Chapter 7

Multiple Division Techniques

Outline

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)
- Comparison of FDMA, TDMA, and CDMA
- Walsh Codes
- Near-far Problem
- Types of Interferences
- Analog and Digital Signals
- Basic Modulation Techniques
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
  - Quadrature Phase Shift Keying (QPSK)
  - Quadrature Amplitude Modulation (QAM)
Frequency Division Multiple Access (FDMA)

- Single channel per carrier
- All first generation systems use FDMA

Time Division Multiple Access (TDMA)

- Multiple channels per carrier
- Most of second generation systems use TDMA
**Code Division Multiple Access (CDMA)**

- Users share bandwidth by using code sequences that are orthogonal to each other
- Some second generation systems use CDMA
- Most of third generation systems use CDMA

**Types of Channels**

- **Control channel**
  - Forward (Downlink) control channel
  - Reverse (Uplink) control channel
- **Traffic channel**
  - Forward traffic (traffic or information) channel
  - Reverse traffic (traffic or information) channel
Types of Channels (Cont’d)

- Reverse channel (Uplink)
- Control channels
- Traffic channels
- Forward channels (Downlink)

FDMA

- Reverse channels (Uplink)
- Forward channels (Downlink)
FDMA: Channel Structure

Guard Band $W_g$  Sub Band $W_c$

Total Bandwidth $W = NW_c$

$f_1'$ $f_2'$ $f_n'$  $f_1$ $f_2$ $f_n$

Reverse channels  Protecting bandwidth  Forward channels

TDMA

Frequency $f'$ Slot

Reverse channels (Uplink)

Forward channels (Downlink)
**TDMA: Channel Structure**

(a). Forward channel

(b). Reverse channel

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**TDMA: Frame Structure (Cont’d)**

Channels in Simplex Mode
TDMA: Frame Structure (Cont’d)

Frequency

Frame Structure

Frame

Frame

Time

Guard

time

Head

Data

Note: $C_i' \times C_j' = 0$, i.e., $C_i'$ and $C_j'$ are orthogonal codes,
$C_i \times C_j = 0$, i.e., $C_i$ and $C_j$ are orthogonal codes

Code Division Multiple Access (CDMA)

Frequency $f'$

Reverse channels
(Uplink)

Frequency $f$

Forward channels
(Downlink)

Note: $C_i' \times C_j' = 0$, i.e., $C_i'$ and $C_j'$ are orthogonal codes,
$C_i \times C_j = 0$, i.e., $C_i$ and $C_j$ are orthogonal codes
Comparisons of FDMA, TDMA, and CDMA
(Example)

<table>
<thead>
<tr>
<th>Operation</th>
<th>FDMA</th>
<th>TDMA</th>
<th>CDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocated Bandwidth</td>
<td>12.5 MHz</td>
<td>12.5 MHz</td>
<td>12.5 MHz</td>
</tr>
<tr>
<td>Frequency reuse</td>
<td>7</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Required channel BW</td>
<td>0.03 MHz</td>
<td>0.03 MHz</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>No. of RF channels</td>
<td>12.5/0.03=416</td>
<td>12.5/0.03=416</td>
<td>12.5/1.25=10</td>
</tr>
<tr>
<td>Channels/cell</td>
<td>416/7=59</td>
<td>416/7=59</td>
<td>12.5/1.25=10</td>
</tr>
<tr>
<td>Control channels/cell</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Usable channels/cell</td>
<td>57</td>
<td>57</td>
<td>8</td>
</tr>
<tr>
<td>Calls per RF channel</td>
<td>1</td>
<td>4*</td>
<td>40**</td>
</tr>
<tr>
<td>Voice channels/cell</td>
<td>57x1=57</td>
<td>57x4=228</td>
<td>8x40=320</td>
</tr>
<tr>
<td>Sectors/cell</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Voice calls/sector</td>
<td>57/3=19</td>
<td>228/3=76</td>
<td>320</td>
</tr>
<tr>
<td>Capacity vs FDMA</td>
<td>1</td>
<td>4</td>
<td>16.8</td>
</tr>
<tr>
<td>Delay</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

* Depends on the number of slots  ** Depends on the number of codes

Direct Sequence Spread Spectrum for CDMA

![Diagram of Transmitter and Receiver in Direct Sequence Spread Spectrum for CDMA]
Concept of Frequency Hopping Spread Spectrum

An Example of Frequency Hopping Pattern
Walsh Codes (Orthogonal Codes)

Wal (0, t)
Wal (1, t)
Wal (2, t)
Wal (3, t)
Wal (4, t)
Wal (5, t)
Wal (6, t)
Wal (7, t)

Near-far Problem

Received signal strength

Distance

MS1
MS2
BS

Distance

d2
0
d1
Types of Interference in CDMA

Adjacent Channel Interference in CDMA
Power Control in CDMA

Controlling transmitted power affects the CIR

\[
\frac{P_r}{P_t} = \frac{1}{(\frac{4\pi df}{c})^\alpha}
\]

- \( P_t \): Transmitted power
- \( P_r \): Received power in free space
- \( d \): Distance between receiver and transmitter
- \( f \): Frequency of transmission
- \( c \): Speed of light
- \( \alpha \): Attenuation constant (2 to 4)

Modulation

- Why need modulation?
  - Small antenna size
    - Antenna size is inversely proportional to frequency
    - e.g., 3 kHz \( \rightarrow \) 50 km antenna
    - 3 GHz \( \rightarrow \) 5 cm antenna
  - Limits noise and interference,
    - e.g., FM (Frequency Modulation)
  - Multiplexing techniques,
    - e.g., FDM, TDM, CDMA
Analog and Digital Signals

- Analog Signal (Continuous signal)
  - Amplitude
  - Time
  - Frequency (Hz)
  - Human hearing
  - Frequency cutoff point
  - Guard band
  - Frequency (Hz)

- Digital Signal (Discrete signal)
  - Amplitude
  - Time
  - Frequency (Hz)
  - Human speech
  - Frequency cutoff point
  - Guard band
  - Frequency (Hz)

Hearing, Speech, and Voice-band Channels
Amplitude Modulation (AM)

- Message signal \( x(t) \)
- Carrier signal
- AM signal \( s(t) \)

Amplitude of carrier signal is varied as the message signal to be transmitted. Frequency of carrier signal is kept constant.

Frequency Modulation (FM)

- Message signal \( x(t) \)
- Carrier signal
- FM signal \( s(t) \)

FM integrates message signal with carrier signal by varying the instantaneous frequency. Amplitude of carrier signal is kept constant.
**Frequency Shift Keying (FSK)**

1/0 represented by two different frequencies slightly offset from carrier frequency

- **Carrier signal 1** for message signal ‘1’
- **Carrier signal 2** for message signal ‘0’

**Message signal** $x(t)$

**FSK signal** $s(t)$

**Phase Shift Keying (PSK)**

- Use alternative sine wave phase to encode bits

- **Carrier signal** $\sin(2\pi f_c t)$
- **Carrier signal** $\sin(2\pi f_c t + \pi)$

**Message signal** $x(t)$

**PSK signal** $s(t)$
QPSK Signal Constellation

(a) BPSK

(b) QPSK

All Possible State Transitions in $\pi/4$ QPSK
Quadrature Amplitude Modulation (QAM)

Combination of AM and PSK

Two carriers out of phase by 90 deg are amplitude modulated

Rectangular constellation of 16QAM