It Takes Two to Tango: Using Wi-Fi and WiMAX to Deliver Broadband Wireless Services to Fixed and Mobile Clients
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WiMAX in perspective

If it is a truism that all new technologies take longer than expected to reach a mass market, few examples can have evoked more disappointment than WiMAX. Conceived almost 10 years ago in the Institute of Electrical Engineers (IEEE), it has progressed through such headlines as ‘It’s clear that 2005 will be the make or break year for WiMAX’ (Wireless Watch, 10 January 2005) to ‘The curse of WiMAX’ (Fortune, 30 November 2007). Along the way, optimistic claims and projections have contrasted with slow progress on the ground. Will 2008, finally, be the breakthrough year for WiMAX?

Proponents of WiMAX claim that already more than 500 operators worldwide hold spectrum licenses suitable for the technology, and over 150 are in trials, but there are few, if any large-scale commercial networks. WiMAX as a technology is ready for takeoff, but various non-technical obstacles have conspired to keep it grounded thus far. Nevertheless, WiMAX offers cutting-edge wireless performance, a ‘flat’ network architecture ideal for IP-based services and the strong commitment of a pivotal vendor of client hardware. How soon will WiMAX emerge as a successful technology, and in what guise?

This paper seeks to answer these questions from the viewpoint of a Wi-Fi network manager. The key questions are how soon WiMAX networks will be available, and how could WiMAX be made to work in conjunction with a Wi-Fi deployment. To reach conclusions, it is necessary to clear up many misconceptions that have arisen over the capabilities and timelines of WiMAX technology.

Applications for wireless: WLAN, WMAN, WWAN

Wireless technologies and standards focus on particular combinations of range and data rate. As the diagrams show, Wi-Fi targets wireless local area networks (WLANs), whereas WiMAX is termed a wireless metropolitan area network (WMAN), but in practice also covers wireless wide area networks (WWANs). Although these are the intended applications for the standards, they can certainly be modified for use in alternate scenarios. For instance, Wi-Fi is capable of point-to-point long distance performance rivaling WiMAX, while WiMAX could be adapted for short-range communications.

Figure 1


**WiMAX history**

WiMAX was born in the IEEE 802 standards group. This is where Wi-Fi (802.11) was invented, and in the late 1990s the 802.16 group was formed to address standards for wireless metropolitan area networks (WMANs), contrasting with 802.11’s brief for wireless local area networks (WLANs). These terms of reverence immediately imply longer range; 802.16 is intended to cover areas more like today’s cellular networks, and indeed, many proponents of WiMAX see it as a candidate for the next generation of cellular networks.

Since it was instituted at about the same time, 802.16 uses many of the same RF techniques as 802.11. Orthogonal frequency division multiplexing (OFDM) is the central modulation technique, and they both incorporate multiple input, multiple output (MIMO) techniques. Each standard regularly incorporates new techniques, and bragging rights change as new versions are released. 802.16e (2005) introduced MIMO in WiMAX, but 802.11n (probably to be finalized in 2008) uses MIMO in arguably more advanced form. Meanwhile the 802.16m and 802.11 very high speed (VHS) task groups are already working on the next wave of improvements. But for the moment at least, both 802.11 and 802.16 are using similar techniques at the RF layer.

In parallel with the technical standardization efforts in IEEE 802.16, a number of equipment vendors and service providers formed the WiMAX forum. While 802.16 deals only with the physical (PHY) layer and media access control (MAC) layer of the over-the-air protocol, the WiMAX forum has defined a comprehensive service provider architecture that allows equipment vendors to build complete networks. This is important, because most observers agree that WiMAX networks will be far simpler and less expensive to operate than the alternatives that evolve from today’s cellular networks, with all the backward-compatibility baggage they carry. WiMAX networks are ‘flatter’ and all-IP based, including quality of service (QoS), and allowing flexible deployment of voice-over-IP (VoIP) and video-over-IP services.

But the WiMAX Forum cannot move faster than the technical specifications provided by the IEEE. The first important standard to emerge from 802.16 was originally known as 802.16d, now as 802.16-2004. This addresses broadband wireless service for fixed clients. The infrastructure comprises a number of transmitting points, like today’s cell towers, and the customer equipment is a small modem with an integral antenna, or for longer distances, an antenna mounted on the outside of the building. This allows delivery of broadband Internet service to residences or small businesses, comparable in bandwidth terms to digital subscriber lines (DSL) or cable modems, but without requiring wiring to the premises.
Most of the current WiMAX trials are of this 802.16-2004, fixed-client version of WiMAX, delivering broadband Internet in rural areas where there is little cable in the ground. But the proponents of this technology had a much bigger target in mind: a better mobile cellular network. The IEEE delivered a standard called 802.16e, now 802.16-2005 that includes mechanisms for handoff between cells and other features to allow for a true mobile network. In doing so, they made the new standard incompatible with the old one: 802.16-2004 networks will never be able to support 802.16-2005 clients and vice versa. Thus there are two current WiMAX standards, presenting a dilemma to operators: the older equipment is less expensive and more reliable, but less flexible than the newer products.

Two markets for WiMAX

WiMAX has two significant opportunities for success when deployed by service providers in licensed spectrum. Currently, the major market for WiMAX is in providing wireless broadband services to fixed clients, hence the term ‘wireless DSL.’ There is considerable promise for this application, particularly in developing countries without copper or fiber in the ground: voice communication in many developing countries is based on cellular infrastructure rather than wired telephony, and the expectation of WiMAX proponents is that broadband can follow a similar path. In this mode, WiMAX should be able to deliver speeds in the order of 10 Mbps over several miles with 802.16-2004.

At this stage, ‘fixed’ WiMAX deployments are said to number in the hundreds world-wide, but the majority of these are limited trials. It would be fair to say that fixed WiMAX has not yet broken through in large-scale, commercially successful networks, but this should be just a matter of time: the economics are now quite well understood, and the characteristics of suitable market opportunities have been thoroughly researched, and medium-scale trials are underway. The most promising opportunity for fixed WiMAX is in developing countries, where there is little copper or fiber in the ground and the expense of reaching homes and businesses by wireless compares favorably with the alternatives. India is a good example of such a market opportunity.

In the U.S., WiMAX has been pioneered by Clearwire, a company that offers fixed wireless broadband in approximately 50 cities nationwide, including Jacksonville, Florida and Dayton, Ohio. In Dayton, Clearwire offers Internet service with up to 2 Mbps download speeds starting from $50/month, based on a standalone modem terminal or PC card, with VoIP service bundled as an option. Users may move anywhere in the coverage area, but the Clearwire service does not yet offer handover, so it can be described as ‘nomadic’ rather than ‘mobile.’ Also, there is no cellphone-like handset offering. Clearwire has spectrum in the 2.5 GHz band that could cover about 30% of the US population, roughly 110 million people, but to build out such a network would take much more than the more than the ~$1.2 billion it has raised to date.

However, wireless broadband to fixed or ‘nomadic’ terminals may be just a prologue. If everything goes as the enthusiasts hope, WiMAX will be the future technology for today’s cellular operators. However, this outcome is not a foregone conclusion: LTE (long-term evolution) from the GSM proponents and UMB (ultra broadband) from Qualcomm’s ecosystem are significant competitors, and it will be some years before any of these replace existing 2.5G and 3G cellular systems. But the combination of spectrally-efficient RF technology with QoS, and a design for a low-cost, high-performance all-IP core network make the mobile flavor of WiMAX a solid contender for the next-generation cellular network.

Sprint is the second U.S. owner of spectrum suitable for WiMAX, after Clearwire. Sprint first announced plans to build a nationwide mobile WiMAX network in 2006, and in August 2007 announced the service as Xohm, introducing partners to supply cellphone-like devices as well as fixed modem terminals. The aggressive rollout plan called for significant national coverage to be achieved by 2008. However, Sprint’s recent financial concerns and related executive reassignments have called this plan into question. A partnership with Clearwire, allowing full roaming capability, wherein Sprint would cover approximately 180 million residents (mostly in urban areas) to Clearwire’s 110 million, was rescinded in November 2007.
In the U.S., almost all viable WiMAX spectrum is owned by Clearwire and Sprint. More spectrum may come available, such as when the U.S. government auctions off around 100 MHz in the 700 MHz band in early 2008. Whoever wins the auction will probably deploy a mobile voice and broadband data service, but there is no guarantee they will choose WiMAX over technologies such as LTE and UMB, as noted above.

Obstacles to WiMAX’s success

WiMAX is excellent technology, but – trials aside – it has not yet enjoyed success in worldwide markets. Many of the reasons are not technical: any new service provider technology faces hurdles, with Qualcomm’s early struggles to promote CDMA a good example. Here are some of the issues that WiMAX must be overcome to break out as a global success.

Spectrum

As WiMAX is a technology for licensed spectrum, suitable spectrum must be available and licensees must use that spectrum for WiMAX rather than competing technologies. There are two main bands available for WiMAX:

- A 3.5 GHz band is available in much of the world outside the U.S. 3.5 GHz has worse propagation characteristics than the current cellular bands (around 2 GHz): this means more cell towers are needed to cover a given area, but it is not a significant drawback.
- The U.S. has a band at 2.5 GHz. Most of the U.S. spectrum in this band is owned by Sprint-Nextel and by Clearwire.

Adjacent bands at 2.3 and 2.6 GHz are available in some countries and are suitable for fixed and mobile WiMAX, but the 2.5 and 3.5 GHz bands comprise most of the opportunity for fixed WiMAX. Also, there are a variety of allowed channel bandwidths within these bands, depending on jurisdiction. The lack of harmonized worldwide WiMAX spectrum fragments the WiMAX vendors, who must build equipment to local requirements rather than a single world-wide standard. Also, there is in most countries a shortage of spectrum, constraining the number of potential WiMAX operators or the number of subscribers each can service, and incumbent cellphone incumbents would be expected to lobby regulators to disrupt any release of new WiMAX-friendly spectrum to newcomers.

Equipment availability

For all wireless networking technologies, availability of client devices lags the infrastructure technology, and WiMAX is no different. Base stations are widely available, core infrastructure is also emerging, but where are the clients? The answer to this question is in two parts. Every fixed WiMAX base station vendor has some kind of matching customer equipment, compliant with 802.16-2004. However, the mobile version of WiMAX is still awaiting volume production of clients.

Since silicon and handset design are very expensive projects, vendors don’t like to start development unless they can be guaranteed a significant volume of sales. Of course it is also difficult for network operators to commit to building networks unless they can be assured of a variety of inexpensive (volume-produced) clients, and a waiting game often ensues until the market sees a significant move from a large player. So it is with WiMAX.

The strongest sign for hope is Intel’s support for WiMAX technology. It was arguably Intel’s incorporation of Wi-Fi radios in the Centrino chipsets of 2003 that spurred the growth of that technology; many PCs became Wi-Fi capable out-of-the-box and at minimal extra cost. Intel is an enthusiastic supporter of WiMAX, and its public commitment to build hardware support into its next-generation chipsets (code name ‘Montevina’, for shipment in 1H 2008) would provide a ready supply of WiMAX-ready PC clients. Voice handsets for use with
WiMAX are another story: it seems that only a large-scale deployment such as the Sprint Xohm project will spur the handset makers to action. Sprint gathered an impressive group of client vendors, including Samsung, Nokia and Motorola for its Xohm announcement in August 2007, but the future of the project is already in doubt (see later notes on the U.S. market).

The preponderance of evidence is that PCs with embedded WiMAX will be shipping late in 2008, while voice handsets (WiMAX mobile phones) will not be available till 2009 at the earliest.

WiMAX and near-WiMAX equipment

Few labels have proven as irresistible as WiMAX. From almost before the name was coined, equipment vendors have touted ‘WiMAX-based’, ‘WiMAX-compliant’, but very few have been able to say ‘WiMAX certified.’ Indeed, an early public demonstration of WiMAX was widely ridiculed as it used Wi-Fi equipment under the covers: subsequently vendors found it expedient to use Wi-Fi chips for the MAC layer, when building ‘WiMAX’ point-to-point radio equipment. Many vendors have labeled equipment ‘WiMAX-compliant’ and claim to have tested interoperability with small groups of other vendors. But one important goal of the standardization process is that certified equipment from diverse vendors will interoperate, allowing multiple client vendors to compete for business, and indeed allowing customers to switch network operators while retaining their investment in client equipment. This is the situation with GSM mobile phones, and the competition between phone vendors, network operators and distribution channels has contributed greatly to the success and health of such mobile phone services. It is also responsible for the fast growth of Wi-Fi, as the Wi-Fi Alliance logo is a guarantee of world-wide interoperability.

Although many products are advertised as ‘WiMAX-compliant’ or similar, the WiMAX Forum has to date only certified base station and client equipment for the 3.5 GHz band, using 802.16-2004 for fixed applications. The WiMAX Forum was expected to finalize a certification program for mobile WiMAX at the end of 2007 for a small number of profiles and specific combinations of spectral band and channel configuration.

While the current regime continues, the lack of any-to-any guaranteed interoperability is an obstacle to widespread network rollouts, as operators must specify and test only a small variety of clients for their networks. For instance, the Clearwire deployments claim to be WiMAX but use ‘Expedience’, a proprietary modulation technique now owned by Motorola. Clearwire has only one vendor for client equipment and will not be able to take advantage of standard WiMAX clients without a network upgrade, but that was a known tradeoff as the network rollout predated 802.16 ratification.

Performance

The most common figures quoted for WiMAX are a bandwidth of 70 Mbps over a range of 30 miles (50 km). Both these figures are misleading. 70 Mbps is a reasonable maximum data rate for a single client very close to the base station. And while it is certainly possible to achieve communications over 50 km, large (high-gain) antennas will be required, and the bandwidth will be very low, perhaps sub-1 Mbps. In reality, bandwidth is shared among all active clients in the cell, and bandwidth decreases as distance increases.

Mobile WiMAX is even more constrained, as antennas are smaller, devices are battery-powered and signals fluctuate as the client moves. Recent mobile WiMAX trials in Malaysia prompted estimates from Motorola of 3-4 Mbps per client with a cell radius of 1-2 km, while the operator involved in the trial indicated current performance is closer to 1 Mbps. It was not clear how many simultaneous clients the network could support (Business Week, 27 November 2007).
When compared with Wi-Fi, it is clear that WiMAX has greater range. However, as we discuss later, this is almost entirely due to the licensed spectrum used by WiMAX, where much higher transmit power is allowed. Thus a licensed WiMAX network can transmit to mobile clients over a radius of perhaps 2 km, whereas unlicensed Wi-Fi would be limited to 200 meters at best under similar conditions. For fixed, AC-powered clients with directional antennas, these figures might increase by a factor of 10 for both technologies, given near line-of-sight conditions. In either case, the bandwidth available at the client would range from perhaps 5-50 Mbps, depending on conditions.

**Economics**

Fixed WiMAX is an alternative to wired DSL or cable modem, and these alternatives define price points, where they are available. Examples of such services include Clearwire, which starts service at about $50/month in U.S. cities. (It is not clear what the cost of the Clearwire service might be: they certainly take a loss at these price points and with the current user base.) In areas where there is no alternative broadband Internet service, the price is limited by what the customer is prepared to pay. This might cover some rural parts of the U.S., where initial trials have included IPTV service for the ‘triple-play’ to fixed clients. But neither of these examples demonstrates proven profitability, pointing to the major market for fixed WiMAX to date, which is in developing countries that lack a ubiquitous copper or coax wired infrastructure. India in particular is in the early stages of large WiMAX deployments from BSNL and Bharti Airtel among others. None of these operators has yet published a tariff, but it should be possible to build a fixed WiMAX network and provide 2 Mbps broadband Internet service in the range of $30/month, depending on customer uptake.

While fixed WiMAX competes with DSL and cable broadband services, mobile WiMAX will compete with the existing cellular networks. Indeed, for many observers mobile WiMAX makes sense only as a next-generation cellular technology offering voice, broadband data and video as fixed and mobile services. As espoused by Sprint, this is a much more ambitious undertaking. Inherent in mobility is ubiquity, meaning the network must be built-out over a wide area before it becomes useful, and hence considerable capital investment precedes any significant revenues. Sprint has publicly estimated a budget of $2.5 billion to build-out only enough U.S. coverage for an initial service, and this does not include spectrum costs; a full national build-out would entail a capital budget of at least $10 billion. In the face of competition from existing cellular providers that have already built and depreciated their networks, and notwithstanding the accepted advantage of WiMAX in capital and operating costs over current cellular technology, it is this huge capital investment that presents the most significant barrier to entry for new mobile WiMAX operators.

**Competition from incumbents**

Broadband communications service providers are usually few in number in a particular geography. It has been argued that the business is a natural monopoly, as increased size drives economies of scale and beneficial network effects in terms of population covered. Whether or not this may be true, the services offered by WiMAX, broadband fixed and mobile IP services are already offered by large, well-capitalized incumbents, and this represents a barrier to the technology.

The first question to be answered is why, since WiMAX offers a superior customer experience at a lower infrastructure cost, these incumbents would not adopt it for their next generation networks. In the case of DSL and cable, the answer is likely that their already-depreciated plant can be extended at lower cost than building a wireless network for which they have no expertise. Similarly, incumbent cellular operators are more likely to look first at extending the life of their existing architecture rather than face the disruption from building a new overlay WiMAX network. To date, incumbents have seen WiMAX more as a competitive threat to their business than an easy choice of next-generation technology: in fact, Sprint’s sudden endorsement of WiMAX was seen by many as an act of desperation, as it was losing ground in the marketplace and sought to disrupt its larger,
more successful competitors. Note that since its Xohm announcement, Sprint’s CEO has been replaced and it has rescinded its joint WiMAX operation with Clearwire; many observers doubt it has the resolve or financial resources to build a nationwide WiMAX network on its own.

If incumbents see significant costs and risks in switching to WiMAX, there should be room in the market for new entrants that are not encumbered by legacy networks. Starting from a clean sheet of paper, a WiMAX network would cost considerably less to build and operate than a cellular network, and it would offer both fixed and mobile broadband services. There are rumors that new entrants such as cable operators and notably Google will bid for spectrum in the U.S. 700 MHz auctions in January 2008. However, building a national WiMAX network will require not only spectrum, but capital investment of maybe $10 billion, and WiMAX clients and handsets are not yet on the market at price points that challenge existing cellular and DSL products. Hence there are significant barriers to entry in this market – not that it cannot be done, but the required set of circumstances has not yet converged in the U.S.

Applications for Wi-Fi and WiMAX

There are many different ways to deliver broadband wireless services to fixed and mobile clients, and all of them cross over and compete to some degree. It would be naïve to suggest that Wi-Fi, WiMAX and other cellular technologies inhabit discrete segments of the market, never to compete; but they are not created equal in every respect. This section contrasts the strengths and weaknesses of the two technologies.

Performance

As noted earlier, Wi-Fi and WiMAX both use similar state-of-the-art RF techniques for wireless communication, but much else about them is distinct – and their adoption will differ by topology, device, geography and price tag. Both Wi-Fi and WiMAX are based on specifications developed by the IEEE, 802.11 and 802.16 respectively. They are promoted in the market by the Wi-Fi Alliance and the WiMAX Forum, trade associations comprised mainly of companies with an interest in furthering sales of equipment.

Similarities derive from the underlying radio modulation techniques – both WiMAX and Wi-Fi use OFDM (orthogonal frequency division modulation) with MIMO options. This means that given similar constraints of transmit power, channel bandwidth, spectral band and antenna gain, Wi-Fi and WiMAX systems should deliver equivalent performance from the viewpoint of range and bandwidth.

Why then the various claims and counter-claims quoting a vast range of distances and data rates? It is generally accepted that Wi-Fi is good for several hundred Mbps data rates, but only to a few hundred meters distance at best, while the most widely-quoted figures for WiMAX are 70 Mbps at 30 km. Since the underlying technologies are similar, we can deduce that the constraints must be different and the figures depend on different combinations of transmit power, channel bandwidth, spectral bands and antenna gain.

The best explanation of performance derives from the original IEEE mandates. Wi-Fi is good for wireless local area networks, extending to 100-200 meters from the radio, with a data rate of 5-150 Mbps at the client, and perhaps 50 Mbps sustained aggregate throughput per cell. For WiMAX the figures would be 10x the range, 0.1x the data rate and aggregate throughput figures of 1-2 km, 0.5-15 Mbps and 5 Mbps respectively.

Cost of equipment and network buildout

Wi-Fi benefits from high volume shipments over several years, so chips are now shipping in hundreds of millions per year and prices of home access points are sub-$50. This is a considerable advantage over WiMAX, which can promise such quantities but has so far not delivered. Thus fewer vendors can ship WiMAX chips, and prices are considerably higher than for Wi-Fi. At this point, WiMAX is at a cost disadvantage, but that could change quickly if Intel follows through on its commitment to package WiMAX in its new PC chipset in 2008.
After the cost of customer equipment, service providers are interested in how much investment is necessary to build out a network: first for basic coverage, then to provide the required capacity for users. Here Wi-Fi does not have a good answer – the metropolitan mesh market is discussed later, and has not been a great success to date. It may be possible for WiMAX to fill this gap, but trials to date have not been large enough to prove the business case. As noted earlier, the benchmark for mobile WiMAX must be the evolving cellular technologies rather than Wi-Fi.

Our suggestions for possible Wi-Fi / WiMAX combination networks later in this paper arise from assumptions that Wi-Fi clients will continue to be ubiquitous and inexpensive. For example, the new Wi-Fi / cellular dual-mode phones appear to bear no price premium over cellular-only equivalents, while even very cheap PCs today incorporate Wi-Fi. Since Wi-Fi entails no service subscription, we believe it will prevail as the universal connectivity option for all manner of consumer and business devices, while WiMAX will be less available and more expensive.

Licensed and unlicensed deployment

Although they stem from sister standards groups within the IEEE, Wi-Fi and WiMAX are championed by very different groups of silicon designers, equipment vendors and service providers, and the result has been a thicket of performance claims and counter-claims, as the interested parties seek to establish the superiority of their respective technologies.

WiMAX is above all a technology for licensed spectrum. Licensed bands allow higher transmit power and antenna gains for base stations, and these can drive longer ranges and higher data rates. But equipment can only be deployed by owners of the license.

In contrast, Wi-Fi is deployed in unlicensed spectrum and has to abide by the rules for this regime. Since any organization or individual can purchase and utilize equipment in the unlicensed bands, the FCC regulatory rules in the U.S. impose caps at relatively low power levels, allowing many uncoordinated users of the spectrum by intentionally reducing the effective range.

Although the RF characteristics of the two technologies are similar, their MAC layers are quite different because of their respective licensing regimes. Wi-Fi has a collision-avoidance mechanism, where each station autonomously ‘sniffs’ the air to determine if it is clear to transmit: a backoff and retransmit mechanism is called into play if other stations interfere by transmitting simultaneously. WiMAX, on the other hand, assumes all stations in range are coordinated and controlled by a single base station, that manages a master transmitting schedule. WiMAX can be expected to perform poorly when different networks operate in the same geography, on the same RF channel. Wi-Fi, too, even under good conditions, loses some data transmission efficiency because of the uncoordinated MAC behavior of stations.

The licensed – unlicensed distinction drives the major differences enterprise users will see when using the technologies. The typical license-holders for WiMAX spectrum will be service providers, the same companies that today operate cellular networks and enterprises and individuals will contract for service from these providers. Conversely, Wi-Fi gear is sold directly to the end user, and once the equipment is paid for, there are no further charges.
Wireless ISPs and unlicensed WiMAX

In the U.S. there is a niche industry where Internet Service Providers (ISPs) in rural areas need to bring the Internet to homes and small businesses, often over inhospitable territory with little copper or fiber in the ground. These wireless ISPs (WISPs) are often very small, and do not have access to spectrum licenses: they use radio technology, until recently a mix of proprietary equipment and Wi-Fi, to provide point-to-multipoint wireless distribution to their customers. The demands of this market are sufficiently different from mainstream consumer and enterprise Wi-Fi applications that some specialist radio vendors influenced the WiMAX Forum to add a profile in the 5.8 GHz band. In this mode ‘unlicensed’ WiMAX operates in a band where it directly competes with Wi-Fi. The two stumbling blocks to this solution, transmit power and interference, were discussed earlier, but it may yet prove a successful venture if the radio vendors can package the right mix of ruggedization, mesh/repeater capabilities and robust installation aids as they build WISP products.

Licensed point-point links and lite-licensing

U.S. spectrum licensing is sufficiently arcane to provide many capable engineers with lifetime employment. It embodies not just technical considerations but political influence and significant lobbying efforts, and one consequence is that various niches have been pared away over the years. An example is ITF, where churches and various educational institutions were allowed licenses to radio spectrum so they could broadcast over relatively short distances (approximately 70 miles). Much of this spectrum is routinely sub-let and it can represent an opportunity for a local government or other organization to gain an exclusive license to certain channels over a limited area. This is an opportunity for WiMAX, but because of the fragmentation, may not be significant enough for equipment vendors to bring cost-effective products to markets.

Indeed, some of this spectrum is being recovered and re-leased by the Federal Communications Commission (FCC), and the 802.11 (Wi-Fi) group has recently completed work on 802.11y in the 3.65-3.70 GHz band which will be ‘lite licensed’. In this case lite licensing means that transmitter locations and channels must be registered on an FCC Web site, but usage is open to all organizations willing to complete a simple, low-cost application. In order to comply with FCC requirements, 802.11y includes a contention-based protocol to sense other primary users of the band.

Wi-Fi deployments in conjunction with WiMAX

The discussion above has shown that for the most part, Wi-Fi and WiMAX will be applied in different situations. WiMAX will be deployed in licensed spectrum by service providers and Wi-Fi used in unlicensed bands by end-users.

That said, there are some areas where Wi-Fi and WiMAX could compete. The metropolitan hot-zone is one such application. The concept is to provide wireless broadband service in urban and suburban areas, sometimes combined with communications services for government and public safety employees, and residential Internet service (particularly subsidized service for families on the wrong side of the ‘digital divide.’) To date, many cities in the U.S. and elsewhere have rolled out coverage in limited areas, a few tens of square km at most, relying primarily on mesh Wi-Fi technology. While Wi-Fi is a good choice for the last link to the terminal, as most PCs and some phones today are Wi-Fi capable, it is a short-range technology so access points must be densely deployed 100-300 meters apart. The multi-hop Wi-Fi meshing technology used to backhaul traffic to high-bandwidth wired hubs has been challenging.
WiMAX can offer an alternate metro mobile broadband solution in two ways. First, even if the final connection to the terminal is Wi-Fi, backhaul from access points can use WiMAX to allow direct connection to the network hubs rather than multi-hop meshing. This solution depends on the availability of spectrum: the most likely short-term scenario would be for broadband cellular data connections, but as WiMAX becomes available in an area, this option is a possibility that should provide higher bandwidth.

It remains to be seen whether metro broadband wireless deployments are any more financially viable with WiMAX backhaul than Wi-Fi meshing: there has been much parsing of the business case in recent months.
Naturally, WiMAX enthusiasts would take this argument a step further and suggest that it provides a viable alternative to Wi-Fi. Indeed, if Intel starts building WiMAX support into all its PC chipsets, wouldn’t it be a faster, better, cheaper solution to just provide mobile broadband service directly from the WiMAX base station without intermediate Wi-Fi transmitters? The answer is “perhaps” - more on this later.

**Figure 5**

**Sensible ways to use WiMAX with Wi-Fi**

The scenario above turns out to be the viable model for using WiMAX in a Wi-Fi world. Consider the usual configuration of a Wi-Fi access point: it provides service to Wi-Fi clients, and connects to the Internet (or corporate network) by a wired Ethernet connection. The alternative, whether in a corporate or metropolitan network, would be to use a mesh Wi-Fi connection.

**Figure 6**
This can be useful but requires access to different locations to complete the mesh and connect at a wired Internet hub. If a cellular data or WiMAX connection is available, it is possible to use this for the backhaul connection. As broadband mobile data rates increase and coverage expands, it becomes viable to incorporate a cellular NIC card into a Wi-Fi access point and build a highly-mobile Internet service. Just power-up the access point and it provides Wi-Fi coverage for local clients while connecting to the outside world over an EDGE or CDMA EV-DO Rev A or similar connection. Aruba, for one, has built solar-powered demonstration models that require no wires whatsoever! WiMAX improves on this model by increasing the bandwidth available for the backhaul link.

WiMAX could be used in this backhaul model either as a primary backhaul connection, or as a backup in case the primary wired connection fails. This would be particularly attractive for small offices with significant requirements for reliable service levels. Of course, a true WiMAX enthusiast would look for the ultimate configuration.
Provisioning WiMAX service
Whenever a WiMAX service is used, clients must be provisioned and a billing relationship established, in the same way as mobile phone or cellular data service. Rather than a SIM card, as in GSM networks, or a hardcoded equipment identifier as in CDMA, the WiMAX subscriber is identified by an X.509 certificate embedded in the client device. The provisioning steps for the scenarios above will require the Wi-Fi network manager to identify the WiMAX client cards used, and to activate them with the WiMAX network operator. All WiMAX trials and services so far use operator-supplied client cards, and in this case it may be necessary to insert the WiMAX card in a PC to activate it, then to transfer the card to the Wi-Fi / WiMAX unit. This is a requirement today for 2.5G and 3G cellular data cards, partly because the operators only support a single operating system for card activation. Mobile operators do not yet offer comprehensive provisioning and activation procedures for embedded data client cards, so it is likely that this will be a troublesome issue for some time when seeking to realize this type of Wi-Fi / WiMAX solution.

Private WiMAX service
As discussed in this note, it is possible that a few network managers in the U.S. will gain access to licensed spectrum for their geographic area, with perhaps local governments the most likely to benefit from this. This scenario would enable integrated management of both the Wi-Fi and WiMAX network, with important implications.

Implementations of WiMAX backhaul for Wi-Fi access points
Various options exist, or can be envisaged, when considering the most likely combination of Wi-Fi with WiMAX: a Wi-Fi access point offering service to local Wi-Fi clients, but backhauled using WiMAX. This takes advantage of the longer range expected of WiMAX networks, or indeed of any 3G/4G cellular network. Note that in nearly every case the WiMAX link will be the bottleneck in this configuration.

Back to back cable connections
Where the WiMAX operator provides a proprietary client modem, either because the service is ‘near-WiMAX’ or for commercial reasons, it will be necessary to work with this unit. Since longer-range devices will typically incorporate a directional antenna, it will not be necessary to devise a mounting such that the antenna can be pointed for best WiMAX signal strength. Since the modem is likely to be an indoor design, an environmental enclosure may be necessary for outdoor mounting as shown below:

Figure 9
Outdoor Wi-Fi hotspot with integrated WiMAX backhaul

Alternately, where a WiMAX client in PC card form-factor is available, it may be possible to integrate this into an access point. Since various PC card profiles exist – PCI, mini PCI, SD, etc. - and initial WiMAX clients are not miniaturized, it may be difficult to find a match initially. Also, such a solution would probably need to have provision for external antennas, enabling extended range or increased data rates as this device will be servicing many PC clients. If WiMAX Forum certification assures interoperability and the service provider allows a choice of clients, this may become a successful design.

![Figure 10](image10.png)

Personal Wi-Fi hotspot with integrated WiMAX backhaul

Aruba prototyped an access point with broadband cellular data backhaul using EV-DO or HSPDA running on today’s 3G networks, to provide wide-area connectivity for a personal Wi-Fi access point. This concept can be easily converted to WiMAX when suitable client modems are available.

![Figure 11](image11.png)
WiMAX as a redundant WAN link for small Wi-Fi offices

Finally, WiMAX offers an attractive redundant connection for a small branch or home office access point where very high availability is required or the primary Internet connection is subject to interruption. Indeed, should tariffs be attractive, e.g. flat-rate rather than usage-based, WiMAX could provide the primary connection in this scenario.

![Figure 12](image_url)

WiMAX in the 5.8 GHz unlicensed band

As the fixed WiMAX standard was in development, one of the interested constituencies was the wireless Internet service providers (WISPs). This is a group of mostly small, mostly rural U.S. ISPs that deliver wireless broadband Internet service to fixed clients in just the model adopted for fixed WiMAX. Since they own no spectrum, and so cannot use the 2.5 or 3.5 GHz bands, many of them currently use point-to-multipoint and mesh wireless products with outdoor radios, operating in the 5.75-5.85 GHz band which is an unlicensed band also used by Wi-Fi.

There are other applications today for private, point-to-point wireless connections, and a wide variety of solutions exist. In the U.S. most use unlicensed bands at 900-928, 2400-2480 or 5150-5850 MHz. Many WiMAX equipment vendors have a history of serving this market, and may be able to deliver a targeted product line combining appropriate ruggedization, power and packaging options. However, one would not expect such WiMAX equipment to perform any better than Wi-Fi in range or data rate terms, as it would be subject to the same regulatory constraints.

In order to provide a solution for these WISPs, the WiMAX Forum defined a profile in the 5.75 – 5.85 GHz band for fixed WiMAX, and a number of radio vendors have developed products for this market.
Conclusion

WiMAX is an excellent standard for WMAN and WWAN services in licensed spectrum. It incorporates state-of-the-art RF technology, comparable to Wi-Fi and superior to current cellular standards, offering usable data rates of 0.1 to 10 Mbps over distances of 1km for mobile and 10km for fixed clients. A significant attraction of WiMAX for service providers is its clean design for IP multimedia services: a core network for WiMAX should be considerably simpler to build and manage than today’s cellular networks.

The first and most developed market for WiMAX (802.16-2004) is in serving fixed clients, for homes or offices in areas where it is difficult to connect over wire or fiber. This is indicative of current successful fixed WiMAX trials in countries such as India and Malaysia. Cisco’s 2007 acquisition of Navini Networks is aimed at exploiting this emerging market for wireless DSL service in developing countries.

The newer, mobile flavor of WiMAX (802.16e or 802.16-2005) is incompatible with earlier versions. It has made less commercial progress, with trials in Malaysia and Australia, and Sprint’s late 2007 Xohm soft-launch the most notable. However, many of the newer fixed WiMAX network operators are now specifying 802.16-2005 so they can support both fixed and mobile terminals.

While network equipment and proprietary fixed modem clients are available, much of the equipment in current trials is near-WiMAX rather than certified WiMAX. This is especially true for mobile equipment, none of which is yet certified by the WiMAX Forum. While bilateral interoperability testing can establish enough interoperability for particular network operators to obtain multi-sourced clients, this lack of a large pool of certified devices is certainly a drag on deployments.

Indeed, most industry participants are looking for a breakthrough event, when a large, influential service provider adopts WiMAX and jump-starts the market. Currently the only such prospect in the U.S. is Sprint. Sprint’s publicly announced Xohm network as of early 2008 has set up cells in Baltimore and Chicago, allocating terminals to company employees only. Several handset vendors have stated that they intend to build WiMAX phones for Xohm, and of course Intel has a long-standing commitment to build WiMAX into their mainstream chipsets in 2008. However, Sprint has experienced considerable financial stress, and it remains to be seen whether it can find the determination and capital investment necessary to continue to build out Xohm into a national U.S. mobile WiMAX network. If it happens at all, most observers do not expect to see that milestone achieved until 2009 at the earliest.

The commentary above is important because the only way most U.S. enterprises will be able to use WiMAX will be as subscribers, in the same way they are beginning to use EV-DO and similar cellular data services, but of course at higher data rates. An enterprise would go to Clearwire and Sprint for the service (potentially purchasing Sprint WiMAX equipment from a third-party) and then combine the WiMAX terminal equipment with Wi-Fi WLANs, for which we discussed several options above. Generally, WiMAX will be useful for providing intermediate-distance backhaul for Wi-Fi access points, sometimes a preferable arrangement to Wi-Fi mesh technology.

While WiMAX point-to-point equipment is already available for the 5.8 GHz unlicensed band in the U.S., it offers similar performance to Wi-Fi equipment operating in that band as it is governed by the same regulations for transmit power. Further, WiMAX is less robust than Wi-Fi in co-existing with other users in this band: if a number of WiMAX networks are operating in the same region, they are likely to suffer from mutual interference to a greater degree than Wi-Fi networks. WiMAX vendors may package their equipment so it is more attractive, for instance high-density rack-mount radios for base station applications, as these vendors have an existing market with WISP service providers. However, Wi-Fi vendors offering both point-to-point and access point functionality are likely to provide seamless management regimes for the network as a whole, which should prove a significant benefit.
Meanwhile the more significant competitor for WiMAX is the next generation of cellular technology, known as LTE. While several years behind in development, this will offer today’s cellular operators a smoother upgrade path to a network with similar performance to WiMAX, albeit somewhat hamstrung by the need to support legacy equipment in the core network. LTE will not be deployable until at least 2010, so WiMAX will be the leading WMAN and WWAN technology for a few years, but the costs of licensing spectrum and building WiMAX networks may be a sufficient barrier to entry to forestall any new, national mobile WiMAX networks. The next few years promise significant turbulence in wide-area communications as this battle plays out.

About Aruba Networks, Inc.

Aruba Networks is a leading provider of next-generation network access solutions for the mobile enterprise. The company’s Mobile Virtual Enterprise (MOVE) architecture unifies wired and wireless network infrastructures into one seamless access solution for corporate headquarters, mobile business professionals, remote workers and guests. This unified approach to access networks enables IT organizations and users to securely address the Bring Your Own Device (BYOD) phenomenon, dramatically improving productivity and lowering capital and operational costs.

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