Wireless Local Area Network Planning: An Overview

Sam Bartels
WAND Network Research Group
Computer Science Department
University of Waikato
sjb48@cs.waikato.ac.nz

Murray Pearson
WAND Network Research Group
Computer Science Department
University of Waikato
mpearson@cs.waikato.ac.nz

ABSTRACT

When planning a wireless local area network, there are design issues that need to be considered. In this paper, the fundamentals of planning a wireless local area network are introduced and discussed to highlight the requirements involved. Network constraints, as encountered in the physical environment, are discussed and their relevance to wireless network design is investigated. The paper concludes with an overview of wireless network planning solutions including commercial and free software, and an introduction to the author's research.

Categories and Subject Descriptors

C.2.3.a [**Computer Systems Organisation**]: Network Operations—*Network management*; C.4.a [**Computer Systems Organisation**]: Performance of Systems—*Design studies*; C.2.1.k [**Computer Systems Organisation**]: Network Design—*Wireless*

Keywords

wireless, network, planning, constraints

1. INTRODUCTION

This paper will introduce the concept of planning a wireless local area network and give an overview of the steps involved. The fundamentals of wireless local area network planning will be introduced and their relevance will be discussed. There will be a large focus on the physical environment of the network, as the physical environment dictates the layout and behaviour of the resulting network. Node placement will not be discussed, but this paper will highlight the importance of placement with respect to an optimal network.

Some may argue that in many cases, nodes could be placed anywhere and simply be set to full transmission power, thus creating an operational wireless network. However the network would most likely be of an inefficient design, as power usage and interference would be significant. Requirements of good network design are discussed in section 2. The paper will then briefly discuss some of the current network planning solutions available, and introduce the author's research. The paper then concludes with a summary of the key ideas presented.

NZCSRSC 2008, April 2008, Christchurch, New Zealand.

2. NETWORK REQUIREMENTS

Gast[10] states that when planning a wireless network, "end user requirements and information [must be gathered] to find out which expectations are important". Without this consideration, unexpected behaviour could seriously hinder the performance of the network, possibly to such a point that the network ceases to operate. When considered, the 'unexpected behaviour' is usually revealed to be some form of interference or a property of radio wave propagation. Gast lists some of the requirement gathering necessary for planning an IEEE 802.11[12] network. Though some of these requirements will obviously be IEEE 802.11 specific, the following are generic enough to be applied to any network.

It is essential that the characteristics of the network applications are defined, as they will have a direct bearing on the other network requirements. For example, a wireless network providing internet access to students at a university is very different to a wireless sensor network and these differences need to be considered. In networks where access points are required for delivering wireless connectivity, coverage is an important requirement. Networks typically want to maximize their coverage, but poor planning in this regard can lead to problems such as interference.

Throughput is highly dependant on the application; there are two fundamental factors, reliability and bit rate. For a particular bit rate to be reliable, the signal level must be higher than the noise level in order for the radio to decode the data. This relationship is known as the signal to noise ratio (SNR). As bit rates increase, the SNR needs to increase also, otherwise the radio can no longer decode the data. This becomes a problem in longer links, as noise is relatively constant, and signal decreases with distance. The solution is either to increase the transmission power of long-link nodes, or limit them to lower bit rates.

Mobility is important when movement of users is expected. Users should be able to transition from one access point to another with minimal overhead, such that the delay of transition is not noticed by the user. User population needs to be considered and preliminary research should be engaged to determine user densities. There are often areas of high density, such as an airport for example. The network should be designed such that if the user population increases, the network can be extended or upgraded easily to deal with the increase in users.

The operating frequency of terrestrial, high-speed data networks is typically 400 MHz to 6 GHz, but this may not always be the case. The selection of what frequency to use can have a direct impact on power usage and transmission loss. Temperature and humidity have minor effects [10] but these effects are specific to 2.4 GHz. Other frequencies may be more susceptible to climatic conditions. The number of channels available at the chosen frequency can also have an effect on interference in the network - the less channels available, the higher the probability of interference. For example, IEEE 802.11b/g only has three channels that do not overlap one another. Vaughan and Anderson[13] state that "frequency choice and power levels cannot be used indiscriminately and, in nearly all countries, users have laws to follow and a spectrum policing organisation to enforce the laws". The International Telecommunication Union (ITU)[4] is the union of such policing organisations, and is responsible for producing the international recommendations that the policing organisations use to determine what frequencies can and cannot be used by the general public, as well as setting limits on transmission power.

Power supply is another issue that should be considered. In situations where mains power is available, there is generally no problem. However, when located in remote areas, power becomes an issue. Often the best solution is solar power, but there may be situations where this is not viable, and large backup batteries may be needed. The choice of power supply will be dictated by the application characteristics and the site environment (such as proximity to mains power).

Connectivity of the network is an important issue, as without connectivity a network is not possible. The network must be connected in such a way that each node can reach every other node, whether directly or via other nodes. These connections are typically wireless, but there is no reason why they cannot be wired, such as multiple wireless networks connected via a wired backbone. Some networks can be fully connected, such that each node has a direct link to every other node but this is inefficient and rarely necessary.

Redundancy is required when reliability is important. In a network with no redundancy, the failure of a single node can partition the network and sever communication. In the worst case, the failed node might be the Internet gateway, and the network would lose all Internet communication. This situation needs to evaluated with respect to the application, as this will have varying consequences depending on what is expected of the network. Redundancy can be introduced by creating loops in the network and having at least two Internet gateway nodes.

Finally the site environment needs to considered; this involves all physical objects in the environment, which will be referred to as constraints from this point forward. Constraints include objects such as buildings, roads, rivers and trees. All constraints have some effect on the planning of wireless networks. Some effects are minor and can be ignored, but others will have a pronounced influence on the network design. These issues will be discussed in section 3.

3. IDENTIFYING CONSTRAINTS

Constraints are physical objects in the site environment - in fact, the site environment is simply a collection of these constraints. These constraints are often referred to as clutter in the geographical community. Terrain is the primary constraint to be considered, usually in terms of height but slope, structure and composition can also be useful in various situations. Vegetation and water bodies such as streams, rivers and lakes are also constraints. When human input is considered, constraints such as roads, power transmission lines and buildings can be identified to name a few. Each of the named constraints is only a category, as each category can be further redefined. For example terrain can be further explored to reveal plains, hills, valleys and mountains. Each constraint will have its own unique effect on the planning of wireless networks, both in terms of node placement and radio wave propagation.

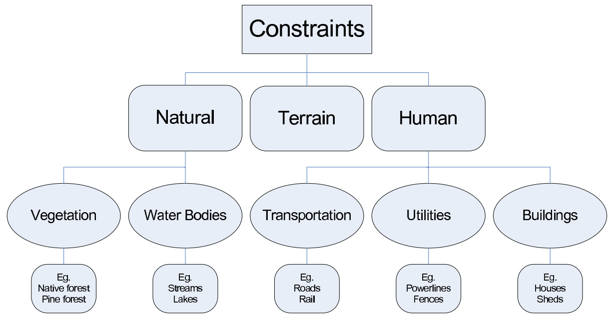

Figure 1: An example of constraint categories.

Anderson and Kirtner[8] point out that "unless you have calculations or measurements that demonstrate a statistically significant difference in terms of their relative impact on radio signals, having the additional [redefined] categories does not provide more accurate signal predictions". For example, there is no point separating trees in to various sub-categories unless there is a proven statistical difference in the way they affect radio wave propagation. Identification of these constraints is typically simple when at the site in question, but when working from aerial photos and maps identification can be more difficult. Even if constraints can be identified, the scale of the photos or maps is important. Macroscopic constraints are features that exceed the scale of the map or photo. For example, if the map has a scale of 100m, an area of forest 300x300m would be shown on the map and hence could be identified as a constraint. Microscopic constraints are features that are smaller than the scale of the map or photo, and therefore would not be present. This raises the importance of having highly accurate maps and photos of the area, or conducting a thorough site visit.

The effects that constraints have on node placement are fairly obvious; either nodes can be placed in or on the constraint, or they can not. However this can also depend on the node itself. For example, a typical node could not be placed in a stream, but if sufficient precautions were taken it might be possible, and even desirable, that the node is placed in the stream. The stability of the constraint may also affect whether or not a node can be placed there; again additional precautions could be taken if necessary. Node placement is also dependant on the application, and will dictate what the cost factor will be for various constraints, and what addition costs are required if precautions are necessary.

Constraint effects on radio wave propagation are not so obvious. There are three types of interaction that can occur when a radio wave encounters a constraint - reflection, diffraction and refraction[9]. The unique properties of the constraint determine which the proportion of each interactions take place, as more than one interaction will normally occur. These interactions depend on properties such as the size, shape and texture. Reflection occurs when the radio wave is reflected off the constraint; this is usually referred to as scattering, which is diffuse reflection as opposed to specular reflection.

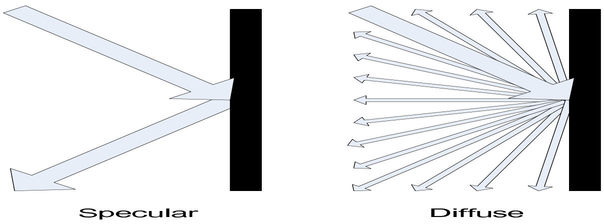

Figure 2: An example of specular and diffuse reflection.

Another interaction that can occur is diffraction, which is when the constraint causes the bending or spreading of the radio wave. Refraction is when the radio wave experiences a change in velocity while passing through the constraint, resulting in a change of direction. These interactions can have positive and negative connotations. For example, a positive effect is that radio waves can be diffracted over hills and buildings when line of sight is not present. Together, these interactions lead to the phenomena known as multipath.

Multipath occurs when the radio signals traverse two or more paths to the receiving antenna. Multiple paths are a result of constraint interaction such as reflection and refraction. Since multiple signals are being received simultaneously, constructive or deconstructive interference can occur. Constructive interference is when the signals are in phase, hence amplifying the signal power. However if the signals are out of phase, then the signal power is attenuated and deconstructive interference has taken place. Deconstructive interference is commonly known as fading.

4. CURRENT SOLUTIONS

There are several network planning solutions available of varying complexity. We briefly discuss six proprietary solutions, four of which are commercially available and two which are free software.

4.1 Commercial software

EDX Signal Pro[2] is a wireless network engineering tool that provides coverage, point-to-point and route analysis. It supports frequencies of 30MHz to 60 GHz and over 20 published propagation models. Full point-to-point analysis including path profile and cross-link interference modelling is possible, and a module for multipoint analysis is also present. The coverage module provides a comprehensive selection of tools such as line of sight, path loss, received power and bit error rate (BER) analysis. Geographic Information System (GIS) layers can be added, including the manual addition of trees, buildings or terrain elevation modifications.

EDX SignalMX[2] is a network design application for designing mesh and WiFi networks, and can be used standalone or as an add-on with Signal Pro. It incorporates intelligent scale design using area studies and mesh link analysis, and supports multiple ways for initial node layout. These include options such as automatic mesh layout using defined spacing recommendations, and site location import via Microsoft Excel. SignalMX can analyse mesh layouts using an area study with a recommended propagation model. Based on initial coverage analysis, coverage holes can then be filled by adding new sites. Mesh link analysis includes point-to-point path loss, received signal strength prediction and hop count to nearest backhaul point. Link details can then be examined and the designer can then identify and resolve problematic sites.

Forsk Atoll[3] is a scalable and flexible multi-technology network design platform, that can be used from initial design of the network through to densification and optimisation. Support is provided for multi-format/multi-resolution geographical databases and GIS data such as digital elevation models (DEMs) and clutter data. Atoll supports a large range of technologies, such as GSM, GPRS, CDMA and WiMAX. An SDK is provided, which allows external modules to be created and used, particularly with propagation models. The microwave module for Atoll adds extra analysis tools such as fresnel zone clearance and automatic antenna height optimisation.

Pathloss[5] is a comprehensive path design tool for radio links that supports frequencies from 30 MHz to 100 GHz. It provides eight path design modules, an area signal coverage module and a network module which integrates the previous modules. Structures such as trees and buildings can be added as single structures or a range of structures to enhance clutter data. The antenna heights module provides the capability for determining path clearance with set criteria, and allows for custom antenna definition. Pathloss also has a coverage module and a reliability module that includes multipath and worst month analysis.

ComsiteDesign[1] is a wireless network engineering software tool, designed to have maximised compatibility with Microsoft Office. It supports frequencies of 40 MHz to 40 GHz and provides a microwave point-to-point module. Propagation models and characteristics can be assigned to each site and antenna, including the Longley-Rice and Okumura-Hata propagation models. ComsiteDesign has a path profile viewer with terrain and clutter displays, as well as sector-based propagation modelling and an antenna height optimiser. Shapefiles and other geospatial data are supported, and ComsiteDesign is compatible with ESRI ArcView. Comsite Design is used by the U.S. Border Patrol and the Commonwealth of Australia.

4.2 Free software

There are two freeware network analysis tools that have briefly been evaluated - Radio Mobile[6], and SPLAT![7]. Radio Mobile is a free windows design tool for amateur radio users, whereas SPLAT! runs on Linux and is open-source. Both utilities support fresnel zone plotting and can predict received signal strength based on transmit power, path loss and transmitter antenna radiation pattern. They also use the Longley-Rice Irregular Terrain Model for determining path loss, using Space Shuttle STS-99 Radar Topography Mission elevation data, and can support a large range of frequencies. KML output is also possible, allowing for network and coverage maps to be viewed in Google Earth. SPLAT! is also capable of predicting minimum antenna height for determining line-of sight clearance. It is important to note that both tools are for analysis, it is still up to the user to design the actual network.

4.3 Summary of current solutions

Most of the current solutions discussed in this section support the same set of features. A large range of frequencies is supported and a number of different propagation models are available. Most allow clutter data to be imported and the use of geographical data layers. A large range of technologies is supported, mainly being cellular such as GSM and CDMA. Some include the capability of determining antenna heights for optimal path clearance. A significant issue is whether or not these software solutions can be used by someone that is not an engineer. This is difficult to tell without trialling the software itself.

5. FUTURE RESEARCH

The author of this paper is investigating how a cost-optimised algorithm can be developed for wireless network design in rural environments. The algorithm will focus on node placement and link establishment, taking in to account the physical environment and radio wave propagation. Operations research techniques are currently being explored, such as the concept of linear programming[11]. A significant aim of this research would be to develop a design framework for planning wireless networks that are low-cost and energy-efficient. Another aim would be simplicity of use and to be open-source. It would be useful to support as many of the features discussed in Section 4 as possible, but with a focus on wireless local area networks. Thus, only a small set of technologies and frequencies will need to be supported. As part of this research, experiments will be undertaken to determine the variance of path loss through different mediums. The results of these experiments will be used to create formulas for use in designing wireless local area networks.

6. SUMMARY

This paper has introduced the requirements involved in planning a wireless network and the considerations that need to be made. The importance of identifying constraints has been highlighted with respect to optimal network design. Properties of radio waves were discussed to raise the relevance of these constraints when planning a wireless network, and reinforces the argument of Anderson and Kirtner[8]. Software solutions were discussed briefly to identify the current state of network planning. Finally, future research to be undertaken by the author was introduced.

7. REFERENCES

[1] Comsitedesign. http://www.rcc.com/products/comsitedesign/index.asp, 2007.

[2] Edx. http://www.edx.com, 2007.

[3] Forsk atoll. http://www.forsk.com, 2007.

[4] International telecommunication union. http://www.itu.int, 2007.

[5] Pathloss. http://www.pathloss.com, 2007.

[6] Radio mobile. http://www.cplus.org/rmw/english1.html, 2007.

[7] Splat! http://www.qsl.net/kd2bd/splat.html, 2007.

[8] H. R. Anderson and J. L. Kirtner. Clutter data assists system design.

[9] L. Barclay, editor. *Propagation of Radiowaves, 2nd Edition*. The Institution of Electrical Engineers, 2003.

[10] M. S. Gast. *802.11 Wireless Networks: The Definitive Guide*. O'Reilly and Associates, Inc, 2002.

[11] A. A. L. Geraldo R. Mateus and R. C. Rodrigues. Optimal network design for wireless local area network.

[12] IEEE. *IEEE STD 802.11*, part 11: wireless lan medium access control (mac) and physical layer (phy) specifications edition, 1999.

[13] R. Vaughan and J. B. Anderson. *Channels, Propagation and Antennas for Mobile Communications*. The Institution of Electrical Engineers, 2003.