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 (information) channel
  - Reverse traffic (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 $W = NW_c$

Reverse channels

Forward channels

Protecting bandwidth

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Reverse channels
(Uplink)

Forward channels
(Downlink)
TDMA: Channel Structure

(a). Forward channel

(b). Reverse channel
TDMA: Frame Structure (Cont’d)

Frequency $f = f'$

Frame

Forward channel

Reverse channel

Frame

Forward channel

Reverse channel

Time
TDMA: Frame Structure (Cont’d)
Code Division Multiple Access (CDMA)

Frequency $f'$

Reverse channels (Uplink)

MS #1

MS #2

\vdots

MS #n

$C_1'$

$C_2'$

\vdots

$C_n'$

Forward channels (Downlink)

Frequency $f$

$C_1$

$C_2$

\vdots

$C_n$

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>
</tbody>
</table>

* Depends on the number of slots
** Depends on the number of codes
Concept of Direct Sequence Spread Spectrum

Transmitter

Digital signal $s(t)$

Spreading

Code $c(t)$

Power

Frequency

Spreading signal $m(t)$

Receiver

De spread

Code $c(t)$

Power

Frequency

Digital signal $s(t)$
Concept of Frequency Hopping Spread Spectrum

Transmitter

Digital signal

Spreading

Hopping Pattern

Power

Frequency

Spreading signal

Receiver

Digital signal

Despread

Hopping Pattern

Power

Frequency
An Example of Frequency Hopping Pattern

Frequency

Time
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

MS₂  d₂  BS  d₁  MS₁

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Types of Interference

Interference in spread spectrum system
Adjacent Channel Interference

\[
\text{Power} \quad \text{Frequency}
\]

\( f_1 \quad f_2 \)

MS\(_1\) \quad MS\(_2\)
Power Control

Controlling transmitted power affects the CIR

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

\(P_t\) = 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
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
  - Limit noise and interference,
    
    e.g., FM (Frequency Modulation)
  - Multiplexing techniques,
    
    e.g., FDM, TDM, CDMA
Analog and Digital Signals

- Analog Signal (Continuous signal)
  
  Amplitude

\[ S(t) \]

- Digital Signal (Discrete signal)
  
  Amplitude

\[ 1 \quad 0 \quad 1 \quad 1 \quad 0 \quad 1 \]

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Hearing, Speech, and Voice-band Channels

Human hearing

Human speech

Voice-grade Telephone channel

Pass band

Guard band

Frequency cutoff point

Frequency (Hz)

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Amplitude Modulation (AM)

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

Frequency of carrier signal is kept constant.
Frequency Modulation (FM)

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 binary ‘1’

Carrier signal 2
for binary ‘0’

Message signal
x(t)

FSK signal
s(t)
```

Time
Time
Time
Time
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