Link Layer Services

- Framing:
  - encapsulate bits into frame, adding header
  - multiplexing: frame header to identify source, dest
    - example: MAC address
  - error detection and correction

- Flow control:
  - pacing between adjacent sending and receiving nodes

- Link access (interference and quality of service control)
  - media access control (also called multiplexing)
Multiple Access Control

Two transmissions cannot conflict in all dimensions!
FDMA

FDMA: frequency division multiple access

- Channel divided into frequency bands
- A transmission uses a frequency band

<table>
<thead>
<tr>
<th>frequency bands</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
TDMA

TDMA: time division multiple access

- Time divides into frames; frame divides into slots
- A transmission uses a slot in a frame
SDMA

SDMA: space division multiple access

• Transmissions at different locations, if far enough, can transmit simultaneously (same freq.)
  – Example: the cellular technique

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Suppose 24 MHz spectrum, 30 K per user

\[
\text{#user supported: } = \frac{24 MHz}{30 KHz} = 800
\]

Using cell

\[
\text{#user supported: } = \frac{6 MHz}{30 KHz} \times 16 = 200 \times 16 = 3200
\]

Q: why not divide into infinite small cells?
CDMA

CDMA (Code Division Multiple Access)

• Unique “code” assigned to each user; i.e., code set partitioning

• All transmissions share the same frequency and time; each transmission uses DSSS, and has its own “chipping” sequence (i.e., code) to encode data
  – e.g. code = -1 1 1 -1 1 -1 1

Examples: Sprint and Verizon, 3G WCDMA and CDMA2000
CDMA: Deal with Multiple-User Interference

- If codes are orthogonal, multiple users can “coexist” and transmit simultaneously with minimal interference

\[
\begin{align*}
C_1: & \quad 1 \quad 1 \quad 1 \quad -1 \quad 1 \quad -1 \quad -1 \quad -1 \\
C_2: & \quad 1 \quad -1 \quad 1 \quad 1 \quad 1 \quad -1 \quad 1 \quad 1 \\
C_1 \bullet C_2 = & \quad 1 + (-1) + 1 + (-1) + 1 + 1 + (-1) + (-1) = 0
\end{align*}
\]

Analogy: Speak in different languages!
Capacity of CDMA

• In realistic setup, cancellation of others’ transmission is incomplete
• Assume the received power at base station from all nodes is the same $P$ (how?)
• The power of the transmission with known code is increased to $NP$, where $N$ is chipping expansion factor
• The others remain on the order of $P$
• Assume a total of $M$ users
• Then

$$SNR = \frac{NP}{(M - 1)P + N_0} \approx \frac{N}{M - 1}$$

For IS-95 CDMA,

$N = \frac{1.25M}{4800} = 260$
Generating Orthogonal Codes

• The most commonly used orthogonal codes in current CDMA implementation are the Walsh Codes

• Property of Walsh: every row is orthogonal to every other row.
If user 1 is given code [1,1,-1,-1], what codes can we give to other users?
WCDMA Orthogonal Variable Spreading Factor (OSVF)

- Flexible code (spreading factor) allocation
  - up link SF: 4 – 256
  - down link SF: 8 - 512
## W-CDMA Down Link Capacity

<table>
<thead>
<tr>
<th>Spreading factor</th>
<th>Channel symbol rate (kbps)</th>
<th>Channel bit rate (kbps)</th>
<th>DPDCII channel bit rate range (kbps)</th>
<th>Max. user data rate with ½ rate coding (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>512</td>
<td>7.5</td>
<td>15</td>
<td>3-6</td>
<td>1-3 kbps</td>
</tr>
<tr>
<td>256</td>
<td>15</td>
<td>30</td>
<td>12-24</td>
<td>6-12 kbps</td>
</tr>
<tr>
<td>128</td>
<td>30</td>
<td>60</td>
<td>42-51</td>
<td>20-24 kbps</td>
</tr>
<tr>
<td>64</td>
<td>60</td>
<td>120</td>
<td>90</td>
<td>45 kbps</td>
</tr>
<tr>
<td>32</td>
<td>120</td>
<td>240</td>
<td>210</td>
<td>105 kbps</td>
</tr>
<tr>
<td>16</td>
<td>240</td>
<td>480</td>
<td>432</td>
<td>215 kbps</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>960</td>
<td>912</td>
<td>456 kbps</td>
</tr>
<tr>
<td>4</td>
<td>960</td>
<td>1920</td>
<td>1872</td>
<td>936 kbps</td>
</tr>
<tr>
<td>4, with 3 parallel codes</td>
<td>2880</td>
<td>5760</td>
<td>5616</td>
<td>2.3 Mbps</td>
</tr>
</tbody>
</table>
Summary

• SDMA, TDMA, FDMA and CDMA are basic media partitioning techniques
  – divide media into smaller “pieces” (space, time slots, frequencies, codes) for multiple transmissions to share

• Pros and cons of each.
  – FDMA: not flexible for variation in # users and demands; hand off is not smooth.
  – TDMA:
  – CDMA