Making Wide-Area Wi-Fi Work with an Outdoor Wireless Network

By Dave Park

The adoption of wireless local area networks (WLAN) has exploded in the last few years, spawning “hot zones” and even city-wide “Wi-Fi clouds.” But what the market expects from these networks is not always in line with the current capabilities of the technology.

Network operators are discovering that current wireless networking options that are suitable for small hot spot deployments don’t scale well enough to meet larger network requirements. Current options compromise on quality, capacity and reach when they are stretched beyond the 100 ft radius of the traditional hot spot, and integrating voice and video is simply not an option.

In fact, current outdoor-based wireless networking solutions are actually indoor solutions brought outdoors by encasing the APs in sealed packages. Since the network architecture remains unchanged, so do all the difficulties of scaling an indoor network.

To address wide-area Wi-Fi requirements, a different kind of wireless networking product and architecture are needed.

The product must be specifically designed for outdoor deployment, enable the creation of a scalable architecture, require minimal cabling, and provide maximum coverage.

CRITERIA FOR OUTDOOR WIDE-AREA WI-FI SYSTEMS

Four key criteria must be met for any wireless product to adequately address the needs of wide area WLANs:

- **Designed for Outdoor Deployment** The ideal outdoor system must be designed from the ground up for outdoor operation and based on a very scalable architecture. It must be optimized for outdoor operation, in tune with relevant environmental standards, and subject to relevant stress testing.

- **Require Minimal Cabling** The ideal wide-area Wi-Fi system must minimize the need for cabling between access points (AP) and from the AP to the Internet (i.e., backhaul) to allow the network to scale cost-effectively. It should, therefore, integrate backhaul into the system. It should exploit the wireless network to avoid wiring, by *wirelessly* connecting APs to each other and to the backhaul.

- **Provide Maximum Coverage** In an optimal carrier-class WLAN system, the AP and antenna must provide coverage in a three-dimensional space. An outdoor-based WLAN system should improve overall coverage and take advantage of directional antennas to isolate the energy transmission as required.

- **Minimize Interference** Outdoor-based WLAN systems must be designed to minimize interference. Because WLANs operate in...
the unlicensed spectrum, frequencies from outside networks can interfere with deployment. This means antenna design must minimize the antenna’s response to energy outside of the intended coverage region.

Of course, the ideal networking system is useless unless it enables a carrier-grade network architecture. The ideal WLAN infrastructure design must be scalable, both to enable very large deployments and also to support incremental and cost-effective growth of the network. And it must be designed such that very few new APs need to be deployed as the network grows.

Current solutions to networking WLAN access points include:

- Point-to-point
- Point-to-multipoint
- Multipoint-to-multipoint

All of these solutions, however, present their own challenges and none completely addresses the problems associated with deploying wide-area Wi-Fi networks.

**POINT-TO-POINT: LOW AVAILABILITY**

Point-to-point networks (Figure 1) are the most mature wireless solution. Rather than sharing the medium, point-to-point systems use a defined link (one-to-one) between nodes and can thus rely on more deterministic capacities and latencies. This provides network operators with clear metrics for link availability and enables them to make service level agreement (SLA) commitments to their clients.

Point-to-point systems can also take advantage of directional antennas, which have greater gain because their energy is focused in a particular direction rather than dispersed over a 360° radius. Directional antennas thus improve the link budget at both ends (both transmit and receive), as well as improving overall reach. However, directional antennas require pointing—often resulting in considerable installation challenges and, therefore, additional costs.

The primary issue with point-to-point wireless networks is that they have no redundancy, thus the overall availability of the system can be low. In traditional microwave backhaul, availability is enhanced by deploying a second network for redundancy, but this doubles the amount of equipment at any site.

**POINT-TO-MULTIPOINT: LOW THROUGHPUT**

In a point-to-multipoint system, a central base station connects wirelessly to numerous “child” nodes in a one-to-many configuration. This is the basic mode of operation of the access portion of a wireless LAN, where a single AP connects multiple wireless clients (e.g., laptops, PDAs) to the backbone. This approach has also been extended from the point of access to the wireless backhaul.

In some systems the nodes are fixed, as in broadband wireless access (BWA), where a central base-station connects to multiple customer premises equipment (CPE) attached to the outside of a building. The CPE then has an Ethernet connection to the inside of the building. In situations of fixed-data use—such as residential applications where the user is stationery in the building—these CPEs are located inside the building, with an antenna external to the building. (Figure 2)

Using this approach, a single AP can serve the wireless needs of a large population of mobile clients. However, for the purposes of backhaul, point-to-multipoint has a number of drawbacks due to the use of a shared medium to backhaul multiple nodes: The network’s channels often need to be reused due to the limited unlicensed spectrum. In practice, just three or four channels in the 2.4 GHz spectrum are available for network use, so if more than three APs are required, channel sharing must occur.

APs on the same channel are unable to transmit at the same time, and during transmission, the coverage of each node decreases, reducing the usable throughput of each node (the good-put) and increasing delays in data transmission. These difficulties can be alleviated by using Time Division Multiplex (TDM) or polling techniques to allow the nodes to more gracefully share the spectrum. However, the fundamental issue of sharing a single channel between nodes remains.

The shared medium also limits scalability of the network, as the client node-to-master-node ratio must be kept low to ensure performance and to achieve acceptable levels of service. To cover multiple nodes, the central base station must use a wide-beam width antenna, trading off for lower gain and, subsequently, lower reach. To increase the range, highly directional antennas are sometimes used. These require pointing, which increases installation complexity and cost.

Of greater concern, perhaps, is that a point-to-multipoint network is vulnerable to a single point of failure. Where a single node subtends many other nodes, its failure removes them all from the network.

**MULTIPOINT-TO-MULTIPOINT: BIG APPETITE**

In a multipoint-to-multipoint system, each node in the wireless network can “talk” to many other nodes in a many-to-many configuration. Network contention is obviously a concern in these networks, which must provide very high capacity to accommodate the traffic.
A common rendition of such a system is the peer-to-peer *ad hoc* network, or mesh network often deployed informally by technically savvy home users. Such systems have been proposed for larger, infrastructure-scale applications where a network of multiple fixed nodes is deployed, each of which is able to communicate via its radio to multiple other nodes (Figure 3).

Multipoint-to-multipoint wireless networks are attractive because the mesh provides redundancy and increased availability. However, the problems of the shared medium associated with point-to-multipoint systems are increased. With even more nodes competing for access to a shared medium, good-put drops further.

In addition, multipoint-to-multipoint systems do not provide the performance network operators require. CSMA/CD (Carrier Sense Multiple Access, Collision Detect) techniques, such as those implemented in 802.11, enable multipoint-to-multipoint systems to work, but total capacity of the system drops as the medium fills and collisions become more frequent.

Just as with point-to-multipoint systems, antenna beam widths must be wide to see many other nodes. The tradeoff is lower link budgets with correspondingly short reach.

While transmission power can be raised to partially offset low antenna gain, this has its own drawbacks: increased power consumption, increased interference between nodes and significantly increased cost.

**MESH NETWORKS ARE THE KEY**

Wireless mesh networks are proposed as a way to address the issues associated with traditional wireless networking options. But, since early wireless mesh systems were focused on mobile ad-hoc networks, many people assume that all wireless mesh networks are low bandwidth or temporary solutions that cannot scale to deliver the high capacity and quality of service required by enterprises and service providers.

In reality, it is not that mesh networks don’t scale—mesh networks can scale very well. But all wireless mesh networks are not created equal.

Single-radio wireless mesh architectures are built on equipment designed around a single radio for access and backhaul. As such, they must share the available bandwidth, so they don’t deliver enough capacity for broadband service and they can’t scale. As you add more mesh nodes, the system capacity gets worse.

The capacity and scaling ability of wireless mesh infrastructure networks can be improved by using mesh APs that have separate radios for client access and wireless backhaul.

In a dual-radio mesh, the APs have two radios operating on different frequencies. One radio is used for client access and the other radio provides wireless backhaul. The radios operate in different frequency bands, so they can run in parallel with no interference. A typical configuration is 2.4 GHz Wi-Fi for local access and some flavor of 5 GHz wireless for backhaul. Since the mesh interconnection is done with a separate radio operating on a different channel, local wireless access is not affected by mesh forwarding and can run at full speed.

However, in a dual-radio design, the wireless mesh backhaul is the bottleneck and the same shared network contention mechanisms that plague the single radio approach are present. This results in capacity that does not scale up, as well as latency issues that preclude multimedia applications, such as video or voice.

Only the multi-radio mesh network is ideal for wide-area Wi-Fi.

**MULTI-RADIO MESH DELIVERS CAPACITY AND WIDE AREA COVERAGE**

Like a dual-radio wireless mesh, a multi-radio wireless mesh separates access and backhaul, but it goes a step further to provide increased capacity by addressing the shared backhaul network issues that limit the dual-radio mesh architecture.

In a multi-radio wireless mesh, multiple radios in each mesh node are dedicated to the backhaul wireless mesh. The backhaul mesh is no longer a shared network, since it is built from multiple point-to-point wireless links and each of the backhaul links operates on different independent channels.

This type of multi-radio design is called a multiple point-to-point mesh. It is possible to create very rich mesh topologies with this multi-radio approach and just a few backhaul radios at each node. (Figure 4)

When used for backhaul in this fashion, the performance of a multi-radio mesh is similar to switched, wired connections between the mesh nodes. The mesh radios operate independently on different channels so latency is very low. There are only two nodes per mesh link, so contention is very low. In fact, it is possible to run a customized protocol on the mesh backhaul links that optimizes throughput in this simple two-node, contention-free environment.
There are other advantages of the multi-radio mesh approach.

**Performance**—Performance in a multi-radio mesh is much better than the dual radio or single radio mesh approaches. The capacity of the mesh continues to scale as the network grows and more nodes are added.

**Co-existence**—A multi-radio mesh is much more flexible. Each access radio can be assigned a different channel, so the co-existence problem is isolated to the coverage area of a single mesh AP—not the whole system. Multi-radio meshes fit into their environment and share the unlicensed spectrum better.

**Interference**—Multi-radio meshes are very flexible in terms of channel assignment on the access or backhaul radios. They can adapt to interference because each access radio can be set to the channel that is least used in a given area.

**Latency**—The dedicated point-to-point links in the multi-radio mesh keep backhaul latency low and predictable. Single-radio mesh and dual-radio mesh approaches have a shared backhaul network using a contention based protocol with unpredictable latency. Multi-radio mesh is suitable for voice applications, the others are not.

**CARRIER-GRADE WIDE-AREA WI-FI IS POSSIBLE**

So, to address wide-area Wi-Fi requirements, a different kind of wireless networking product and architecture are needed.

The product must be specifically designed for outdoor deployment, enable the creation of a scalable architecture, require minimal cabling, and provide maximum coverage.

The network must be able to scale to accommodate building, campus, and city-wide deployments. It must provide always-on, consistent access, high speed connections, and the ability to handle a large number of simultaneous users. It must also offer secure connections back to private corporate networks, using virtual private networking (VPN), and it must have the capability to support value-added services such as voice and video.

In short, the networking product and the architecture must be designed from the ground up as a multi-radio mesh system.

Dave Park has 16 years’ experience designing wireless systems. Prior to joining BelAir Networks, he held progressively senior engineering and management positions with Marconi Communications, STC technology, Bell Northern Research, and Nortel Networks. He has worked on most of the commercially successful wireless standards of the last decade and has designed and engineered cellular base stations, pico-cellular systems, in-building wireless systems and fixed wireless access terminals. He holds a Master of Electrical Engineering from the University of Surrey in Guildford, England, and has three patents with four pending in wireless and optical systems.