E2-E3: CONSUMER MOBILITY

CHAPTER 6

WI-MAX OVERVIEW

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Introduction

The WiMAX (Worldwide Interoperability for Microwave Access) technology, based on the IEEE 802.16-2004 Air Interface Standard is rapidly proving itself as a technology that will play a key role in fixed broadband wireless metropolitan area networks. The first certification lab, established at Cetecom Labs in Malaga, Spain is fully operational and more than 150 WiMAX trials are underway in Europe, Asia, Africa and North and South America. In December, 2005 the IEEE introduced the 802.16e which adds the features and attributes to the standard necessary to support mobility. The WiMAX Forum is now defining system performance and certification profiles based on the IEEE 802.16e Mobile Amendment and going beyond the air interface, the WiMAX Forum is defining the network architecture necessary for implementing an end-to-end Mobile WiMAX network.

Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. The Mobile WiMAX Air Interface adopts Orthogonal Frequency Division Multiple Access (OFDMA) for improved multi-path performance in non-line-of-sight environments. Scalable OFDMA (SOFDMA) is introduced in the IEEE 802.16e to support scalable channel bandwidths from 1.25 to 20 MHz. The Mobile WiMAX System Profile enables mobile systems to be configured based on a common base feature set thus ensuring baseline functionality for terminals and base stations that are fully interoperable. Some elements of the base station profiles are specified as optional to provide additional flexibility for deployment based on specific deployment scenarios that may require different configurations that are either capacity-optimized or coverage optimized. Mobile WiMAX will cover 5, 7, 8.75, and 10 MHz channel bandwidths for licensed worldwide spectrum allocations in the 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands.

The WiMAX Forum founded in April 2001 to bring together leaders in the communication and computing industries to drive a common platform for global deployment of IP based wireless broadband services. The WiMAX forum certifies products for conformance and interoperability based upon IEEE 802.16 standards. WiMAX forum has various working groups as follows.
Network Working Group (NWG) is developing the higher-level networking specifications for Mobile WiMAX systems beyond what is defined in the IEEE 802.16 standard that simply addresses the air interface specifications. The combined effort of IEEE 802.16 and the WiMAX Forum help define the end-to-end system solution for a Mobile WiMAX network. Mobile WiMAX systems offer scalability in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and service offerings. Some of the salient features supported by Mobile WiMAX are

- **High Data Rates:** The inclusion of MIMO antenna techniques along with flexible sub-channelization schemes, Advanced Coding and Modulation all enable the Mobile WiMAX technology to support peak DL data rates up to 63 Mbps per sector and peak UL data rates up to 28 Mbps per sector in a 10 MHz channel.

- **Quality of Service (QoS):** The fundamental premise of the IEEE 802.16 MAC architecture is QoS. It defines Service Flows which can map to Different Service code points or MPLS flow labels that enable end-to-end IP based QoS. Additionally, sub-channelization and MAP-based signaling schemes provide a flexible mechanism for optimal scheduling of space, frequency and time resources over the air interface on a frame-by-frame basis.
Scalability: Despite an increasingly globalized economy, spectrum resources for wireless broadband worldwide are still quite disparate in its allocations. Mobile WiMAX technology therefore, is designed to be able to scale to work in different channelization from 1.25 to 20 MHz to comply with varied worldwide requirements as efforts proceed to achieve spectrum harmonization in the longer term. This also allows diverse economies to realize the multi-faceted benefits of the Mobile WiMAX technology for their specific geographic needs such as providing affordable internet access in rural settings versus enhancing the capacity of mobile broadband access in metro and suburban areas.

Security: The features provided for Mobile WiMAX security aspects are best in class with EAP-based authentication, AES-CCM-based authenticated encryption, and CMAC and HMAC based control message protection schemes. Support for a diverse set of user credentials exists including; SIM/USIM cards, Smart Cards, Digital Certificates, and Username/Password schemes based on the relevant EAP methods for the credential type.

Mobility: Mobile WiMAX supports optimized handover schemes with latencies less than 50 milliseconds to ensure real-time applications such as VoIP perform without service degradation. Flexible key management schemes assure that security is maintained during handover.

WiMAX forum Profiles are defined by the following parameters:
- Spectrum band
- Duplexing-TDD/FDD
- Channel bandwidth
IEEE 802.16-2004 profile uses OFDM with 256 subcarriers and 802.16e profiles are based on Scalable OFDMA and supports mobility.

End-to-End WiMAX Architecture
The IEEE only defined the Physical (PHY) and Media Access Control (MAC) layers in 802.16. This approach has worked well for technologies such as Ethernet and Wi-Fi, which rely on other bodies such as the IETF (Internet Engineering Task Force) to set the standards for higher layer protocols such as TCP/IP, SIP, VoIP and IPSec. In the mobile
wireless world, standards bodies such as 3GPP and 3GPP2 set standards over a wide range of interfaces and protocols because they require not only air-link interoperability, but also inter-vendor inter-network interoperability for roaming, multi-vendor access networks, and inter-company billing. Vendors and operators have recognized this issue, and have formed additional working groups to develop standard network reference models for open inter-network interfaces. Two of these are the WiMAX Forum’s Network Working Group, which is focused on creating higher-level networking specifications for fixed, nomadic, portable and mobile WiMAX systems beyond what is defined in the IEEE 802.16 standard, and Service Provider Working Group which helps write requirements and prioritizes them to help drive the work of the Network WG.

The Mobile WiMAX End-to-End Network Architecture is based on an All-IP platform, all packet technology with no legacy circuit telephony. The use of All-IP means that a common network core can be used.

In order to deploy successful and operational commercial systems, there is need for support beyond 802.16 (PHY/MAC) air interface specifications. Chief among them is the need to support a core set of networking functions as part of the overall End-to-End WiMAX system architecture.

1. The architecture is based on a packet-switched core network.
2. This type of architecture permits decoupling of access architecture (and supported topologies) from connectivity IP service.
3. The architecture allows modularity and flexibility to accommodate a broad range of deployment options such as:
   - Small-scale to large-scale (sparse to dense radio coverage and capacity) WiMAX networks
   - Urban, suburban, and rural radio propagation environments
   - Licensed and/or licensed-exempt frequency bands
   - Hierarchical, flat, or mesh topologies, and their variants
   - Co-existence of fixed, nomadic, portable and mobile usage models

**Support for Services and Applications:** The end-to-end architecture includes the support for: a) Voice, multimedia services and other mandated regulatory services such as emergency services and lawful interception, b) Access to a variety of independent Application Service Provider (ASP), c) Mobile telephony communications using VoIP, d) Support interfacing with various interworking and media gateways permitting delivery of
various services translated over IP (for example, SMS over IP, MMS, WAP) to WiMAX access networks.

**Interworking and Roaming** is another key strength of the End-to-End WiMAX Network Architecture with support for a number of deployment scenarios. In particular, there will be support of a) Interworking with existing wireless networks such as 3GPP and 3GPP2 or existing wireline networks such as DSL, with the interworking interface(s) based on a standard IETF suite of protocols, b) Global roaming across WiMAX operator networks, consistent use of AAA for accounting and billing, and consolidated/common billing and settlement, c) A variety of user authentication credential formats such as username/password, digital certificates, Subscriber Identity Module (SIM), Universal SIM (USIM), and Removable User Identify Module (RUIM).

WiMAX Forum industry participants have identified a WiMAX Network Reference Model (NRM) that is a logical representation of the network architecture. The NRM identifies functional entities and reference points over which interoperability is achieved between functional entities. The architecture has been developed with the objective of providing unified support of functionality needed in a range of network deployment models and usage scenarios (ranging from fixed – nomadic – portable – simple mobility – to fully mobile subscribers).

Figure illustrates the NRM, consisting of the following logical entities: MS, Access Service Network (ASN), and Connectivity Service Network (CSN) and clearly identified reference points for interconnection of the logical entities. The figure depicts the various interface points R1-R5. Each of the entities, MS, ASN and CSN represent a grouping of functional entities. Each of these functions may be realized in a single physical device or may be distributed over multiple physical devices.

The intent of the NRM is to achieve interoperability among different realizations of functional entities.
The **Access Service Network (ASN)** defines a logical boundary and represents a convenient way to describe aggregation of functional entities and corresponding message flows associated with the access services. The ASN represents a boundary for functional interoperability with WiMAX clients, WiMAX connectivity service functions and aggregation of functions by different vendors. The WiMAX Forum is in the process of network specifications in a manner that would allow a variety of vendor implementations that are interoperable and suited for a wide diversity of deployment requirements.

The **Connectivity Service Network (CSN)** is defined as a set of network functions that provide IP connectivity services to the WiMAX subscriber(s). A CSN may comprise network elements such as routers, AAA proxy/servers, user databases and Interworking gateway devices.

The WIMAX architecture also allows both IP and Ethernet services, in a standard mobile IP compliant network. The flexibility and interoperability supported by the WiMAX network provides operators with a multi-vendor low cost implementation of a WiMAX network even with a mixed deployment of distributed and centralized ASN’s in the network.
WiMAX Network IP Based Architecture

Physical Layer Description

**OFDMA Basics**

**Orthogonal Frequency Division Multiplexing (OFDM)** is a multiplexing technique that subdivides the bandwidth into multiple frequency sub-carriers as shown in Figure. In an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier. Since OFDM has a very sharp, almost “brick-wall” spectrum, a large fraction of the allocated channel bandwidth can be utilized for data transmission.

OFDM exploits the frequency diversity of the multipath channel by coding and interleaving the information across the sub-carriers prior to transmissions. OFDM modulation can be realized with efficient Inverse Fast Fourier Transform (IFFT), which enables a large number of sub-carriers (up to 2048).
Basic Architecture of OFDM System
In an OFDM system, resources are available in the time domain by means of OFDM symbols and in the frequency domain by means of sub-carriers. The time and frequency resources can be organized into sub-channels for allocation to individual users. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access/multiplexing scheme that provides multiplexing operation of data streams from multiple users onto the downlink sub-channels and uplink multiple accesses by means of uplink sub-channels.

OFDMA Symbol Structure and Sub-Channelization
The OFDMA symbol structure consists of three types of sub-carriers as shown in Figure.

- Data sub-carriers for data transmission
- Pilot sub-carriers for estimation and synchronization purposes
- Null sub-carriers for no transmission; used for guard bands and DC carriers

OFDM sub Carrier Structure
Active (data and pilot) sub-carriers are grouped into subsets of sub-carriers called sub-channels. The WiMAX OFDMA supports sub-channelization in both DL and UL.
TDD Frame Structure
The 802.16e supports TDD and Full and Half-Duplex FDD operation; however the initial release of Mobile WiMAX certification profiles will only include TDD. With ongoing releases, FDD profiles will be considered by the WiMAX Forum to address specific market opportunities where local spectrum regulatory requirements either prohibit TDD or are more suitable for FDD deployments. TDD is the preferred duplexing mode for the following reasons:

- **TDD enables** adjustment of the downlink/uplink ratio to efficiently support asymmetric downlink/uplink traffic, while with FDD, downlink and uplink always have fixed and generally, equal DL and UL bandwidths.
- **TDD assures** channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.

- **Unlike FDD**, which requires a pair of channels, TDD only requires a single channel for both downlink and uplink providing greater flexibility for adaptation to varied global spectrum allocations.
- **Transceiver** designs for TDD implementations are less complex and therefore less expensive.

Figure illustrates the OFDM frame structure for a Time Division Duplex (TDD) implementation. Each frame is divided into DL and UL sub-frames separated by Transmit/Receive and Receive Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. In a frame, the following control information is used to ensure optimal system operation:

- **Preamble:** The preamble, used for synchronization, is the first OFDM symbol of the frame.
- **Frame Control Header (FCH):** The FCH follows the preamble. It provides the frame configuration information such as MAP message length and coding scheme and usable sub-channels.
- **DL-MAP and UL-MAP:** The DL-MAP and UL-MAP provide sub-channel allocation and other control information for the DL and UL sub-frames respectively.
- **UL Ranging:** The UL ranging sub-channel is allocated for mobile stations (MS) to perform closed-loop time, frequency, and power adjustment as well as bandwidth requests.
- **UL CQICH:** The UL CQICH channel is allocated for the MS to feedback channel state information.
UL ACK: The UL ACK is allocated for the MS to feedback DL HARQ acknowledge.

**Other Advanced PHY Layer Features**

Adaptive modulation and coding (AMC), Hybrid Automatic Repeat Request (HARQ) and Fast Channel Feedback (CQICH) were introduced with Mobile WiMAX to enhance coverage and capacity for WiMAX in mobile applications.

Support for QPSK, 16QAM and 64QAM are mandatory in the DL with Mobile WiMAX. In the UL, 64QAM is optional. Both Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding are supported. Table below provides the coding and modulation schemes supported in the Mobile WiMAX profile.

<table>
<thead>
<tr>
<th></th>
<th>Down Link</th>
<th>UpLink</th>
</tr>
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<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td>Code Rate</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/2, 2/3, 3/4, 5/6</td>
<td>1/2, 2/3, 5/6</td>
</tr>
<tr>
<td></td>
<td>CTC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/2, 2/3, 3/4, 5/6</td>
<td>1/2, 2/3, 5/6</td>
</tr>
<tr>
<td></td>
<td>Repetition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>x2, x4, x6</td>
<td>x2, x4, x6</td>
</tr>
</tbody>
</table>

**Supported code and Modulation**

The base station scheduler determines the appropriate data rate (or burst profile) for each burst allocation based on the buffer size, channel propagation conditions at the receiver, etc. A Channel Quality Indicator (CQI) channel is utilized to provide channel-state information from the user terminals to the base station scheduler. Relevant channel-state
information can be fed back by the CQICH including: Physical CINR, effective CINR, MIMO mode selection and frequency selective sub-channel selection.

**Hybrid Auto Repeat Request (HARQ)** is supported by Mobile WiMAX. HARQ is enabled using $N$ channel “Stop and Wait” protocol which provides fast response to packet errors and improves cell edge coverage. Chase Combining is supported to further improve the reliability of the retransmission. A dedicated ACK channel is also provided in the uplink for HARQ ACK/NACK signaling. WiMAX provides signaling to allow fully asynchronous operation. The asynchronous operation allows variable delay between retransmissions which gives more flexibility to the scheduler at the cost of additional overhead for each retransmission allocation.

**MAC Layer**
The 802.16 standard was developed from the outset for the delivery of broadband services including voice, data, and video. The MAC layer can support bursty data traffic with high peak rate demand while simultaneously supporting streaming video and latency-sensitive voice traffic over the same channel. The resource allocated to one terminal by the MAC scheduler can vary from a single time slot to the entire frame, thus providing a very large dynamic range of throughput to a specific user terminal at any given time. Furthermore, since the resource allocation information is conveyed in the MAP messages at the beginning of each frame, the scheduler can effectively change the resource allocation on a frame-by-frame basis to adapt to the bursty nature of the traffic.

**Quality of Service (QoS) Support:** With fast air link, asymmetric downlink/uplink capability, fine resource allocation mechanism, Mobile WiMAX can meet QoS requirements for a wide range of data services and applications. In the Mobile WiMAX MAC layer, QoS is provided via service flows. This is a unidirectional flow of packets that is provided with a particular set of QoS parameters. Before providing a certain type of data service, the base station and user-terminal first establish a unidirectional logical link between the peer MACs called a connection. The QoS parameters associated with the service flow define the transmission ordering and scheduling on the air interface. The connection-oriented QoS therefore, can provide accurate control over the air interface. Since the air interface is usually the bottleneck, the connection-oriented QoS can effectively enable the end-to-end QoS control. The service flow parameters can be dynamically managed through MAC messages to accommodate the dynamic service demand. The service flow based QoS mechanism applies to both DL and UL to provide
improved QoS in both directions. Mobile WiMAX supports a wide range of data services and applications with varied QoS requirements.

<table>
<thead>
<tr>
<th>QoS Category</th>
<th>Applications</th>
<th>QoS Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(UGS) Unsolicited Grant Services</td>
<td>VoIP</td>
<td>UGS is designed to support constant bit rate (CBR) such as T1/E1 emulation, VoIP without silence suppression.</td>
</tr>
<tr>
<td>(rtPS) Real-Time Polling Services</td>
<td>Streaming Audio or Video</td>
<td>rtPS is designed to support real time data that generate variable size data packets on a periodic basis, such as MPEG video</td>
</tr>
<tr>
<td>(nrtPS) Non-Real-Time Polling Services</td>
<td>File Transfer Protocol</td>
<td>nrtPS is designed to support non-real-time SF that require variable size data grant burst type on a regular basis, such as FTP.</td>
</tr>
<tr>
<td>(BE) Best Effort</td>
<td>Data Transfer, Web browsing etc.</td>
<td>Best effort services are typically provided by the Internet today for web surfing</td>
</tr>
</tbody>
</table>

MAC Scheduling Service: The Mobile WiMAX MAC scheduling service is designed to efficiently deliver broadband data services including voice, data, and video over time varying broadband wireless channel. The MAC scheduling service has the following properties that enable the broadband data service.

- **Fast Data Scheduler**: The MAC scheduler must efficiently allocate available resources in response to bursty data traffic and time-varying channel conditions. The scheduler is located at each base station to enable rapid response to traffic requirements and channel conditions. The data packets are associated to service flows with well defined QoS parameters in the MAC layer so that the scheduler can correctly determine the packet transmission ordering over the air interface.

- **Scheduling for both DL and UL**: The scheduling service is provided for both DL and UL traffic.

- **Dynamic Resource Allocation**: The MAC supports frequency-time resource allocation in both DL and UL on a per-frame basis. The resource allocation is delivered in MAP messages at the beginning of each frame. Therefore, the resource allocation can be changed frame-by-frame in response to traffic and channel conditions.
- **QoS Oriented:** The MAC scheduler handles data transport on a connection-by-connection basis. Each connection is associated with a single data service with a set of QoS parameters that quantify the aspects of its behavior.

**Mobility Management:** Battery life and handoff are two critical issues for mobile applications. Mobile WiMAX supports Sleep Mode and Idle Mode to enable power-efficient MS operation. Mobile WiMAX also supports seamless handoff to enable the MS to switch from one base station to another at vehicular speeds without interrupting the connection.

**Power Management:** Mobile WiMAX supports two modes for power efficient operation – Sleep Mode and Idle Mode. Sleep Mode is a state in which the MS conducts pre-negotiated periods of absence from the Serving Base Station air interface. These periods are characterized by the unavailability of the MS, as observed from the Serving Base Station, to DL or UL traffic. The Sleep Mode also provides flexibility for the MS to scan other base stations to collect information to assist handoff during the Sleep Mode.

Idle Mode provides a mechanism for the MS to become periodically available for DL broadcast traffic messaging without registration at a specific base station. Idle Mode benefits the MS by removing the requirement for handoff and other normal operations and benefits the network and base station by eliminating air interface and network handoff traffic from essentially inactive MSs while still providing a simple and timely method (paging) for alerting the MS about pending DL traffic.

**Handoff:** There are three handoff methods supported within the 802.16e standard – Hard Handoff (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO). Of these, the HHO is mandatory while FBSS and MDHO are two optional modes. The WiMAX Forum has developed several techniques for optimizing hard handoff within the framework of the 802.16e standard. These improvements have been developed with the goal of keeping handoff delays to less than 50 milliseconds.

When Fast Base Station Switching (FBSS) is supported, the MS and BS maintain a list of BSs that are involved in FBSS with the MS. This set is called an Active Set. In FBSS, the MS continuously monitors the base stations in the Active Set. Among the BSs in the Active Set, an Anchor BS is defined. When operating in FBSS, the MS only communicates with the Anchor BS for uplink and downlink messages including
management and traffic connections. Transition from one Anchor BS to another (i.e. BS switching) is performed without invocation of explicit HO signaling messages. Anchor update procedures are enabled by communicating signal strength of the serving BS via the CQI channel. A FBSS handover begins with a decision by an MS to receive or transmit data from the Anchor BS that may change within the active set. The MS scans the neighbor BSs and selects those that are suitable to be included in the active set. The MS reports the selected BSs and the active set update procedure is performed by the BS and MS. The MS continuously monitors the signal strength of the BSs that are in the active set and selects one BS from the set to be the Anchor BS. The MS reports the selected Anchor BS on CQICH or MS initiated HO request message. An important requirement of FBSS is that the data is simultaneously transmitted to all members of an active set of BSs that are able to serve the MS.

For MSs and BSs that support MDHO, the MS and BS maintain an active set of BSs that are involved in MDHO with the MS. Among the BSs in the active set, an Anchor BS is defined. The regular mode of operation refers to a particular case of MDHO with the active set consisting of a single BS. When operating in MDHO, the MS communicates with all BSs in the active set of uplink and downlink unicast messages and traffic. A MDHO begins when a MS decides to transmit or receive unicast messages and traffic from multiple BSs in the same time interval. For downlink MDHO, two or more BSs provide synchronized transmission of MS downlink data such that diversity combining is performed at the MS. For uplink MDHO, the transmission from a MS is received by multiple BSs where selection diversity of the information received is performed.

Security: Mobile WiMAX supports best in class security features by adopting the best technologies available today. Support exists for mutual device/user authentication, flexible key management protocol, strong traffic encryption, control and management plane message protection and security protocol optimizations for fast handovers. The usage aspects of the security features are:

- **Key Management Protocol**: Privacy and Key Management Protocol Version 2 (PKMv2) is the basis of Mobile WiMAX security as defined in 802.16e. This protocol manages the MAC security using PKM-REQ/RSP messages. PKM EAP authentication, Traffic Encryption Control, Handover Key Exchange and Multicast/Broadcast security messages all are based on this protocol.

- **Device/User Authentication**: Mobile WiMAX supports Device and User Authentication using IETF EAP protocol by providing support for credentials that
are SIM-based, USIM-based or Digital Certificate or UserName/Password-based. Corresponding EAP-SIM, EAP-AKA, EAP-TLS or EAP-MSCHAPv2
authentication methods are supported through the EAP protocol. Key deriving methods are the only EAP methods supported.

- **Traffic Encryption**: AES-CCM is the cipher used for protecting all the user data over the Mobile WiMAX MAC interface. The keys used for driving the cipher are generated from the EAP authentication. A Traffic Encryption State machine that has a periodic key (TEK) refresh mechanism enables sustained transition of keys to further improve protection.

- **Control Message Protection**: Control data is protected using AES based CMAC, or MD5-based HMAC schemes.

- **Fast Handover Support**: A 3-way Handshake scheme is supported by Mobile WiMAX to optimize the re-authentication mechanisms for supporting fast handovers. This mechanism is also useful to prevent any man-in-the-middle-attacks.

**Advanced Features of Mobile WiMAX**

**Smart Antenna Technologies**: Smart antenna technologies typically involve complex vector or matrix operations on signals due to multiple antennas. OFDMA allows smart
antenna operations to be performed on vector-flat sub-carriers. OFDMA is very well-suited to support smart antenna technologies. In fact, MIMO-OFDM/OFDMA has evolved as the corner-stone for next generation broadband communication systems. Mobile WiMAX supports a full range of smart antenna technologies to enhance system performance. The smart antenna technologies supported include:

- **Beam-forming**: With beam-forming, the system uses multiple-antennas to transmit weighted signals to improve coverage and capacity of the system and reduce outage probability.

- **Space-Time Code (STC)**: Transmit diversity is supported to provide spatial diversity and reduce fade margin.
• **Spatial Multiplexing (SM):** Spatial multiplexing is supported to take advantage of higher peak rates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput compared to single antenna systems. With 2x2 MIMO, SM increases the peak data rate two-fold by transmitting two data streams. In UL, each user has only one transmit antenna, two users can transmit collaboratively in the same slot as if two streams are spatially multiplexed from two antennas of the same user.

**Fractional Frequency Reuse:** Mobile WiMAX supports frequency reuse of one, i.e. all cells/sectors operate on the same frequency channel to maximize spectral efficiency. However, due to heavy co-channel interference (CCI) in frequency reuse one deployment, users at the cell edge may suffer degradation in connection quality. With Mobile WiMAX, users operate on sub-channels, which only occupy a small fraction of the whole channel bandwidth; the cell edge interference problem can be easily addressed by appropriately configuring sub-channel usage without resorting to traditional frequency planning.

In Mobile WiMAX, the flexible sub-channel reuse is facilitated by sub-channel segmentation and permutation zone. A segment is a subdivision of the available OFDMA sub-channels.

The sub-channel reuse pattern can be configured so that users close to the base station operate on the zone with all sub-channels available. While for the edge users, each cell or sector operates on the zone with a fraction of all sub-channels available. In Figure F1, F2, and F3 represent different sets of sub-channels in the same frequency channel. With this configuration, the full load frequency reuse one is maintained for center users to maximize spectral efficiency and fractional frequency reuse is implemented for edge users to assure edge-user connection quality and throughput. The sub-channel reuse planning can be dynamically optimized across sectors or cells based on network load and interference conditions on a frame by frame basis. All the cells and sectors therefore, can operate on the same frequency channel without the need for frequency planning.
BSNL Plans for WiMAX

In line with the government objective of bridging digital divide and with a vision of inclusive growth, BSNL has been looking forward to extensive WiMax deployment to provide wireless broadband solution to a larger section of population. In 2004 itself BSNL deployed 802.16d-2004 standard based WiMAX system at 10 locations- 6 being in urban metros and 4 locations being in rural areas of Haryana on pilot basis. The equipment deployed was of M/s Aperto Network.

Now BSNL has adopted different models for deployment of WiMAX Services:

- In GJ, MH & AP Circle- deployment by M/s Soma Network in revenue sharing agreement with BSNL.
- In PB & KL Circle – Own deployment by BSNL about 1600 WiMAX BTS of 802.16e-2005 standard.
- DIT Bharat Nirman Project- About 1000 BTS to cover 16000 blocks of rural areas and provide access to wireless broadband.
- In remaining 16 LSA deployments through franchise on revenue sharing agreement basis.

Spectrum for BSNL 20 MHZ spectrum has been allocated to BSNL in July 2008. Gujarat, Maharashtra & Andhra Pradesh in FDD Mode 2540 & 2640 MHZ with 10 MHz in each band and Rest of India 20 Mhz with TDD Mode with carrier frequency of 2645 Mhz.
Planned BSNL WiMAX Network

CSN & ASN for WiMAX network has been provided at the following Locations:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Circle</th>
<th>Station</th>
<th>ASN or CSN+ASN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maharashtra</td>
<td>Pune</td>
<td>CSN+ASN</td>
</tr>
<tr>
<td>2</td>
<td>AP</td>
<td>Hyderabad</td>
<td>CSN+ASN (DR Site)</td>
</tr>
<tr>
<td>3</td>
<td>Rajasthan</td>
<td>Jaipur</td>
<td>CSN+ASN</td>
</tr>
<tr>
<td>4</td>
<td>Bihar</td>
<td>Patna</td>
<td>CSN+ASN (DR Site)</td>
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Conclusion:
WiMAX technology is a promising up-coming Broadband Wireless Access (BWA) technology. BSNL has a head start as BSNL has been allocated 20 MHz bandwidth for WiMAX services whereas for private operators auction of BWA spectrum will take place soon.

WiMAX is an all IP network. Adaptive modulation, MIMO, OFDMA and HARQ are some of the features which make WiMAX radio technology suitable supporting higher user data rates. Presently BSNL is deploying 802.16e-2005 certified products which support full mobility.
Chapter 6: Wi-Max Overview

Sample self study objective type questions

1. Wi-MAX stands for_________________
   a) Worldwide Interchangeability for Microwave Access.
   b) Worldwide Interoperability for Microwave Access.
   c) Work Information Microwave Access Technology.
   d) None of the above.

2. Mobile Wi-MAX air interface adopts_________________
   a) Quadrature Phase shift keying (QPSK) technique.
   b) Binary Phase Shift keying (BPSK) technique.
   c) Orthogonal Frequency Division Multiple Access (OFDMA)
   d) None of the above.

3. IEEE 802.16 standard simply addresses________________
   a) The MAC interface specifications.
   b) Air interface specifications.
   c) Router standard specifications.
   d) Switch standard specifications.

4. Peak DL (Down Link) data rates up to 63Mbps per. sector can be achieved in Wi-MAX because_______
   a) MIMO Antenna technique use.
   b) Flexible Sub channelization
   c) Advanced Coding and Modulation
   d) All of the above are correct.

5. ASN stands for_________________
   a) Access Service Network.
   b) Account Service Network.
   c) Accessibility Service Network.
   d) Advanced Service Network.
6. Preamble is used for synchronization which is also the__________
   a) Last symbol of the frame.
   b) First OFDM symbol of the frame.
   c) Both at first & last symbols of the frame.
   d) Not used as first symbol of the frame.

7. Ranging is used only in the__________
   a) Uplink sub frame
   b) Downlink sub frame
   c) Both (a) & (b)
   d) None of the above

8. Out of three Handoff methods used i.e. Hard Handoff (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handoff (MDHO), the mandatory is__________
   a) Fast Base Station Switching
   b) Macro Diversity Handoff
   c) Hard Handoff
   d) All of the above

9. Mobile Wi-MAX supports__________
   a) Fractional Frequency Reuse.
   b) Flexible sub-channel reuse.
   c) Fractional frequency reuse for edge users to assure edge-user connection quality and throughput
   d) All of the above are correct.

10. Spectrum for BSNL for using Wi-MAX is______
    a) 20 MHz
    b) 25 MHz
    c) 30 MHz
    d) 10 MHz