ECE2305 Lecture Slides

William Stallings Data and Computer Communications Eighth Edition
Section 5.2 – “Digital Data, Analog Signals”

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Adapted from Prentice Hall instructor resources
Basics of Signal Encoding

- Important function of the physical layer: Convert data (e.g. bits) to signals (e.g. voltages).
- The signal must be designed to **efficiently propagate through the medium**.
- The signal must also be designed so that the receiver can **correctly interpret** it.
How to convey
digital information with signals

• Need two things:
  – A set of $M=2^L$ distinct signals
    • Each signal is called a “symbol”
    • The set is called an “alphabet”
  – A unique mapping between blocks of $N$ bits and each signal

• Example (N=2)
  – Signal set = \{ $\square$ $\square$ $\wedge$ $\vee$ \} ($2^2 = 4$ signals)
  – Unique mapping
    • Logical 00 <-> $\square$
    • Logical 01 <-> $\Box$
    • Logical 10 <-> $\wedge$
    • Logical 11 <-> $\vee$

What does this signal mean? $\Box\wedge\Box$
An Example of a Bad Alphabet

Why is this alphabet bad?
“Analog” Signaling Basics

• Recall “digital” signaling, e.g.

• Digital signaling is inappropriate in many scenarios (interference with other signals or inefficient propagation):
  – Wireless communication
  – Optical communication
  – Cable modems
  – Digital subscriber loops (DSL)
  – Even basic voiceband modems (300Hz-3400Hz channel)

• Need “analog” signals in these cases
Common “Analog” Signals for Communication

• Main idea: Alphabet composed of sinusoidal signals with distinct amplitude, frequency, and/or phase shifts

• Sinusoidal signals allow control of signal spectrum
  – Efficient propagation in desired medium
  – Avoid interference with other signals

• Pure methods:
  – Amplitude shift keying (ASK)
  – Frequency shift keying (FSK)
  – Phase shift keying (PSK)

• Hybrid methods:
  – Quadrature amplitude modulation (QAM) (signals distinguished by both amplitude and phase shifts)
Figure 5.7  Modulation of Analog Signals for Digital Data
Amplitude Shift Keying

- encode data in signal amplitude, e.g.
  - Logical 0 -> $0\sin(\omega t)$
  - Logical 1 -> $A\sin(\omega t)$
- Can have more than two amplitudes, e.g.
  - Logical 00 -> $0\sin(\omega t)$
  - Logical 01 -> $A\sin(\omega t)$
  - Logical 10 -> $2A\sin(\omega t)$
  - Logical 11 -> $3A\sin(\omega t)$
- Used for
  - up to 1200bps telephone modems
  - optical fiber (light on/off)

Higher data rate but either increased power or likelihood of error at receiver
Frequency Shift Keying

- encode data in signal frequency, e.g.
  - Logical 0 $\rightarrow$ $\sin(\omega t)$
  - Logical 1 $\rightarrow$ $\sin(2\omega t)$
- Can have more than two frequencies, e.g.
  - Logical 00 $\rightarrow$ $\sin(\omega t)$
  - Logical 01 $\rightarrow$ $\sin(2\omega t)$
  - Logical 10 $\rightarrow$ $\sin(3\omega t)$
  - Logical 11 $\rightarrow$ $\sin(4\omega t)$
- Better error resistance than ASK
- Used in old voiceband modems (300 bps)

Higher data rate but either increased bandwidth or increased likelihood of error at receiver
Phase Shift Keying

- encode data in signal phase, e.g.
  - Logical 0 → sin(wt+0)
  - Logical 1 → sin(wt+π)
- Can have more than two phases, e.g.
  - Logical 00 → sin(wt+0)
  - Logical 01 → sin(wt+π/2)
  - Logical 10 → sin(wt+π)
  - Logical 11 → sin(wt+3π/2)
- This is called quadrature PSK (QPSK) – very popular for wireless communication

Higher data rate but increased likelihood of error at receiver
QPSK Modulator Block Diagram

- **Binary input**
  - \( R = \frac{1}{T_b} \)
  - \( a_n = \pm 1 \)
- **2-bit serial-to-parallel converter**
- **I(t)**
- **Q(t)**
  - \( b_n = \pm 1 \)
- **Carrier oscillator**
  - \( \frac{\cos 2\pi f_c t}{\sqrt{2}} \)
  - \( \frac{-\sin 2\pi f_c t}{\sqrt{2}} \)
- **Phase shift**
  - \( \pi/2 \)
- **Signal out**
  - \( s(t) \)
### Spectral Efficiency

\[ \eta = \frac{R}{B} \]

<table>
<thead>
<tr>
<th></th>
<th>( r = 0 )</th>
<th>( r = 0.5 )</th>
<th>( r = 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASK</strong></td>
<td>1.0</td>
<td>0.67</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Multilevel FSK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M = 4, L = 2 )</td>
<td>0.5</td>
<td>0.33</td>
<td>0.25</td>
</tr>
<tr>
<td>( M = 8, L = 3 )</td>
<td>0.375</td>
<td>0.25</td>
<td>0.1875</td>
</tr>
<tr>
<td>( M = 16, L = 4 )</td>
<td>0.25</td>
<td>0.167</td>
<td>0.125</td>
</tr>
<tr>
<td>( M = 32, L = 5 )</td>
<td>0.156</td>
<td>0.104</td>
<td>0.078</td>
</tr>
<tr>
<td><strong>PSK</strong></td>
<td>1.0</td>
<td>0.67</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Multilevel PSK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M = 4, L = 2 )</td>
<td>2.00</td>
<td>1.33</td>
<td>1.00</td>
</tr>
<tr>
<td>( M = 8, L = 3 )</td>
<td>3.00</td>
<td>2.00</td>
<td>1.50</td>
</tr>
<tr>
<td>( M = 16, L = 4 )</td>
<td>4.00</td>
<td>2.67</td>
<td>2.00</td>
</tr>
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<td>5.00</td>
<td>3.33</td>
<td>2.50</td>
</tr>
</tbody>
</table>
Bit Error Rates

![Graph showing the theoretical bit error rate for multilevel FSK and PSK](image)

Figure 5.13 Theoretical Bit Error Rate for Multilevel FSK and PSK
Hybrid method: Quadrature Amplitude Modulation (QAM)

- Basic idea: encode data in both **phase** and **amplitude**, e.g.
  - Logical 00 -> $A \cos(wt) + A \sin(wt)$
  - Logical 01 -> $A \cos(wt) - A \sin(wt)$
  - Logical 10 -> $-A \cos(wt) + A \sin(wt)$
  - Logical 11 -> $-A \cos(wt) - A \sin(wt)$

- No binary methods, but lots of higher order QAM:
  - 4QAM (2 bits per signal, like QPSK)
  - 16QAM (4 bits per signal)
  - 64QAM (6 bits per signal)
  - 256QAM (8 bits per signal)
  - ...

- Used in applications where spectral efficiency is critical, e.g. DSL and high data rate wireless
QAM Modulator Block Diagram
Which “Analog” Modulation Scheme Should I Use?

• **It depends...**

• **Power efficiency** important?
  – FSK is energy efficient but not bandwidth efficient

• **Spectral efficiency** important?
  – QAM, PSK, ASK are more bandwidth efficient but less energy efficient

• **Optical** systems?
  – ASK (very difficult to control/detect phase in optical transmission)

• Lots of tradeoffs. Best choice depends on the application.
Figure 7.66  Comparison of several modulation methods at $10^{-5}$ symbol error probability.

From Communication Systems Engineering
Proakis & Salehi