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TP08
Delay, loss and throughput in packet-switched networks (part 2)

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TP08: Delay, loss and throughput (part 2)

Overview:

- Transmission of data
- Maximum data rate
- Nyquist formula
- Shannon formula

Transmission of data

- Data transmission involves converting bits in electric, electromagnetic or optical signals

- Signals may suffer from:
  - Attenuation: reduction of the amplitude of the signals
  - Delay distortion: different speeds for different frequencies

- The transmission of binary data involves:
  - Modulation (AM, FM, PM, mixing)
  - Power of the information signal vs Power of the noise
  - A propagation delay related with the transmission medium

Maximum Data Rate (channel capacity)

- Data rate governs the speed of data transmission

- Depends upon 3 factors:
  - Bandwidth available
  - Number or levels in digital signal (resulting from modulation)
  - Quality of the channel – the level of noise

- Two theoretical formulas were developed to calculate the data rate in digital communication systems:
  - One by Nyquist, considering a noiseless channel
  - Other by Shannon, for a noisy channel

Nyquist formula

- Assumes a noise-free channel
- Defines the theoretical maximum bit rate, from:
  - Bandwidth available (in Hz)
  - Number or levels in the digital signal (resulting from modulation)

Factor of "2" in the formula

arises from the need to sample the signal at least twice per cycle (according to the Nyquist sampling theorem) in order to accurately reconstruct the original signal.

$$C = 2\,B\,\log_2 M \qquad \text{bps}$$

C – Maximum Bit Rate
B – Bandwidth
M – Levels of signalling

- Bandwidth is fixed, so data rate is directly proportional to the number of signal levels

Nyquist formula (exercises)

- Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. What can be the maximum (theoretical) bit rate?

BitRate = 2 * 3000 * log2(2) = 6000bps

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

$265000 = 2 * 20000 * \log_2(L)$

$\log_2(L) = 6.625$

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

Increasing the number of signal levels…

…also increases the complexity of the transmission and reception processes, and may require higher signal-to-noise ratios for reliable communication.

Shannon formula

- Channels in reality are always noisy
- Defines the theoretical highest data rate for a noisy channel, from:
  - Bandwidth available (in Hz)
  - The signal-to-noise (S/N) ratio
  - Bandwidth is fixed, so data rate is directly proportional to S/N

$C = B \log_2 (1 + S/N)$ bps

S – Signal power (Watt)
N – Noise Power (Watt)

or...
C = B log2(1 + 10^(SNR(dB)/10))
If S/N ratio in dB

- SNR may be expressed in dB (decibels), given by:

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

  Example: For a S/N of 1000: $10 * \log_{10} (1000) = 30$ dB

Shannon formula (exercises)

- A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communication. The SNR is usually 3162. What will be the capacity for this channel?

  $C = 3000 * \log_2(1 + SNR) = 3000 * 11.62 = 34860$ bps

- The SNR is often given in decibels. Assume that SNR(dB) is 36 and the channel bandwidth is 2 MHz. Calculate the theoretical channel capacity.

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

  $SNR = 10^{(SNR(dB)/10)}$

  $SNR = 10^{3.6} = 3981$

  Hence, $C = 2 * 10^6 * \log_2(3982) = 24$ MHz

TP08: Summary

What we have covered here?

- Transmission of data
- Attenuation and distortion
- Nyquist and Shannon formulas
- Usage examples (exercises)