Physical Layer (Part 2)
Data Encoding Techniques
Data Encoding Techniques

- Digital Data, Analog Signals [modem]
- Digital Data, Digital Signals [wired LAN]
- Analog Data, Digital Signals [codec]
  - Frequency Division Multiplexing (FDM)
  - Wave Division Multiplexing (WDM) [fiber]
  - Time Division Multiplexing (TDM)
  - Pulse Code Modulation (PCM) [T1]
  - Delta Modulation
Figure 2-23. The use of both analog and digital transmissions for a computer-to-computer call. Conversion is done by the modems and codecs.
Digital Data, Analog Signals

[Example – modem]

- Basis for analog signaling constant-frequency is a continuous, signal known as the carrier frequency.
- Digital data is encoded by modulating one of the three characteristics of the carrier: amplitude, frequency, or phase or some combination of these.
Signal Modulation

A binary signal

Amplitude modulation

Frequency modulation

Phase modulation

Figure 2–24.
All advanced modems use a combination of modulation techniques to transmit multiple bits per baud.

Multiple amplitude and multiple phase shifts are combined to transmit several bits per symbol.

QPSK (Quadrature Phase Shift Keying) uses multiple phase shifts per symbol.

Modems actually use Quadrature Amplitude Modulation (QAM).

These concepts are explained using constellation points where a point determines a specific amplitude and phase.
Figure 2-25.

(a) QPSK.
(b) QAM-16.
(c) QAM-64.

\[ V = 64 \]
\[ v = \log_2 V = 6 \]
Digital Data, Digital Signals

[the technique is used in a number of LANs]

- Digital signal – is a sequence of discrete, discontinuous voltage pulses.
- Bit duration :: the time it takes for the transmitter to emit the bit.
- Issues
  - Bit timing (sender/receiver clock drift)
  - Recovery from signal
  - Noise immunity
NRZ (Non-Return-to-Zero) Codes

Uses two different voltage levels (one positive and one negative) as the signal elements for the two binary digits.

NRZ-L (Non-Return-to-Zero-Level)
The voltage is constant during the bit interval.

1 ↔ negative voltage
0 ↔ positive voltage

NRZ-L is used for short distances between a terminal and modem or terminal and computer.
NRZ (Non-Return-to-Zero) Codes

NRZ-I (Non-Return-to-Zero-Invert on ones)

The voltage is constant during the bit interval.

1 ⇔ existence of a signal transition at the beginning of the bit time
   (either a low-to-high or a high-to-low transition)

0 ⇔ no signal transition at the beginning of the bit time

NRZI is a differential encoding scheme (i.e.,
   the signal is decoded by comparing the
   polarity of adjacent signal elements.)
Bi-phase codes - require at least one transition per bit time and may have as many as two transitions.

→ the maximum modulation rate is twice that of NRZ

→ greater transmission bandwidth is required.

Advantages:

Synchronization - with a predictable transition per bit time the receiver can “synch” on the transition [self-clocking].

No d.c. component

Error detection - the absence of an expected transition can be used to detect errors.
Manchester Encoding

- There is **always** a mid-bit transition {which is used as a clocking mechanism}.
- The **direction** of the mid-bit transition represents the digital data.

1 ⇔ **low-to-high** transition

0 ⇔ **high-to-low** transition

Consequently, there may be a second transition at the beginning of the bit interval.

Used in 802.3 baseband coaxial cable and CSMA/CD twisted pair.

Some textbooks disagree on this definition!!
Differential Manchester Encoding

- mid-bit transition is **ONLY** for clocking.

<table>
<thead>
<tr>
<th>1</th>
<th>absence of transition at the beginning of the bit interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>presence of transition at the beginning of the bit interval</td>
</tr>
</tbody>
</table>

Differential Manchester is both differential and bi-phase.

Note – the coding convention for Differential Manchester is the opposite convention from NRZI.

Used in 802.5 (token ring) with twisted pair.

* Modulation rate for Manchester and Differential Manchester is **twice** the data rate ➔ inefficient encoding for long-distance applications.
Bi-Polar Encoding

1 ⇔ alternating +1/2, -1/2 voltage
0 ⇔ 0 voltage

- Has the same issues as NRZI for a long string of 0's.
- A systemic problem with polar is the polarity can be backwards.
# Digital Encoding Techniques

**Unipolar NRZ**

**Polar NRZ**

**NRZ-Inverted (Differential Encoding)**

**Bipolar Encoding**

**Manchester Encoding**

**Differential Manchester Encoding**

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León-Garcia & Widjaja: Communication Networks
The most common technique for using digital signals to encode analog data is PCM.

Example: To transfer analog voice signals off a local loop to digital end office within the phone system, one uses a codec.

Because voice data limited to frequencies below 4000 HZ, a codec makes 8000 samples/sec. (i.e., 125 microsec/sample).
Multiplexing {general definition} :: Sharing a resource over time.

(a)  
A → B → C
(b)  
MUX
A → MUX
B → MUX
C → MUX

Trunk group

Leon-Garcia & Widjaja: Communication Networks
Frequency Division Multiplexing (FDM) vs Time Division Multiplexing (TDM)

Example:
4 users

K & R

Advanced Computer Networks
Data Encoding
(a) Individual signals occupy $H$ Hz

(b) Combined signal fits into channel bandwidth
Figure 2-31. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.
Wavelength Division Multiplexing

Figure 2-32.
When a communication link is shared by time-division multiplexing, time is divided into frames. Each frame is divided into time slots that are allocated in a fixed order to the different incoming channels.
In statistical multiplexing, the multiplexer visits the incoming channel buffers in some order. The multiplexer empties a buffer before moving to the next one. The buffer contents are tagged to indicate their incoming channel. An idle channel does not waste transmission time.
T1 System

Leon-Garcia & Widjaja: Communication Networks
T1 - TDM Link

Figure 2-33. T1 Carrier (1.544Mbps)

- Bit 1 is a framing code
- 7 Data bits per channel per sample
- Bit 8 is for signaling

193-bit frame (125 μsec)
Pulse Code Modulation (PCM)

T1 example for voice-grade input lines:

implies both codex conversion of analog to digital signals (PCM) and TDM.
Pulse Code Modulation Stages

Figure 5.17 PCM Block Diagram
Pulse Code Modulation (PCM)

- Analog signal is sampled.
- Converted to discrete-time continuous-amplitude signal (Pulse Amplitude Modulation)
- Pulses are quantized and assigned a digital value.
  - A 7-bit sample allows 128 quantizing levels.
Pulse Code Modulation (PCM)

- PCM uses non-linear encoding, i.e., amplitude spacing of levels is non-linear.
  - There is a greater number of quantizing steps for low amplitude.
  - This reduces overall signal distortion.
- This introduces *quantizing error* (or noise).
- PCM pulses are then encoded into a digital bit stream.
- 8000 samples/sec × 7 bits/sample = 56 Kbps for a single voice channel.
Figure 5.16 Pulse-Code Modulation Example

<table>
<thead>
<tr>
<th>PAM value</th>
<th>1.1</th>
<th>9.2</th>
<th>15.2</th>
<th>10.8</th>
<th>5.6</th>
<th>2.8</th>
<th>2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantized code number</td>
<td>1</td>
<td>9</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PCM code</td>
<td>0001</td>
<td>1001</td>
<td>1111</td>
<td>1010</td>
<td>0101</td>
<td>0010</td>
<td>0010</td>
</tr>
</tbody>
</table>
Figure 5.18 Effect of Nonlinear Coding
Delta Modulation (DM)

- The basic idea in delta modulation is to approximate the derivative of analog signal rather than its amplitude.
- The analog data is approximated by a staircase function that moves up or down by one quantization level at each sampling time. => output of DM is a single bit.
- PCM preferred because of better SNR characteristics.
Figure 5.20 Example of Delta Modulation
Data Encoding Summary

- Digital Data, Analog Signals [modem]
  - Three forms of modulation (amplitude, frequency and phase) used in combination to increase the data rate.
  - Constellation diagrams (QPSK and QAM)

- Digital Data, Digital Signals [wired LANs]
  - Tradeoffs between self clocking and required frequency.
  - Biphas e, differential, NRZL, NRZI, Manchester, differential Manchester, bipolar.
Data Encoding Summary

- Analog Data, Digital Signals [codec]
  - Multiplexing Detour:
    • Frequency Division Multiplexing (FDM)
    • Wave Division Multiplexing (WDM) [fiber]
    • Time Division Multiplexing (TDM)
    • Statistical TDM (Concentrator)

- Codex functionality:
  - Pulse Code Modulation (PCM)
  - T1 line {classic voice-grade TDM}
  - PCM Stages (PAM, quantizer, encoder)
  - Delta Modulation