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:

- 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 may reduce the reliability of the system.

Channel Capacity

Data rate can be calculated using

- Nyquist theorem for noiseless channel
- Shannon capacity for noisy channel

Nyquist theorem

Maximum data rate of a <u>noiseless</u> channel = $2 * B * log_2(L)$ bps

- Where B = Bandwidth
- L = the number of discrete levels

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

BitRate = $2 \times 3000 \times \log_2 2 = 6000$ 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

BitRate = $2 \times 3000 \times \log_2 4 = 12,000$ bps

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:

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

 $\log_2 L = 6.625$ $L = 2^{6.625} = 98.7$ levels

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate

Channel Capacity

- Shannon (which includes noise)
 - Maximum data rate (in bps) = $B \times log_2(1 + SNR)$
 - B = bandwidth
 - SNR= signal to Noise Ratio

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

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

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

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

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

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

$$SNR_{dB} = 10 \log_{10} SNR$$
 \longrightarrow $SNR = 10^{SNR_{dB}/10}$ \longrightarrow $SNR = 10^{3.6} = 3981$ $C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$

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?

Solution

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

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

Example 4 (continued)

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.

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



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



In networking, we use the term 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 second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.

Channel Capacity

As the bandwidth increases, so too can the data rate.

Stated another way, to transmit a high data rate, we need a wide bandwidth.

OR

We need to use a signaling technique that has a high number of signal levels.

PERFORMANCE

One characteristic that measures network performance is bandwidth.

Measuring values: bandwidth in hertz and bandwidth in bits per second.

- Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass.
- Bandwidth in Bits per Seconds; The number of bits per second that a channel, a link, or even a network can transmit.

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Throughput

It is a measure of how fast we can actually send data through a network

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 = 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

Propagation time = Distance / (Propagation Speed)

Transmission Time = (Message size) / Bandwidth

Bandwidth-Delay Product

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

