Process, Promise, Problems: Developing WiMAX as an International Standard

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Abstract

The WiMAX set of wireless broadband standards (IEEE 802.16x) represents a joint effort between a traditional standards development organization and industry stakeholders, with facilitation and leadership by the U.S. National Institute of Standards and Technology (NIST). This hybrid approach seems to have added significant value to the overall development effort, and to have hastened commercialization and market development of WiMAX technology and services. This paper describes the process by which WiMAX evolved and explores its market potential and impact on public and private stakeholders. Although WiMAX shows great promise as an internet protocol native, high quality, high throughput wireless pipe with greater range than competing existing technologies, the future of the technology is not ensured due to technical, business, and standards competition issues. Still, an industrial and business ecosystem capable of ensuring some role for WiMAX, in peripherals as well as 4G telephony, is rapidly emerging.

Introduction and Methodology

Participants in standards development want to know how their investment in the process of standardization can be recouped whether at the level of an individual firm participating in the process as well as at the national level. Standards participation is costly both in terms of money (time, labor, travel, and other resources) and risk (possible loss of intellectual property, paying for freeriders, etc). This paper is a narrative of the evolution of Worldwide Interoperability for Microwave Access (WiMAX) standards, which is a cooperative effort between an international standards development organization (IEEE), government (NIST), and an industry alliance for testing and compliance (WiMAX Forum). Our premise is that this widely based cooperation enhanced the pace and value of WiMAX standards, their international acceptance, and the ecosystem of vendors and service providers of WiMAX products and technology, and the global market for these products and services.

The move toward broadband wireless technologies represents the fusion of two major technological revolutions; telephones and personal computers are morphing into fully integrated mobile devices, creating many opportunities for networked systems. WiMAX is a revolutionary communications technology that makes any desktop computer application possible wirelessly, on the road, at broadband speeds, with a new and growing family of internet-connected devices. WiMAX is capable of mobile data rates several times faster than current third-generation (3G) cellular speeds. Based on the IEEE 802.16 standard, WiMAX is a new technology with the potential to ultimately allow societies to become connected internally as well as globally.

This topic was selected following an activity in which NIST canvassed its laboratories for examples of high impact documentary standards with NIST involvement (Puskar 2007). This paper provides an overview of the development of the WiMAX standard, a summary of benefits and costs to the stakeholders, market potential in WiMAX systems and components, social benefits of the technology, and its impact on innovation and competitiveness. We also review NIST's role in the development of the standard and attempt to determine its usefulness. Of course, as a disruptive and transformative technology, there are also risks and challenges associated with WiMAX, and these are discussed as well. Addressing these goals, the authors used a small survey of ten active participants in the IEEE 802.16 community, a literature review of wireless technologies and related market assessments and forecasts, and data gathering from industry analyses, news reports and articles

This paper is not an economic analysis, but a descriptive narrative meant to explore the role of government/industry cooperation in standardization of a new technology, and resulting market creation and projected impacts. It is still several years too early to conduct a thorough economic analysis of WiMAX. The lack of an available methodology for measuring impact was also a constraining factor.

The IEEE 802.16 Standards Development Effort

History

In 1998, NIST began looking at a different wireless application: fixed broadband wireless access providing high-speed network access to businesses, homes, and other stationary sites, generally through rooftop antennas. NIST found little evidence of U.S. or worldwide efforts to standardize such services, although an early program in the European Telecommunications Standards Institute (ETSI) had begun. This application seemed ripe for standards, but industry needed a catalyst. NIST assumed the role and called a meeting to discuss the topic in August 1998, and crafted a plan to initiate the standardization process.

This group did not follow the traditional telecommunications model of creating one or more national standards leading to international standards competition. Instead, they followed traditions established in data communications that had led to the global standards underlying the Internet. Following that model, the NIST-initiated group, after considering possible consortium development, elected to proceed with standardization through the ANSI-accredited IEEE Standards Association (IEEE-SA), which is the standards developing arm of the Institute of Electrical and Electronics Engineers (IEEE), a transnational nonprofit technical society of over 350,000 members. In particular, that group approached the IEEE 802 LAN/MAN (Local/Metropolitan Area Networks) Standards Committee.

Within six months, the new IEEE 802.16 Working Group on Broadband Wireless Access was chartered to develop its first standards project. The project attracted broad global interest, drawing members from many countries. The core standard defining the WirelessMAN® air interface was approved as IEEE Standard 802.16 in 2001. Additional standards to enhance the applicability of the work and aid deployment of the systems have also been published, with

several more under development. The Worldwide Interoperability for Microwave Access (WiMAX) Forum was formed in 2001 and has developed compliance tests.

Beginning in late 2002, the IEEE 802.16 Working Group undertook to expand the WirelessMAN standard to mobile as well as fixed user devices. This project, 802.16e, resulted in another surge of membership and concluded with publication of IEEE 802.16e-2005. The resulting standard became the basis of the Mobile WiMAX certification procedures and led to the commitment of hundreds of companies into the ecosystem. A very big step for WiMAX was being recognized by the ITU-R as an IMT-2000 technology in October of 2007 (Corner 2007).

NIST's Role

Supporting the development of standards for broadband wireless access technology provided NIST the opportunity to fulfill its mission in several ways such as: encouraging the use of voluntary consensus standards; accelerating the standardization process and hence deployment of the technology; being able to support the development of more broadband access alternatives to a wider range of U.S. consumers and businesses; and increasing the chances for export market opportunities due to the broad global participation in the 802.16 Working Group.

It is interesting to see how other IEEE 802.16 participants viewed NIST's active role in the development of the standard. Overall, NIST's leadership role was cited positively by the comments. There was an underlying assumption that some firms, in particular smaller ones, feel that they may not be able to compete fairly at the standards setting table. Some examples of the comments include:

- *NIST's leadership and involvement allowed the standard to be developed in a much less biased environment than is typical with standards. It served to protect companies, especially small ones from being dominated.*
- *NIST leadership enabled development of 802.16 within the procedural rules of IEEE without it becoming subject to miscreant forces*
- *In a fiercely competitive environment, NIST was a neutral facilitator.*

Few ventured how long the standard would have been delayed without NIST's participation; those that did estimated from one to two years. Twenty (20) percent of the respondents stated that without NIST's involvement industry participation would have been less, 40 percent thought it had no impact, and 40 percent did not know or did not answer. This may suggest that NIST's influence, while important, has limits. One respondent cautioned that while NIST's role as enabler of the process was very useful, it must be careful not to "become a troubleshooter for industry's internal standards issues". Other critical factors cited included the backing of large industry players (especially chip makers), not being beholden to a single firm's intellectual property, and the role of the WiMAX Forum in certification and commercialization of the technology.

Development Costs

Companies and government organizations are generally cognizant of the costs involved with developing a standard, certainly more so than with the benefits that accrue to them as a result of participation. An attempt has made to identify to estimate the total cost of developing the IEEE 802.16 standard from 1999 when the first official session of the Working Group was held. From 802.16's inception in May 1999, NIST participated in every meeting, with a minimum of one attendee. NIST's cost of participation included fully loaded salary for the Chair of the Working Group, travel expenses, management oversight and administrative support. Several guest researchers also supported this effort. For the seven year period the NIST cost was calculated at $3.0 million.[1] This is an upper bound.

Private sector costs in any standards group are always an issue and can act as a barrier to entry. A total of 47 sessions were held from the very first session in May 1999 until the final meeting of 2006. The number of attendees at these sessions totaled 7,490. These are not all unique individuals; in many cases one person would attend multiple sessions. A total of 730 companies participated in the 802.16 working group, representing 28 countries[2]. No company participated in all sessions and participating companies changed significantly from the early days of the in 1999-2001 to present. The average company participated in approximately 10 sessions.

From our survey results and data available on the 802.16 website we attempted to estimate the costs of participation for firms in the IEEE 802.16 Working Group. Survey respondents on average sent 93 people to these sessions with a median of 65. The average amount spent by firms was $942,000. The median figure was, however, much lower at $180,000 and is probably more representative for a firm with continuing participation. This figure represents staff and/or consultant's time, fees, travel expenses and overhead. The reported range was $94,000 to $3 million. As one of the respondents was a large Fortune 500 firm that participated heavily in the process, they and another very active (but smaller) company skewed the average results significantly higher. Therefore the median cost per participant ($2769 in our survey) is a deemed a better indicator [3]. Using the average of 10 meetings attended, a typical firm therefore spent approximately $28,000 participating in the Working Group between 1999 and 2006. There are of course many small firms that participated rarely during this period.

The total estimated cost of both NIST and the private sector participants to develop the 802.16 series of standards through 802.16 (2005) was $30.7 million, as summarized in Table 1.[4] As a number of large and active participants may have spent several million dollars each, this is probably a conservative estimate. The Working Group activity peaked in 2004 and 2005 before declining slightly in 2006 (Figure 1). It has since ramped up again.

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[1] Data from NIST, EEEL, Electromagnetics Division, Boulder, Colorado.

[2] Source: IEEE 802.16 Working Group website. This figure represents instances where the country of origin was identified. In 99 cases it was not.

[3] One of the respondents did not directly participate in the 802.16 effort and two other respondents did not know or want to disclose their costs.

[4] Based on number of participants times the median cost of attendance. $1 million per year between 2000 and 2006 was added to incorporate the higher reported costs of some survey respondents which would not otherwise have been reflected.

Table 1: Total Cost of Participation in the IEEE 802.16 Working Group (in thousands)

Year	NIST	Private	Total
1999	$354	$961	$1,315
2000	$369	$3,434	$3,803
2001	$376	$3,334	$3,710
2002	$390	$2,348	$2,738
2003	$404	$2,285	$2,689
2004	$396	$5,344	$5,740
2005	$415	$5,511	$5,926
2006	$322	$4,525	$4,847
Total	$3,026	$27,742	$30,768

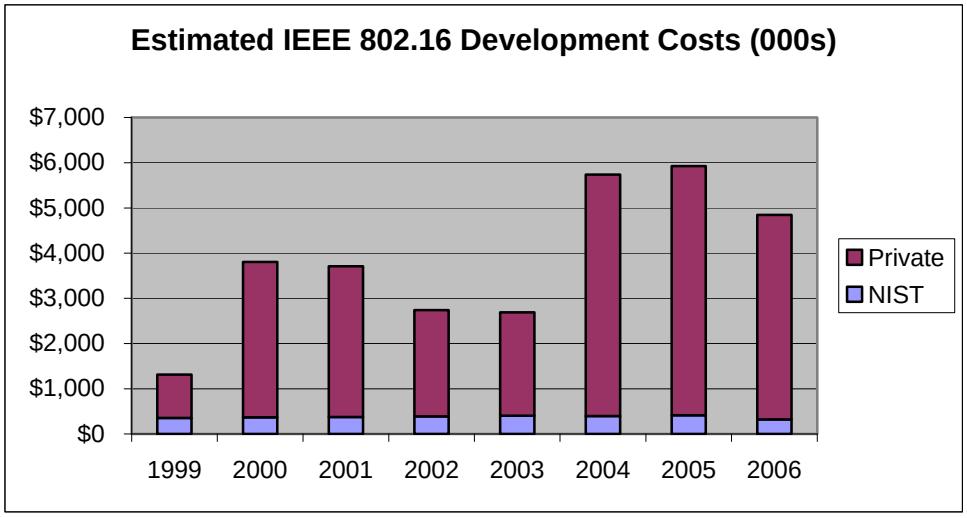

Figure 1: IEEE 802.16 Development Costs by Year

Firms track and assign their costs differently. Companies committed different number and level of staff, and the number of years also varies. In most cases the survey respondents were involved in the standards process since 2001. However each firm accounts for the costs, it is the firm's own perception of their cost of participation that is important. Therefore even though direct comparison of the figures may not be appropriate for detailed analysis, the self-reported figures represent what the respondents think they have spent or contributed to this effort as a cost of doing business.

Overview of WiMAX Market and Potential Benefits

Prior to any significant WiMAX adoption, broadband wireless access (BWA) in 2005 generated worldwide service revenues totaling $1.8 billion and equipment revenues of $750

million (Fellah and Syputa 2006, p. 138).[5] Most of the equipment sold in 2005 was non-conformant or proprietary technology. However, WiMAX is gaining traction in the marketplace as adoption of the industry-wide standards enables both service providers and technology vendors to make commercial commitments to the technology, forming the foundation of a WiMAX ecosystem. During 2006 service provider trials moved into launch phase in many areas. WiMAX service revenues in 2006 are estimated by analysts in the hundreds of millions of dollars and equipment revenues range from $143 million (Fellah and Syputa 2006) to $549 million[6]. For 2007, world-wide sales of WiMAX equipment totaled nearly $800 million, representing 46% growth.[7] WiMAX chipsets will be embedded into laptops by 2008, handheld devices by 2009, and consumer electronics in of 2010. These developments will spur mass market adoption.

Full adoption of such services by significant numbers of consumers requires an ecosystem of devices that can connect to the service. WiMAX is now promoting new mobile devices with advanced functionality and that support high-speed handoffs, roaming and multiple antenna technologies. Initial mobile WiMAX equipment will include notebook-based subscriber units (mini PCMCIA cards, PCI Express, PCI Express mini, USB modules, etc.) and desktop units. Various mobile devices now are available with embedded WiMAX devices, such as notebooks, Ultra Mobile PCs (UMPC), PDAs, smart phones and other wireless devices. In addition to VoIP, other real-time applications like mobile video and audio streaming, videoconferencing, and gaming will greatly benefit from the quality of service and low latency offered by WiMAX. New applications and functionality not yet considered may also result.

Benefits to Actors and Stakeholders

Stakeholders in WIMAX can be aggregated as follows:

- *Operators*. Operators include the subscription service providers for telephony, communication, data, and other network services to end users. Some of these are major phone and internet service providers whose networks cover huge areas, while others can be small and specialized, both in regional area and in customer base.
- *Legacy Incumbents*. These are existing fixed voice and data service providers using technologies, primarily DSL and cable, and to a lesser extent fiber optics.
- *Vendors/Manufacturers*. These include makers and marketers of chipsets, devices, base stations and servers, peripherals, and test and certification systems as well as consulting services to owners and operators of communications systems.
- *SDO's/SSO's*. Standards development organizations and standards setting organizations develop families of standards. IEEE is the dominant SDO stakeholder in this group.
- *Governments*. A key metric for inter- and intra-national comparisons is the depth of broadband connectiveness within countries. Governments therefore have a public policy interest in broadband projects.

[5] WiMAX is a technology segment within the overall broadband wireless access market.
[6] Infonetics Research. "Landmark year for WiMAX: mobile WiMAX debuts, fixed WiMAX jumps 254% in 2006", press release, March 15, 2007
[7] Infonetics Research. "WiMAX equipment market up 46% in 2007, forecast to hit $7.7B in 2011", press release, February, 2008.

- *End Users—Business*. Business customers are concerned with bandwidth, security, and reliability of the communications services they contract for (this stakeholder group would also account for Government end users).
- *End Users—Public*. Public end-users, whether household or individual, are critical to the success of any technology-based service in that return on investment depends on subscriber-generated revenue. Likewise, sales of WIMAX-embedded consumer devices (PDA's, cameras, laptops etc) are driven by numbers of subscribed end users.

Identifying benefits, costs, risks

The benefits of WiMAX are multiple and manifest, and some or all of them accrue to many stakeholders. Table 2 identifies the perceived primary (but non-exhaustive list of) benefits of WIMAX systems and applications and which stakeholder groups enjoy these, while Table 3 treats reduced benefits and increased costs.

Table 2. Stakeholders Affected by Benefit/Cost Savings.

Type of Benefit or Cost Saving	Operators	Incumbents	Vendor/ Manufacturer	SDO's/SSO's	Government	End Users—Business	End Users—Public
802.16 standards accelerates WIMAX development and adoption	√		√	√	√	√	√
Standards participation increases ROI	√		√				
Fixed WIMAX enables "last mile" connectivity and service	√	√			√	√	√
Fixed WIMAX is efficient in backhaul operations	√	√	√		√	√	√
Fixed WIMAX covers more area than WiFi at lower capital cost per user	√		√		√		
Mobile WIMAX enables efficient applications for SCADA, security, other municipal operations	√		√		√	√	
Mobile WIMAX integrates 3G/4G phone with high bandwidth data	√		√	√	√	√	√
WIMAX systems increase competition and improve quality, availability, and affordability	√		√	√	√	√	√
Creative business models create stronger services (bundling)	√				√	√	√
Hybrid systems utilize legacy hardware, software	√	√	√				
Variety reduction leads to economies of scale	√		√				
Lower system integration costs due to content of standards	√		√	√	√		
Supplier alliances benefits small business	√		√				

Table 3. Stakeholders Affected by Costs and Risks

Type of Cost Increase or Benefit Reduction	Operators	Incumbents	Vendors/ Manufacturers	SDO's/SSO's	Government	End Users—Business	End Users—Public
"Real world" effects restrict WIMAX potential (range, bandwidth, QoS)	√		√	√	√	√	√
Business models not tested; revenue, profit may not meet projections	√	√			√		
ARPU may not be sufficient for good ROI	√				√		
Chipset power consumption difficult to solve	√		√	√		√	√
Competition threatens operators of legacy systems	√	√		√	√		
Available spectra may be limited or costly	√	√			√		

Industry Benefits

WiMAX has been gaining traction in the marketplace as the establishment of industry-wide standards enables both service providers and technology vendors to make commercial commitments to the technology, thereby forming the foundation of a WiMAX ecosystem. This technology looks to be a major component of the broadband wireless industry. The standard has created opportunities to expand the size of the market well beyond what it has been to date. Although three years have passed since the adoption of 802.16(2004), significant market impact is only in the beginning phases. The initial results in terms of market success achieved by industry actors is not readily available and as a result the ability to conduct a quantitative analysis on revenues (or cost savings) attributable to the standard is limited.

It is expected that WiMAX will increase revenues for the companies participating in the new ecosystem. Projected revenue estimates were not provided by our survey respondents except for one firm, and the answer it gave was very general. However, six of the respondents stated that the 802.16 standards effort has hastened adoption of WiMAX technology, and therefore have accelerated revenues or cost savings for the company. Four stated an acceleration of 1 to 2 years, while two suggested an acceleration of 3 or more years, pointing out that there might have been very little adoption at all without a consensus standard. Only one stated that there was no acceleration, while the others did not know or did not answer. Figure 2 displays the results.

Another key benefit of the standard is increased efficiencies. These can manifest themselves in a number of ways. Within the WiMAX industry some of these include reduction of entry barriers to new entrants, evident from the large number of firms which participated in the IEEE 802.16 process as well as the very large membership of the WiMAX Forum, including many small companies. Also, fewer base stations required greatly reduces network capital and maintenance costs. The WiMAX standard has allowed for interoperability between products

from different vendors which has an impact on cost. According to our survey respondents, market access/creation was the largest single benefit of adopting the 802.16 standard for their company and was identified by 80% of the respondents. The second and third most common benefit identified supply chain flexibility followed by mix-and-match interoperability (Figure 3).

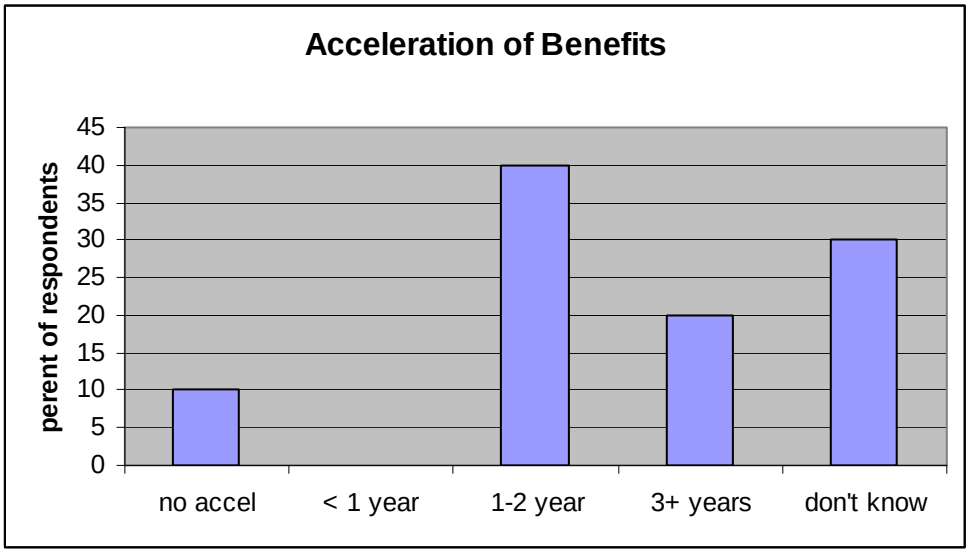

Figure 2: Estimate of the Acceleration of Benefits Due to the 802.16 Standard

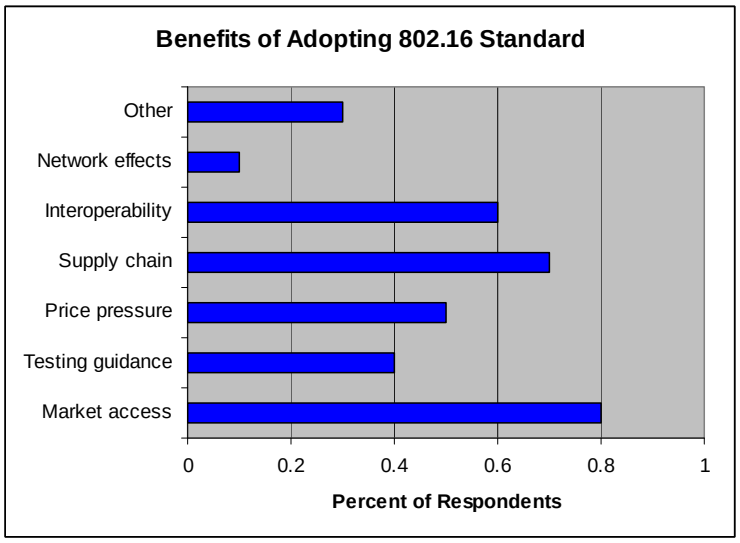

Figure 3: Survey Results of the Benefits of Adopting the 802.16 Standard

Social/Public Benefits

The societal benefits of WiMAX accrue to government or other public institutions, to individual users and consumers, or both. Early evidence suggests significant government savings attributable to broadband wireless systems is possible; Allegany County Maryland, which installed a pre-WiMAX system (a bridging technology) to provide high-speed Internet access to the county's government buildings, schools and libraries, is saving $560,000 in operational and telecommunications costs (Wong 2007, p. 39). One of the biggest potential benefits to individual consumers is the availability of bundled high-speed internet voice and data service, accessible with multiple devices (a mobile phone, home computer, consumer electronics devices and productivity tools) at a set price. The private efficiency benefits should quickly be passed on to consumers in the form of lower monthly rates.

Large scale consumer adoption benefits government and enterprise uses as well, since vertical applications like surveillance, public safety, connectivity to remote devices, inventory fleet tracking, fleet management and educational services are also supported by mobile WiMAX network with little or no incremental cost to network operators.

WiMAX is in the process of being rolled-out in many countries in the developing world. One of the primary reasons for this is that they have little copper-wire infrastructure and cannot afford to begin to lay fiber connections. This allows these countries to compete on equal footing with the developing world in telecommunications platforms and invite foreign investment and promote economic growth in the country. Developing countries overall competitiveness will be enhanced in the realm of globalization (NSR 2007, p. 2).

The Digital Divide

An unserved area can be defined as an area in which residents and businesses are unable to obtain broadband connectivity at prices, level of service and quality of service levels comparable to areas which are adequately served. There are approximately 1.5 billion people in 800,000 villages without connection to Information and Communication Technologies (ICTs). According to a recent UNCTAD report, the Digital Divide is narrowing when it comes to basic access to the Internet and mobile phones taking on new forms in terms of the differences in the speed and quality of access to ICTs. The information and content gap is still growing (ITU 2007). Standards can be an important tool for bridging the divide and spurring economic development. If firms in poor and developing countries can opt for these technical advances represented in that technology, the standards can then provide an important means for the technological catch-up process in such countries (Hesser, Czaya and Riemer 2006, p.76).

WiMAX along with WiFi and VoIP have been identified as enabling technologies which allow access to ICT to be expanded to rural areas and improve the speed and quality of service in unserved and underserved areas at an acceptable price-point. These deployments do not require significant capital investment, are environmentally green and have low operating costs. Early experience gained through several demonstration networks in developing countries indicate that a reasonably-sized community can be provisioned for a capital investment on the order of $25,000 - $40,000 (Owen 2007).

The digital divide is not just an issue for the developing world. There are either pockets or large sparsely occupied areas of developed countries which have this issue. WiMAX will be a key component of national broadband network to be developed by the Government of Australia called Australia Connected to provide broadband services to rural and regional communities with the goal of ensuring that 99 percent of the population has access to fast affordable broadband.[8] Many state and local governments in the United States have plans to reach their underserved or unserved areas through wireless broadband initiatives which include WiMAX.

Impact on Innovation and Competitiveness

Standardization can both support and hinder innovation. A standard can precede innovation by establishing a baseline for design and performance that will satisfy user requirements—such standards must provide enough flexibility that suppliers or manufacturers can vary features, function or price to establish a niche that positions them with a marketplace advantage. In other cases, innovation comes first, and the resulting standard becomes the physical documentation of an agreed-upon solution that has already been tested and proven. Timing is an important issue in such cases. Blind has proposed that there is a dynamic dimension to communications technology standards, because they play a crucial role in research and innovation with various feedback loops along the research and development cycle, from pure basic research through the diffusion of new products (Blind 2006).

From our survey, eight of ten survey respondents stated that the 802.16 standard promotes innovation in WiMAX technologies (while two did not answer). Some of the reasons given for these responses centered on the general framework of the standard, and the built-in ability to co-exist with other state-of-the-art technologies. The creation of a WiMAX ecosystem was noted as being crucial both for innovation as well as competition, as manufacturers are encouraged to differentiate their products within the general bounds of the standard, which generates both innovation and competition.

Challenges

Despite the promise of WiMAX as an IP-based, high throughput, long-range, fixed/mobile wireless technology, there are serious challenges to its ultimate success. These fall into three general categories: business plans, real-world performance, and competition for growth in international standardization. The US market is also impacted negatively by the loss of momentum in providing low-cost wireless broadband to underserved municipal areas through public/private cooperative efforts; service providers are pulling out or drastically scaling back their projects in numerous cities as their costs rose and market projections failed to realize (Urbina 2008). Some dissatisfaction has surfaced with the technical performance, including range and penetration, of WiMAX in an early Australian pilot, while others state it is too early for conclusions (Hansell 2008). And while WiMAX has been touted as a key standard for 4G telephony because of its potential for high quality IP streaming video in addition to high

[8] Minister for Communications, Information Technology and the Arts. Media Release, 80/07, Monday 18 June 2007

throughput voice and data, some manufacturers are clustering their support around competing technologies such as the LTE (Long Term Evolution) standards based on CDMA technology (Schenker 2007). In spite of these growth pains, WiMAX bolsters its potential with momentum. Sprint/Nextel is obligated to a baseline WiMAX deployment in the US in the terms of its spectrum agreements and recently announced a joint venture with Clearwire to build a nation-wide network. The industrial ecosystem that is being built includes countless peripheral devices in addition to phones and computers. Finally, ITU standardization approval for WiMAX indicates that if not the backbone 4G technology, it likely will be a major supported standard.

Conclusions

The IEEE 802.16 standards development process is notable for several reasons. First, the early proponents of the technology made a decision to pursue the model followed by data communications standards developers and established a working group within the IEEE family with broad global participation to help ensure a international support for the developed set of standards. The IEEE Working Group then quickly pushed for adoption as formal international standard. Secondly, the standards effort was initially championed and then lead by a NIST staff member which is not necessarily the norm for NIST or the U.S. Government. Finally the creation and cooperation of the WiMAX Forum with a large overlap in membership with the 802.16 Working Group is responsible for jump starting commercialization and adoption of the technology.

The WiMAX family of standards has started to impact lives around the world in many ways, including individuals representing global firms who helped develop the standard, developers of the technology and the service providers, and end-users or consumers of the new products and services that will result from WiMAX. Although both business and technical challenges remain, millions are expected to be users of this technology. The benefits to industry of participation in the standards working group have been identified and the costs have been estimated to be at a minimum approximately $27 million. NIST's total cost relative to industry's is likely to be somewhere between 5-10%, more likely closer to 5 percent considering that the $27 million is a lower bound. Industry appreciated the leadership role of NIST in the standards development process as an unbiased facilitator and believes that development of the standard was expedited as a result. It remains for a further more detailed study to determine the actual economic impact, but a net positive benefit is anticipated. Having a methodology for measuring the impact of a standard available to guide such a study would be useful.

The future for information technology is practically limitless. WiMAX is poised to play a very significant role in bringing transformational communications capabilities to people, enterprises, and governments across the globe including hard to reach locations. Development of the standards that enable WiMAX serves as a model of successful public/private cooperation in the standards arena.

References

Blind, K. "The impact of ICT standards: three views", from International Standardization as a Strategic Tool, IEC Centenary Challenge, 2006.

Corner, C. "WiMAX joins cellular as an ITU standard", iTWire, October 23, 2007.

Fellah, A. and Syputa, R. "WiMAX and Broadband Wireless (Sub-11GHz) Worldwide Market Analysis and Trends 2006-2012", Maravedis, 4th ed., September 2006.

Ginevan, S. "Will WiMAX go the distance?" Information Week, March, 2008.

Hansell, S. "WiMAX gets less than max grades in Australia", New York Times, March 24, 2008.

Hesser, C. (ed.) and Pham, T. "Standardisation in Companies and Markets", Helmut Schmidt University Hamburg, September, 2006.

Hesser, C. (ed.), Czaya, A., and Riemer, N. "Standardisation in Companies and Markets", Helmut Schmidt University Hamburg, September, 2006.

Horrigan, John. "Why it Will be Hard to Close the Broadband Divide", Pew Internet & American Life Project, 8/1/2007.

ITU. "World information society report 2007", United Nations Conference on Trade and Development, International Telecommunication Union, June, 2007.

NSR. "Technological leapfrogging via WiMAX", Northern Sky Research White Paper series, February, 2007.

Owen, D. "Expanding Rural Access: White Paper", February 26, 2007.

Owen, D. "Vietnam LMI: Associated Working Papers", December 20, 2006.

Puskar, E. "Selected impacts of documentary standards supported by NIST", National Institute of Standards and Technology, report number NISTIR 7398, March 2007.

Puskar, E. and Aanstoos, T. "An overview of the development and potential impact of the IEEE 802.16 (WiMax) standard", Report No. NISTIR 7473, NIST, Gaithersburg, MD, October, 2007.

Schenker, J. "A 4G standards war is brewing", Business Week/Wireless World, October 29, 2007.

Urbina, I. "Hopes for cities fade as internet providers pull out", The New York Times, March 22, 2008.

Verlag, B. "Economic benefits of standardization", DIN German Institute for Standardization e.V. 2000.

Wong, W. "Discovering the wonders of WiMAX: cities and counties are beginning to take a chance on 802.16 technology to build high-speed municipal wireless networks", STATETECH Magazine, July/August 2007.