Evolution of Municipal Wireless Networks

This paper examines the evolution of citywide broadband wireless networks.

Summary

Wireless broadband initiatives for cities are receiving significant attention today. However, while some major cities have already announced citywide wireless networks, the market for municipal wireless broadband is still in the early stages. Most of these large networks will almost certainly experience numerous changes before they are fully deployed. Most of the existing municipal wireless networks are located in small rural towns and support a single application. The business models and the infrastructure technology for municipal wireless networks are still evolving at a rapid pace and are converging on a managed-service or public/private partnership model. This paper will examine the evolution of these municipal wireless networks.

The Early Municipal Wireless Market

Public safety networks owned and operated by municipalities drove the early municipal wireless market. Police, fire departments, and other emergency responders have been using cellular data networks for their mobile communications needs. Cellular carriers are phasing out cellular digital packet data (CDPD) and moving to broadband cellular data services, and mobile applications for emergency responders are shifting from text-based to multimedia. These changes have led some cities to consider building their own wireless network in an unlicensed band, rather than paying monthly fees to a cellular carrier for each of their mobile users.

For smaller towns with manageable terrain, wireless mesh networks operating in the unlicensed 2.4-GHz band proved to be a cost-effective solution. The early networks included proprietary client mesh capability that allowed mobile emergency responder teams to form instant networks in the field, communicate with each other, and connect to headquarters. A slight modification to make these networks support standard Wi-Fi clients opened up many other possible municipal wireless applications. In these scenarios, the wireless mesh is still used to interconnect nodes in the infrastructure, but the client devices are standard Wi-Fi and do not participate in the mesh.

Factors Driving the Municipal Wireless Evolution

There are many factors driving the current evolution of municipal wireless networks. These include the following:

- **Mobility**—Users are accustomed to mobile voice and now expect mobile data access as well.
- **Availability of Wi-Fi technology**—Wi-Fi costs continue to drop, and Wi-Fi is increasingly built into smaller, more mobile devices such as phone handsets and portable games.
- **Broadband evolution**—The performance expectations of broadband access keep increasing, as a richer set of Internet applications consume more bandwidth.

- **The cost of a wireless data bit**—Broadband data consumes more bits than voice on digital wireless networks. A lower-cost wireless data bit is required to deliver the mobile broadband services users expect.
- **Ubiquity of IP access**—Different wireless access technologies such as 3G cellular, digital cable, and WiMAX are all converging on IP, just as Wi-Fi and Ethernet did.
- **Wireless spectrum availability**—The success of wireless broadband in the unlicensed bands has prompted regulatory agencies around the world to make more of the unlicensed spectrum available. New licensed bands are also becoming available, as unused bands are being reallocated for new services.

Key Drivers for Municipal Wireless Network Adoption

Each city is unique in its requirements for wireless broadband. Most early networks were developed by cities to support a single application. Over time, citywide wireless infrastructure will support many different applications, some of which are detailed here.

Public Safety

Wireless communications are critical for public safety. First responders can set up an instant network at the scene of an incident with a wireless mesh. A citywide wireless mesh infrastructure can support secure mobile communication for police and fire departments in the 4.9-GHz public safety band and also deliver video surveillance over the unlicensed 2.4-GHz band for national security.

Digital Inclusion

A wireless infrastructure may provide low-cost or free Internet access and could be part of a program to make computers and Internet access available to disadvantaged families. Voice over IP (VoIP) could be part of this service.

Economic Revitalization

High-speed wireless Internet access can help revive ailing downtown areas. Low-cost broadband Internet access can attract more businesses to town, help increase tourism in resorts, or simply make an area more attractive as a destination.

More Efficient City Governments

Many city workers can do their jobs more efficiently if they have access to the city network out in the field. A municipal wireless network allows instant access to important city records and databases for tax collectors, auditors, and building inspectors. Citywide wireless networks also enable new applications, such as automated meter reading for utilities and parking meters, or intelligent traffic networks.

Commercial Internet Access

In areas with limited broadband choices, a wireless mesh can be used to deliver residential broadband. Depending on the design of the network, the service can be positioned as a lower-cost alternative to DSL or cable, or as a higher-performance service with the added benefit of mobility.

Covering Large Areas with Wi-Fi

Wi-Fi has been the technology of choice for building citywide broadband wireless networks. But Wi-Fi, based on the IEEE 802.11 standard, didn’t start out as an outdoor wireless standard. Wi-Fi was designed as an indoor wireless local area network. Wi-Fi has an indoor range of about 50 meters through walls. Deploying Wi-Fi outdoors and covering entire cities was originally thought to be a stretch.

The use of Wi-Fi for citywide networks is driven by economics more than technology. Wi-Fi has been extremely successful in the enterprise and consumer space. Today Wi-Fi is built into a variety of mobile client devices—notebook computers, handhelds, mobile phones, and even portable games—at almost no incremental cost. Since users already have what they need to connect to the network, including a “free” client adapter, Wi-Fi is a compelling choice for building citywide wireless networks.

Stretching Wi-Fi

Building a citywide Wi-Fi network requires a new infrastructure that stretches Wi-Fi technology without making any modifications to Wi-Fi clients. The technical challenge is two-fold: first, each access point must cover a much larger area than is typical with Wi-Fi; and second, these access points must be interconnected to each other and to a wired Internet point of presence (POP) cost-effectively.

Access points were developed that cover much larger areas by using high-gain antennas and customized radios with greater receive sensitivity and higher transmit power. These access points can support standard, low-power Wi-Fi clients at ten times the range of conventional indoor access points. Even at this scale, 25 to 30 access points are required per square mile in a suburban setting. Providing a T1 line or fiber connection to each access point location is cost-prohibitive. This is where the wireless mesh comes into play. Using a wireless link to interconnect the access points makes it practical and more cost-effective to deploy a large number of access points throughout a city. Variants of Wi-Fi are being optimized for long haul wireless backhaul in an outdoor environment, in much the same way as Ethernet was transformed from a very simple protocol that ran over a single physical medium, into metro-area and wide-area fiber networks that were never envisioned as part of the original standard.

The first wave of municipal wireless infrastructure products combined an outdoor ruggedized, high-power Wi-Fi access point with a wireless mesh router. These systems use a single radio operating in the 2.4-GHz band for both client access and mesh interconnection. The mesh features make the wireless backhaul network more reliable and easier to configure. Usually, each mesh access point can communicate with more than one of its neighboring mesh router access points. There are multiple paths through the mesh networks to the backhaul network, and the mesh routing protocol determines the best route on a packet-by-packet basis. A wireless mesh also supports multiple wireless hops between a remote mesh router (mesh access point) and the wired point of presence connected to the root access point. The multi-hop mesh eliminates the requirement for a direct line-of-sight link from the wired location to each node in the mesh, resulting in more installation flexibility.

In the early days, municipal wireless development was usually driven by a single application in each city: first responder networks, automated meter reading, public Internet access, or simply alternative residential broadband. In most cases, the cities owned and operated the network. A few alternative service provider entrepreneurs also built Wi-Fi mesh networks for commercial use.

The single-radio mesh infrastructure is a good approach for low-cost coverage of large open areas, but performance is constrained by the mesh and capacity is limited. A single Wi-Fi channel is shared amongst all nodes in the mesh and must be used for both client access and forwarding traffic through the mesh to the wired point of presence.

Furthermore, single-radio wireless mesh infrastructure does not scale to large systems; the more nodes in the network, the more severe the impact of sharing the channel for client access and packet forwarding through the mesh. To minimize the performance limitations, each mesh cluster is usually limited to four or five nodes, operates on a different radio channel than neighbor clusters when possible, and has a wired or fixed wireless backhaul connection to the data center.

The early stage municipal wireless networks were adequate for coverage of large areas, but a more advanced wireless infrastructure is required to move beyond the performance limitations as these networks grow to support more users and more applications over even larger areas.

Enhanced Performance Wireless Mesh

The dual-radio mesh architecture overcomes many of the performance limitations of the single-radio mesh solutions. In this approach, wireless client access is separated from wireless backhaul. One radio is dedicated to Wi-Fi client access in the 2.4-GHz band. A second radio is dedicated to the wireless mesh backhaul system and typically operates in the 5-GHz band, which is also unlicensed. Since the radios are in different bands, they can operate independently at full speed.

The dual-radio architecture delivers higher performance than single-radio mesh. There is more capacity available per square mile. It is possible to build larger wireless mesh systems, thereby reducing the number of wired connections or fixed wireless backhaul links needed per square mile. Dual-radio systems offer improved radio coexistence in the unlicensed bands, since the access radio in each mesh node can be set to a different channel. Each mesh access point can set its client access radio to the least used Wi-Fi channel in the area. Dual-radio mesh systems offer improved performance to support more advanced applications by offering lower and more predictable packet latency throughout the network. These performance improvements enable new applications for municipal wireless mesh networks and deliver enough capacity to support multiple applications or even multiple service providers on the same network.

Emergence of a Managed Service Model

Most of the larger cities are calling for a public/private partnership to build their municipal networks. Cities have a natural role in the development of these networks; they own the real estate required to build the network infrastructure, such as street lights and public buildings. Cities also are important users of these networks and many of citywide wireless projects specify that the city may be an “anchor tenant” and run many of their private applications on the wireless network. The city may also be motivated to build a network for political reasons, such as bridging the digital divide or helping with economic revitalization. However, the city does not necessarily have to own and operate the network itself, as doing so requires large capital expenditures and highly trained in-house IT resources. Instead, cities are increasingly specifying that the network not incur any capital expense and minimal IT maintenance requirements. To satisfy this requirement, service providers large and small have started to create innovative outsourced solutions specifically for municipal outdoor networks.

With service providers now taking a more active role in the development of municipal wireless networks, outdoor wireless networks are moving to unprecedented levels of adoption. The business drivers for municipal wireless vary according to the type of service provider. For some, the opportunity to fulfill the city’s mobile communications needs and act as a wholesaler to other service providers is sufficient. The local cable company or DSL provider may see a municipal wireless cloud as a way to add mobility services to their offerings. ISPs formed during the dial-up age may be attracted to municipal wireless networks as a way to create and own broadband infrastructure. Wireless carriers can develop municipal wireless networks and use unlicensed wireless spectrum to augment their existing licensed spectrum and deliver more services or support more mobile users. In some cases, service providers are brought in simply because the complexity of operating a citywide wireless network with multiple services is beyond the capabilities of a city’s IT department.

To fulfill this need, service providers require carrier-grade infrastructure equipment and deployment tools. They also need scalable systems that can grow with the network’s needs. Across a city, the network load is not uniform. Some areas will have very low utilization with just a few users, and therefore will require only minimal coverage with very low capacity. In densely populated areas, the network must deliver much higher capacity and support many simultaneous users.

As municipal mesh networks become more sophisticated and support a mix of applications and traffic types, many of the management and security features and deployment tools developed for large-enterprise Wi-Fi networks become increasingly important. Multiple SSIDs and a service selection gateway are required to support multiple service providers. Different virtual LANs (VLANs) are required to enable multiple traffic types with different priorities for various applications. Private applications such as police or fire department networks must be kept secure with wireless encryption and end-user authentication, and they must be separated from other applications and services that run on the same network infrastructure, particularly from public Internet access, which requires a more open network. Subscriber management tools can enable residential broadband, guest Internet access, and digital inclusion.

In modern enterprise wireless LAN systems, these functions are handled by WLAN controllers and a centralized network management system. This centralized WLAN controller architecture was a service provider concept from the cellular world applied to the enterprise to manage the complexity of installations with hundreds of wireless access points. Therefore, applying this same WLAN architecture to large municipal wireless networks is natural. Because the wireless mesh infrastructure for municipal networks is usually installed on city light poles or buildings, it is very expensive to visit each mesh node to reset or change its configuration. This is why a high-performance wireless mesh based on a WLAN controller architecture with centralized RF management and deployment tools is the most compelling solution for municipal wireless networks today.

Increasing Capacity in Municipal Wireless Networks

Here are a few ways to increase capacity in municipal wireless networks:

More Channels

The ultimate way to increase capacity is to make more wireless spectrum available for municipal networks. 50 MHz of spectrum in the 4.9-GHz band has been allocated to public safety applications in the United States. New spectrum in the 5- GHz band is now being allocated for unlicensed use and will eventually be used for both backhaul and access.

Shrinking Coverage Areas

As usage increases, decrease the RF power and reduce the size of the coverage area of each access point. The first step is to deploy smaller base stations mounted lower so they cover a smaller area, just as the cellular industry did in big cities. This leads to more access points in a given area operating on different channels. More access points, with each one supporting fewer users, means more capacity is delivered throughout the system. However, the benefit of this approach in the unlicensed spectrum is limited by frequency reuse, especially in the 2.4-GHz band, where there are only three independent channels available.

Directional Antennas

Directional antennas can increase capacity on the wireless backhaul network by reducing the number of nodes that share the same radio link. Initially, backhaul mesh interconnection is a shared wireless mesh, with omnidirectional antennas at every node. For more capacity, separate access and backhaul in different bands. The next step to increase capacity is adding directional antennas on towers to form dedicated point-to-point links at the core of the backhaul network. Then, as demand increases, move directional antennas out to the edge to increase capacity in high-traffic areas.

Improvements in the Media Access Protocol

The media access protocol of the backhaul network can be optimized For licensed backhaul, WiMAX will offer a more efficient MAC protocol that delivers more usable bandwidth within the same channel size.

Scalable Multiuse Systems—The Next Evolution of Municipal Wireless

The municipal wireless system of the future will be a single infrastructure that supports different wireless access technologies: Wi-Fi, WiMAX, cellular, and the 4.9-GHz public safety band. The infrastructure will include a mix of licensed and unlicensed technology. The network will usually be owned and operated by a service provider. Some of the services will support city applications, and some will be commercial wireless services.

Both cellular and WiMAX are wide-area wireless technologies. They are deployed with a macro-cell architecture and use base stations and antennas mounted on towers that typically cover a few square miles each. Third-generation (3G) broadband data services are already straining the cellular network infrastructure. As these systems attract more users, they will need to deliver increased capacity, especially in dense urban areas. Capacity can be increased by having more, smaller cell sites in high-traffic areas. These micro-cells would be mounted lower, on streetlights instead of cell towers. The wireless mesh techniques that we use today for stretching Wi-Fi to cover an entire town can compliment WiMAX and cellular networks by enabling practical deployment of micro-cells (or pico-cells) in dense urban areas.

Ultimately, all of these technologies will be combined into a common citywide wireless infrastructure, but this will take time. These technologies are evolving independently at different rates. Combining the different technologies is a complex problem. Economic forces are already driving convergence on the client side. Dual-mode Wi-Fi cellular handsets are coming to market now. When mobile WiMAX arrives on the client side, it will usually be combined with a Wi-Fi client. As the demand for mobile data increases, tri-mode clients can't be far behind. It is only natural for the citywide wireless infrastructure to evolve into a converged, multiservice infrastructure.

Conclusion

This review of the evolution of wireless networks in cities leads to the following conclusions :

- **Municipal wireless networks are just getting started.**

  The broad market for citywide wireless infrastructure is still ahead. The first wave of municipal wireless used single-radio Wi-Fi mesh infrastructure. It validated the technology and helped cities and service providers define the business models. This market is bigger than just Wi-Fi access or Wi-Fi mesh.

- **As municipal wireless networks evolve, they become multipurpose.**

  Citywide wireless network infrastructure will support multiple applications. The same network that delivers automated meter reading for the utility company and mobile communications for police and fire departments can offer free Internet access in public parks, residential broadband, or commercial VoIP services throughout a city.

- **Wireless mesh networks will help reduce the cost of the wireless data bit.**

  Wireless mesh backhaul enables practical deployment of micro-cells for Wi-Fi, cellular, and WiMAX.

- **Municipal wireless networks will increasingly be run by commercial service providers.**

  A citywide broadband wireless infrastructure can augment the existing business of service providers and help them compete in the rapidly changing telecom business. Municipal wireless networks can be a mobility play for fixed-line service providers or a way to leverage both licensed and unlicensed spectrum to meet the needs of an increasingly bandwidth-hungry user base.

  The growing complexity of these citywide networks calls for the sophisticated management, security, and deployment capabilities that service providers already employ in their other networks. Service providers will require carrier-grade infrastructure hardware, end-to-end quality of service (QoS), client and infrastructure security, and centralized management and deployment tools.

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Printed in USA

C11-378713-00 11/06