Computer Networks

Fundamental Limits (§2.1)

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Topic

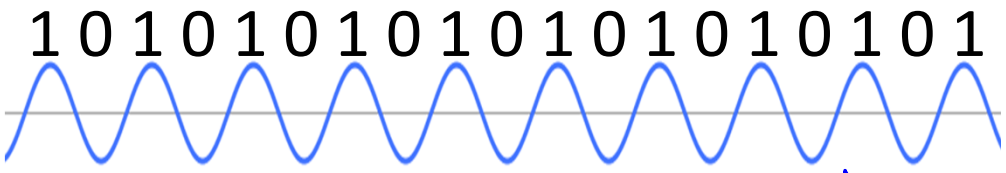
- How rapidly can we send information over a link?
  - Nyquist limit (~1924) »
  - Shannon capacity (1948) »
- Practical systems are devised to approach these limits

Key Channel Properties

- The bandwidth (B), signal strength (S), and noise strength (N)
  - B limits the rate of transitions
  - S and N limit how many signal levels we can distinguish

Nyquist Limit

- The maximum <u>symbol</u> rate is 2B



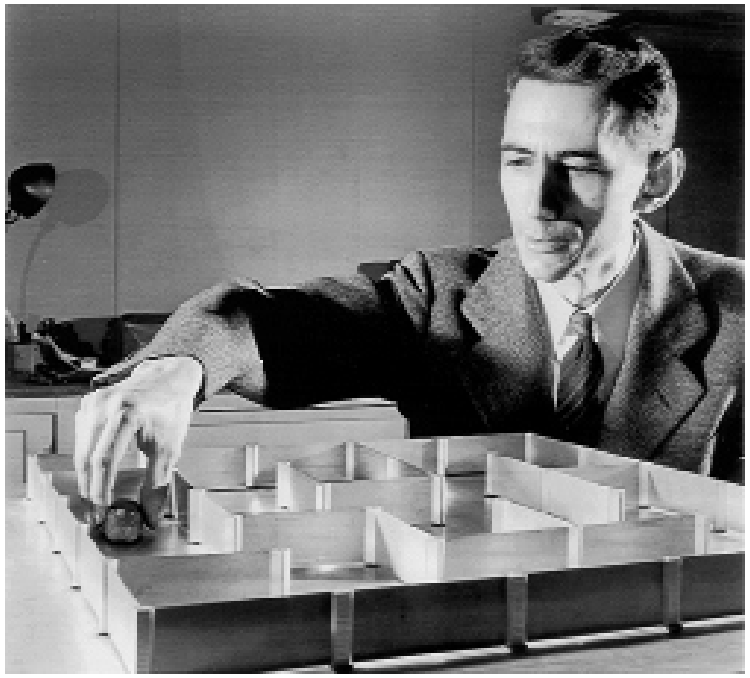
$\log_2 V$ bits

- Thus if there are V signal levels, ignoring noise, the maximum bit rate is: $R = 2B \log_2 V$ bits/sec

Claude Shannon (1916-2001)

- Father of information theory
  - "A Mathematical Theory of Communication", 1948
- Fundamental contributions to digital computers, security, and communications

Electromechanical mouse that "solves" mazes!



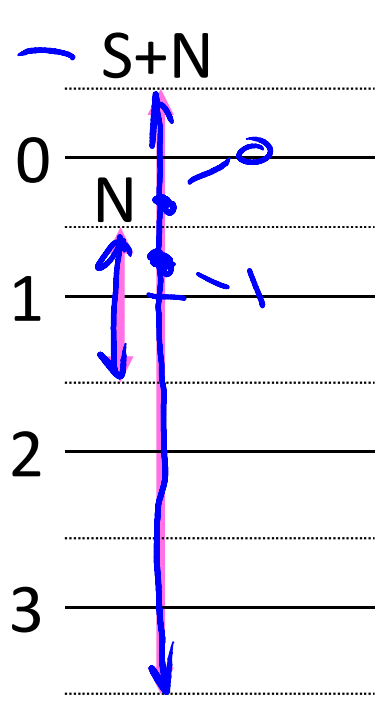
Credit: Courtesy MIT Museum

Shannon Capacity

- How many levels we can distinguish depends on S/N
  - Or SNR, the Signal-to-Noise Ratio
  - Note noise is random, hence some errors
- SNR given on a log-scale in deciBels:
  - $SNR_{dB} = 10\log_{10}(S/N)$

$\frac{S}{N} = 1000 \rightarrow 30$ dB

100 → 20 dB
10 → 10 dB
2 → 3 dB



Shannon Capacity (2)

- Shannon limit is for capacity (C), the maximum information carrying rate of the channel:

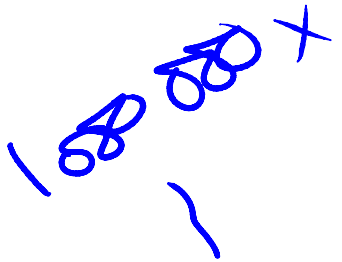
$$C = B \log_2(1 + S/N) \text{ bits/sec}$$

bits

$\frac{S+N}{N} = \frac{S}{N} + 1$

Wired/Wireless Perspective

- Wires, and Fiber
  - Engineer link to have requisite SNR and B
  - → Can fix data rate
- Wireless
  - Given B, but SNR varies greatly, e.g., up to 60 dB!
  - → Can't design for worst case, must adapt data rate



Wired/Wireless Perspective (2)

- Wires, and Fiber

  Engineer SNR for data rate

  – Engineer link to have requisite SNR and B

  →Can fix data rate

- Wireless

  Adapt data rate to SNR

  – Given B, but SNR varies greatly, e.g., up to 60 dB!

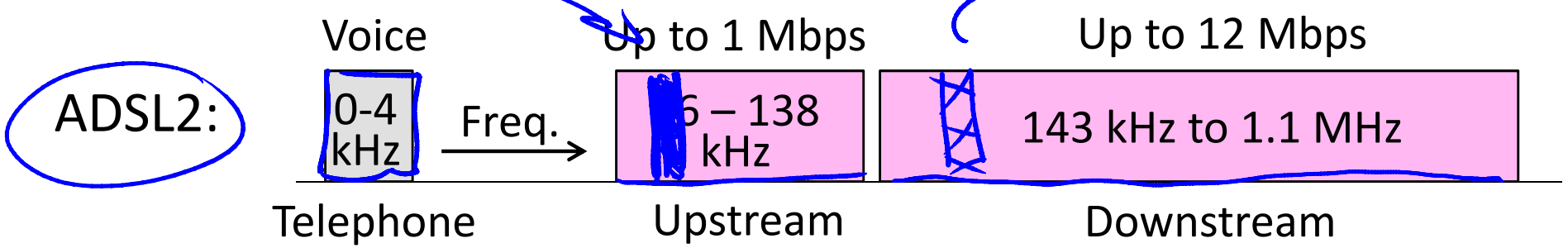
  →Can't design for worst case, must adapt data rate

Putting it all together – DSL

- DSL (Digital Subscriber Line, see §2.6.3) is widely used for broadband; many variants offer 10s of Mbps
  - Reuses twisted pair telephone line to the home; it has up to ~2 MHz of bandwidth but uses only the lowest ~4 kHz

DSL (2)

- DSL uses passband modulation (called OFDM §2.5.1)
  - Separate bands for upstream and downstream (larger)
  - Modulation varies both amplitude and phase (called QAM)
  - High SNR, up to 15 bits/symbol, low SNR only 1 bit/symbol



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