Introduction to Computer Networks

30 September 2016
Where we are in the Course

- Beginning to work our way up starting with the Physical layer

| Application |
| Transport |
| Network |
| Link |
| Physical |
Scope of the Physical Layer

- Concerns how signals are used to transfer message bits over a link
  - Wires etc. carry analog signals
  - We want to send digital bits

10110
...
1011
0
Types of Links

- **Guided/Wired Media**
  - Twisted Pair Cables
  - Coax Cables
  - Power Lines
  - Fiber Optics

- **Unguided/Wireless Media**
  - Radio
  - Microwave
  - IR & Light/Laser
  - Satellites
Types of Links

- **Full-duplex**
  - Bidirectional

- **Half-duplex**
  - Bidirectional

- **Simplex**
  - Unidirectional
• Analog signals encode digital bits. We want to know what happens as signals propagate over media.

![Signal Diagram]

10110 ...

...1011
What happens to signals over a media?

1. The signal is delayed
2. The signal is attenuated
3. Frequencies above a cutoff are highly attenuated
4. Noise is added to the signal
Frequency Representation

- A signal over time can be represented by its frequency components (called Fourier analysis)

\[ g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n ft) + \sum_{n=1}^{\infty} b_n \cos(2\pi n ft) \]

Signal over time

weights of harmonic frequencies

amplitude
Effect of Less Bandwidth

- Fewer frequencies (=less bandwidth) degrades signal
How fast can we send information?

- Two guiding principles
  - 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 symbol rate is $2B$

- 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:
  – $\text{SNR}_{\text{dB}} = 10\log_{10}(S/N)$
Shannon Capacity (2)

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

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

• **Media** propagate **signals** that carry **bits** of information

• We’ll look at some common types:
  – Wires »
  – Fiber (fiber optic cables) »
  – Wireless »
Wires – Twisted Pair

- Very common; used in LANs and telephone lines
  - Twists reduce radiated signal

Category 5 UTP cable with four twisted pairs
Wires – Coaxial Cable

- Also common. Better shielding for better performance

- Other kinds of wires too: e.g., electrical power (§2.2.4)
Fiber

- Long, thin, pure strands of glass
  - Enormous bandwidth (high speed) over long distances

![Diagram of fiber optic setup]

- Light source (LED, laser)
- Light trapped by total internal reflection
- Optical fiber
- Photo-detector
Fiber (2)

- Two varieties: multi-mode (shorter links, cheaper) and single-mode (up to ~100 km)