WiMAX: Features and Applications

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***Cuvinte cheie**. WiMAX, Mobile WiMAX, comparații WiMAX/WiFi*

***Rezumat**. Lucrarea prezintă principalii parametri ai tehnologiei WiMAX şi apreciază rolul ei în ansamblul tehnologiilor moderne de comunicații. Sunt realizate comparații cu tehnologia WiFi şi se subliniază principalele avantaje ale variantei pentru comunicatâții mobile (Mobile WiMAX). În final sunt discutate posibilele evoluții ale standardului.*

***Key words**. WiMAX, Mobile WiMAX, comparisons WiMAX/WiFi*

***Abstract.** The main technical parameters of the WiMAX technology are presented and its role in the modern communication technologies is envisaged. Comparisons with WiFi technology are made and the main advantages of its variant for mobile com-munications (Mobile WiMAX) are underlined. Finally, future development of the standard are discussed.*

1. Introduction

WiMAX (**W**orldwide **I**nteroperability for **M**icrowave **A**cce**ss**) is a relatively new standard based on the IEEE 802.16 family of Wireless MAN (Metropolitan Access Networks) standards [1], [2], [3]. It is data-centric and aimed at fixed and mobile applications. It fills the gap between low mobility data-centric standards such as IEEE 802.11 (WLAN - Wireless Local Area Network) and high mobility voice-centric standards such as GSM. Other standards fit within this category such as 3G and their future versions, but the market in this area is big, enabling several players to co-exist.

IEEE 802 refers to a family of IEEE standards dealing with local area networks and metropolitan area networks. More specifically, the IEEE 802 standards are restricted to networks carrying variable-size packets. The number 802 was simply the next free number IEEE could assign, though "802" is sometimes associated with the date the first meeting was held (February 1980). The services and protocols specified in IEEE 802 map to the lowest two layers (Data Link and Physical) of the seven-layer OSI networking reference model. IEEE 802 splits the OSI Data Link Layer into two sub-layers denoted as Logical Link Control (LLC) and Media Access Control (MAC), respectively.

WiMAX describes the interoperable implementations of IEEE 802.16 wireless networks [4], [5], [6]. It promises to solve the distance limitations of Wi-Fi (802.11) by offering 70 Mbps speeds station - a sufficient amount of bandwidth to simultaneously support hundreds of businesses with T1/E1-type connectivity and thousands of homes with DSL-type connectivity - with a single base station over a 50 Kilometers of service area, allowing users to get broadband connectivity without the need of direct line-of-sight (LOS) to the base station. It provides interoperable broadband wireless connectivity to fixed, portable and nomadic users. The technology also promises to enable operators to rollout the network at significantly lower costs than wired broadband or 3G. So WiMAX is a high-capacity, open standard, IP-based technology that

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can be deployed as a new network installation or as an overlay to complement existing 2G or/and 3G wireless networks. In either case WiMAX networks are capable of interworking with cellular and wired networks. High speed Internet access, services and applications supported by WiMAX can deliver higher revenues per user, new subscribers, lower churn, and additional revenues from wholesale and new service partners.

The massive range and the high speeds claimed by the WiMAX proponents do not reflect, however, the actual performance that can be experienced by users in field deployments [7], [8]. The often-mentioned 70 Mbps speed on a WiMAX network is the total shared bandwidth capacity available to multiple users on a 2 x 20 MHz frequency spectrum. Actually, per user data rates are likely to be around 1–3 Mbps only. The promised 50 Km range can be reached only in LOS deployments, which are not possible in most areas due to obstructions presented by buildings and trees. Practical deployments indicate that coverage of 1–3 Km in urban areas and 5–10 Km in rural areas are more realistic limits [9], [10]. Expectations of rolling out WiMAX networks, using a few radio towers to cover a large city and offering DSL-type speeds are not feasible yet.

WiMAX seeks to build on the success of established business models that have reaped benefits in the field. WiMAX represents a significant leap forward in ensuring the standardization of the Wireless MAN protocols. OFDM and NLOS (non-LOS) technology can be used to backhaul 802.11 hotspots and WLANs to the Internet, provide campus connectivity, and enable a wireless alternative to cable and DSL for last mile broadband access.

Similar to IEEE 802.16 is the European (ETSI) standard **HiperMAN**. WiMAX and HiperMAN are partially based on same IEEE standards.

HiperMAN and WiMAX selected the common mode of operation of these two standards, that is 256FFT OFDM. Concentrated in 2-11 GHz Wireless MAN, it has the following set of features:

- Service area range 50 Km;
- NLOS operation;
- QoS (Quality of Service) designed in for voice/video, differentiated services;
- Very high spectrum utilization: 3.8 bit/Hz;
- Up to 280 Mbps per base station;
- True broadband for portable users - based on IEEE 802.16e connectivity for laptops and PDAs (Personal Digital Assistant) with integrated WiMAX technology.

WiBro [11] is the service name for Mobile WiMAX in Korea and uses the same standards, system and certification profiles and certification processes as Mobile WiMAX. It has the same functionality defined by the Mobile WiMAX system profile, with identical PHY, MAC and Power Classes, uses equipment to be certified under one of the Mobile WiMAX certification profiles that designate frequency, duplexing and bandwidth requirements. The Koreans sought to develop WiBro as a regional and potentially international alternative to 3.5G or 4G cellular systems. But given the lack of momentum as a standard, WiBro has joined WiMAX and agreed to harmonize with the similar OFDMA 802.16e version of the standard. WiBro will go up against 3G and very high bandwidth wire-line services rather than as gap-filler or rural under-served market deployments as is often exampled as the 'best fit' markets for WiMAX.

2. Spectrum allocation issues

The 802.16 specification applies across a wide swath of the RF spectrum. However, there is no uniform global licensed spectrum for WiMAX (Table 1 and Table 2). Each geographical region defines and

regulates its own set of licensed and license-exempt bands. In the US, the biggest segment available is around 2.5 GHz and it is already assigned. Elsewhere in the world, the most bands used are around 3.5 GHz, 2.3/2.5 GHz or 5 GHz, with 2.3/2.5 GHz being most important in Asia. In addition, several companies have announced plans to utilize the WiMAX standard in the 1.7/2.1 GHz spectrum band for the deployment in USA of "Advanced Wireless Services" (AWS). There are several variants of 802.16, depending on local regulatory conditions and thus on which spectrum is used, even if everything but the underlying radio frequencies is the same. WiMAX equipment is not, therefore, as portable as it might have been - perhaps even less so than Wi-Fi, whose assigned channels in unlicensed spectrum vary little from jurisdiction to jurisdiction. The actual radio bandwidth of spectrum allocations is also likely to vary.

Table 1

WiMAX band allocation around the World

Country/Geographic area	Bands Used
North America , Mexico	2.5GHz and 5.8GHz
Central and South America	2.5GHz , 3.5GHz and 5.8GHz
Western and Eastern Europe	3.5GHz and 5.8GHz
Middle East and Africa	3.5GHz and 5.8GHz
Asian Pacific	3.5GHz and 5.8GHz

Table 2

Frequency bands' availability for WiMAX

Band	Frequencies	License required	Availability
2.5 GHz	2.5 to 2.69 GHz	Yes	Allocated in Brazil, Mexico, some Southeast Asian countries and the U.S. (The WiMAX Forum also includes 2.3 GHz in this band category because it expects to cover 2.3 GHz with the 2.5 GHz radio.)
3.5 GHz	3.3 to 3.8 GHz but primarily 3.4 to 3.6 GHz	Yes , in some countries	In most countries the 3.4 GHz to 3.6 GHz band is allocated for broadband wireless
5 GHz	5.25 to 5.85 GHz	No	In the 5.725 GHz to 5.85 GHz portion many countries allow higher power output (4 watts) which can improve coverage

Because WiMAX's goal is to promote the interoperability of equipment based on either the 802.16d or HiperMAN standards, the WiMAX Forum has chosen to support the 256 OFDM mode exclusively and to only certify equipment supporting that particular PHY mode. Wi-Fi 802.11a and 802.11g also use OFDM and have established an excellent performance record for robust wireless networking. However, Wi-Fi uses 64 OFDM.

The frequency band between 10 and 66 GHz is provided for LOS solutions for a variety of licensed frequencies (10.5, 25, 26, 31, 38 and 39 GHz) and the 2 to 11 GHz frequency band for NLOS solutions over both licensed and license-exempt frequencies. The minimum channel bandwidth for WiMAX is 1.75 MHz per channel, 10 MHz being considered as an optimum. It remains to be seen what impact potential interference may have, especially on QoS commitments.

WiMAX equipment operating in license-exempt frequency bands uses time-division duplexing (TDD) and equipment operating in licensed frequency bands uses either TDD or frequency-division duplexing (FDD).

3. The 802.16 standards and deployment evolution

WiMAX has two versions: one based on the IEEE 802.16 standard for fixed networks and another on the IEEE 802.16e standard for mobile networks, which is the latest. This version also supports a form of multiple-input-multiple-output (MIMO), so more than one receiver might be needed in the mobile device.

IEEE 802.16 was originally design to be a radio standard for cost-effective last-mile broadband connectivity to users not served by wired broadband such as DSL or cable. By now, this WMAN (Wireless MAN) standard is addressing a broader market for mobile, low-cost, high-speed broadband connections. It is optimized for high, bursty data-rates, but can simultaneously support real-time multimedia and isochronous applications such as Voice-over-IP (VoIP).

The current 802.16 standard is IEEE 802.16e-2005, approved in December 2005. It followed on from IEEE 802.16-2004 (known as "fixed" or "nomadic" WiMAX), which replaced IEEE Standards 802.16-2001 (the original WiMAX standard for the 10 to 66 GHz), 802.16c-2002, and 802.16a-2003. IEEE 802.16-2004 (also known as 802.16d) addresses only fixed systems. 802.16e adds mobility components to the standard.

IEEE 802.16e-2005 (known as 802.16e or Mobile WiMAX) provides an improvement on the modulation schemes stipulated in the original (fixed) WiMAX standard. The WiMAX standard enables system vendors to create many different types of WiMAX-based products, including various configurations of base stations and customer premise equipment (CPE).

WiMAX supports a variety of wireless broadband connections:

- High-bandwidth MANs to home and small-business users, replacing DSL and cable modems;
- Backhaul networks for cellular base stations, bypassing the public switched telephone network.

WiMAX's channel sizes range from 1.25 MHz to 20 MHz, giving a WiMAX network the flexibility to support a variety of data rates such as T1 (1.5Mbps) and higher. This flexibility allows WiMAX to adapt to the available spectrum and channel widths in different countries or licensed to different service providers. Equally important, quality-of-service features ensure high performance for voice and video.

WiMAX employs 64-state quadrature amplitude modulation (64QAM) and orthogonal frequency-division multiplexing (OFDM), which together demand exceptionally high linearity so the subcarrier spacing (Δf) is set to 10 KHz. WiMAX systems also require good error-vector-magnitude (EVM) performance as a benchmark of modulation fidelity.

For fixed wireless and mobile NLOS applications OFDMA can be used. SOFDMA (Scalable OFDMA) improves upon OFDM256 for NLOS applications. This can be made utilizing advanced antenna diversity schemes, and hARQ (hybrid-Automatic Retransmission Request). Using high-performance coding techniques such as Turbo Coding and Low-Density Parity Check (LDPC) will enhance security and NLOS performance. Using downlink sub-channelization, allow administrators to trade coverage for capacity or vice versa. For improved coverage there were introduced Adaptive Antenna Systems and MIMO technologies that eliminate channel bandwidth dependencies on sub-carrier spacing and allow for equal performance under any RF channel spacing (1.25-20 MHz). This brings potential benefits in terms of coverage, self installation, power consumption, frequency re-use and bandwidth

efficiency. Enhanced Fast Fourier transform (FFT) algorithm can tolerate larger delay spreads, increasing resistance to multipath interference [12].

In the case of 802.16d and 802.16e standards the lower frequencies suffer less from inherent signal attenuation and therefore give improved range and in-building penetration.

Systems based on the IEEE 802.16-2004 standard are the only standardized OFDM based Wireless MAN platforms. In the case of 802.16-2004, the OFDM signal is divided into 256 carriers instead of 64 as with the 802.11 standard. As previously stated, the larger number of subcarriers over the same band results in narrower subcarriers, which is equivalent to larger symbol periods. The same percentage of guard time or cyclic prefix (CP) provides larger absolute values in time for larger delay spread and multi-path immunity.

The minimum received signal in the downlink direction is ~91 dBm. The standard specifies the maximum adjacent channel rejection to be 11 dB.

The specifications for IEEE802.11a and IEEE802.16e receivers are shown in Table 3.

Table 3

IEEE Design Specifications for WiFi and WiMAX

Modulation	Coding Rate	SNR (dB)		Input Sensitivity (dBm)	Data Rate (Mbps)
		WiFi	WiMAX		
QPSK	1/2	5	5	–80	12
	3/4	7	8	–78	18
16-QAM	1/2	10	10,5	–73	24
	3/4	14	14	–71	36
64-QAM	1/2	18	18	–66	48
	3/4	19	20	–65	54

The standard improves in several key aspects, but mainly in *multi-path interference, delay spread,* and *robustness*.

Multi-path interference and delay spread improve performance in situations where there is not a direct line-of-sight path between the base station and the subscriber station. The 802.16-2004 MAC is optimized for long-distance links because it is designed to tolerate longer delays and delay variations. The 802.16 specification accommodates MAC management messages that allow the base station to query the subscriber station, but there is a certain amount of time delay. The standard covers both the MAC and the PHY (PHysical laYer). A number of PHY considerations were taken into account for the target environment. At higher frequencies, line of sight is a must. This requirement eases the effect of multipath, allowing for wide channels, typically greater than 10 MHz in bandwidth. This gives IEEE 802.16 the ability to provide very high capacity links on both the uplink and the downlink.

The original IEEE 802.16 MAC was enhanced to accommodate different PHYs and services, which address the needs of different environments. The standard is designed to accommodate either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD) deployments, allowing for both full and half-duplex terminals in the FDD case.

4. MAC

The MAC was designed specifically for the PMP (Point-to-MultiPoint) wireless access environment. It supports higher layer or transport protocols such as

ATM (Asynchronous Transfer Mode), Ethernet or IP (Internet Protocol), and is designed to easily accommodate future protocols that have not yet been developed. The MAC is designed for very high bit rates (up to 268 Mbps each way) of the truly broadband PHY, while delivering ATM compatible QoS; the frame structure allows terminals to be dynamically assigned uplink and downlink burst profiles according to their link conditions. This allows a trade-off between capacity and robustness in real-time, and provides roughly a two times increase in capacity on average when compared to non-adaptive systems, while maintaining appropriate link availability.

The 802.16 MAC uses a variable length PDU (Protocol Data Unit) along with a number of other concepts that greatly increase the efficiency of the standard. Multiple MAC PDUs may be concatenated into a single burst to save PHY overhead. Additionally, multiple SDU (Service Data Unit) for the same service may be concatenated into a single MAC PDU, saving on MAC header overhead. Fragmentation allows very large SDUs to be sent across frame boundaries to guarantee the QoS of competing services. And payload header suppression can be used to reduce the overhead caused by the redundant portions of SDU headers. The MAC uses a self-correcting bandwidth request/grant scheme that eliminates the overhead and delay of acknowledgements, while simultaneously allowing better QoS handling than traditional acknowledged schemes. Terminals have a variety of options available to them for requesting bandwidth depending upon the QoS and traffic parameters of their services. They can be polled individually or in groups, can steal bandwidth already allocated to make requests for more, can signal the need to be polled, and they can piggyback requests for bandwidth.

5. Competing technologies

Within the marketplace, WiMAX's main competition comes from widely deployed wireless systems with overlapping functionality such as UMTS and cdma2000, as well as a number of Internet oriented systems such as HiperMAN and WiBro [13].

Two of the three major 3G systems, cdma2000 and UMTS, compete with WiMAX. Both offer DSL-class Internet access in addition to phone service. UMTS has also been enhanced to compete directly with WiMAX in the form of UMTS-TDD, which can use WiMAX oriented spectrum and provides a more consistent, if lower bandwidth at peak, user experience than WiMAX. 3G cellular phone systems usually benefit from already having entrenched infrastructure, being upgrades from earlier systems. Users can usually fall back to older systems when they move out of range of upgraded equipment, often relatively seamlessly. The major cellular standards are being evolved to so-called 4G, high bandwidth, low latency, all-IP networks with voice services built on top. With GSM/UMTS, the move to 4G is the 3GPP Long Term Evolution effort. For AMPS/TIA derived standards such as cdma2000, a replacement called Ultra Mobile Broadband is under development. In both cases, existing air interfaces are being discarded, in favor of OFDMA for the downlink and a variety of OFDM based solutions for the uplink. These will bring Internet access speeds comparable to, or better than, WiMAX.

6. 802.16 (WiMAX) vs. 802.11 (WiFi)

Possibly due to the fact that both WiMAX and Wi-Fi begin with the same two letters, and are based upon IEEE standards no. 802.xx, and are vaguely to do wireless connectivity and the Internet, confusions between the two are frequent [14], [15], [16]. Despite having in common the use of OFDM, the use of multiple pilot tones, and the support of modulations ranging from BPSK to 64 QAM, they have some major differences, as follows:

1. Rather than a fixed 20 MHz bandwidth with 52 subcarriers as in 802.11, WiMAX systems can use variable bandwidths from 1 to 28 MHz with 256 subcarriers (192 data subcarriers) in either licensed or unlicensed spectrum.

2. WiMAX supports subchannelization, meaning that instead of transmitting on all 192 data subcarriers, one can transmit on just a subset. Using the same amount of power over fewer carriers, the system achieves greater range. Because CPE is typically limited in power, concentrating the power over fewer subcarriers in the uplink can balance the power in the uplink and downlink, and enable greater range.

3. The larger number of subcarriers gives WiMAX an advantage over 802.11; the resulting challenge to the system design is that the subcarriers are spaced more closely together, so there are tighter requirements for phase noise and timing jitter. This translates to a need for higher-performance synthesizers.

4. WiMAX uses a variable-length guard interval to improve performance in multi-path environments. The guard interval is a time delay at the beginning of the packet to compensate for multi-path interference. With a very clear channel, the guard interval can be shortened, increasing the throughput. With more subcarriers, and with a variable-length guard interval, a WiMAX system's overall spectral efficiency will be 15 to 40% higher than a WiFi system (Table 4).

Table 4

Wireless Standards' Spectrum Efficiency

	Channel Bandwidth	Maximum Data Rate	Maximum Efficiency
802.16a	10, 20 MHz; 3.5, 7, 14 MHz; 3, 6 MHz	70 Mb/s	5 bps/Hz
802.11a	20 MHz	54 Mb/s	2.7 bps/Hz
EDGE	200 KHz	384 Kbps	1.9 bps/Hz
cdma2000	1.25 MHz	2 Mb/s	1.6 bps/Hz

5. Error-vector magnitude (EVM) requirements for 802.11 are specified at -25 dB, which is required to achieve a 10% packet error rate. For 802.16, EVM is held to -31 dB, which is based on a 1% packet error rate. This lower error rate helps contribute to WiMAX's longer range. Also contributing to the longer range is the receiver noise figure, which is more stringent for 802.16. Specifically, 802.11's maximum noise figure is 10 dB, while 802.16 operates at 7 dB.

6. WiFi only supports time division duplexing (TDD). In contrast, the 802.16 specifications offer more flexibility, supporting TDD, FDD, and H-FDD. An FDD system will cost more because simultaneous Tx/Rx requires two complete radios. However, FDD will allow greater throughput, as bandwidth is dedicated for receive and transmit, and this bandwidth is used simultaneously. The 802.11 standard provides one-fourth of the OFDM options for CP than does the 802.16-2004 standard, which provides 1/32, 1/16, 1/8 and 1/4, where each can be optimally set.

7. Another significant difference between WiMAX and 802.11 is ranging and dynamic transmit range. In 802.11, the output power is virtually fixed, and systems typically transmit at the same power all the time. However, for WiMAX, a ranging process determines the correct timing offset and power

settings. This process ensures that transmissions from each subscriber station arrive at the base station at the proper time and at the same power level. As a result, the 802.16 standard requires that subscriber stations have a 50-dB dynamic transmit range. This allows systems that are close to the base station to back off their transmit power, while those far away can transmit at maximum power. This is significant because WiMAX supports transmit ranges of several Kilometers, and transmitting at maximum power near the base station would be disastrous.

8. WiMAX is longer in range than Wi-Fi: WiMAX is a long range - many Kilometers system, which uses licensed spectrum to deliver a point-to-point connection to the Internet from an ISP to an end user. WiMAX furnishes broadband connectivity over a much wider area than Wi-Fi and does not require a direct line of sight between subscriber terminals and access points. This distinction points up the difference between the two standards: Wi-Fi is a LAN technology, while WiMAX is a MAN technology. The “metropolitan” in “MAN” does not restrict WiMAX to urban environments, however. This technology is ideal for providing broadband services in rural areas that may be underserved by DSL or cable.

9. Different 802.16 standards provide different types of access, from mobile (analogous to access via a cellphone) to fixed (an alternative to wired access, where the end user's wireless termination point is fixed in location). WiMAX is designed to operate in both the licensed radio band and unlicensed radio band. When WiMAX operates in the licensed radio band, it is free to broadcast with many times more channels and power that any unlicensed radio solution, as long as the broadcaster owns the license for that radio band. This means that licensed WiMAX operation will typically be used by Wireless ISP operators.

10. WiMAX is more secure than Wi-Fi: WiMAX will actually use a similar authentication and encryption scheme to the Wi-Fi WPA2 standard. The minor difference is that WiMAX security will use either 3DES or AES encryption and a flavor of Extensible Authentication Protocol (EAP) called PKM-EAP. Wi-Fi WPA2 on the other hand will typically use PEAP authentication along with AES encryption.

11. WiMAX is very different from Wi-Fi in the way it works - MAC layer/ Data Link Layer.

- In Wi-Fi the MAC uses contention access - all subscriber stations that wish to pass data through a wireless access point (AP) are competing for the AP's attention on a random interrupt basis. This can cause subscriber stations distant from the AP to be repeatedly interrupted by closer stations, greatly reducing their throughput. This makes services such as VoIP or IPTV, which depend on an essentially constant QoS depending on data rate and interruptibility, difficult to maintain for more than a few simultaneous users.
- In contrast, the 802.16 MAC uses a scheduling algorithm for which the subscriber station need compete once (for initial entry into the network). After that it is allocated an access slot by the base station. The time slot can enlarge and contract, but remains assigned to the subscriber station which means that other subscribers cannot use it. The 802.16 scheduling algorithm is stable under overload and over-subscription (unlike 802.11). It can also be more bandwidth efficient. The scheduling algorithm also allows the base station to control QoS parameters by balancing the time-slot assignments among the application needs of the subscriber stations. WiMAX also addresses the requirements of those subscribers that want to be able to use their broadband connection regardless of location, functionality that DSL and cable modem services do not support.

7. Main advantages of Mobile WiMAX

a) Advanced IP-based architecture

WiMAX is a next-generation technology that will facilitate the cellular operators' transition to all-IP networks. Cellular networks are also moving towards an IP core with the LTE and System Architecture Evolution (SAE) efforts. WiMAX fully supports IMS2 and its 3GPP2 counterpart, Multimedia Domain (MMD), emerging architectures that will enable service providers to introduce a wide range of rich voice and data applications rapidly and at a low marginal cost. With IMS and MMD, service providers can develop applications independently of the access technology within a flexible layered architecture in which application modules can be easily modified or reused. The IP core network at the basis of WiMAX will simplify interworking with other IP technologies. Support for IMS and MMD will further facilitate interworking and remove existing redundancies in the core network. At the beginning, however, WiMAX will have to be seamlessly integrated with existing cellular networks [17], [18].

b) Flexible channel bandwidth

As the distance between a subscriber and the base station (or AP) increases, or as the subscriber starts to move by walking or driving in a car, it becomes more of a challenge for that subscriber to transmit successfully back to the base station at a given power level. The IEEE 802.16-2004 and IEEE 802.16e standards have flexible channel bandwidths between 1.5 and 20 MHz to facilitate transmission over longer ranges and to different types of subscriber platforms. In addition, this flexibility of channel bandwidth is also crucial for cell planning, especially in the licensed spectrum. With a dedicated antenna, each sector has the potential to reach users with more throughputs over longer ranges than can an omni-directional antenna. Net-to-net, flexible channel bandwidth is imperative for cell planning. The 802.16-2004 standards have strong commercial backing to go along with its technical capabilities.

c) QoS robust control

Several features of the WiMAX protocol ensure robust quality-of-service (QoS) protection for services such as streaming audio and video. As with any other type of network, users have to share the data capacity of a WiMAX network, but WiMAX's QoS features allow service providers to manage the traffic based on each subscriber's service agreements on a link-by-link basis. Service providers can therefore charge a premium for guaranteed audio/video QoS, beyond the average data rate of a subscriber's link. One aspect of WiMAX QoS provisioning is a grant-request mechanism for letting users into the network. This mechanism's operation and value become apparent from a comparison of WiMAX with the CSMA/CD or CSMA/CA mechanisms used in LAN technologies such as 802.11. When a CSMA/CA-based wireless LAN has fewer than 10 users per access point, the network experiences little contention for use of airtime. Occasional packet collisions occur, and they require back-off and retransmissions, but the resulting overhead does not waste a significant amount of bandwidth.

If the number of CSMA/CA access-point users goes up to dozens or hundreds of users, many more users tend to collide, back-off and retransmit data. In such an environment, average network loading factors can easily raise past 20 to 30 percent and users notice delays—especially in streaming-media services. WiMAX avoids such issues by using a grant-request mechanism that allocates a small portion of each transmitted frame as a contention slot. With this contention slot, a subscriber station can enter the network by asking the base station to

allocate an uplink (UL) slot. The base station evaluates the subscriber station's request in the context of the subscriber's service-level agreement and allocates a slot in which the subscriber station can transmit (send UL packets). The WiMAX grant-request mechanism establishes a fixed overhead for airtime contentions and prevents large numbers of subscribers from interfering with one another. Overall, the mechanism allows for much higher utilization of available channel resources. Even when a base station has thousands of users and a high load factor, the network does not bog down with packet collisions and retransmissions. As more users join a WiMAX network, the base station schedules the subscribers using dynamic scheduling algorithms that the service provider can define and modify to achieve the promised level of service to each subscriber.

Another aspect of WiMAX QoS provisioning is link-by-link data-rate manageability. The signal strength between base and subscriber stations affects a wireless link's data rate and ability to use various modulation schemes within the 256 OFDM frameworks. Signal strength depends mainly on the distance between the two stations. If the network were restricted to a single modulation scheme per carrier, subscribers that are farther away from the base station would limit the network's ability to use the most efficient scheme. WiMAX enables optimization of each subscriber's data rate by allowing the base station to set modulation schemes on a link-by-link basis. A subscriber station close to the base station could use 64QAM modulation, while the weaker signal from a more remote subscriber might only permit the use of 16QAM or QPSK. The 802.16 MAC can even use a different modulation method for each subscriber's downlink and uplink bursts.

Optimizing overall bandwidth usage and maximizing each subscriber's data rate establishes a solid foundation for high quality of service. In addition to these general-purpose QoS features, WiMAX provides specific QoS support for voice and video. To enable toll-quality voice traffic, for example, voice packets can be tagged as such. The base-station's scheduler then manages the passage of these packets through the air interface to provide deterministic latency.

d) Superior performance

WiMAX meets all the requirements for mobile Internet access. It supports multiple handoff mechanisms, ranging from hard handoffs (with break-before-make links) to soft handoffs (with make-before-break links), power-saving mechanisms for mobile devices, advanced QoS and low latency for improved support of real-time applications, and advanced Authorization, Authentication, and Accounting (AAA) functionality.

The advanced performance of mobile WiMAX is largely tied to its use of OFDMA, a multiplexing technique well suited to multipath environments that gives network operators higher throughput and capacity, great flexibility in managing spectrum resources, and improved indoor

WiMAX performance is further enhanced by the use of Time Division Duplex (TDD), but it can also support Frequency Division Duplex (FDD) which dominates in 3G networks. Whereas FDD keeps the uplink and the downlink channels separate in frequency, TDD is a less complex, more efficient mechanism that uses a single frequency channel, with uplink and downlink traffic separated by a guard time. In addition, for IP-based services the use of a single channel for the uplink and the downlink makes it substantially less complex and more cost-effective to implement MIMO and beamforming in WiMAX networks than in CDMA-based networks. MIMO and beamforming are expected to bring a substantial improvement in throughput in TDD-based WiMAX networks.

e) Flexibility

WiMAX was designed from the ground up to be an all-IP technology that is optimized for high-throughput, real-time data applications and that is not beholden to a legacy infrastructure. WiMAX can be deployed both in deployments, where network operators rely exclusively on WiMAX for the edge infrastructure, and in overlay or complementary networks, where operators embed WiMAX within their networks to increase capacity and throughput as necessary to deliver true wireless broadband service.

Cellular networks based on GSM, CDMA, WCDMA and EV-DO use spectrum resources that are limited and typically too expensive for cost effective high capacity and high-throughput broadband services. Mobile WiMAX broadband networks offer service providers a profitable model to deploy multiple value-added services that bring in additional revenues streams. The additional cost of bundling new mobile services with existing ones is low, as the operators already have an established relationship with the subscriber and can leverage their existing marketing, branding and customer service operations to support the new services.

Global roaming among WiMAX service providers will allow subscribers to access different networks using the same device and a single, familiar interface. Global roaming will become an essential feature of the mobile service offering that will increase the attractiveness to the subscribers and generate additional revenues. If they offer access through their partners using roaming agreements similar to those in place for cellular networks, service providers will be able to get the desired footprint in their market without having to build an extensive infrastructure.

Mobile WiMAX can be deployed in several licensed bands (2.3 GHz, 2.5 GHz, 3.3 GHz, and 3.4-3.8 GHz) with channel sizes ranging from 3.5 MHz to 10 MHz. This gives operators the flexibility to use WiMAX in multiple spectrum bands and with the amount of spectrum they have. WiMAX Forum Certified equipment will be approved in additional spectrum bands in response to the needs of operators worldwide. The WiMAX Forum recognizes the importance of spectrum availability to network operators and is taking a proactive role in promoting an increased availability of spectrum for WiMAX deployments.

f) Cost effectiveness

WiMAX meets the growing mass-market demand for cost-effective, high-throughput broadband wireless services. The business case for WiMAX is attractive as the cost of the equipment is kept low by a combination of interoperable components based on open standards, mass adoption of subscriber units, an attractive IPR structure, and a high base station capacity. In turn, its contained infrastructure costs and efficient spectrum utilization allow service providers to address demand from the mass market, by offering personal broadband services at a price point that both business and consumer users will find attractive.

Interoperability brings more choices to network operators and increases competition among vendors. Network operators are not dependent on a single vendor to provide both base stations and subscriber units, or to decide the pace and availability of upgrades. The cost of open-standards equipment tends to decrease rapidly with the increase in volume and the market entry of high-volume, low-cost, vendors. Also is possible to make the integration of Wi-Fi and WiMAX in a single chipset.

8. Cost & CPE availability

WiMAX backers often talk about inexpensive customer premise equipment (CPE) and, eventually,

embedding WiMAX chips in laptops and mobile devices. However, delivery of this promise is still in its infancy. Even when available, early versions are likely to remain expensive until economies of scale are realized. WiMAX is still at the hype stage and operators need to tread carefully before investing in a big way into setting up networks.

The WiMAX certification allows vendors with 802.16d products to sell their equipment as WiMAX certified, thus ensuring a level of interoperability with other certified products, as long as they fit the same profile.

Among the mobile devices that have or are expected to have a WiMAX interface are:

- Data centric devices: notebooks, PDAs, Ultra Mobile PCs
- CE devices: game consoles, MP3 players
- Voice and voice/data devices: cellular phones, smartphones
- Vertical applications devices: CCTV cameras, in-vehicle devices.

Equipment built to 802.16e is not compatible with 802.16d: the 802.16d WiMAX specifications cover only fixed point-to-point links, while 802.16e addresses both fixed and mobile links. The basic appeals of WiMAX are performance and cost; it costs less than competing cell technologies because it requires far fewer network elements, they are built in to the basic WiMAX device and the shoe box-sized antennas can be mounted to existing poles or buildings.

Revision 802.16f is intended to improve multi-hop functionality, and 802.16g is supposed to deal with efficient handover and improved QoS.

9. Future developments: IEEE 802.20

MBWA (Mobile Broadband Wireless Access) is a technology developed by IEEE 802.20. It is the future technology standard for true wireless broadband or 4G and so far iBurst is the only pre-selected solution with over a dozen commercial deployments worldwide. IEEE 802.20 was established by IEEE as MBWA for operation from 120 to 350 Kmph. The PAR was not for a broad mobile application. Since conception, the standard has been re-purposed as filling general requirements for NGMN. In so doing, 802.20 standard has taken on many of the methods of mobile WiMAX, including dynamic modulation up to 64 QAM and similar scalable OFDMA capabilities. It apparently retains fast hand-off, FEC and cell edge enhancements. But 802.20 is being shunned by ETSI 3GPP LTE, major network operators in North America and EU, and is unlikely to become broadly accepted. Compared to mobile WiMAX, the momentum has stalled. Mainstream of development efforts for both WiMAX and LTE have shifted to MIMO-AAS-OFDMA and SC-OFDM for LTE on the up-link. WiMAX 802.16e-2005 has been proposed as IP-OFDMA for inclusion as the sixth wireless link system under IMT-2000. Both WiMAX and LTE will achieve 100 Mbps mobile and 1 Gbps fixed-nomadic bandwidth goals set by ITU for 4G NGMN systems through the adaptive use of MIMO-AAS and smart, granular network topologies.

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