CS 498wn: Wireless Networking

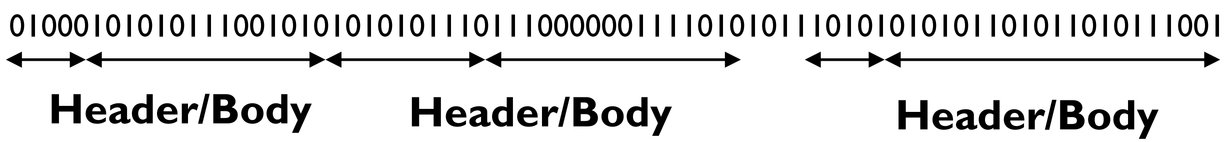
Physical Layer – Coding and Modulation

 Fall 2017

From Signals to Packets

Packet Transmission

Packets

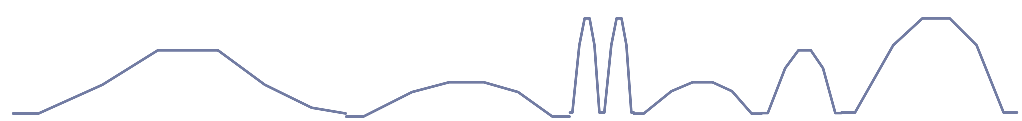


Bit Stream

0 0 1 0 1 1 1 0 0 0 1

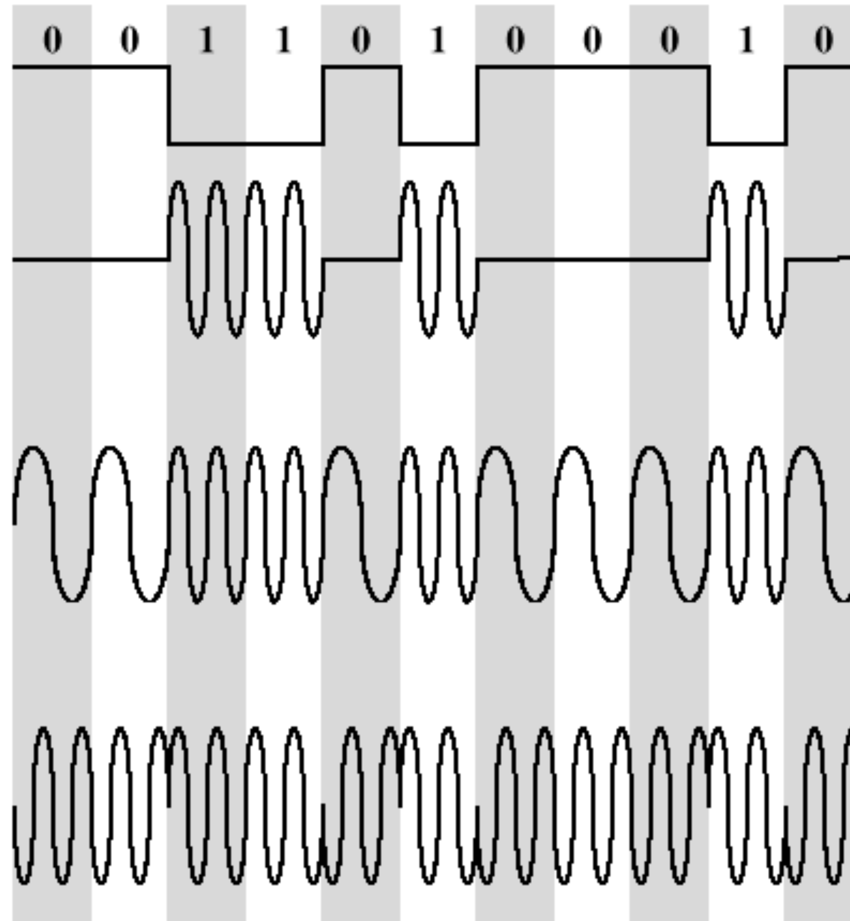
Digital Signal

Analog Signal



Basic Modulation Techniques

- Encode digital data in an analog signal
- Amplitude-shift keying (ASK)
  - Amplitude difference of carrier frequency
- Frequency-shift keying (FSK)
  - Frequency difference near carrier frequency
- Phase-shift keying (PSK)
  - Phase of carrier signal shifted



Amplitude-Shift Keying

- Binary digit (1)
  - Represented by presence of carrier, at constant amplitude
- Binary digit (0)
  - Represented by absence of carrier

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases}$$

  - where the carrier signal is $A\cos(2\pi f_c t)$
- Inefficiencies
  - Sudden gain changes
  - Only used when bandwidth is not a concern, e.g. on voice lines (< 1200 bps) or on digital fiber

Binary Frequency-Shift Keying (BFSK)

- Binary digits (0 and 1)
  - Represented by two different frequencies near the carrier frequency

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

    - where f_1 and f_2 are offset from carrier frequency f_c by equal but opposite amounts
- Less susceptible to error than ASK
- Sometimes used for radio (3 to 30 MHz) or coax
- Demodulator looks for power around f_1 and f_2

Multiple Frequency-Shift Keying (MFSK)

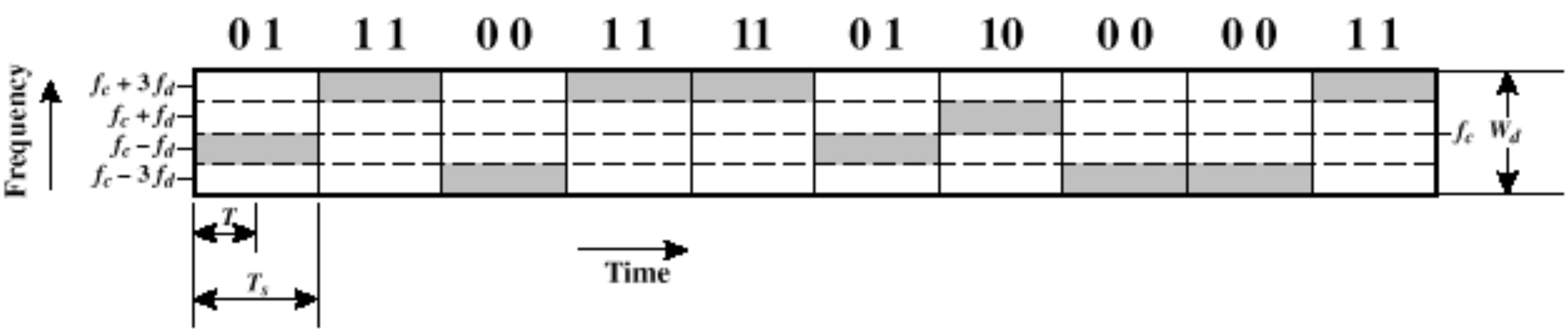
- More than two frequencies are used
  - More bandwidth efficient but more susceptible to error

$$s_i(t) = A\cos 2\pi f_i t \quad 1 \le i \le M$$

  - $f_i = f_c + (2i - 1 - M)f_d$
  - f_c = the carrier frequency
  - f_d = the difference frequency
  - M = number of different signal elements = 2^L
  - L = number of bits per signal element

Multiple Frequency-Shift Keying (MFSK)

- More than two frequencies are used
  - More bandwidth efficient but more susceptible to error
- Each symbol represents L bits
  - Symbol length is $T_s = LT$ seconds, where T is the bit period



Phase-Shift Keying (PSK)

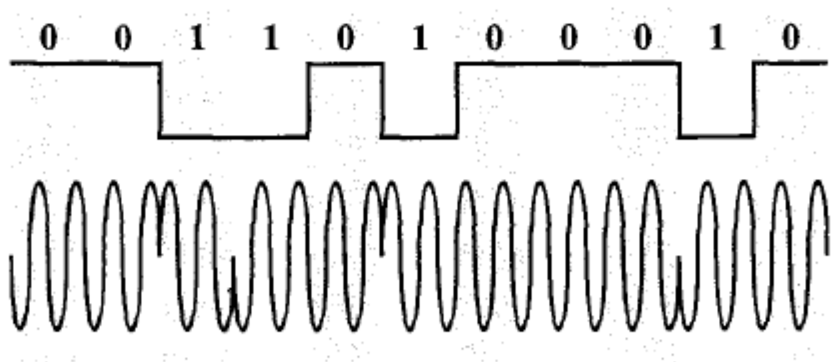
- Two-level PSK (BPSK)
  - Uses two phases to represent binary digits

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ A\cos(2\pi f_c t + \pi) & \text{binary 0} \end{cases}$$

$$= \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ -A\cos(2\pi f_c t) & \text{binary 0} \end{cases}$$

Phase-Shift Keying (PSK)

- Differential PSK (DPSK)
  - Phase shift with reference to previous bit
    - Binary 0
      - Signal of same phase as previous signal burst
    - Binary 1
      - Signal of opposite phase to previous signal burst



Phase-Shift Keying (PSK)

- Four-level PSK (QPSK)
  - Each element represents more than one bit
  - Ex. Phase shift of multiples of 2π (90°)

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \frac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \frac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \frac{\pi}{4}\right) & 10 \end{cases}$$

Phase-Shift Keying (PSK)

- Multilevel PSK
  - Each angle has more than one amplitude
  - Multiple signals elements

$$D = \frac{R}{L} = \frac{R}{\log_2 M}$$

- D = modulation rate, baud
- R = data rate, bps
- M = number of different signal elements = 2^L
- L = number of bits per signal element

Performance

- B_T : Bandwidth of modulated signal
- R: Bit rate
  - $0 < r < 1$; related to how signal is filtered

- ASK, PSK $B_T = (1+r)R$
- FSK $B_T = 2DF+(1+r)R$

  $DF = f_2 - f_c = f_c - f_1$

Performance

- B_T : Bandwidth of modulated signal
- R: Bit rate
  - 0 < r < 1; related to how signal is filtered

- MPSK
$$B_T = \left(\frac{1+r}{L}\right)R = \left(\frac{1+r}{\log_2 M}\right)R$$

- MFSK
$$B_T = \left(\frac{(1+r)M}{\log_2 M}\right)R$$

- L: Number of bits encoded per signal element
- M: Number of different signal elements

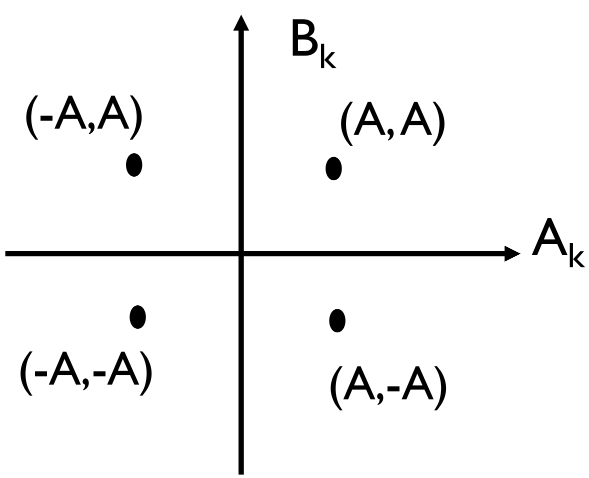
Quadrature Amplitude Modulation (QAM)

- QAM uses two-dimensional signaling
  - ASK and PSK
  - A_k modulates in-phase $\cos(2\pi f_c t)$
  - B_k modulates quadrature phase $\sin(2\pi f_c t)$

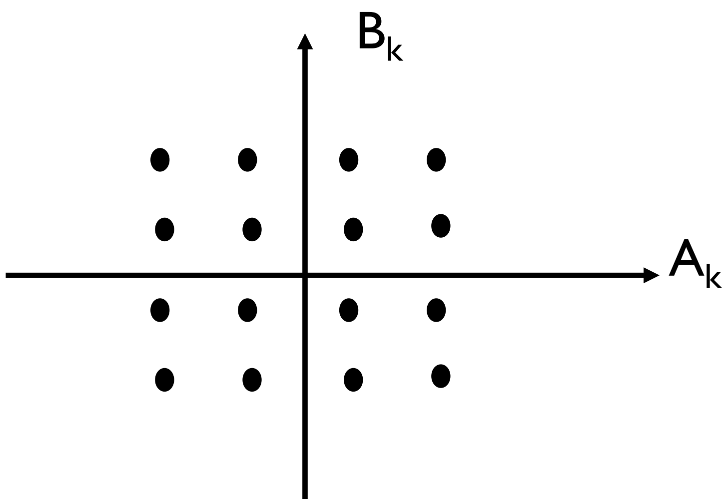
$$s(t) = A_k(t)\cos 2\pi f_c t + B_k(t)\sin 2\pi f_c t$$

Signal Constellations

- Each pair (A_k, B_k) defines a point in the plane
- Signal constellation set of signaling points



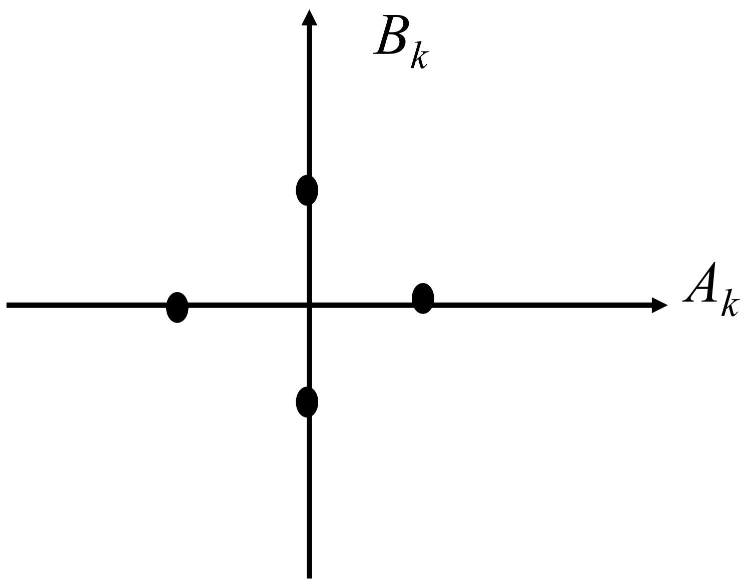
4 possible points per *T* sec.
2 bits / pulse



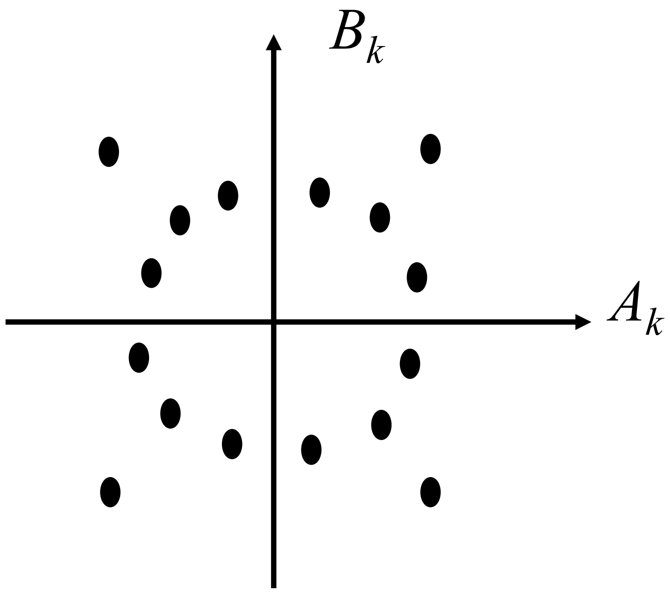
16 possible points per *T* sec.
4 bits / pulse

Other Signal Constellations

- Point selected by amplitude & phase



4 possible points per *T* sec.



16 possible points per *T* sec.

Adapting to Channel Conditions

- Channel conditions vary
  - Physical environment of the channel
  - Changes over time (slow and fast fading)
- Fixed coding/modulation scheme will often be inefficient
  - Too conservative for good channels
  - Too aggressive for bad channels
- Adjust coding/modulation based on channel conditions – "rate" adaptation
  - Controlled by the MAC protocol
  - E.g. 802.11a: BPSK – QPSK – 16-QAM – 64 QAM

Bad ⟷ Good

Some Examples

- Gaussian Frequency Shift Keying
  - 1/-1 is a positive/negative frequency shift from base
  - Gaussian filter is used to smooth pulses– reduces the spectral bandwidth – "pulse shaping"
  - Used in Bluetooth
- Differential quadrature phase shift keying
  - Variant of "regular" frequency shift keying
  - Symbols are encoded as changes in phase
  - Requires decoding on $\pi/4$ phase shift
  - Used in 802.11b networks
- Quadrature Amplitude modulation
  - Combines amplitude and phase modulation
  - Uses two amplitudes and 4 phases to represent the value of a 3 bit sequence