Wireless MANs

David Tipper
Associate Professor
Graduate Telecommunications and Networking Program
University of Pittsburgh
dtipper@mail.sis.pitt.edu

Wireless Networks

– Wireless Wide Area Networks (WWANs)
  • Cellular Networks:
    – GSM, cdmaone (IS-95), UMTS, cdma2000 EVDO
  • Satellite Networks:
    – Iridium, Globalstar, GPS, etc.

– Wireless Metro Area Networks (WMANs)
  • IEEE 802.16 WiMAX

– Wireless Local Area Networks (WLANs)
  • IEEE 802.11, a, b, g, etc. (infrastructure, ad hoc, sensor)

– Wireless Personal Area Networks (WPANs)
  • IEEE 802.15 (Bluetooth), IrDa, Zigbee, sensor, etc.
Wireless MANs

- Wireless Metropolitan Area Networks (WMANs): provide wireless connectivity across a geographical area the size of a city

**Wireless MANs**

- Want broadband data rates for last mile connectivity to businesses, homes and network bridging
- Triple play service (video, voice, data)
- **Claimed** Advantages: support for QoS, lower cost than cabling, user mobility in future.
- Currently variety of technologies, speeds, cost, coverage range, spectrum, etc.
- Market is fragmented among technology and small
  - Proprietary Solutions
    - Free Space Optical
    - LMDS (Local Multipoint Distribution Systems)
    - MMDS (Multipoint Microwave Distribution Systems)
    - Wireless multi-hop mesh networks (based on 802.11)
  - Standards Based Solutions
    - IEEE 802.16 also called WiMAX, WirelessMAN
    - IEEE 802.11 with multi-hop extensions
Wireless MANs

- Proprietary Solutions
  - Free Space Optical:
    - point to point high data rates (100 Mbps - 2.5Gbps) over short distances
    - Unlicensed, uses infrared lasers
    - LOS required – severely effected by weather
  - LMDS (Local Multipoint Distribution Systems)
    - Bulk of deployment focused on backhaul extension of fiber infrastructure and cellular networks
    - Operates in 28, 29 GHz spectrum
    - Range 3-5 miles, weather effects
  - MMDS (Multipoint Microwave Distribution Systems)
    - Operates in 2.5-2.7MHz licensed spectrum
    - Originally intended for wireless cable TV distribution
    - 20MHz spectrum → 99 10Mbps channels
    - Range ~25Km (LOS and NLOS possible)
    - Data rates ~ .5-1 Mbps on 10Mbps channel
  - WLAN equipment with mesh routing, scheduling, flow control
    - Use 802.11a/g equipment to build mesh – need many APs
  - Proprietary equipment seen as a hindrance to market growth

IEEE 802.16/WiMAX Standard

- Worldwide Interoperability for Wireless Microwave Access (WiMAX)
- IEEE 802.16 Broadband Wireless Access Standards Working Group
  - Started in 1998 led by NIST
  - Since July 1999 IEEE 802.16 working group meeting bimonthly
  - Suite of WiMAN standards
  - As in WLAN standard focus is Physical and MAC layers only!
- In parallel to IEEE 802.16, European Telecommunication Standards Institute (ETSI) HiperMAN and HIPERACCESS work
  - High performance radio metropolitan area network (HiperMAN)
- IEEE 802.16 and HiperMAN have largely converged
  - Same MAC layer and 802.16a OFDM as Physical layer baseline
### IEEE 802.16/WiMAX Standard

- **Worldwide Interoperability for Wireless Microwave Access (WiMAX) industry alliance (WiMAX Forum) started to promote equipment development and interoperability testing/conformance**
- **http://www.wimaxforum.org**
  - Interoperable multi-vendor fixed/nomadic/mobile/ wireless access networks using microwaves - line of sight not required
  - Define a set of "profiles" for interoperability/conformance testing
  - Profile specify the physical layer for a frequency band and various MAC layer parameters
- **According to In-Stat**
  - ~220,000 WiMAX subscribers in 2006
  - predict 19.7 million by 2010 – mostly fixed service in underdeveloped countries/regions - largest announced network build out in Pakistan
- **Alvarion dominant equipment vendor, Intel dominant chip set vendor.**

### IEEE 802.16 /WiMAX Standard

- **IEEE 802.16** developed as a Wireless Metropolitan Area Network (MAN) protocol
- **Focus** wireless alternative to DSL and T1 level services for last mile broadband access and backhaul for other technologies (WiFi, cellular)
- **Characteristics of 802.16**
  - Point to Multipoint (PMP) and Mesh protocol
  - NLOS wireless broadband services including bandwidth on demand
  - QoS support
  - Security
  - Scope expanded to include mobility and higher data rates
- **Focus on both licensed and unlicensed spectrum deployment** – supports multiple service providers/licenses in same area
- **TDD and FDD duplexing support with flexible channel sizes**

- **802.16 Terminology**
  - Base Station (BS) is WiMAX cell site/access point
  - Subscriber Station (SS) is customer premise equipment and terminates the wireless link to the user location
  - Mobile Station (MS) is a standalone consumer device equipped with a WiMAX radio
WiMAX Architecture

WiMax Service Architectures

WiMax services
Point to Multi-Point
• Non-LOS, Wi-Fi sort of service, where a small antenna on a computer/ roof top connects to the tower. Later upgrade for mobile service to computer/handset
• LOS, where a fixed antenna points straight at the WiMax tower from a rooftop or pole. (LOS can provide higher data rates)
Point to Point
• Focused LOS antennas – high data rates with longer distances
IEEE 802.16 WiMAX Standards

- Scope of standard is bottom two protocol layers same as other 802 standards

**IEEE 802.16 WiMAX Standards**

- Suite of standards for WiMANs
  - 802.16: approved 12/2001 10-66GHz range LOS only
  - 802.16a-2003: System for 2-11GHz range NLOS
  - 802.16-2004 (802.16d): System for 2-6 GHz range supports nomadic/limited mobility

- In a fashion similar to IEEE 802.11 – multiple physical layers with common MAC layer defined
  - 802.16 a and 2004 define three physical layers
    - SCa – single carrier
    - OFDM – 256 carriers
    - OFDMA – 2048 carriers (OFDM multiple access) (multiple access by assigning a subset to a user)

- Physical layer standards often called "WirelessMAN" standard
  - Most equipment/WIMAX conformance on OFDM 256 carrier 802.15-2004 (802.16d) standard – which is common to ETSI HIPERMAN standard
**Main IEEE 802.16 Standards**

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.16a</th>
<th>802.16-2004</th>
<th>802.16e-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Completed</td>
<td>December 2001</td>
<td>January 2003</td>
<td>June 2004</td>
<td>December 2005</td>
</tr>
<tr>
<td>Spectrum</td>
<td>10-66 GHz</td>
<td>2-11 GHz</td>
<td>2-11 GHz</td>
<td>2- 6 GHz</td>
</tr>
<tr>
<td>Operation</td>
<td>LOS</td>
<td>Non-LOS</td>
<td>Non-LOS</td>
<td>Non-LOS and Mobile</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>32-134 Mbps</td>
<td>Up to 75 Mbps</td>
<td>Up to 75 Mbps</td>
<td>Up to 15 Mbps</td>
</tr>
<tr>
<td>Omni-directional Cell Radius</td>
<td>1-3 miles</td>
<td>3-5 miles</td>
<td>3-5 miles</td>
<td>1-3 miles</td>
</tr>
</tbody>
</table>

**Techniques used in 802.16-2004**

- Orthogonal Frequency Division Multiplexing (OFDM)
  - to reduce multipath effects and provide higher speeds
- Forward error correction rather than ARQ
  - FEC uses an outer RS block code and an inner convolutional code
- Adaptive modulation and coding
  - adjust the modulation/coding depending on the quality of the radio link, subscriber by subscriber, burst by burst, up and downlink
- Admission control
  - Ensures that new flows do not degrade the quality of established flows
- MAC Layer Scheduling:
  - traffic scheduling to provide QoS traffic classes
- Flexible Channel size
  - nx1.25Mhz, n x 1.5MHz, n x 1.75 MHz, Max of 20MHz
- TDD and FDD modes supported
- Smart antenna technology
## Physical layers for 802.16a/d

<table>
<thead>
<tr>
<th></th>
<th>Sca – single carrier</th>
<th>OFDM</th>
<th>OFDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>2-11 GHz</td>
<td>2-11 GHz</td>
<td>2-11 GHz</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>BPSK, QPSK, 16QAM, 64QAM, 256QAM</td>
<td>BPSK, QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td><strong>No. of subcarriers</strong></td>
<td>N/A</td>
<td>256</td>
<td>2048</td>
</tr>
<tr>
<td><strong>Duplexing</strong></td>
<td>TDD, FDD</td>
<td>TDD, FDD</td>
<td>TDD, FDD</td>
</tr>
<tr>
<td><strong>Channel Bandwidth</strong></td>
<td>1.75-20 MHz</td>
<td>1.75-20 MHz</td>
<td>1.75-20 MHz</td>
</tr>
</tbody>
</table>

OFDM 256 Carrier option is currently available
192 Carriers used for data, 8 pilot channels, 56 guard bands

---

## IEEE 802.16d Coding/Modulation

- Table of the maximum data rate in Mbps for the various channel/coding/modulation options in 802.16d with 256 carrier OFDM physical layer
- Modulation rate used on a set of 256 carriers depends on RSS

<table>
<thead>
<tr>
<th>Channel Bandwidth</th>
<th>QPSK 1/2</th>
<th>QPSK 3/4</th>
<th>16 QAM 1/2</th>
<th>16QAM 3/4</th>
<th>64 QAM 2/3</th>
<th>64 QAM 3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75 MHz</td>
<td>1.04</td>
<td>2.18</td>
<td>2.91</td>
<td>4.36</td>
<td>5.94</td>
<td>6.55</td>
</tr>
<tr>
<td>3.5 MHz</td>
<td>2.08</td>
<td>4.37</td>
<td>5.82</td>
<td>8.73</td>
<td>11.88</td>
<td>13.09</td>
</tr>
<tr>
<td>5.0 MHz</td>
<td>3.95</td>
<td>6.00</td>
<td>8.06</td>
<td>12.18</td>
<td>16.30</td>
<td>18.36</td>
</tr>
<tr>
<td>7.0 MHz</td>
<td>4.15</td>
<td>8.73</td>
<td>11.64</td>
<td>17.45</td>
<td>23.75</td>
<td>26.18</td>
</tr>
<tr>
<td>10.0 MHz</td>
<td>8.31</td>
<td>12.47</td>
<td>16.63</td>
<td>24.94</td>
<td>33.25</td>
<td>37.40</td>
</tr>
<tr>
<td>20.0 MHz</td>
<td>16.62</td>
<td>24.94</td>
<td>33.25</td>
<td>49.87</td>
<td>66.49</td>
<td>74.81</td>
</tr>
</tbody>
</table>
802.16-2004 Data Ranges

• Achievable data rate depends on distance to BS, LOS/NLOS, propagation environment – will vary!

![Diagram showing data rates and modulation schemes](image)
802.11/802.16 Spectrum

ISM: Industrial, Scientific & Medical Band – Unlicensed band (802.11a,b,g)
UNII: Unlicensed National Information Infrastructure band – Unlicensed band
Licensed band 2.5 GHz US and 3.5 GHz International

802.16 has both licensed and license-exempt options

Licensed Systems in U.S.

- U.S. has licensed spectrum 2.459 – 2.69 GHz
- License 22.5 MHz - 8 licenses per geographic area – operator can acquire multiple licenses
- Outside U.S. 3.5 GHz, 4.8GHz and 10.5 GHz bands used for licensed WIMAX
- Main unlicensed band is U-NII 5.725-5.825 GHz
- TDD and FDD options for every band
  - For example,
    - TDD used with 5 MHz channels in 2.5 GHz band
    - FDD pair of 2.5 MHz channels (one uplink, one downlink) in 3.5 GHz band
  - TDD cheaper implementation and is recommended more for unlicensed spectrum
IEEE 802.16-2004 MAC Layer

- MAC Layer is independent of physical layer used
- Point to Multipoint
- TDMA Scheduled Uplink/Downlink Frames
- Flexible QoS offerings
- Connection oriented
  - Per Connection QoS
- Integrated Security Sublayer
- Selective ARQ
- Adaptive Modulation and Coding selection
  - Increase capacity and vary data rates
  - Burst by burst, per subscriber station
- Adaptive Power Control

MAC Addressing

- SS has a 48 bit IEEE 802 MAC address
- BS has a 48 bit BS ID – 24 bits are a network operator indicator
- Each flow to a SS is assigned a 16bit connection ID (CID) used in the MAC protocol data units and to provide QoS class identifier
Multiple Access

• On DownLink SS addressed in TDM stream
• On Uplink, SS allotted a variable length TDMA slot
• TDD
  – DL & UL time share the RF channel
  – Dynamic asymmetry
  – SS doesn’t transmit receive simultaneously (lowers cost)
• FDD
  – DL & UL separate RF channels
  – Static asymmetry
  – Half Duplex SSs supported (lower cost)
• IUC – interval usage code specifies a modulation, rate and FEC for a time interval on DL or UL

TDD Structure

TDD frames is 1ms durations adaptively partitioned among up and downlink

\[ n \text{ PS} = (\text{Symbol Rate} \times \text{Frame Length}) / 4 \]
TDD Structure

DL part of frame contains DL-MAP which specifies the modulation and coding for various TDM slots. UL-MAP determines which SS gets slots in UL part of frame and modulation and coding used.

FDD Structure

DL part of frame contains DL-MAP which specifies the modulation and coding for various TDM slots. TDMA portion is for support of half duplex users. UL-MAP determines which SS gets slots in UL part of frame and modulation and coding used.
TDD/FDD UL Structure

Contention part for SS to initiate connection followed by TDMA slots

FDD Framing

Allows scheduling flexibility
QoS Services

Classes of Uplink Service

- Unsolicited Grant Services (UGS)
  - For constant bit rate (CBR) or CBR like emulation (e.g., leased T1 service)
- Real Time Polling Services (rtPS)
  - For rt-variable bit rate (rt-VBR) flows such as video
- Non-Real Time Polling Services (nrtPS)
  - For non-rt flows that need better than best effort service such as file transfer
- Best Effort (BE)
WiMax Applications

- According to WiMax Forum it supports 5 classes of applications:
  1. Multi-player Interactive Gaming.
  2. VOIP and Video Conference
  3. Streaming Media
  4. Web Browsing and Instant Messaging
  5. Media Content Downloads

- Basically the Triple Play
- These are mapped into QoS requirements for the MAC layer

Application Requirements

<table>
<thead>
<tr>
<th>Class</th>
<th>Application</th>
<th>Bandwidth</th>
<th>Latency</th>
<th>Jitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interactive Gaming</td>
<td>Low Bandwidth</td>
<td>50 kbps</td>
<td>Low Latency</td>
</tr>
<tr>
<td>2</td>
<td>Voice Telephone (VoIP) Video Conference</td>
<td>Low Bandwidth</td>
<td>320 kbps</td>
<td>Low Latency</td>
</tr>
<tr>
<td>3</td>
<td>Streaming Media</td>
<td>Low to High Bandwidth</td>
<td>5 kbps - 2 Mbps</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Instant Messaging Web Browsing</td>
<td>Moderate Bandwidth</td>
<td>10 kbps - 2 Mbps</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>Media Content Download</td>
<td>High Bandwidth</td>
<td>&gt; 1-2 Mbps</td>
<td>N/A</td>
</tr>
</tbody>
</table>
IEEE 802.16 Security

- Security is a sublayer of the MAC in the standard
- Security Mechanisms
  - Authentication and Registration
    - PKI at the BS with X.509 digital certificates installed by manufacturers in SSs
    - Downloaded to BS with manufacturers public key
  - Access Control
    - (similar to WiFi - WPA)
    - MAC/IP address filtering
    - VPN at higher layers, passwords, etc.
  - Privacy
    - DES with 128 bit key (triple DES)
    - Plans to move to AES
    - PKI for key distribution
    - Key refreshed based on activity max usage 20 hours

WiMax Rollout

- WiMax Forum anticipates rollout of its technology in 3 phases:
  - Phase 1: Fixed Location, Private Line Services, Hot Spot Backhaul.
  - Phase 2: Broadband Wireless Access/Wireless DSL
  - Phase 3: Fully Mobile/Nomadic Users.
WiMax Evolution Path

<table>
<thead>
<tr>
<th>Fixed access</th>
<th>Limited mobility</th>
<th>Full mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominating standard</td>
<td>IEEE 802.16-2004</td>
<td>IEEE 802.16e</td>
</tr>
<tr>
<td>Services</td>
<td>Alternative to T1, DSL, cable, Backhaul for cellular and Wi-Fi</td>
<td>Plus: VoIP, QoS-based applications; enterprise networking</td>
</tr>
<tr>
<td>CPE form factor</td>
<td>External CPE</td>
<td>Desktop CPE</td>
</tr>
<tr>
<td>CPE price tag</td>
<td>$500-$300</td>
<td>$100</td>
</tr>
<tr>
<td>Residential markets</td>
<td>Underserved areas</td>
<td>Initial deployments in competitive markets</td>
</tr>
<tr>
<td>Business markets</td>
<td>Underserved areas</td>
<td>Underserved and competitive areas</td>
</tr>
<tr>
<td>2005</td>
<td>2006</td>
<td>2007</td>
</tr>
</tbody>
</table>

Wireless Networks

<table>
<thead>
<tr>
<th>Network</th>
<th>Geographic Coverage</th>
<th>Typical Throughput</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMANs</td>
<td>Metro, suburb, campus 1-15 km</td>
<td>2-100 Mbps</td>
<td>IEEE 802.16</td>
</tr>
<tr>
<td>WLANs</td>
<td>In building, campus wide, subdivision wide, Range ~ 100 M per AP</td>
<td>1-106 Mbps</td>
<td>IEEE 80211a, b, g, etc.</td>
</tr>
<tr>
<td>WPANs</td>
<td>5-10 M around device</td>
<td>.1 – 1Mbps</td>
<td>IEEE 802.15 IrDa, BlueTooth, Zigbee</td>
</tr>
</tbody>
</table>
### Frequency Allocations

<table>
<thead>
<tr>
<th></th>
<th>Europe</th>
<th>USA</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WWANs</strong></td>
<td><strong>Licensed</strong></td>
<td><strong>Licensed</strong></td>
<td><strong>Licensed</strong></td>
</tr>
<tr>
<td></td>
<td>Cellular: 453-457 MHz, 463-467 MHz;</td>
<td>Cellular</td>
<td>Cellular: 810-826 MHz, 940-956 MHz;</td>
</tr>
<tr>
<td></td>
<td>PCS: 890-915 MHz, 935-960 MHz;</td>
<td>824-849 MHz, 869-894 MHz; 1850-1910 MHz, 1930-1990 MHz;</td>
<td>1429-1465 MHz, 1477-1513 MHz; 1918.1-1980 MHz; 2110-2170 MHz;</td>
</tr>
<tr>
<td></td>
<td>1710-1785 MHz, 1805-1880 MHz; 3G: 1920-1996 MHz</td>
<td>2110-2186 MHz</td>
<td></td>
</tr>
<tr>
<td><strong>WMANs</strong></td>
<td><strong>Licensed</strong></td>
<td><strong>Unlicensed</strong></td>
<td><strong>Unlicensed</strong></td>
</tr>
<tr>
<td></td>
<td>IEEE 802.16</td>
<td>3.4-3.6 GHz Same as WLANs</td>
<td>IEEE 802.16</td>
</tr>
<tr>
<td></td>
<td>3.4-3.6 GHz</td>
<td>2.5 – 2.6 GHz, 2.7-2.9GHz Same as WLANs</td>
<td>4.8-5 GHz Same as WANS</td>
</tr>
<tr>
<td><strong>WLANs</strong></td>
<td><strong>Unlicensed</strong></td>
<td><strong>Unlicensed</strong></td>
<td><strong>Unlicensed</strong></td>
</tr>
<tr>
<td></td>
<td>IEEE 802.11</td>
<td>2400-2483 MHz, 5.7-5.825 GHz HIPERLAN 1 5176-5270 MHz</td>
<td>IEEE 802.11</td>
</tr>
<tr>
<td></td>
<td>2400-2483 MHz (b, g)</td>
<td>2400-2483 MHz (b, g)</td>
<td>2471-2497 MHz (b, g)</td>
</tr>
<tr>
<td></td>
<td>5.7 – 5.825 GHz (a)</td>
<td>5.7 – 5.825 GHz (a)</td>
<td>5.7-5.825 MHz (a)</td>
</tr>
<tr>
<td><strong>WPANs</strong></td>
<td><strong>Unlicensed</strong></td>
<td><strong>Unlicensed</strong></td>
<td><strong>Unlicensed</strong></td>
</tr>
<tr>
<td></td>
<td>IEEE 802.15</td>
<td>2400-2483 MHz</td>
<td>IEEE 802.15</td>
</tr>
<tr>
<td></td>
<td>2400-2483 MHz</td>
<td></td>
<td>2471-2497 MHz</td>
</tr>
</tbody>
</table>

### Summary

- **Wireless MANs**
  - Architecture
  - Standards
  - Protocol