Wireless Communications Lab

Lecture #2

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Introduction to Digital Communication

Learning Objective:

Explain why digital communication is relevant
Introduction to digital communication

- Principles of communication
  - Transmitter: generate information "source"
  - Channel: transfers signal from transmitter to receiver
    - Includes propagation medium + analog circuitry
  - Receiver: processes received signal "sink"
- Analog vs. digital
  - Analog source is a continuous-time waveform
  - Digital source is digital (binary)
  - Both analog and digital send a continuous-time waveform
Digital communication
- Fault tolerance: Resilient to noise, resilient to analog imperfections
- Suitable for digital data
- Analog communication is effectively "dead"
  => no jobs, few opportunities
- Compression is possible, easy, makes system very efficient
- Digital signal processing is easy
  => Take advantage of Moore's Law
  Easy power benefits
- Easier to implement security
- Easy to multiplex users
Components of a Digital Communication System

Learning Objective:

Explain the components of a digital communication system and define relevant terminology
Components of a digital communication system:

TX:
- Source
  - Source encoder
  - Encryption
  - Channel code
  - Modulation
  - Channel
    - Prop. medium
    - Analog

RX:
- Sink
  - Source decoder
  - Decrypt
  - Channel decode
  - Demodulate
17.3.8 PMD operating specifications (general)

General specifications for the BPSK OFDM, QPSK OFDM, 16-QAM OFDM, and 64-QAM OFDM PMD sublayers are provided in 17.3.8.1 through 17.3.8.8. These specifications apply to both the receive and transmit functions and general operation of the OFDM PHY.

17.3.8.1 Outline description

The general block diagram of the transmitter and receiver for the OFDM PHY is shown in Figure 17-12. Major specifications for the OFDM PHY are listed in Table 17-11.

![Transmitter and receiver block diagram for the OFDM PHY](image)

Figure 17-12—Transmitter and receiver block diagram for the OFDM PHY

### Table 17-11—Major parameters of the OFDM PHY

<table>
<thead>
<tr>
<th>Information data rate</th>
<th>6, 9, 12, 18, 24, 36, 48, and 54 Mb/s (6, 12, and 24 Mb/s are mandatory) (20 MHz channel spacing)</th>
<th>3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s (3, 6, and 12 Mb/s are mandatory) (10 MHz channel spacing)</th>
<th>1.5, 2.25, 3, 4.5, 6, 9, 12, and 13.5 Mb/s (1.5, 3, and 6 Mb/s are mandatory) (5 MHz channel spacing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation</td>
<td>BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM</td>
<td>BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM</td>
<td>BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM</td>
</tr>
<tr>
<td>Error correcting code</td>
<td>K = 7 (64 states convolutional code)</td>
<td>K = 7 (64 states convolutional code)</td>
<td>K = 7 (64 states convolutional code)</td>
</tr>
<tr>
<td>Coding rate</td>
<td>1/2, 2/3, 3/4</td>
<td>1/2, 2/3, 3/4</td>
<td>1/2, 2/3, 3/4</td>
</tr>
<tr>
<td>Number of subcarriers</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>OFDM symbol duration</td>
<td>4.0 μs</td>
<td>8.0 μs</td>
<td>16.0 μs</td>
</tr>
<tr>
<td>GI</td>
<td>0.8 μs (T_{GI})</td>
<td>1.6 μs (T_{GI})</td>
<td>3.2 μs (T_{GI})</td>
</tr>
<tr>
<td>Occupied bandwidth</td>
<td>16.6 MHz</td>
<td>8.3 MHz</td>
<td>4.15 MHz</td>
</tr>
</tbody>
</table>

*Refer to 17.3.2.4.
Annex A (informative):
Reference configuration

Interfaces and vocabulary:
(1) info + parity bits
(2) coded bits
(3) interleaved bits
(4) encrypted bits
(5) modulating bits
(6) information bits (receive)
- Source encoder / decoder
  - Perform compression (+ reverse)
  - Lossy: information discarded
  - Lossless: information retained
- Encryption / decryption
  - Component of a security protocol
  - Public key encryption (exchange key)
- Channel code / decode
  - Basic: Add known redundancy to correct channel errors
  - Error correction: repair receive signal
  - Error detection: determine if there was an error e.g. CRC (cyclic redundancy check)
  - Code rate = \( \frac{\text{# uncoded bits}}{\text{# coded bits}} \)
History of forward error correction (FEC)

1) Block code (developed in 30's)
   Take a "block" of 5 bits and produce a longer block

   Example: Rate 1/2 block code length 5
   5 bits → 10 coded bits

   \[
   \begin{pmatrix}
   10 \\
   \vdots \\
   11
   \end{pmatrix}
   \begin{bmatrix}
   51 \\
   \vdots \\
   55
   \end{bmatrix}
   =
   \begin{bmatrix}
   c_1 \\
   c_2 \\
   52 \\
   53 \\
   54 \\
   55
   \end{bmatrix}
   \]

   \[
   \begin{pmatrix}
   10 \\
   \vdots \\
   11
   \end{pmatrix}
   \begin{bmatrix}
   c_1 \\
   c_2 \\
   52 \\
   53 \\
   54 \\
   55
   \end{bmatrix}
   \]

   CRC, Reed Solomon, Fire code, etc.
Convolutional code (developed 60's - 70's)

- Convolve data with multiple impulse responses

\[ b[n] \xrightarrow{g_1[k]} g_1[k] \xrightarrow{\text{interleave}} c[n] \]

\[ g_2[k] \xrightarrow{\text{FIR kernel}} v[n+1] \]

Rate 1/2 \( C_{0,0} \)

Example

\[ C[2n] = b[n] \oplus b[n-1] \]
\[ C[2n+1] = b[n] \oplus b[n-2] \]

Decoding is important + complex

Viterbi decoder
Better available (iterative)
(1) Trellis code (dav. in 1980s)
   - Coded modulation
   - Combined coding + modulation
   - Viterbi decoder
(2) Turbo codes (dav. 93+)
   - Filtering w/ FIR filter
   + Interleaving between branches
   + Iterative decoder

(3) Long block length
(4) LDPC codes (dav. 2000s)
   - Low density parity check
   - Block code + smart decoder
   - mmWave WiGig available?
(5) Polar codes (??)