Computer Network

Lecture-10

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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.

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.

Noise

Signal-to-Noise Ratio(SNR)

The signal-to-noise ratio is defined as

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

Note: A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

Because SNR is the ratio of two powers, it is often described in decibel units, SNR(dB), defined as

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

Example :

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)?

Example : Find SNR and SNR(dB) for noiseless channel.

Noiseless Channel: Nyquist Bit Rate

For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate.

$$\textbf{Bit Rate} = \mathbf{2 \times B \times \log_2 L}$$

In this formula, **B** is the bandwidth of the channel, **L** is the number of signal levels used to represent data, and **Bit Rate** is the bit rate in bits per second.

Note: Increasing the levels of a signal may reduce the reliability of the system.

Example: Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. Find the maximum bit rate.

Solution: $\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$

Noise

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

Solution:

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625$$

Therefore, $L = 2^{6.625} = 98.7$ levels

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.

Noisy Channel: Shannon Capacity

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:

$$\mathbf{C = B \times \log_2 (1 + SNR)}$$

In this formula, **B** is the bandwidth of the channel, **SNR** is the signal-to-noise ratio, and **C** is the capacity of the channel in bits per second.

Note: We cannot achieve a data rate higher than the capacity of the channel.

Noisy Channel: Shannon Capacity

Example: A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. Compute the capacity of this channel.

Solution:

$$C = B \log_2 (1 + SNR) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$

$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

Note: 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.

Noisy Channel: Shannon Capacity

Example: The signal-to-noise ratio is often given in decibels. Assume that SNR(dB) = 36 and the channel bandwidth is 2 MHz. Compute the theoretical channel capacity.

Solution:

We know that, $SNR(dB) = 10 \log_{10} SNR$

Therefore, $36 = 10 \log_{10} SNR$

$SNR = 10^{3.6} = 3981$

Now, Channel capacity $C = B * \log_2(1+SNR)$

$= 2 * 10^6 \log_2(1+3981)$

$= 24$ Mbps (approx.)

Note: 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

C = B X SNR(dB)/3

Noisy Channel: Shannon Capacity

Example: 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?

Solution:

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

$C = B * \log_2 (1 + SNR) = 10^6 * \log_2 (1 + 63) = 10^6 * \log_2 64 = 6$ 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.

$$\text{Bit rate} = 2*B*\log_2 L$$

$$4 \times 10^6 = 2 \times 10^6 \times \log_2 L$$

Therefore, $L = 4$

Noisy Channel: Shannon Capacity

Example: If a binary signal is sent over a 3 kHz channel whose signal to noise ratio is 20dB. What is the maximum achievable data rate ?

Solution:

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

$20 = 10 * \log_{10} SNR$

$SNR = 100$

For maximum achievable data rate

$C = B * \log_2 (1 + SNR) = 3000 * \log_2 (1 + 100) = 3000 * \log_2 101$

$= 3000 * 6.658 = 19.974$ kbps

Nyquist Bit rate $= 2 * B * \log_2 L = 2 * 3000 * \log_2 2$

$= 6000$ bps

The bottleneck is therefore the Nyquist limit giving a maximum channel capacity of **6** kbps.