ECS455: Chapter 4
Multiple Access

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Office Hours:
BKD 3601-7
Tuesday 9:30-10:30
Friday 14:00-16:00
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fixed WiMAX</th>
<th>Mobile WiMAX</th>
<th>HSPA</th>
<th>1x EV-DO Rev A</th>
<th>Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards</td>
<td>IEEE 802.16-2004</td>
<td>IEEE 802.16e-2005</td>
<td>3GPP Release 6</td>
<td>3GPP2</td>
<td>IEEE 802.11a/g/n</td>
</tr>
<tr>
<td>Peak down link data rate</td>
<td>9.4Mbps in 3.5MHz with 3:1 DL-to-UL ratio TDD; 6.1Mbps with 1:1</td>
<td>46Mbps&lt;sup&gt;a&lt;/sup&gt; with 3:1 DL-to-UL ratio TDD; 32Mbps with 1:1</td>
<td>14.4Mbps using all 15 codes; 7.2Mbps with 10 codes</td>
<td>3.1Mbps; Rev. B will support 4.9Mbps</td>
<td>54 Mbps&lt;sup&gt;b&lt;/sup&gt; shared using 802.11a/g; more than 100Mbps peak layer 2 throughput using 802.11n</td>
</tr>
<tr>
<td>Peak uplink data rate</td>
<td>3.3Mbps in 3.5MHz using 3:1 DL-to-UL ratio; 6.5Mbps with 1:1</td>
<td>7Mbps in 10MHz using 3:1 DL-to-UL ratio; 4Mbps using 1:1</td>
<td>1.4Mbps initially; 5.8Mbps later</td>
<td>1.8Mbps</td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>3.5MHz and 7MHz in 3.5GHz band; 10MHz in 5.8GHz band</td>
<td>3.5MHz, 7MHz, 5MHz, 10MHz, and 8.75MHz initially</td>
<td>5MHz</td>
<td>1.25MHz</td>
<td>20MHz for 802.11a/g; 20/40MHz for 802.11n</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16 QAM, 64 QAM</td>
<td>QPSK, 16 QAM, 64 QAM</td>
<td>QPSK, 8 PSK, 16 QAM</td>
<td>BPSK, QPSK, 16 QAM</td>
<td></td>
</tr>
<tr>
<td>Multiplexing</td>
<td>TDM</td>
<td>TDM/OFDMA</td>
<td>TDM/CDMA</td>
<td>TDM/CDMA</td>
<td>CSMA</td>
</tr>
<tr>
<td>Duplexing</td>
<td>TDD, FDD</td>
<td>TDD initially</td>
<td>FDD</td>
<td>FDD</td>
<td>TDD</td>
</tr>
<tr>
<td>Frequency</td>
<td>3.5GHz and 5.8GHz initially</td>
<td>2.3GHz, 2.5GHz, and 3.5GHz initially</td>
<td>800/900/1,800/1,900/2,100MHz</td>
<td>800/900/1,800/1,900MHz</td>
<td>2.4GHz, 5GHz</td>
</tr>
<tr>
<td>Coverage (typical)</td>
<td>3–5 miles</td>
<td>&lt; 2 miles</td>
<td>1–3 miles</td>
<td>1–3 miles</td>
<td>&lt; 100 ft indoors; &lt; 1000 ft outdoors</td>
</tr>
<tr>
<td>Mobility</td>
<td>Not applicable</td>
<td>Mid</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
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4.1 TDD and FDD

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Duplexing

- Allow the subscriber to send “simultaneously” information to the base station while receiving information from the base station.
  - Talk and listen simultaneously.

- Definitions:
  - **Forward channel** or **downlink (DL)** is used for communication from the infrastructure to the users/stations
  - **Reverse channel** or **uplink (UL)** is used for communication from users/stations back to the infrastructure.

- Two techniques
  1. Frequency division duplexing (FDD)
  2. Time division duplexing (TDD)

[Rappaport, 2002, Ch 9]
Frequency Division Duplexing (FDD)

- Provide *two distinct bands* of frequencies (simplex channels) for every user.
- The **forward band** provides traffic from the base station to the mobile.
- The **reverse band** provides traffic from the mobile to the base station.
- Any *duplex* channel actually consists of two *simplex* channels (a forward and reverse).
- Most commercial cellular systems are based on FDD.
FDD Examples

[Karim and Sarraf, 2002, Fig 5-1]

[Karim and Sarraf, 2002, Fig 6-1]
Time Division Duplexing (TDD)

- The UL and DL data are transmitted on the **same carrier frequency** at different times. (Taking turns)
  - Use time instead of frequency to provide both forward and reverse links.
  - Each *duplex* channel has both a **forward time slot** and a **reverse time slot**.
- If the *time separation* between the forward and reverse time slot is **small**, then the transmission and reception of data *appears* simultaneous to the users at both the subscriber unit and on the base station side.
- Used in Bluetooth and Mobile WiMAX
- Each transceiver operates as either a transmitter or receiver on the same frequency
Problems of FDD

• Each transceiver simultaneously transmits and receives radio signals
  • The signals transmitted and received can vary by more than 100 dB.
  • The signals in each direction need to occupy bands that are separated far apart (tens of MHz)
• A device called a duplex is required to filter out any interference between the two bands.

[Tse and Viswanath, 2005, Ch 4, p 121]
Advantages of FDD

- TDD frames need to incorporate guard periods equal to the max round trip propagation delay to avoid interference between uplink and downlink under worst-case conditions.

- There is a time latency created by TDD due to the fact that communications is not full duplex in the truest sense.
  - This latency creates inherent sensitivities to propagation delays of individual users.
Advantages of TDD

- Duplexer is not required.
- Enable *adjustment* of the downlink/uplink ratio to efficiently support *asymmetric* DL/UL traffic.
  - With FDD, DL and UL always have fixed and generally, equal DL and UL *bandwidths*.
- Assure *channel reciprocity* for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.
- Ability to implement in *nonpaired spectrum*
  - FDD requires a pair of channels
  - TDD only requires a single channel for both DL and UL providing greater flexibility for adaptation to varied global spectrum allocations.
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4.2 Introduction to Multiple Access
Multiple Access Techniques

- Allow many mobile users to share simultaneously a finite amount of radio spectrum.
- For high quality communications, this must be done without severe degradation in the performance of the system.
- Important access techniques
  1. Frequency division multiple access (FDMA)
  2. Time division multiple access (TDMA)
  3. Spread spectrum multiple access (SSMA)
     - Frequency Hopped Multiple Access (FHMA)
     - Code division multiple access (CDMA)
  4. Space division multiple access (SDMA)
  5. Random access
     - ALOHA
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Multiple Access

4.3 FDMA and TDMA
Multiple Access Techniques

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  5. Random access
     - ALOHA
Frequency division multiple access (FDMA)

- The *oldest* multiple access scheme for wireless communications.
- Used exclusively for multiple access in 1G down to individual resource units or physical channels.
- Assign individual channels to individual users.
  - Different carrier frequency is assigned to each user so that the resulting spectra do not overlap.
  - During the period of the call, no other user can share the same channel.
- **Band-pass filtering** (or heterodyning) enables separate demodulation of each channel.
FDMA (2)

- If an FDMA channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity.
  - It is essentially a wasted resource.
- In FDD systems, the users are assigned a channel as a pair of frequencies.

[Rappaport, 2002, Ch 9, p. 449]
Time division multiple access (TDMA)

- Divide the radio spectrum into **time slots**.
- In each slot only one user is allowed to either transmit or receive.
- A channel may be thought of as a particular time slot that reoccurs every frame, where $N$ time slots comprise a frame.
- Transmit data in a **buffer-and-burst method**
  - The transmission for any user is non-continuous.
  - Digital data and digital modulation must be used with TDMA.
  - This results in low battery consumption, since the subscriber transmitter can be turned off when not in use (which is most of the time).
- An obvious choice in the 1980s for digital mobile communications.
Frequency-Domain Analysis

Shifting Properties:
\[ g(t - t_0) \overset{\mathcal{F}}{\longrightarrow} e^{-j2\pi f t_0} G(f) \]
\[ e^{j2\pi f_0 t} g(t) \overset{\mathcal{F}}{\longrightarrow} G(f - f_0) \]

Modulation:
\[ m(t) \cos(2\pi f_c t) \overset{\mathcal{F}}{\longrightarrow} \frac{1}{2} M(f - f_c) + \frac{1}{2} M(f + f_c) \]
Spectrum of Digital Data

\[ c(t) = A \times 1_{[t \in [0, T)]} \]

\[ s(t) = \sum_{k=0}^{n-1} m_k c(t - kT) \xrightarrow{\mathcal{F}} S(f) = C(f) \sum_{k=0}^{n-1} m_k e^{-j2\pi fkT} \]

This is also the spectrum of \( c(t - kT) \) for any \( k \).
TDMA Spectrum

\[ c(t) = A \times 1 \begin{bmatrix} t \in [0, T) \end{bmatrix} \]

\[ m = [-1, -1, 1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1, -1, 1, 1, -1, -1, 1, 1, -1, 1, 1, -1, 1, 1] \]

\[ s(t) = \sum_{k=0}^{n-1} m_k c(t - kT) \xrightarrow{\mathcal{F}} S(f) = C(f) \sum_{k=0}^{n-1} m_k e^{-j2\pi fkT} \]
FDMA vs. TDMA
Tradeoffs

• TDMA transmissions are slotted
  • Require the receivers to be synchronized for each data burst.
  • Guard times are necessary to separate users. This results in larger overheads.
  • FDMA allows completely uncoordinated transmission in the time domain
    • No time synchronization among users is required.

• The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.

• Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.

• FDMA needs to use costly bandpass filters.
  • For TDMA, no filters are required to separate individual physical channels.
Guard Band vs. Guard Time

FDMA

TDMA
Example: GSM

- GSM utilizes a combination of FDMA and TDMA
- Two-dimensional channel structure

Each narrowband channel has bandwidth 200 kHz.
- Time is divided into slots of length $T = 577 \, \mu s$.  

Figure 7.2, Heine, 1998
The FDMA/TDMA structure of GSM

- In full-rate configuration, eight time slots (TSs) are mapped on every frequency.

A BS with 6 carriers, as shown here, has 48 (8 times 6) physical channels (in fullrate configuration).

[Figure 7.1, Heine, 1998]
Classifications of Medium Access Control (MAC)

- MAC Protocols
  - Scheduled Access
    - Static: TDMA, FDMA, CDMA
    - Dynamic Reservation
  - Random Access
    - Static ALOHA
    - Dynamic Tree, FCFS
<table>
<thead>
<tr>
<th>Cellular System</th>
<th>Multiple Access Technique</th>
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<tr>
<td>Advanced Mobile Phone System (AMPS)</td>
<td>FDMA/FDD</td>
</tr>
<tr>
<td>Global System for Mobile (GSM)</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>US Digital Cellular (USDC)</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>Pacific Digital Cellular (PDC)</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>CT2 (Cordless Telephone)</td>
<td>FDMA/TDD</td>
</tr>
<tr>
<td>Digital European Cordless Telephone (DECT)</td>
<td>FDMA/TDD</td>
</tr>
<tr>
<td>US Narrowband Spread Spectrum (IS-95)</td>
<td>CDMA/FDD</td>
</tr>
<tr>
<td>W-CDMA (3GPP)</td>
<td>CDMA/TDD</td>
</tr>
<tr>
<td>cdma2000 (3GPP2)</td>
<td>CDMA/FDD</td>
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<td>CDMA/TDD</td>
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