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MOBILE WIMAX TECHNOLOGY AND ITS COMPARISON WITH VARIOUS COMPETING TECHNOLOGIES

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ABSTRACT

Mobile WiMAX has officially become a major global cellular wireless standard along with 3GPP UMTS/HSPA and 3GPP2 CDMA/ EVDO. Mobile WiMAX is an OFDM-based technology available for deployment today, and new WIMAX devices come to market at much reduced cost than that of current 3G solutions. This article provides an overview of the mobile WiMAX system and compares the WiMAX technology with the various competent technologies.

Keywords :- HSPA, Mobile WiMAX, MIMO, OFDMA, OFDM, 802.16e,



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INTRODUCTION

The Mobile WiMAX (Worldwide Interoperability for Microwave Access.) standard of 802.16e is divergent from Fixed WiMAX. It attracted a significant number of Forum members towards an opportunity to substantively challenge existing 3G technology purveyors. While clearly based on the same OFDM base technology adopted in 802.16-2004, the 802.16e version is designed to deliver service across many more sub-channels. The 802.16e standard adds OFDMA 2K-FFT, 512-FFT and 128-FFT capability. Sub-channelization facilitates access at varying distance by providing operators the capability to dynamically reduce the number of channels while increasing the gain of signal to each channel in order to reach customers farther away. The reverse is also possible. For example, when a user gets closer to a cell site, the number of channels will increase and the modulation can also change to increase bandwidth. At longer ranges, modulations like QPSK (which offer robust links but lower bandwidth) can give way at shorter ranges to 64 QAM (which are more sensitive links, but offer much higher bandwidth). Each subscriber is linked to a number of sub channels that obviate multi-path interference. This concept of adaptive modulation is the key feature of mobile WiMAX.

WiMAX systems are based on the IEEE 802.16-2004 and IEEE 802.16e-2005 standards which define a physical (PHY) layer and the medium access control (MAC) layer for broadband wireless access systems operating at frequencies below 11 GHz. The first of these standards, published in 2004, addresses fixed services, and the second, published in 2005, is intended for mobile services. The IEEE 802.16e-2005 specifications actually define three different PHY layers: Single-carrier transmission, orthogonal frequency-division multiplexing (OFDM), and orthogonal frequency-division multiple access (OFDMA). The multiple access technique used in the first two of these PHY specifications is pure TDMA, but the third mode uses both the time



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and frequency dimensions for resource allocation. From these 3 PHY technologies, OFDMA has been selected by the WiMAX Forum as the basic technology for portable and mobile services. Compared to TDMA-based systems, it is known that OFDMA leads to a significant cell range extension on the uplink (from mobile stations to base station). This is due to the fact that the transmit power of the mobile station is concentrated in a small portion of the channel bandwidth and the signal-to-noise ratio (SNR) at the receiver input is increased. Cell range extension is also achievable on the downlink (from base station to mobile stations) by allocating more power to carrier groups assigned to distant users.

The 802.16e version of WiMAX also incorporates support for multiple-input-multiple-output (MIMO) antenna technology as well as Beamforming and Advanced Antenna Systems (AAS), which are all "smart" antenna technologies that significantly improve gain of WiMAX systems as well as throughput. The 802.16e standard is being utilized primarily in licensed spectrum for pure mobile applications. Many firms have elected to develop the 802.16e standard exclusively for both fixed and mobile versions. The 802.16e version of WiMAX is the closest comparable technology to the emerging LTE mobile wireless standard. Or rather, it is more proper to say that LTE is the most comparable to Mobile WiMAX in terms of capabilities as well as technology. The two competing technologies are really very much alike technically.

With the increased market recognition for WiMAX, it is now regularly compared with Wi-Fi. While the two do indeed share some fundamental technical characteristics, they are approaching the wireless space from completely different perspectives. Further, different design approaches will make it unlikely that the two will actually compete except by coincidence.

In the following section we introduce the mobile WiMAX Network Architecture followed by protocol structure of Mobile WiMAX in the next section. We then describe Quality of Service supported in mobile WiMAX. We then present the comparison of mobile WiMAX system with



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other competent technologies. The last section gives brief explanation of the future of mobile WiMAX.

NETWORK ARCHITECTURE

Mobile WiMAX is a cellular system which is based on the IEEE 802.16e standard, an evolution of the IEEE 802.16 - 2004 standard for fixed wireless Metropolitan Area Network (MAN) access [2]. It adds both the mobility and Multiple Input Multiple Output (MIMO) functionalities to the IEEE 802.16- 2004 standard. The WiMAX network supports the following key functions:

- All Internet Protocol (IP) Access and core service Networks Support for fixed, nomadic and mobile access.
- Interoperability with existing networks via internetworking functions.
- Open interfaces between ASN's and between the ASN and the CSN
- Support for differential quality of service depending on the application.
- Unbundling of the Access, core and application service networks.

The Figure 1 illustrates the interconnection of these networks.



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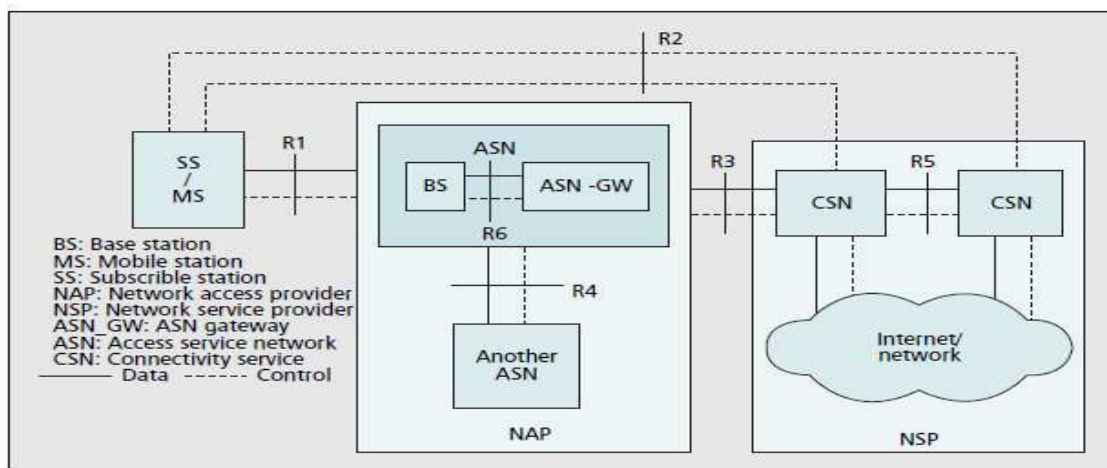


Figure 1: WiMAX network architecture [6]

Mobile WiMAX network architecture mainly has the following components:

ASN (Access Service Network)

The ASN is the access network of WiMAX and it provides the interface between the user and the core service network. Its mandatory functions as defined by the WiMAX forum include the following:

- Handover
- Authentication through the proxy authentication, authorization and accounting (AAA) server
- Radio resource management
- Interoperability with other ASN's
- Relay of functionality between CSN and MS, e.g. IP address allocation



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- Base Station (BS):
- The base station is what actually provides the interface between the mobile user and the WiMAX network.

ASN Gateway:

The ASN Gateway performs functions of connection and mobility management and inter-service provider network boundaries through processing of Subscriber control and bearer data traffic. It also serves as an Extensible Authentication Protocol (EAP) authenticator for subscriber identity and acts as a Remote Authentication Dial in User Service (RADIUS) client to the operator's AAA servers.

CSN(Core Services Network):

The CSN is the transport, authentication and switching part of the network. It represents the core network in WiMAX. It consists of the home agent (HA) and the AAA system and also contains the IP servers, gateways to other networks i.e. Public Switched Telephone Network (PSTN), 3G.WiMAX has five main open interfaces which include; the R1, R2, R3, R4 and R5 interface. The R1 interface interconnects the subscriber to the base station in the ASN and is the air interface defined on the physical layer and Medium Access Control (MAC) sub layer. The R2 is the logical interface between the mobile subscriber and the CSN. It is associated with authorization, IP host configuration management, Services management and mobility management. The R3 is the interface between the ASN and CSN and supports AAA, policy enforcement and mobility management capabilities. The R4 is an interface between two ASN's. It is mainly concerned with coordinating mobility of Mobile Stations (MS's) between different ASN's. The R5 is an interface between two CSN's and is concerned with internetworking between two CSN's. It is through this interface that activities such as roaming are carried out.



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The unbundling of WiMAX divides the network based on functionality. The ASN falls under the Network Access Provider (NAP). The NAP is a business entity that provides WiMAX network access to a Network Service Provider (NSP) which is a business entity that provides core network services to the WiMAX network and consists of the CSN. The Applications services fall under the Applications Services Provider (ASP).

BASIC PROTOCOL STRUCTURE OF MOBILE WIMAX

The high-level MAC/PHY protocol structure for mobile WiMAX as specified in IEEE 802.16-2005[5] is shown in Fig. 2. This structure is built on a simple OFDMA-based PHY and a MAC layer composed of two sub layers: the CS and MAC common part sub layer (MAC CPS).



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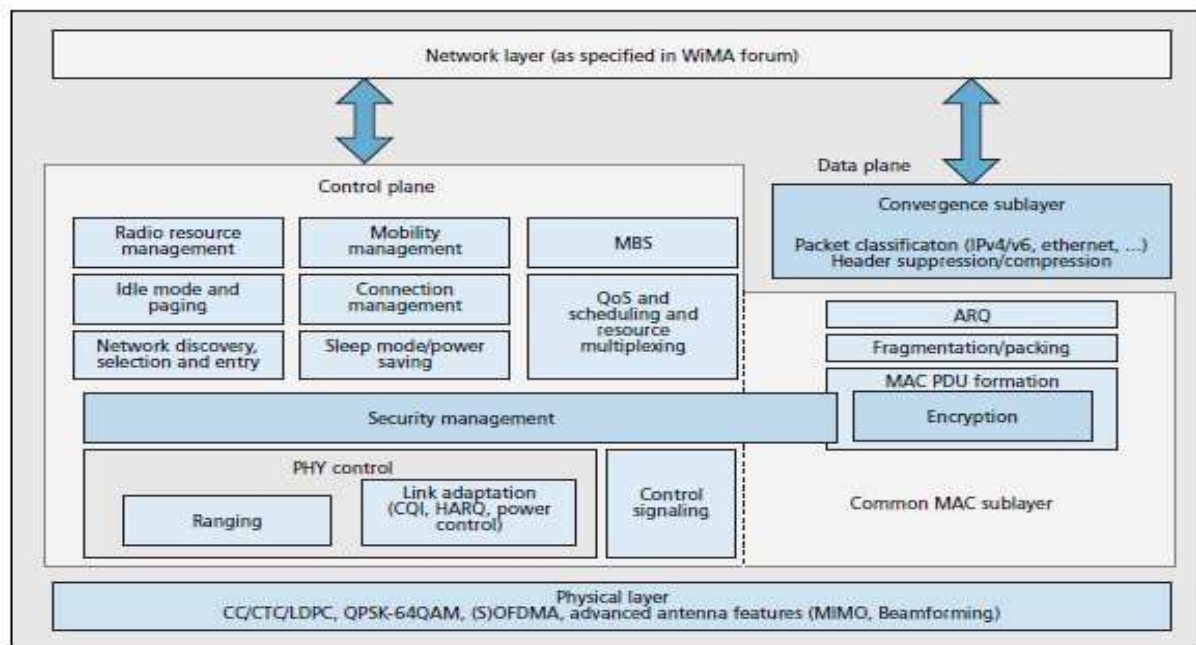


Figure 2: MAC/PHY protocol structure in mobile WiMAX [6]

The functional blocks in the CPS may be logically classified into upper MAC functions responsible for mobility control and resource management, and lower MAC functions that focus on control and support for the physical channels defined by the PHY. Although not formally separated in the standard, one may also classify functions into control plane and data plane functions. The upper MAC functional group includes protocol procedures related to radio resource control and mobility related functions such as:

- Network discovery, selection, and entry
- Paging and idle mode management



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- Radio resource management
- Layer 2 mobility management and handover protocols
- QoS, scheduling, and connection management
- Multicast and broadcast services (MBS)

On the control plane, the lower MAC functional group includes features related to layer 2 Security and sleep mode management as well as link control and resource allocation and multiplexing functions. The PHY control block handles PHY signaling such as ranging, measurement/feedback (CQI), and hybrid automatic repeat request (HARQ) acknowledgment (ACK)/negative ACK (NACK). The control signaling block generates resource allocation messages. On the data plane, the ARQ block handles MAC ARQ function. For ARQ-enabled connections, the ARQ block logically splits MAC signaling data units (SDUs) into ARQ blocks and numbers each logical ARQ block. The fragmentation/packing block performs fragmenting or packing MSDUs based on scheduling results from the scheduler block.

FRAME STRUCTURE AND PHYSICAL CHANNELIZATION

The IEEE802.16e PHY supports both TDD and FDD operation. The FDD mode also defines a half duplex FDD mode to support lower-complexity terminals in which one radio front unit is time-shared between UL(uplink) and DL(downlink). While Mobile WiMAX Release 1.0 includes only the TDD profile, in Release 1.5 both TDD and FDD systems are supported. Figure 3 illustrates the OFDMA frame structure for TDD mode, where each 5 ms radio frame is flexibly divided into DL and UL sub frames.



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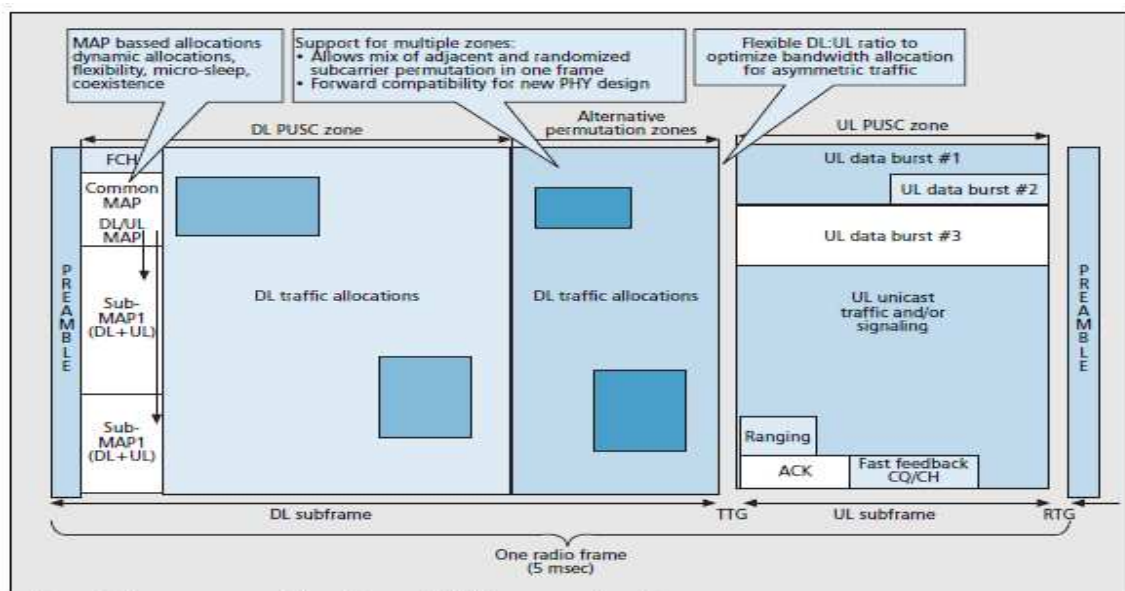


Figure 3: Frame structure and channelization for TDD system in release 1.0. [6]

The DL and UL sub frames are separated by small transmit/receive and receive/transmit transition gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. This frame structure defines the following physical channels:

- Preamble: broadcast in the first orthogonal frequency-division multiplexed (OFDM) symbol of the frame in DL and used by the MS initial and handover related scanning as well as PHY synchronization with the BS.
- Frame control header (FCH): follows the preamble and provides the frame configuration information, such as MAP message length and coding scheme and usable sub channels.



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- DL-MAP and UL-MAP: provide resource allocation and other control information for the DL and UL sub frames, respectively. The MAP is typically broadcast across the cell using a robust modulation and coding scheme (MCS). To reduce the MAP overhead, the system may also define one or more multicast sub-MAPs that can carry traffic allocation messages at higher MCS levels for users closer to the BS and with higher CINR conditions.
- UL ranging: The UL ranging sub channel is allocated for an 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 ACKs.

In IEEE 802.16-2005, the scalable OFDMA PHY defines channels ranging from 1.25 to 10 MHz and also includes a 20 MHz OFDMA channel with 2K fast Fourier transform (FFT). In mobile WiMAX the PHY layer defines various combinations of modulation and coding rates providing a fine resolution of data rates to be used as part of link adaptation.

The 802.16 standard specified multiple channel coding schemes, including convolutional coding, convolutional turbo coding, and LDPC coding combined with both HARQ Chase and IR. The system profile, however, requires only convolutional and convolutional turbo coding combined with asynchronous HARQ Chase.

QUALITY OF SERVICE

QoS refers to different parameters in the network that determine the types of traffic that can be supported, and the type of experience a user will have. For each application and for each



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customer, a different set of requirements is critical. Typical network parameters that determine QoS are bit error rate, jitter, latency, average data throughput.

QUALITY OF SERVICE OF MOBILE WIMAX

The MAC layer of the WiMAX architecture is responsible for QoS. Sub channelization and different coding schemes enable end-to-end QoS. High data rate and flexible scheduling can enhance the QoS [13]. To allow quality-of-service (QoS) differentiation, the uplink traffic flows are grouped into four types of applications for 802.16 MAC:

- Unsolicited grant services (UGS): UGS is designed to support constant bit rate services, such as T1/E1 emulation and voice over IP (VoIP) without silence suppression.
- Real-time polling services (rtPS): It is used to support real-time variable bit rate services, such as MPEG video and VoIP with silence suppression.
- Non real-time polling services (nrtPS): It is used to support non real time variable bit rate services, such as FTP.
- Best-effort (BE) services: With BE services, packets are forwarded on a first-in-first-out basis using the capacity not used by other services. Web browsing is one example of it.

The 802.16 MAC is connection oriented and every traffic flow is mapped into a connection, which is identified by a CID and assigned to one of the above four service types with a set of QoS and traffic parameters. The UGS traffic flow has the highest priority while the BE service has the lowest.



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The fundamental premise of the IEEE 802.16e media access control (MAC) architecture is QoS. Mobile WiMAX QoS features enable operators to optimize network performance depending on the service type (e.g., voice, video, gaming) and the user's service level. The standard defines service flows which can be mapped to fine, granular IP sessions or coarsely differentiated services code points to enable end-to-end IP based QoS. Additionally, sub-channelization and media access protocol (MAP) based signaling schemes provide a flexible mechanism for optimal scheduling of broadcast and unicast traffic on a frame-by-frame basis.

COMPARISON OF MOBILE WIMAX WITH ITS COMPETING WIRELESS TECHNOLOGIES

A Comparison of Wimax & 3G [7] [8]

In this section WiMAX is compared with other wireless technologies. According to several industry sources, the key features of Mobile Wimax are that it uses OFDMA, MIMO, Beam-forming and a number of other recent technology advancements that are labeled as features in 4G [LTE]. It supports several new features necessary for delivering mobile broadband services at vehicular speeds greater than 120 km/hr with QoS. Some of WiMAX key new features and benefits over other wireless technologies are [8]:

1. Introduces OFDMA, which improves spectrum efficiency (amount byte transferred on given width of frequency) around two times more than current 3G technologies or Wi-Fi. Wimax only need about half of the base station as would for HSPA.



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2. Enables a wide range of advanced antenna systems including MIMO, beam-forming, Space-time coding and spatial multiplexing. It thus increases the covering range of Wimax; it also can dynamically allocate frequency band (from 1.5 to 20 MHz) based on User's signal strength, bandwidth requirement. By this it makes better use of available frequency to support more users, so have better spectral efficiency.

3. Dynamic Power Conservation Management ensures power efficient operation of battery operated mobile handheld and portable devices in Sleep and Idle modes. This may be critical for small devices like cell phones.

4. With 5 millisecond latency between hand hold devices and cellular tower, plus the support of QoS, make Wimax good for high quality VOIP, this wireless data network also competes with 2G and 3G on voice service.

5. Wimax is an open standard, which means there will be no or very little royalty. This is one of the biggest advantages of Wimax.

6. Another important feature of Wimax is that it defines a Framework or APIs and leave Implement details to individual company. It thus makes it possible to plug in those most Recent progresses and keep itself up-to-date, and this also encourage competition to develop better system.

7. The industry is working fast to offer high-speed data connection to portal devices, but the market has split into two camps: one stands by wireless standards such as WiMax and Wi-Fi, while the other supports mobile technology 3G and HSDPA. Wireless broadband technologies



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Wi-Fi and WiMax are among the hot favorites. WiMax can support Web connection of up to 75Mbps and a single base station can cover an area with a radius of up to 30 miles.

Wi-Fi and WiMax have been largely confined to facilitating high-speed connectivity to laptops and PDAs, while 3G and HSDPA have focused on mobile phones. However, there are now suggestions that 3G can be extended to laptops, particularly as the data speeds offered by these mobile standards catch up to those provided by WiMax or Wi-Fi. But mobile standards 3G and High Speed Downlink Packet Access (HSDPA) are fast becoming hot buzzwords. HSDPA is a beefed up version of the Wideband CDMA (WCDMA) 3G technologies that specifically improves the downlink speed, and is capable of supporting data connection of up to 1.4Mbps.

COMPARISON WITH HSPA [10]

UMTS/HSDPA is an enhancement of the previously deployed UMTS system, therefore, offering new data services in addition to the ones already provided by UMTS. On the other hand, WiMAX was originally conceived to provide fixed wireless access, and recently evolved to new concepts to support mobility. UMTS/HSDPA and Mobile WiMAX are both systems able to provide high data rates to several users. Although the main purpose is the same, there are some differences regarding technical issues used by each one of the systems [9] [10].

Parameters	HSPA	Mobile wimax
Physical Signal format	DL code aggregation UL DS CDMA	OFDMA for both DL and UL



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Hybrid ARQ with soft combining	Adaptive IR+ Chase Combining	Chase Combining
Multi-level Qos	Yes	Yes
Link Adaption	QPSK 16QAM, 64QUAM Lowest code rate: 1/3	QPSK 16QAM, 64QUAM Lowest code rate: 1/2
Duplex System	FDD	TDD
Frequency Band	850MHz to 2600MHz	2.3GHz, 2.6GHz and 3.4-3.8GHz
Handover	Hard Handover Soft Handover	Hard Handover
Frequency reuse one	1	1
Advance Antenna Technologies	Closed and open loop transmit diversity Spatial multiplexing Beam Forming	Open loop transmit diversity Spatial multiplexing

Table 1 :- Technical comparison of HSPA and Mobile Wimax



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UMTS/HSDPA and Mobile WiMAX adopted advanced techniques to improve data rates. Some of them are employed in both systems like HARQ, Fast Scheduling and AMC. However, Mobile WiMAX adopts OFDMA, allowing better spectral efficiency, QoS and robustness. Also, by supporting 64QAM, it enables data rates higher than UMTS/HSDPA. The use of TDD allows Mobile WiMAX to dynamically adjust DL/UL traffic. Regarding cell radius, there are typical values for UMTS/HSDPA that range from 2 to 5 km, being the latter an optimistic approach. As for Mobile WiMAX, cell radius can go up to 5 km. UMTS/HSDPA uses the frequency band of 2 GHz previously established for UMTS, while Mobile WiMAX uses the 2.5, 3.5 and 5.8 GHz frequency bands. The different used frequencies make a difference regarding the cell radius for each system, since the frequency has some influence in the path loss, determining the distance that the user must be to receive a certain throughput.

Mobile WiMAX with MIMO offers a higher spectral efficiency than the one presented by UMTS/HSDPA, which is due to the use of OFDM and OFDMA, as it provides a high resource allocation and supports a wide range of antenna technologies. Regarding throughput, Mobile WiMAX presents results more than two times higher than the ones obtained for UMTS/HSDPA, both for DL and UL. On the other hand, CDMA has the advantage of providing better QoS and higher mobility functionalities.

Comparison of WiMAX with other Broadband Wireless Technologies

Parameter	Fixed WiMAX	Mobile WiMAX	HSPA	1x EV-DO Rev A
Standards	IEEE	IEEE 802.16e-2005	3GPP	3GPP2



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	802.16-2004			
Throughput	Upto 75 Mbps	Up to 30Mbps	Up to 10 Mbps	Up to 2.4 Mbps
Bandwidth	3.5MHz and 7MHZ in 3.5GHz band; 10MHz in 5.8Ghz band	3.5MHZ, 7MHz,5MHz, 10MHz,and 8.75MHz initially	5MHz	1.25MHz
Modulation	QPSK,16 QAM,64 QAM	QPSK,16 QAM,64 QAM	QPSK,16QAM	QPSK, 8PSK,16QAM
Multiplexing	TDM	TDM/OFDMA	TDM/CDMA	TDM/CDMA
Duplexing	TDD,FDD	TDD initially	FDD	FDD
Frequency	3.5 GHz and 5.8GHz initially	2.3 GHz, 2.5GHz, and 3.5 GHz initially	800/900/1,800/ 1,900/2,100MHz	800/900/1,800/ 1,900 MHz



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Table 2: Comparison of WiMAX with other Broadband Wireless Technologies

COMPARISON WITH WI-FI

	WiMax (802.16e)	Wi-Fi (802.11b)	Wi-Fi (802.11a / g)
Primary Application	Broadband Wireless Access	Wireless LAN	Wireless LAN
Frequency Band	Licensed 3.5, 7, 8.75, 10 MHz	2.4 GHz ISM	2.4 GHz ISM 5 GHz U – NII
Channel Bandwidth	20 MHz	25 MHz	25 MHz
Half / Full Duplex	Full	Half	Half
Radio Technology	SOFDMA	Direct Sequence Spread Spectrum	OFDM (64 channels)
Bandwidth Efficiency	≤ 4.5 bps / Hz	≤ 0.44 bps / Hz	≤ 2.7 bps / Hz
Modulation	BPSK, QPSK, 16-, 64-, 256- QAM	QPSK	BPSK, QPSK, 16-, 64- QAM
FEC	Convolutional Code Reed- Solomon	None	Convolutional Code
Encryption	Mandatory -3DES	Optional – RC4	Optional – RC4



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	Optional – AES	(AES in 802.11i)	(AES in 802.11i)
Access Protocol	Request / Grant	CSMA / CA	CSMA / CA
-Best Effort	Yes	Yes	Yes
-Data Priority	Yes	802.11e WME	802.11e WME
-Consistent Delay			

Table 3: comparison with wi-fi

BENEFITS OF MOBILE WIMAX [12]

Improved Air Interface: The Mobile WiMAX air interface utilizes Orthogonal Frequency Division Multiple Access (OFDMA) for improved multipath performance in non-line-of-sight environments and high flexibility in allocating resources to users with different data rate requirements.

High Data Rates: A variety of antenna techniques are supported by Mobile WiMAX to increase throughput, especially at the cell edge. For example, the use of multiple-input multiple-output (MIMO) antenna techniques combined with flexible sub-channelization schemes, adaptive modulation and variable coding rates enable Mobile WiMAX technology to support peak downlink (DL) data rates up to 46 Mbps per sector and peak uplink (UL) data rates up to 14 Mbps per sector in a 10 MHz channel (DL 2x2 MIMO, 3:1 DL/UL ratio; UL 1x2 collaborative MIMO; 1:1 ratio).

Quality of Service (QoS): The fundamental premise of the IEEE 802.16e media access control (MAC) architecture is QoS. Mobile WiMAX QoS features enable operators to optimize network performance depending on the service type (e.g., voice, video, and gaming) and the user's service level. The standard defines service flows which can be mapped to fine, granular IP



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sessions or coarsely differentiated services code points to enable end-to-end IP based QoS. Additionally, sub-channelization and media access protocol (MAP) based signaling schemes provide a flexible mechanism for Optimal scheduling of broadcast and unicast traffic on a frame-by frame basis.

Scalability: Mobile WiMAX technology utilizes scalable OFDMA (SOFDMA) and, according to the initial Mobile WiMAX system profiles, has the capability to operate in channel sizes of 5, 7, 8.75, and 10 MHz to comply with various spectrum allocations.

Security: Mobile WiMAX technology incorporates the most advanced security features currently used in IEEE 802 wireless access systems. These include Extensible Authentication Protocol (EAP)-based authentication, Advanced Encryption Standard (AES)- based authenticated encryption, Cipher-based Message Authentication Code (CMAC) and Hashed Message Authentication Code (HMAC)-based control message protection schemes.

FUTURE DEVELOPMENT:802.16M: THE FUTURE EVOLUTION OF WIMAX

The IEEE 802.16m standard is the core technology for the proposed Mobile WiMAX Release 2, which enables more efficient, faster, and more converged data communications. IEEE 802.16m is one of the major candidates for IMT-Advanced technologies by ITU. Among many enhancements, IEEE 802.16m systems can provide four times faster data speed than the current Mobile WiMAX Release 1 based on IEEE 802.16e technology.

In a practical deployment, using 4X2 MIMO in the urban micro cell scenario with only a single 20 MHz TDD channel available system wide, the 802.16m system can support both 120 Mbit/s downlink and 60 Mbit/s uplink per site simultaneously.



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802.16m [14] will work in TDD and also FDD mode, where there is a lot of spectrum globally. The channel bandwidths of 802.16m are targeted up to 20MHz and possibly 40MHz channels. In these higher channels OFDMA becomes extremely capable, more so than other technologies, in terms of capacity and performance, That's because OFDMA works by breaking down traffic going through the channel bandwidth into many different sub-channels. The IEEE 802.16m documents talk about evolving the 802.16e standard towards higher data-rates, higher mobility, lower latencies and higher-capacity and state that: minimizing the system latency under various conditions (e.g. handover, re-entry from Idle Mode, and packet transmission) should be required. The peak data rate in the downlink will be three times as much. For a 20MHz sector the peak data rate in the downlink in 802.16e is 128mbps, it will be in the order of 350mpbs in 802.16m. In the uplink, per sector it is 28mbps in 802.16e, it will be 200mbps in 802.16m. Mobility in 802.16e is 60-120km/h, in 802.16m it will be up to 350km/h. That will make WiMAX technology more efficient for sensitive VoIP services, with latency of less than 10ms, and handoff of 20ms.



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SUMMARY

Mobile WiMAX has spurred tremendous interest from operators seeking to deploy high-performance yet cost-effective broadband wireless networks. WiMax signals the arrival of the next wave of wireless data technologies. Unhampered by the short range and data orientation of wireless LANs, these technologies hold the promise of taking high speed wireless out of the coffee shop and out on the road. The flexibility of the WiMax technology gives it a significant advantage, addressing both fixed and nomadic users, operating in licensed or unlicensed bands, providing both consistent- and variable-delay services while operating in a carrier-scale environment. On paper, WiMax looks like a strong contender. Now we will have to see if the proponents can translate that technology into marketable services.

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