WHITE PAPER

WiMAX: E vs. D
The Advantages of 802.16e over 802.16d

While 802.16e has been called the mobile standard, in actuality, 802.16e supports fixed, nomadic, portable and mobile solutions.

The emergence of the WiMAX standards has spurred tremendous interest from operators seeking to deploy high-performing, cost-effective broadband wireless networks. However, the availability of 802.16e and 802.16d as two different and incompatible iterations of the WiMAX standards has in some cases added confusion to the operator's investment decisions. While 802.16d has often been considered the "fixed standard" and 802.16e as the "mobile standard", in actuality, 802.16e supports the full spectrum of fixed, nomadic, portable and mobile solutions.

With the introduction of the initial 802.16d products in 2006 and the initial 802.16e products becoming generally available in early 2007, the gap between product introductions has closed and time to market advantages for 802.16d have diminished. As a result, operators must weigh the merits of the two standards and their long-term role in the industry when making investment decisions. This paper focuses on the advantages of 802.16e over 802.16d and how 802.16e will lead to better performance and lower cost, even for fixed applications.

WiMAX E vs. D

The WiMAX nomenclature was introduced by the WiMAX Forum, an industry consortium, to promote the Institute of Electrical and Electronics Engineers (IEEE) 802.16 family of standards for broadband wireless access systems. The early iterations of IEEE 802.16 focused on line-of-sight (LOS) applications using high-frequency bands between 10 to 66 GHz. More recently, efforts have been focused on specifying amendments to the early standards to support non-line-of-sight (NLOS) applications between 2 to 11 GHz. The 802.16-2004 standard, more commonly known as 802.16d, was published in 2004. The 802.16e standard is an amendment to the 802.16d standard and was ratified at the end of 2005 and published as 802.16-2005. While the 802.16d standard supports fixed and nomadic applications, the 802.16e standard supports fixed, nomadic, portable and mobile solutions.

WiMAX has been loosely coined and refers to both the 802.16d and 802.16e standards. Both standards are broadly defined by IEEE to support a variety of applications and network solutions. The WiMAX label refers to a defined subset of technology specifications from the 802.16d and 802.16e standards called "profiles". By conforming to the WiMAX profiles, vendors are able to certify their products with an independent testing lab and ensure interoperability with certified products from other vendors. The initial products supporting 802.16d were relased in 2006 and the first 802.16e products are becoming generally available in early 2007.

NOT BACKWARDS COMPATIBLE

Operators seeking to make a WiMAX investment must first recognize that 802.16e is not backward compatible with 802.16d. While some 802.16d vendors propose base station equipment with additional hardware complexity or software programmability to allow a switch to 802.16e, this will not impact any 802.16d end-user devices already deployed These 802.16d end-user devices will not operate within an 802.16e network and the imperative for low cost end-user devices makes it prohibitive to introduce additional hardware to attempt an upgrade to 802.16e compliance. Adding upgrade capability to the base station may also result in a large cost penalty.

Many of the 802.16d deployments are expected to follow a Frequency Division Duplexing (FDD) frequency plan driven by the 802.16d WiMAX profiles. The prioritized profiles for 802.16e are expected to follow a Time Division Duplexing (TDD) frequency plan. This will add complexity to any potential migration path as TDD and FDD in the same spectruym allocation will have severe interference issues. Additionally, an operator who deploys 802.16d and then attempts to roll in 802.16e equipment at a later date will be disadvantaged by having to split the available licensed spectrum between the two technologies. Without a true upgrade path from 802.16d to 802.16e and the necessity to preserve spectrum to support network growth, 802.16e provides the best long term protection for an operator's WiMAX investments.

LOWER COST

As the broadband wireless market continues to grow, the industry should expect to benefit from cost reductions enabled by volume deployments and economies of scale. Portable and mobile applications have a very strong track record for accelerating volume. Mobile deployments of 802.16e will bring cost points down below solutions engineered solely for fixed applications using 802.16d. Additionally, major chipset manufacturers such as Intel have announced publicly that 802.16e will be the premier standard for WiMAX applications, pointing to a substantial embedded base of consumer products with 802.16e support. These same chipsets used in laptops and PDAs can be leveraged in the manufacture of indoor and outdoor fixed customer premise equipment. It becomes quickly apparent that 802.16e offers the critical advantage of allowing the operator to ride a downward trending cost curve.

THE AIR INTERFACES

802.16d supports both Orthogonal Frequency Division Multiplexing (OFDM) with 256 FFT (Fast Fourier Transform) and Orthogonal Frequency Division Multiple Access (OFDMA) with 2048 FFT. OFDM is a digital modulation technique where a signal is split into several narrowband subchannels to mitigate self-interference due to frequency selective fading channels and is particularly well suited to support broadband high-speed data transmission. WiMAX has selected to specify OFDM with 256 FFT for the 802.16d physical layer profile and not OFDMA with 2048 FFT. With 802.16e, WiMAX makes enhancements to the physical layer by employing Scaleable OFDMA (S-OFDMA). In view of the above we make all comparisons of 802.16e to the 256 FFT OFDM mode of 802.16d.

FTT Length	128	512	1024	2048
System BW (MHz)	1.25	5	10	20
Subcarrier Separation (kHz)	10.94	10.94	10.94	10.94
Symbol Duration (µs)	102.86	102.86	102.86	102.86
Number of OFDM Symbols (5ms)	48	48	48	48

Table 1 – Carrier Bandwidth Scaling

SCALABLE SYSTEM BANDWIDTH

A benefit of the 802.16e OFDMA specification is that the bandwidth of the system is scalable. There is a fixed relationship between the occupied bandwidth and the OFDM symbol sample rate. FFT sizes of 128, 512, 1024, and 2048 are supported by the 802.16e specification permitting the implementation of a bandwidth-scalable air interface, where the subcarrier separation and symbol duration remain invariant as the deployment bandwidth changes. Table 1 shows an example of such a carrier bandwidth-scaling process for a 5ms frame duration, where the cyclic prefix (CP) duration is 1/8 of the useful symbol duration.

The ability to scale system bandwidth while maintaining constant symbol duration provides greater commonality in equipment components and offers the operator the advantage of being able to deploy today and grow their system bandwidth tomorrow at lower cost and reduced network impact.

SUBCHANNELIZATION TECHNIQUES

Additionally, 802.16e OFDMA provides for subchannelization techniques as a means to better manage network performance to address specific coverage and capacity requirements. The OFDMA physical layer divides the available OFDM symbols and component subcarriers into distinct logical and physical subchannels. OFDMA subchannelization techniques include Frequency Diverse and Frequency Selective Transmission schemes.

Frequency Diverse Transmission

Frequency Diverse Transmission schemes can be grouped into Full Usage of Subchannels (FUSC) and Partial Usage of Subchannels (PUSC) modes. These modes support frequency diverse transmission, where the subcarriers assigned to each logical subchannel are pseudo-randomly distributed across the available subcarrier set. The use of Frequency Diverse Transmission schemes provide frequency diversity that is better suited to handle varying channel conditions and benefits network coverage and capacity

Frequency Selective Transmission

Frequency Selective subchannelization is supported through the Band Adaptive Modulation and Coding (AMC) mode. Band AMC permits subchannel construction through physically adjacent subcarrier allocations. The system scheduler can utilize closed loop channel feedback techniques to determine the optimal subchannels to be allocated to each end-user based on the unique channel conditions. A capacity improvement of up to 30% can be achieved using Frequency Selective scheduling over Frequency Diverse scheduling at the expense of system overhead. There is less flexibility with scheduling in an 802.16d system where only one user can be scheduled per symbol as opposed to OFDMA where multiple users can be scheduled per symbol.

The ability to scale bandwidth and leverage subchannelization techniques with 802.16e OFDMA provides significant advantage over the 802.16d OFDM physical interface. Operators have a greater set of tools to manage their network's performance to meet specific coverage and capacity requirements as well as ease network expansion to meet growing usage demands.

HIGHER PERFORMANCE

While both 802.16d and 802.16e standards specify various requirements and optional techniques to enable a high-performing broadband wireless channel, 802.16e IEEE has extended these requirements and options to guide vendors to further enhancements in capacity, coverage, power reduction, Quality of Service, and support for rich IP applications.

CAPACITY

Higher Performing Coding Techniques

802.16d and 802.16e support a variety of forward error correction techniques to increase the capacity of the broadband wireless system. While basic Convolutional Codes and ARQ are required, options for higher performing coding techniques such as Convolutional Turbo Codes (CTC) and Hybrid ARQ (HARQ) are also specified. However, the first generation of 802.16d products are not expected to utilize such high performance forward error correction techniques.

802.16e furthers the advanced coding options to include low complexity Low-Density Parity Check (LDPC) and will leverage the high performance coding techniques like CTC codes from the first product shipments.

Enhanced Subchannelization Support

802.16e provides subchannelization techniques to more efficiently manage the channel bandwidth among multiple end-users. Subchannelization is employed by the base station to optimize scheduling of multiple users having distinct spatial signatures. The various subchannelization schemes offered by 802.16e allows more efficient scheduling of users based on channel quality, priority, power, and bandwidth allocation.

COVERAGE

Antenna Diversity Techniques

Optional solutions for improving coverage capabilities exist for both 802.16d and 802.16e through techniques such as antenna diversity and space-time coding (STC). These capabilities are further deepened in 802.16e with guidance on additional diversity and adaptive antenna techniques. Support for multi-antenna operation is provided for base station transmitters including optional Advanced Antenna Subsystem (AAS) modes, open-loop Space Time Coding (STC) modes (supporting between 2 to 4 transmit antennas), and closed-loop Multiple-Input Multiple Output (MIMO) modes. Support for uplink coordinated Spatial Division Multiple Access (SDMA) is also provided in 802.16e.

Multipath Resilience

WiMAX specifies up to a 2048 FFT for 802.16e (for 20 MHz BW) compared to the 256 FFT for 802.16d specified by WiMAX. For a larger bandwidth, OFDM-256 implies short OFDM symbol time. As such, the fading channel delay spread that can be tolerated by 802.16e is larger than that of the OFDM-256 system.

Single Cell Frequency Reuse

OFDM-256 for 802.16d cannot be deployed using 1-cell reuse patterns while Scalable 802.16e offers this capability. As such, OFDM-256 is likely to have lower spectral efficiency than scalable OFDMA.

POWER REDUCTION

802.16e defines a series of sleep and idle mode power management functions to enable power conservation and preserve battery life for end-user devices. The mobility enhancements provided by the latest 802.16e amendment further enhances operation at vehicular speeds, by providing improved support for inter-cell handoff, directed adjacent-cell measurement and sleep modes to support low-power mobile station operation.

QUALITY OF SERVICE

802.16e introduces Extended Real-Time Polling Service (ERTPS). ERTPS allows the 802.16e solution to manage traffic rates and transmission policies as well as improving latency and jitter. The advantages afforded by the Quality of Service techniques are especially important in the support of Voice over IP (VoIP) applications.

MULTICAST / BROADCAST

802.16e also supports multicast and broadcast services. Single Frequency Network (SFN) operation can be achieved using OFDMA for broadcast/multicast services enabling very high data rate coverage at cell edge. Rich IP multimedia applications such as IP TV that make use of streaming video are greatly advantaged by multicast and broadcast capabilities to better manage bandwidth and content delivery

Comparison of 802.16e and 812.16d

The following table provides a comparision of the WiMAX standard specifications for 802.16d and 802.16e:

	802.16-2004 (d)	802.16e
Multiple Access Method	OFDM / OFDMA[1]	S-OFDMA
Bandwidth supported (MHz)	1.75/3/3.5/5.5/7 (OFDM)[1] 1.25/3.5/7/14/28 (OFDMA)	1.25/2.5/5/10/20 1.75/3/3.5/5.5/7
FFT Size	256(OFDM)/2048(OFDMA)[1]	128.256.512.1024.2048
Sub-carrier spacing (kHz)	22.5 (OFDM @ 5 MHz)[1] 2.8 (OFDMA @ 5MHz)	11.2 for all BW modes
Duplexing	FDD/TDD/Half Duplex FDD[2]	FDD/TDD/Half Duplex FDD
Frame Duration (ms)	2/2.5/4/5/8/10/12.5/20	2/2.5/4/5/8/10/12.5/20
Channel Coder	Concatenated Convolutional RS code, Block TC, CTC[3]	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

[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

Conclusion

Delays in certification and availability of 802.16d products significantly closed the gap before the emergence of the first 802.16e products. The first 802.16e products will be generally available in early 2007 and follow with a long line of network and end-user equipment offered by major equipment vendors with strong heritage in telecommunications solutions. Additionally, the industry can expect to see a significant base of consumer devices with embedded 802.16e chipsets provided by the major chipset manufacturers. 802.16d has all appearances of being an interim technology with no true upgrade path to 802.16e. Operators should protect their early WiMAX investments by selecting solutions based on the 802.16e standard. While 802.16e provides a path to mobility for operators seeking to introduce mobile broadband applications, 802.16e will outperform 802.16d and benefit from economies of scale even for fixed applications.

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