Internetworking Atlantic Inc.

White Paper

Municipal Mesh Network Design

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1 Summary

This document provides a wireless mesh network design for the downtown area of the Town of Wolfville, Nova Scotia. This design serves as an example of municipal wireless networks that can be built to provide free broadband Internet access to end users using IEEE 802.11a/b/g wireless technology. The design utilizes exiting infrastructure provided by the Valley Community Fibre Network[1] (VCFN) and the Common Infrastructure backbone.

2 Network Architecture

This section describes the network architecture designed to deliver broadband Internet access using mesh technology. The section starts with a brief introduction to mesh networks and an overview of the proposed network architecture. The last subsection includes a description of main network components using vendor specific terminology.

2.1 Overview of Mesh Networks

Wireless mesh networks have emerged as an extension to wired infrastructure in public and private outdoor installations such as academic campuses, municipalities, and city downtown areas. Mesh networks include both single-radio and multi-radio solutions. Single-radio mesh solutions use a single radio device to provide wireless access to the end user and connectivity on the backhaul mesh network. Albeit simpler in design, single-radio solutions suffer from diminished throughput that limits the scalability of the overall network. In contrast, multi-radio mesh designs allow the separation of user access and mesh backhaul operations of the wireless network, resulting in greater available capacity and better scaling. Dual-radio networks are typically sufficient to realize the benefits of separation of the user access and backhaul planes.

Forwarding data packets over the mesh topology may be accomplished at OSI layer 3 using IP packets. The data forwarding may also be accomplished at layer 2 using IEEE 802.11 frames. In either case a path is chosen by a routing algorithm. The routing algorithm is a major variant between vendors of mesh solutions.

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2.2 Architecture Overview

Figure 1 depicts the network architecture of the proposed mesh wireless network. The architecture consists of three tiers; each using a different connection technology. Client access technology is based on the IEEE 802.11b/g (WiFi) standard. The wireless access can be established between client nodes and mesh access points using 2.4 GHz radios.

In the mesh tier, client packets and network management traffic traverses backhaul wireless links from client nodes towards the Internet. The mesh tier is a self-forming, self-healing, multi-hop network based on IEEE 802.11a radio technology in the 5GHz frequency band. The self-forming capability allows mesh access points to discover their neighbours and establish efficient paths across the mesh to the Internet. The self-healing nature of the mesh layer provides a mesh access point with the ability to select a new path towards the intended destination whenever the topology changes due to link or node failure.

The wired backbone tier includes a Network Operations Center (NOC) located at City Hall and one Mesh Egress Point (MEP) location. The NOC provides the mesh tier with a gateway to the Internet over wired infrastructure based on IEEE 802.3 technology (Ethernet). The NOC is also responsible for the management functions of the mesh network. The MEP provides additional wired termination points for the mesh tier for enhanced throughput and reliability. Inter-connections between MEPs and the NOC consist of fibre links. Although not shown in the diagram, the NOC and MEP may connect to multiple mesh access points as the network expands in the future.

2.3 Network Components

The proposed network is based on Cisco Systems' wireless mesh networking solution[2]. The main components of this network are identified as follows:

2.3.1 Cisco 1520 Series outdoor mesh access points:

The core component of the wireless network is the Cisco 1520 Series outdoor mesh access points (AP)s. The 1520 series AP is a lightweight access point (LAP), which is a device that allows client wireless nodes to connect to a wireless network using a wireless standard such as IEEE 802.11a/b/g. The LAP relays client traffic (e.g. from laptops) to a directly connected wired network and also operates as a relay node for other LAPs that are not connected directly to a wired network. Unlike an autonomous wireless AP, a LAP is designed to be controlled by a Wireless LAN controller (WLC).

The Cisco 1520 mesh access point (MAP) is equipped with two simultaneously operating radios: a 2.4-GHz radio used for client access and a 5-GHz radio used for data backhaul to another MAP. A MAP that is directly connected to the wired infrastructure is referred to as Root Access Point (RAP). At least one RAP is needed in a mesh network to provide access to the Internet.

2.3.2 Cisco Wireless LAN Controller

Wireless LAN Controllers (WLCs) automate the configuration and management functions within the mesh network. Tasks such as association or authentication of wireless clients are done by the WLC utilizing the Control And Provisioning of Wireless Access Points (CAPWAP) protocol (RFC4564). Mesh APs register themselves with a WLC and tunnel all the management and data packets to the WLCs, which then switch the packets between wireless clients and the wired portion of the network.

2.3.3 Cisco Wireless Control System (WCS)

The Cisco Wireless Control System (WCS) is a management tool that adds to the capabilities of the web user interface and command line interface (CLI) of a WLC and allows the management of a network of controllers. WCS includes the same configuration, performance monitoring, security, fault management, and accounting options used at the controller level and adds a graphical view of multiple controllers and managed access points. WCS can run as a normal application or as a service on Windows and Linux servers.

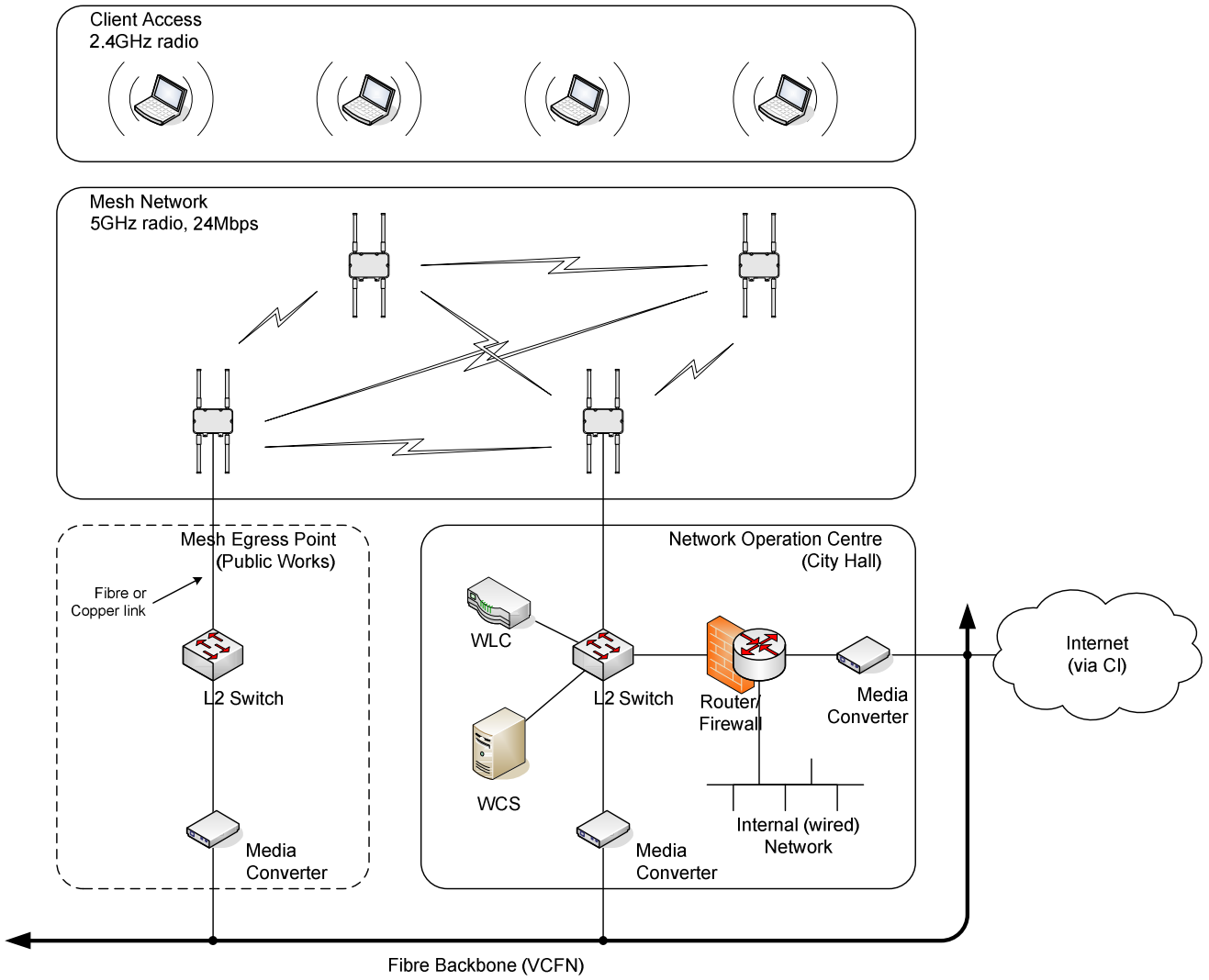

Figure 1 Architecture Overview

3 Mesh Topology

A set of design rules and manufacturer recommendations were followed to design each of the tiers described in the previous section. Note that the recommended data rate and coverage distances discussed here represent conservative estimates. Final data rates and coverage area will be determined at the implementation stage.

The network is designed to fulfill the general requirements summarised below:

- The network main application is to provide Internet access.
- Coverage area should include the downtown area (Main Street and Front Street).
- The network should be operationally compatible with existing infrastructure.
- The network is based on IEEE 802.11 (Wi-Fi) technology.
- Bandwidth offered to users should ensure a quality experience but prohibit misuse.

Figure 2 shows the proposed physical layout of the mesh network. The MAP locations are approximate and may change during the implementation stage.

Figure 2 Physical Topology

3.1 Access Tier

The access tier provides wireless network access to individual users. As a result the access layer radio frequency selection is limited by the equipment readily available to users. Most laptops today incorporate client IEEE 802.11b/g radios, operating within the 2.4-GHz band as a standard feature.

To estimate the coverage area for a MAP, it was assumed that the CPE device has a 100 milliwatt transmit power (20dBm) and the desired data bit rate is up to 5.5Mbps. To optimize mesh behaviour, omni-directional antennas are selected for the design. Moreover, MAP height is recommended not to exceed 10-12 meters above the street level.

Using the antenna parameters listed below, Table 1 lists the distance of None Line of Sight (NLOS) omni-directional coverage in suburban environment similar to the targeted service area. Note that greater distances can be achieved in environments with fewer obstacles such as high buildings and dense foliage.

Table 1 Access coverage distance for 5.5Mbps data bit rate

Parameter	MAP		CPE
Antenna gain (dBi)	5.5 omni	8.0 omni	0 omni
Antenna height (meter)	10	10	2
TX power (dBm)	28	28	20
Cable loss (dB/100ft)	No cable	No cable	No cable
EIRP (dBm)	33.5	36	20
NLOS suburban (meter)	**153**	**177**	
NLOS urban/dense foliage (meter)	124	140	

Figure 2 shows that three MAPs, with coverage area of 150 meters radius, are sufficient to cover the targeted service area of downtown Wolfville. A fourth MAP can be added to improve reliability. The diameter of the fourth MAP is expected to be higher due to the presence of a large parking lot. See Appendix B for photographs of the targeted services area.

In North America, IEEE 802.11b/g offers 11 usable frequency channels with only three non-overlapping (non-interfering) channels. This channel spacing governs the use and allocation of channels in a multi-AP environment. APs should be deployed in a cellular fashion where adjacent APs are allocated non-overlapping channels to minimize interference from adjacent cells. Moreover, deploying an AP with multiple antennas can effectively increase the gain on a 2.4-GHz radio to 2.7 dB by adding two antennas and to 4.5 dB, by adding three antennas.

3.2 Mesh Tier

The mesh network is comprised of Cisco Aironet 1522AG Lightweight Outdoor Access Points. This AP is a dual-radio system with one 5-GHz radio and one 2.4-GHz radio. The RAP-MAP and MAP-MAP interconnections in the mesh tier are established over the IEEE 802.11a radios. The 5-GHz band provides a separate plane for backhaul traffic that co-exists with client access technology in the same physical space; thus, improving the overall throughput of the network and allowing for better scalability.

The 5-GHz band offers the advantage of higher bit rate and less susceptibility to interference at the expense of shorter distance and weaker obstacle penetration. A backhaul data rate of 24 Mbps is recommended because it provides similar coverage to the client access. That is, the distance between MAPs using 24 Mbps data rate should allow for maximum coverage for client access with suitable overlap. Table 2 lists the achievable distances using various types of antennas.

Table 2 Backhaul coverage distance for 24Mbps data bit rate

Parameter	MAP 1			MAP 2
Antenna gain (dBi)	8.0 omni	14.0 patch	17.0 sector	8.0 omni
Antenna height (meter)	10	10	10	10
TX power (dBm)	27	27	27	27
Cable loss (dB/100ft)	No cable	10	No cable	No cable
EIRP (dBm)	35	40.9	44	35
LOS w/ Fresnel zone clearance (meter)	4,120	8,210	9,690	
LOS w/o Fresnel zone clearance (meter)	680	1,220	1,670	
NLOS suburban (meter)	**520**	**750**	**900**	
NLOS urban/dense foliage (meter)	130	180	220	

The equipment vendor categorizes the mesh access points into Root Access Point (RAP) and Mesh Access Point (MAP). A RAP is attached directly to the wired infrastructure and relays data traffic from neighbouring MAPs to the wired network over backhauls wireless links. The mesh network must have at least one RAP to function properly. More RAPs can be added to provide multiple egress points to wired networks. The Cisco Aironet 1522AG can be configured to function as a RAP or a MAP.

MAPs use the Cisco Adaptive Wireless Path Protocol (AWPP) to determine the best path through the other RAPs/MAPs to reach the controller. All possible wireless links among the MAPs and RAPs form the wireless mesh network. Both MAPs and RAPs can provide wireless access to clients using IEEE802.11b/g radio.

In large-scale deployments, the number of wireless hops that a data packet may traverse should be limited to three or four to maintain sufficient backhaul throughput, which is approximately halved over every hop. In the proposed network, end user traffic travels two wireless hops at most.

3.3 Wired Backbone Tier

The wired backbone tier shown in Figure 1 consists for the network operations centre and an optional mesh egress point. The role of this tier is illustrated in Figure 3, which shows the logical topology of the proposed network. The fibre backbone, the fibre-copper media converters and the layer 2 switches are represented by the wired LAN segment in the figure.

The Wireless LAN Controller (WLC) and the Wireless Control System (WCS) are vital components in the mesh wireless system. The WLC main function is to automate configuration functions, such as transmission power, frequency channel selections, and user authentication. The WLC also associates each IEEE 802.11b/g service set identifier (SSID) to a VLAN, which allows the network administrator to handle several groups of end users, each with access to a VLAN with unique privileges and/or applications.

The Cisco WLC2106 is selected to manage the APs in the proposed network. The 2106 WLC can operate up to six RAPs/MAPs, which makes it ideal for a network of this size. As the mesh network grows larger, additional 2106 controller can be added. Using multiple WLCs also improves the network reliability and provides load balancing.

The WCS enhances the ability to manage the network by providing a GUI access to various configuration options on the WLC in addition to the ability to manage several WLCs collectively.

The router/firewall provides access to the Internet as well as other, exiting, wired networks. It is assumed in this design that the firewall, the access to the fibre backbone, and the access to Internet are existing infrastructure and are not included in the design and the proposed bill of material.

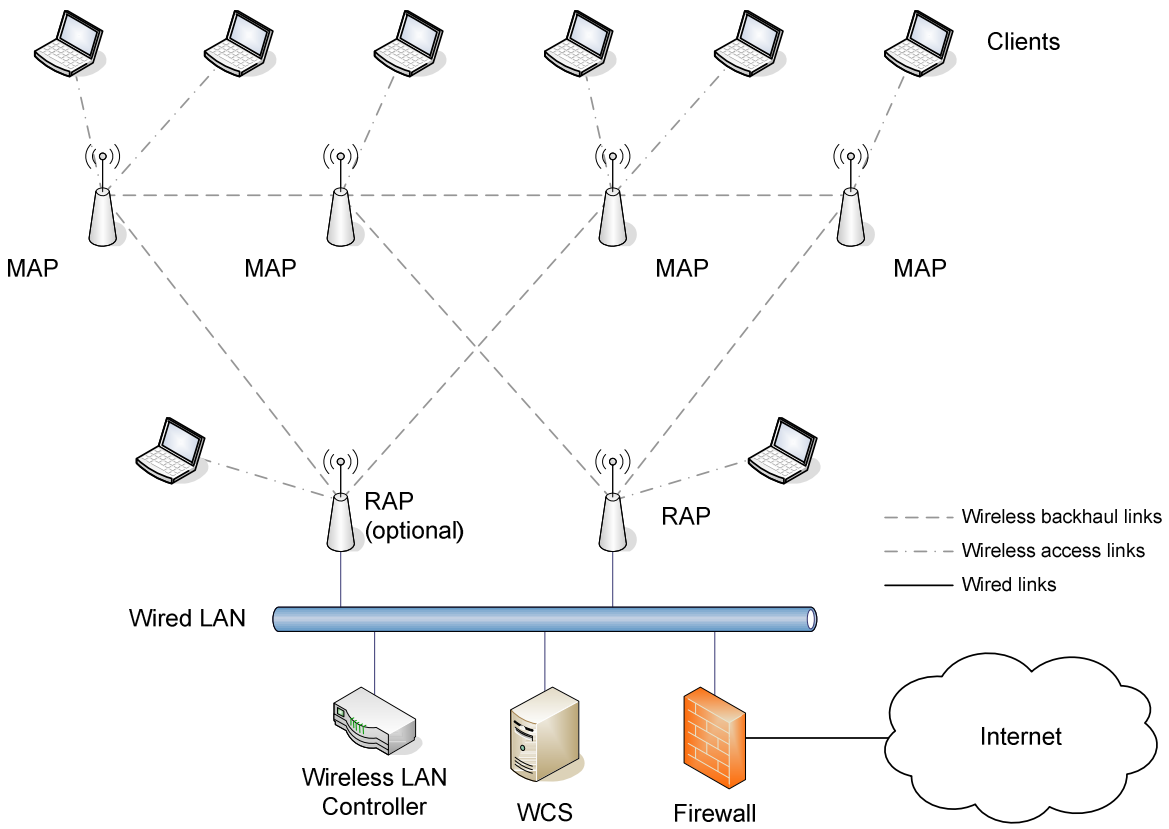

Figure 3 Logical Topology

4 Summary

This document provides a wireless mesh network design for the downtown area of the Town of Wolfville covering the commercial sections of Main St. and Front St. The network's main features are:

- The main application is to provide free Internet access to end users in the targeted service area.
- The mesh network consists of up to four Cisco Mesh Access Points.
- Cisco mesh networks are based on multi-radio mesh technology compatible with IEEE 802.11 (WiFi).
- Client access is provided using IEEE 802.11b/g at data bit rate of 5.5Mbps or higher.
- Mesh backhaul traffic is provided using IEEE 802.11a typical bit rate of 24Mbps.
- A network operations centre at City Hall provides the main egress point to the Internet.
- The NOC includes a wireless LAN controller and a wireless control system that manage the access points.
- Enhanced reliability options include additional connection to the wired network and backup batteries.
- Access points will be mounted on suitable infrastructure in locations that will be determined in the implementation stage.

5 References

[1] www.vcfn.ca

[2] http://www.cisco.com/en/US/products/ps5679/Products_Sub_Category_Home.html