Shannon showed that there is a fundamental limitation to reliable data transmission.

- ther wider the bandwidth (Hz) the higher the reliable throughput
- the noisier the channel, the smaller the reliable throughput

  $\rightarrow$ overhead spent dealing with corrupted bits

Channel Coding Theorem (Shannon): Given bandwidth W, signal power P_S, noise power P_N, channel subject to white noise,

$$C \;=\; W \log \left(1 + \frac{P_S}{P_N}\right) \text{ bps.}$$

$\rightarrow P_S/P_N$: signal-to-noise ratio (SNR)

Implications for networking:

- Increase bandwidth W (Hz) to proportionally increase reliable throughput

  → e.g., FDM, OFDM

  → best possible way

  → wireless bandwidth: scarce resource

- Power control (e.g., handheld wireless devices)

  → trade-off w.r.t. battery power

  → trade-off w.r.t. multi-user interference: doesn't work if everyone increases power

  → signal-to-interference ratio (SIR)

Signal-to-noise ratio (SNR) is expressed as

$$\text{dB} \;=\; 10 \log_{10}(P_S/P_N).$$

Ex.: Assuming a decibel level of 30, what is the channel capacity of a telephone line?

First, $W = 3000$ Hz, $P_S/P_N = 1000$. Using Channel Coding Theorem,

$$C \;=\; 3000 \log 1001 \;\approx\; 30 \text{ Kbps}.$$

$\longrightarrow$ compare against 28.8 Kbps modems

$\longrightarrow$ what about 56 Kbps modems?

$\longrightarrow$ xDSL lines?

Nyquist's sampling criterion:

→ modern communication: mainly for digitizing analog audio (music and voice)

→ key issue: digitizing time

→ digitizing amplitude: less critical due to log-response of auditory system

Sampling Theorem (Nyquist): Given continuous bandlimited signal $s(t)$ with bandwidth W (Hz), $s(t)$ can be reconstructed from its samples if

$$\nu > 2W$$

where ν is the sampling rate.

$\longrightarrow$ ν: samples per second

Ex.: human auditory system

→ sensitivity: 20 Hz–20 KHz range (roughly 20 KHz)

→ voice: 300 Hz–3.3 KHz (roughly 4 KHz)

T1 TDM line: 1.544 Mbps

→ frame size 193 (24 users, 8 bits-per-user, 1 preamble bit)

→ 8000 samples per second

→ $193 \times 8000 = 1.544$ Mbps

CD quality audio: 44100 samples per second

→ also denoted Hz (44.1 KHz)

DVD quality audio: 96 samples per second (and higher)