WiMAX
Opportunities and Challenges in a Wireless World

1. Summary of Findings

Over the last two years there has been a fair amount of hype and confusion surrounding WiMAX (Worldwide Interoperability for Microwave Access), the trade name given to a group of wireless technologies based on the IEEE 802.16 standard. Unfortunately, this hype and confusion has resulted in raising the bar to such a high level that it will be very difficult for WiMAX to live up to expectations, despite potentially achieving a lot.

Further, because expectations have been raised to such a high level, in particular regarding the mobility aspect of WiMAX, there is a tendency to compare WiMAX with 3G-based cellular technologies and reach the conclusion that WiMAX will compete with 3G or even replace it. The reality of WiMAX is somewhat different, although the technology can still fulfill a valuable role in the wireless ecosystem.

WiMAX is a credible solution to a number of problems that have plagued the fixed wireless industry since its inception - namely, the lack of an open standard and the absence of major silicon vendors and equipment suppliers. Once WiMAX certified equipment is available from a number of suppliers, increased competition can occur, and with volumes of units shipped, more attractive price points can be reached.

If WiMAX continues to gain more support from the industry, it can also provide broadband access in remote regions and developing parts of the world where basic voice or broadband access using fixed line service is not economically feasible. Additionally, WiMAX can potentially be used to provide backhaul in cellular networks or it can be used to significantly enhance the performance of public Wi-Fi (Wireless Fidelity) hot spots by increasing the throughput in the backhaul network and by making it easier and more economical to deploy Wi-Fi access points. WiMAX is also developing a "mobile" standard which is not compatible with the fixed-based solution. The "mobile" standard theoretically means that WiMAX can provide broadband wireless access in a vehicular environment. While technically this feature can be achieved [with some very important caveats that are further detailed in this paper], the business case for such a service offering is more challenging, while it will only have marginal impact, at best, on the growth and usage of 3G services. Publicly accessible Wi-Fi spots are already widely available, especially in highly desirable locations such as hotels, airports and college campuses. Wi-Fi hot spots are also increasingly available for free to consumers as a service differentiator from restaurants and coffee shops and as a free public service from local municipalities. Additionally, by the time the mobile version of WiMAX is available in user equipment in high volumes from a number of suppliers, advanced 3G data networks using 1xEV-DO and HSDPA will be available extensively from a well-established ecosystem. In order for WiMAX to successfully compete in the mobile environment, it will need to offer something more compelling than the 3G/Wi-Fi combination can offer and/or it will need to offer the same level of service for a more attractive price.

Due to technology agnostic factors, such as site acquisition and preparation costs, not to mention power requirements, both RF and electrical, the cost to deploy a carrier grade WiMAX radio access network is approximately on par with that of a 3G radio access network [exclusive of the already sunk spectrum costs] and far more expensive than a typical Wi-Fi network. The Wi-Fi coverage, of course, would be much more limited while WiMAX will be able to take advantage of the cost efficiencies associated with an all-IP core network - the part of the network "behind" the base stations. Further, Wi-Fi data cards or embedded Wi-Fi solutions are already

reaching extremely attractive prices while 3G solutions are falling rapidly in price and likely to become far more attractively priced in the next two years.

Major notebook computer suppliers also recognize that they can only fit a limited number of RF (radio frequency) solutions in their notebooks. In order for a notebook computer to contain an embedded WiMAX solution it will have to replace an already existing and familiar wireless technology. Embedded 3G solutions are already available and more solutions should be available by the end of the year; Wi-Fi solutions are nearly ubiquitous now, and are expected to continue evolving as IEEE 802 completes its work on 802.11n.

WiMAX has yet to fully address the services layer, and in the absence of compelling content and services unique to WiMAX, consumers who already utilize 3G and Wi-Fi services will have less incentive to adopt WiMAX. Those that do make the switch will likely continue using their cellular service provider, which at best indicates that WiMAX complements 3G while trying to compete with already inexpensive Wi-Fi services and both complementing and/or competing with traditional wireline broadband services.

Operators, representing a good cross-section of potential WiMAX providers, which were interviewed as part of this study, concur that WiMAX can potentially provide a role in their overall service offering. Most of these operators are planning to conduct field trials later in 2005 or 2006 with a focus on fixed wireless services, noting that it is too premature to seriously evaluate WiMAX as a portable or mobile service offering. Unlike Wi-Fi, the initial adoption of WiMAX and the subsequent trend toward attractive price points and more widespread usage is heavily dependent upon the success of the operator business model.

The views expressed by several of the potential service providers suggest that when WiMAX becomes commercially available, the underlying economics, combined with some very important qualifications regarding features and performance, will make it challenging for the technology to achieve widespread success, especially within the next couple of years.

2. Introduction

WiMAX (Worldwide Interoperability for Microwave Access) is the trade name for a group of wireless technologies that emerged from the IEEE 802.16 WirelessMAN (Wireless Metropolitan Area Network) family of standards. Although the term WiMAX is only a few years old, 802.16 has been around since the late 1990s, first with the adoption of the 802.16 standard (10-66GHz) and then with 802.16a (2-11GHz) in January 2003. Despite the establishment of the 802.16a standard, the FWA (fixed wireless access) market has never really taken off; although it is worth noting that during this time period the overall telecommunications industry was struggling.

In 2001, the WiMAX Forum was created in order to promote the standard and to help ensure compatibility and interoperability across multiple vendors, much like the Wi-Fi Alliance does for the IEEE 802.11x family of standards. A key facet of the IEEE standards process, which is discussed in more detail in an upcoming section, is that it is limited to the Physical and MAC (Medium Access Control) layers and that it does nothing to ensure interoperability, RF constraints, or minimum performance levels. In that regard, the WiMAX Forum fulfills a much needed requirement.

IEEE 802.16a has all but been forgotten as the focus recently has been on IEEE 802.16-2004, which is also known as 802.16REVd or .16-2004. 802.16-2004 is an improvement to the .16a standard that was certified in October 2004. Separately, there is also IEEE 802.16e, another variation of WiMAX that follows the 802.16-2004 standard, but is incompatible with it. The one thing that both of these proposed standards have in common is that they address the same frequency range (sub 11GHz).

In its very early days, the WiMAX Forum was comprised of just a few relatively small equipment suppliers that had a history of providing fixed wireless equipment to a relatively small market, and two major semiconductor companies - Intel and Fujitsu. No major OEM was on board, although Nokia was loosely associated with the forum, and organizations like Motorola believing that it was better off pursuing these opportunities with its proprietary Canopy solution. Likewise, and perhaps more importantly, the technology lacked the endorsement of an operator, large or small.

Without potential customers and with an undeveloped standard that was headed down a path toward adopting any and all access techniques (two flavors of OFDM, TDD, FDD, point-point, point-to-multipoint, mesh, etc.), it was difficult to envision how WiMAX could be successful. Today, there are approximately 300 companies participating in the WiMAX Forum, including a smattering of operators and several major OEMs - Alcatel, Ericsson, Lucent, Motorola, Nortel, and Siemens, to name a few. And later this year, WiMAX certified equipment could finally become available, thus proving those early skeptics wrong.

This white paper will explain WiMAX in simple terms. Once this foundation has been established, this paper will examine some of the technical hurdles that still must be overcome before WiMAX can be commercialized, as well as examine the business case for both fixed and mobile/portable services. Finally, the relationship between WiMAX and other wireless services, including WLAN (wireless local area network) and 3G cellular services will be discussed.

3. The Family of WiMAX standards

It is often thought that WiMAX is one homogenous technology when in fact it is a trade name for a group of IEEE wireless standards. In that respect, WiMAX and Wi-Fi are analogous. Wi-Fi is not a standard, but a trade name that can be applied to a series of 802.11 IEEE standards, including 802.11b, 802.11a, and 802.11g. It is assumed that the term Wi-Fi will be applied to 802.11n once that standard is ratified.

The WiMAX umbrella currently includes 802.16-2004 and 802.16e. 802.16-2004 utilizes Orthogonal Frequency Division Multiplexing (OFDM), to serve multiple users in a time division fashion in a sort of a round-robin technique, but done extremely quickly so that users have the perception that they are always transmitting/receiving. 802.16e utilizes Orthogonal Frequency Division Multiple Access (OFDMA) and can serve multiple users simultaneously by allocating sets of "tones" to each user.

3.1 IEEE 802.16-2004

IEEE 802.16-2004 is a fixed wireless access technology, meaning that it is designed to serve as a wireless DSL replacement technology, to compete with the incumbent DSL or broadband cable providers or to provide basic voice and broadband access in underserved areas where no other access technology exists; examples include developing countries and rural areas in developed countries where running copper wire or cable does not make economic sense. 802.16-2004 is also a viable solution for wireless backhaul for WiFi access points or potentially for cellular networks, in particular if licensed spectrum is used. Finally, in certain configurations, WiMAX Fixed can be used to provide much higher data rates and therefore be used as a T-1 replacement option for high-value corporate subscribers.

Typically, the CPE (consumer premise equipment) consists of an outdoor unit (antenna, etc.) and an indoor modem, meaning that a technician is required to get a commercial or residential subscriber connected to the network. In certain instances, a self-installable indoor unit can be used, in particular when the subscriber is in relatively close proximity to the transmitting base station. The trend toward self-installable indoor units is likely to develop more noticeably in the next few years. As it does, the fixed wireless technology would introduce a degree of nomadic

capability since the subscriber could travel with the CPE and use it in other fixed locations - office, hotel and coffee shop, etc. Additionally, self-installable CPEs should make 802.16-2004 more economically viable as a large part of the customer acquisition cost (installation, CPE) is dramatically reduced. Although it is technically feasible to design an 802.16-2004 data card, handheld devices with an embedded 802.16-2004 solution do not appear to be a top priority within the industry at this time.

The fixed version of the WiMAX standard was approved in June 2004, although interoperability testing will not begin until later in 2005. A project to fix bugs in the published standard is ongoing, and is expected to complete in September 2005. Further, base station and CPE chipsets from the major vendors are just reaching the point where potential customers are sampling them with the Intel Rosedale chipset sampling since September 2004 and Fujitsu having announced its first WiMAX chipset earlier this year.

3.2 IEEE 802.16e

IEEE 802.16e is as yet an unpublished standard that is intended to offer a key feature that 802.16-2004 lacks - portability and eventually full-scale mobility. This standard requires a new hardware/software solution since it is not backward compatible with 802.16-2004 - not necessarily a good thing for operators that are planning to deploy .16-2004 and then upgrading to .16e.

Another major difference between the .16-2004 and .16e standards is that the .16-2004 standard is based, in part, upon a number of proven, albeit proprietary, fixed wireless solutions, thus there is a good likelihood that the technology will achieve its stated performance targets. The .16e standard, on the other hand, tries to incorporate a wide variety of proposed technologies, some more proven than others. Since there has been only modest justification of proposed features on the basis of performance data, and the final composition of these technologies has not been completely determined, it is difficult to know whether a given feature will enhance performance.

From a timing perspective, the 802.16e standard was scheduled to be approved in mid- 2005, however that date has now passed and it appears that it will be approved later this year. Several vendors are promising field and market trials in early 2006, although, as discussed later in this paper, much work still remains to be done outside of the standards body and it is therefore too early to tell when the technology will be ready for commercial deployments.

3.3 WiBro

Another acronym worth mentioning is WiBro (Wireless Broadband). WiBro is a South Korean initiative and an opportunity for the country to establish a "homegrown" wireless technology, much like the Chinese are doing with TD-SCDMA. WiBro will now likely be included within the .16e umbrella, thus making it another potential WiMAX profile. Specifically, WiBro is a TDDbased system that operates in a 9MHz radio channel at 2.3GHz with OFDMA as its access technology. According to its proponents, WiBro supports users traveling at speeds up to 120km/h (previously it was advertised as being limited to 60km/h) and peak user data rates of 3Mbps in the downlink (uplink = 1Mbps) and 18Mbps of peak sector throughput in the downlink (uplink = 6Mbps). Average user data rates are advertised as being in excess of 512kbps, and with the cell radius limited to 1km, it will largely be deployed in densely populated areas. Initially, WiBro was perceived as being a portable solution, even though it could support mobile users, since the technology did not support seamless cell handoffs. With its potential future adoption into the WiMAX family of profiles, there could be a desire to introduce vehicular mobility, or near seamless handoffs.

It isn't entirely clear how WiMAX/WiBro will evolve, but it is foreseeable that the technology will

first try to incorporate limited portable features, and then, based upon customer demand, technology advancements, and the underlying economics of an inherently more expensive solution, move toward more "seamless mobility" - a moniker that Motorola first coined. Korea Telecom, in conjunction with Samsung, is promising commercial WiBro services by April 2006, while the Nortel and LG WiBro joint-venture, which was announced in March 2005, is currently suggesting customer trials in the second half of 2006. Given the lag between infrastructure and CPEs, the "commercial" service will likely lack commercially viable CPEs until at least late 2006.

4. WiMAX in a bit more detail - performance and features

As discussed in a previous section, WiMAX is comprised of a fixed wireless solution (.16-2004) and a portable/mobile solution (.16e). Given that there are more differences than similarities between the two solutions, it is only natural that some confusion exists. However, this confusion has also created a fair amount of market hype and has resulted in raised expectations that will be difficult, if not impossible, for WiMAX to achieve.

The first point of confusion is in regards to actual performance, both with respect to distance as well as to throughput. For example, WiMAX was originally billed as a wireless technology that can deliver 70Mbps and extend coverage to 50 kilometers, or roughly 30 miles. Most press reports also assumed that 70Mbps is achievable everywhere, including at the cell edge. In large part, not much has been done to correct these misconceptions.

In order to achieve this level of performance a fixed wireless point-point technology with LOS (line of sight) locations and directional antennas is required, meaning that all of the power is essentially dedicated to supporting that one connection - a rather expensive and impractical application for WiMAX under most scenarios. Wireless backhaul and wireless access to SMEs (small and medium enterprises) are notable exceptions where the subscription cost of the service offering could justify the dedicated resources. Achieving 70Mbps in a mobile environment with WiMAX will not be feasible or economical in the foreseen future.

Further, when the 70Mbps data rate in a fixed point-to-point Line of Sight (LOS) environment was demonstrated, a radio channel of 20MHz bandwidth was used. More recently, other companies such as Nortel, have reported comparable data rates in a narrower channel bandwidth with the use of smart antenna technologies, but again it was a fixed scenario and at a lower frequency. Additionally, there is still an inherent tradeoff between data rates and distance with the higher data rates only achievable near the center of the cell. In other words, in order to achieve 70Mbps data rates throughout an entire cell, it would require very small cell radii. This level of performance is not extraordinary.

There are also several non-WiMAX solutions, in particular microwave radio solutions, which can transmit a point-to-point signal that supports hundreds of megabits per second or more. Simply crank up the power and allocate spectrum and virtually anything is possible.
These high data rates may well be limited to fixed scenarios under certain special conditions, similar to those provided above. It is much more difficult to achieve high data rates in mobile environments.

4.1 WiMAX Profiles

Since 802.16-2004 addresses the entire sub-11GHz frequency range, there is an inherent need for a number of different solutions, or profiles to use the vernacular of the WiMAX Forum. Presently, the WiMAX Forum has identified at least five profiles for 802.16-2004 that allow the technology to accommodate different frequency bands, channel bandwidths, and duplexing schemes (TDD/FDD). Interestingly, the aforementioned 20MHz radio channel that was required to achieve 70Mbps of throughput is not one of the focus points at the moment. Some equipment

providers are also currently targeting a 700MHz solution for use in rural deployments, although it remains to be seen when, or even if, a profile is developed for this spectrum. (Note: 700MHz is a very favorable spectrum for mobile use.) The use of profiles is clearly needed in order to support a wide range of deployment options, in particular it reduces an abundance of options to a manageable number and also causes the industry to focus on those profiles that should be implemented first

4.2 802.16-2004 performance characteristics

Based upon modeling done by one of the technology's proponents, 802.16-2004, the fixed version of the WiMAX standard, should be able to achieve throughput of 11Mbps, assuming the use of an outdoor antenna and a 3.5MHz paired channel allocation[1] in the 3.5GHz spectrum band. With NLOS (non-LOS), the claimed average throughput decreases to 8Mbps with a cell radius of 100 meters in a dense urban area and reaching a few kilometers in a rural deployment. 802.16-2004 can also support VoIP (Voice over Internet Protocol), and assuming that the G.729 (8kbps) codec is used, it reportedly supports up to 96 simultaneous voice calls in a 3.5MHz radio channel.

For comparison purposes CDMA2000 1X can currently support 90 to 100 calls for systems deployed in a fixed WLL (wireless local loop) configuration with an allocation of 2.5 MHz of paired spectrum, the equivalent of two 1.25 MHz paired radio channels. For mobile networks, CDMA2000 1X supports a capacity of 70-80 concurrent users in equivalent bandwidth, since it needs to account for additional overhead associated with soft handoffs and mobility.

These figures (theoretical versus actual) indicate that fixed WiMAX (.16-2004) performance on a like-for-like basis is on par with existing WWAN mobile technologies, suggesting that WiMAX offers potential operators another alternative technology to consider, but not necessarily a better performing technology. Given these comparative figures, it is unlikely that a mobile operator would ever use WiMAX to deliver fixed wireless VoIP services. Mobile operators could consider WiMAX to offload high data users; however, they will more than likely wait for the mobile implementation of WiMAX, 802.16e. Additionally, non-traditional operators or licensees of WiMAX compatible spectrum might consider WiMAX to deliver these services.

In the past, companies such as Winstar attempted to compete in this market with little success. However, with the introduction of the WiMAX standard, multi-vendor interoperability could lead to competition and volumes, which in turn would lead to more attractive price points. Remember, being a standard doesn't necessarily mean lower prices; only after high volumes are achieved can lower prices be realized.

Alternatively, 802.16-2004 could use unlicensed spectrum, which in certain scenarios, like rural areas, may not be impacted by unacceptable levels of interference, while in licensed spectrum, the fixed nature of the system could facilitate greater coverage. The tradeoff is increased path losses at frequencies such as 5.8GHz. It is unlikely that an operator would use 2.4GHz to offer voice services due to the higher probability that interference could develop (simple microwave ovens radiate RF in the 2.4GHz band).

4.3 802.16e features

IEEE 802.16e is the portable or mobile version of WiMAX, which promises to support voice and data sessions at vehicular speeds of up to 120 kilometers per hour. The current strategy within the WiMAX Forum is to launch 802.16e with portable features in order to achieve rapid time to market. As the technology and market opportunity matures, the Forum intends to introduce full-scale mobility. Irrespective of the portable/mobility factor, less is known about the actual performance of the standard, largely because the standard has not been ratified. Still, it is widely

acknowledged that 802.16e is not compatible with 802.16-2004.

The primary reason for this incompatibility is that 802.16e uses S-OFDMA (scalable-OFDMA) in both the uplink and downlink. S-OFDMA means that the number of OFDM tones increases, or scales (128 tones up to 2,048 tones), based upon the quality of the RF signal for a particular user, the user's requirements and the width of the radio channel that is used. S-OFDMA allows multiple users to transmit at the same time which results in improved network efficiency and a better user experience. However, there isn't a 256 tone option - 802.16-2004 is strictly fixed at 256 tones. It isn't clear if the exclusion of a 256 tone option was done for political or technical reasons, but the point remains that the lack of a 256 tone option will prevent 802.16e from being compatible with 802.16-2004.

Additionally, the 802.16e MAC layer introduces new header information that is essential to support mobility (cell handoffs, etc). Even if there was a 256 tone option with 802.16e, the differences between the two MAC layers would prevent the fixed and mobile versions from working together.

In the future, dual-mode chipsets are being planned, much like there are GSM/CDMA2000 multimode/multi-band chipsets today. Still, this incompatibility places a natural damper on the fixed market opportunity - that is for those operators that are interested in offering a portable/mobile solution.

5. The Market Opportunities for WiMAX

There are several market opportunities for WiMAX, some more viable than others. In many instances these opportunities are being addressed today by proprietary solutions from small companies, suggesting that a new market opportunity isn't being created, but rather being redefined.

The broadband FWA industry has struggled for years to gain traction with a total market today that is only in the low hundreds of millions of dollars. By coming together and creating a standard, more companies have entered into the market, thus increasing competition and eventually leading to lower prices. As WiMAX chipsets from Intel, Fujitsu and others become commercially ready equipment suppliers will be able to reduce their BOM (bill of material) costs, which in turn will also help drive the fixed wireless access market. Finally, once the WiMAX certification process for the fixed wireless standard begins in the second half of 2005, multivendor interoperability should be possible as soon as early 2006, meaning that operators will no longer have to lock themselves into product from one vendor.

As a side note, "WiMAX-ready" (i.e., proprietary version) equipment based on 802.16-2004 that is shipping today may or may not be easily upgradeable to be compliant with the 802.16 standard, although some vendors claim that only software changes should be required to make their equipment fully compliant with the standard and interoperable with other vendors' equipment. This claim is somewhat contentious with most companies and Signals Research Group believing that new ASICs will be required, in particular for the CPEs. As history has proven with other wireless technologies, the time required to complete interoperability testing is always much longer than anticipated.

With the exception of the portable/mobile service offering, the market opportunities discussed later in this section could be satisfied by either the .16-2004 (fixed) or the .16e (portable/mobile) standard. Put another way, the portable/mobile standard (.16e) can be used to offer fixed/nomadic services, but the fixed standard (.16-2004) may not support portable use and definitely not mobile services. Given that most of the industry appears to be focused on developing the .16e standard, it is entirely likely that a fixed wireless service could utilize the .16e standard, due to the availability of more solutions and increased competition (better pricing

environment). It is, however, too early to tell with any degree of certainty.

5.1 Developing and Underserved Markets

In several regions of the world, copper wire to the home or business just doesn't exist. In these situations, a fixed wireless offering that is based upon an open standard may make more economic sense than deploying copper wire that can easily be ripped out and resold on the open market. Several of the companies that were founding members of the WiMAX Forum have been providing their proprietary wireless base stations and CPEs to these markets for a number of years. The total market has so far been relatively small, but the technologies have provided a much needed service offering in those countries.

5.2 DSL and cable modem replacement and extension

Even in developed markets, such as the U.S. and Canada, there are regions of the country where the economics of running cable or putting in DSLAMs does not make sense. In these cases, a fixed broadband wireless access technology might be more appropriate. There are already a number of WISPs (Wireless Internet Service Providers) around the nation's heartland, and even in very urban surroundings, using one of the aforementioned proprietary technologies. Not all of these WISPs have been successful, with the total infrastructure costs and subscriber numbers being very modest. Yet, the availability of WiMAX equipment in large volumes from a number of suppliers could help improve the economics and, in turn, increase the total addressable market.

In Europe, British Telecom (BT) is currently deploying a modest pre-WiMAX fixed wireless network at 5.8GHz in Northern Ireland to address this particular market segment. The operator, however, is not taking an aggressive stance toward deploying the technology until it has access to equipment that can be easily upgraded to support the portable/mobile solution.

5.3 Wireless backhaul in a cellular network

Microwave radios have been used since virtually the beginning of the cellular industry to provide backhaul, or transport, of voice and data traffic from outlying cell sites to the operator's core network. Typically, operators utilize copper, fiber links or microwave radios that operate at much higher frequencies than addressed by WiMAX, but that is not to suggest that operators in the future wouldn't be open to the idea of using WiMAX.

In large part, the operator's decision will be based upon the availability of sufficient spectrum to meet their backhaul requirements, in particular with the increased requirements as the result of 3G data services. Some operators might even consider using WiMAX in unlicensed spectrum for their backhaul needs, but this scenario is unlikely in most instances since the potential for interference would exist and this interference could detrimentally impact the quality of the overall network.

In all likelihood, the greatest challenge that WiMAX will have with respect to becoming a wireless backhaul solution in a cellular network will be access to sufficient spectrum, in particular if an operator wants to daisy-chain, or combine, the traffic from several cell sites onto one WiMAX radio link.

5.4 Wireless backhaul in a Wi-Fi network

A more likely scenario is that WiMAX will be used to provide backhaul in a Wi-Fi network. One

of the biggest limitations with public Wi-Fi service is the backhaul constraint in which an 11Mbps or 54Mbps air interface is fed into a 500kbps or 1.5Mbps T-1 line. In this case, the saying, "a chain is only as strong as its weakest link" applies since an otherwise impressive broadband connection in the air interface is reduced dramatically once it reaches the backhaul chokepoint.

It is worth noting that the aforementioned Wi-Fi data rates are theoretical peak data rates and that once overhead is removed, actual data rates are reduced by approximately half. Additionally, the air interface and the backhaul could be shared by multiple users, thus lowering the data rate to any one user.

Another limitation with public Wi-Fi is the cost and inconvenience associated with the wireline backhaul. Currently, a Wi-Fi access point can only be located where there is already wireline access, or where wireline access can be installed. Further, although DSL or cable broadband service is relatively inexpensive, leasing a T-1 line is not. Depending upon the operator's business model, the use of WiMAX may be appropriate. If nothing else, the network throughput could be dramatically increased for far less cost than possible with copper or fiber.

5.5 Portable or Mobile coverage

Much of the focus and interest of the WiMAX community is the scenario in which the subscriber has a seemingly ubiquitous broadband wireless connection that can provide connectivity in a portable environment and even mobile environment. This service offering would require WiMAXenabled data cards for PCs and potentially lead to embedded solutions and new types of devices. This usage scenario is the most appealing, since it implies broadband access and other voice/data services anytime and anywhere. At the same time, a portable/mobile solution is also more challenging to implement and it will not be the first WiMAX solution that enters the market place.

6. By the numbers - WiMAX spectrum availability

As discussed earlier in this paper, WiMAX covers a range of spectrum below 11GHz. There is also the potential to deploy WiMAX in cellular bands [if allowed] and the 700MHz bands. Despite the seemingly abundance of spectrum, some of this available spectrum poses its own set of problems. Additionally, a wide variety of spectrum choices also results in incompatibility or the need for multi-band devices.

Within this range of frequencies, the most likely spectrum is available at 2.3GHz, 2.4GHz, 2.5GHz, 3.5GHz, 5.8GHz and potentially 700MHz. As a consequence, in order to ensure worldwide interoperability, WiMAX CPEs, data cards or embedded chipset solutions would have to support up to 5 frequency bands. Either that or the industry initially focuses on only a couple of the spectrum bands with 3.5GHz likely to receive some of the initial focus.
The available spectrum falls into two distinct categories: unlicensed and licensed.

6.1 Unlicensed

In most markets, the unlicensed spectrum that could be used for WiMAX is 2.4GHz and 5.8GHz. Since the spectrum is unlicensed, the barrier to entry is low, thus making it easier for a potential operator to begin offering services using the spectrum. In some instances, this can be advantageous for obvious reasons. Unfortunately, there are also several disadvantages. In certain countries, in particular in Europe, the concept of "light licensed" spectrum applies, meaning that the intended user has to file its intent to use the unlicensed spectrum. In turn,

regulators have a better understanding of who is using the spectrum, controlling the number of licensees and potentially minimizing the impact of interference.

There are four primary disadvantages associated with using unlicensed spectrum.
Interference - Because unlicensed spectrum can be used by several different RF systems, there is a high probability of interference. Unlicensed RF systems can include anything from competing WiMAX networks or Wi-Fi access points. Cordless phones and Bluetooth (2.4GHz only) also use this spectrum. Both WiMAX and Wi-Fi support DFS (Dynamic Frequency Selection) which allows a new channel to be used if necessary (e.g., when interference is detected). However, DFS may also introduce higher latency which in turn impacts real-time applications such as VoIP.

Increased Competition - Operators who use unlicensed spectrum have to assume that another operator could easily enter the market using the very same spectrum. In large part, the relatively high number of public Wi-Fi access points is due to this fact. However, the capital expenditures associated with installing a commercial-grade Wi-Fi access point are relatively trivial (hundreds of dollars at most) versus the cost associated with deploying a WiMAX network, which could be on par with the cost of deploying a cellular network. WiMAX deployment costs are discussed in another section.

Limited Power - Another disadvantage with the unlicensed spectrum is that government regulators typically limit the amount of power than can be transmitted. This limitation is especially important at 5.8GHz where the higher power could offset the propagation loss associated with spectrum in higher frequencies - more on this topic later.
Availability - While the 2.4GHz spectrum is universally available, the 5.8GHz spectrum is not currently available in a number of countries.

Given these disadvantages, operators will carefully evaluate the potential use of unlicensed spectrum, in particular at 2.4GHz, before rolling out a network. There are exceptions, including in rural or remote regions where there is less likelihood of interference and competition.

6.2 Licensed

Licensed spectrum comes at a potentially high price, but it is well worth it, especially when the service offering requires high quality of service. The greatest advantage of having licensed spectrum is that the licensee has exclusive use of the spectrum. It is protected from outside interference while competitors can only enter the market if they also own or lease spectrum. The licensed spectrum is found at 700MHz, 2.3GHz, 2.5GHz and 3.5GHz, with the latter two frequency bands currently receiving the most attention.

6.2.1 2.5GHz

The 2.5GHz spectrum band is more interesting since it is available for terrestrial use in North America, Latin America, and eventually across Europe when the 3G extension band is auctioned in the next few years. With respect to Europe, two big questions must be raised. Will European operators pay a large sum of money for spectrum and then use it for WiMAX, especially when they may need to use the limited spectrum for 3G voice and data capacity? Will they allow WiMAX to be used in a frequency band that has been designated for 3G? Should the answer to either question be no, WiMAX at 2.5GHz in Europe won't happen. Some potential WiMAX operators in Europe are also campaigning the UK regulators to allow them to deploy WiMAX at 2.5GHz - spectrum that could be acquired in an upcoming auction. Should this scenario pan out, the 2.5GHz licensee would still have to decide to use the spectrum for WiMAX and not its 3G cellular service offering.

In the United States, Sprint-Nextel will become one of the largest holders of the 2.5GHz spectrum assuming that their pending merger goes through. It is worth noting that a large part of the operator's spectrum holdings is leased from other entities, meaning that ultimately it may not have complete control of the spectrum. According to Nextel, the operator is focused on 1xEVDO Rev 0 and then Rev A for its PCS spectrum while it is considering the 2.5GHz spectrum to complement its PCS broadband offering. However, in order to use the spectrum, Sprint-Nextel would first have to clear a lot of the spectrum and isolate channels so that interference with other spectrum users (Catholic Church, etc.) doesn't occur. More importantly, there would still need to be a lot of education required with respect to any potential broadband service offering while the operators have indicated that it is too early to evaluate WiMAX other than for wireless backhaul. Sprint-Nextel has several options and it is by no means a foregone conclusion that it will select WiMAX, although it will likely evaluate the technology. In any event, it may be several years before the merged entity does anything with its 2.5GHz spectrum.

Cingular Wireless, another large holder of 2.5GHz spectrum, is also evaluating its WiMAX opportunities. That said, the operator is evaluating WiMAX with a penchant toward using the technology to provide wireless backhaul for their Wi-Fi APs and their cellular network. Cingular Wireless, for example, is currently using microwave radio along the Garden State Parkway in New Jersey.

6.2.2 3.5GHz

The 3.5GHz frequency band is currently available for use in virtually every country except the United States. In addition to the RF propagation challenges inherent to this band, many European licenses restrict how the spectrum can be used, since in this particular band cell handoffs are not currently allowed, which is not exactly ideal when trying to offer a mobile voice and data service that requires uninterrupted service for voice calls. The WiMAX Forum is currently petitioning regulators to change this policy. Additionally, in some regions of the world like Japan and Korea, portions of the spectrum are being used to offer satellite services. Most WiMAX proponents also believe that 3.5GHz is not suitable for mobility, largely because of the RF propagation at this frequency.

6.2.3 700MHz

At this time there isn't a WiMAX profile for the 700MHz spectrum, however there is at least some interest within the WiMAX community to introduce WiMAX in this frequency band.

The 700MHz spectrum band is heavily utilized in many regions of the world, including North America and most of Europe. Currently, this spectrum is being used by analog TV broadcasters, meaning that the ability to deploy WiMAX, or any other wireless technology, in this spectrum band is currently limited due to concerns about the potential for inter-service interference. With the transition to digital TV, broadcasters in North America will eventually vacate this spectrum, freeing up the spectrum for other potential uses.

The timing of when this takes place is an unknown, but it could take place as early as 2007, or it could continue to be delayed for several more years. As discussed in a subsequent section, 700MHz is a very attractive spectrum band in remote regions due to the favorable propagation conditions that exist at this lower frequency (the lower the frequency the farther the signal can be propagated, all things being equal).

6.2.4 2.3GHz

The use of the 2.3GHz spectrum band is largely limited at this time to certain applications in

South Korea (WiBro), Australia, New Zealand and the United States. In the U.S., TeraBeam, Verizon and BellSouth are some of the largest holders of the spectrum while in New Zealand, Woosh Wireless owns a nationwide 2.3GHz footprint, but is currently deploying TD-CDMA in 2.1GHz spectrum. While there is 2.3GHz spectrum available in the United States, it is not attractive for WiMAX, namely because usage in adjacent channels limits the amount of available bandwidth.

7. WiMAX - technical and market challenges

All emerging technologies face their own set of challenges that they must overcome in order to become a technical and market success. WiMAX is no different. For WiMAX, its challenges include unfavorable radio frequency (RF) propagation in the relatively high spectrum being considered in some situations, the amount of unfinished work that must take place outside of the IEEE standards body for equipment to be WiMAX certified, and its economic merits relative to 3G and other broadband wireless services that currently exist.

7.1 RF propagation at higher frequencies is more challenging

As a rule of thumb, the effective cell radius at 700/800MHz is twice the size as it would be at 1.9GHz, meaning that four times as many base stations are required at 1.9GHz versus 700/800MHz. Between 1.9GHz and 2.5GHz the same multiples apply, as it does between 2.5GHz and 3.5GHz. Interpolating these numbers, a network deployed at 3.5GHz could require roughly sixty to eighty percent more cell sites as it would at 2.1GHz (UMTS spectrum) - all things being equal. WiMAX could include the use of smart antenna technologies, but this will probably not be enough to compensate for the loss. Smart antenna technologies can also prove to be costly and may not be well-suited to support a vehicular user that is moving at 120km/h, or even much slower.

7.2 Deployment costs are not trivial

The increased number of cell sites, as a result of using higher frequency bands, raises site acquisition/leasing and construction costs, regardless of the technology being deployed. The cost to acquire a site in North America can easily reach $25,000, plus ongoing lease costs, while an operator may have to spend up to $75,000 on construction costs to get the site up and running - assuming the operator starts from scratch. Further, the logistical challenges of getting enough sites to deploy a ubiquitous mobile network can pose a tremendous challenge, regardless of the cost factor. Operators in Europe are now struggling to find enough sites for their UMTS networks that are being overlayed on their 900/1800MHz GSM networks. Therefore, it is only natural that the logistics of finding enough sites for a seamless 3.5GHz mobile WiMAX network, not to mention the impact on costs, are even more daunting. This is one of the reasons why potential WiMAX operators want to use lower frequency bands (e.g., 2.5GHz and below).

That said, WiMAX will likely have a lower cost structure with respect to the core network, or the portion of the network that is "behind" the base stations. Specifically, WiMAX uses an all-IP core which means it is scalable and can therefore support a higher level of user traffic for a given amount of network resources. Additionally, WiMAX makes use of off-the-shelf routers versus a combination of circuit switches and other network components, that, although are similar to off the-shelf routers, have been specially customized for use in a cellular network. It is important to point out, however, that 3G is also transitioning to an all-IP core at which point it will greatly reduce its own cost structure and achieve higher scalability than possible today.

7.3 Unfinished business

While the .16e standard could be completed in late 2005, it does not necessarily suggest that the

technology will then be ready for commercial deployment. Even for the .16d standard, multi vendor interoperability testing, commonly referred to as "Plugfests," has yet to occur, although it is expected to begin later this year.

7.3.1 Incomplete air interface

For starters, in its rush to complete the standard, the IEEE standards body may not have allowed sufficient time for proposals to be adequately reviewed and analyzed before being voted on and potentially adopted into the standard. Further, at the beginning of the year there were still a number of proposals being submitted to the forum for review and possible acceptance into the standard. Experience has shown that when there is that much work being done on a standard, it is only inevitable that unforeseen problems will develop, if not now, then in the developing and testing period. The most documented example is perhaps UMTS which was ratified in 2001, yet never achieved its first true measure of technical maturity and commercial success until 2-3 years later.

7.3.2 Incomplete network architecture

The .16e standard only addresses the physical (PHY) and medium access control (MAC) layers, leaving it to the WiMAX Forum to tackle issues such as call control, session management, security, the network architecture, roaming, etc. To put things in perspective, as the standard is currently written, each WiMAX base station is virtually oblivious of its surrounding base stations while the MAC layer only has placeholders for the messaging traffic associated with implementing a handover. As a consequence, the notion of seamless mobility doesn't exist while power management issues could result in reduced performance, in particular for users at the cell edge (25-35% of the network) where inter-cell interference would be the most evident.

The WiMAX Forum created a network architecture working group in late 2004 to address some of these unresolved issues, but it is unrealistic to expect all of them to be solved, let alone tested and verified, in a few months. As it stands now, the first revision of the networking specification is scheduled to be completed by the end of the year.

As an interim step, the WiMAX Forum is moving to first implement a portable solution which lacks some of the network intelligence required to support higher vehicular speeds (up to 120km/h) and seamless handoffs. In lieu of applications and services, such as voice, that require seamless handoffs and in the absence of widespread coverage, a portable broadband connection should more than adequately meet the needs of high bandwidth data users.

7.3.3 WiMAX chipset availability

Another major uncertainty is the availability of chipsets. In addition to Intel and Fujitsu, several private companies are also promising very compelling .16e chipset solutions and they may, in fact, beat the larger silicon suppliers to the market. Regardless of who is first to market, it will be challenging to have silicon available for sampling anytime soon. For one, the mobile standard won't be finished until later in 2005 and the initial profiles have not been selected yet, meaning that while some work can currently be done, the fine technical details cannot be implemented until after the standard is fully ratified.

Equally important, the major semiconductor companies who are important to the success of WiMAX are not necessarily first-to-market suppliers of wireless chipsets (Wi-Fi and cellular technologies are two examples). Given some of the requirements for the mobile WiMAX solution, it could take more than one die spin to manufacture a chipset that supports the initial WiMAX profiles and does so with adequate performance (size, power requirements, etc.).

7.3.4 Interoperability testing and market field trials

Interoperability testing always takes longer than anticipated, in particular if an entirely new standard is being tested and if companies not normally accustomed to this type of activity are involved. Assuming that interoperability testing is successful and that commercially-viable solutions (e.g., data cards) are available, potential operators could then take months conducting field trials before moving to a market trial and then potentially a broader-scale commercial rollout. Clearwire, with a $20 million investment from Intel and with Clearwire's largest investor also owning its equipment provider (NextNet), is an exception. Clearwire has announced plans to deploy a proprietary NextNet fixed wireless solution in a number of U.S. markets in 2005.

It is interesting to note that current plans for WiMAX "plugfests" are to certify equipment against one of the many WiMAX targeted profiles. Since the Forum targets multiple profiles for different regions and applications, many interoperability activities will be required. Additionally, end-to-end "plugfests" cannot be a reality until WiMAX base stations and WiMAX CPEs are available. If history is a guide, the WiMAX base stations will be ready for interoperability testing well before the CPEs will be ready.

7.4 Uncertain economics

Like with other wireless technologies, the economics of using WiMAX to offer fixed wireless services in regions of the world where wireline deployments have not taken place or where there is little competition, are attractive. By eliminating the need to deploy copper or fiber, an operator can significantly reduce its upfront capital expenditures while at the same time reduce the risk of service disruption, brought on by vandalism or by theft of the buried cabling. Once consumers can self-install the CPE, the deployment costs become even more compelling.

It isn't clear if the same can be said for other market opportunities, especially when the network operator is designing its network to support seamless mobility and voice - far more base stations are required, regardless of the air interface that is used. However, if the operator deploys its WiMAX network in select, albeit geographically large, areas where portable/mobile broadband that area, its cost structure will be reduced.

Put simply, deploying a mobile network is not an inexpensive proposition and with an abundance of mobile operators in most countries, these regions may not be able to support another Greenfield mobile operator. These regions could, however, support a service that differentiated itself by offering higher data rates with the tradeoff coming in the form of reduced coverage and lower quality of service - seamless handoffs, high-speed vehicular support, etc.

7.4.1 WiMAX in a Wi-Fi world

WiMAX is often compared to Wi-Fi with the implication that WiMAX will follow in the footsteps of Wi-Fi and become a huge overnight success. Wi-Fi took years to achieve its recent popularity even though the same frequency band was available in virtually all countries (2.4GHz). Further, its success hasn't been dependent upon an operator-driven business model since most Wi-Fi users seldom, if ever, subscribe to use a public Wi-Fi service. Those that do pay to use public APs first purchased Wi-Fi and used it at home and then in the office before eventually migrating to the pay-for-use service.

More recently 802.11a (5.8GHz) has been gaining some traction, but it isn't a universal phenomenon and its success is nowhere near the success of 802.11b/g. One also cannot ignore that when the 54Mbps 802.11g was introduced as an enhancement to the 11Mbps 802.11b

solution, it also included a mode that made it backwards compatible with 802.11b. As discussed earlier in this paper, no such compatibility exists at the moment between the fixed and mobile versions of WiMAX.

Proponents of WiMAX assert that in the long term, users will migrate their wireless technology from Wi-Fi to WiMAX. For service providers, the migration from Wi-Fi to WiMAX could take place, but it will take longer than most predictions suggest with the migration not even beginning until after the technology has proven itself in field trials. Complicating the picture is the fact that Wi-Fi will continue to evolve to become more efficient, and with the completion of 802.11n, Wi-Fi will provide even higher data rates and even greater ranges.

In the early stages, the WiMAX deployments will likely be limited until after the business case is proven. Cometa Networks, with its vision for a nationwide Wi-Fi network with tens of thousands of APs, is a classic example of what can go wrong if a prudent rollout schedule is not adhered to. At the same time, rapid consumer adoption cannot take place until after ubiquitous coverage is possible - not only on a localized basis, but on a regional, national, or international level. Should this scenario pan out (ubiquitous coverage, attractive price points), it could make sense to embed WiMAX into notebook computers.

7.4.2 WiMAX in a 3G world

7.4.2.1 Operators are in evaluation mode

A number of operators are currently considering WiMAX, but most indicated that while they are not ruling out the portable/mobility potential of WiMAX; their main interest at this time is the potential that WiMAX offers with respect to backhaul (Wi-Fi and cellular) and fixed wireless service.

France Telecom (Orange), for example, is a member of the WiMAX Forum and is currently evaluating the technology for potential use at 3.5GHz to complement its Wi-Fi offering and to provide wireless backhaul. At this point, the operator believes that the portable/mobile version of the WiMAX standard isn't advanced enough for the operator to compare it with HSDPA or other IP-centric broadband wireless technologies, although its proponents feel that WiMAX is a "must have."

In a presentation in early 2005, Vodafone compared the anticipated performance of WiMAX with that of the existing TD-CDMA solution. It found that there is "little difference between TDD [TDCDMA] mode technology and WiMAX from a performance perspective." There will likely be further advancements with TD-CDMA over the next few years, including advanced multi-user detection and MIMO, which will further improve the capabilities of the technology, thus extending the performance gap with WiMAX.

Non-traditional mobile operators, such as broadcast cable and DSL providers, and fixed line operators, such as British Telecom, represent the organizations that are most likely to deploy the portable/mobile version of WiMAX. With this assumption as the backdrop, it could easily be argued that WiMAX will compete and/or complement existing broadband wireline service providers and not the traditional 3G operators.

As previously discussed, BT is already deploying limited amounts of "pre-WiMAX" and it is giving serious consideration to deploying a portable solution that can then be upgraded to support full mobility. As a major Wi-Fi provider, the operator also recognizes that a case could be made for just deploying more Wi-Fi access points and forgoing the need for a new portable/mobile WiMAX network. That said, the operator also believes that Wi-Fi is not adequate to deliver complete coverage in the event that this becomes a requirement, and in order to offer a differentiated service, the operator wants users to experience >500Kbps data rates in a portable/mobile

environment.

7.4.2.2 3G applications and services remain compelling and are still needed

From the view of the consumer, in order for there to be a compelling need to purchase a WiMAX-enabled device and to then subscribe to the service offering, the WiMAX service must offer something that existing services cannot offer or deliver the same level of service for a more attractive price.

The portable/mobility version of WiMAX is still in its infancy and much work remains to define the technology, let alone establish the services and applications that will utilize a WiMAX network. The cellular industry, on the other hand, has been introducing more value-added applications for over a decade. Cellular subscribers take ubiquitous and seamless voice services, including national and international roaming, for granted. In turn, these subscribers rely on their mobile phone to keep them in constant communication with their home or office. With the introduction of the E-911 mandate in the United States and similar mandates in other countries around the world, the mobile phone also fills the role as an invaluable security tool that can be used to summon help for the distressed caller who may not know his or her location. It is very difficult to imagine this same level of service and network intelligence in a WiMAX network.

Mobile data represents the other compelling element of cellular services, which is made even more compelling by the advent of advanced 3G technologies. Within that framework, there is a tendency to compare peak and average data rates in order to determine which technology is "better." The reality, however, is that there is an inherent tradeoff between higher data rates and other performance features, such as full-scale mobility and network performance characteristics, such as toll-quality voice services that most consumers now take for granted, or issue complaints when it isn't to their satisfaction.

Mobile operators fear nothing more than becoming a dumb broadband pipe, and for this reason they are using their 3G networks (UMTS, 1xEV-DO) to offer a compelling suite of content and applications that are targeted for enterprise users and everyday consumers. Put another way, without a compelling portfolio of content and services, 3G would not have had the success that it has had to date. In the absence of these types of content and services, the portable/mobility aspect of WiMAX risks becoming a marginalized service that only appeals to a finite customer base - a customer base that already has access to 3G data coverage that is augmented by Wi-Fi access points in those locations where stationary users frequently congregate.

7.4.2.3 The cost differences between WiMAX and 3G are not significant

Regarding cost, it has already been noted that a WiMAX radio access network is not fundamentally less expensive to deploy than a Greenfield 3G network, in particular when taking into consideration that the actual cost of the infrastructure (base stations, etc.), represents only a modest percentage of the overall capital expenditures - site acquisition and preparation costs are technology agnostic and generally cost far more than the equipment deployed to the site. There are inherent savings in the core network since WiMAX adopts an all-IP infrastructure. However, the radio access network generally represents 60-70% of an operator's capital expenditures with the core network only representing 15-20% of the total deployment costs.[2] Having said this, 3GPP and 3GPP2 are defining all IP cores for WCDMA and CDMA2000. These mobile operators will realize the same cost savings in the long run.

Likewise, the cost of user equipment, beginning with data cards and potentially expanding to include notebook computers and other handheld devices (e.g., an iPAQ) with embedded WiMAX technology, will command a premium price relative to Wi-Fi- or 3G-enabled devices, driven in large part by the sheer lack of volumes. The combined effect of high capital expenditures and the cost of the CPE will represent the single biggest challenge for WiMAX as it tries to establish its footing as another portable/mobile wireless data offering.

As previously indicated, the number of base stations required to support full mobility is dramatically higher than the number required to support a fixed/nomadic service offering. As such, WiMAX operators, which in most instances will not be an incumbent mobile operator, will be severely challenged to find and gain access to sites in the right locations for their base stations. Further, these "non-traditional" operators will have to have access to substantially higher financial resources due to the inherent higher costs associated with deploying and maintaining a carrier-grade "mobile" network.

With a fixed/nomadic service offering, consumers may accept modest amounts of "dead zones" and they may not notice interrupted service when moving between cell sites. However, if mobility is advertised, and especially if the operator is offering a voice service (VoIP), the subscribers will expect the same level of service, including drop call rates of only a few percentage points, which they have become accustomed to with 2G or 3G. Consequently, WiMAX operators will not be able to cut corners when deploying their networks while they will be taking a big risk that their networks will be able to provide a level of service that is commensurate with being based on a next-generation technology.

7.4.2.4 Embedding WiMAX in devices isn't trivial

From a device perspective, major notebook computer manufacturers are currently evaluating WiMAX. However, other than having a place holder for a mid-2007 product entry point, at least some of these manufacturers are not making any commitments to the technology at this time. It should be noted that some of the largest notebook computer manufacturers are not participating in the WiMAX Forum, although they are involved in other wireless standards bodies (Wi-Fi Alliance, WiMedia, 3GPP, etc.).

One of their concerns is the underlying business model and who will sell the service offering. Although these companies recognize that mobile customers want more than what wireless hot spots can provide, these manufacturers also point out that 3G services are already widely available. Some of these manufacturers, therefore, will likely introduce their first notebook computers with embedded 3G technology later in 2005, or early 2006, with Sony having already announced its first 3G notebook computer.

In the event that demand develops for WiMAX, these notebook computer manufacturers will likely offer an embedded WiMAX solution. The challenge, however, is that notebook computers can only contain so many RF solutions. Wi-Fi is virtually ubiquitous in all of the notebook computers that are shipped, and other RF solutions, including UWB, Bluetooth and 802.11x, are either currently available or will be available in advance of WiMAX.

In order for WiMAX to be included in this list, the technology would need to replace one of the embedded solutions in order to free up enough space. 3G, it appears, would be the most likely candidate, given that this technology has the most in common with WiMAX - both feature wide area coverage. The unanswered question then is will there be enough demand for WiMAX at a particular frequency (remember, there are multiple options), outside of the demand for 3G, to justify a separate product offering? The answer could be yes, but if consumers are forced to choose between WiMAX and a pre-existing 3G/Wi-Fi offering, the market adoption of WiMAX would be curtailed, which could further impact an already questionable operator business model. After all, without operators, WiMAX cannot be a success.

Despite some of the challenges that WiMAX will face in a 3G world, it does create a market opportunity for the non-traditional operators who want to offer a portable/mobile broadband service offering, and given the dependence of WiMAX upon the operator-driven business model, it will be up to these operators to make the technology a commercial success.

Conclusion

The fixed version of the WiMAX standard, 802.16-2004, addresses a particular market need, that being the availability of a low-cost, standards-based solution that can provide basic voice and broadband access in regions of the world where the economics of a fixed wireline service do not make sense. Additionally, the fixed standard can help drive the proliferation of Wi-Fi access points while at the same time reducing operating [backhaul] costs and improving the user experience through higher data rates.

While these market opportunities are readily available and worth pursuing, much of the industry focus is on the portable/mobile standard, 802.16e, and its potential to offer mobile broadband wireless service. At this juncture, there is still a large amount of work remaining to be done before the .16e standard is commercially ready and before operators can seriously consider utilizing the technology. To the extent that WiBro can be considered within the WiMAX family [it arguably is], South Korea could have the first network available in early 2006, although the availability of end-user devices is a major uncertainty.

In that regard, it is important to recognize that even after the portable/mobile standard is ratified, there remains much work to be done as chipsets, followed by base stations and CPEs, still need to be developed, the network architecture still needs to be defined, security issues need to be addressed, and the technology still needs to be proven in a field trial. After successful field trials by the equipment providers, the technology will then be ready for extensive operator trials which could then lead to broader-scale commercial deployments. It goes without saying that operator trials don't always lead to commercial rollouts.

The jump to full mobility is still a bit tenuous, even after the .16e standard is ratified. In all probability it will take far longer than currently predicted for the technology to be commercially and economically feasible - the timing depends to a large degree on the final complexity of the network architecture. In the absence of compelling content and services, consumers who already utilize 3G and Wi-Fi services will be hard pressed to abandon their cellular service provider and adopt WiMAX. Those that do adopt WiMAX as a broadband data pipe will likely continue using their cellular service provider, which at best indicates that WiMAX complements 3G while trying to compete with already inexpensive Wi-Fi services. To some extent, WiMAX will also have to compete with the 3G/Wi-Fi combination in order to find room in next-generation notebook computers.

Those non-traditional operators that currently lack a mobile offering are the most likely candidates to use the portable/mobile capabilities of WiMAX. However, they will still be challenged by the requisite need for WiMAX-enabled user equipment and in some instances by their lack of suitable spectrum. Further, these operators will be challenged by the technical hurdles that are inherent in deploying any new wireless technology and by the economic challenges associated with offering a service that must attract interest from consumers that are already familiar with the 3G/Wi-Fi combo of services. Ultimately, the technical challenges can be addressed and the market opportunity for a portable/mobile WiMAX service can then begin to develop. WiMAX success in the market, given its high dependence upon the need for successful operator-driven business models, is a bit more suspect and could in the end prove to be the single biggest detriment.

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