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Myths and Realities of Wi-Fi Mesh Networking

Executive Summary

Decision Point:	Optimizing Broadband Wireless Technologies in a Converged Technology Environment
The Bottom Line:	Mesh technology enables Wi-Fi to be deployed affordably in campus and metro arenas. However, today's vendor solutions need to continue to evolve to support the multi-use requirements of large municipal networks (i.e., technology versatility, performance and application support).
Key Concepts:	Wi-Fi mesh, municipal, 2.4 GHz, 4.9 GHz, public safety, municipal applications
Who Should Read:	CIO, CTO, CEO, VP of marketing

Practice Leader: *Phil Marshall, Ph.D., Vice President, pmarshall@yankeegroup.com, 617-880-0260*

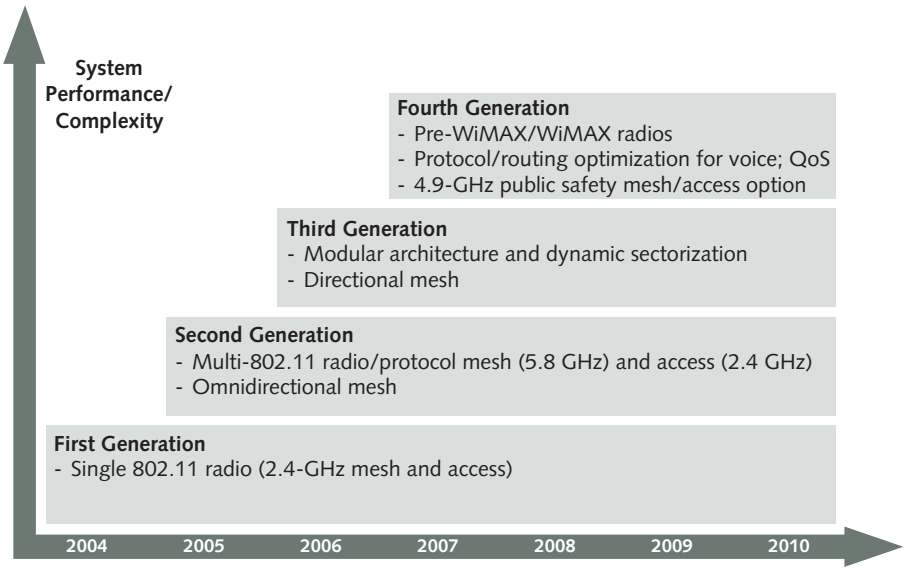
Wi-Fi mesh networking has gained recognition during the past year, but the technology is still in the early stages of its evolution. Deployed in small communities, it still has not demonstrated whether it is scalable enough for a large municipality to serve both public safety and public access requirements; and if so, which vendor solutions will prevail. Although single-radio systems are simple to deploy and affordable, today's multi-radio systems more closely match the requirements laid out in recent municipal proposals.

Third-generation systems have flexible modular architectures based on open standards that are easily scalable and upgradable (see Exhibit 1). They also address interference and reliability issues by separating access and backhaul on different frequencies: 2.4-GHz access and 5.8-GHz backhaul. Cities also frequently demand 4.9-GHz access/backhaul solutions that can leverage radio spectrum dedicated for public safety.

Exhibit 1.

Wi-Fi Mesh Networking Evolution

Source: Yankee Group, 2006



Correspondingly, the vendor market has not yet shaken out. Startups are climbing over each other while large established vendors such as Cisco, Nortel and Motorola are threatening to take hold of the space. In this event, there would likely be room for only two or possibly three mesh startups. It's important for startup vendors to position themselves as acquisition targets by continuing to evolve their technology, and seek partnerships with systems integrators and service providers well positioned to win major municipal bids. There are also niche market opportunities, such as public safety, where mesh vendors can tailor technology solutions to gain market foothold.

Mesh does not stand alone but is a component of a total Wi-Fi networking solution. The technology supply chain encompasses integration services, service platforms and public access gateways for connecting with the internet, third-party applications and services, and private networks. The access network consists of wireless access points that are meshed to provide efficient local transmission, and a variety of transmission and backhaul solutions to provide connectivity to the public access gateways.

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I. Introduction

A new breed of wireless infrastructure is creating a means to rapidly deploy low-cost wireless broadband in metro, campus and enterprise environments. Based on mesh routing technology from traditional suppliers such as Nortel, Motorola and Cisco as well as a number of startups, wireless mesh networking is competing with traditional macro cellular technology in price/performance in the wireless broadband market offering local- and metropolitan-area network connectivity.

Mesh networking addresses two issues that are critical in rendering metropolitan-area Wi-Fi deployments practical: covering a large area (relative to conventional Wi-Fi) with each access point and providing cost-effective backhaul using the wireless meshing technique. Used primarily for outdoor hot zone implementations, mesh networking extends typical Wi-Fi networks by using multiple low-cost 802.11 radios as routing nodes that pass data among themselves and require far fewer backhaul connections. In mesh network architecture, Wi-Fi access points themselves act as transmission nodes to provide short-haul connectivity back to centralized transmission connection points within the vicinity of the Wi-Fi nodes.

In addition to providing radio access to subscriber devices, each access point has radio equipment to enable it to provide a transmission circuit to a nearby node. This nearby node also offers access to subscriber devices in its vicinity and provides transmission capabilities for its own traffic and those for which it is acting as a transmission node. Typically in a reasonably loaded network, it is necessary to offload the meshed transmission to dedicated transmission connections within its vicinity. The access points either use the same radio frequencies (typically 2.4 GHz) for access and transmission or separate unlicensed radio frequencies, most commonly 2.4 GHz for access and 5.8 GHz for transmission. The 4.9-GHz band is also now being used for public safety applications. Typically, wireless nodes capable of operating at 5.8 GHz can be retuned to 4.9 GHz without a great deal of difficulty.

The first-generation mesh network architecture is evolving. Although single-radio systems are most affordable, today's mesh systems generally use multiple 802.11 radios with enhanced routing algorithms for increased scalability, reliability and bandwidth, and include value-added features such as QoS, security and mobility.

Planned upgrade paths to 802.11n MIMO and 802.16 radio modules are designed to ensure longevity of these systems. In many Wi-Fi mesh solutions, vendors are opting for pre-WiMAX point-to-multipoint connections offered by companies such as Motorola (Canopy) and Alvarion (BreezeMAX).

Startups Tropos Networks, BelAir, PacketHop, SkyPilot, Strix Systems and RoamAD are currently leading in the deployment of Wi-Fi mesh networking. Unlike traditional players, they are focused solely on this market opportunity. Although they lack the resources of their established counterparts, they are more flexible, nimble and responsive to customer needs.

Large vendors move slower but they can draw upon other areas of expertise within their company, such as smart antenna technology, competencies in CDMA and OFDM radio technologies, and network routing algorithms. They will ultimately dominate the market by supplementing internal product development via partnership or acquisition. Already, Nortel has partnered with PacketHop, Lucent partnered with BelAir, and Motorola and Cisco made acquisitions to enhance their own products in the wireless mesh space. In 2004, Motorola purchased MeshNetworks, a mesh vendor focused on the public safety market, to develop its quad-radio MOTOMESH product. Cisco drew upon its purchase of WLAN switch startup Airespace to bring to market WLAN switching capabilities to complement a dual-radio mesh product.

Differentiation: Where Does Wi-Fi Mesh Networking Fit in Broadband Wireless?

Mesh networking enables Wi-Fi providers to extend beyond the limitations of hotspots and offer broadband service in a wider coverage area of outdoor and indoor deployment.

Still in an early stage of market acceptance, we believe that mesh networking is an incubation area for new markets. It provides an opportunity platform for new technology and service model innovation without having to commit to a large-scale investment. As such, it is an opportunity for testing new business models and pricing schemes. As it evolves, it can be adopted and rolled across to a more mature scaled environment. Mesh networking's complementary role today is a reflection of where the technology is in its development cycle: Startup companies playing in unlicensed spectrum dominate today; as the technology matures, it will be promoted more by established vendors operating in the licensed bands.

Wi-Fi mesh is already being used as a service infrastructure by a new set of service providers that don't go after major markets (i.e., EarthLink and Google) and smaller regional internet service providers (ISPs). Generally, major mobile service providers are not considering mesh networking because it does not operate on a large enough scale to support nationwide services. Major mobile operators that have made significant investments in WLAN hotspots or in the distribution of WLAN service, such as T-Mobile USA, might consider using meshing to extend the capabilities of the hotspots that they have deployed. Because of the unlicensed spectrum operations associated with mesh-based wireless solutions, a new set of service providers is serving metros and rural communities.

Unlicensed spectrum wireless networks that rely on mesh technology complement the larger wireless mobile marketplace. Vendors are pursuing targeted market segments and business models that cannot be readily addressed by the mobile market. Law enforcement, public safety and community services are among the target markets for applications such as video surveillance, vehicle tracking and localized content for municipalities (i.e., local school or bus schedules with real-time updates and traffic monitoring information).

Wi-Fi mesh networking is vertically focused for specific applications rather than a general market solution. However, networks can and should be designed to take advantage of installed technologies and be able to incorporate emerging technologies such as WiMAX as they mature. Similarly, business models are evolving. Many municipal networks were introduced with free or low-cost service; as they scale, they are transitioning to more of a commercial model with support for a range of services across different user segments with built-in QoS.

Wireless mesh networking offers a metro-scale solution that will drive the development of mobile metropolitan networks. However, the benefits are balanced by limitations (see Exhibit 2).

Exhibit 2.
Pros and Cons of Wireless Mesh Networking
Source: Yankee Group, 2006

Pros	Cons
Ease of planning and deployment: Intelligent nodes mean less site surveying; indoor and outdoor nodes can coexist.	**Latency:** The more nodes there are in the network, the more hops to route traffic, meaning increased latency.
Reduced backhaul requirements: Several nodes are able to use one wireless/wireline dedicated point-to-point or point-to-multipoint link.	**Security:** Point-to-point communications are more predictable. Routing from multiple different nodes means greater vulnerability, and exposure to unauthorized access if adequate controls are not established. Rogue access points can be easily set up within the mesh.
Resilience: Data packets have multiple paths and can be dynamically rerouted around failed nodes or interference transparent to the user.	**Non-incremental network deployment:** Meshes don't lend themselves to incremental approaches; they have to be almost completely built out within a coverage area to be useful.
Expandability: New nodes can easily be added to self-adjusting networks.	**Scalability:** Single mesh networks are generally not scalable because system capacity is reduced as more mesh APs are added. Dual- or multi-radio mesh where access and backhaul radios operate on different frequencies increase scalability.

II. Wi-Fi Network Supply Chain

Mesh does not stand alone but is a component of a total Wi-Fi networking solution. Exhibit 3 demonstrates the technology supply chain and its associated vendor participants, and encompasses integration services, service platforms and public access gateways for connecting with the internet, third-party applications and services, and private networks. The access network consists of wireless access points that are meshed to provide efficient local transmission, and a variety of transmission and backhaul solutions to provide connectivity to the public access gateways.

Exhibit 3.
Wi-Fi Network Ecosystem
Source: Yankee Group, 2006

Integrator	Service Platform	Public Access Gateways	Wireless Backhaul	Wireless Point-to-Multipoint	Wireless Mesh	Wireless Access
Act as prime, assemble team of component vendors	OSS subscriber management security portal	Internet gateways for public access networks: multi-use, multi-revenue	Long-haul point-to-point or microwave	Proprietary or pre-WiMAX links	Meshed links for campus or metro zone environments	Access points for hot buildings
- Ericsson - Siemens - WFI - IBM - HP - Motorola - Lucent - Nortel	- VeriSign - Airpath - Pronto Networks - PicoPoint - Aptilo - Conxx	- Cisco - ADC - Nomadix - Colubris - IP3 Networks	- Ericsson - Alcatel - Harris - Marconi	- Motorola Canopy - Proxim - Ceragon - Alvarion - Aperto - NextNet - BelAir	- Tropos - BelAir - Nortel - Motorola - Strix Systems - Nortel - SkyPilot	- Cisco - Aruba - Trapeze - Proxim

Systems Integration

Large city network deployments require the leadership of a veteran systems integrator that can provide network design and installation services. Wi-Fi networking involves new technology and vendors; an experienced systems integrator can play a critical role in network testing, resolving reliability, QoS, scalability and backhaul issues.

For large systems integrators or technology infrastructure companies, Wi-Fi mesh networking in municipal or enterprise arenas is a natural evolution:

- HP is bidding to build Wi-Fi networks in six US cities including Philadelphia and Minneapolis, and currently operates in two smaller city networks.
- Lucent has assembled a team of startup companies to bid on Philadelphia, including Wi-Fi mesh vendor BelAir and service platform provider Airpath.
- WFI, an established contractor for government, carrier and enterprise accounts, is targeting municipalities with mesh vendor Tropos.
- IBM has stayed out of large multipurpose network installations but wants to be the leader in applications deployment. It is waiting for deployment of the mesh infrastructure and will then layer applications on top.

These large equipment vendors may act as the systems integrator or work with local companies. However, smaller players, including MobilePro's subsidiary NeoReach, MetroFi and US Internet, are winning municipal contracts.

Because unlicensed radio spectrum is not centrally coordinated by a licensed spectrum holder (such as a wireless service provider), it is susceptible to interference, particularly in the 2.4-GHz frequency band. A variety of companies, including Ekahau and Wireless Valley, work with systems integrators and service providers, using specialized Wi-Fi network planning tools to find suitable placements for the antennas and optimize channel allocations.

Service Platform Technology

The Wi-Fi solution requires service infrastructure that ensures the following:

- Adequate security, including authentication and authorization
- Network configuration and fault management, and performance management
- Portal infrastructure for self-service and service lifecycle management, roaming, clearinghouse and settlement functions
- Roaming and network wholesaling enablement
- Back-office transaction operations, including billing for different user groups, subscriber management, prepaid and postpaid billing systems, credit card billing options (predominantly to support expatriate subscribers), one-time password, scratch card and e-voucher solutions

Vendors such as VeriSign and Telcordia are experienced in serving both mobile and fixed network vendors to provide solutions that integrate with existing networks and add features specific to a Wi-Fi solution. Startup companies Airpath, Conxx, PicoPoint, Aptilo Networks and Pronto Networks offer innovative solutions and are beginning to gain recognition in small municipal network configurations and team with established network vendors. Customers can opt to license software solutions or use a service hosted by the vendor.

Transmission

Mesh networking eliminates the need for dedicated point-to-point backhaul to every node (i.e., a hub-and-spoke network architecture). Because the number of nodes that can be meshed is limited, dedicated transmission and backhaul connections are still needed to provide connectivity from nodes in the vicinity of the Wi-Fi meshes to the edge routing equipment and central office infrastructure. Among mesh vendors, BelAir also provides integrated point-to-multipoint and point-to-point backhaul. Other vendors work with third parties, as indicated in Exhibit 3. In some cases, such as indoor installations, dedicated transmission networks are used instead of meshed solutions. A variety of transmission options can be used:

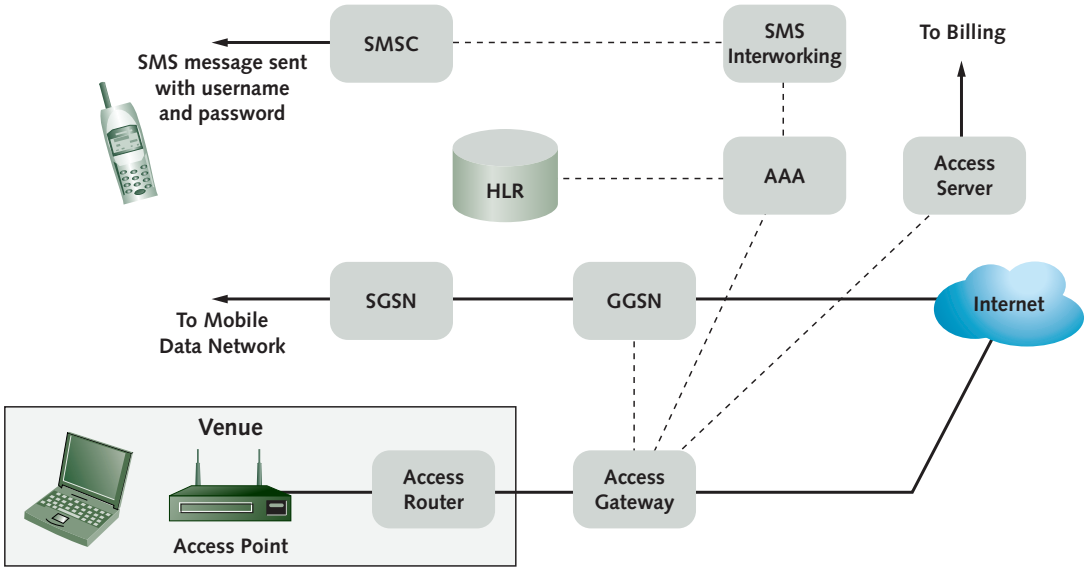
- Wireless transmission, using a pre-WiMAX point-to-multipoint or dedicated point-to-point microwave transmission
- Wireless mesh transmission to a wireless point-to-multipoint hub (used most commonly in cases where outdoor Wi-Fi access points are implemented over a large area of at least one square kilometer)
- Wireline transmission using existing fiber, DSL or T1 lines

Wi-Fi/Cellular Integration

If a cellular operator deploys a Wi-Fi network to complement an existing cellular network service, the network operator can leverage existing transmission and central office network facilities in addition to legacy billing and customer care capabilities.

Exhibit 4 demonstrates the integration of Wi-Fi in a GSM network: We show the access gateway as a separate element to that of the GGSN. Because both network elements essentially provide much of the same functionality, the access gateway can be integrated into a GGSN or, in the case of CDMA, the PDSN. However, in many cases, differences in functionality render an integrated approach inefficient. Integration via the AAA to the HLR for existing mobile subscribers can be facilitated with internetworking functionality. Existing provisioning and inventory management systems must be adapted to incorporate the Wi-Fi system. Provisioning can be facilitated through a logon internet portal the operator can develop internally, through its channel partners or a hosted third party.

Exhibit 4.
Integrated Wi-Fi/GSM Network Configuration
Source: Yankee Group, 2006



III. Vendor Discussion

Initially dominated by small startup companies, but now joined by Cisco, Motorola and Nortel, wireless mesh is still early in its market evolution.

Exhibit 5 evaluates the vendors based on two criteria:

- **Market penetration:** Number and size of customer contracts either in deployment or fully deployed
- **Technology versatility:** Based on a set of predetermined criteria

Market Penetration

In an emerging market, and especially for startup companies, deployments provide credibility and revenue return. Some of the early startups have multiple deployments but they are for the most part relatively small community or rural areas or a limited deployment within a larger city.

Tropos and BelAir have dominated early market penetration. But in both cases, many of these contracts are very small in terms of unit size and have not been fully deployed. Tropos claims to have realized $30 million in bookings in 2005 with 200 customers in the United States and internationally. It is part of the winning bid for the lucrative Philadelphia contract and is a finalist for Minneapolis. The networks it has deployed are typically small—including towns such as Corpus Christi, Tex. and Chaska, Minn., where 250 Tropos MetroMesh routers cover 16 square miles and serve 2,000 subscribers. BelAir has approximately 120 deployments. Among its larger installations is Galt, Calif., with almost 100 nodes deployed to date.

The largest vendor deployment in the United States is Tempe, Ariz., where Strix Systems recently launched a voice, data and video network over a 40-square-mile area. Strix is also the mesh vendor for a nationwide network being deployed in Macedonia by On.Net. It has two relatively small additional deployments in Sacramento, Calif., and Akron, Ohio. Among other third-generation mesh vendors, SkyPilot is working with MetroFi and is deploying for three municipalities in the Bay Area. Although RoamAD, based in New Zealand, is relatively unknown in the United States, it has secured one homeland security-oriented contract in Arizona. In Europe, it has secured an OEM partnership with HiTel and a distribution agreement with Siemens, and has deployments in Italy, Ireland and Sweden. In Asia-Pacific, it has implementations in Australasia and Malaysia.

Among the traditional networking leaders, Motorola has a fully deployed 1,000-node system in Garland, Tex., and a number of smaller public safety deployments that it may now be able to migrate to its newly announced MOTOMESH solution. It claims to be deploying MOTOMESH in 12 cities. To date, Cisco has only two small deployments that are not metro scale (Dayton, Ohio and Lebanon, Ore.). Meanwhile, Nortel has the honor of the first really large deployment announcement: It's aiming for 10,000 nodes in Taipei, Taiwan. After a number of delays, network installation has reached about 3,300 nodes to date.

Technology Versatility

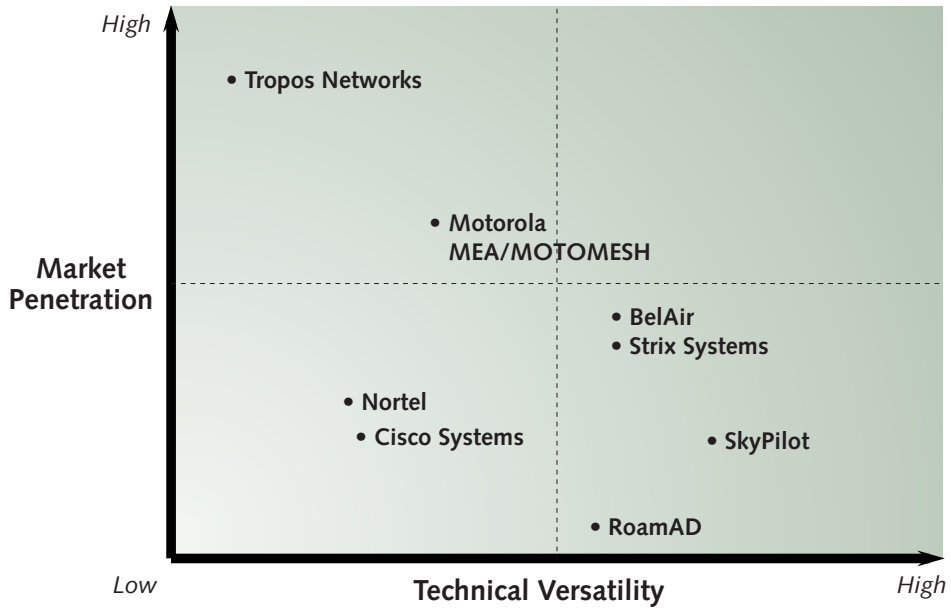
Our assessment of technology versatility is based on the following criteria:

- Ability for technology to be applied to multiple operating scenarios with futureproofing and migration path
- Ability to integrate with mainstream solutions for transport and OSS functions
- Ability to effectively manage interference so the technology can scale in the unlicensed spectrum environment
- Robustness to support operating requirements of the public Wi-Fi environment
- Support of security features including RADIUS, WPA/WPA2, 802.1x and X.509 mesh AP authentication
- Ability to support enhanced mesh networking capabilities including self-healing, failover, autodiscovery and dynamic rerouting

Exhibit 5 presents our assessment of the positioning of the major mesh network vendors today. Tropos leads in terms of market penetration, but is lacking in technology versatility. At the other end of the spectrum, BelAir, Strix Systems, SkyPilot and RoamAD have innovative next-generation technology solutions that more closely meet our definition of technology versatility, but have not yet attained Tropos' market recognition. They also go the farthest in matching the requirements of large munis as expressed in recent RFPS: namely, open standards-based modular solutions, with 2.4-GHz radios for network access and dedicated 5.8-GHz radios for backhaul. Many municipalities also want 4.9-GHz support for public safety, which is relatively straightforward for solutions incorporating 5.8-GHz radios.

Wi-Fi mesh technology is not yet standardized. Although networks may be based on 802.11, they are all proprietary solutions today—meaning they don't mesh with other vendor products and are differentiated based on the strength of the mesh algorithm. A mesh-networking standard, 802.11s, is in development. We expect the standardization process to produce a firm proposal toward the end of 2006 or the beginning of 2007, with ratification following a year later. Smaller companies would rather avoid standardization because once it becomes a commodity, they won't be able to compete with the larger players (i.e., Motorola, Cisco and Nortel).

Exhibit 5.
Wi-Fi Mesh Vendor Competitive Rating
Source: Yankee Group, 2006



Typically, vendors are segmented by the mesh backhaul configuration:

- First-generation mesh systems (Tropos) share a single radio with Wi-Fi subscribers using omnidirectional antennas for the mesh.
- Second-generation mesh systems (Cisco, Nortel) use multiple radios to separate Wi-Fi subscribers from a mesh backhaul that uses omnidirectional antennas.
- Third-generation mesh systems (BelAir, SkyPilot, Strix, RoamAD) use multiple radios to separate Wi-Fi subscribers from a mesh backhaul of managed directional antennas.

First Generation: Single-Radio Systems

In a single-radio mesh, nodes and clients share the same radio spectrum bands and may interfere with one another. Systems cannot scale beyond 3 to 5 nodes without self-interference and latency issues. This makes them unsuitable for voice or video applications. However, single- and dual-radio systems offer a relatively low-cost option that can be appealing to cable operators, enterprises and cities in appropriate environments.

Dual-radio mesh solutions address capacity and interference issues by separating the access and backhaul. A dual-radio mesh AP has two radios operating on different frequencies, while a multi-radio wireless mesh takes it a step further and uses dedicated radios for wireless backhaul, enabling further improvements in performance and scalability and better support for mixed-use networks and multi-user groups.

Tropos uses a single band (2.4 GHz) for local transmission and client access, and is teamed with Motorola Canopy or Alvarion for backhaul. Although Tropos can offer a lower cost solution, it depends on a greater number of connection points to dedicated transmission, which adds to the expense and network complexity and is therefore less effective in large-scale installations. There will continue to be an opportunity for single-radio systems in the near term as standalone systems and in a hybrid configuration as part of a large muni network.

Among multi-radio vendors, BelAir, Motorola and SkyPilot also have single-radio options.

Second Generation: Multi-Radio Systems

Greater reliability is achieved by separating access and backhaul on discrete frequency bands. Radios operating in both unlicensed 2.4-GHz and 5.8-GHz spectrum have separate spectrum bands for user access and the mesh backbone, enabling the network to better adapt to interference. BelAir, Cisco, Nortel and SkyPilot offer second-generation dual-radio meshes—one for 802.11b/g subscribers and one 802.11a radio for 5-GHz backhaul.

Cisco is well positioned to succeed in this space, but there are a number of questions: What is its level of commitment to mesh and the extent to which the technology is acquired by its installed and emerging base? In addition, to what extent will Cisco accelerate development of its solution, whether through acquisition or internal development? Cisco's entrance with a dual-radio system (rather than a multi-radio system) reflects the company's focus on serving enterprise campuses more than municipalities. The mesh is positioned as an element of its unified network architecture. On the other hand, Cisco dominates the Wi-Fi hotspot market in terms of access point deployment, which would give it an advantage in the muni space if it decided to transform hotspots into mesh zones.

Nortel's dual-radio system uses a switched array of six directional antennas to increase the range between nodes. The offering is strengthened by the network vendor's existing security and network management capabilities. Nortel's Optivity Network Management System provides centralized monitoring and managing of network operations, discovery and visualization of equipment, fault management and real-time performance metrics. Nortel also pulls on partnerships to supplement its own capabilities. Nortel was working with Wireless Valley, using its simulation tools for capacity planning, but Wireless Valley was recently purchased by Motorola. On the WiMAX front, Nortel is working with Airspan to upgrade its existing system to WiMAX mesh backhaul with Wi-Fi access.

Third Generation: Modular Architecture, Multi-Radio Portfolio

BelAir, SkyPilot and Strix Systems have developed modular architecture with a multi-radio product portfolio supporting multiple network configurations. Multi-radio systems (radios that dedicate each separate function of the mesh, such as client access, backhaul ingress and backhaul egress) offer further improvements in performance and scalability.

Modular architectures enable flexibility in system design and an easier upgrade to future technologies, including WiMAX. A new module can be swapped in, avoiding new product development. These third-generation systems also provide advanced features including auto discovery, self-provisioning and self-optimizing, and QoS. Multi-service traffic can be prioritized based on user class or traffic types.

However, among third-generation systems, there are subtle differences in architecture that may give one vendor advantages in a specific operating environment, depending on coverage requirements, interference concerns and so forth. For example, a switched mesh configuration may provide greater capacity than a shared mesh and the QoS needed for voice applications; sectorized antenna arrays have advantages in range but require time-sharing

schemes. In a still nascent market, vendors are looking to differentiate in terms of the mesh architecture. Their differentiation may also reflect their previous market focus (whether indoor WLAN or fixed wireless systems, for example) and the existing technology development they bring to Wi-Fi mesh networking.

BelAir came to market first with a multi-radio product and now offers a full portfolio of single-, dual- and multi-radio products. Four-, two- and one-radio system options can all work together in a single system. Usually the multi radio (one access radio and up to three backhaul radios in a switched mesh) is at the core of the network and the single radio (shared mesh and client access on the same radio) is at the edge. BelAir can also now design small clusters of the single radio at the edge.

Since 2003, BelAir's product was purpose-built as a carrier-grade outdoor unit; unlike Strix, whose product originated for the indoor environment, and SkyPilot, whose product originated in the fixed wireless environment. A switched mesh, multi-radio architecture and hardware router make it better suited to support VoIP and QoS.

Backhaul is a series of multiple point-to-point or point-to-multipoint pre-WiMAX links in 5.8 GHz (up to three independent 54-Mbps links). The mesh function and backhaul are one integrated product. Mesh software creates the optimal network routing and decides which of the links to use when the network is in operation.

BelAir has a road map for WiMAX. Fixed WiMAX is first used on the backhaul side. It already integrates pre-WiMAX backhaul radios and has customer-committed WiMAX radios scheduled for delivery this summer. If mobile WIMAX is successful as a client technology, it's used as an access radio module. It plans to use micro-cells to cover urban areas and talk back to WiMAX base stations mounted on cell towers.

Strix Systems' Access/One Network modular product architecture offers options for two, four or six radios. Beginning as a vendor of indoor WLAN systems, it has created an enclosure box for outdoor protection. Additional radios can be easily added. However, the sectorized antenna is external, which may create space constraints but also offers flexibility in the type of antenna configuration. Strix uses a timing mechanism within the data stream to provide clocking for the mesh network. To increase security, Strix chooses to use a separate server to handle authentication, unlike its competitors.

SkyPilot's modular architecture includes a dual-radio, dual-band SkyExtender product. The SkyPilot system has several differentiating characteristics that can take scalability and performance to the next level. Unlike its competitors, it uses synchronous protocols to create a 5-GHz directional and deterministic mesh with integrated backhaul. Multiple concurrent conversations can be handled at the same time on the same frequency. The synchronous design could also enable an easier migration path to WiMAX mesh networking.

SkyPilot started as a fixed wireless vendor and added 802.11 at the edge. It uses an eight-sector switched antenna array. Each of the sectors is configured as a point-to-point link with TDD and GPS used to manage coordination between sectors. SkyPilot also offers Sky Connector, CPE for guaranteed fixed wireless that enables a reliable DSL/cable replacement service.

RoamAD has opted for a standards-based modular platform that allows for self-configuring capabilities. It publishes a hardware reference design that equipment vendors can utilize, with its licensed software stack, and enables service providers to assemble their own nodes and reduce overall costs. Like Strix and SkyPilot, RoamAD has solutions that enable antenna sectorization for optimum coverage.

4.9-GHz Support

With the dedication of 4.9 GHz to public safety, munis are looking for solutions that include both 2.4 GHz for public access and 4.9-GHz support for critical public safety applications. 4.9 GHz promises relatively lower risk of interference and higher reliability.

With its significant penetration in the public safety market, Motorola recently introduced a quad-radio product that operates in both 2.4 GHz and 4.9 GHz. MOTOMESH is based on Motorola's Mesh Networks technology. MOTOMESH uses two standard 802.11 radios and two proprietary Mesh Enabled Architecture (MEA) radios in one hybrid solution. (2.4-GHz MEA/Wi-Fi and 4.9-GHz MEA/Wi-Fi). The four radios can be turned up as needed and intelligently configured, either as access or backhaul on a link-by-link basis. Motorola continues to support its older Canopy product, a proprietary line-of-sight system that can be used for mesh backhaul and has been most commonly married with the Tropos system, but will now also be married with MOTOMESH where it can provide 5.8-GHz backhaul. Eventually, MOTOMESH will also be married with WiMAX as part of Motorola's Wi4 strategy once 802.16e is standardized and profiled to work in the unlicensed band.

Other MOTOMESH features include fast self-forming, self-healing, built-in location and tracking of radios via triangulation, and support for connectivity for users at higher speeds. The system can also support seamless hand off between nodes. Other vendors may support session persistence, but not seamless connectivity with no interruption. General availability of MOTOMESH was recently announced and it is currently being deployed in 12 US cities.

Other mesh vendors are planning 2.4-/4.9-GHz products. Among them, BelAir is planning to provide a 4.9-GHz option later this year. At this time, SkyPilot provides an option to retune 5.8-GHz radios to work at 4.9 GHz. Strix can also support 4.9 GHz; at lower power levels, merely a firmware change is required to the existing modular system. For higher power, a new module is required to meet FCC requirements. However, neither SkyPilot nor Strix has yet demonstrated these capabilities in a working network.

Among other features important to public safety networks is the ability to create temporary or ad hoc networks during emergencies. This can be achieved by a client mesh where every node in the network, including clients and APs, act as a router and one client can hop through another client to reach network access points. As a result, clients can extend coverage and create more data paths through the network. First responders can instantly form an interoperable network with their own radio equipment without the presence of an AP. Only Motorola and PacketHop can support client meshing today (PacketHop does not simultaneously support both infrastructure and client mesh capabilities like Motorola).

Vendor Partnerships

Mesh cannot stand alone, but must be knitted together with other technologies and is dependent on vendor cooperation. Cisco launched with IBM and HP as global SI partners in smaller towns and plans to work with a niche set of outdoor broadband-focused VARs. Other mesh vendors are also teaming with SIs and component providers to offer total solutions and with service providers/WISPs in serving communities with public access.

Exhibit 6 illustrates recent teaming in response to municipal RFPs.

Tropos is using partnerships to strengthen its market position as vendors like Cisco enter the arena with more robust radio architectures. It has launched a MetroMesh Partner program with 18 development partners and has opened up its APIs to allow them to package their systems software with Tropos' mesh management code. Ruckus Wireless is

incorporating its smart antenna technology into Tropos customer equipment. Pepco is providing network installation and monitoring services.

Exhibit 6.
Examples of Vendor Partnerships for Muni Wi-Fi Mesh Deployments
Source: Yankee Group, 2006

Prime (Service Provider, WISP, Systems Integrator)	Muni Deployment	Mesh Vendor
EarthLink	Selected in Philadelphia, finalist in Minneapolis	Tropos/Motorola Canopy
Google	Mountain View, Calif. (Bidding on SF)	Tropos/Motorola Canopy
MobilePro	Tempe, Ariz.	Strix Systems
MetroFi	San Francisco Bay Area	SkyPilot Networks
Frontier	Morgan City, La.	Strix Systems
Frontier	Granbury, Tex.	Tropos Networks/Motorola Canopy
WavHost	Community Wi-Fi in upper NY State	Nortel
Atria Networks	Waterloo, Ontario	BelAir

BelAir goes to market through large integrators, such as Lucent, and has taken a lead in pursuing strategic partnerships with MSOs and cable companies looking to enter the municipal wireless space. (Comcast Interactive Capital is a major investor). BelAir has optimized its products for deployment on existing cable plant (its single- and dual-radio mesh nodes can be strand-mounted and plant-powered, and offer a DOCSIS interface). Tropos also has teamed with Scientific-Atlanta to bring metro-scale Wi-Fi mesh to cable networks, but the partnership was undermined by two recent events: Cisco's purchase of Scientific-Atlanta and Cisco's entry into the mesh market.

IV. Chances for Success

Wi-Fi mesh is new technology, but it's already moving beyond merely startup companies to being embraced by traditional network vendors. The entrance of Cisco has given new credibility to Wi-Fi mesh. However, Cisco's positioning of mesh within a larger unified networking architecture including indoor and outdoor WLAN infrastructure, security and services integration illustrates the key to its success.

Today, the vendors with the biggest marketing budget are the most successful. In the long run, this will not work. These companies are investing in marketing, but not in product development. In doing so, they are doing the industry a disservice. A first-generation single-radio system will not be able to support a large municipal deployment or the multimedia services that will be required in the future.

Wi-Fi mesh networking is currently more vertically focused rather than a general market solution. Although it may work for community access where users will tolerate best efforts, it may not be able to provide the service quality business users expect and productivity depends on, or be reliable enough for VoIP. However, networks can and should be designed to take advantage of installed technologies and be able to incorporate emerging technologies such as WiMAX as they emerge.

As these networks become more complex, the network management systems will become critical. Vendors such as Nortel have existing solutions; others rely on third parties or develop systems in conjunction with third parties. Integration with other systems such as HP Open View will also be critical.

V. Recommendations for Vendors

- **Continue to evolve and optimize your mesh technology.** Modular architectures ensure flexibility and the easy addition of radios, increasing the scalability and upgradability of the network to future technologies such as WiMAX. Give preference to dual- or multi-radio implementations because of the increased robustness they afford. In cases where vendors use single-radio mesh nodes, clear justification must be provided.
- **Ensure support for multi-user groups with prioritization based on user class or traffic type.** Support for a range of services across different user segments with QoS will become critical as multi-service municipal business models evolve.
- **Build best-of-breed partnerships with strategic players in the value chain.** Mesh can't stand alone; it must be knitted together with other technologies and is dependent on vendor cooperation. Recognize the impact of value chain complexities on the ability to implement innovative solutions. Coordination across the entire value chain is critical.
- **Startups need to anticipate the role of the large established networking players.** Either build a strong position in a niche market such as public safety, or position yourself as acquisition target by continuing to evolve your solution and attract customers. It's not good enough to remain at a first-generation technology.
- **Recognize advanced network management systems will be a key differentiator.** Network management is critical to system performance regardless of the radio design. In addition to providing centralized monitoring, fault management and real-time performance metrics, systems should also integrate with other vendors' systems such as HP OpenView.
- **Identify and align with the key systems integrators or service providers bidding on large municipal contracts.** No matter how superior your mesh solution, municipalities will select solutions based on the perceived strength of the integrator or service provider, and the attractiveness/relevancy of their proposed business model.

VI. Further Reading

Yankee Group DecisionNotes℠

EarthLink and Google Redefine Private/Public Partnerships in Municipal Broadband Wireless, October 2005

The Future of Wireless Communications for Public Safety, June 2005

Cities Need Wireless Broadband Network Models That Reflect Their Unique Objectives, June 2005

Yankee Group Report

Rationalizing Mobile WiMAX, October 2005

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