Modulation

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Modulation

• Digital modulation: digital data (0 and 1) is translated into an analog signal --- the baseband signal.

• E.g., dial-up modem. The telephone line can only transmit analog signals.

• In wired LAN, digital transmission is used.

• Wireless networks: digital transmission can not be used.
The basic sine signal

- $s(t) = A \sin(2\pi ft + \phi)$
  - Amplitude: $A$
  - Frequency: $f$
  - Phase: $\phi$
  - Wavelength: $\lambda$, $\lambda f = v$ (speed of light).
Figure 2.3 \[ s(t) = A \sin (2\ ft + \phi) \]
Digital modulation

• Three basic methods
  – Amplitude shift keying (ASK)
  – Frequency shift keying (FSK)
  – Phase shift keying (PSK)
Analog modulation

• Shift the center frequency of the baseband signal generated by the digital modulation up to the radio carrier.

• Antennas: the size of an antenna must be in the order of the signal’s wavelength to be effective.
  – The wavelength of 1MHz signal is about hundreds of meters; while that of 1GHz signal is about .1 meters.
  – Recall the frequency of the cordless phone: 2.4 GHz or 5.8 GHz.
Analog modulation

- Frequency division multiplexing
  - Analog modulation shifts the baseband signals to different carrier frequencies.
Analog modulation

• Medium characteristics
  – Signal propagation depends heavily on the wavelength of the signal.
  – The larger the wavelength, the better the penetration.
  – The smaller the wavelength, the more the behavior resembles that of light.
  – Long waves for submarines, short waves for handheld devices, very short waves for directed microwave transmission.
Analog modulation

• Amplitude modulation (AM)
• Frequency modulation (FM)
• Phase modulation (PM)
Modulation

Digital data (101101001) → Digital modulation → Analog baseband signal → Analog modulation → Radio carrier → Radio transmitter

Radio carrier → Analog demodulation → Analog baseband signal → Synchronization decision → Digital data (101101001) → Radio receiver
Amplitude shift keying (ASK)

- Use different amplitude to represent 0 and 1.
  - Simple, low bandwidth
  - Sensitive to interference.
    - Multi-path propagation, noise or path loss heavily influence the amplitude.
    - A constant amplitude in wireless environment cannot be guaranteed.

- Used in wired optical communication.
  - A light pulse =1, no light =0.
Frequency shift keying (FSK)

- **Binary FSK (BFSK)**
  - One frequency for 0 and one frequency for 1.
  - Needs larger bandwidth

- **Avoid discontinuity**
  - Discontinuity creates high frequencies as side effects.
  - Continuous phase modulation (CPM) can be used.

- **Demodulation:**
  - Use two bandpass filters for 2 frequencies.
Phase shift keying (PSK)

- Use shift in phase to represent data.
- Binary PSK (BPSK)
  - Shift the phase by 180.
- Synchronization is important
- More resistant to interference
- More complex transmitters and receivers.
ASK, FSK and PSK
Advanced modulation

- Advanced Frequency Shift Keying
- Advanced phase shift keying
- Quadrature Amplitude Modulation
- Hierarchical Modulation
Advanced Frequency Shift Keying

• Minimum shift keying (MSK)
• Goal: avoid sudden change.
• Two frequencies are used, $f_2 = 2f_1$.
• Separate into even and odd bits.
• The duration of each bit is doubled.
  – A higher frequency is chosen if even and odd bits are equal.
  – The signal is inverted if the odd bit equals 0.
• Exercise: verify that this scheme does not have phase shift.
MSK

Data

Even bits

Odd bits

Low frequency

High frequency

MSK signal

<table>
<thead>
<tr>
<th>bit</th>
<th>even</th>
<th>odd</th>
</tr>
</thead>
<tbody>
<tr>
<td>signal value</td>
<td>h n n h</td>
<td>- - + +</td>
</tr>
</tbody>
</table>

h: high frequency
n: low frequency
+: original signal
-: inverted signal

No phase shifts!
Advanced phase shift keying

- Phase domain: use a vector (or a point) in the plane to represent the signal.
- Length of the vector: amplitude:
- Angle: phase.

\[ I = M \cos \phi \]
\[ Q = M \sin \phi \]
Advanced phase shift keying

- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - robust, used in satellite systems
QPSK (Quadrature Phase Shift Keying)

- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex

- Transmitter and receiver are synchronized very often.
Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- It is possible to code $n$ bits using one symbol
- $2^n$ discrete levels, $n=2$ identical to QPSK
- Bit error rate increases with $n$, but less errors compared to comparable PSK schemes
Quadrature Amplitude Modulation

- Example: 16-QAM (4 bits = 1 symbol)
- Symbols 0011 and 0001 have the same phase $\phi$, but different amplitude $a$. 0000 and 1000 have different phase, but same amplitude.
- Used in standard 9.6K bit/s modems
Hierarchical Modulation

- DVB-T (Digital TV standard) modulates two separate data streams onto a single DVB-T stream.
  - A 64 QAM can code 6 bits per symbol.
  - The 2 most significant bits are used for the QPSK signal.
  - good reception: resolve the entire 64QAM constellation.
  - poor reception: resolve only QPSK portion.
  - Standard resolution data is coded with high priority.
  - High resolution data is coded with low priority.
Multi-carrier modulation

• This is used to improve the robustness to multi-path fading and Inter Symbol Interference (ISI).
• ISI: adjacent symbols get messed up, due to multi-path fading.
• Higher data rate are more vulnerable to ISI.
Multi-carrier modulation (MCM)

- Split the high data rate stream to many low data rate streams, each being sent through an independent carrier frequency.
- Orthogonal frequency division multiplexing (OFDM): the maximum of one subcarrier frequency appears exactly at a frequency where all the others subcarriers are zero.
Multi-carrier modulation (MCM)

- One type of frequency division multiplexing.
- Frequency selective fading only influences one subcarriers and not the whole signal.
Summary

• Modulation
  – Amplitude modulation
  – Frequency modulation
  – Phase modulation

• Advanced modulation
  – Advanced frequency shift keying
  – Advanced phase shift keying
  – Quadrature amplitude modulation
  – Multi-carrier modulation

• Cellular systems