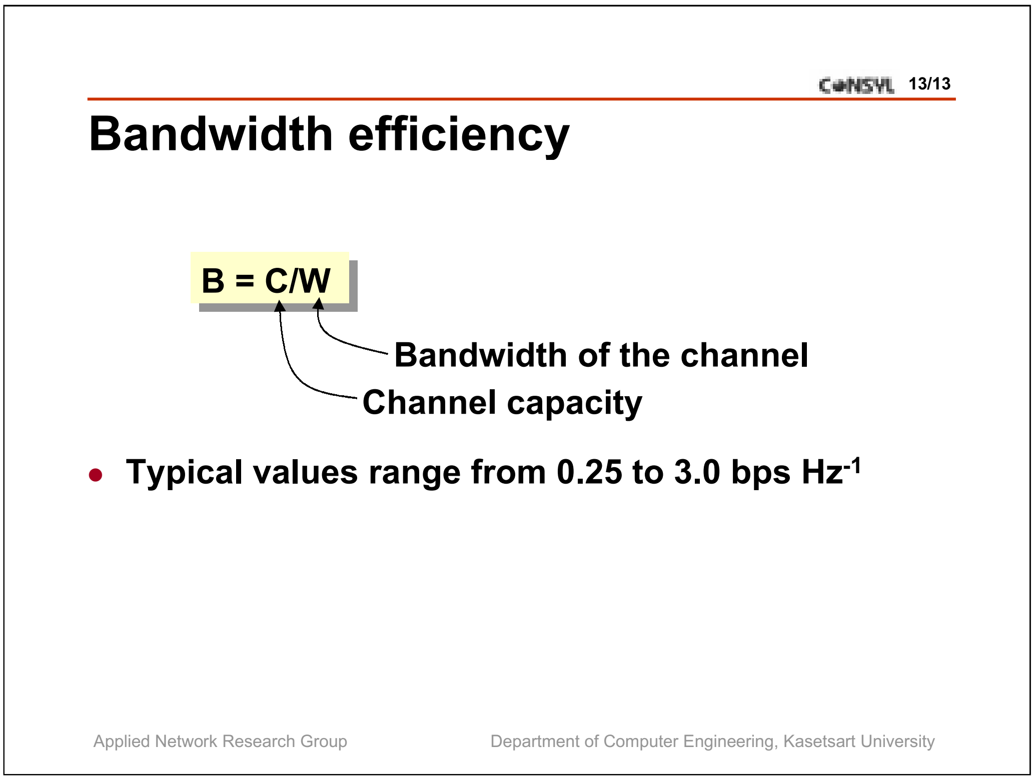
C = 3000xlog2 (1001)
~ 30 Kbps

Claud Shannon carried Nyquist's work further and extended it to the case of a channel subject to random noise. Shannon's theorem give the theoretical upper bound to the capacity of a link as a function of the signal-to-noise ratio, measured in dB.

As an example, consider a voice channel has a bandwidth 3000 Hz and transmit data with normally has S/N = 30 dB or 1000.

$$C = 3000 \log_2(1+1000)$$
$$= 29{,}897 \text{ bps}$$

This is the limit of today's 28.8-Kbps modems. Higher data rates are achieved if the quality (SNR) of the phone network improves or by using compression.



From the bandwidth efficiency expression, the higher the bit rate relative to the available bandwidth, the higher the bandwidth efficiency. The ratio of C/W gives an efficiency of a digital transmission

Typical values of B range from 0.25 to 3.0 bps Hz^{-1}, the first corresponding to a low bit rate relative to the available bandwidth and the second a high bit rate that requires a relatively high signaling rate.[Halsall p.38]