Physical Layer - Part 2
Data Encoding Techniques
Analog and Digital Transmissions

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**.
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
Digital Data, Analog Signals

[Example - modem]

- Basis for analog signaling is a continuous, constant-frequency 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.
A binary signal

Amplitude modulation

Frequency modulation

Phase modulation

Figure 2-24.
Modems

- 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.
Constellation Diagrams

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

Figure 2-25.

\[
V = 64 \\
\nu = \log_2 V = 6
\]
Digital Data, Digital Signals
[the technique 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
  - 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.

<table>
<thead>
<tr>
<th>1</th>
<th>negative voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>positive voltage</td>
</tr>
</tbody>
</table>

**NRZ-L** is used for short distances between 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 $\Leftrightarrow$ existence of a signal transition at the beginning of the bit time (either a low-to-high or a high-to-low transition)

0 $\Leftrightarrow$ 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

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.

\[
\begin{align*}
1 & \Leftrightarrow \text{low-to-high transition} \\
0 & \Leftrightarrow \text{high-to-low transition}
\end{align*}
\]

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.**

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 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.
Unipolar NRZ

Polar NRZ

NRZ-Inverted (Differential Encoding)

Bipolar Encoding

Manchester Encoding

Differential Manchester Encoding

Copyright ©2000 The McGraw Hill Companies

Leon-Garcia & Widjaja: *Communication Networks*
Analog Data, Digital Signals
[Example – PCM (Pulse Code Modulation)]

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

Figure 4.1

Leon-Garcia & Widjaja: Communication Networks
Frequency Division Multiplexing

(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.
Time Division Multiplexing

(a) Each signal transmits 1 unit every $3T$ seconds

(b) Combined signal transmits 1 unit every $T$ seconds
Time Division Multiplexing

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.
Concentrator
[Statistical Multiplexing]

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
T1 - TDM Link

Figure 2-33. T1 Carrier (1.544Mbps)
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.
- $8000 \text{ samples/sec} \times 7 \text{ bits/sample} = 56 \text{ Kbps}$ for a single voice channel.
Figure 5.10  Pulse Code Modulation

<table>
<thead>
<tr>
<th>Digit</th>
<th>Binary equivalent</th>
<th>PCM waveform</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0000</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0010</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0011</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0100</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0101</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0110</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0111</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1001</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1010</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1011</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1101</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1110</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1111</td>
<td></td>
</tr>
</tbody>
</table>
PCM
Nonlinear Quantization Levels

---

Figure 5.11  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.
Delta Modulation

Signal Amplitude

Analog input

Staircase function

Slope overload noise

Quantizing noise

step size \( \frac{\delta}{T_s} \)

sampling time

Time

Delta modulation output

0

1