Delivering on the Promise of WiMAX:

A White Paper from WireIE's Office of the CTO

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TABLE OF CONTENTS

REVISION HISTORY

Revision	Date	Details
1.5	October 2, 2007	Draft Release.
2.0	October 3, 2007	Executive Summary Updated. Images encoded.
2.5	October 12, 2007	Incorporation of Peer Feedback.
2.6	February 23, 2008	Addition of Copyright Notice.

EXECUTIVE SUMMARY

The last ten years have seen rapid evolution on two technological fronts. First, the World Wide Web has matured to the point where it's become an integral part of everyday life for a large percentage of the human population. In parallel, wireless telephony has freed users from a wired infrastructure, allowing un-tethered phone access – largely unconstrained by location.

Until recently these technologies evolved independently. Thanks to a new wireless internet standard known as WiMAX, these disparate technological paths are about to converge, leading to vast and exciting new opportunities.

WiMAX is a wide-coverage, high capacity wireless internet technology offering coverage comparable to a PCS telephone network and with speeds reaching those of a wired DSL or Cable internet service. WiMAX coverage, capacity, network configuration flexibility and cost structure all add up to a compelling business case for the network operator. This innovative technology also holds the promise of bringing broadband internet access to regions of the world where deploying wired networks is impractical or cost excessive.

Subscriber equipment for WiMAX is becoming abundant in the form of external Customer Premises Equipment (CPE) devices, in addition to WiMAX embedded chipsets in notebook computers and other consumer electronics devices. As a standards-based macro network technology, WiMAX is fully integrated with the widely embraced Wi-Fi standard for wireless Local Area Networks (LAN).

WiMAX has countless mechanisms within the network to optimize the user experience while also efficiently managing precious network resources. Indeed, WiMAX is both powerful and efficient.

WiMAX also offers the network operator the ultimate in flexibility in defining levels of service based on subscriber applications. Versatile billing plans are easily linked to these classes of service. Quality of Service (QoS) is supported, allowing voice and multimedia opportunities to be exploited by the operator.

With chipset makers and network equipment manufacturers broadly adopting the 802.16e-2005 version of the WiMAX standard (also referred to as 802.16e), the stage is now set for explosive growth in WiMAX deployments throughout the world.

The intent of this white paper is to elaborate on the technological features, benefits and opportunities of WiMAX technology and to describe its position in the context of the broader telecommunications environment. Specifically, the paper contrasts the role of WiMAX with Wi-Fi; details the WiMAX network feature set and the significant advantages therein; profiles the spectrum issues and opportunities for WiMAX and explores the evolution of the standard for the foreseeable future. The paper concludes with an overview of potential new applications using WiMAX.

WIMAX: SOLVING THE CONVERGENCE DILEMMA & BRIDGING THE DIGITAL DIVIDE

The past decade has seen two profound technological developments the impact of which will likely be felt for many decades to come. The first has been global embrace of the World Wide Web[1] (more commonly referred to as 'the Web'). The second has been the broad adoption of mobile telephony. As a result of these ground-breaking technologies, two fundamental consumer expectations have emerged:

1. Access to information and entertainment should be immediate and to the greatest extent possible, user-defined (the Web).

2. User location should not be a constraint in access to service (wireless).

Despite the incredible evolution in wireless and web technology, these fundamental principles have yet to converge in a meaningful, cost effective way. While devices such as Apple's iPhone and RIM's BlackBerry product line push the convergence envelope, relatively slow data rates along with device form factor limitations, stand in the way of a rich and engaging user experience. High speed data services from wireless carriers using technologies such as EV-DO (Evolution-Data Optimized) and HSDPA (High-Speed Downlink Packet Access) offer high speed mobile data plans at premium prices – out of reach for many consumers.

Another example of partial convergence of these principles is Wi-Fi[2] where users can enjoy a rich, broadband web experience but only while within the very limited coverage range of a Wi-Fi access point.

With these constraints in mind, there is now a clear opportunity to marry the advantages of wireless portability with a high speed, broadband web experience. This opportunity comes in the form of WiMAX (Worldwide Interoperability for Microwave Access).

WiMAX is a suite of wireless internet standards which recognize and resolve the convergence dilemma. Using concepts similar to those used in wireless telephone networks, WiMAX promises delivery of web access wirelessly at speeds only seen up to this point through dedicated physical connections.

While the opportunity to resolve the wireless/web convergence dilemma is vast, WiMAX may have a nobler role. Up to this point, copper wire and fiber optic cable have been key ingredients in the delivery of broadband internet service. Many parts of the developed world take for granted the presence of copper or fiber to the home or business in what is commonly referred to as the last mile. There is a large part of the developing world, however, where this infrastructure was never put in place and never will be due to the prohibitive cost. This disparity between cabled and un-cabled societies is commonly known as the 'digital divide'. With its last mile access capabilities, WiMAX is perfectly positioned to bridge the digital divide by placing everyone on an equal footing.

While WiMAX is a wireless broadband standard designed to reach the subscriber, it is also viable as a network backhaul solution. This means that WiMAX base station sites can be linked back to the core network by WiMAX backhaul where copper wire, fiber optic cable or microwave either do not exist or are too costly to deploy.

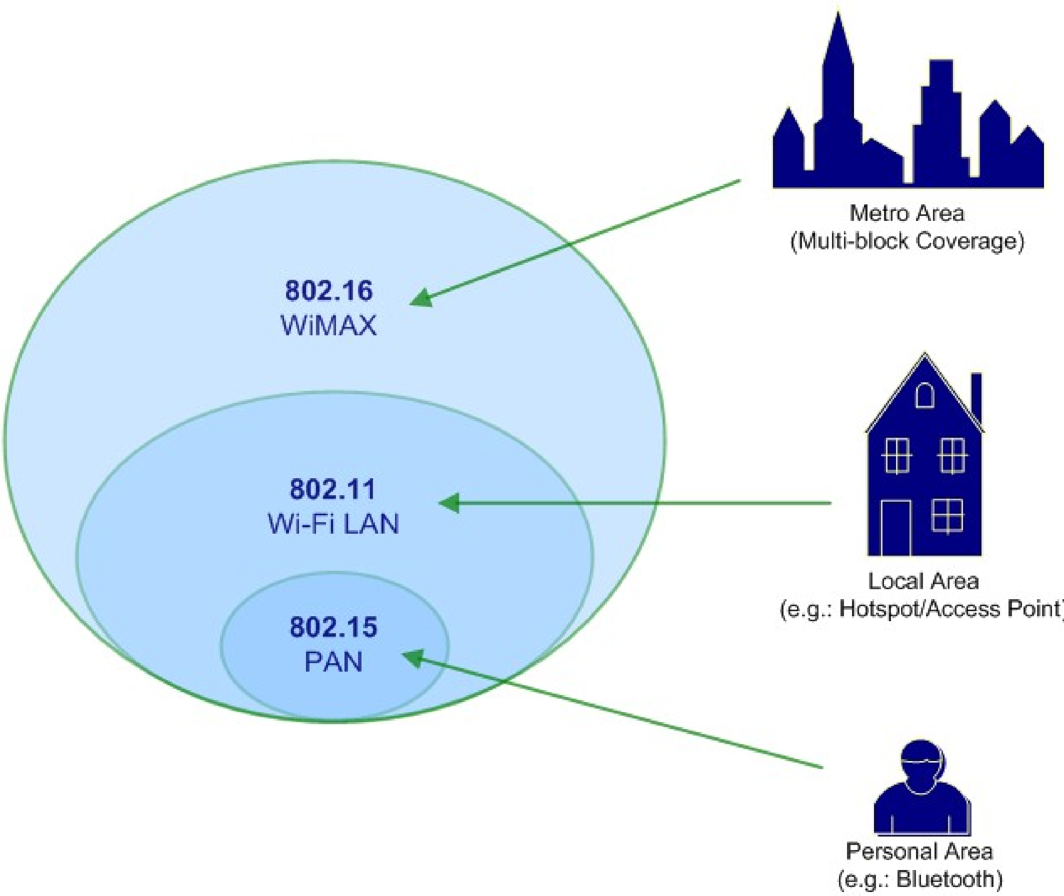
There are significant advantages in WiMAX being a standards-based Broadband Wireless Access (BWA) technology. First, standardization ensures interoperability between products from different manufactures. The network operator can control costs by not being tied down to one vendor for their network infrastructure or subscriber equipment. Equally important, the baseline cost for WiMAX will be lower as common chipsets continue to hit the market. The economies of scale inherent in this evolution make WiMAX a compelling business case for the network operator.

[1] Supported by the development of browser technology, the World Wide Web is a system of interlinked documents and multimedia services accessed via the Internet using technologies such as XHTML, CSS, JavaScript, along with host based capabilities such as PHP and ASP.
[2] Standardized under the Institute of Electrical and Electronics Engineers (IEEE) as: 802.11a, 802.11b, 802.11g & 802.11n.

For incumbent Wireless Internet Service Providers (WISPs), the opportunity to dissociate from proprietary, non-standard network technology will help reduce costs while also opening the door to consolidation, leading many operators to first-time profitability. Many Tier One telcos also find WiMAX an appealing adjunct to their 3G wireless networks as finite radio frequency spectrum is consumed by legacy services such as voice. WiMAX allows the Tier One telco to decouple mobile voice services from enriched data services.

The Standards Based Wireless Network Ecosystem

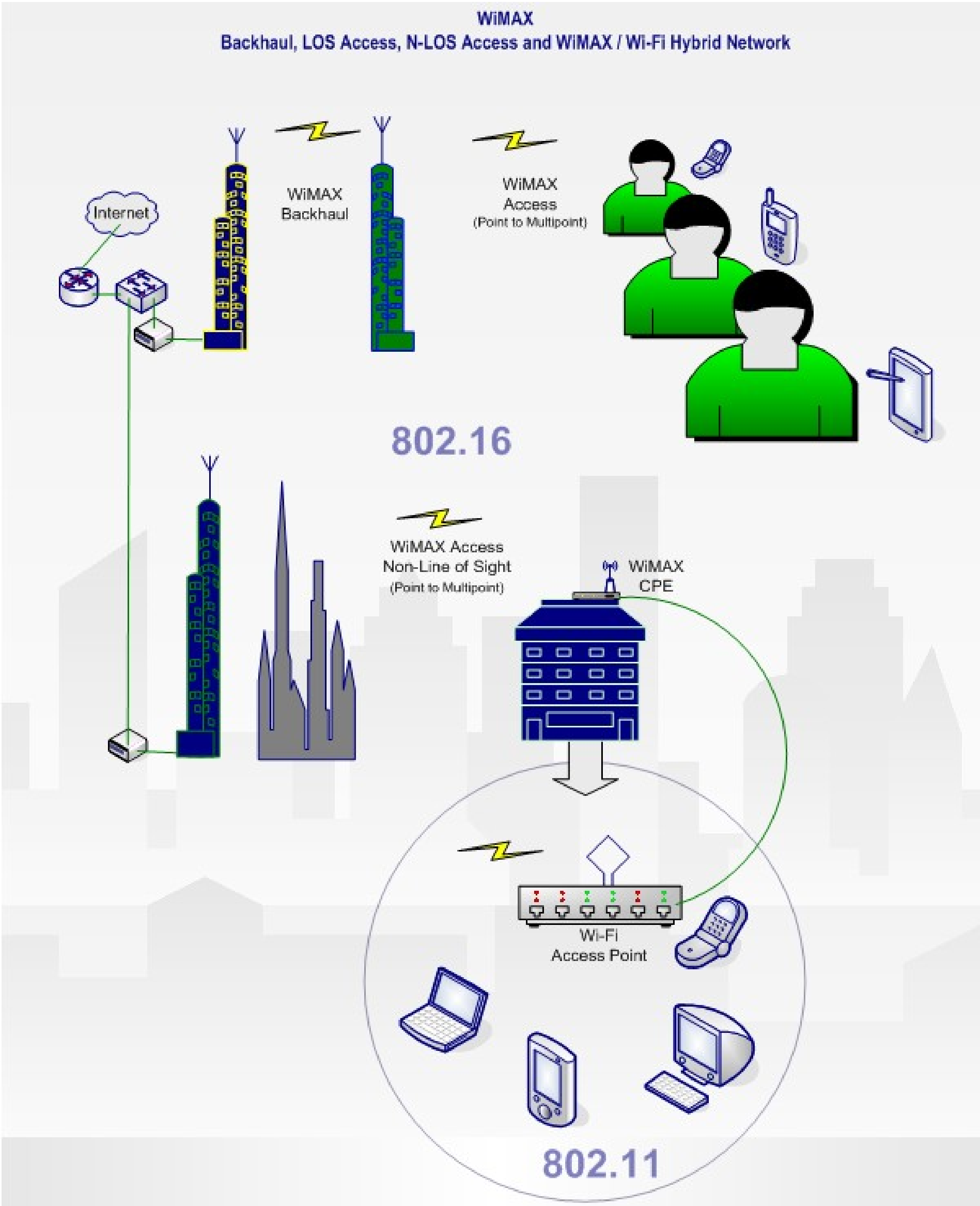
Among its many roles, the Institute of Electrical and Electronics Engineers (IEEE) is the North American based authority for setting wireless broadband standards[3]. In developing the WiMAX suite of standards, the IEEE ensured both existing and future wireless technologies would fully integrate with WiMAX.



As a standards-based ecosystem, users of a Wi-Fi access point can hand-off to the broader coverage WiMAX network as they leave access point coverage. The reverse is also true as the user enters Wi-Fi hotspot coverage.

A WiMAX CPE (Customer Premises Equipment) device can have fully integrated Wi-Fi Access Point functionality. As depicted on the following page, the WiMAX network delivers internet to the building's CPE wirelessly through a Non-Line of Site (NLOS) link. From there, devices inside the building can use the Wi-Fi access point as a means of connecting to the internet.

[3] IEEE 802 refers to a family of IEEE standards dealing with local area networks and metropolitan area networks.


WiMAX
Backhaul, LOS Access, N-LOS Access and WiMAX / Wi-Fi Hybrid Network
Internet
WiMAX
Backhaul
WiMAX
Access
(Point to Multipoint)
802.16
WiMAX Access
Non-Line of Sight
(Point to Multipoint)
WiMAX
CPE
Wi-Fi
Access Point
802.11

The WiMAX Standard

Known as the Worldwide Interoperability for Microwave Access, WiMAX is derived from the Institute of Electrical and Electronics Engineers (IEEE) 802.16 Working Group on Broadband Wireless Access Standards. Established by IEEE Standards Board in 1999, the mandate of the working group is to prepare formal specifications for the global deployment of broadband Wireless Metropolitan Area Networks (W-MANs). WiMAX is a standard with two fundamental roles:

1. Provide broadband wireless as a 'last mile' access technology.

2. Provide a reliable, high capacity, robust backhaul alternative to traditional methods.

In the context of access, a single WiMAX subscriber under perfect RF (radio frequency) conditions can theoretically derive 70 megabits per second performance. The range of a WiMAX signal can be as great as 48 kilometers, although performance (throughput and latency) will deteriorate significantly with distance and subscriber loading. Practically speaking, a subscriber using portable equipment with a moderate gain antenna with clear line-of-sight will realize speeds of 10 megabits per second at a distance of 10 kilometers. In urban environments where line-of-site is much less likely, users may only realize 10 megabits per second within 2 kilometers. WiMAX has a maximum bandwidth of 100 megabits per second and a low latency of 25 - 40 milliseconds.

Contrasting Wi-Fi and WiMAX

WiMAX and Wi-Fi are complimentary standards, each fulfilling a different set of objectives. Regardless, network operators have attempted to use Wi-Fi for applications better suited to WiMAX – often with very disappointing results.

Coverage is but one of several factors differentiating WiMAX from Wi-Fi. Capacity and the management of network resources are others. The WiMAX standard covers both media access control (MAC) and physical (PHY) layers for fixed, nomadic and mobile operation in both licensed and unlicensed frequency bands. The MAC layer is optimized for greater distances because it was designed specifically to tolerate longer delays and delay variations. WiMAX based voice service can work on either traditional time division multiplexed (TDM) or Internet Protocol (IP) based voice, also known as Voice over IP (VoIP).

Subscriber access to a WiMAX network is based on what is known as a grant-request mechanism, or scheduler. The advantages of this approach become apparent when compared with Wi-Fi access methods based on what are known as CSMA/CD (Carrier Sense Multiple Access/Collision Detect) or CSMA/CA (Carrier Sense Multiple Access/Collision Avoid) mechanisms.

When a Wi-Fi node has fewer than ten users, the network experiences little contention for use of radio frequency resources. Packet collisions will occasionally occur, with back-off and retransmissions assuring the interaction between subscriber and Wi-Fi access point are eventually completed. Under relatively light network loading, link overhead is kept quite low and a satisfactory user experience is achieved.

If, on the other hand, the number of Wi-Fi users increases into the dozens, the rate of collisions and retransmissions will increase dramatically resulting in perceptible performance degradation. Latency dependant services such as VoIP quickly become unusable. While the 2.4 GHz noise floor is inherently high (microwave ovens, cordless phones, baby monitors, security cameras), the compounding effect of uncoordinated access points can prevent user access while also causing interference with neighboring access points. A further source of 2.4 GHz Wi-Fi interference is the channel overlap between 802.11b and 802.11g versions of the Wi-Fi standard.

In addition, interoperability issues between different manufacturers (proprietary deviations from the IEEE standard) can disrupt connections or lower throughput speeds. Furthermore, the 802.11 specification does not define an intelligent channel selection algorithm to guide the user to the channel with the lowest interference.

The recently ratified 802.11n version of the Wi-Fi standard is viewed as a solution to some of the issues encountered with previous 802.11 versions. 802.11n increases capacity to hundreds of megabits per second from the current 54 megabits per second claimed today (assuming single session and a perfect 802.11g RF link). This dramatic capacity increase is achieved by 'ganging' multiple 802.11n RF transceivers within a single Wi-Fi device. While this approach is attractive, it does have one key shortcoming. Frequency coordination is often not practiced in unlicensed spectrum such as where Wi-Fi resides. As a result, neighboring 802.11n devices will remain potential sources of co-channel and adjacent channel interference. In many situations, the transceiver 'ganging' approach may exacerbate the interference problem as aggregate RF energy raises the noise floor.

It must be noted that preceding observations are in no way intended to dismiss Wi-Fi as a viable wireless broadband technology. These observations are made merely as a means of contrasting WiMAX's more sophisticated approach to channel contention and session management. The fact remains, Wi-Fi is, and will continue to be, a very powerful technology, and in many applications it compliments WiMAX beautifully. The key to a high performance Wi-Fi network is to ensure a coherent system design (antenna pattern, antenna placement and channel coordination) is done through the services of a certified professional, and that the actual installation conforms to the design specification. WireIE has both the design and installation expertise to meet any Wi-Fi enterprise application.

WIMAX NETWORK FEATURES

WiMAX's Scheduler & Adaptive Modulation Control

WiMAX's scheduler approach addresses network contention and resultant interference in an orderly fashion. Each WiMAX frame is transmitted with a small portion allocated as a contention slot. When an initial request for network resources is made, the network evaluates the requesting station's service level rating and a slot is subsequently granted based on the service level criteria. This slot can be thought of as reserved network bandwidth for which no other subscriber will contend. This reservation of bandwidth assures a consistent user experience assuming RF conditions are kept constant. A negative user experience would only occur when a new request is received from a fully loaded base station (i.e.: all slots have been previously assigned and RF resources are essentially exhausted).

This approach of assuring a predictable, quality assured user experience is vastly superior to the ad hoc, unpredictable, unmanaged approach with access methods deployed in Wi-Fi networks[4]. Equally significant, it is a statistical reality that the scheduler based access method in WiMAX assures much higher overall bandwidth utilization on a per channel basis. In addition, the WiMAX network operator can tweak the schedule algorithm to assure business objectives (such as QoS) are met.

Another aspect of WiMAX's link quality management relates to dynamic modulation adjustments based on RF conditions. As RF conditions vary, modulation schemes can be changed on per subscriber basis. For example a subscriber close to a base station with good signal strength will engage using a highly efficient modulation scheme (e.g.: 64 QAM[5]) while a distant subscriber in a noisy RF environment will engage a less efficient but more robust modulation scheme (e.g.: 16 QAM or QPSK[6]).

[4] The 802.11e modification to the Wi-Fi standard enhances MAC layer functionality to address Quality of Service (QoS), along with other delay sensitive applications.
[5] Quadrature Amplitude Modulation.
[6] Quadrature Phase Shift Keying.

A further nuance to this ingenious approach is WiMAX's ability to assign different modulation schemes to the uplink and downlink of a single subscriber session based on the quality dynamics of the RF path.

WiMAX's scheduler and link modulation management technology are profoundly advantageous tools in managing bandwidth, network capacity and ultimately the quality of a user's experience. The absence of similar capabilities in Wi-Fi makes it inappropriate for heavily loaded, macro network applications. With this in mind, it is suspected the absence of this functionality could explain low consumer interest in municipal Wi-Fi networks. The short range coverage associated with Wi-Fi also makes it unsuitable in addressing macro network coverage objectives.

NON LINE OF SITE COVERAGE

Most commercial wireless technologies operate in frequencies which are line-of-sight. Behaving similar to a beam of light, if one station (the subscriber for example) can see the other station (the base station for example), communication is achieved. Obstructions such as buildings or mountains will degrade the signal. These obstructions cause the signal to bounce off as a reflection (again much like the reflection of a beam of light). Reflected signals are time-delayed (the reflected signal will arrive later than the direct signal), and as a result, reflected signals have been traditionally regarded as a source of interference to the primary signal.

Remarkably, with the evolution of digital signal processing, the liability of a delayed signal has now become an asset. The developers of the WiMAX standard recognize this and have fully exploited it. With the intelligence found in modern digital radio receiving equipment, the delayed signal can now be processed and ultimately reconciled and augmented with the direct signal. Even if the direct signal isn't available at the receiver, it is possible to reconstruct the original signal using various reflected signals. These reflected signals are quite often Non-Line of Site (NLOS). The same concept is applied to the transmitted signal. Space and time coding variations in WiMAX's modulation scheme ensure the effects of RF interference and fading are reduced, and often eliminated[7].

WIMAX ERROR CORRECTION TECHNIQUES

To compliment WiMAX's robust PHY layer, error correction techniques have been incorporated in the MAC layer to reduce the impact of a poor RF signal to noise ratio. Strong Reed Solomon FEC (Forward Error Correction), convolutional encoding, and interleaving algorithms are used to detect and correct errors. These techniques help recover error plagued frames that may have been lost due to selective fading or burst errors. Automatic repeat request (ARQ) is used to correct errors that cannot be corrected by the FEC. The end result is improved bit error rate (BER) performance.

WIMAX RF POWER CONTROL

Power control algorithms are used to improve system performance and to reduce interference. The base station sends power control instructions to each subscriber to regulate the transmit power level based on a closed loop feedback system. Subscriber transmit power is kept at a level sufficient for reliable communication, yet not excessive to the point where the spectrum noise floor is detrimentally affected. WiMAX's power control reduces overall power consumption of the CPE while also reducing the risk of interfering with neighboring CPEs.

[7] These benefits generally tend to diminish in high frequency bands as reflected signals in these bands tend to propagate poorly.

SUPPORT FOR QUALITY OF SERVICE (QOS)

For applications such as voice and streaming video, WiMAX provides for robust quality-of-service (QoS) protection on a per subscriber basis. As with any network, WiMAX capacity is finite. WiMAX's QoS features, however, allow service providers to manage the traffic based on each subscriber's service level agreement. As a result service providers can charge a premium for a guaranteed QoS of a subscriber's link.

WIMAX DUPLEXING METHODS

In order to separate the uplink (UL) channel from the downlink (DL) channel, the WiMAX standard provides for two duplex methods, Time Division Duplex (TDD), and Frequency Division Duplex (FDD).

With TDD, a single channel is shared amongst the uplink and downlink. The channel is half-duplex, meaning either the uplink or the downlink can use it but never both at the same time. TDD divides the data stream into frames. Within each frame, time slots are assigned to uplink and downlink transmissions. This allows both types of transmissions to share the same transmission medium (i.e.: the same radio frequency), while using only the part of the bandwidth required by each type of traffic.

Since TDD can dynamically allocate the amount of time slots assigned to each direction (uplink and downlink) an operator can define the percentage of uplink versus downlink traffic. This is especially important for web based activity where the ratio of uplink to downlink traffic need not be constrained to a fixed 50/50 split. Because the uplink and downlink allocation is dynamic, there is very little waste of spectrum for asymmetric operations. With TDD, a guard band is not required to separate the uplink and downlink as they both use the same frequency. A guard period, however, is necessary for synchronization purposes and to accommodate the turnaround time and round trip delay whenever switching from uplink to downlink. Some spectrum is still lost to guard periods, but this is negligible compared to the total length of data in a time slot.

With FDD, a discrete frequency channel is assigned to the uplink and downlink. At any particular instant in time, uplink traffic uses a frequency different from the frequency used by the downlink traffic. The Base Station Unit (BSU) may receive uplink traffic while it simultaneously transmits on the downlink.

FDD is typically used in applications that require an equal uplink and downlink bandwidth – Time Division Multiplexing (TDM) voice applications being a classic example. Therefore, regulatory authorities grant uplink and downlink channels of equal capacity for FDD based WiMAX systems.

Due to the symmetric nature of FDD transmission channels, and the FDD legacy as duplex method of choice for TDM voice applications, FDD transmission channels are always of equal size (50% for uplink and 50% for downlink). In applications such as web browsing (typically asymmetric in nature), a large percentage of the available uplink bandwidth remains unused and is, therefore, wasted.

A guard band about two times the size of the uplink or downlink channel is required to separate the uplink and downlink channels. This amounts to an additional 50% loss in spectrum.

COMPARISON OF FDD & TDD

Factor	Multiplexing Method	
	FDD	TDD
Guard Band	FDD requires a guard band to separate the UL and DL channels.	No guard bands are required.
Guard Time	No guard time is required at the end of DL transmission.	Guard time is required between transmit and receive. The guard time is equal to a unit's turn-around time plus the round trip delay. A unit's turn-around time is in the order of 50 microseconds. The round trip delay is in the order of 66 microseconds. Thus the round trip delay can absorb the transmitter's turn-around time whenever the direction of traffic switches. The loss in throughput due to guard time for a 5 microsecond frame is about 2%.
Frequency Plan and Reuse	The adjacent channel interference is much lower than in a TDD scheme.	Frequency planning is required only for one channel. If all TDD based systems are synchronized to GPS, using the same frame size and DL/UL partitioning can mitigate interference.
Dynamic Bandwidth Allocation	Once the channel bandwidth is granted by the regulator the UL/DL allocation cannot be modified. This leads to unused spectrum for asymmetric operations such as web traffic.	Where cell interference is not a problem, adaptive UL/DL allocation allows dynamic bandwidth allocation for UL and DL traffic. This is especially important for asymmetric, web based traffic.
Latency	The average FDD latency in a point-to-multipoint system is 1 frame and the best case latency is about 0.5 frame.	The average TDD latency in a point-to-multipoint system is 2 frames and the best case latency is about 1 frame.
Adaptive Antenna System/ Multiple Input-Multiple Output (AAS/ MIMO) Advantages	For closed loop beam forming, FDD requires the CPE to provide the channel response for the DL direction. This increases the latency and reduces the performance of the beam former.	TDD allows the CPE to estimate the DL channel as both DL and UL are operating on the same frequency. The performance of the beam former is therefore better.

WiMAX Spectrum Allocation

The 802.16 PHY layer is divided into two broad spectrum segments. The first segment is 10 GHz – 66 GHz band LOS (Line of Sight) and the second is 2 GHz – 11 GHz band for NLOS (Non Line of Sight) operation. This paper will focus on the 2 GHz – 11 GHz segment. Its overall design is based on the demand for NLOS propagation. The available spectrum in the 2 GHz – 11 GHz segment are:

Band	Status
2.1 GHz	MDS[8] Frequency (Currently Uplink spectrum for MMDS[9] operation, 12 MHz available bandwidth)
2.3 GHz	WCS[10] Frequency
2.4 GHz	ISM[11] Band (Unlicensed spectrum)
2.5 – 2.7 GHz	MMDS Frequency
3.4 – 3.7 GHz	MMDS Frequency
5.8 GHz	ISM Band (Unlicensed spectrum)

CONTRASTING LICENSED & UNLICENSED SPECTRUM

Licensed	Unlicensed
Required for assuring QoS and service reliability.	Unlicensed spectrum in rural areas means lower cost for the end customer.
Generally preferred in heavily populated areas.	Fast roll outs – no need to wait for the licensing process.
Network scalability under control of operator.	Interference issues cannot be controlled
Operator predetermines impact of license fees on business case.	
Fewer operators mean less crowding.	

FREQUENCY SELECTION CRITERIA

The frequency of operation is largely dependant on available spectrum in the country of operation and associated regulatory policies. It is also fair to assume that licensed spectrum will be highly desirable over the unlicensed counterpart due to the issues of interference.

In the licensed spectrum, the front runners are 2.5 GHz and 3.5 GHz and they have the largest momentum from equipment vendors and regulatory bodies around the world. Propagation characteristics are also preferable in these bands. Deployment in widely adopted WiMAX profiles is prudent because they offer the benefit of economies of scale, with lower cost of equipment and improved CPE availability.

The deployment strategy currently embraced by operators around the globe is 3.5 GHz for fixed, LOS business applications, and 2.5 GHz as an overlay for mobility and residential installations. There is no overwhelming advantage to deploy in both bands. Careful study of the operator's business goals and revenue objectives will identify the best strategy for network deployment.

[8] Multipoint Distribution Service
[9] Multi-channel Multipoint Distribution Service
[10] Wireless Communications Service
[11] Radio frequency bands assigned for Industrial, scientific and medical use.

WIMAX PROFILES

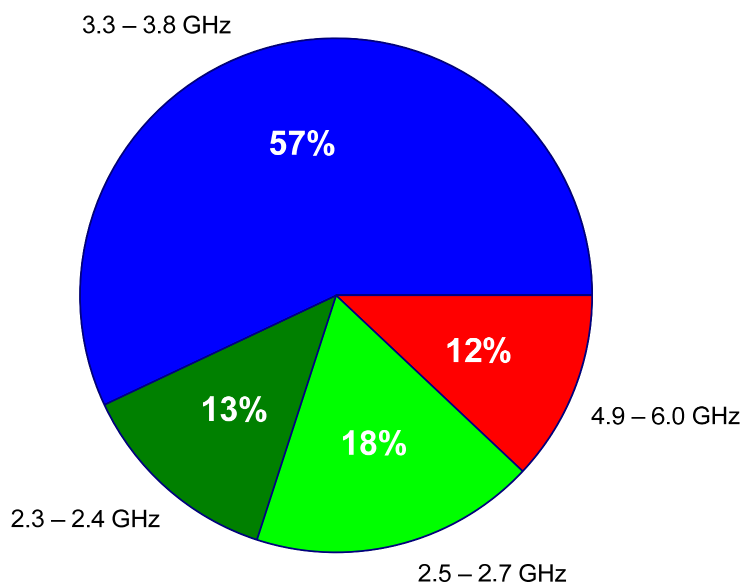
The table below shows the different WiMAX profiles. It is important to note the development and certification of profiles is an ongoing process.

System Profile	Spectrum	Duplex	Channel Width
Mobile WiMAX, IEEE 802.16e-2005	2.3 - 2.4 GHz (100 MHz)	TDD	5/10, 8.75 MHz (only in Korea)
	2.496 - 2.690 GHz (190 MHz)	TDD	5/10 MHz
	3.3 - 3.4 GHz (100 MHz)	TDD	5, 7 MHz
	3.4 -3.6 GHz (200 MHz)	TDD	5, 7, 10 MHz
	3.4 -3.8 GHz (400 MHz)	TDD	5, 7, 10 MHz
Fixed WiMAX IEEE 802.16-2004	3.4 – 3.6 GHz	TDD	1.75, 3.5, 7 MHz
	3.4 – 3.6 GHz	FDD	1.75, 3.5 , 7 MHz
	5.725 – 5.850 GHz	TDD	5/10 MHz

BROAD CATEGORIES OF WIMAX OPERATION AROUND THE WORLD

Band	Region
2.4 GHz	Australia, Singapore, Korea, Malaysia
2.5 – 2.7 GHz	USA, Caribbean, Latin America and parts of Europe
3.4 – 3.6 GHz	More suitable for fixed applications. Used in many countries

WiMAX Band Usage Worldwide[12]



12 Used with the permission of Maravedis Telecom Market Research and Analysis.

CONTRASTING WIMAX WITH THIRD GENERATION (3G) PCS/CELLULAR TECHNOLOGIES

Both WiMAX and 3G are capable of supporting voice and data. From its inception, however, WiMAX was developed primarily as a data standard. On the other hand, 3G PCS is intended to leverage legacy wireless voice network infrastructure in its offering of broadband data services. In some markets, PCS network operators are exploring WiMAX as an adjunct to 3G because of concerns over insufficient PCS RF spectrum. From other vantage points within the wireless telecommunications industry, WiMAX presents a threat to 3G because of its broadband capabilities, comparable coverage, and ability to support voice with full QoS.

COVERAGE AREA AND MOBILITY

Standard	Range	Mobility
Wi-Fi 802.11	Up to 305 Meters	<160 km/hr.
WiMAX 802.16	Up to 48 Kilometers (LOS) Up to 8 Kilometers (NLOS)	<120 - 150 km/hr.
3G	Typically 1.5 – 8 kilometers	500 km/hr. at 144 kbps 120 km/hr. at 384 kbps 10 km/hr. at 2Mbps

RELIABILITY AND SECURITY

Standard	LOS/NLOS	Security
Wi-Fi 802.11	NLOS	WEP[13] / WPA[14]
WiMAX 802.16	LOS/NLOS	X.509 / DES / Triple DES
3G	NLOS	Based on GSM with enhancements

WIMAX BACKHAUL OPPORTUNITIES

Deploying or leasing backhaul facilities can be costly and in certain cases these solutions do not scale well for data applications. Perhaps more significant, in many jurisdictions the fundamental question of backhaul availability can limit an operator's options in terms of WiMAX or PCS base station placement. WiMAX's high bandwidth makes it attractive as a backhaul option both for data and in certain cases, PCS/cellular. Given wired infrastructure limitations in certain developing countries, the costs to collocate a WiMAX station on an existing PCS/cellular tower or even as a solitary hub, are comparatively low.

[13] Wired Equivalent Privacy.
[14] Wi-Fi Protected Access.

THE WIMAX STANDARD TODAY AND IN THE FIVE YEARS TO COME

As of this writing, there is a relative abundance of network infrastructure and CPE solutions to support fixed installations under WiMAX version 802.16-2004 (more commonly, yet incorrectly referred to as 802.16d). This version also claims to support nomadic subscriber behavior, although portable CPEs for 802.16-2004 remain uncommon.

The WiMAX community is rife with excitement over claims of support for mobility in the 802.16e-2005 version of the standard (more commonly referred to as 802.16e). There is growing skepticism in certain circles, however, as to this version's viability as fully mobile solution. It should also be noted 802.16e-2005 is not backwards compatible with 802.16-2004.

Skepticism aside, 802.16e holds great promise for WiMAX. First, there is broad belief that 802.16e will usher in an extensive, holistic product ecosystem for WiMAX. Chipset leaders such as Intel are committed to having 802.16e WiMAX / Wi-Fi chipsets embedded in notebook computers and other devices early in 2008. Cost reductions will be derived from the increased volume and resultant economies of scale. The recently announced NextWave Wireless NW1000 Series WiMAX chipset is geared toward next generation multimedia applications including mobile TV, streaming audio and video, and video surveillance.

While the jury is out on 802.16e as mobility platform, there is no debate with regards to the version's viability as a fixed, nomadic baseline for WiMAX. Many view 802.16e as the birth of WiMAX on a broad, sustainable scale. In fact, many industry experts refer to 802.16e as WiMAX's "Plan of Record".

WireIE contends the mobility 'advantage' is limited to very few real-life applications – voice being the most prevalent[15]. The mobile voice opportunity is questioned in light of the presence of mature, ubiquitous PCS networks worldwide, however. With that in mind, if one removes voice from the WiMAX equation, the requirement for mobility diminishes significantly. While beyond the scope of this paper, the emerging belief is that 802.16e will form the basis for 802.16m – a future iteration of the WiMAX standard where *true* mobility will be supported. Some network infrastructure manufacturers are already claiming a software upgradeable path from 802.16e to 802.16m.

This is not to say that mobile applications on current and near future WiMAX networks will not be supported. The key distinction is the mobile applications with the greatest potential can tolerate brief disruptions in network connectivity. In fact, most mobile data applications are written to tolerate temporary session disruptions. Common scenarios for session disruption include handing-off to another sector, or as the application moves through a null in network coverage and temporarily loses network connectivity. Even if the session is briefly disrupted at the network layer, the application can be sustained until reconnection at the network layer is established. In the case of a hand-off, intelligence in the network's IP core will ensure such a transition is virtually seamless to the application. A comparable scenario is the seamless transition of a data application from a Wi-Fi network to a WiMAX network (and vice versa).

WireIE is of the belief that focusing too much on 'full' mobility in the WiMAX standard could very well take energy and intellectual capital away from building new, unique mobile applications designed to operate on a network where brief session disruption at the network layer is an accepted reality. Put another way, WiMAX and WiMAX / Wi-Fi hybrid networks hold immense potential in supporting new fixed, nomadic and mobile data applications, even without a mechanism for PHY layer hand-off.

WireIE believes WiMAX and WiMAX / Wi-Fi hybrid networks will usher in a wealth of new fixed, nomadic and mobile broadband wireless data applications not previously feasible due to prohibitively costly data plans on PCS networks.

[15] Streaming audio and video are potential applications which may benefit from mobility. These, however, are viewed as fringe applications at this point.

As a standard built for data from the ground up, WiMAX is conducive to supporting such applications. These exciting and vast opportunities will be detailed in a separate white paper from WireIE.

Perhaps another approach to the mobility argument is a pragmatic one. Mobility dramatically changes the cost dynamics for the operator – both from a CAPEX and OPEX perspective. A major attraction of a fixed/nomadic WiMAX network is the comparatively low cost.

A base station is estimated to cost approximately $35,000 (plus antenna and support structure), to cover an area with a radius of 5 – 8 kilometers (i.e.: 44 – 125 square kilometers). Given the increased demands inherent in communicating with mobile clients, the radius of a mobile base station coverage area will likely be reduced to 1.6 – 4.8 kilometers (i.e., 4.8 – 45 square kilometers), resulting in greater base station density. More base stations also mean increased backhaul costs, as the network will have to be centrally controlled to manage handoffs, along with interconnection with the PSTN (Public Switched Telephone Network).

Finally, on the assumption all agree WiMAX support for 'full' mobility only benefits mobile voice, perhaps sparse commitments from handset manufacturers for 802.16e mobile product will put the discussion off until 802.16m is ratified[16].

While on the subject of voice, WireIE enthusiastically promotes fixed and nomadic VoIP applications on a WiMAX or WiMAX / Wi-Fi hybrid network. These vast and exciting opportunities will be the subject of a future paper.

WiMAX's 700 MHz Panacea

The FCC in the United States is auctioning off spectrum in the 700 MHz band formally occupied by analog UHF television. License(s) are expected to be awarded in Q1, 2008 with the spectrum being released on February 17, 2009.

This spectrum has been dubbed "Prime Waterfront Real Estate" by industry analysts because of its desirable propagation characteristics. Coverage per sector is much greater than microwave frequency bands currently allocated to WiMAX. The band also has a much greater tendency to penetrate buildings and will even *bend* over hills to a certain extent. Assuming all coverage objectives are equal, cell density can be reduced significantly when using 700 MHz, thereby reducing deployment and operating costs. Frequency reuse becomes more critical in the 700 MHz band, however. Whereas microwave propagation is highly predictable, the tendency of 700 MHz signals to bend over the horizon and penetrate buildings means co-channel and adjacent channel locations need greater study during the cell planning process.

A key criterion of the FCC in the auction is the degree of openness each bidder has to releasing restrictions on new applications and devices. Leading search engine and online application provider, Google, are bidding against incumbent telcos. Google's offering in this space promises to be radically innovative whereas the telcos are rumored to want the spectrum merely for expanding legacy services. Consumers, particularly younger consumers, consistently complain the incumbents lack agility when it comes to offering new services and technologies. The explosive popularity of innovative services such as Skype and YouTube (among countless others) validates this assertion.

Google's mission is to "organize the world's information and make it universally accessible and useful". To date this has all occurred at the application layer with arguably exceptional innovation and utility. As it has grown in recent years, Google has been acquiring dark fiber across the United States. The prospect of owning the 'last mile' through the 700 MHz band (supported by these expansive fiber facilities) would give Google direct access to their consumers.

[16] Targeted for late 2009. More likely early 2010.

The current model where the ISP (Internet Service Provider) is an intermediary, and not always a friendly one at that[17], all but disappears. This brings a radical new dimension and unprecedented opportunities for new applications through Google. One of the obvious applications is voice but analysts anticipate voice services through Google would be innovative and novel.

While premature to confirm, WiMAX is the obvious technology on which Google would offer these wireless services. Google's alliance with Sprint/Nextel WiMAX announced in July 2007 adds fuel to the speculation that, should they be the successful bidder for 700 MHz, WiMAX would be the technology of choice.

Jurisdictions outside of the US may opt to use 700 MHz for domestic broadband wireless services with WiMAX being the natural access technology of choice. Analyst's remarks in reference to "Google World Domination" are likely from a very US-centric perspective, although having said that, Google would only benefit by having its wireless presence world-wide. Their challenge of course is radio spectrum is controlled by national governments and foreign ownership of spectrum is closely controlled in most countries.

Ensuring WiMAX Equipment Integrity and Interoperability

One of the lessons learned from early Wi-Fi days was the need for an independent, objective body to oversee equipment standards compliance, conduct interoperability testing and certify as appropriate. The WiMAX Forum was created to address such needs. The WiMAX Forum has more than 470 members including network operators, along with component and equipment manufacturers.

The WiMAX Forum is an industry-led, not-for-profit organization based upon the harmonized IEEE 802.16/ETSI[18] HiperMAN standard. Products meeting WiMAX Forum certification criteria are viewed to be fully interoperable.

The WiMAX Forum's mission is to "promote and accelerate the introduction of cost-effective broadband wireless access services into the marketplace". It adds, "Standards-based, interoperable solutions enable economies of scale that, in turn, drive price and performance levels unachievable by proprietary approaches, making WiMAX Forum Certified products the most competitive at delivering broadband services on a wide scale".

THE WIMAX USER EXPERIENCE

WiMAX Delivery of Broadcast and Multicast Multimedia

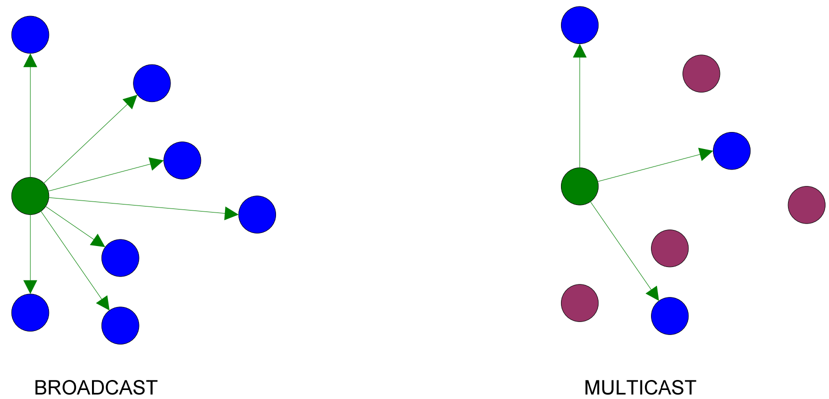
Consumer appetite for multimedia content is growing rapidly. While high mobility alternatives to conventional radio and television have not been technologically feasible up to this point, WiMAX offers a genuine opportunity to change that.

WiMAX can be used as a digital broadcast mechanism through a Single Frequency Network (SFN). This approach assumes a simplex downlink where data (in this case the multimedia content) is streamed to the user through multiple base stations on the network, all using the same RF channel. The protocol assumes the user need not transmit acknowledgements back to the base station as would be the case in interactive duplex mode applications such as web browsing or email activity. Unlike conventional analogue broadcasting where a single site typically transmits the content, multiple WiMAX base stations transmit the content – all using the same RF channel.

[17] In recent years, commentators on the two-tiered internet / net neutrality debate often use an example where the ISP would apply a price premium to Google because of its vast popularity and resultant high network traffic.
[18] European Telecommunications Standards Institute.

Not only does the SFN approach optimize spectral efficiency, it also makes user transition from one sector to another virtually seamless. The SFN approach has never been feasible with conventional analog broadcasting modulation techniques (and most digital telephony modulation schemes) because of issues around co-channel interference[19]. The WiMAX modulation scheme, known as OFDM (Orthogonal Frequency-Division Multiplexing) is conducive to an SFN because the modulation is spread spectrum, making co-channel interference a non-issue.

A variation on the broadcast model is what is known as multicast. Whereas broadcast assumes a one-to-all model, multicast assumes one-to-many. Business cases for multimedia would determine the suitability of one model over the other. The two are contrasted below.



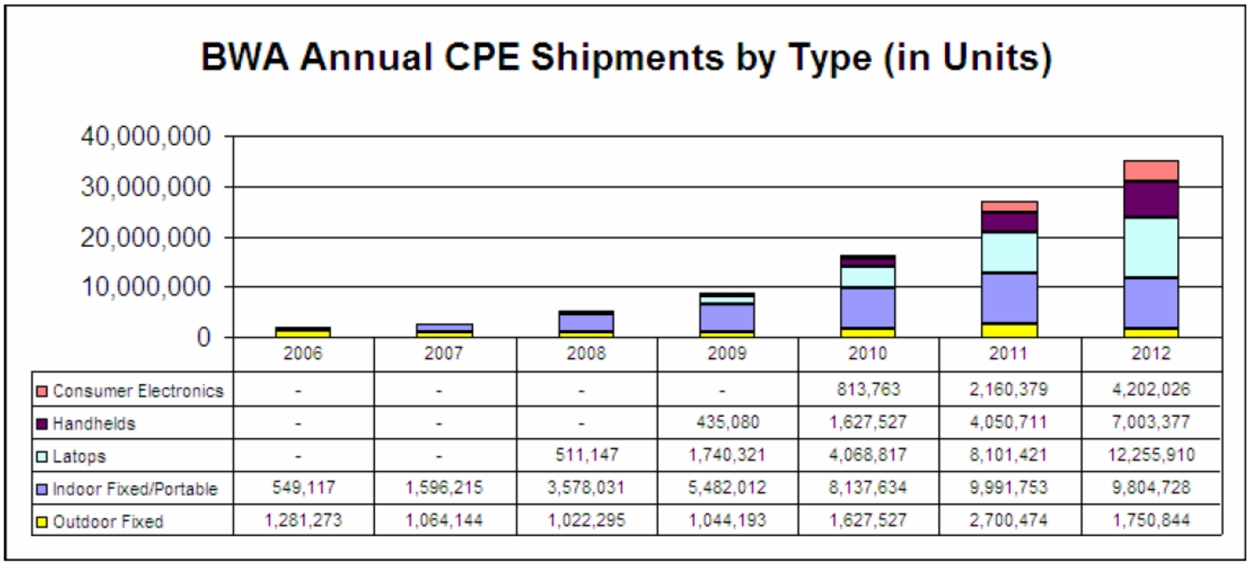
Embedding WiMAX in Consumer Electronics

Apple's recent announcement of wireless access to the iTunes Store via some of their Wi-Fi equipped media players is a bellwether sign. In addition to purchasing music wirelessly, a groundswell of consumer electronic devices have embedded Wi-Fi for direct content upload[20]. WiMAX's capacity, wide coverage and tight integration with 802.11 are opening new possibilities for sharing content.

The WiMAX vendor ecosystem in support of the consumer electronics industry is substantial. Six of the world's top ten semiconductor companies are either producing actual products or have a WiMAX strategy. Fifty WiMAX embedded consumer electronics products have already been announced. As this trend takes hold, the concept of using a computer as an intermediary device to transfer content from a consumer electronics device (such as a digital camera) to a sharing environment on the web will all but disappear. Key consumer electronics categories for WiMAX include cameras, camcorders, portable media players, vehicle multimedia systems, gaming platforms, computers, smart phones and PDAs[21].

[19] Some FM radio broadcasters use two or more carefully situated synchronized co-channel transmitters – usually with mixed results. Topological isolation is critical and the inevitable 'contention zone' between transmitters is usually rife with co-channel interference. Variations in propagation due to seasonal 'ducting' in the troposphere further aggravate the situation.
[20] Nikon's Wi-Fi embedded Coolpix S51c with Flickr integration is but one example.
[21] Courtesy of Maravedis Telecom Market Research and Analysis.

BWA CPE FORECAST



	2006	2007	2008	2009	2010	2011	2012
Consumer Electronics	-	-	-	-	813,763	2,160,379	4,202,026
Handhelds	-	-	-	435,080	1,627,527	4,050,711	7,003,377
Latops	-	-	511,147	1,740,321	4,068,817	8,101,421	12,255,910
Indoor Fixed/Portable	549,117	1,596,215	3,578,031	5,482,012	8,137,634	9,991,753	9,804,728
Outdoor Fixed	1,281,273	1,064,144	1,022,295	1,044,193	1,627,527	2,700,474	1,750,844

Maravedis Telecom Market Research and Analysis

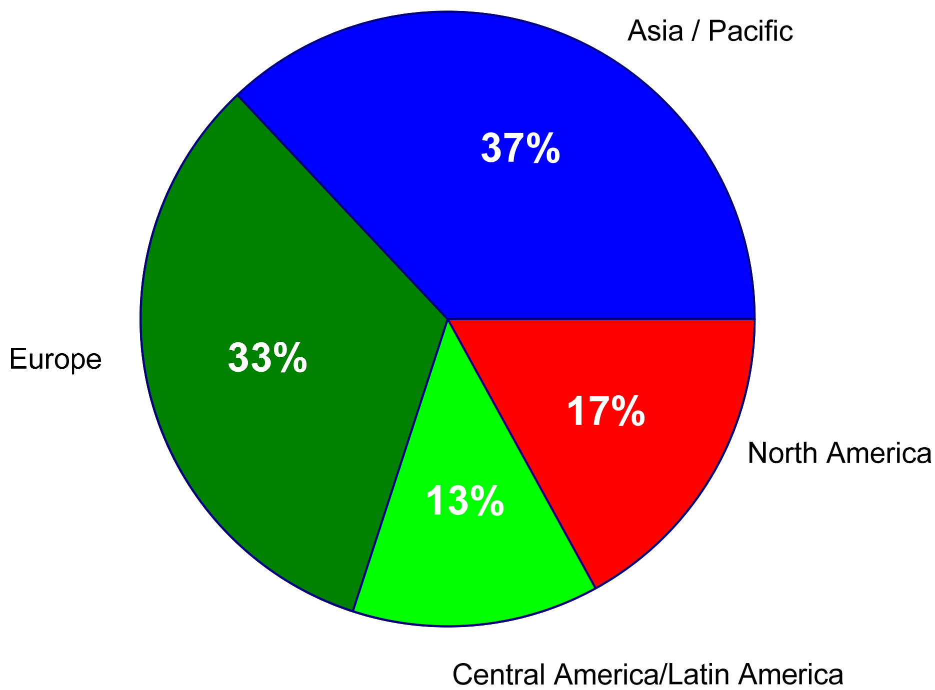
WIMAX MARKET TRENDS

Leading Broadband Wireless research firm Maravedis Market Research & Analysis has uncovered the following findings[22] through their comprehensive online database, *WiMAX Counts*:

- 950,000 BWA/WiMAX subscribers worldwide as of March 31, 2007
- Subscriber Growth: 85% from Q1 2006 to Q1 2007
- Customer mix: 58% residential and 42% business
- Monthly Residential ARPU: $40.76 (US)
- Monthly Business ARPU: $145.54 (US)
- $322 million (US) in service revenue in year 2006
- Deployments are still modest and dominated by business DSL last mile connectivity
- Bandwidth consumed by WiMAX subscribers is very similar to DSL and cable
- Prices charged by WiMAX operators are comparable to DSL and cable
- WiMAX operators are generating attractive ARPU selling fixed/portable services today

[22] Used with permission.

WIMAX MARKET DISTRIBUTION



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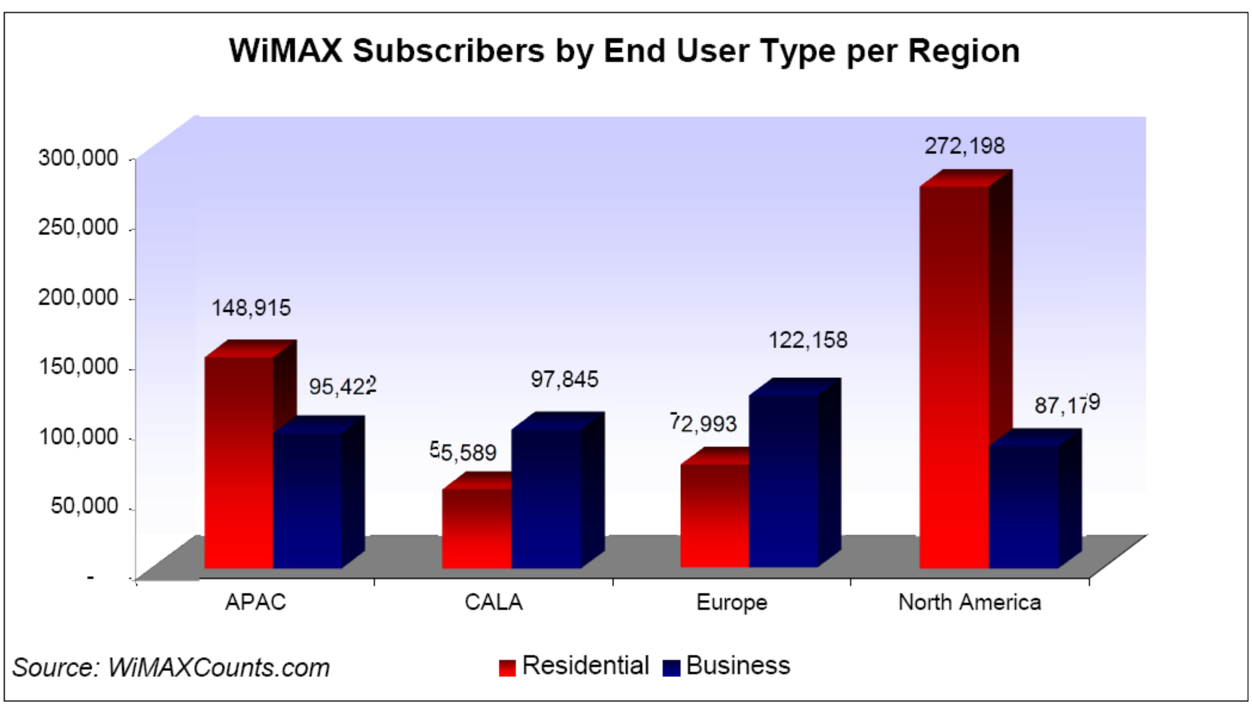

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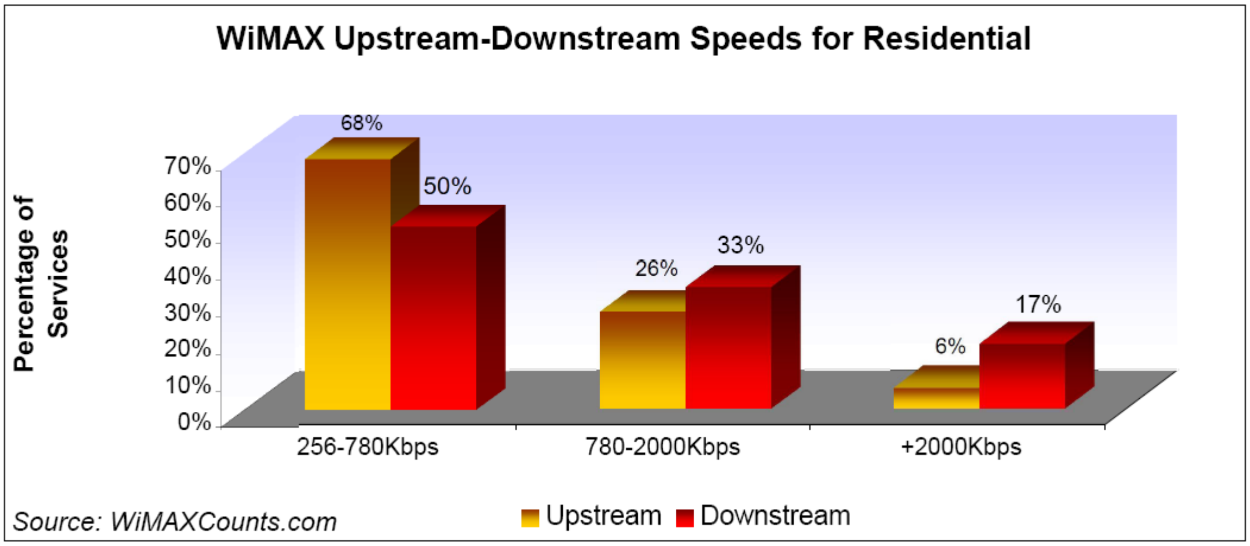

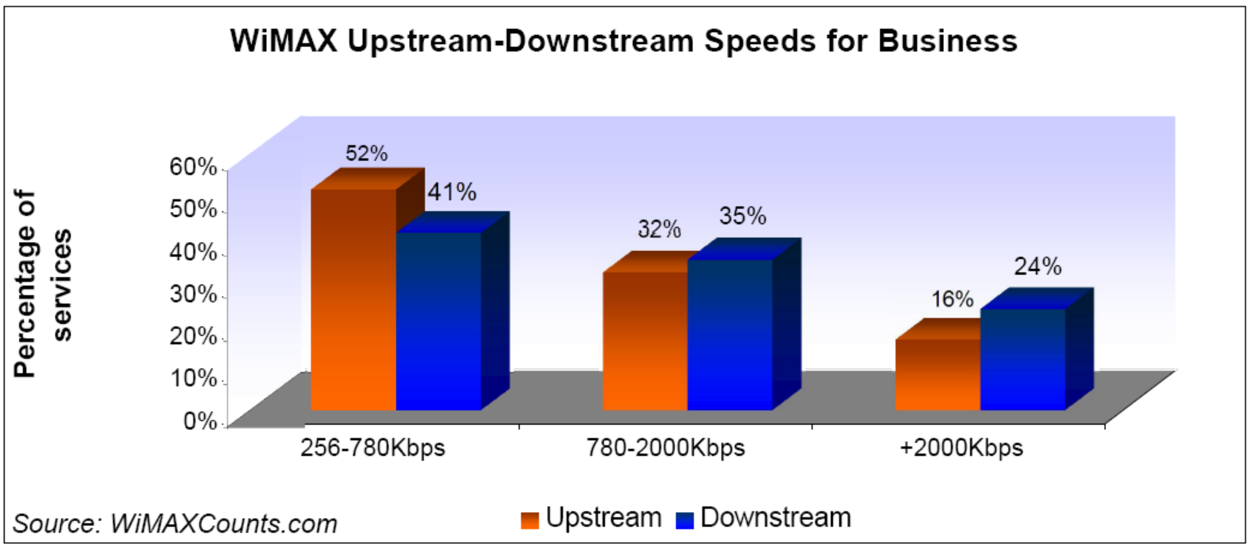

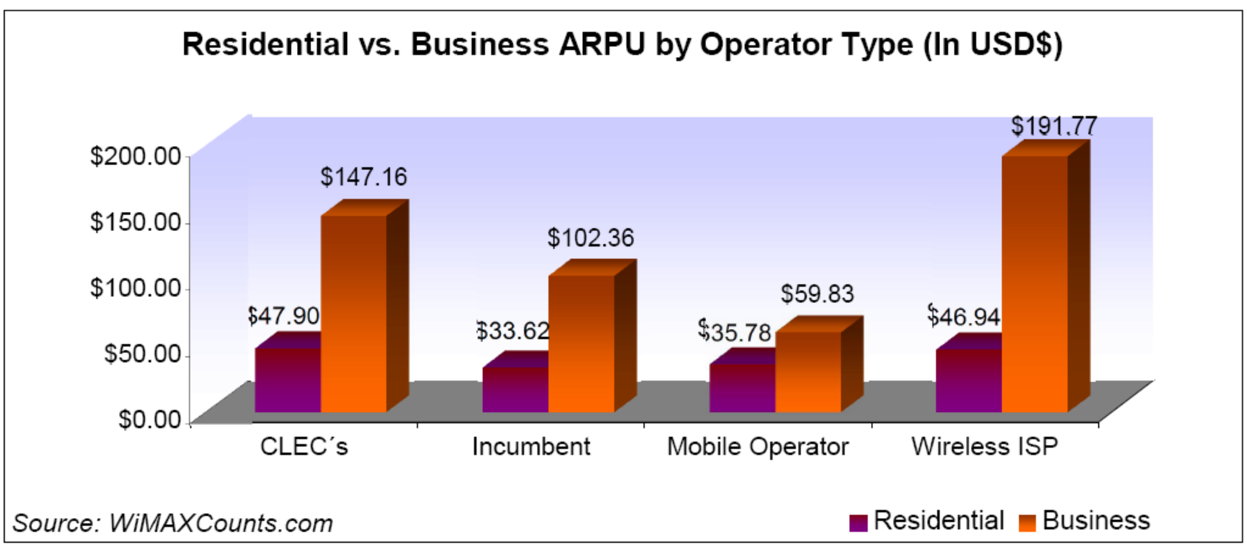

All Charts Used with Permission, Courtesy of Maravedis Telecom Market Research and Analysis.

CONCLUSION

WiMAX holds immeasurable promise as a high capacity, wide coverage broadband wireless standard. The 802.16e-2005 (802.16e) release of the standard places a solid stake in the ground from which network operators can feel confident deploying a future-proof version of WiMAX. CPEs will be abundant, diverse and affordable. Many consumer devices will have an embedded chipset that supports both WiMAX 802.16e-2005 and Wi-Fi. In addition, economies of scale will see WiMAX network equipment costs come down.

Opportunities associated with WiMAX / Wi-Fi hybrid networks are virtually limitless. Countless enterprise applications that up until now have been cost prohibitive from an OPEX perspective will be revived while many new applications will also emerge.

Where appropriate, WiMAX will be used as a reliable backhaul, be it in support of the WiMAX network itself, or potentially an unrelated network such as PCS.

The internet's infinite power to inform and entertain will no longer be constrained by a wired connection, or a costly wireless data plan from a telco. With WiMAX, the day of affordable, unencumbered, ubiquitous, fast internet access is finally here.

ABOUT WIREIE

As an international wireless professional services company, WireIE specializes in the cradle-to-grave deployment of wireless networks including: Site Acquisition, RF Design, IP Core Network Design, Furnish and Installation of network infrastructure, along with Network Monitoring services and Billing solutions. These comprehensive services are supported by leasing options for the operator. In addition, WireIE offers extensive consulting expertise in enterprise wireless solutions.

Our company prides itself on being vendor agnostic and is completely focused on our client needs in offering a whole product solution.

WireIE has offices in Toronto and Barbados, along with an affiliate office in Orlando, Florida.

APPENDIX A: CONTRASTING 802.16-2004 & 802.16E-2005

	802.16-2004	802.16e-2005
Multiple Access Method	OFDM / OFDMA[1]	S-OFDM
Bandwidth Supported (MHz)	1.75/3/3.5/5.5/7 (OFDM)[1] 1.25/3.5/7/14/28 (OFDMA) [1]	1.25/2.5/5/10/20 1.75/3/3.5/5.5/7
FFT Size	256 (OFDM) / 2048 (OFMDA)[1]	128/256/512/1024/2048
Sub-carrier Spacing (kHz)	22.5 (OFDM @ 5 MHz)[1] 2.8 (OFDMA @ 5 MHz)	11.2
Duplexing	FDD/TDD/Half Duplex FDD[2]	FDD/TDD/Half Duplex FDD
Frame Duration (ms)	2/2.5/4/58/10/12.5/20	2/2.5/4/58/10/12.5/20
Channel Coder	Concatenated Convolutional RS code, Block TC, CTC[2]	Concatenated Convolutional RS code, Block TC, CTC, LDPC
Sub-channelization (DL)	FUSC/PUSC/Band AMC	FUSC/PUSC/Band AMC
Sub-channelization (UL)	PUSC/Optional PUSC	PUSC/Optional PUSC
HARQ Support	Yes (2048 OFDMA only)[1]	Yes
Fast CQI Feedback	Yes (2048 OFDMA only)[1]	Yes
AAS	Yes	Yes
STC support	2/4 Antennas	2/3/4 Antennas
Frequency reuse	1 cell reuse not supported	1 cell reuse can be supported
Mobility / Handoff Support	No	Yes
Sleep Modes	No	Yes
Sounding Channel	No	Yes
Multicast/Broadcast Support	No	Yes

NOTES

1	Only OFDM 256 FFT specified in WiMAX 802.16d profiles
2	802.16d profiles specify both TDD & FDD; draft WiMAX profiles for 802.16e specify TDD
3	Turbo Codes specified but not expected in first generation products

Courtesy of Motorola, White Paper: "WiMAX: E vs. D: The Advantages of 802.16e over 802.16d"

APPENDIX B: TERMS & ACRONYMS

TERM	EXPLANATION
3GPP	Third Generation Partnership Project
3GPP2	3G Partnership Project 2
AAS	Adaptive Antenna System also Advanced Antenna System
ACK	Acknowledge
AES	Advanced Encryption Standard
AG	Absolute Grant
AMC	Adaptive Modulation and Coding
A-MiMO	Adaptive Multiple Input Multiple Output (Antenna)
AP	Access point
ARQ	Automatic Repeat reQuest
ASM	Adaptive MIMO Switching
ASN	Access Service Network
ASP	Application Service Provider
BE	Best Effort
BRAN	Broadband Radio Access Network
BS	Base station
BSU	Base station unit
BWA	Broadband Wireless Access
CC	Chase Combining (also Convolutional Code)
CCI	Co-Channel Interference
CCM	Counter with Cipher
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CINR	Carrier to Interference + Noise Ratio
CMAC	Cipher Based Media Access Control
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CSMA/CA	Carrier sense multiple access with collision avoidance
CSMA/CD	Carrier sense multiple access with collision detection
CSN	Connectivity Service Network
CSTD	Cyclic Shift Transmit Diversity
CTC	Convolutional Turbo Code
DL	Downlink
DOCSIS	Data over Cable Service Interface Specification
DSL	Digital Subscriber Line
DSSS	Direct sequence spread spectrum
DVB	Digital Video Broadcast
EAP	Extensible Authentication Protocol
EESM	Exponential Effective SIR Mapping
EIRP	Effective Isotropic Radiated Power
ErtVR	Extended Real Time Variable Rate
ETSI	European Telecommunications Standards Institute
FBSS	Fast Base Station Switch
FCC	Federal Communications Commission
FCH	Frame Control Header
FDD	Frequency Division Duplex

TERM	EXPLANATION
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
FUSC	Fully Used Sub Channel
GPS	Global Positioning System
HARQ	Hybrid Automatic Repeat reQuest
HHO	Hard Hand Off
HiperMAN	High Performance Metropolitan Area Network
HMAC	keyed Hash Message Authentication Code
HO	Hand Off
HTTP	Hyper Text Transfer Protocol
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IEFT	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IMS	IP Multimedia subsystem. An architectural framework for delivering internet protocol (IP) multimedia to mobile users. Developed under 3GPP and is an evolution of 3G mobile networks beyond GSM.
IP	Internet Protocol
IR	Incremental Redundancy
ISI	Inter Symbol Interference
LAN	Local area network
LDPC	Low Density Parity Check
LOS	Line of Sight
LTE	Long Term Evolution. Specification defined by 3GPP for next evolution mobile communication systems. A complementary framework for core network evolution based on IP and incorporating IMS.
MAC	Media Access Control
MAI	Multiple Access Interference
MAN	Metropolitan area network
MAP	Media Access Protocol
MBS	Multicast and Broadcast Service
MDHO	Macro Diversity Hand Over
MIMO	Multiple Input Multiple Output (Antenna)
MMS	Multimedia Message Service
MPLS	Multi Protocol Label Switching
MS	Mobile Station
MSO	Mobile Switching Office
MSO	Multi Services Operator
NACK	Negative Acknowledge
NAP	Network Access Provider
NLOS	Non Line of Site
NRM	Network Reference Model
nrtPS	Non Real Time Packet Service
NSP	Network Service Provider
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
P2MP	Point to Multipoint
P2P	Point to Point
PAN	Personal area network
PER	Packet Error Rate

TERM	EXPLANATION
PF	Proportional Fair (Scheduler)
PHY	Physical layer
PKM	Public Key Management
PoP	Point of presence
PUSC	Partially Used Sub Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of service
QPSK	Quadrature Phase Shift Keying
RF	Radio frequency
RG	Relative Grant
RR	Round Robin (Scheduler)
RRI	Reverse Rate Indicator
RTG	Receive/transmit Transition Gap
rtPS	Real Time Packet Service
RUIM	Removable User Identify Module
SDMA	Space (or Spatial) Division (or Diversity) Multiple Access
SF	Spreading Factor
SFN	Single Frequency Network
SGSN	Serving GPRS Support Node
SHO	Soft Hand Off
SIM	Subscriber Identify Module
SINR	Signal to Interference + Noise Ratio
SISO	Single Input Single Output (Antenna)
SLA	Service Level Agreement
SM	Spatial Multiplexing
SMS	Short Message Service
SNIR	Signal to Noise + Interference Ratio
SNR	Signal to Noise Ratio
S-OFDMA	Scalable Orthogonal Frequency Division Multiple Access
SS	Subscriber station
STC	Space Time Coding
TDD	Time Division Duplex
TEK	Traffic Encryption Key
TTG	Transmit/receive Transition Gap
TTI	Transmission Time Interval
TU	Typical Urban (as in channel model)
UE	User Equipment
UGS	Unsolicited Grant Service
UL	Uplink
UMTS	Universal Mobile Telephone System
USIM	Universal Subscriber Identify Module
UWB	Ultra Wide Band
VLAN	Virtual Local Area Network
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VSF	Variable Spreading Factor
WAN	Wide area network
WAP	Wireless Application Protocol

TERM	EXPLANATION
WDSL	Wireless DSL
WiBro	Wireless Broadband (Service)
Wi-Fi	Wireless fidelity. Used generically when referring to any type of 802.11 network
WiMAX	Worldwide Interoperability for Microwave Access
WISP	Wireless Internet service provider
WLAN	Wireless local area network
WMAN	Wireless metropolitan area network
WWAN	Wireless wide area networks