EE 577 - Wireless and Personal Communications

Broadband Wireless Access

- Bluetooth
- WLAN
- UWB

Inside Office
Inside Building
Low Mobility Outside
High Mobility Outside

- 100 Mbps
- 10 Mbps
- 1 Mbps
- 100 kbps
- 1 Gbps

UMTS
GSM / GPRS
EDGE
CDMA2000 1xEV-DO
802.20

Under Standardization and Development
Existing Wireless Systems

- **3G Cellular (WCDMA)**
  - Frequency Division Duplex (FDD): Paired spectrum
  - Time Division Duplex (TDD): Allows “asymmetric” traffic (adjust time slots in uplink and downlink)
  - Lately: HSDPA and HSUPA
- **3G Cellular (CDMA2000, 1x, 3x, 1xEV-DO, 1xEV-DV)**
- **Wi-Fi**
  - 802.11, 802.11b and 802.11g
  - Unlicensed frequency band
- **WiMAX**
  - 802.16d (fixed); 802.16e (“nomadic”)
  - 2-6 GHz band; 1.5 – 20 Mbps symmetrical BW

3G Evolution

- TDMA
- GSM
- PDC
- cdmaOne
- CDMA2000 1x
- EDGE
- 3GPP Core Network
- WCDMA
- HSDPA/HSUPA
- CDMA2000 1xEV-DO
- CDMA2000 EVDO Rev A

Expected market share

- 2G: First Step into 3G: 90%
- 3G phase 1: 10%
- Evolved 3G: 10%
Global Wireless Handset Shipments

3G (CDMA2000 and WCDMA) will make up 60% of total shipments by 2009.

CDMA/WCDMA Becomes the Dominant Wireless Technology

Worldwide Wireless Subscribers (Billions)
Data Capacity Evolution of 3G Technologies

Evolution of Data Throughput
Average Aggregate Throughput
(Compared to 5MHz bandwidth)

Peak Bit Rates Comparison

STC 7 Dr. Salam Zummo

STC 8 Dr. Salam Zummo
User Data Rates

<table>
<thead>
<tr>
<th>Technology</th>
<th>Peak data rate according to Specification (Mbps)</th>
<th>Average data rate in the Field (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCDMA Release 99</td>
<td>2.0</td>
<td>0.3</td>
</tr>
<tr>
<td>CDMA2000 1xEV-DO</td>
<td>2.5 - 3.1</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>Flash-OFDM (Proprietary)</td>
<td>3.0</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>WCDMA Evolved (HSDPA)</td>
<td>14</td>
<td>2 - 4</td>
</tr>
</tbody>
</table>

3G+ Systems

- Based on existing 3G spectrum (not new spectrum).
- By 2010, 66% of the revenues will come from data services.
- UMTS - Release 99/4 systems alone will not be capable to meet these demands.
- Ultra high speed packet data service (10.8 Mbps)
- All-IP Core Network.
A converged 3G+, WiMAX and WiFi wireless network on a common IMS backbone will provide the lowest cost technology with the widest range of functionality.

**EDGE / UMTS / HSDPA**
Service "Umbrella"

**IP based convergence backbone**

- **WiMAX 802.16d**
- **WiMAX 802.16e**
- **WiFi**

**In-building, Hotspots**
- **PicoCell**
- **MicroCell**
- **MacroCell**

**Urban, Suburban**

**Suburban, Rural**

**Cellular Mobility WAN**

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**Wireless LANs**
WLAN Applications

- Inadequate wired infrastructure
- Need for flexible LANs with mobility
- Hospitals, libraries, production, internet access, coffee shops, training sites, etc…

**Benefits:**
- Portability
- Speed (compared to cellular)
- Simplicity of installation
- Scalability

WLAN Components

- **RF medium:**
  - Spectrum
  - Properties/impairments/interference
  - Antennas

- **Physical layer:**
  - Modulation/encoding
  - Wireless link

- **MAC layer:**
  - DCF – distributed coordination function
  - PCF – point coordination function
Basic Service Set (BSS)

Set of stations operating in a fully-connected network with an AP

Extended BSS (EBSS)

Several BSSs covering an area

BSS: Basic Service Set
ESS: Extended Services Set
Distributed System (DS)
A system that interconnects different BSSs via APs

WLAN Layered Structure

- **Application**
- **Transport**
- **Network**
- **Data**
- **Link**
- **Physical**

**Network Operating System**

- **Logical Link Control (LLC) – 802.2**
- **Medium Access Control (MAC) – Power, security, etc**
- **802.11x: FH, DS, IR, OFDM**
**WLAN Physical Layer Standards**

- **802.11 - (ISM - 2.4 GHz):**
  - Infra-Red (IR), FHSS, DSSS
  - Data rate: 1-2 Mbps
- **802.11b (Wi-Fi) - (ISM - 2.4 GHz):**
  - DSSS - 11 Mbps
- **802.11a - (U-NII – 5 GHz):**
  - OFDM - 54 Mbps
- **802.11g - (ISM - 2.4 GHz):**
  - OFDM - 54 Mbps
  - backward compatible with 802.11b
- **All Share the same MAC layer**

**Unlicensed Spectrum**

- **ISM:** Industrial, Scientific, and Medical band, shared by multiple services including WLAN in 2.4GHz band
- **UNII:** Unlicensed National Information Infrastructure
IEEE 802.11

- Final draft issued in 1997.
- Standard is approved by FCC, ETSI.
- **Band of operation:** ISM: 2400 – 2483.5 MHz.
- Technologies:
  - Radio (RF): FHSS and DSSS.
  - Infra Red (IR).
- **Modulation:**
  - BPSK @ bit rate of 1 Mbps.
  - QPSK @ bit rate of 2 Mbps.

Spread Spectrum

- Most popular now
- Spread signal spectrum over entire channel
- Reduce effect of noise
- Reduce interference with other users

**Two Types:**
- Frequency hopping spread spectrum (FHSS)
- Direct sequence spread spectrum (DSSS)
Frequency Hopping (FHSS)

- Change carrier frequency every few milliseconds (dwell time)
- Hopping occurs between 79 1-MHz channels
- Dwell time = 390 time slots, ~ 0.4 sec
- Modulation used with FHSS:
  - 2/4-level DPSK – (1/2 bits per cycle) – restrict power
    narrowbands – good for secondary users
  - Data whitening – scramble data

Direct Sequence Spread Spectrum (DSSS)

Sender

- Data bits
- Code
- Channel output
- Slot 1
- Slot 0

Receiver

- Received input
- Code
- Channel output
- Slot 1
- Slot 0

\[ Z_{im} = d_i c_m \]

\[ D_i = \sum_{m=0}^{N-1} Z_{im} c_m \]

\[ d_i = \pm 1 \]
IEEE 802.11b

- Final draft was issued in 1999.
- Standard approved by FCC, ETSI.
- Band of operation - ISM: 2400 – 2483.5 MHz.
- Defines only one RF technology: DSSS.
- Offers three 22-MHz non-overlapping channels.
- Bit rate up to 11 Mbps
- Backward compatible with IEEE 802.11.

Channels:
- North America: 11 channel.
- Europe: 13 Channels.
- Japan: 14 Channels.

802.11b Channel Allocation

Center frequencies of channels are separated by 5MHz
IEEE 802.11a

- Final draft issued in 2000.
- Standard approved by FCC.
- Bands of operation:
  - 5.15 – 5.25 GHz,
  - 5.25 – 5.35 GHz
  - 5.725 – 5.825 GHz.
- Based on the use of Orthogonal Frequency Division Multiplexing (OFDM).
- Bit rates up to 54 Mbps.
- Offers eight 20-MHz non-overlapping channels.

IEEE 802.11g

- Finalized by end of 2003.
- Operates in the same band as IEEE 802.11b, around 2.4 GHz (ISM band).
- Offers three non-overlapping channels.
- Bit rates up to 54 Mbps using OFDM.
- Offers backward compatibility with IEEE 802.11b.
Data Link Layer

mobile terminal

application

TCP
IP
LLC
802.11 MAC
802.11 PHY

fixed terminal

server

infrastructure network

access point

application

TCP
IP
LLC
802.11 MAC
802.11 PHY

802.3 MAC
802.3 PHY

Logical Link Control

Contestion-free service

MAC Layer

Point Coordination Function (DCF)

Contention service

Distributed Coordination Function (DCF)

2.4 GHz frequency hopping
spread spectrum
1 Mbps
2 Mbps

2.4 GHz direct sequence
spread spectrum
1 Mbps
2 Mbps

Infrared 1 Mbps
2 Mbps

5 GHz orthogonal
FM
6, 9, 12, 18, 24, 36, 48, 54 Mbps

2.4 GHz direct sequence
spread spectrum
5.5 Mbps
11 Mbps

IEEE 802.11
IEEE 802.11a
IEEE 802.11b

Figure 14.5 IEEE 802.11 Protocol Architecture
Differences From Ethernet

- **Ethernet** operates with CSMA/CD protocol.
- With wireless LANs that idea does not work well because of:
  - Multipath fading of a radio signal
  - Users can not hear all other users
  - Great deal of portability - by portability of a laptop the list of printers becomes invalid
- Roaming from an access point to another

Hidden Terminal Problem

- CSMA inefficient in presence of hidden terminals
- A wants to send to B, but can not hear that B is busy
- A and C cannot hear each other because of obstacles or signal attenuation; so, their packets collide at B
Exposed Station Problem

- B wants to send to C so it senses the channel.
- It falsely concludes that it may not send to C since A is transmitting to D.
- In addition, most radios are half duplex.
- As a result of these problems, 802.11 does not use CSMA/CD

Solution: CSMA/CA

- A sending an RTS (request-to-send) to B
- B responding with a CTS (clear-to-send) to A.
- After CTS is received, A begins transmission
CSMA/CA

- Anyone hearing **RTS** must remain **silent** until **CTS** to be transmitted back to **A**.
- Anyone hearing **CTS** must remain **silent** during the upcoming data transmission, whose **duration** is determined from **CTS**.
- **C** is within range of **A**, but **not** within range of **B**.
  => It hears **RTS from A**, but not **CTS from B**
- Since it does not interfere with the **CTS**, it is **free to transmit while the data frame is being sent**.
- **D** is within range of **B** but **not A**.
  => It does not hear **RTS** but hears **CTS**
- Hearing **CTS**, it waits about to receive a frame, so it holds sending anything until that is expected to be finished.
- **E** hears both **RTS** and **CTS** and must be silent

802.11 MAC Protocol: Priorities

- Defined through different IFS’s
  - **SIFS (Short Inter Frame Spacing)**:
    - Highest priority, for **ACK**, **CTS**, polling response
  - **PIFS (PCF IFS)**:
    - Medium priority, for time-bounded service using **PCF**
  - **DIFS (DCF IFS)**:
    - Lowest priority, for asynchronous data service
Interframe Spacing in 802.11

- **Short Interframe Spacing (SIFS):** Single dialog the chance to go first
- **PCF IFS (PIFS):** Station sending a data frame sequence to finish its frame without anyone interfering
- **DCF IFS (DIFS):** Other stations requesting the medium

Distributed Coordination Function (DCF)

- The sender senses the medium and wait until it is free
- Wait for **DIFS (DCF IFS)**, then the sender sends **RTS**
- After **SIFS (Short IFS)** the receiver sends **CTS**
- Sender can now send data at once, **ACK** via **ACK**
- **Network Allocation Vector:** for silent stations
Point Coordination Function (PCF)

- AP polls MSs, asking them to send - No collision.
- AP broadcasts a **beacon frame** (10 to 100 times per second).
- The beacon frame contains system parameters, such as **hopping sequences** and **dwell times** (for FHSS), **clock synchronization**...
- It invites new stations to sign up for **polling service**.
- **PCF** and **DCF** can coexist within one cell.
MAC - PCF

Like polling
Stop-and-Wait Protocol

A station that wants to transmit will first sense the medium. If the medium is idle, waits for a DIFS. If no other station transmits, then the station will transmit a short RTS packet with required duration. Duration = total transmission time for all further packets that will be transmitted (CTS, data, ACK, plus IFS). AP responds with a CTS, with the same duration information. Receipt of the CTS packet indicates to the transmitter that permission is granted to start the data transmission.
MAC Process

- If the transmitter **does not** receive a CTS, it retries until it either receives ACK or times out after a given number of re-transmissions.
- CTS is received by all MSs, notifying them that another unit will transmit for the **duration** requested.
- MSs will know when the medium will be available again.
- MSs may not have received the RTS because the original transmitting unit is out of range.
- The transmitting station sends its **data frame** to the AP.
- AP checks the **CRC** of the packet and, if correct, returns an ACK packet to confirm successful transmission.

MAC Process

- **Duration** in CTS protects the data transmission from collisions.
- If the **data packet** is very short, RTS may include all the data to be transmitted.
- If RTS contains data, the CTS packet contains a duration of zero, and simply acts as an ACK.
- Typical WLAN protocols use packets several hundred bytes long (up to 2312 bits).
- **Smaller packets** are preferable because:
  - Probability of a corrupted packet increases with packet size
  - In the case of packet corruption, a smaller the packet requires less overhead if it is necessary to re-transmit.
Contestion Window

- If a station senses the medium as busy, it backs off using **binary exponential backoff** algorithm.
- The maximum number of this algorithm is called the **contention window (CW)**.
- A station starts with a minimum CW size set up according to maximum propagation delay.
- Once it senses busy medium, it doubles the CW.
- This doubling continues until a maximum is reached, called maximum CW.
- Heavy load => large CW => high throughput.
- Small load => small CW => high throughput.

Coverage-Oriented Design

- Provides maximum coverage with least APs.
- Low packet rate and low bandwidth applications.
- Uses 14 APs and 25-30 users/AP.
Capacity-Oriented Design

- Used in high density areas
- High packet rate and latency sensitive applications
- Uses 30 APs and 12 users/AP

802.11n Task Group

- High throughput study group formed 2002
- Gained approval March 2003
- **Predictions** for next generation WLAN:
  - 50% annual growth in coming 4 years
  - MAC throughput of 100 Mbps
  - MAC and Physical layers will be enhanced by a factor 2-4
- Most attractive PHY layer enhancement
  - Multiple antenna schemes (2 to 4 antennas)
  - Antenna selection and beamforming
  - Smart Antennas
WiMAX

- **WiMAX**: Worldwide Interoperability for Microwave Access.
- A Forum that ensures interoperability of IEEE 802.16 and other standards (e.g. ETSI HiperMAN)
- Equivalent in purpose to Wi-Fi Alliance for 802.11
- Sets up certification labs for testing equipment
- Provides WiMAX-Certified stamp for approval of interoperability of products
- Wi-Fi and WiMAX are complementary
WiMAX Objectives

- Serves fixed, portable and mobile applications
- **Lower price** through standardization and mass production
- **Interoperability** with other BWA systems and existing Wi-Fi solutions
- **Volume** will be driven by portability/mobility (e.g. notebooks/PDAs)

WiMAX Spectrum

- Supports both **licensed** and **unlicensed** spectrum
- **Unlicensed Spectrum:**
  - No initial cost but limited scalability.
  - Expect RF interference to be a significant issue.
  - Mostly for point-to-point implementations at higher frequencies.
- **Licensed Spectrum:**
  - Initial cost to acquire spectrum.
  - Allows complete control over RF planning and thus interference is limited
  - Point-to-multipoint implementation at lower frequencies with non-line of sight (NLOS) capabilities.
WiMAX Spectrum

- **10 - 66 GHz**
  - Short wavelength
  - Line-of-sight (LOS) required
  - Negligible multipath
- **2 – 11 GHz**
  - Longer wavelength
  - Improved range and in-building penetration
  - LOS not required
  - Multipath effects may be significant

IEEE 802.16 Evolution

- **802.16** Dec 2001
  - Fixed wireless broadband air interface for 10–66 GHz
  - Line-of-sight only
  - Point-to-Multi-Point applications
- **802.16a** Jan 2003
  - Extension for 2-11 GHz Non-line-of-sight
  - Point-to-Multi-Point applications
  - Range-rate tradeoff
- **802.16d** Oct 2004
  - Revised and replaced previous versions
  - WiMAX System Profiles
- **802.16e** Mid 2006
  - An amendment to 802.16d to support mobility
  - MAC/Physical layer enhancements vehicular speeds
IEEE 802.16 Standards

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.16a</th>
<th>802.16e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed</td>
<td>December 2001</td>
<td>January 2003 (802.16a)</td>
<td>2006</td>
</tr>
<tr>
<td>Spectrum</td>
<td>10 - 66 GHz</td>
<td>&lt; 11 GHz</td>
<td>&lt; 6 GHz</td>
</tr>
<tr>
<td>Applications</td>
<td>Line of Sight Only</td>
<td>Non Line of Sight</td>
<td>Non Line of Sight</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>32 – 134 Mbps in 28MHz channel bandwidth</td>
<td>Up to 75 Mbps in 20MHz channel bandwidth</td>
<td>Up to 15 Mbps in 5MHz channel bandwidth</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM and 64QAM</td>
<td>OFDM 256 sub-carriers QPSK, 16QAM, 64QAM</td>
<td>OFDM 1024 sub-carriers</td>
</tr>
<tr>
<td>Mobility</td>
<td>Fixed</td>
<td>Fixed, Portable</td>
<td>Nomadic Mobility</td>
</tr>
<tr>
<td>Channel Bandwidths</td>
<td>20, 25 and 28 MHz</td>
<td>Scalable 1.5 to 20 MHz</td>
<td>Same as 802.16a with UL sub-channels</td>
</tr>
<tr>
<td>Typical Cell Radius</td>
<td>2-5 km</td>
<td>7 to 10 km Max range 50 km</td>
<td>2-5 km</td>
</tr>
</tbody>
</table>

IEEE 802.16

- Published in 12/2001.
- Point-to-multipoint broadband wireless access
- Operates in 10-66 GHz licensed spectrum
- Data rates up to 134 Mbps
- Range up to 50 km
- Requires directional line-of-sight (LOS) propagation
- Provides a cost-effective “Last Mile” solution.
- **Full duplex:** a hybrid TDD/FDD duplexing scheme.
- Support of multiple services with QoS
IEEE 802.16a

- Approved in 1/2003.
- 802.16a came to address the following:
  - Operation in 2-11 GHz unlicensed spectrum
  - Eliminates need for directional LOS propagation
    => NLOS propagation
  - Greater range at lower data rates

Mobile WiMAX - IEEE 802.16e

- Approved in 2006.
- 802.16e came to address the following:
  - Operation in 2-6 GHz licensed spectrum
  - Support of mobility at moderate speeds (60 Km/hr)
  - NLOS implementation through a cellular structure
  - High data rates using advanced PHY layer techniques
Variety of channel bandwidths supported (integer multiples of 1.5 MHz and 1.75 MHz)
This insures interoperability worldwide
802.16 Physical Layer

- Data rates determined by exact modulation and coding schemes
- TDD and FDD supported in 802.16 to accommodate burst profiling
- 802.16d adds OFDM and OFDMA to support NLOS multipath propagation

<table>
<thead>
<tr>
<th>Bit Rate (Mbps)</th>
<th>QPSK</th>
<th>16-QAM</th>
<th>64-QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>32</td>
<td>64</td>
<td>96</td>
</tr>
<tr>
<td>25</td>
<td>40</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>28</td>
<td>44.8</td>
<td>89.6</td>
<td>134.4</td>
</tr>
</tbody>
</table>

IEEE 802.16e PHY Layer

- Physical Layer Options (SC, SCa, OFDM, OFDMA)
- Multiple options for:
  - Channel bandwidths
  - Frame lengths
  - Duplexing modes (TDD, FDD)
  - Channel coding and modulation
- Support for multiple antenna technology
  - Adaptive antenna systems (AAS)
  - TX diversity (STC, MIMO)
- Link adaptation
  - Adaptive modulation and coding per subscriber
  - Scheduling to enhance network capacity
### IEEE 802.16e PHY Modes

<table>
<thead>
<tr>
<th>Designation</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Carrier (SC)</td>
<td>10 - 66 GHz</td>
</tr>
<tr>
<td>Single-Carrier – a (SCa)</td>
<td>Below 11 GHz, Licensed bands</td>
</tr>
<tr>
<td>OFDM</td>
<td>Below 11 GHz, Licensed bands</td>
</tr>
<tr>
<td>OFDMA</td>
<td>Below 6 GHz, Licensed bands</td>
</tr>
</tbody>
</table>

### Data Rates and Range

<table>
<thead>
<tr>
<th>Standard</th>
<th>Data Rate</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.16d</td>
<td>Up to 75 Mbps (20 Mhz channel)</td>
<td>6 - 16 Kms</td>
</tr>
<tr>
<td>802.16e</td>
<td>Up to 30 Mbps (10 Mhz channel)</td>
<td>1 - 5 Kms</td>
</tr>
</tbody>
</table>
Mobile WiMAX Technologies

- Orthogonal Frequency Division Multiple Access (OFDMA)
- OFDMA using 1024 carriers
- Adaptive time-division duplexing (TDD) and frequency-division duplexing (FDD)
- Adaptive modulation and coding
- Hybrid Automatic-Repeat Request (HARQ) for retransmission
- Diversity using MIMO and space-time coding
- Antenna array systems (AAS) to suppress interference (smart antennas)

Channel Quality Indicator

- BS uses Adaptive Modulation and Coding (AMC) to send data to the subscriber stations to optimize throughput.
- BS needs to know how the channel looks to the subscriber so it tells subscriber to measure the carrier to (interference plus noise) ratio.

"I've got data to send you, measure my preamble and send me CQI in the next UL subframe"

"Here's what I see; doesn't look good"

"We'll go slow"
Adaptive Modulation & Coding

- Bit rate adaptation is achieved using adaptive modulation & coding.
- When you are near to the BS => offered high speed,
- When you are far, reliability decreases => offered lower speed.

802.16e Modulation and Coding

- BS and MS nominally support QPSK, 16-QAM and 64-QAM
- Mandatory: tail-biting convolutional code (K=7)
- Optional: Block turbo code (BTC), Convolutional turbo code (CTC)
- CTC encoder is similar performance to 3GPP
- Optional LDPC code under study
Adaptive Antenna Systems

- Make measurements of the channel
- Compute gain and phase coefficients to adapt beam pattern
- Increase link gain, reduce interference

Hybrid Automatic Repeat-Request (HARQ)

- Self-optimizing and adjusts automatically to channel conditions
  - Adds redundancy only when needed
  - Receiver saves failed transmission attempts to help future decoding (Chase Combining)
  - Every transmission helps to increase the packet success probability
- Enabled by $N$-Channel Stop-and-Wait ARQ
  - Receiver sends an ACK or NAK in response to each transmission
**QoS Support**

<table>
<thead>
<tr>
<th>QoS Category</th>
<th>Applications</th>
<th>QoS Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS</td>
<td>VoIP</td>
<td>• Maximum Sustained Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Latency Tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Jitter Tolerance</td>
</tr>
<tr>
<td>rtPS</td>
<td>Streaming Audio or Video</td>
<td>• Minimum Reserved Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Sustained Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Latency Tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic Priority</td>
</tr>
<tr>
<td>EtrPS</td>
<td>Voice with Activity Detection (VoIP)</td>
<td>• Minimum Reserved Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Sustained Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Latency Tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Jitter Tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic Priority</td>
</tr>
<tr>
<td>nrtPS</td>
<td>File Transfer Protocol (FTP)</td>
<td>• Minimum Reserved Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maximum Sustained Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic Priority</td>
</tr>
<tr>
<td>BE</td>
<td>Data Transfer, Web Browsing, etc.</td>
<td>• Maximum Sustained Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic Priority</td>
</tr>
</tbody>
</table>

**802.16 vs. 802.11**

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell Coverage</strong></td>
<td>Up to few blocks</td>
<td>Typical max range: 200–250m</td>
</tr>
<tr>
<td><strong>Service Area</strong></td>
<td>Scales up to city-wide coverage</td>
<td>Campus wide</td>
</tr>
<tr>
<td><strong>Spectrum</strong></td>
<td>10 – 66 GHz (802.16)</td>
<td>2.4 GHz (802.11b)</td>
</tr>
<tr>
<td></td>
<td>2 – 11 GHz (802.16a)</td>
<td>5 GHz (802.11a)</td>
</tr>
<tr>
<td><strong>Bit rate</strong></td>
<td>Up to 134 Mbps</td>
<td>Up to 54 Mbps</td>
</tr>
</tbody>
</table>
## 802.16 vs. 802.11

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duplexing</strong></td>
<td>Full-duplex</td>
<td>Simplex (CSMA/CA)</td>
</tr>
<tr>
<td><strong>Users</strong></td>
<td>Provides broadband wireless access for buildings</td>
<td>Provides wireless access for mobile users</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>will eventually evolve to support mobile users</td>
<td>Supports mobility and inter-cell roaming</td>
</tr>
</tbody>
</table>

## 802.16 vs. 802.11

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connectivity</strong></td>
<td>Connects to UMTS, ATM core networks</td>
<td>Connects to wired Ethernet backbones</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>High initial investment requirements</td>
<td>Low initial cost. Low running cost.</td>
</tr>
<tr>
<td><strong>Target Market</strong></td>
<td>Public. Provides high-speed connection to meet business demands</td>
<td>Private. To address mobility requirement in an organization</td>
</tr>
<tr>
<td><strong>Service Provider</strong></td>
<td>ISP, Telecom companies</td>
<td>Local to the organization</td>
</tr>
</tbody>
</table>
IEEE802.16e Summary

802.16e Pros
- Scalable Bandwidths
- Performs well in high delay spread environments
- Higher data rates
- TDD allows for deployment with less spectrum
- Supports multiple antenna technologies

802.16e Cons
- High peak-to-average power ➔ nonlinear amplifiers distortion
- How will it perform in high interference environment?
- What is performance in high Doppler?
- Signaling overhead
- Spectrum availability
- Network layers not clearly defined yet

Flarion Flash OFDM

Proprietary technology of Flarion Inc USA
- May evolve into a standard in next one / two years
- First mobile OFDMA technology to be commercially deployed
- 1.25 + 1.25 MHz
- Evolution to 5 + 5 MHz
- Spectrum re-use 1/1 in every sector
- Peak Date rate:    DL – 3 Mbps
                   UL – 1.5 Mbps
- VoIP based voice service with low latency
- QoS for data services