WiMAX: The Innovative Broadband Wireless Access Technology

Abdulrahman Yarali
Industrial and Engineering Technology, Murray State University, Murray, USA
Email: abdul.yarali@murraystate.edu

Saifur Rahman and Bwanga Mbula
Virginia Polytechnic and State University, Murray State University, Murray, USA
Email: Srahman@vt.edu , bwanga.mbula@murraystate.edu

***Abstract*—The telecommunication industry has been through disruptive times, but data networking service revenue has continued to rise. The telecom industry is expected to continue to grow as demand increases for cable and high-speed Internet in previously unserviced locations and as local telephone companies upgrade their lines in response to increasing competition. This paper presents an extended overview of the Worldwide Interoperability for Microwave Access (WiMAX) and its applications in higher generation wireless networks as a cost effective solution to answering the challenges posed by the digital divide. It looks at the technology behind WiMAX and networks design and deployment factors that impact WiMAX coverage. A cell site coverage simulation at different frequency bands using Wireless simulation tool is presented. Also the paper makes a comparison of WiMAX with two enhanced third generation (3G) technologies that are potential competitors to WiMAX. It then goes on describe the business models in WiMAX and states some of the benefits and drawbacks of a mobile WiMAX network.**

***Index Terms* — Broadband Access, Digital Divide, WiMAX, , OFDM, MIMO, Cell Coverage, 3G and 4G.**

I. INTRODUCTION

Telecommunications has grown at a tremendous rate in the last ten to twenty years. Improved semiconductor and electronics manufacturing technology, and the growth of the internet and mobile telecommunications have been some of the factors which have fueled this growth in telecommunications. The deployment of state of the art telecommunications infrastructure and services has however been restricted to the developed world. The least developed countries have been left in the technological dark ages with few or none of the next generation networks installed. Developed countries now boast high speed connections with a large percentage of homes having access to the internet and broadband services at an affordable fee. The underdeveloped countries are yet to enjoy such facilities. This is referred to as the digital divide [1]. During the first World Summit on the Information Society (WSIS) held in Geneva in December 2003, the Digital Divide was defined as the unequal access to Information and Communication Technologies (ICTs), where the least developed countries are separated from the developed countries because of a lack of technology particularly information and communication technology [2].

The digital divide has persisted due to the relatively high cost of putting up modern telecommunications infrastructure. This is compounded by the fact that there are a number of different services available and each service requires its own technology and network [3]. Therefore existing technologies such as Wireless Fidelity (WiFi), Digital Subscriber Line (DSL), Global System for Mobile communications (GSM), Integrated Services Digital Network (ISDN), and the relatively new 3G technologies have not been able to provide a total solution to closing the digital divide. Fig. 1 illustrates the main network types and the prevalent technologies associated with each, mapped against usage models and access modes.

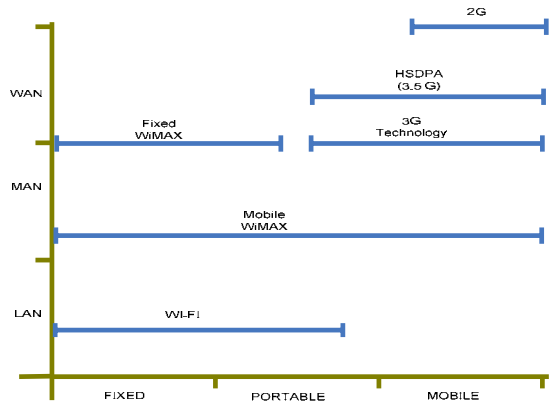

Figure 1. Wireless network type and range.

MAN - Metropolitan Area Network (Citywide, Rural Area) LAN - Local Area Network (Office, Home, Campus) WAN- Wide Area Network (countrywide, International)

WiMax earned an important seal of approval recently when the Radio communication sector of the

International Telecommunication Union (ITU-R) certified it as a 3G (third-generation) mobile data technology. Fig. 2 shows the standard history for 802.16.

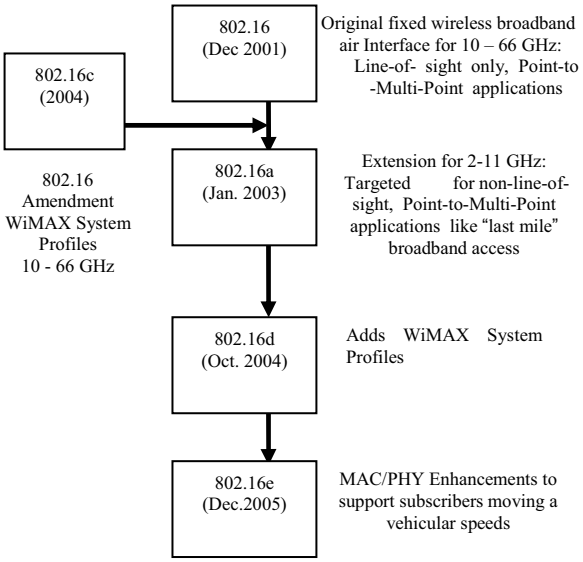

Figure 2. 802.16 Standard Evolution

WiMAX will have a larger impact long term than we have seen from cellular phones in the past two decades. Initial rollouts of WiMAX will begin mostly by competitive local phone service carriers and rural Internet service providers. Larger carriers will utilize fixed WiMAX to deliver services to residential customers many of whom are in underserved markets. WiMAX adoption in these underserved markets will be high due to lack of availability of high-speed data access. These deployments will generate capital to be reinvested for future deployments. Larger customer base will begin driving both the cost of carrier and customer equipment down. As the economy of scale makes deployment less expensive mobile platforms will begin to appear. This development will be spread between high population centers and the rural markets that already have fixed platforms deployed. Fixed platform will act as a springboard for mobile deployment. Then interconnections will begin to form between rural markets and metropolitan markets as carriers form cooperative agreements to share network resources. The economy of scale will increase exponentially at this point and we will notice a negative impact on traditional cellular, Internet and voice services. Once the implementation of initial hot underserved rural markets and high-density metro areas are completed, springboard deployments will quickly take WiMAX coverage to the level of coverage offered by traditional wireless today.

This process will move much faster than the deployment of cellular networks and devices for the following key reasons:

- The manufacturing process for WiMAX devices will be quite similar to that of wireless devices and mostly the changes will be in components and software.
- Readiness of the current wireless fixed and mobile market and waiting on new technology.
- As carriers built out wireless networks, most of the questions in this field have been answered and can now be applied to the development of a mirror network that provides WiMAX access.

II. Network Architecture

WiMAX has a flexible architecture. The Mobile WiMAX End-to-End network architecture is based on an All-IP platform, all packet technology and no circuit switch telephony.

The open IP architecture gives network operators great flexibility when selecting solutions that work with legacy networks or that use the most advanced technologies, and in determining what functionality they want their network to support. They can choose from a vertically integrated vendor that provides a turnkey solution or they can pick and choose from a dense ecosystem of best-of-breed players with a more narrow focus. The architecture allows modularity and flexibility to accommodate a broad range of deployment options such as small scale to large scale, urban, suburban and rural coverage, mesh topologies , flat , hierarchical and their variant, and finally, co-existance of fixed , nomadic portable and mobile usage models [4].

Mobile WiMAX adds both the mobility and Multiple Input Multiple Output (MIMO) functionalities to the IEEE 802.16- 2004 standard. It is one of two standards adopted by the WiMAX forum with the other one being the IEEE 802.16 – 2004. Mobile WiMAX network architecture mainly has three components. These include the Access Services Network (ASN), the Core Services Network (CSN) and the Application Services Network (AS). Fig. 3 illustrates the interconnection of these networks. The WiMAX network supports the following key functions:

- All 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

A. ASN

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

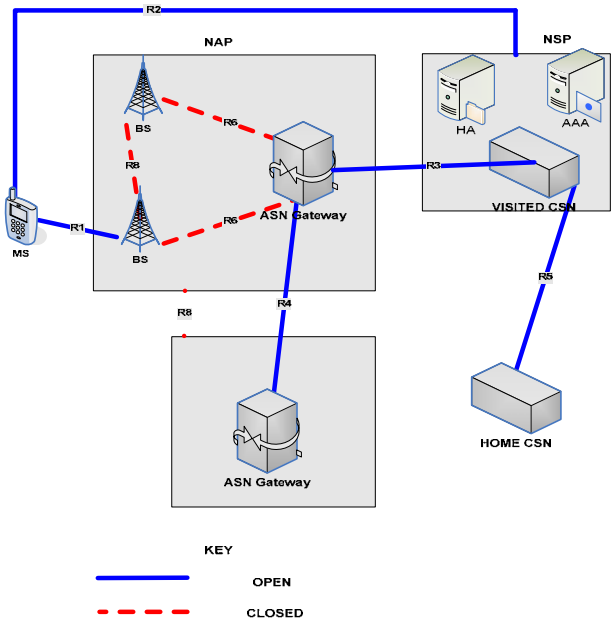

Figure 3. WiMAX Network Architecture [5].

- 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

Base Station (BS). The cell equipment comprises the basic base station equipment, radio equipment and a base station link to the backbone network. The base station is what actually provides the interface between the mobile user and the WiMAX network. The coverage radius of a typical base station in urban areas is around 500 to 900 meters [6]. In rural areas the operators are planning cells with a radius of 4 kilometer (Km). This is quite a realistic number now and quite similar to the coverage areas of GSM and UMTS/HSDPA base stations today.

Deployment is driven either by the bandwidth required to meet demand, or by the geographic coverage required to cover the area. Based on the cell planning of other previous technologies, urban and suburban segments cell deployment will likely be driven by capacity. Rural segment deployment will likely be driven by the cell radius.

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.

B. *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), and 3G.

WiMAX has five main open interfaces which include; reference points R1, R2, R3, R4 and R5 interface [7]. 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.

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). The NSP 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).

III. Technologies Employed by WiMAX

Mobile WiMAX operates in licensed frequency bands in the range of 2 to 6 MHz. The technologies employed by mobile WiMAX include the following:

- Scalable Orthogonal Frequency Division Multiple Access (SOFDMA) on the physical layer
- MIMO
- IP (Internet Protocol)
- Adaptive antenna systems (AAS)
- Adaptive Modulation schemes (AMS)
- Advanced Encryption Standard (AES) encryption

A. *Physical Layer*

Mobile WiMAX will initially operate in the 2.3 GHz, 2.5 GHz, 3.3 GHz, and 3.4-3.8 GHz spectrum bands [8] using SOFDMA. OFDMA is perhaps the most important technology associated with WiMAX. SOFDMA is based on OFDMA which in turn is based on OFDM [9].

OFDM is a form of Frequency Division Multiplexing, but it has higher spectral efficiency and resistance to multi path fading and path loss compare to other multiplexing methods. It divides the allocated frequency spectrum into sub carriers which are at right angles to each other. This reduces the possibility of cross channel interference thereby allowing the sub – carriers to overlap. This reduces the amount of frequency spectrum required, hence the high spectral efficiency. The reduced data rate of each stream reduces the possibility of inter

symbol interference because there is more time between the arrival of symbols from different paths. This feature of OFDM makes it resistant to multi path fading and ideal for non line of site applications. In OFDMA each frequency sub – carrier is divided into sub – channels which can be accessed by multiple users hence increasing the capacity of OFDM [10].

Scalable OFDMA is a form of OFDMA which allows variable channel bandwidth allocation from 1.25 MHz to 20 MHz. SOFDMA has capabilities which make it ideal for the implementation of IP and Hybrid Automatic Repeat Request (HARQ). WiMAX also uses other features to enhance the performance of OFDMA. They include dynamic frequency shifting, MIMO, Adaptive Antenna Systems (AAS) and software defined radios. Dynamic frequency shifting monitors the signal and changes frequencies to avoid interference. Software defined radios are controlled by changing software settings and this gives the equipment more flexibility when switching frequencies.

MIMO is a technology that has already found use in WiFi (IEEE 802.11n). MIMO multiplies the point-to-point spectral efficiency by using multiple antennas and RF chains at both the BS and the MS. MIMO achieves a multiplicative increase in throughput compared to Single Input, Single Output (SISO) architecture by carefully coding the transmitted signal across antennas, OFDM symbols, and frequency tones. These gains are achieved at no cost in bandwidth or transmit power [11].

AAS are spatial processing systems which combine antenna arrays with sophisticated signal processing. They reduce the effects of interference from multiple signal paths thereby also contributing to high capacity of the system and the use of mobile WiMAX in NLOS environments.

B.Mac Sub Layer

The 802.16 Medium Access Control (MAC) sub layer uses a scheduling algorithm for which the subscriber station only needs to compete for initial entry into the network. The scheduling algorithm also allows the base station to control QoS parameters by balancing the time-slot assignments among the application needs of the subscriber stations.

WiMAX supports Quality of Service (QoS) differentiation for different types of applications. The 802.16 standard defines the following types of services [12]:

Unsolicited Grant Services (UGS): UGS is designed to support Constant Bit Rate (CBR) services, such as T1/E1 emulation, and Voice over IP (VoIP) without silence suppression.

Real-Time Polling Services (rtPS): rtPS is designed to support real-time services that generate variable size data packets on a periodic basis, such as MPEG video or VoIP with silence suppression.

Non-Real-Time Polling Services (nrtPS): nrtPS is designed to support non-real-time services that require variable size data grant burst types on a regular basis.

Best Effort (BE) Services: BE services are typically provided by the Internet today for Web surfing.

IV. Network Dimensioning and Design

There is a large range of possible scenarios for the deployment of mobile WiMAX, but main four categories are [13]:

- Fixed and Mobile operator with Enhanced Data for GSM Evolution (EDGE)/3G who uses mobile WiMAX as a complementary extension for data services
- Mobile only operator with EDGE/3G who uses mobile WiMAX as a complementary extension for data services
- Fixed operator who uses mobile WiMAX to compete with 3G operators for data and voice services
- New entrant who uses mobile WiMAX to move into mobile market – threat to incumbent mobile operator.

WiMAX operates in a mixture of licensed and unlicensed bands. The unlicensed bands are typically the 2.4 GHz and 5.8 GHz bands. Licensed spectrum provides operators control over the usage of the band, allowing them to build a high-quality network. The unlicensed band, on the other hand, allows independents to provide backhaul services for hotspots. Typical area licensed WiMAX spectrum allocations are:

- Lower 700 MHz (US) with 2x6 MHz channels
- 2.5 GHz Multichannel Multipoint Distribution Service with 15.5 MHz in US and 72 MHz in Canada
- 3.5 GHz Wireless Local Loop with 2 x 2hMHz channel blocks
- 5.8 GHz UNI (license exempt) with 80 MHz allocation

WiMAX access networks are often deployed in point-to-multipoint cellular fashion where a single base station provides wireless coverage to a set of end users stations within the coverage area. The technology behind WiMAX has been optimized to provide both large coverage distances of up to 30 kilometers under Line Of Sight (LOS) situations and typical cell range of up to 8 kilometers under No LOS (NLOS) [14]. In a NLOS, a signal reaches the receiver through reflections, scattering, and diffractions. The signals arriving at the receiver consists of many components from direct and indirect paths with different delay spreads, attenuation, polarizations, and stability relative to the direct path. WiMAX technology, solves or mitigates the problem resulting from NLOS conditions by using OFDMA, Sub-channelization, directional antennas, transceiver diversity, adaptive modulation, error correction and power control [15]. The NLOS technology also reduces installation expenses by making the under-the-eaves Customer Premise Equipments (CPE) installation a reality and easing the difficulty of locating adequate CPE mounting locations.

Both LOS and NLOS coverage conditions are governed by propagation characteristics of their environment, radio link budget and path loss. In both

cases relays help to extend the range of the base station footprint coverage allowing for a cost-efficient deployment and service [16].

A. *WiMAX Cell Site Design*

One of the most important technical and business issues of any wireless technology is efficiently (cost and performance) providing coverage and capacity, while avoiding the build-out of a large number of new base stations. The first step in designing a wireless system is to develop a link budget. Link budget is the loss and gain sum of signal strength as it travels through different components in the path between a transmitter and receiver. The link budget determines the maximum cell radius of each base station for a given level of reliability and is comprised of two types of components: system related components and non-system related components [17].

These components are important factors when evaluating the complexity and speed in deploying at higher frequency bands, especially in unlicensed bands such as 5.8 GHz (licensed in some countries such as Russia). Other factors like interference from other surrounding networks will also impact network performance and quality of service.

Path loss, shadow margin, environmental effects, and morphology are important factors when planning for an optimum coverage. The morphology and physical surroundings of a cell site play a very important role in determining the cell footprint. A cell site footprint can shrink from 7km in a mostly flat area with light tree densities to 3 km in a hilly terrain with moderate–to-heavy tree densities [17].

Traditional RF planning remains the fundamental limiting factor in system performance in WiMAX. With adaptation of Erceg Model [18], the cell size for several carrier frequencies from 450MHz to 3.5GHz is estimated for WiMAX systems using path loss propagation models for flat rural, hilly rural and urban environment. Equation (1) is used to estimate total path loss.

$$L = A + 10\ \gamma\ \log(d / d_0) + S \quad (1)$$

$$A = 20 \log\left(\frac{4\pi d_0}{\lambda}\right) \quad (2)$$

$$\gamma = a - bh_b + c/h_b \quad (3)$$

In these equations: L is the total path loss in dB, d_0 is the close-in reference distance and d is the Transmitter-Receiver separation distance in Km, S is a random variable , λ is the wavelength of the carrier, A is free space path loss, h_b= base station height, γ is path loss exponent and a, b and c are constant depending on morphology type.

Fig. 4 illustrates a comparison of a path loss simulation for a WiMAX system for different frequency bands using EDX SignalPro wireless planning and design tool. In this EDX simulation study, a scenario with a link budget of 142 dB which provides approximately a 3km cell coverage at 1900MHz has been assumed [18]. Based on the results to obtain the same cell radius of 3km with 2.5 GHz frequency band an additional 4dB for link budget is needed. In a coverage limited design scenario, this 4dB corresponds to about 22 percent reduction in cell coverage footprint and almost 70 percent increase in the

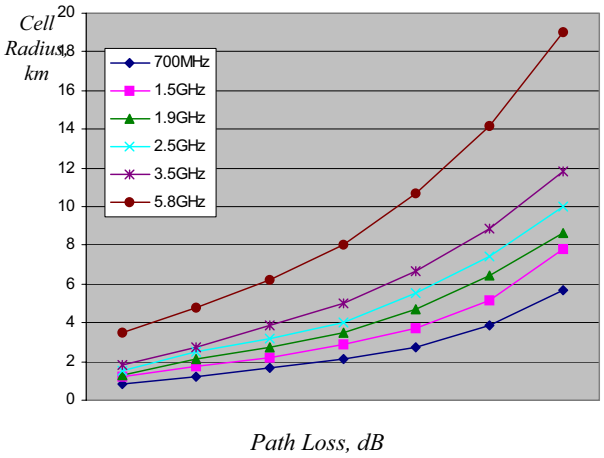

Figure 4. Path loss vs. WiMAX cell radius

cell count. Table I shows cell count calculation for 1900MHz to 3.5 GHz to illustrate the impact that path loss can have, especially when deploying in higher frequency bands. Fig. 5 and 6 show the results of cell count estimation in a flat rural area for frequency operation of 450 MHz and 3.5GHz. Assuming the equal distribution of the coding modulation schemes inside the cells and the probability of terrain coverage of 95%, the system capacity is lower for WiMAX systems at 450MHz frequency, due to large cell size. Compared with existing cellular systems, WiMAX systems implement advanced radio features that compensate for the extra attenuation resulting from higher carrier frequency, larger transmission bandwidth, and deep indoor penetration.

TABLE I. WIMAX CELL COUNT VS. FREQUENCY

Freq. Band	Cell Radius km	Link Budget(dB)	Cell radius Reduction	Cell count increase
1900 MHz	3	142		
2.5GHz	3	146	21-24%	62-75%
3.5GHz	3	151	42-46 %	200-250%

The radio enhancement feature applicable to fixed and mobile WiMAX is subchannelisation. Other enhancement features that are only applicable to mobile WiMAX are convolutional turbo coding, repetition coding (3dB gain), and Hybrid Automatic Repeat Request (HARQ).

Applying smart antennas or MIMO configuration in the different topologies will enhance the cell site coverage footprint. Cell planning options and WiMAX technology features also allow interference and noise handling so that WiMAX can provide sufficient coverage

[19]. Fig. 7 shows global percentage of WiMAX deployment per frequency band.

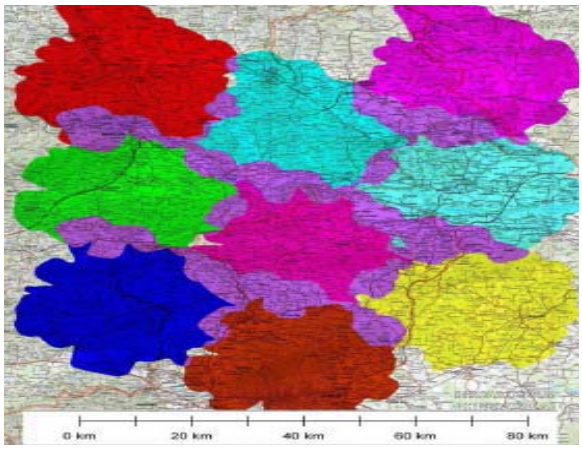

Figure 5.Cell radius for 450 MHz

Source: Jozef Stefan Institute

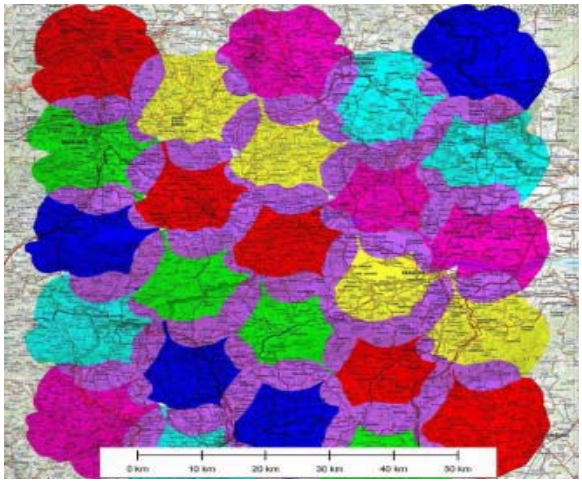

Figure 6. Cell radius for 3.5 GHz

Source: Jozef Stefan Institute

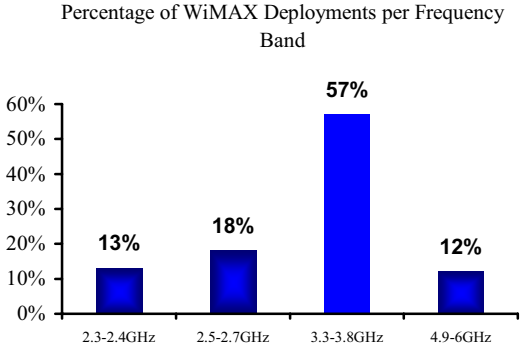

Figure 7. WiMAX deployment per band.
Source: wimaxcounts.com

V. The WiMAX Business Model

This technology offers an attractive package that promises to minimize costs of delivering wireless data services, improve bandwidth efficiency and offer real-time applications like VoIP and other streaming services over an IP-based network. . It is a disruptive technology that, after matching the incumbent technology, has qualities of its own that will allow it to supersede the incumbent's legacy infrastructure. WiMAX, unlike incumbent circuit-switched infrastructure, is a technology that can be quickly and cheaply deployed anywhere in the world. The North American telephony market (services) is estimated to do almost $1.2 trillion in business annually.

WiMAX potentially strikes at the very heart of incumbent telco business paradigm that relied on a high barrier to entry to the voice market. The biggest challenges to deploying WiMAX–based services are business related. Carriers need financial capability to implement infrastructure. The WiMAX business model can be looked from several perspectives. These include the equipment vendors, service providers and application providers and customers.

A. *Equipment Vendors*

As a standard-based technology, WiMAX enables inter-vendor interoperability which brings lower costs, greater flexibility and freedom, and faster innovation to operators.

Within the WiMAX industry there is a strong commitment to ensuring full interoperability through certification and ad-hoc testing between vendors. It is important for network operators to realize how interoperability is established and what it covers so that they understand how different products, solutions and applications from different vendors can coexist in the same WiMAX network.

The two categories of equipment vendors include the network equipment vendors and the terminal equipment vendors. Network equipment includes ASN and CSN equipment. Terminal equipment includes mobile phones, CPE, modems, laptops, smart phones and PDA's.

B. *Service Providers*

The business aspect of the service providers can also be looked at from two perspectives. The first one is where the service provider owns the whole system including the core network and the access network. The second option is the unbundled option where the access network and core networks exist as independent business entities.

The service providers are expected to gain profits through the sale of the different services and applications that WiMAX is capable of carrying. The different services that can be offered on WiMAX networks include best effort VoIP, carrier class IP telephony through the IP multimedia core, music, video conferencing, streaming video, interactive gaming, mobile instant messaging (IM), IP Television (IPTV), basic broadband wireless internet, and other application based services to corporate customers. The concept of unbundling the network reduces the barriers of entry into the mobile

telecommunications industry because a provider does not need to own the whole network.

In emerging markets such as Africa, and south Asia where telecom investment is still nascent and 3G yet to be launched, WiMAX makes complete business sense even at equal cost - better speeds, better spectrum utilization and the promise of broadband to a much sparsely spread population. The low cost of BWA/WiMAX spectrum compared to 3G is a clear driver for service providers to enter the field of wireless services with WiMAX. Fig 8 shows a global WiMAX deployment by region.

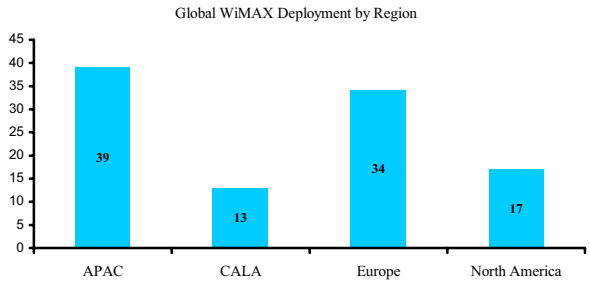

Figure 8.Global WiMAX networks.

Source: wimaxcount.com. APAC= Asia Pacific, CALA= Caribbean and Latin America.

C. Application Providers

WiMAX has already revolutionized the broadband wireless market by standardizing broadband wireless access market, by opening up new service opportunities and by creating the environment for ubiquitous broadband services. The aim is to provide the service that best fits the individual's needs. Applications can be developed in house by the service providers, outsourced from other companies or developed and sold directly to the end user by an independent applications development company.

Applications are based on Internet Protocol (IP), and IP applications are sent back or forth via WiMAX. This allows the users to develop applications independently from the underlying network infrastructure. Some applications will still be developed by operators but the vast majority will come from those working directly in the internet crowd. For them and for the end users competing wireless technologies are very beneficial. Competition spurs network roll outs, offers possibility for new players in the market, and creates competition between device manufacturers. Also, new applications will be introduced more easily and much more quickly as they are no longer forced into a tight framework that takes long time to develop and from which it is difficult to get out again.

D. *WiMAX Customers*

Prospective WiMAX customers can be grouped either geographically or by the level or volume of services. Geographical categories range from urban to rural customers, while categories according to size include individual customers and the corporate customers. Urban areas offer the highest density of customers with more business establishments. In such cases a higher number of cells which are small in size are required to meet the capacity requirements. These are the areas more competition is expected. Rural areas are expected to have a lower penetration of customers, less corporate customers, and bigger cell sizes because emphasis is on coverage rather than capacity. Individual subscribers will use WiMAX for music downloads, interactive gaming, and personal broadband internet, and will form a large percentage the total subscribers.

Corporate subscribers are also expected to contribute to revenues of WiMAX, and their interest will be in applications and services which will enhance their organizations apart from the basic telecommunications services.

Companies are poised to compete with each other in WiMAX network deployment, which will ensure that the prices will be competitive.

VI. Comparison with Competing Technologies

At some point current 2G and 3G network operators will migrate to a 4G network technology. Mobile WiMAX is likely to face competition from third and 4G technology enhancements. They include the Code Division Multiple Access (CDMA) variants CDMA2000 and Wideband-CDMA (WCDMA) and their enhancements which are 1x Evolution Data Optimized (1xEVDO) and High Speed Downlink Packet Access (HSDPA) respectively. Unlike in the early days of the CDMA vs. GSM competition, this higher generation competition will be quite different and fruitful since for these new generations networks and the applications are separated and do not depend on each other. 4G networks will go far beyond 2G and 3G by mainly improving three things:

- Interface Technology: 4G standards will make a radical change and will use OFDM [9]. The new modulation itself will not automatically bring an increase in speed but very much simplifies the following two enhancements:
- Channel Bandwidth: 4G systems will use a bandwidth of up to 20 MHz, i.e. the channel offers four times more bandwidth than channels of current systems. As 20 MHz channels might not be available everywhere, most 4G systems will be scalable, for example in steps of 1.25 MHz. It can therefore be expected that 4G channel sizes will range from 5 to 20 MHz.
- MIMO: The idea of MIMO is to use the multipath phenomena. While this behavior is often not desired, MIMO makes active use of it by using several antennas at the sender and receiver side, which allows the exchange of multiple data streams, each over a single individual wave front. Two or even four antennas are foreseen to be used in a device. How well this works is still to be determined in practice but it is likely that MIMO can increase

throughput by a factor of two in urban environments.

Increasing channel size and using MIMO will increase throughput by about 8-10 times. Thus speeds of 40 MBit/s per sector of a cell are thus possible. Using a commonly accepted evaluation methodology for 3G systems, Mobile WiMAX has been simulated against the 3G enhancements [20]. These simulations have shown that:

- Mobile WiMAX peak data rates are up to 5x better than 3G+ technologies and
- Mobile WiMAX spectral efficiency is 3x better than any 3G+ technology
- Lower equipment cost for WiMAX due to certified products (compare with WiFi)
- WiMAX require new infrastructure while HSPA rides on UMTS
- Roughly the same coverage (average ~5 km)
- Roughly the same performance (average ~2 Mb/s per user)
- HSDPA launches in 2006 while HSUPA will come in 2008
- WiMAX standard set end of 2005 and first products in 2006
- HSPA has a higher acceptance with mobile operator

A. *1xEVDO*

This standard is developed by the Third Generation Partnership Project 2 (3GPP2), the body responsible for CDMA and EVDO. 1xEV-DO is an enhanced version of CDMA2000-1x. There are four versions that have been released; namely Rev. 0, Rev. A, Rev. B and Rev C.

1xEV-DO is a high-speed data only specification for 1.25 MHz Frequency Division Duplex (FDD) channels with a peak Downlink (DL) data rate of 2.4 Mbps.

Improvements to CDMA2000 – 1x in the 1xEV-DO Rev.0 specification include [9]:

Downlink channel is changed from Code Division Multiplex (CDM) to Time Division Multiplex (TDM) to allow full transmission power to a single user.

Downlink power control is replaced by closed loop downlink rate adaptation.

Adaptive modulation and coding (AMC)

HARQ

Fast downlink scheduling

Soft handoff is replaced by a more bandwidth efficient "virtual" soft handoff

1xEV-DO-Rev 0 however, was designed to support only packet data services and not conversational services. In 1xEVDO-Rev A, and EVDO Rev C (also dubbed DORC) additional enhancements were added to the 1xEV-DO specification. They include the following [8]:

Downlink: Smaller packet sizes, Higher DL peak data rate (up to 3.1 Mbps), and Multiplexing packets from multiple users in the MAC layer.

Uplink (UL) : Support of HARQ, AMC, Higher peak rates of 1.8 Mbps, and Smaller frame size

These enhancements in both the UL and DL of 1xEV-DO Rev.A allow it to support conversational services.

B. *HSDPA/HSPA*

The WCDMA specification was enhanced to create the High Speed Downlink Packet Access (HSDPA) and then High Speed Packet Access (HSPA) specifications. The enhancements in HSDPA include, AMC, Multi-code operation, HARQ, Higher DL peak rates (up to 14 Mbps), and De-centralized architecture where scheduling functions are moved from the Radio Network Controller (RNC) to Node-B thus reducing latency and enabling fast scheduling.

HSPA adds enhancement to the uplink of the WCDMA specifications. In reference [9] a quantitative comparison of Mobile WiMAX, 1xEVDO and HSPA system performance, was conducted based on the commonly accepted 1xEV-DV evaluation criterion. The Mobile WiMAX system configuration was based on the WiMAX Forum baseline minimum configuration. Table II illustrates a Comparison of Mobile WiMAX with 3G enhancements [21].

These technologies i.e. EVDO, HSPDA and Mobile WiMAX have several performance enhancing features such as AMC, HARQ, fast scheduling, and bandwidth efficient handoff in common [22].

From the end-user point of view, HSPA and WiMAX are close substitutes; both are enabling same types of services for the same devices and contexts. Differences in the technological performance are also considered to be quite small. This suggests that the technologies will engage in a technological battle, rather than coexist and complement each other.

TABLE II. COMPARISON OF MOBILE WIMAX WITH 3G ENHANCEMENTS

ameter		1xEVDO Rev. A	3xEVDO Rev. B	HSDPA	HSUPA	Mobile WiMAX
Duplex		FDD	FDD	FDD	FDD	TDD
Occupied spectrum (MHz)		2.5	10	10	10	10
Channel bandwidth (MHz)	DL	1.25	5	5	5	DL/UL = 3
	UL	1.25	5	5	5	
Spectral Efficiency	DL	0.85	0.93	0.78	0.78	1.91
	UL	0.36	0.28	0.14	0.30	0.84
Net Information Throughput per channel/Sector (Mbps)	DL	1.06	4.65	3.91	3.91	14.1
	UL	0.45	1.39	0.7	1.50	2.20

C. *WiFi*

WiMAX is different from WiFi in many respects. The WiFi MAC layer uses contention access. This causes users to compete for data throughput to the access point. WiFi also has problems with distance, interference, and throughput and that is why triple play (voice, data, video) technologies cannot be hosted on traditional WiFi. In contrast 802.16 uses a scheduling algorithm. This algorithm allows the user to only compete once for the access point. This gives WiMAX inherent advantages in throughput, latency, spectral efficiency, and advanced antenna support.

Companies developing radical innovations may adopt different stances; not only based on the strategic interests of the company but also they taking into other considerations such as the market and its needs and requirements, as well as other products it may carry.

When comparing WiFi and WiMAX, one is comparing their substitutability and complementary to existing technologies and how different companies have and will view them. WiMAX and WiFi can offer some potentially significant cost savings for mobile network operators by providing an alternate means to backhaul base station traffic from cell site to the base station controllers. Mobile network operators typically utilize some type of wired infrastructure that they must buy from an incumbent operator. A WiFi or WiMAX mesh can offer a much more cost-effective backhaul capability for base stations in metropolitan environments.

The results of the comparison show that mobile WiMAX has better performance in all the areas listed above (where it shares performance enhancing features with EVDO and HSDPA/HSPA). Furthermore, the technologies on which mobile WiMAX is based result in lower equipment complexity and simpler mobility management due to the all-IP core network. They also provide Mobile WiMAX systems with many other advantages over CDMA based systems such as:

- Tolerance to Multipath and Self-Interference
- Scalable Channel Bandwidth
- Orthogonal Uplink Multiple Access
- Support for Spectrally-Efficient TDD
- Frequency-Selective Scheduling
- Fractional Frequency Reuse
- Improved variable Quality of Service (QoS)
- Advanced Antenna Technology

WiMAX gained its expected acceptance by the ITU as an official IMT2000 wireless standard – removing many potential regulatory barriers to its adoption in cellular bands may push the CDMA giant further towards adopting 802.16e. Many governments dictate technologies when they allocate wireless spectrum, and they typically look to the ITU, which is affiliated with the United Nations, to say what technologies qualify. WiMax will now be one of their choices when faced with a requirement for 3G, which the ITU calls IMT-2000. With the prospects for introduction of multimode starting in 2008, WiMAX will become an exceptional enhancement to existing cellular 3G networks. Operators who adopt WiMAX multimode are not pressed into either replacing or displacing service to customers. Instead, they have an evolutionary alternative to provide higher bandwidth services and a ”personal broadband everywhere” triple or quadruple play of services, which will help retain and attract customers.

VII. Applications

The WiMAX standard has been developed to address a wide range of applications. Based on its technical attributes and service classes, WiMAX is suited to supporting a large number of usage scenarios. Table III address a wide range of applications [23].

TABLE III. Summary of WiMAX Applications

CLASS DESCRIPTION	REAL TIME	APPLICATION TYPE	BANDWIDTH
Interactive Gaming	Yes	Interactive Gaming	50-85 Kbps
VoIP, Video Conferencing	Yes	VoIP	4-64 Kbps
		Videophone	32-384 Kbps
Streaming Media	Yes	Music/Speech	5-128 Kbps
		Video clips	20 – 384 Kbps
		Movies streaming	> 2 Mbps
Information Technology	No	Instant Messaging	< 250 byte messages
		Web browsing	> 500 Kbps
		Email (with attachments)	> 500 Kbps
Media Content download (store and forward)	No	Bulk data, Movie download	> 1 Mbps
		Peer to Peer	> 500 Kbps

VOIP & IP

Mobile WiMAX is an all IP network. The use of OFDMA on the physical layer makes it capable of supporting IP applications. It is a wireless solution that not only offers competitive internet access, but it can do the same for telephone service.

Voice over Internet Protocol (VoIP) offers a wider range of voice services at reduced cost to subscribers and service providers alike .VoIP is expected to be one of the most popular WiMAX applications. Its value proposition is immediate to most users. While WiMAX is not designed for switched cellular voice traffic as cellular technologies as are CDMA and WCDMA, it will provide full support for VoIP traffic because of QoS functionality and low latency. IPTV enables a WiMAX service provider to offer the same programming as cable or satellite TV service providers. IPTV, depending on compression algorithms [24], requires at least 1 Mbps of bandwidth between the WiMAX base station and the subscriber. In addition to IPTV programming, the service provider can also offer a variety of video on demand (VoD) services. IPTV over WiMAX also enables the service provider to offer local programming as well as revenue generating local advertising.

VIII. Benefits of WiMAX

WiMAX is a global technology. Different countries refer to their systems by different names for example; WiBro is the name of 802.16e standard in South Korea and HIPERMAN(High Performance Radio Metropolitan Are Network) in Europe. The Widely used international broadband spectrum range is 3.5 GHz. The followings are some of the advantages of WiMAX.

Wireless. By using a WiMAX system, companies/ residents no longer have to rip up buildings or streets or lay down expensive cables.

High Bandwidth. WiMAX can provide shared data rates of up to 70 Mb/s. this is enough bandwidth to support more than 60 businesses at once with T1-type connectivity. It can also support over a thousand homes at 1 Mb/s DSL-level connectivity Also, there will be a reduction in latency for all WiMAX communications.

Long Range. The most significant benefit of WiMAX compared to existing wireless technologies is the range. WiMAX has a communication range of up to 40 Km[25].

Multi-Application. WiMAX uses the Internet protocol and is therefore capable of efficiently supporting all multimedia services from VoIP to high speed internet and video transmission. It also supports a differentiated quality of service enabling it offer dynamic bandwidth allocation for different service types. WiMAX has the capacity to deliver services from households to small and medium enterprises, small office, home office (SOHO), Cybercafés, Multimedia Tele-centers, Schools and Hospitals.

Flexible Architecture. WiMAX supports several systems architectures, including Point-to-Point, Point-to-multipoint, and ubiquitous coverage.

High Security. The security of WiMAX is state of the art. WiMAX supports advanced encryption standard triple data encryption standard. WiMAX also has built-in VLAN support, which provides protection for data that is being transmitted by different users on the same base station. Both variants use Privacy Key Management (PKM) for authentication between base station and subscriber station. WiMAX offers strong security measures to thwart a wide variety of security threats.

QoS. WiMAX can be dynamically optimized for a mix of traffic that is being carried.

Multi Level Service. QoS is delivered generally based on the service level agreement between the end user and the service provider.

Interoperability. WiMAX is based on international, vendor-neutral standard. This protects the early investment of an operator since it can select the equipments from different vendors.

Low Cost and Quick deployment. WiMAX requires little or no external plant construction compared with the deployment of wired solutions. Base stations will cost under $20,000 but will still provide customers with T1-class connections [26].

Worldwide Standardization. WiMAX is developed and supported by the WiMAX forum (more than 470 members). The WiMAX forum collaborates with different international standards organizations that are developing broadband wireless standards with the intent to provide interoperability among the standards. Some of the other broadband wireless standards include HiperMAN/HiperLAN (Europe) and WiBRO (South Korea). These standards are compatible with WiMAX at the physical layer. WiMAX will become a truly global technology based standard for broadband and will guaranty interoperability, reliability and evolving technology and will ensure equipment with very low cost.

IX. Drawbacks of WiMAX

Broadband wireless in general and WiMAX in particular face a number of challenges that could impede their adoption in the marketplace. The most significant challenge is that WiMAX is a new technology with emerging support.

Hesitancy. Companies are very hesitant of setting up WiMAX base stations today since it has not yet reached widespread use. Intel has made their Centrino laptop processors WiMAX enabled. All laptops are expected to have WiMAX by 2008[27].

Exclusion of Start-Up Companies. Even though cost provides a low barrier to entry, none of the startup companies are projected to be major players in the development of WiMAX. Intel and Cisco seem to have an obvious advantage today, and by the time it reaches widespread use, large operators will find WiMAX to be a very attractive new way of raising revenues.

Research and Development. For WiMAX to succeed, new products must be researched and developed to incorporate WiMAX. Without the help of major companies investing in this R&D, WiMAX could be gravely underutilized.

X. Conclusion

Broadband wireless is a significant growth marketplace for the telecom industry to deliver a variety of applications and services to both mobile and fixed users. The combination of both advanced radio features and flexible end-to-end architecture makes WiMAX attractive solution for diverse operators. It provides many different services on one network, services which required different networks in the past. It also provides convergence of fixed and mobile networks. It provides high speed access to the subscriber at a reasonable cost, thereby enabling the service provider to make a profit from the technology, using economies of scale. It offers the advantage of reduced total cost of ownership during the lifetime of a network deployment.

We compared WiMAX with other 3G technologies. While it is clear that WCDMA has the advantage when referring to voice and soft handoff of voice, these advantages disappear for data-centric applications. There are some additional advantages of WCDMA in equipment performances; however, these advantages are not sufficient to overcome the advantages of OFDMA. As data traffic continues to grow, there will be an increasing need to offload data from 3G to and OFDMA based network optimized for data. Mobile WiMAX (802.16e) provides the only standards-based OFDMA WAN technology. WiMAX is an excellent complement to other wireless technologies that are designed to work in the LAN (WiFi) or that offer wider coverage but with more limited capacity (GSM, CDMA, UMTS, EV-DO). Recent inclusion of WiMAX in IMT2000, and the ITU decision may push the CDMA giant further towards adopting 802.16e

In regard to WiMAX cell design and coverage, the radio enhancement feature applicable to fixed and mobile WiMAX compensate for the extra attenuation resulting

from higher carrier frequency, larger transmission bandwidth, and deep indoor penetration.

WiMAX is expected take prominence in about five years (2012). The strengths of WiMAX lie in its ability to address the requirements of modern telecommunications networks and the commitment that has been shown to its development and wide acceptance by a number of leading equipment vendors and service providers. WiMAX could potentially be deployed in a variety of spectrum bands: 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz. The biggest challenges to deploying WiMAX–based services do not stem very much from the spectrum, but from business case issues.

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A. Yarali (S'92, M'96-IEEE) is a faculty member of Telecommunication Systems Management and Industrial Engineering Technology at Murray State University where he has developed a wireless option program. He has worked as a technical advisor in wireless industry since 1995. Dr. Yarali is currently conducting research program in wireless mobile systems design and implementation at Murray State University.

Saifur Rahman (S'75, M'78, SM'83, F'98 – IEEE) is the director of the Advanced Research Institute at Virginia Tech where he is the Joseph Loring Professor of electrical and computer engineering. He also directs the Center for Energy and the Global Environment at the University. Professor Rahman has served as a program director in engineering at the US National Science Foundation between 1996 and 1999. He has served on the IEEE Power Engineering Society Governing Board as VP of industry relations, and VP of publications between 1999 and 2003. In 2006 he served as the vice president of the IEEE Publications Board, and a member of the IEEE Board of Governors. He is also a member-at-large of the IEEE-USA Energy Policy Committee. He has published over 300 papers on conventional and renewable energy systems, load forecasting, uncertainty evaluation and infrastructure planning.

Bwanga Mbula is a graduate student at Murray State University. He has worked in telecommunication field for several years. Bwanga's research interest is in wireless mobile communication filed.