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Location of Access Points in Wireless Local Area Networking

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Abstract

A model is presented for finding the most effective location of Access Points to create a Wireless Local Area Network (WLAN). WLANs have a number of advantages over traditional wired Local Area Networks, including enabling user mobility and having reduced wiring costs. Wireless Local Area Network deployment also brings with it a different set of decisions than faced when implementing wired Local Area Networks. With wired Local Area Networks, the topology, or geographic layout of links between terminals and concentrators, is a critical design issue. Wireless Local Area Networks, not having physical links between user devices and access points, must consider the coverage area of the radio signals used and ensure that all users are able to communicate with an access point from the locations that are identified as their coverage area. Computational experiments that evaluate a number of factors affecting feasibility and performance of Wireless Local Area Networks are conducted.

Keywords: Wireless technologies, communications infrastructure, location, planning

Introduction

Wireless communication has a number of advantages over wired communications, including user mobility and reduced wiring costs. These advantages lead to several important results for business organizations. Communication is enabled in circumstances where a fixed infrastructure is too expensive (Stallings 2002). Flexibility of communication is also enabled, so people can access information in places that they previously could not. This is very conducive for ad hoc meetings with business colleagues, with the increased usage of mobile devices that can be used to access information on organization servers.

The number of organizations establishing wireless communications has increased rapidly within the last several years due to the standardization of 2.4 GHz radio technology. The Institute of Electrical and Electronics Engineer's (IEEE) published the 802.11b Wireless Local Area Network (WLAN) standard in 1999. This standard supports data rates of 11 Mbps in the 2.4 GHz frequency range. Another important factor leading to the adoption and use of WLANs has been the formation of the Wireless Ethernet Compatibility Alliance (WECA) by major vendors of WLAN equipment, to ensure compatibility and interoperability of WLAN technologies.

WLAN devices conforming to the IEEE 802 standards have a number of limitations. Wireless access points (APs), also referred to as base stations, which are the radio transmitters and receivers used for wireless communication, only communicate in a finite range. Typical manufacturer's 2.4-Ghz indoor range specifications are between 30 meters (100 feet) and 90 meters (280 feet) (Trulove 2002). The maximum range of the signal is higher for outdoor ranges, but the indoor range is limited due to walls, windows and floors within buildings. In addition to the distance limitation, wireless access points can only support a limited number of users. In most environments, a single 802.11b channel can support 30 to 50 users (Molta 2001). Another limitation presented by WLAN devices is that there is a limit to the number of devices that can overlap, or operate concurrently in the same location. Specifically, the 802.11b specification has a limit of 3 overlapping access points in a covered area. If more than three access points overlap in a given area, they will interfere with each other's operation.

Due to these limitations, decisions regarding the implementation of WLAN infrastructure must take into consideration both the ability of an access point to cover, or reach, specific locations and its capacity to support users in the locations that it covers. In implementing WLANs site surveys are conducted to help determine the best location for access points and determine the boundaries of coverage areas, or cells (Ciampa 2001). These site surveys can be costly since trained professionals require many hours or days to conduct the surveys. When more than one access point is used, more complex decisions arise due to limitations in the number of overlapping cells permitted and determining which access point covers which users. If these decisions are not made correctly, the capability of WLANs to function properly will be affected.

This research effort focuses on WLAN technology infrastructure decisions and develops a model that can be used to determine the lowest cost solution that supports all specified users. In addition to the overall cost of the solution, the model directly determines the location and number of access devices as well as the users that will be supported by each access point, taking into consideration the capacity and technology specific limitations of each access point. Computational analysis is conducted to better understand the affect that the technology limitations have upon feasible decisions. While the need still exists for site surveys to be performed, the use of this model can help focus these efforts and at least somewhat reduce the time and cost of performing the required site surveys.

There has been several research papers recently published that specifically addresses the placement of access points in wireless indoor communications networks. Frühwirth and Brisset (2000) develop a prototype that determines the placement of base stations given a blueprint of the installation site and information about the wall and ceiling materials. Branch and Bound was used to determine the minimum number of base stations and their locations. One limitation of their research is that the number of users or capacity supported by each access device was not considered. In a different study, Mateus, et.al. (2001) developed a location model for WLAN design which included a base station location problem and channel assignment to reduce signal interference. Their model assumed a given number of base stations and did not consider user density, allowing for the possibility of network throughput degradation and stating that they only had a few mobile users in their pilot study.

The modeling approach used in this research problem is based on research in facility location problems, specifically set covering location models. The objective of set covering location models is to locate the minimum number of facilities required to "cover" all of the demand nodes (Current, Daskin and Schilling 2002). There are several unique characteristics to this problem. First, there is no variable cost incurred based on which AP each user is connected to, since there are no “links” as there are in wire-based networks. Secondly, there is a capacity to each AP. Thirdly, there is a limitation in the number of APs that can overlap.

The rest of this paper is organized as follows. The next section describes the formulation of the WLAN infrastructure decision model. The following section discusses assumptions made in generating test problems and summarizes preliminary computational results.

The Model

The mathematical model for use in supporting wireless LAN infrastructure decisions is now presented. A number of assumptions are made in this model, including a predefined set of locations for wireless access points, and locations of users. The following notation is used in the mathematical model:

Table 1. Notation Used in Mathematical Model

Variable	Description
I	The set of possible locations considered for placing access devices.
J	The set of user locations.
y_i, i=1,..,I	Decision variable y_i=1 if an access point is located in location i, 0 otherwise.
f_i, i=1,..,I	The fixed cost for locating a wireless access device in location i.
x_{ij}, i=1,..,I, j=1,..,J	Decision variable x_{ij}=1 if access device at location i is used to enable users at location j access to the LAN, 0 otherwise
S_j, j=1,..,J	The set of all access devices that can provide access to users at location j.
m	The maximum number of access devices that can operate (overlap) in a give location.
p	The prescribed number of users that can be supported by each access device.

Using this notation, the WLAN infrastructure decision model is formulated as:

$$\text{Min} \quad \sum_{i \in I} f_i y_i \tag{1}$$

$$\text{s.t.} \quad \sum_{j} x_{ij} \leq p y_i \qquad \forall i \in I \tag{2}$$

$$\sum_{i \in S_j} x_{ij} \geq 1 \qquad \forall j \in J \tag{3}$$

$$\sum_{i \in S_j} y_i \leq m \qquad \forall j \in J \tag{4}$$

$$y_i \in \{0,1\} \qquad \forall i \in I \tag{5}$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in I, \forall j \in J \tag{6}$$

Figure 1. WLAN Infrastructure Decision Model

The objective function of the model (1) is to minimize the cost of placing access devices. Constraints (2) require that the total number of users assigned to each access device is less than or equal to the prescribed number of users that the access device can support. Constraints (3) require all users to be assigned to at least one access device. Constraints (4) limit the number of access devices covering a specific user to the maximum number allowed by the technology in use. This is an innovated model characteristic, as it utilizes the set of all access devices that can provide coverage to a given location and limits the number to the maximum allowed. Constraints (5) and (6) restrict the variables to values of 0 or 1. It should be noted that even though the objective function of this model is to minimize the cost of the access devices selected, the true purpose of the model is to identify solutions that support all users.

Computational Results

In order to evaluate the wireless LAN infrastructure model presented in the previous section, test problems were randomly generated in the following manner. An area of 1000 feet by 1000 feet was considered, with users' locations being randomly assigned within that area. Once all user locations were generated, an initial set of access points was assigned based on the minimum number of access points for the problem. This minimal number was determined based on both number of users and the area to be covered. These access points were then uniformly distributed across the coverage area, ensuring that every user in the entire area would be covered by at least one access point. Since this number of access points is not necessarily feasible depending on the distribution of users, additional access points were randomly assigned to enable overlapping coverage.

Costs were randomly generated for each access point by assuming a base cost of $500 per access point and then a randomly generated cost between $0 and $1000 for placing access points in the specified location. This cost would vary in practice due to additional electrical wiring and wiring connections between the access point and other network devices. Four different problem types were examined, corresponding to either 100 users or 300 users and access point coverage radii of either 100 feet or 300 feet. Using the coverage radius value, the set of covering access points was generated for each user. (It should be noted that in practice, the radius changes due to obstructions such as building walls. This site survey would give detailed information about which locations would be covered by which access points, and the model is designed to use that detailed information in its calculations.) The number of users to each access point was limited to 30 based on the cited range of users to access points discussed in the introduction. Five problems were generated for each of these combinations and the exact solutions for each problem was obtained using the software package CPLEX (run on a 350 MHz computer with Windows NT operating system). The preliminary computational results are presented in the following table with solution values reported being the average of the five problems for each combination.

Table 2. Preliminary Computational Results

Problem Characteristics			**Solution Characteristics**		
Users	AP Radius (ft)	Users to AP	APs in Solution	Cost ($)	CPU (Sec)
100	100	30	32.4	38,603	0.5
100	300	30	7	9,807	0.5
300	100	30	45	56,513	1.7
300	300	30	11[a]	14,806	4.3

Only one of the five problems had a feasible solution.

It can be observed from these preliminary results that when the coverage range of the access point changes from 100 feet to 300 feet, the number of access points required is reduced from 32.4 to 7 when there are 100 users and from 45 to 11 when there are 300 users. Given the cost assumptions made, this translates to a significant cost reduction. Keeping the access point coverage range the same, when going from 100 users to 300 users, the number of access points increases from 32.4 to 45 for AP coverage radius 100 feet and from 7 to 11 for AP coverage radius 300 feet. Of specific interest is the fact that only 1 of the 5 problems had a feasible solution when the AP radius was 300 feet and the number of users was 300. When a problem does not have a feasible solution, it means that not all users can be covered by the set of access points considered. This indicates the potential for performance problems and need for additional consideration with a higher density of users. Specific implications of these findings are that as there is an increase in the number of mobile users within an organization or location, more complex designs using multiple types of access points or access point coverage areas will be required. This illustrates a limitation of the current model, which only considers one type of access point at a time.

Conclusion

This paper had presented a model for finding the most effective location of access points to create a Wireless Local Area Network (WLAN). This model supports decision makers who must consider the effects of the coverage area of the radio signals used and ensure that all users are able to communicate with an access point from the locations that are identified as their coverage area. In small, lightly used WLANs, current design and planning efforts utilize site surveys to determine the best location for the access point and to determine the boundaries of the coverage area created. This research addresses a more comprehensive problem that occurs when multiple access points are used. The simultaneous consideration of all coverage areas used must be done in order to ensure that each area doesn't interfere with other areas (resulting in interference and ultimately an infeasible situation), while ensuring that the communication support of all mobile users are accommodated by an access point. Computational experiments were conducted that evaluate a number of factors affecting both the performance and feasibility of Wireless Local Area Networks. The results indicate higher costs and greater number of access points are needed when the coverage area of each access point is smaller. While cost alone would indicate that larger coverage areas should be used when there are more users, this is no longer a feasible option. Extensions of this research will study problems with even higher user density, as well as the simultaneous consideration of multiple types of access points. Extensions to computational studies will incorporate limitations to coverage areas due to doors, walls, and other obstructions.

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