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The Mobile Broadband WiMAX Standard

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TR2006-096 September 2007

Abstract

Mobile worldwide interoperability for microwave access (WiMAX) is a wireless standard that introduces orthogonal frequency division multiple access (OFDMA) and other key features to enable mobile broadband services at a vehicular speed of up to 120 km/h. WiMAX complements and competes with wireless local area networks (WLANs) and the third generation (3G) wireless standards on coverage and data rate. More specifically, WiMAX supports a much larger coverage area than WLAN, does not require line of sight for a connection, and is significantly less costly compared to the current 3G cellular standards. Although the WiMAX standard supports both fixed and mobile broadband data services, the latter have a much larger market. Therefore, this article will briefly present the mobile WiMAX standard, the technologies deployed for the air interface and the network, and the development of the standards to support mobile multihop relays in a WiMAX network.

IEEE Signal Processing Magazine

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BACKGROUND

MOTIVATION

Wireless broadband data communication is experiencing a rapid expansion, and WiMAX equipment sales are expected to hit US$3 billion by 2009. Mobile data communication revenues, in particular, already account for at least 20–30% of carriers' revenues in many affluent countries. To keep up with this noteworthy growth in the demand for wireless broadband, new technologies and architectures are needed to greatly improve system performance and network scalability while significantly reducing the cost of equipment and deployment.

Digital Object Identifier 10.1109/MSP.2007.904740

OBJECTIVES

The objective of the Mobile WiMAX standard is to fill the gap between the WLANs (which provide very high data rate but short-range coverage) and the 3G cellular systems (which provide highly mobile long-range coverage but low data rate) by providing a specification that supports a mobile broadband access system [including functions to enable handoff between base stations (BSs) or sectors]. Furthermore, the target is to greatly reduce the cost of WiMAX infrastructure per unit data rate by significantly increasing the system capacity compared to the current 3G standard systems.

ISSUING BODY AND SCHEDULE

Mobile WiMAX air interface specifications are based on the IEEE 802.16-2004 Air Interface standard and the IEEE 802.16e amendment, ratified in late 2004 and 2005, respectively. Although confined only to the physical (PHY) and medium access control (MAC) layer specifications, these standards are very extensive. The WiMAX Forum, a nonprofit organization of 414 member companies, was formed to trim down these specifications to a manageable size and ensure interoperability of equipment among different vendors through its certification process. In addition, the WiMAX Forum Network Working Group is developing the higher-level networking specifications that are not covered in the IEEE 802.16 standards. These combined efforts will help to define the end-to-end system specifications for the Mobile WiMAX standard. The first version of the higher-layer networking specifications for the Mobile WiMAX standard is expected to be finalized in early 2007. A commercial system is anticipated in the year 2008.

TARGET APPLICATIONS

The Mobile WiMAX standard has targeted application areas for WiMAX systems such as voice over Internet protocol (VoIP), video conferencing, streaming media, multiplayer interactive gaming, Web browsing, instant messaging, and media content downloading. These applications consume significant bandwidth and, in some cases, require short end-to-end latency.

STRUCTURE OF THE STANDARD

The Mobile WiMAX specifications basically consist of the document for the fixed system (IEEE 802.16-2004 Air Interface standard), the document for the mobile system (IEEE 802.16e amendment), and the document for the higher-layer networking from the WiMax Forum. The first two documents define specifications for the PHY layer (such as the frame structure, OFDMA, modulation, and coding) and the MAC layer (such as the data and control plane and the sleep mode for the terminals). The higher-layer networking document includes the reference network architecture and specifies how wide-area roaming and handoff protocol are being addressed.

TECHNOLOGY

FUNCTIONALITIES

The Mobile WiMAX standard addresses all classes (fixed, nomadic, and mobile) of users. The standard developed

1053-5888/07/$25.00©2007IEEE

specifications that provide: 1) a very high capacity and high bandwidth capable of catering to both real time and data traffic, 2) a flexible architecture to ease deployment, 3) wide area mobility and worldwide coverage, 4) quality of service (QoS) to prioritize and optimize traffic, and 5) interoperability of equipment.

Systems using the WiMAX standard can provide ubiquitous mobile services. A user may be using a wireless videophone, a laptop, or a PDA for data services and may also be performing video streaming or uploading photos from a wireless digital camera. The user could be video conferencing on the run (for instance, at the airport or on a train), connected to a private or public network, from home to office and anywhere around the globe. In the area of public safety, a fire team could download the internal maps of a building on fire while the rescue vehicles are still on the road and could transmit real-time information on a patient before the ambulance even reaches the hospital. Similarly, a teaching institution could provide cost-effective distance education to students inside and outside the campus with different levels of service in voice, data, and video provided for by the WiMAX built-in QoS. For operators keen to capture a slice of the underserved mobile broadband market, WiMAX offers a network architecture that is highly scalable, low in cost, and easy to deploy in a licensed or licensed-exempt spectrum. A licensed spectrum is a spectrum leased by an operator(s) for a given locality, whereas the licensed-exempt spectrum is the so-called "free" spectrum in which anybody can use the spectrum provided certain rules are followed.

ARCHITECTURE

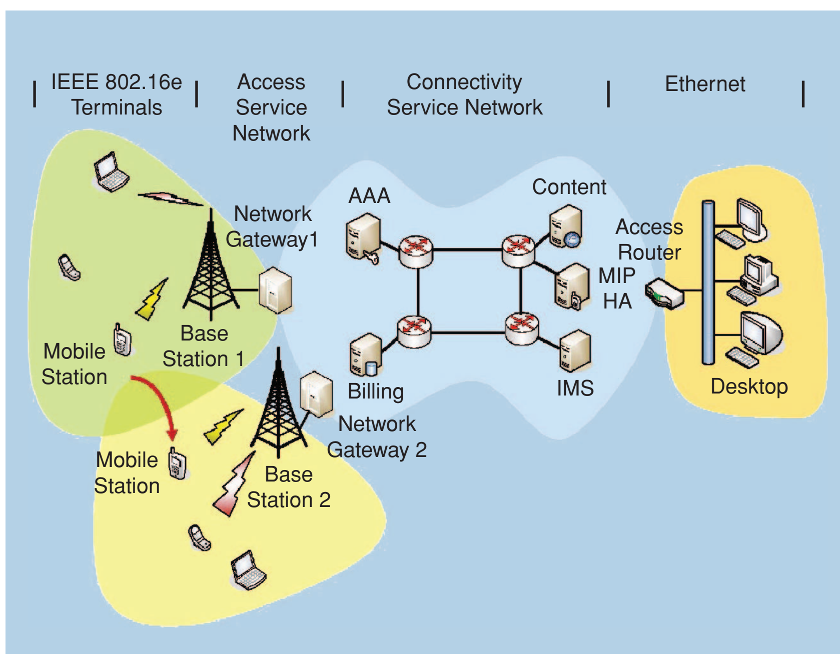
Mobile WiMAX defines an all-Internet protocol (IP) end-to-end network architecture, which is an integrated telecommunications network architecture that uses IP for the end-to-end transport of all user data and signaling data. Core networks based on IP routers and switches are easily scalable and easier to install and operate than a circuit switched network.

The basic tenets of the Mobile WiMAX network architecture are: 1) separation of the access architecture from the IP connectivity service, 2) organization in a hierarchical, flat, or mesh topology, 3) support of fixed, nomadic, and mobile subscribers, and 4) support of global roaming and inter-working with other 3G wireless systems. Each of these basic tenets is briefly explained next using the illustration of the basic WiMAX network architecture in Figure 1. This figure illustrates the roaming of the mobile users within the overlapped coverage of two access stations connected to a common core IP network.

Separation of the access architecture from the IP connectivity service is achieved by delimiting the access service network (ASN) from the connectivity service network (CSN). The ASN provides an aggregation of functional entities for the access services and represents the boundary for functional interoperability with different classes of WiMAX terminals such as laptops and phones. The CSN provides a set of network functions that help achieve IP connectivity and related services to the WiMAX subscribers. A CSN may consist of AAA (authentication, authorization, accounting) servers, mobile IP (MIP) agents, IP multimedia subsystem (IMS) servers, user databases, and interworking gateway devices. IMS uses the standard IP, which allows existing (e.g., VoIP and circuit-switched phone) and new services to be provided.

Organization in a hierarchical, flat, or mesh topology includes 1) sharing of ASN(s) of a network access provider (NAP) among multiple network service providers (NSPs) and vice versa; 2) NAP that consists of one or more ASNs; 3) most basic deploying of a single ASN together with a small number of CSN functions to provide basic Internet access without roaming; and 4) different ASN topologies including hierarchical or distributed (multihop interconnects) for flexibility in scaling the network. For example, Figure 1 shows each BS having its separate gateway or both BSs sharing one gateway, depending on their localities and traffic loading of the gateway.

Support of fixed, nomadic, and mobile users means that the architecture supports both mobility and handoff. Handoff is a process by which an active



[FIG1] IP-based WiMAX network architecture. AAA, IMS, MIP, MIP HA denote authentication, authorization, accounting servers; IP multimedia subsystems; mobile IP agents; and mobile IP home agents, respectively.

call is transferred from one cell to another. As depicted in Figure 1, a mobile station (MS) can move from one cell to another (indicated by the red arrow), and a handoff between the BSs through the network can be executed. MIP at its core network includes elements such as home agents (HAs) that would allow seamless handoff of services when a user moves from one cell coverage to another. The WiMAX architecture also supports dynamic and static home address configurations and dynamic assignment of the HA to optimize routing and load balancing.

Support of global roaming and interworking with other 3G wireless systems means that the architecture allows and supports roaming among NSPs and enables both vertical and intertechnology handoffs with such networks as WLAN and 3G partnership project (3GPP).

TOOLS

The superior system capacity performance of Mobile WiMAX is made possible by the combination of OFDMA and advanced antenna technologies, adaptive modulation and coding techniques, and fine granularity QoS.

1) *OFDMA* is an extended, multiuser orthogonal frequency division multiplexing (OFDM) that can accommodate many users at the same time on the same channel. This technique has also been adopted by Mobile WiMAX where multiplexing of sets of OFDM subcarriers within the same channel is provided to data streams from multiple users. OFDMA has been used because it provides tolerance to multipath, frequency-selective fading, scalable channel bandwidth, and high compatibility with advanced antenna technology.

Tolerance to multipath in OFDMA is accomplished because OFDM is an efficient technique to resolve the multipath delay spread that often occurs in a non-line-of-sight wireless channel. OFDM subdivides the bandwidth of a signal into a number of orthogonal frequency subcarriers. By doing so, an input data stream is branched into several data paths with lower data rate, thus increasing the symbol duration and thereby reducing the relative multipath delay spread. By introducing a guard time that is greater than the delay spread for each OFDM symbol, the intersymbol interference due to delay spread can be almost eliminated.

Impact of frequency-selective fading is minimized when using OFDMA with frequency-selective scheduling (that is, simply by selecting the right subcarriers for each user).

Bandwidth scalability is made possible by proportionate adjustment of the fast Fourier transform (FFT) size to the channel bandwidth with fixed subcarrier frequency spacing and symbol duration, thereby incurring minimum additional implementation complexity and simultaneously maintaining transparency to the higher layers. Therefore, Mobile WiMAX can deliver truly "worldwide interoperability," as it adjusts its bandwidth to adapt to the spectrum allocation in different countries and regions and to a wide variety of traffic loading requirements.

Compatibility of OFDM/OFDMA with advanced antenna technology is a notable strength. OFDM/OFDMA translates a wideband frequency-selective channel into a number of flat narrow band subcarriers. This allows antenna technology processing to be performed on a flat subcarrier vector without the need for complex equalizers that are often required in a wideband frequency-selective fading channel. Currently, Mobile WiMAX supports space time coding (STC), spatial multiplexing (SM), and smart antenna beamforming, which are some of the most powerful techniques to significantly improve spectral efficiency and system capacity. OFDMA and advanced antenna technology will help further boost Mobile WiMAX spectral efficiency, coverage, and system capacity.

2) *Adaptive modulation and coding techniques*, and coding ranging from half-rate QPSK to 5/6 64 QAM, were deployed by Mobile WiMAX to further boost the level of system capacity. The amount of error tolerated depends on the reliability and QoS requirement of each connection. A higher modulation index offers a larger throughput and can be easily exploited by users near the BS where the signal-to-noise ratio is generally high.

3) *Fine granularity QoS* can be provided over the air interface for both downlink and uplink because Mobile WiMAX is connection oriented and its QoS is defined on a per-service-flow basis. In addition, OFDMA plus the very high system capacity and flexible mechanism of optimal scheduling of space, frequency, and time resources on a frame-by-frame basis enables better enforcement of QoS. As a result, Mobile WiMAX systems can support a wide range of services, such as voice and video with vastly different QoS requirements.

COMPARISON WITH OTHER STANDARDS

WLAN standards such as IEEE 802.11a and IEEE 802.11g provide user throughput of 1 Mb/s or more, and allow broadband access to the Internet within a cell radius of a couple of hundred meters. On the other hand, current 3G cellular networks, which are optimized for voice, provide paging and low-data-rate services within a very large area. As stated earlier, Mobile WiMAX is a metropolitan access technique that was developed to provide not only broadband wireless access but also larger area coverage. Both WLAN and Mobile WiMAX provide high-data-rate services but with quite different area of coverage; therefore, they complement each other. However, in the long run, the existing 3G networks may be threatened by the emergence of a successful Mobile WiMAX.

To respond to this threat, another competing standard—3GPP long-term evolution (LTE)—is currently being developed to include—among others—advanced antenna technology, OFDMA, and flexible transmission bandwidth. In short, 3GPP LTE and Mobile WiMAX share many common technologies and architectures, but also exhibit differences. One of the main differences is in the uplink, where the single-carrier

FDMA (SC-FDMA) is being adopted. The SC-FDMA signal carries a lower peak-to-average power ratio and hence has better power efficiency for the subscriber units compared to OFDMA (as used in the Mobile WiMAX standard). 3GPP LTE targets a 100-Mb/s downlink and 50-Mb/s uplink peak data rate throughput at 20-MHz channel bandwidth. Peak data rate throughput implies that the mobile resides near the BS and operates at its peak performance. The targeted peak spectra efficiencies are 5 b/Hz/s for downlink and 2.5 b/Hz/s for the uplink. The targeted speed with handoff of the mobile units is about 350 km/h. Alhough 3GPP LTE is expected to compete against Mobile WiMAX, the 3GPP LTE system is not expected to become commercial before 2010, i.e., at least a year or two later than Mobile WiMAX.

PERFORMANCE

The performance of a wireless data system is often measured in terms of the peak or average data throughput of a BS and throughput for a user at the cell edge. WiMAX with a two-antenna configuration (2×2) MIMO at 10-MHz channel bandwidth can achieve a theoretical peak data rate of 60 Mb/s for a total downlink operation (without uplink) and 28 Mb/s for a total uplink operation. The cell coverage ranges from a few hundred meters to less than 1 km in a dense urban area, 1 to 3 km in a suburban area, and beyond 10 km in a rural area. In general, system capacity is heavily dependent on the geographical distribution of the users in the coverage area and the scheduler that determines the distribution of the capacity to each user. The best case is when all users are very close and within the line of sight of the BSs. The worst case is when all users are at the cell edges. For example, the cell edge rate is expected to achieve 1–2 Mb/s for downlink and 300–400 kb/s for the uplink for a single user at a 2% outage (probability of user not achieving the expected data rate). As far as mobility is concerned, it is expected to support a speed of up to 120 km/h with handoff. In general, except for the mobility speed, many of the performance targets of Mobile WiMAX are comparable to 3GPP LTE.

FURTHER TECHNICAL DEVELOPMENTS

A new task group, IEEE 802.16j, was officially established in March 2006 to

WiMAX RESOURCES

Tutorials

- A. Ghosh, D.R. Wolter, J.G. Andrews, and R. Chen, "Broadband wireless access with WiMAX/802.16: Current performance benchmarks and future potential," *IEEE Commun. Mag.*, vol. 43, no. 2, pp. 129–136, Feb. 2005.
- I. Koffman and V. Roman, "Broadband wireless access solution based on OFDM access," *IEEE Commun. Mag.*, vol. 40, no. 4, pp. 96–103, Apr. 2002.

Overviews

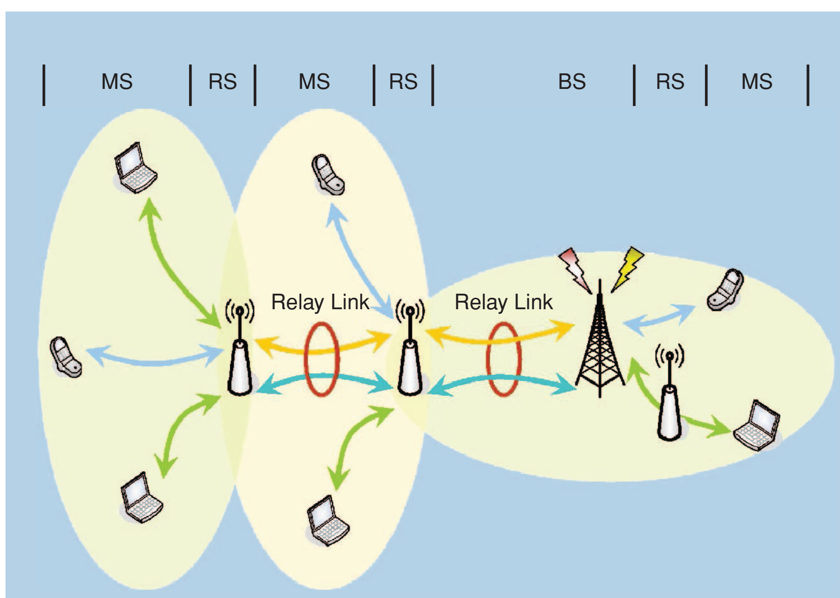
- "Mobile WiMAX—Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August 2006 [Online]. Available: http://www.wimaxforum.org/technology/downloads/
- "Mobile WiMAX—Part II: A Comparative Analysis," WiMAX Forum, May 2006 [Online]. Available: http://www.wimaxforum.org/technology/downloads/

Books

- C. Eklund, R. Marks, S. Ponnuswamy, K.L. Stanwood, and N.J.M. Van Waaes, *WirelessMAN: Inside the IEEE 802.16 Standard for Wireless Metropolitan Area Networks*. New York: IEEE Press, May 2006.

Resources for Further Developments

- WiMAX Forum white papers [Online]. Available: http://www.wimaxforum.org/news/downloads/
- IEEE 802.16's Mobile Multihop Relay (MMR) Study Group [Online]. Available: http://www.wirelessman.org/sg/mmr/
- WiMAX, NLOS, and Broadband Wireless Access Worldwide Market Analysis 2004–2008 [Online]. Available: http://www.gii.co.jp/english/mar18033_bwa.html
- WiMAX and RAN equipment sales [Online]. Available: http://www.infonetics.com/resources/purple.shtml?ms06.ran.wom.wl.2q06.nr.shtml



[FIG2] A topology of future IEEE 802.16j MMR networks.

WiMAX PRODUCTS

- Base station: Airspan's MacroMAX and MicroMAX, Alvarion's BreezeMAX, Redline Communications' RedMAX, Telsima's StarMAX, Aperto's PacketWave 1000, Axxcelera's ExcelMax
- Subscriber unit: Airspan's EasyST, SR Telecom's SymmetryOne, Aperto's PacketWave 100&200, Axxcelara's ExcelMax CPE, Telsima's StarMAX
- Network: Airspan's Netspan, Alvarion's WALKair and eMGW, SR Telecom's Angel
- For product references, please refer to http://www.wimax.com/education/equipment-guide/overview/

amend the current IEEE 802.16e standard to support mobile multihop relay (MMR) operation in wireless broadband networks. The objective of this standard is to improve the capacity and coverage of the current Mobile WiMAX standard. The uplink is the weaker link because of the limited transmitted power of the terminal. An envisioned topology of a future IEEE 802.16j MMR network is depicted in Figure 2.

One natural consequence of relay is traffic "aggregation" on these relay links between a BS and a relay station (RS), or between a pair of RSs. As RSs have to carry traffic originated from and destined to multiple MSs, the notion of "aggregation" of traffic in a relay link is simply inherent and tends to grow larger with the number of hops. Given the inherent complexity of MMR networks, it is conceivable that numerous technical challenges need to be addressed, which include, but are not limited to, OFDMA frame structure design, path management and routing, handoff, security architecture, and relay link reliability.

RESOURCES

Relevant WiMAX resources are included in "WiMAX Resources."

PRODUCTS

Fixed WiMAX-compliant products are now available on the market and were deployed in the licensed 3.5-GHz band and license-exempt 5.8-GHz band after the first certification test lab was established in Malaga, Spain, in July 2005. A second certification lab has also recently been established in Korea, and both labs will be fully ready for the Mobile WiMAX Release-1 profile certifications when the first products are expected to roll out in mid-2007. Mobile WiMAX is expected to operate in the licensed 2.3-, 2.5-, and 3.5-GHz bands.

Fixed WiMAX BS products are available especially for last-mile broadband access for single office home office and residential customers operating mostly in the 3.5-GHz spectrum to compete against connection with a digital subscriber line or cable modem. Some vendors also provide QoS settings for video, voice, and data services. The fixed WiMAX subscriber products can accommodate several interfaces with traditional Ethernet and optional POTS (VoIP) interface. The products, which include both indoor and outdoor versions, cater to both residential and business users. The network products give operators the capability to easily deploy, expand, control, collect, and analyze traffic statistics and monitor with friendly graphical user interfaces. The network also allows equipment software to be upgraded through the central office. Relevant software and hardware in WiMAX products are included "WiMAX Products."

AUTHORS

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