Channel Capacity

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- Channel capacity: maximum data rate at which data can be transmitted over a given communication channel
- Relate:
  - Data rate, *C* [bits per second]
  - Bandwidth, *B* [Hertz]
  - Noise
  - Error rate
- Two theoretical models:

  Nyquist Capacity: assumes noise-free environment

  Shannon Capacity: considers noise

Nyquist Capacity

- Assumes channel that is noise free
- Given a bandwidth of B, the highest signal rate is $2B$
- Single signal element may carry more than 1 bit; signal with M levels may carry $\log_2 M$ bits

$$C = 2B \log_2 M$$

- Tradeoffs:
  - Increase the bandwidth, increases the data rate
  - Increase the signal levels, increases the data rate
  - Increase the signal levels, harder for receiver to interpret the bits (practical limit to M)

Example of Nyquist Capacity

A telephone system with modem allows bandwidth of 3100 Hz. What is the maximum data rate? M=2

Shannon Capacity

- With noise, some bits may be corrupted; higher data rate, more bits corrupted
- Increasing signal strength overcomes noise
- Signal-to-noise ratio:

$$SNR = \frac{signalpower}{noisepower}$$

- Shannon capacity:
  - $C = B \log_2 (1 + SNR)$
- Tradeoffs:
  - Increase bandwidth or signal power, increases data rate
  - Increase of noise, reduces data rate
  - Increase bandwidth, allows more noise
  - Increase signal power, causes increased intermodulation noise

Example of Shannon and Nyquist Capacity

A channel uses spectrum of between 3MHz and 4MHz, with $SNR_{dB} = 24dB$. How many signal levels are required to achieve Shannon capacity?

Example

- A channel has B=4kHz and SNR =30dB. Determine maximum information rate for 128 level encoding.

Solution

- Nyquist capacity=56kbps
- Shannon capacity=**39.8kbp**s
- Smallest of two values decide channel capacity.