WiMAX

Part I: PHY

Raj Jain
Professor of CSE
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

Audio/Video recordings of this lecture are available on-line at:
http://www.cse.wustl.edu/~jain/cse574-08/
Overview

- What is WiMAX
- Previous Broadband Wireless Access: LMDS, MMDS
- WiMAX PHY Layer
- Frequency Reuse
- Subchannelization
- Frame structure
What is WiMAX?

- **Point to Point**
  - ≤50km
  - Base Stations (BSs)

- **Point to Multipoint**
  - (Rural Areas)
  - Subscriber Station (SSs)
  - <70Mbps

- **Uplink (UL)**
- **Downlink (DL)**
  - (Congested Areas)
  - <70Mbps

- **Mobile Users**
  - <120km/sec
Data rate vs. Mobility

- Vehicular
- Nomadic
- Stationary
- Cellular
- WiMAX
- WiFi

User/Link Bit Rate Mbits/second

0.1 1 10 100 ++
Key Features of WiMAX

- Works on many bands: 2.3 GHz, 2.5 GHz, 3.5 GHz, …
- Scalable - Can use any available spectrum width: 1.25 MHz to 28 MHz
- Strong security
- Open technology like WiFi
- Reach and mobility like Cellular but much higher data rates
  - High data rate, up to 70Mbps
  - Long distance, up to 50kms
  - Mobility, up to 120 to 150 km/hour
- Data rate vs Distance trade off using adaptive modulation. 64QAM to BPSK
- Offers non-line of site (NLOS) operation
- Strong QoS - Guaranteed services for data, voice, and video
Prior Attempts: LMDS & MMDS

- Local Multipoint Distribution Service (1998)
  - 1.3 GHz around 28 GHz band (Ka Band)
    - 28 GHz ⇒ Rain effects
- Multi-channel Multipoint Distribution Services (1999-2001)
  - 2.1, 2.5-2.7 GHz Band ⇒ Not affected by rain
  - Issues: Equipment too expensive, Roof top LoS antennas, short range (LMDS) or too small capacity (MMDS)
WiMAX

- WiMAX ≠ IEEE 802.16
- Worldwide Interoperability for Microwave Access
- 420+ members including Semiconductor companies, equipment vendors, integrators, service providers. Like Wi-Fi Alliance
- Narrows down the list of options in IEEE 802.16
- Plugfests started November 2005
- WiMAX forum lists certified base stations and subscriber stations from many vendors
- [http://www.wimaxforum.org](http://www.wimaxforum.org)
# Spectrum Options

<table>
<thead>
<tr>
<th>Designation</th>
<th>Frequency GHz</th>
<th>Bandwidth MHz</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 GHz</td>
<td>3.4-3.6; 3.3-3.4; 3.6-3.8</td>
<td>200 Total. 2×(5 to 56)</td>
<td>Not in US. Considering 3.65-3.70 for unlicensed</td>
</tr>
<tr>
<td>2.5 GHz</td>
<td>2.495-2.690</td>
<td>194 Total. 16.5+6 paired.</td>
<td>In USA.</td>
</tr>
<tr>
<td>2.3 GHz</td>
<td>2.305-2.320; 2.345-2.360</td>
<td>2×5 paired. 2×5 unpaired.</td>
<td>US, Kr, Au, Nz</td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>2.405-2.4835</td>
<td>80 Total</td>
<td>Lic exempt. Worldwide.</td>
</tr>
<tr>
<td>5 GHz</td>
<td>5.250-5.350; 5.725-5.825</td>
<td>200 MHz</td>
<td>Worldwide.</td>
</tr>
<tr>
<td>700 MHz</td>
<td>0.698-0.746; 0.747-0.792</td>
<td>30+48</td>
<td>US</td>
</tr>
<tr>
<td>Adv W. Serv.</td>
<td>1.710-1.755; 2.110-2.155</td>
<td>2×45 paired</td>
<td>Used for 3G</td>
</tr>
</tbody>
</table>
Effect of Frequency

- Higher Frequencies have higher attenuation, e.g., 18 GHz has 20 dB/m more than 1.8 GHz
- Higher frequencies need smaller antenna
  \[ \text{Antenna} \geq \text{Wavelength/2}, 800 \text{ MHz} \Rightarrow 6" \]
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules
- Higher frequencies have more bandwidth and higher data rate
- Higher frequencies allow more frequency reuse
  They attenuate close to cell boundaries. Low frequencies propagate far.
- Mobility \( \Rightarrow \) Below 10 GHz
<table>
<thead>
<tr>
<th>Function</th>
<th>LOS</th>
<th>Freq. Band</th>
<th>Carrier</th>
<th>Duplexing</th>
</tr>
</thead>
<tbody>
<tr>
<td>WirelessMAN SC</td>
<td>Pt-to-pt</td>
<td>LOS</td>
<td>10-66 GHz</td>
<td>Single</td>
</tr>
<tr>
<td>WirelessMAN SCa</td>
<td>Pt-to-pt</td>
<td>LOS</td>
<td>2-11 GHz Licensed</td>
<td>Single</td>
</tr>
<tr>
<td>WirelessMAN OFDM (16d)</td>
<td>Pt-to-mpt</td>
<td>NLOS</td>
<td>2-11 GHz Licensed</td>
<td>256</td>
</tr>
<tr>
<td>WirelessMAN OFDMA (16e)</td>
<td>Pt-to-mpt</td>
<td>NLOS</td>
<td>2-11 GHz Licensed</td>
<td>2048</td>
</tr>
</tbody>
</table>
IEEE 802.16 PHY: Features

- Features discussed previously:
  - Scalable OFDMA
  - TDD and FDD
  - Adaptive Modulation and Coding
  - Space Time Block Codes (STBC)
  - Adaptive Antenna System

- Other Features:
  - Subchannelization and permutation
  - Slots, tiles, and clusters, bursts
Frequency Reuse

- NxSxK frequency reuse pattern
- N = Number of cells per cluster
- S = Number of sectors in a cell
- K = Number of frequency allocations per cell

1X3X3
Frequency Reuse (Cont)
Fractional Frequency Reuse

- Users close to the BS use all frequency subchannels
- Users at the cell boundary use only a fraction of available subchannels
OFDM Subcarriers

- Data subcarriers
- Pilot Subcarriers: Used for channel estimation
- Guard subcarriers: At the edges. No power
- DC subcarrier: At the center for frequency band. No power.
Subchannelization

- Subchannel = Group of subcarriers
- Each user is given one or more subchannel.
- Subcarriers of a subchannel can be contiguous or distributed
  - Subchannel 1

- Contiguous
  - Subchannels allocated based on use's SINR
  - Band AMC
  - Not suitable for mobile applications
Subcarrier Permutations

- Subcarriers are randomly assigned to a channel and changed every symbol time ⇒ Frequency hopping
- All subcarriers are used ⇒ Full Usage of Subcarriers (FUSC) – Not in WiMAX Forum Profiles
- Partial Usage of Subcarriers (PUSC) - in WiMAX Forum profiles ⇒ commonly used
Downlink Partial Usage of Subcarriers

- Subcarriers are divided into 6 groups and only some groups may be used in a sector or cell.
- Data and pilots are arranged in clusters of 14 subcarriers over 2 symbols = 24 data + 4 pilot.
- Clusters are renumbered using a pseudo random numbering scheme.
- The clusters are then divided into 6 groups (segments 0 through 5).
- Subchannel = Two clusters from the same group.
- It is possible to allocate some subset of groups to each transmitter in a cell, e.g., 2 groups per sector.
Symbols, Clusters, and Slots (PUSC DL)

10 MHz = 1024 FFT = 840 subcarriers + 1 DC + 183 Guard
Total 30 subchannels = 30×28 = 840 subcarriers

- **Subcarriers**
- **Subchannel** = 28 subcarriers
- **Cluster** = 2 symbols × 14 subcarriers
- **Slot** = 2 Clusters

Symbols, Clusters, and Slots (PUSC DL)
Symbols, Tiles, and Slots (PUSC UL)

- 10 MHz = 1024 FFT = 840 subcarriers + 1 DC + 183 Guard
- Total 35 subchannels = 35X24 = 840 subcarriers

Subcarriers

Subchannel = 24 subcarriers

Tile = 3 symbols × 4 subcarriers

Slot = 6 Tiles

Symbols

Frequency

Time
802.16 Frame Structure

TDD = Time Division Duplexing
DL = Downlink (Base to subscriber)
FCH = Frame control header:

FDD = Freq Div Duplexing
UL = Uplink
Burst Profile, Down-link map, Uplink map, DL channel descriptor, etc.
Mobile WiMAX Frame
Frame Structure

- **DL Preamble**: Time and frequency synchronization
- **Frame Control Header (FCH)**: MAPs lengths, modulation and coding, usable subcarriers
- **Downlink MAP**: Burst profile (time, frequency, modulation, coding) to each user
- **Uplink MAP**: Burst profile for transmission from each user. MAPs can be compressed
- **Contention-based region**: Ranging, bandwidth request, best-effort data
- **Ranging Channel**:
  - Closed loop frequency, time, and power adjustments
  - Channel quality indicator channel (CQICH)
  - **Ack Channel**: subscriber stations
- Initially, 5 ms frames only.
Subscriber Initialization

- Subscriber scans pre-set frequencies for base station.
- Subscriber finds base transmissions and synchronizes to it.
- Subscriber sends a ranging-request to BS at low power.
- Subscriber resends a ranging-request to BS at higher powers.
- Base sends ranging response giving management conn IDs.
- Base accepts subscriber or rejects some PHY capabilities.
- Subscriber reports its PHY capabilities (modulation, coding, xDD).
- Base-Subscriber Authentication using X.509 Certificates.
Summary

- WiMAX supports non-line of sight using scalable OFDMA
- Any band any bandwidth
- Sophisticated frequency reuse
- 2D frame structure
References: Books


Note: These are the best 3 of 12+ books on WiMAX.