

Appendix A: Radio Frequency (RF) Analysis

This section of the report discusses data collected, observations, methodologies and recommendations regarding the use of the 2.4-2.5GHz and 5-6GHz frequency bands for supporting a municipal Wi-Fi wireless network throughout Lakewood.

The RF testing within Lakewood area was completed on September 8-11, 2006 and includes the following:

- **RF spectrum scans.** Spectrum scans involved the use of a spectrum analyzer to measure signal activity in the 2.4-2.5GHz and 5-6GHz frequency bands at locations throughout the test area.

Numerous spectrum scans were done using an AirMagnet Spectrum Analyzer Card inserted into a laptop running AirMagnet's Survey software. This spectrum analyzer used an external omni-directional antenna. The software automatically captured a spectrum scan every five seconds while the test team drove throughout the test area. The software plotted the location of each spectrum scan on a map (Microsoft MapPoint) based on coordinates obtained through a GPS, with external antenna for better position accuracy. The test team drove throughout the test area in a manner to capture multiple spectrum images of the 2.4-2.5GHz and 5.0-6.0GHz frequencies throughout the test area.

Refer to Appendix B for the identification of chosen spectrum image locations and resulting spectrum images.

- **Wireless LAN scans.** The wireless LAN scans were done through the use of AirMagnet Survey software interfaced with an 802.11a/b/g radio card and a GPS. The software automatically recorded the SSID (Service Set Identifier), RF channel setting, signal strength and noise levels of wireless LAN access points while the test team drove throughout the entire test area in approximately 1 to 1.5 mile increments. This provides a sample of the wireless LANs active within the test area.

Refer to Appendix C for images that depict the routes driven throughout the test area and maps indicating average noise and access point signal amplitudes.

RF Spectrum Observations

The existing signals shown in the spectrum images and wireless LAN scans in Appendix B and Appendix C, respectively, will offer a limited level of noise to a municipal Wi-Fi network. These existing signals are emanating from wireless LANs and radio equipment currently operating throughout the City.

The average noise levels are below -90dBm throughout most of the test area in the 2.4-2.5GHz and 5.0-6.0GHz bands (refer to Appendix C, Figure C-3). This consistent average noise does not pose significant potential problems to the use of these frequencies for supporting mesh nodes within the City. It's comparable to other cities successfully implementing citywide Wi-Fi networks.

There are existing signals indicated in the spectrum scans in the 2.4-2.5GHz band at that will require careful design to avoid the impacts of RF interference and optimize the performance of a city-wide Wi-Fi network. The max signal levels in the 2.4-2.5GHz frequencies are moderately high (above -80dBm) in parts of the band at some locations, such as locations 2 and 6 in the overall area, locations 1, 2, 3, 4, 7, 8, and 10 in the northeast residential area, and locations 2, 7, 6, 13, 14, 15 and 16 in the Alameda/Union residential area (depicted in Appendix B). These signals are likely emanating from existing Wi-Fi access points and other radio equipment. In most cases, it will be possible, though, to tune the mesh nodes of the citywide Wi-Fi network in the applicable locations to frequencies that will significantly reduce the interference.

Despite the presence of these existing signals, the proper design and deployment of the network should allow effective operation of the system.

The wireless LAN scans shown in Appendix C indicate that there are numerous wireless LANs operating throughout the test area. The AirMagnet Survey software captured approximately 1,590 wireless LAN access points as the test team drove along the test route shown in Appendix C, Figure C-1. This constitutes a sample of the total number of existing wireless LANs based on the drive route taken by the test team.

Even though there are many wireless LAN access points currently operating within the City, the signal levels from these existing networks are relatively low when measured outdoors, where the citywide network will be operating. The vast majority of these existing wireless LANs are installed inside buildings, which attenuate the signals as they propagate outside to levels that will likely have minimal impacts on the citywide network.

As shown in Appendix C, the signal strength of the existing 802.11b/g wireless LAN access points (measured outdoors) is mostly between -85dBm and -60dBm. The largest percentage (42 percent) of the existing access points are operating on channel 6, the common default channel. By setting the citywide Wi-Fi mesh nodes to non-overlapping channels in relation to channel 6 (such as channel 1 or channel 11), the majority of the interference from existing access points can be avoided. Only 0.19 percent of the access points found by the AirMagnet Survey software were 802.11a access points operating in the 5GHz bands. Thus, the impact of existing 802.11a access points is insignificant.

RF Spectrum Recommendations

- **SNR Values.** The SNR (signal-to-noise ratio) in all areas of the citywide Wi-Fi network should be at least 15dB SNR to enable stable connections. In addition, signal levels of the Wi-Fi network should be high enough in all areas to provide required data rates as indicated in the technical specifications of the client radio cards that the City decides to support. If the wireless network will be supporting voice applications, then the SNR will likely need to be higher based on the specifications of the supported wireless voice handsets. For example, Cisco recommends a minimum of 25dB SNR for the Cisco 7920 Wireless IP Phone. The installation of the network should adhere to these values to ensure that existing noise levels doesn't limit range and performance of the municipal wireless network. In addition, it's important to understand that these minimum SNR values must be present at the location of the wireless user device and the mesh node to ensure effective two-way communications.
- **Back Haul Frequencies.** In order to reduce RF interference between backhaul and existing systems operating in the 2.4-2.5GHz band, the backhaul frequencies should be in the 5.0-6.0GHz band. This avoids excessive retransmissions and potential lower performance that may occur in the 2.4-2.5GHz bands.
- **Client Access Frequencies.** As mentioned before, many (42 percent) of the existing wireless LANs operating in the 2.4-2.5GHz band are set to channel 6. As a result, the mesh nodes of the citywide Wi-Fi network should be set to channels that don't conflict with channel 6 (such as channel 1 or channel 11).
- **Dynamic RF Channel Selection.** The continual proliferation of wireless LANs and other radio frequency equipment throughout the City will introduce additional sources of potential interference in the future. As a result, the use of access points or mesh nodes that dynamically choose the least congested channel may improve the performance of a city Wi-Fi network. Keep in mind that static channels should be chosen, however, if the wireless network will be supporting wireless voice applications. Most Wi-Fi phone specifications recommend using static channels to avoid excessive handset roaming and resulting dropped calls.

Mounting Asset Analysis

This section of the report discusses observations and recommendations regarding potential mounting assets for mounting wireless mesh nodes, gateways, and backhaul devices that will comprise a municipal Wi-Fi wireless network throughout Boulder.

Mounting Asset Data

Lakewood Public Works, in collaboration with the City's enterprise Geographic Information System (GIS), provided a detailed electronic City map indicating the location of street light and traffic light poles, which are primary mounting assets. General observations were made regarding potential mounting assets while the test team drove throughout the City area.

Mounting Asset Observations

In some parts of Lakewood, especially the commercial areas, there are sufficient traffic light poles and city-owned buildings for installing mesh nodes and backhaul equipment. This is indicated on the mounting asset maps provided by the City. These mounting assets alone, however, will not provide enough mounting points for mesh nodes in order to facilitate city-wide signal coverage. The use of street light poles will be necessary, especially within residential areas, in order to provide full coverage.

Lakewood has two primary types of light poles. One type of light pole found on nearly all main streets and thoroughfares in Lakewood are the light poles having a horizontal arm. These are conventional light poles found in most other cities. There should be no problems installing mesh nodes on these types of poles. Lakewood also has non-conventional vertical light poles, which are found on many of the interior residential streets. The light pole shown in Figure 1 is characteristic of this type of light pole. At this time it's not known whether these poles will meet the weight and electrical power requirements of mesh nodes. In addition, these poles appear to be of a decorative type, and Lakewood may encounter resistance from neighborhoods if installing mesh nodes on these poles.



Figure 1. Non-Conventional Light Poles

A line-of-sight (LOS) path will likely not exist between most mesh node / gateway installation locations (i.e., traffic light poles and light poles) and potential city-owned locations providing the system headend. The city-owned buildings are too low to provide LOS conditions for backhaul communications. As a

result, it may be necessary to erect a tower on top of one of the city-owned buildings located near the center of the City in order to make LOS communications possible.

Traffic Light Poles

NOTE: The majority of Light Poles are currently owned and operated by Xcel Energy. There are numerous traffic light poles on the primary streets throughout the City for use as mounting assets for wireless mesh nodes and gateways. These should be used as much as possible because they allow mounting of the nodes near the center of the street, which is ideal for maximum propagation.

Water Towers

NOTE: There are several water towers in the City. If needed, these towers could be used as relay points for backhaul. This assumes that electrical power is available near the top of the water towers and that access is granted by the owner (such as Rocky Mountain College of Art and Design or water districts).

Mounting Asset Recommendations

The following are mounting asset recommendations for deploying a municipal Wi-Fi wireless network throughout the City:

- **Mesh node installation locations.** The City should mount mesh nodes on the arm of light poles and traffic light poles, with the node as close to the center of the road as possible rather than along the side of the road. This generally maximizes signal propagation. The mounting assets should be clear of trees if possible. In addition, mesh nodes should be installed on mounting assets that are located ideally at street intersections. This makes best use of the mesh node for covering larger areas. If only straight poles (no arms) are available, then it's best to stagger installation of the nodes on poles along both sides of the street. It's important to not use mounting assets for wireless mesh nodes that are higher than the structures surrounding them. This avoids existing wireless LAN signals and RF noise from impacting the operation of the node and the users it supports.
- **Gateway/backhaul installation locations.** The location of gateways and backhaul components should be installed on mounting assets offering unobstructed line of sight with the headend or a relay point. The City has access to several sites, but the buildings are relatively low. It may be necessary to erect a tower on top of a centralized building in order to make LOS communications possible with the head-end of the system.