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The Strategic Approach to WiMAX
Demystifying Fixed and Mobile WiMAX Standards

WiMAX White Paper

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WiMAX is a promising, standards-based technology for delivering advanced fixed and mobile broadband wireless services in emerging, high growth and developed markets. There are currently two standards on which WiMAX is based: IEEE 802.16-2004 and IEEE 802.16e-2005, creating some confusion in the marketplace as to which standard is 'better.' Adding to the complexity is the surge in WiMAX chipset and other vendor solutions that continue to drive the introduction and growth of the WiMAX ecosystem. The purpose of this white paper is to highlight some of the key features of the two standards and to illustrate the reasons for these differences.

WiMAX technologies are widely accepted as a cost-effective and reliable solution for delivering advanced communications services. To be successful, operators must carefully select the right WiMAX products and technologies that will deliver the services they need. This white paper is an effort to highlight some of the premises on which the two flavors of WiMAX are based and to assist operators in understanding these areas for the planning of for the services expected to be deployed by the carrier.

We begin with an overview of the IEEE standardization activities on which the fundamental core technology of WiMAX rests. We'll review current and recently undertaken WiMAX Forum activities in order to make the distinction between fixed and mobile applications. Later, we explore into a comparison of the two standards to highlight the differences and explain the rational for such differences. We conclude by showing that fundamentally, activities around 802.16e-2005 have been directed towards mobility applications while those around 802.16-2004 are focused on fixed applications. Each standard has its strength and weaknesses. It is a matter of how these strength and weaknesses are managed and resolved that will directly impact how operators will take advantage of the environment and application for which the standard serves the operator.

IEEE Standard Overview:

The IEEE 802.16 is an *evolutionary* air interface standard that has been in development since 1999. As an air interface standard, it specifies the first two layers of the OSI networking stack (the physical and medium access control layers). '*WirelessMAN'* is the standard commonly referred to for "*wireless metropolitan area networks.*" indicating the target scale of a deployment which is about the size of a city. The aim of the IEEE 802.16 technology is to provide wireless broadband access, that bridges the gap between the core infrastructure network and the user. This gap has been traditionally bridged with wire line or fiber solutions that are costly to install, manage and maintain. Broadband wireless access leverages significant technology advancements to bypass such limitations providing a compelling and cost effective solution.

As an evolutionary standard, IEEE 802.16 underwent a few iterations. The original standard (802.16-2001) addressed line-of-sight (LOS) scenarios in the 10-66 GHz frequency range (December 2001). In January 2003, the IEEE 802.16a-2003 added physical layer support for frequencies below 11 GHz and targeted NLOS, PTP applications. This was later refined with the 802.16-2004 (June 2004) standard which rendered the original 802.16-2001 version obsolete. This version of the standard then underwent a 'corrigenda' process (Cor1) whereby corrections to the standard were made. This process was completed in November 2005. The IEEE 802.16-2004 standard addresses fixed access and allows for significant level of flexibility such as providing *nomadic* services whereby the device can move while not in operation as roaming is not supported (i.e. no handoff support).

In December 2005, an amendment to the standard for mobile wireless broadband was completed. Commonly referred to as IEEE 802.16e-2005, this standard enables roaming for portable devices such as laptops and PDAs in the licensed frequency bands under 6 GHz.

At present, the IEEE 802.16e-2005 is undergoing a corrigenda process (Cor2) of its own, similar to the process that IEEE 802.16-2004 underwent. In December 2006, a new IEEE PAR (Project Authorization Request) was approved by the IEEE executive committee to begin work on a new amendment to the standard (802.16m) to address ITU-R (International Telecommunication Union – Radio Communications Sector) requirements for 4G networks, mainly providing mobile broadband services with throughput of 100 Mbps in over 80% of the coverage area. This amendment is commonly referred to as IEEE 802.16m and is expected to be completed in the 2008 or 2009 timeframe.

WiMAX Forum Overview:

The WiMAX Forum, an organization of more than 400 leading operators, communications component and equipment companies, was established in June 2001, to help remove some of the barriers to wide-scale adoption of Broadband Wireless Access (BWA) technology. It was clear that a standard alone was not enough to influence mass adoption of the technology. The Forum is working to certify interoperability and compatibility of the equipment based on the IEEE 802.16 technology and to ensure that WiMAX Forum certified equipment meet service provider and customer's requirements.

To achieve its goals, the WiMAX Forum created a number of working groups to address the technical, marketing, regulatory and other requirements for wide-scale adoption and deployment of broadband wireless systems. Some of the workgroups include:

- Technical Working Group (TWG): The working group that specified the technical parameters for mobile networks. These parameters are grouped into what's commonly referred to as a 'system profile' which is a subset of the IEEE 802.16e-2005 standard. The TWG (formerly know as Mobility Task Group) has selected the Scalable-OFDMA (Orthogonal Frequency Division Multiple Access) physical layer.
- Enhanced Technical Working Group (ETWG): The working group that specifies the technical parameters for fixed and portable systems based on the OFDM physical layer as defined in 802.16-2004 and 802.16e-2005.
- Certification Working Group (CWG): The working group that specifies system certification requirements and profiles. A 'certification profile' is a set of parameters that include primarily frequency bands, channel bandwidths, and access modes. To achieve WiMAX Forum Certification status, base station and CPE devices must undergo a number of tests covering conformance to the IEEE standard (protocol and radio conformance testing) and interoperability testing with other vendors' equipment.
- Network Working Group (NWG): The working group responsible for addressing the requirements of the access and core networks at a higher protocol stack level than the IEEE 802.16 standard. The requirements developed by this working group enable the interoperability between the infrastructure network elements such as switches (since WiMAX is an all IP network) and WiMAX base stations.
- Service Provider Working Group (SPWG): Provides the WiMAX Forum with the perspective of the network operator. The SPWG develops and communicates requirements to the rest of the WiMAX Forum working groups.

In accordance with the WiMAX Forum and industry nomenclature, we will refer subsequently to the IEEE 802.16-2004 system as "Fixed WiMAX" and the IEEE 802.16e-2005 based systems as "Mobile WiMAX".

WiMAX, in both of its Fixed and Mobile versions, is based on a next-generation all-IP core network, which offers low latency, advanced security, QoS (Quality of Service), and, in the case of mobility, worldwide roaming capabilities. Service providers also benefit from the low costs that a technology based on open standards, vendor interoperability, and favorable Intellectual Property Rights (IPR) brings to the Market.

WiMAX Certification Process:

Certification of equipment by the WiMAX Forum constitutes a major activity designed to ensure compliance to the standard and interoperability among equipment. Certification fosters a competitive ecosystem of base station and subscriber devices from various vendors. This promises an accelerated and wide-scale adoption of WiMAX.

The WiMAX Forum certifies equipment in certain 'certification profiles' which, as described earlier, specifies system parameters related to frequency band, channel bandwidth and access mode (e.g. TDD or FDD). Certification tests are scheduled to occur in waves with each subsequent release adding further mandatory technical features and capabilities (and henceforth, superceding and obsolescing the earlier certification wave). There are currently two defined certification waves for Fixed and Mobile WiMAX.

Table 1 shows the approved WiMAX Forum certification profiles as of December 2006. As can be seen, certification for Mobile WiMAX centers on the lower frequency bands while certification for Fixed WiMAX centers on the higher frequency bands. This split is not coincidental. Propagation and wall penetration losses are more severe in the higher frequency bands. The result is an increase in the number of cell sites (and associated base stations) for higher frequency bands that reduces the financial viability of mobile networks, when compared with those found in lower frequency bands.

	Frequency Band (GHz)	Channel Bandwidth (MHz)	Duplex Mode
Fixed WiMAX	3.4-3.6	3.5, 7	TDD, FDD
	5.8	10	TDD
Mobile WiMAX	2.3-2.4	8.75	TDD
	2.496-2.69	5, 10	TDD

Table 1 WiMAX Forum Certification Profiles (approved profiles as of the time of December 2006)

Today, there are over 28 Fixed WiMAX products (base station and subscriber stations) that have been certified in the 3.4-3.6 GHz band according to WiMAX Forum fixed certification wave 1 (CW1) requirements. Currently, the WiMAX Forum designated certification laboratory (or WFDCL) is AT4 Wireless in Malaga, Spain. Currently, AT4 is in the process of validating the test scripts and test bed for the requirements of the second fixed certification wave (CW2). It is expected that the lab will certify equipment in Q2 2007. This will be about a year following the availability of the first CW1 compliant systems (Fixed WiMAX certification designation became available in January 2006).

The WiMAX Forum alongside ETSI and the designated certification test lab are currently in the process of defining the test plans, test case and validating the test tools for Mobile WiMAX. The WiMAX Forum has selected Profile 1A (2.3 GHz; 8.75 MHz channel, commonly known as WiBRO) to be the first Mobile WiMAX certified profile to adhere to the mobile CW1 system profile. Profile 3A (2.5-2.7 GHz; 5/10 MHz channels) is the second selected certification profile to adhere to the mobile CW2 system profile which adds tests primarily targeted at advanced physical layer features such as MIMO (Multiple Input Multiple Output) antenna technology. CW1 is expected to start sometime in the first half of 2007, to be followed by CW2 later in the year.

As Mobile WiMAX adds many features necessary to support mobility (e.g. sleep mode, handovers, etc.) the number of tests required for certification is expected to increase when compared with that of Fixed WiMAX. Furthermore, Mobile WiMAX networks are envisioned to be larger in scope than Fixed WiMAX networks due to the coverage ubiquity and roaming requirements necessary for mobility. Therefore, compliance and interoperability testing for Mobile WiMAX must be more rigorous and comprehensive than that of Fixed WiMAX. Given the added complexity of mobility and the necessity of having system compatible with CW2, deployments of certified Mobile WiMAX systems is not expected until 2008 (at the earliest).

Technology Overview:

Fixed WiMAX technology is based on a 256 sub-carrier OFDM physical layer. Part of the advantages of OFDM is that it provides frequency diversity and higher tolerance for multipath fading. In an environment where certain OFDM sub-carriers ‘fade’, the overall link would still be maintained by other non-faded sub-carriers. In OFDM, communication between the base station and a subscriber is scheduled within defined time intervals using the full channel bandwidth (i.e. all available frequency sub-carriers are assigned to one user). Nevertheless, it is possible for a subscriber to communicate with the base station over a partial number of sub-carriers. This feature is known as ‘uplink subchannelization’. It allows the subscriber unit to increase the transmit power since total power is concentrated over fewer number of sub-carriers.

Fixed WiMAX systems work in either TDD or FDD access modes and are both included for the certifiable profiles. While FDD was designed to support legacy spectrum allocations, TDD provides improvements in spectral efficiency for broadband services that are characterized by higher downlink traffic (base station to subscriber) than uplink traffic (subscriber to base station). This is a key advantage when supporting IP based data networks that require asymmetrical traffic flows in the network. Additionally, having the same frequency for the downlink and uplink facilitates the implementation of throughput-enhancing advanced antenna techniques.

Mobile WiMAX is based on the Scalable-OFDMA physical layer (S-OFDMA). Scalability implies that a higher number of sub-carriers are used as the channel bandwidth increases. For instance, a 5 MHz channel uses 512 sub-carriers, whereas a 10 MHz channel uses 1024 sub-carriers. In addition, communication between the base station and subscribers can be scheduled in both the downlink and uplink using a partial number of sub-carriers. Therefore, mobile WiMAX implements 'downlink subchannelization' in addition to 'uplink subchannelization'. Through downlink subchannelization, groups of subchannels can be allocated to different sectors of the base station or all the groups can be allocated to one sector.

Either way, it is a useful feature for mobile systems as it allows for tight frequency reuse plans which are necessary for optimizing large scale mobile network deployments. However, spreading subchannel groups over multiple sectors reduces throughput, which may be acceptable in a mobile system. We will discuss in more detail the use of downlink subchannelization in the following section.

The manner in which sub-carriers are assigned to subchannels is referred to as the permutation mode. There are a number of different modes defined for Mobile WiMAX including partial utilization of subchannels (PUSC), full utilization of subchannels (FUSC) and adaptive modulation and coding (AMC). The difference between these modes centres around how the sub-carriers are allocated to the subchannels.

PUSC and FUSC modes are generally referred to as '*diversity*' modes (subchannels composed of non-adjacent sub-carriers) while AMC is referred to as a '*contiguous'* mode (subchannels composed of adjacent sub-carriers). The PUSC mode has been preferred for Mobile WiMAX as it is most suitable for mobile applications given the relatively higher number of pilot signals and frequency diversity feature.

Table 2 details the number of sub-carriers in a channel for fixed and Mobile WiMAX (PUSC mode). Note the relatively large number of pilots on the uplink of Mobile WiMAX which is necessary to correct for distortions introduced by mobility such as phase noise. This leads to particularly lower physical layer rates on the uplink path in comparison to the downlink path as will be shown later.

	Mobile WiMAX (PUSC Mode)				Fixed WiMAX	
	5 MHz		7/8.75/10 MHz		3.5/7/10 MHz	
	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink
Total Sub-carriers	512	512	1024	1024	256	256
Used Sub-carriers (data plus pilot)	420	408	840	840	200	200
Data Sub-carriers	360	272	720	560	192	192
Pilot Sub-carriers	60	136	120	280	8	8
Null Sub-carriers	92	104	184	184	56	56

Table 2 Number of subcarriers for different channel bandwidth in Fixed and Mobile WiMAX.

Additionally, Mobile WiMAX implements features critical to mobility services. For example, handovers allow the user to move between base stations while sleep and idle modes conserves battery life – a necessity for handheld devices but largely inconsequential for user equipment in fixed applications where power is readily available.

Both Fixed and Mobile WiMAX provide different modulation schemes and the ability to change modulation schemes depending on the quality of the link. Table 3 provides the modulation schemes and coding rates defined by the IEEE standard and mandated by the WiMAX Forum as part of the system profile. The Fixed WiMAX coding schemes illustrated are Reed Solomon and convolutional codes whereas convolutional turbo codes are used in Mobile WiMAX.

Note the absence of the 64QAM modulation rates in Mobile WiMAX which results in lower uplink throughput. Also, Fixed WiMAX features a BPSK mode which is unavailable in Mobile WiMAX. This provides increased reach for the serving base station to distant subscribers.

	Mobile WiMAX		Fixed WiMAX	
	Downlink	Uplink	Downlink	Uplink
BPSK-1/2	×	×	✓	✓
QPSK-1/2	✓	✓	✓	✓
QPSK-3/4	✓	✓	✓	✓
16QAM-1/2	✓	✓	✓	✓
16QAM-3/4	✓	✓	✓	✓
64QAM-2/3	✓	×	✓	✓
64QAM-3/4	✓	×	✓	✓

Table 3 WiMAX modulation and coding schemes

Another key feature of WiMAX is the availability of different Quality of Service levels. This allows the system to carry different types of services including voice, video and data. The WiMAX base station dynamically allocates downlink and uplink radio resources according to the traffic load and subscriber QoS demand. Table 4 summarizes the available QoS levels supported by WiMAX.

Service	Description	Application	QoS Service Flow Parameters
Unsolicited Grant Service (UGS)	Real-time data streams of fixed size packets issued at periodic intervals.	VoIP (without silence suppression) E1/T1	Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, Request/Transmission Policy Minimum Reserved Traffic Rate parameter = Maximum Sustained Traffic Rate
Real Time Polling Service (rtPS)	Real-time data streams of variable-sized data packets issued at periodic intervals.	VoIP Video MPEG	Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency, Request/Transmission Policy
Non-Real Time Polling Service (nrtPS)	Delay-tolerant data streams of variable-sized data packets for which a minimum data rate is required.	FTP	Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Traffic Priority, Request/Transmission Policy
Best Effort (BE)	Data streams for which no minimum service level is required.	HTTP (web browsing, data transfer)	Maximum Sustained Traffic Rate, Traffic Priority, Request/Transmission Policy

Table 4 WiMAX QoS Levels

In addition to the above, Mobile WiMAX also adds a fifth QoS level, enhanced rtps (or ertPS), which combines certain features of UGS and rtPS to support applications such as VoIP with silence suppression.

WiMAX security provides support for mutual device/user authentication (EAP-based), flexible key management protocol (PKMv2), strong data encryption (AES) along with control and management plane protection (CMAC and HMAC).

A Discussion on the Physical Layer (PHY) of WiMAX

Performance of wireless systems is determined to a large extent by the propagation channel between the transmitter and the receiver. The propagation channel introduces impairments for the communication signal. Physical (PHY) and medium access control (MAC) schemes are designed to reduce the effects of these impairments by various corrective (e.g. error control coding) or avoidance (e.g. diversity, interleaving, scheduling, diversity, ARQ, etc.) schemes. Therefore, the type of propagation channel has a significant impact on the design of the PHY and MAC layers. In this section, we will concentrate on describing elements of the PHY layer of Fixed and Mobile WiMAX to illustrate how the propagation channel impacts design choices at the physical layer.

Mobile and Fixed wireless systems differ in the type of propagation channel. This is due to several reasons, including:

1. Impairments induced by mobility (e.g. Doppler spreading of the signal in the frequency domain which causes intersymbol interference), or more particularly in OFDM inter-carrier, and
2. Impairments induced by the usage model. For example, in mobility applications the signal envelop has a high probability of being Rayleigh distributed (i.e. there is no dominant signal component between the transmitter and the receiver) whereas the chances of having a Rician channel are much higher in a fixed application (i.e. there is a dominant signal component between the transmitter and receiver). Since in fixed applications many devices are either in outdoor or window-mount units, there is a larger propensity for a dominant signal component between the base station and the user equipment.

Both 802.16-2004 and 802.16e-2005 support robust PHY and MAC layers that are designed to mitigate propagation channel impairments. However, the S-OFDMA PHY layer of 802.16e-2005 incorporates downlink subchannelization not available in 802.16-2004, a feature primarily aimed at addressing the following challenges:

1. Allows sharing of the same frequency between different sectors of a base station. Mobility deployments require ubiquitous coverage which in turn places higher constraints on frequency spectrum utilization. Frequency planning becomes more difficult when there are more sources of interference to consider, due in part to the scale of the network. This constraint is eased by sharing sub-carriers belonging to the same frequency channel on all sectors of the same site. Although this reduces throughput available at any one sector, it is deemed an acceptable compromise since throughput requirements in mobile applications are not as onerous as those in fixed applications where high data rates are of paramount importance (e.g. a SME would have different throughput and quality of service requirements than an individual with a PDA using the public transit system).

2. Allows averaging of interference. Sub-carriers are assigned to users in a random manner. In environments where two base stations are in close proximity to one another they could generate relatively strong downlink interference. Downlink subchannelization capabilitites average the interference among users (e.g. sub-carriers from a signal to a certain user in Cell A interfere with a fewer subset of sub-carriers assigned to multiple users in Cell B).

Fixed and Mobile WiMAX also differ in the number of pilot signals. As Table 2 shows, while the percentage of pilot carriers constitutes only 3% of the number of sub-carriers in Fixed WiMAX, it is 12% and 27% for the downlink and uplink in Mobile WiMAX, respectively. The requirements of mobility with a more ‘agile’, faster changing channel makes pilots an important addition. Pilot carriers correct phase noise resulting from frequency errors.

Since Mobile WiMAX uses higher number of narrower-band sub-carriers, it is more susceptible to phase noise than Fixed WiMAX. The inclusion of a higher number of pilot carriers would reflect on the physical layer throughput capabilities for Mobile and Fixed WiMAX, as illustrated in Table 5. Fixed WiMAX shows a physical layer throughput advantage over Mobile WiMAX of 7% on the downlink and 37% on the uplink.

	Mobile WiMAX - PUSC Mode								Fixed WiMAX			
Bandwidth (MHz)	5		7		10		8.75		3.5		7	
Subframe	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
BPSK 1/2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.8	0.5	1.5	1.0
QPSK 1/2	2.0	1.0	2.9	1.5	4.0	2.1	3.6	1.9	1.5	1.0	3.1	2.0
QPSK 3/4	3.0	1.6	4.3	2.2	6.0	3.2	5.4	2.9	2.3	1.5	4.6	3.0
16QAM 1/2	4.0	2.1	5.8	2.9	8.1	4.3	7.2	3.8	3.1	2.0	6.1	4.0
16QAM 3/4	6.0	3.1	8.6	4.4	12.1	6.4	10.8	5.7	4.6	3.0	9.2	6.0
64QAM 2/3	8.1	N/A	11.5	N/A	16.1	N/A	14.4	N/A	6.1	4.0	12.3	8.0
64QAM 3/4	9.1	N/A	13.0	N/A	18.1	N/A	16.2	N/A	6.9	4.5	13.8	9.0
Based on 5 ms frame; 1/8 cyclic prefix; 60:40 traffic ratio. DL = Downlink; UL = Uplink.												

Table 5 Physical (PHY) Layer Throughput (Mbps) for Mobile and Fixed WiMAX

To mitigate against propagation channel impairments, both Fixed and Mobile WiMAX use strong forward error correction (FEC) coding schemes. Fixed WiMAX concatenates an inner Reed-Solomon code with an outer convolutional code. Mobile WiMAX implements turbo convolutional codes which provide additional gains that can be used to provide higher levels of 'interference tolerance' which are required due to more severe impairments encountered in a mobile channel. Table 6 shows the required SNR and calculated theoretical receiver sensitivity for Fixed and Mobile WiMAX systems.

User devices in mobile networks use omni-directional antennas which radiate in all directions to enable connection to any cell within a certain radius of the mobile user. This implies higher levels of interference being generated in direction away from the serving cell than in fixed applications where directional antennas are used. Convolutional turbo codes (CTC) become a necessary and essential feature of Mobile WiMAX to gain back capacity lost to interference (through a lowering of the modulation rate to maintain a link). Therefore, the lower receiver sensitivity rates are used in a mobile setting not for distance enhancement, but to gain back capacity lost to a smaller frequency reuse plan.

	Mobile WiMAX		Fixed WiMAX	
Modulation	**Rx SNR (dB)**	**Rx Sensitivity (dBm)**	**Rx SNR (dB)**	**Rx Sensitivity (dBm)**
BPSK 1/2	N/A	N/A	3	-91.0
QPSK 1/2	2.9	-93.9	6	-88.0
QPSK 3/4	6.3	-90.5	8.5	-85.5
16QAM 1/2	8.6	-88.2	11.5	-82.5
16QAM 3/4	12.7	-84.1	15	-79.0
64QAM 2/3	16.9	N/A	19	-75.0
64QAM 3/4	18	N/A	21	-73.0
CTC with repetition of 2 is used for Mobile WiMAX. 7 dB noise figure and 5 dB implementation loss are assumed in the receiver sensitivity calculations.				

Table 6 SNR and theoretical receiver sensitivity for Fixed and Mobile WiMAX

Aspects of Mobile and Fixed Network Design:

We will now investigate network design choices for both Fixed and Mobile WiMAX networks. First we need to frame this discussion with a review of some of the typical usage scenarios.

1- Mobile Application: The user would typically have a handheld device such as a phone or a PDA (size and weight constraints). These devices are operated by battery, and as battery life is of paramount importance, there are stringent power consumption requirements that typically limit the level of transmitter power. Typical transmitter power in WiMAX mobile devices is expected to be around 20 dBm. Furthermore, the relative small size of devices precludes the implementation of high gain antennas. Typically, antenna gain on mobile devices is about 0 dBi.

2- Fixed Applications: In contrast to mobile applications, the user is stationary. The user equipment in this case can be a desktop modem which is powered from an AC outlet (easing of size and weight constraints). Hence, there are no battery life constraints, which ease the requirements for transmitter power levels of CPEs. Typical transmitter power in Fixed WiMAX devices is around 24 dBm, and higher in future generations of CPEs. Furthermore, the larger size of the unit allows for the implementation of higher gain antennas which can be as high as 10 dBi if integrated into the modem itself or even higher if an external directional antenna is used for the CPE.

3- Portable Applications: This is an emerging class of applications that exhibit certain commonality with both mobile and fixed applications. This mode features larger client devices such as laptops computers which still have size and weight requirements, but are less onerous than devices for mobile applications. Battery life remains important such that transmitter power levels are still constrained, but now, there is more space to implement antennas with higher gain. For example, a PCMCIA card with an omni directional antenna can have about 2-3 dBi of gain. The transmitter power would be a similar level to that of mobile devices – about 20 dBm.

The usage scenarios are important as they impact the design of the network in the following manner.

a. Cell size: Transmitter power and antenna gain impact the size of the cell. The higher the transmitter power and the higher the antenna gain, the larger the cell size. Mobile devices are characterized by lower transmitter power and antenna gain which implies a smaller cell size. Furthermore, fading impacts cell size. Fading is more severe in mobile than in fixed applications, requiring a higher temporal fade margin and further reducing the size of the mobile cell.
b. Quality of Service: Fixed applications are typically characterized by a service level agreement where the carrier agrees to provide the user with a certain type and level of service. Mobile applications have different constraints on the type and level of service. For instance, users expect coverage for mobile devices everywhere. In contrast, fixed subscribers expect services such as VPN, VLAN, video surveillance, etc. which may not be required for a mobile user.
c. Throughput requirements: Fixed applications would typically require higher throughput than mobile applications particularly in enterprise, SME and other such customers. A larger wireless device may have higher throughput and capacity demands as it enables applications that require higher throughput (e.g. video is a more suitable application over a larger screen as in a laptop than a small screen as in a handset.)

These differences impact the link budget in the manner summarized in Table 7. It can be seen that in fixed scenarios the network would have an inherent advantage of at least 15 dB over a mobile scenario, which implies larger cell sizes for the fixed scenario and therefore a lower number of base stations required for the deployment. This will allow the operator to deploy a very cost-effective base station approach using Fixed WiMAX.

Parameter	Mobile Scenario	Portable Scenario	Fixed Scenario	Advantage of Fixed over Mobile and Portable Scenarios
Transmitter power	20 dBm	20 dBm	24 dBm	4 dB
Antenna Gain	0 dBi	2-3 dBi	10 dBi	7-10 dB
Temporal Fade Margin	8 dB	8 dB	4 dB	4 dB
Total Link Budget Difference				15-18 dB

Table 7 Link Budget Difference between Mobile and Fixed Applications

The above difference provides the basis for a separate business case to support mobile and fixed networks whereby the network is optimized for the particular application and usage scenario. For example, designing a network for mobile scenario with fixed devices would lead to interference caused by the higher power and higher antenna gain of fixed devices, whereas designing for fixed usage scenarios leads to 'coverage holes' for mobile devices as they will not be able to operate due to lack of sufficient signal.

Network Design Aspects Related to Operating Frequency

Having investigated network design issues, we turn our attention to an important topic: matching spectrum to the usage model. We have already seen that mobility scenarios possess an inherent disadvantage in system gain and allowable path loss of at least 15 dB in comparison to fixed scenarios. To allow for a competitive business case, where cell size is directly related to site count, mobile applications are more attractive in the lower frequency bands. That is, 2.5 GHz or lower, but not too low where the wavelength becomes large enough to preclude compact handset design.

To illustrate this point further, we look at the dependency of the cell count on the frequency of operation. Table 8 summarizes the required number of cells to cover a 100 km^2 market at four different frequencies. For the frequencies most applicable to WiMAX, 50% more sites are required at 3.5 GHz than required at 2.5 GHz.

Frequency (MHz)	900	1800	2500	3500
Cell Radius (m)	4900	3245	2670	2186
Path Loss at 4900 m (dB)	150	158	162	165
Site Count for 100 km^2 market	2	4	6	9
Relative Site Count	1.0	2.0	3.0	4.5
Assumes a maximum allowable path loss of 150 dB. Cell radius was calculated using the Erceg Type B model with 30 m base station height and 2 m subscriber station height. Added 6.5 dB for 75% contour confidence interval resulting in 90% area confidence interval. Path loss dependency on frequency is $20\times\log_{10}(f) + 6\times\log_{10}(f/1900)$. The latter term is a correction factor to account for the fact that the model parameters were based on measurements taken at 1900 MHz. Hexagonal cells are assumed for cell count calculations.				

Table 8 Cell Count Dependency on Operating Frequency

In the above analysis, we have not considered the difference in propagation losses through walls at different operating frequencies. Higher penetration losses are encountered at higher operating frequencies. It becomes clear that a profitable business case for mobility systems are clearly better achieved in the lower frequency bands.

This is one of the reasons for the large initiative in certifying Mobile WiMAX in the lower frequency bands while focusing Fixed WiMAX applications to the higher frequency bands. The higher system gain typically associated with fixed usage scenarios due to higher transmit power and antenna gain compensates for the attenuation at higher frequencies.

Additional Considerations:

The previous sections attempted to highlight differences between Fixed and Mobile WiMAX, primarily based on the technical background for each option. However, there are other issues which are related to implementation and deployment that need to be considered for the operators. Some of these issues include the following.

1- Capital expenditure requirements. The scale of mobile networks can be very large and therefore, requires a much larger investment than a fixed network which can be targeted at select customers in select areas where return on investment can be achieved in a relatively short period.
2- Network roll out scenario. A mobile network needs to be constructed and enabled at one time to provide simultaneous coverage and support for an area. This is required for a mobile network to maximize revenues for the operator. A fixed network on the other hand can be rolled out at multiple stages where different areas are targeted and built out depending on their profitability potential.
3- Network complementarities. Mobile and fixed networks require different complementing applications. For instance, a Greenfield deployment of Mobile WiMAX must consider VoIP services as this is currently the main ARPU driver. However, Fixed WiMAX deployments must consider business data services such as high throughput guarantees, VLAN, and other such services that are critical to SME-type users

	Mobile WiMAX	Fixed WiMAX
Maturity of Standard at the IEEE	In corrigenda phase	Corrigenda completed
Certification Status	In the process of defining the test cases for the first and second certification waves.	First certification wave has been completed (Jan ’06) and the WFDCL is validating the test bed for the second certification wave.
Certification Profiles	1A: 2.3 GHz/8.75 MHz/TDD for CW1 (no MIMO) 3A: 2.5 GHz/5&10 MHz/TDD for CW2 (with MIMO)	3.5 GHz/3.5&7 MHz/TDD & FDD 5.8 GHz/10 MHz/TDD (pending)
Usage Scenario	Mobility Applications: - Sleep Mode to save battery life on handheld devices - Handover for mobility and roaming - Requirement of advanced features to enable a realistic business case (e.g. MIMO, AAS)	Fixed Applications: - High power devices with high antenna gain for outdoor and indoor desktop usage, PC cards to follow.
Frequency Band	Lower frequency bands for maximizing coverage (≤2.x GHz)	Higher frequency bands where business case for mobility is not as attractive (≥3.x GHz)
Deployment Mode	Wide area coverage to enable mobility and roaming	Coverage of selected areas to provide operators with immediate revenue opportunities
Network Complementarities	Necessity of VoIP to compete with existing 2G and 3G systems. Coexistence and complementarities with existing cellular systems is essential.	Necessity of business services such as VLAN, VPN, Video surveillance, TDMoIP, etc.
Required Investment	Large capital expenditure to build a large scale network. Must support profitable and less profitable areas.	Relatively small capital expenditure to support selected areas which can be prioritized according to ROI potential

Roll-out Model	Build and enable the network at one time – necessary to allow for handover and improve the business case.	Limited and focused roll out in select areas. No need to deploy the full network at one time.
Customer Set	Individual consumers	Businesses (SOHO, SME, etc.) along with residential consumers

Table 9 Summary of Key Points Applicable to the Status and Characteristics of Fixed and Mobile WiMAX

Conclusion:

The intent of this paper was to provide an overview of Fixed and Mobile WiMAX and demonstrate the key drivers behind each system. Both of these systems feature an OFDM-based physical layer which is considered by many as the most effective implementation to provide high data rates at lower computational cost than what's possible with current single carrier system.

The review outlined in this paper provides an overview that details the considerations for each technology. Some of these considerations are technical and related to the specific usage model which will in-turn result in a choice of technology and its related features for the operator. Other considerations are practical and financial in terms of justifying a viable business model for the operator.

About the author:

Frank Rayal is Director, Product Line Management at Redline Communications, a leading provider of standards-based wireless broadband solutions. Redline's RedMAX™ WiMAX Forum Certified™ systems have been trialed or deployed by more than 100 operators worldwide and the company's award-winning RedCONNEX™ family of broadband wireless infrastructure products are supporting more than 35,000 voice, video and data communications networks. Redline is committed to maintaining its wireless industry leadership with the continued development of WiMAX and other advanced wireless broadband products. With its global network of over 100 partners, Redline's experience and expertise helps service providers, enterprises and government organizations roll out the services and applications that drive their business forward. For more information, visit www.redlinecommunications.com.

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