Open Standards for Broadband Wireless Networks: Wi-Fi and WiMAX

A Technology Whitepaper
October, 2004

Introduction

High volume, open standard radio technology (802.11 Wi-Fi, 802.16 WiMAX and future standards) offers unprecedented advantages to network operators and users. For the first time, consumer electronics volumes and industry-wide investment, innovation and competition are driving broadband wireless networking technologies. Network operators and users alike benefit from a wide array of high-performance, feature-rich and low-price products. Industry coalescence around standards has enabled price, performance and functionality points never seen before in wireless products. Moore's Law cost curves continue to drive new capabilities and better economics. Global operation is now possible on a scale never before achieved. With an installed base of more than 75 million client connections and growing, Wi-Fi is, in effect, the world's first global broadband unlicensed radio standard. The result is products ranging from Wi-Fi laptops to PDAs to video cameras to Wi-Fi phones and even Wi-Fi parking meters that all offer 20 times the price-performance of competing closed, proprietary standards like EV-DO.

The primary recommendations of this paper for wireless network operators are as follows:

- Deploy unlicensed metro-scale Wi-Fi networks today to capture the benefits of open-standard radio and to bring low-cost wireless service to urban and suburban areas as an early market mover.
- As unlicensed WiMAX 802.16-2004 P2MP products appear on the market in 2005, use them for backhaul from mesh infrastructure to points-of-presence (PoPs) to further reduce costs and increase flexibility.
- If fully licensed operation is desired, introduce licensed WiMAX 802.16-2004 for intra-mesh transport as WiMAX products from Tropos Networks become available in 2006.
- Again, if licensed operation is desired, introduce MetroMesh routers with WiMAX 802.16e client interfaces when they become available from Tropos Networks in 2007 or 2008. Connect to clients using WiMAX silicon from Intel and other chip vendors in this timeframe.
- If unlicensed operation is desired, monitor the price/feature/performance trends of WiMAX and Wi-Fi as they evolve and introduce WiMAX using Tropos Networks products if and when these trends move in its favor.
- Use 802.16-2004 for P2MP links in rural, low density areas and for small/medium enterprise, last-mile service.

Wi-Fi is revolutionizing the market for unlicensed client access radios, both indoors and out, in a wide variety of applications. Starting in 2005, the WiMAX 802.16-2004 standard for fixed-position radios will do the same for point-to-multi-point (P2MP) wireless products in both the licensed and unlicensed bands. Later, 802.16e WiMAX for mobile operation will standardize client radios in unlicensed and, for the first time, licensed bands and will provide an alternative to Wi-Fi for client connections. As with Wi-Fi, the result will be dramatic price/performance and variety improvement in last-mile radio infrastructure.

Network operators who want to deploy metro-scale broadband wireless networks at the highest performance and lowest cost should design solutions that take advantage of both established and emerging 802.11 Wi-Fi and emerging 802.16 WiMAX products. This paper offers a pragmatic approach to the integration of WiMAX into today's Wi-Fi-dominated world: which technology will work best in what environment, for what applications and in what timeframe. It does so in the context of metro-scale wireless broadband mesh networks and is based on practical experience gained over four years and over 135 production deployments of these networks.

Metro-Scale Wi-Fi Mesh Networks Today

Today's metro-scale wireless broadband mesh networks consist of several layers, as illustrated in figure 1. The client layer provides access between user devices and the mesh routers in the infrastructure. The mesh layer provides wireless transport for data traveling from clients through mesh routers to mesh routers acting as gateways. The backhaul layer provides connectivity between mesh router gateways and local points-of-presence (PoPs) which, in turn, connect to the Internet.

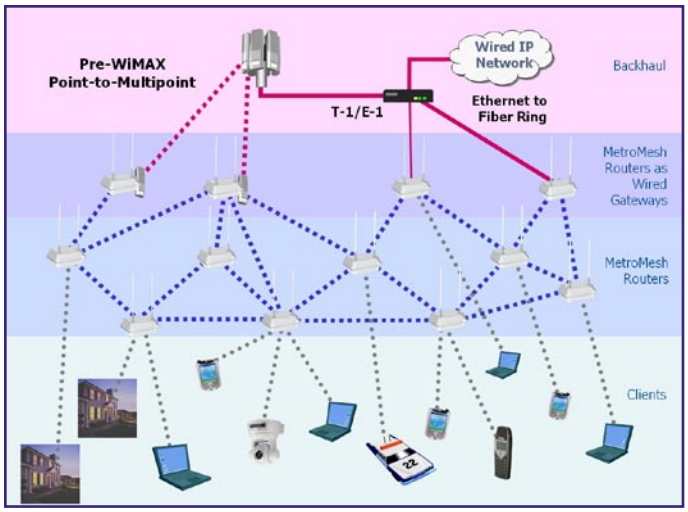

Figure 1: Today's Metro-Scale Wireless Mesh Networks

For today's metro-scale wireless broadband mesh networks, Wi-Fi is the medium of choice for both client connections and mesh connectivity. The reasons are straightforward.

On the client side, in 2004, Wi-Fi has an installed client base of more than 75 million units. This is expected to grow to over 100 million units in 2005. Because Wi-Fi networking capability is now a standard feature of many laptops, these client connections come at low to no incremental cost to users. With Wi-Fi client access being offered by access points in the home, office and coffee shop hotspots, the natural extension is to offer the same clients ubiquitous, anytime, anywhere access.

For mesh connectivity, Wi-Fi is also advantageous today. Wi-Fi chipsets are readily available, well-proven, economical and can operate in unlicensed spectrum. These chipsets can be used as the basis for carrier class radios in metro-scale mesh networks, delivering a mesh technology that offers high, reliable performance at lowest cost. In short, the mesh connections, like the client connections, can take advantage of all of the benefits of open standard radio today.

Demystifying the Hype

As is the case with most new technologies, market participants and pundits today assign almost mystical qualities to the performance characteristics of WiMAX. This will almost inevitably be followed a period when WiMAX will be unfairly maligned for not living up to its original, highly inflated expectations and then a period of high customer satisfaction when expectations and reality are in line.

We hope to speed this process. In reality, WiMAX will improve price/performance in important parts of the wireless last mile just as Wi-Fi has done for client connections. However, WiMAX cannot change the laws of RF physics and information theory. Unfortunately, meeting what appear to be the market's current expectations would require WiMAX to do just that.

True wireless broadband offers a user experience similar to that provided by a wired LAN in an office. This requires bandwidth measured in Megabits per second, not kilobits per second. As discussed in the Tropos Networks white paper "Price-Performance Comparison: 3G vs. Tropos MetroMesh" (available at http://www.tropos.com/pdf/price-performance.pdf), delivering true wireless broadband requires a dense mesh router architecture, no matter what radio technology and spectrum is employed. This is dictated by the laws of RF physics and Shannon's Law, a basic tenet of communications theory. While the referenced paper uses the specific example of EV-DO, its conclusions can be generalized to any RF technology, including WiMAX.

At the 2.4 GHz band that Wi-Fi operates in, mesh router densities in the range of 10-20 per square mile are needed deliver strong signals in support of true, symmetrical, multi-megabit broadband. At higher frequencies, higher mesh router densities will be required. This will be true for WiMAX as well.

Economically deploying and supporting dense mesh routers across metropolitan areas requires:

1. Wireless mesh routers and P2MP wireless backhaul links connecting the mesh to a point-of-presence (PoP).

2. Low-cost mesh routers achieved by leveraging the economics of scale inherent to open-standard radio such as Wi-Fi and WiMAX.

In its 802.16-2004 version, WiMAX can deliver very high performance, very long transmissions distances and low cost in P2MP configurations. The 802.16e version of WiMAX can deliver high-performance, low-cost client mobility that will improve upon Wi-Fi, especially in the licensed bands. Unfortunately, RF physics and Shannon's Law dictate that WiMAX cannot do both at the same time, just as Wi-Fi cannot and EV-DO cannot. Delivering true broadband performance across a metro-area with mobility requires a dense mesh router architecture, even when WiMAX is employed. Therefore, WiMAX, when used to implement a metro-scale wireless broadband network, will require the use of mesh technology, just as Wi-Fi does today.

A variety of options are now available for connecting the wireless mesh to the PoP that, in turn, connects to the Internet. These options include local area networks, such as city-wide fiber networks, wide-area networks, such as T-1/E-1 lines, and wireless, P2MP solutions such as those from Motorola Canopy, Trango, Redline, Aperto and others. In many cases, P2MP wireless links offer the fastest, easiest and lowest cost solution, especially when fiber is not accessible and when WANs are not economical.

Using currently available, proprietary wireless P2MP solutions, equipment costs are approximately $1,000 to $2,000 per link – not insignificant but well below the cost of T-1 service for a year. Because the links are wireless, installation is relatively inexpensive, without the cost and inconvenience of things like trenching that might be required with a fiber network. The use of unlicensed spectrum means that licensing fees are not required. Many wireless P2MP products offer bandwidth of 6 Mbps or greater, making them a better match for Wi-Fi's 54 Mbps bandwidth than WAN connections.

In short, P2MP wireless offers many advantages as a backhaul technology. However, as previously noted, currently available products are proprietary. As a result, they don't offer the price-performance advantages of open standard radio.

WiMAX Integration

Later in 2005, WiMAX products based on the 802.16-2004 standard will appear and will bring with them the open standard radio benefits that currently accrue to Wi-Fi. Their first application will be as a backhaul technology for connecting metro meshes to local PoPs using both licensed and unlicensed spectrum. Later, WiMAX will be used for links within the mesh, again using both licensed and unlicensed spectrum. Finally, after significant demand appears, WiMAX will be used for licensed and unlicensed client access.

The Evolution of Wi-Fi

With attention focused on WiMAX, it's easy to forget that Wi-Fi is also rapidly evolving based on massive research and development investment which is in turn driven by the size of the actual and potential market. Wi-Fi radios are appearing not just in laptops and PDAs, but in equipment as diverse as mobile phones, parking meters, security cameras and home entertainment equipment. As a result, Wi-Fi will continue to become faster, more secure, more reliable and more fully-featured. These advances will in turn drive continued adoption, which will, in turn, drive even more R&D investment. For this reason, the future of Wi-Fi is very bright indeed.

Numerous standards committees, working under the IEEE 802.11 (Wi-Fi) umbrella, are developing enhancements that will expand the applicability of 802.11 wireless technologies to new application areas. The results of the active work underway will be future industry-standard versions of Wi-Fi that run at 100+ Mbps speed, have QoS support for applications such as voice and video, enable mobility-speed roaming and much, much more.

The evolution of Wi-Fi includes the following 802.11 standards that are under development:

802.11e defines enhancements to provide quality of service (QoS). It will include support for prioritized access to different classes of data traffic and user types. This will lead to greatly improved performance for applications such as video, multimedia streaming and voice, in addition to providing prioritized access on a per-user or per-application basis.

802.11j defines extensions to allow for operation in the 4.9 GHz and 5GHz bands in Japan.

802.11k focuses on standardizing the radio measurements that will allow uniform measurement of radio information across different manufacturer platforms. This will lead to 802.11 networks that are easier to monitor and manage and that can make more efficient use of the available spectrum.

802.11n focuses on creating a standard to further increase the throughput of wireless networks. The goal is to achieve greater than 100 Mbps usable throughput over an 802.11 communications channel.

802.11r reduces handoff latency when client devices move between access points or mesh routers. Faster handoffs will be critical to meeting the real-time requirements of delay-sensitive applications such as voice, especially in mobile settings where client devices can be expected to roam frequently.

802.11s defines a mesh architecture overlaid on 802.11 that would allow for adaptive, self-configuring and fault-tolerant mesh networks that would expand the applicability and utility of 802.11 networks into hard-to-wire areas and larger campuses.

For more details about Wi-Fi's evolution, see the Tropos Networks' technology brief "802.11 Technologies: Past, Present and Future" available at http://www.tropos.com/pdf/wi-fi_technologies.pdf.

Integration Pase 1: WiMAX as Backhaul

When the first P2MP WiMAX products hit the market, anticipated in 2005, their initial application in metro-scale wireless broadband mesh networks will be as a lower-cost, more flexible alternative to the proprietary P2MP wireless solutions used to provide backhaul between the mesh and the PoP.

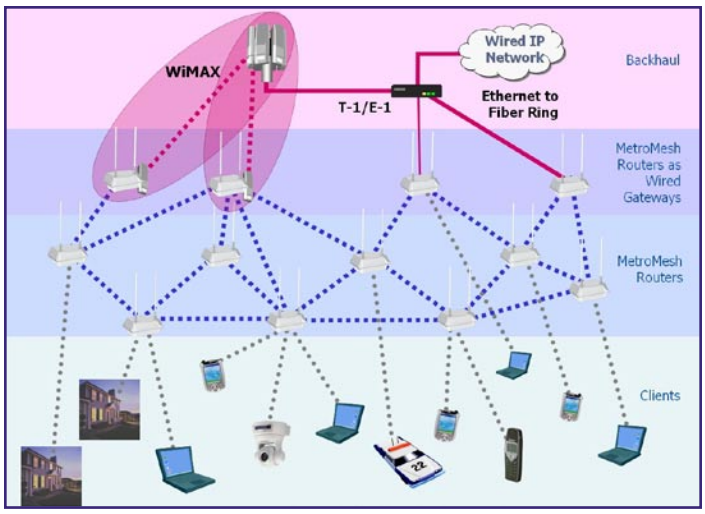

Figure 2: Phase 1 - WiMAX Used as Mesh-to-PoP Backhaul

WiMAX will prove superior to proprietary solutions in this application because it will bring the price-performance benefits of open standard radio to what was previously the domain of proprietary solutions. Not only will prices be lower, performance will be better, especially across the long distances often encountered by P2MP backhaul links. The 802.16 media access control (MAC) is optimized for long distance links because it is designed to tolerate longer delays and delay variations. WiMAX (or, more correctly, 802.16) also offers more deployment flexibility because it uses licensed and unlicensed bands up to 11 GHz, offers flexible channel bandwidth and flexible modulation schemes. The use of licensed spectrum provides more comfort that interference will not be an issue than does the use of unlicensed spectrum, where Wi-Fi runs and versions of WiMAX will run.

This integration of P2MP WiMAX used as mesh-to-PoP backhaul will be the first phase in the integration of WiMAX into metro-scale wireless broadband mesh networks.

Integration Phase 2: WiMAX as Transport within the Mesh

As merchant silicon solutions for WiMAX become more readily available, it will become feasible to integrate WiMAX into mesh networking products. This is expected to begin to occur in 2006.

When this happens, MetroMesh routers from Tropos Networks will integrate WiMAX as an option for transport within the mesh. In this application, WiMAX and various forms of Wi-Fi will combine to offer optimal end-to-end performance. MetroMesh routers will automatically choose between numerous forms of intra-mesh transport, selecting the options that provide the best end-to-end path performance.

WiMAX will offer a useful alternative to Wi-Fi in this application. All of the advantages of WiMAX for mesh-to-POP backhaul also apply to intra-mesh links, including use of licensed and unlicensed bands up to 11 GHz, flexible channel bandwidth and flexible modulation schemes. Also, because the WiMAX MAC offers scheduling ability, it can offer enhanced quality of service (QoS) capabilities for enforcement of service level agreements (SLAs) if deployed both within the mesh and between the mesh and PoP.

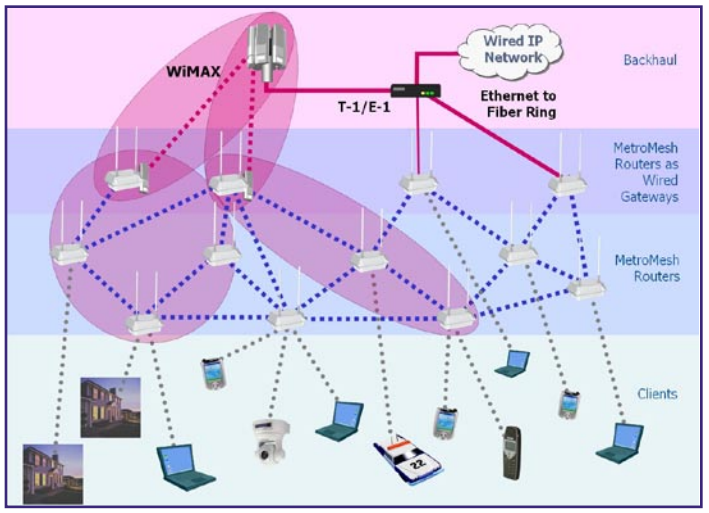

Figure 3: Phase 2 - WiMAX as Intra-Mesh Transport Option

Use of WiMAX as an option for transport within the mesh will form the second phase of the integration of WiMAX into metro-scale wireless broadband mesh networks. It will be especially advantageous to operators that wish to make use of licensed spectrum and offer strong SLAs through QoS mechanisms. With WiMAX used as both the backhaul transport and the intra-mesh transport, carriers can build licensed infrastructures out to the last hop to the client, using highly available Wi-Fi for the last connection. This scenario provides the carrier the comfort of a licensed-band network with the leverage of Wi-Fi clients. It also paves the way for phase 3 of the Tropos strategy.

Integration Pase 3: WiMAX as Client Connection

By 2007 or 2008, extensions such as client mobility (802.16e) will become part of WiMAX standard, chip vendors will roll out low cost, hybrid Wi-Fi/WiMAX client silicon and manufactures of client systems such as laptops and handhelds will increasingly integrate this technology into their products. Because these clients will support both technologies, they will be able to tap into the widely available base of Wi-Fi networks and take advantage of WiMAX connectivity when it is available.

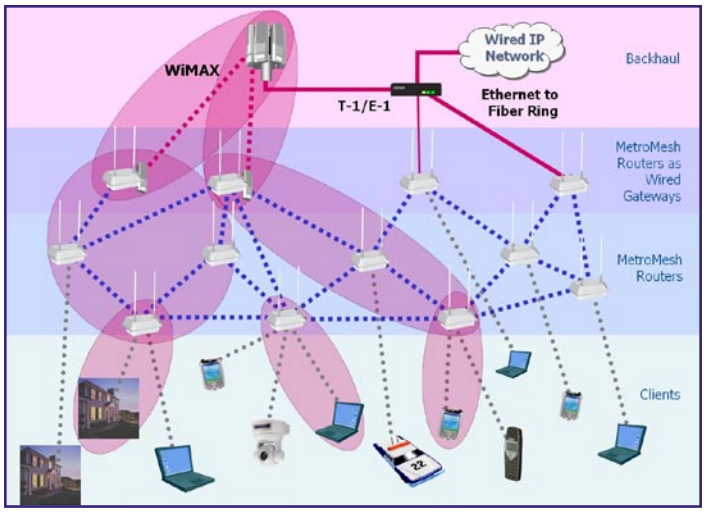

Figure 4: Phase 3 - Hybrid Wi-Fi, WiMAX Client Access

In the same timeframe, MetroMesh routers from Tropos and others will offer support for both Wi-Fi and WiMAX client connections. Just as client devices will provide hybrid connectivity, so must the network infrastructure.

When WiMAX client devices first appear, the vast majority of the installed base of wireless clients will still support only Wi-Fi connectivity. Continuing to serve the installed base while supporting integration of WiMAX will necessarily require networks to serve both types of clients. Intelligent network devices will take this a step further, recognize that some client devices support both Wi-Fi and WiMAX, and will connect to client to the network using the technology that offers the best performance given available connection speeds, QoS requirements, the amount of bandwidth consumed by other network users and RF conditions.

Many of the advantages of WiMAX for mesh-to-PoP backhaul and intra-mesh links also apply to client connections, including use of licensed and unlicensed bands up to 11 GHz, flexible channel bandwidth, flexible modulation schemes and enhanced QoS capabilities. WiMAX, 802.16e in particular, will also offer client mobility enhancements that will enable it to offer better on-the-go performance than does Wi-Fi.

Client connectivity will be the third and final phase in the integration of WiMAX into metro-scale wireless broadband mesh networks.

Getting From Here To There

Should metro-scale network operators deploy Wi-Fi today or wait for WiMAX? If Wi-Fi is deployed today, how should WiMAX be introduced into the installed network?

Tropos Networks recommends the deployment of metro-scale Wi-Fi mesh networks today and integration of WiMAX as products mature. Metro-scale Wi-Fi mesh networks offer great utility and attractive economics today, as witnessed by the strong interest in their deployment around the world. Those who take advantage of these fundamental factors can immediately tap into today's installed base of over 75 million Wi-Fi clients and will garner important first-mover advantages including client base, brand equity, access to mounting assets and operational experience.

With metro-scale Wi-Fi mesh networks installed, integration of WiMAX will be straightforward. WiMAX P2MP links can be added to existing networks, in licensed or unlicensed bands, to inject additional backhaul as additional capacity is required or to expand the network expands geographically. As dual-mode Wi-Fi/WiMAX MetroMesh routers from Tropos become available, they can be introduced into the network in licensed or unlicensed band. Because the new MetroMesh routers will be dual mode, they will

interoperate seamlessly with existing, Wi-Fi-only MetroMesh routers, always selecting the best path for delivering maximum end-to-end user throughput. When they connect to other dual-mode MetroMesh routers, they will take into account the different frequency bands and access methods available to them in making the path selection decision. After dual-mode Wi-Fi/WiMAX MetroMesh routers supporting 802.16e are introduced into the metro-scale infrastructure, dual-mode clients will be able to take advantage of this infrastructure seamlessly.

Summary

In summary, delivering true metro-scale wireless broadband requires use of a dense mesh router architecture that is best implemented using open standard radio technology such as Wi-Fi and, in the future, WiMAX. These solutions will evolve from the current model – using Wi-Fi for client connections and intra-mesh transport and proprietary P2MP products for backhaul links – by injecting WiMAX in stages. First, WiMAX will be used for mesh-to-PoP backhaul, later it will complement Wi-Fi as an option for transport within the mesh and, finally, as a client access option for hybrid Wi-Fi/WiMAX clients. We expect this transition to occur as WiMAX technology matures between now and 2008.

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