Optimization of AP Placement and Channel Assignment in Wireless LANs

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Abstract—**The design of a wireless local area network (WLAN) has an important issue of determining the optimal placement of access points (APs) and assignment of channels to them. WLAN services in the outdoor as well as indoor environments should be designed in order to achieve the maximum coverage and throughput. To provide the maximum coverage for WLAN service areas, APs should be installed such that the sum of signal measured at each traffic demand point is maximized. However, as users connected to an AP share wireless channel bandwidth with others in the same AP, AP placement should be carefully decided to maximize the throughput by considering load balancing among APs and channel interference for the user traffic demand. In this paper, therefore, we propose an approach of optimizing AP placement and channel assignment in WLANs by formulating an optimal integer linear programming (ILP) problem. The optimization objective is to minimize the maximum of channel utilization, which qualitatively represents congestion at the hot spot in WLAN service areas. It is seen from the simulation results that the proposed method finds the optimal AP placement and channels which minimize the maximum of channel utilization.**

Index Terms—**Network Design, WLAN, IEEE 802.11b, load balancing, ILP, Optimization**

I. INTRODUCTION

Although the WLAN [1] is designed to provide LAN connections to the area where the premises wiring systems are not available for the conventional wired LAN service, it begins to support mobile computers throughout a building or a campus. In general, WLANs operate in the unlicensed industrial, scientific, and medical (ISM) bands at 915 MHz, 2.4 GHz, and 5 GHz. The first version of WLAN specification, IEEE 802.11, provides only up to 2 Mbps, which allows direct sequence or frequency-hopping spread spectrum to be used in 2.4 GHz or operation at the infrared frequencies. However, the IEEE 802.11b standard has emerged to provide high rate WLAN service up to 11 Mbps in 2.4 GHz, which uses the modified version of IEEE 802.11 direct sequence spread spectrum. Recently, a new version of high rate WLAN standard, IEEE 802.11a, can provide up to 54 Mbps at the 5 GHz UNII band. WLANs consists of mobile computers with network adapters (NAs) and access points (APs) which are connected to high speed wired LANs. While WLANs have been considered to be used in the indoor environment such as in a building, their usage has been extended to the Internet access service in the outdoor environment like within a campus or on the street.

In designing WLAN services, the most important problem is to determine where APs should be located so that the coverage and the throughput of the service area are maximized. Therefore, the WLAN service design process will be composed of following steps.

1) Estimation of the demand area map: The WLAN service area will be given to Internet Service Providers (ISPs) according to user demand. Then, ISPs should draw the complete map of the service area by investigating the physical space with walls or barriers. The service area map will be divided into smaller demand points where signal is measured from APs and the number of users or traffic demand is estimated. For example, the demand point can be a small square unit of $1 \times 1\ m^2$.
2) Selection of candidate locations for APs: As the physical location of APs may be restricted to particular areas because of the connection to the wired LAN, the power supply, and the installation and administration costs, ISPs will select the candidate locations to APs.
3) Signal measurement at the demand point in the service area: In order to provide the maximum coverage and throughput, signal measured or estimated at each demand point should be greater than the threshold with which the minimum rate is guaranteed. For example, in IEEE 802.11b, the automatic rate fallback (ARF) function will provide several kinds of rates such as 1/2/5.5/11 Mbps according to the distance between APs and mobile computers. In addition, as the barrier to the wave will change the power of the signal even if two demand points are located in the same distance to an AP, the signal measurement procedure is important to provide the maximum service coverage.
4) Decide APs without channel interference: In general, given the service areas and the signal measurement in-

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formation map, ISPs will decide the best locations of APs to meet user traffic demand and performance metrics in the minimum cost. In IEEE 802.11b, if one AP uses the same channel assigned to a neighboring AP, WLAN performance is significantly degraded due to the channel interference. Therefore, neighboring APs should use different channels with the minimum channel distance which is defined to avoid the channel interference. When deciding APs, usually, the optimization objective for the maximum WLAN service area is to maximize the sum of the signal throughout the demand points. However, the throughput of mobile hosts can be improved by placing APs appropriately according to user popularity and traffic demand.

5) Re-configuration of APs and channels with feedback information: After installation of APs, ISPs will collect the utilization statistics of APs and incoming/outgoing traffic flows per AP. Then, new APs may be installed at congested areas, or idle APs may be moved to other areas in order to enhance the WLAN service. In addition, channel assignment may be reconfigured to avoid interference.

Research on the AP placement and channel assignment in WLANs has only been recently studied, although there have been many studies on capacity planning in cellular networks [2]. The traditional coverage-oriented WLAN design method addresses only how to deliver the maximum signal to every WLAN service area. In [3], the coverage-oriented WLAN design problem has been formulated in ILP to maximize the sum of signals seen at each traffic demand point. The ILP problem formulation included the channel assignment problem with no channel interference. [4] explained the general WLAN design method in large-scale WLAN service areas. And, [5] proposed optimization algorithms to maximize both the coverage area and the overall signal quality.

However, when APs are installed in the WLAN service areas to support a lot of mobile hosts, not only coverage but also load balancing among APs should be considered, because the number of active hosts connected to APs will affect the WLAN network performance. For example, when each WLAN service area has a different population of mobile hosts, one AP to which a lot of mobile hosts are connected may be congested, whereas other neighboring APs are idle with no users. The basic IEEE 802.11b Medium Access mechanism is called Distributed Coordination Function (DCF), and is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. Thus, channel utilization of an AP represents the network performance in the WLAN service area. Bandwidth provided to each user will be decreased by the number of users contending the same medium of an AP [6]. This problem may frequently happen at WLAN service areas because of the dynamics of mobile hosts and users. Therefore, APs in WLANs should be installed to maximize the network performance such that the maximum throughput is provided to each user by distributing user requests to APs. In this paper, hence, we propose an optimization method of AP placement and channel assignment in WLANs in order to minimize the maximum of channel utilization.

The remainder of this paper is organized as follows. In section II the optimization problem formulation of AP placement and channel assignment in WLANs is explained. The results of the performance evaluation by simulation are discussed in section III. Section IV explains a reconfiguration method of APs, and section V concludes this paper.

II. AP PLACEMENT AND CHANNEL ASSIGNMENT PROBLEM

A. Assumptions

To simplify the problem, we assume the following conditions concerning traffic demand, WLAN service areas, and APs.

- A set of traffic demand points, N_d : Demand points in a WLAN service area are defined to measure the signal from the AP, or to estimate the amount of traffic demand or user popularity. For example, a square unit of $1 \times 1 m^2$ represents a traffic demand point.
- The average volume of traffic demand per demand point, T_i : At each demand point, traffic demand is given with the measured or estimated traffic volume per wireless host. Each demand point will be assigned to one AP.
- A set of AP candidate points, N_a : Candidates points where APs will be installed are given. For a given set of demand points, candidate AP location points are specified such that every demand point is connected to at least one AP. The maximum number of APs which can be installed at the same area will be three in IEEE 802.11b, when each AP uses non-overlapping channels.
- Signal matrix, $S = \{s_{ij}\}$: the Signal-to-Noise Ratio (SNR) value, s_{ij}, at demand point i from AP j is given.

Given the assumptions, we generate an AP assignment graph and a channel assignment one which will be used in the process of the ILP problem formulation.

- AP assignment graph, $G = (N, E)$
  - Nodes (N) consist of a set of demand points, N_d, and a set of candidate APs, N_a.
  - A link is connected between a point i and a candidate AP j if the signal from j to i (s_{ij}) is greater than a threshold.
- Channel assignment graph, $G_a = (N_a, E_a)$
  - Nodes consists of candidate APs, N_a.
  - A link exists between APs if APs are within a channel interference distance. Then, non-overlapped chan-

nels should be assigned to them to ensure that performance does not degrade.

An example of generating G and G_a is given in Fig. 1. The demand points and candidate AP location points are given as shown in Fig. 1-(a). By connecting each traffic demand point to candidate APs within signal distance, we generate an AP assignment graph G (Fig. 1-(b)). Also, a channel assignment graph, G_a (Fig. 1-(c)), is created by connecting APs within channel interference distance.

B. Problem Formulation

The problem of designing the WLAN service under different user densities at each area is to find the best location of APs with non-overlapped channels such that the available bandwidth at each WLAN service area as well as the coverage area are maximized.

In this subsection, we formulate the problem of minimizing the maximum of channel utilization of an AP, while satisfying the traffic demand.

Prior to the problem formulation, the following variables and constants are defined.

- x_{ij} : the binary variable, 1 if point i is assigned to AP j, otherwise 0.
- c_{ki} : the binary variable, 1 if channel k is assigned to AP i, otherwise 0.
- B_j : the maximum bandwidth provided by a channel of AP j (e.g., 11 Mbps in IEEE 802.11b). Although the capacity of a channel at an AP will be defined as a function of users and their connections [6], it is assumed, in this paper, that the constant bandwidth is provided by a channel of each AP to simplify the problem formulation.
- a_j : the binary variable, 1 if AP j is selected, otherwise 0.
- K : a set of available channels
- α : the maximum of channel utilization. This metric represents the maximum of traffic loads assigned to APs, which is the practical metric for the WLAN network performance, because it explains qualitatively congestion of WLAN service areas.

The ILP formulation of AP placement and channel assignment problem considering traffic demand is defined by extending the conventional topological design problems [7] as follows.

$$Minimize \quad \alpha \tag{1}$$

subject to

$$\sum_{j \in N_a} x_{ij} = 1, \quad \forall i \in N_d \tag{2}$$

$$\sum_{i \in N_d} T_i \cdot x_{ij} \leq \alpha \cdot B_j, \quad \forall j \in N_a \tag{3}$$

$$x_{ij} \leq a_j, \quad \forall i, j \tag{4}$$

$$a_j \leq \sum_{k \in K} c_{kj}, \quad \forall j \in N_a \tag{5}$$

$$c_{ki} + \textstyle\sum_{l \in \{\{k-d+1, \dots, k+d-1\} | (k-d+1 \geq 1) \wedge (k+d-1 \leq |K|)\}} c_{lj} \leq 1, \\ \forall k \in K, \forall i \in N_a, \forall (i,j) \in G_a \tag{6}$$

The objective (1) is to minimize the maximum of channel utilization at each AP. Constraint (2) states that each demand point should be assigned to one AP. Constraint (3) is the condition that the total traffic demand of demand points should be less than the wireless link bandwidth provided by an AP. Constraint (4) denotes the AP j is selected if the demand point i is connected to the AP j. Constraint (5) says that a channel should be assigned to the selected AP. Constraint (6) describes the non-overlapping channel condition with the minimum channel distance.

Aside from minimizing the maximum of channel utilization, the optimization objective may be to minimize the number of APs for the minimum cost ($\sum a_j$) or to maximize the sum of the signal power ($\sum s_{ij}$).

III. PERFORMANCE EVALUATION

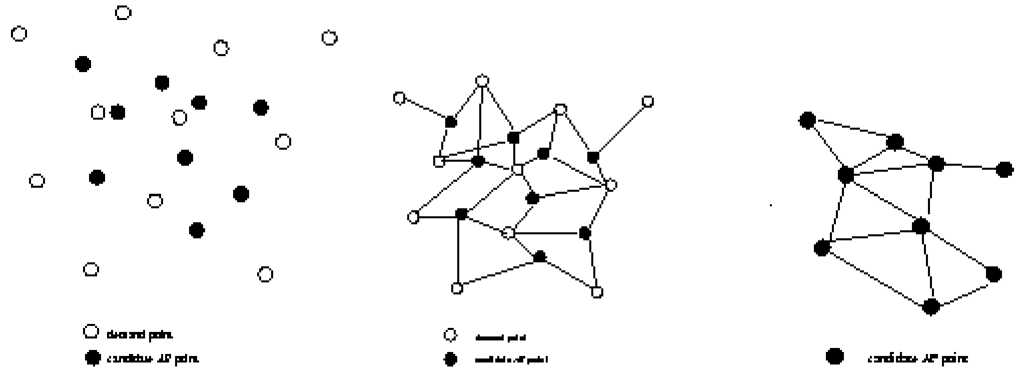
A. Environments

We used CPLEX [8] to solve the ILP formulated problem. For the ARF function, we assumed that 11, 5.5, 2, and 1 Mbps bandwidth connections are established when the distance between the mobile host and an AP is less than 160, 270, 400, and 550 m, respectively. The channel interference distance is set to 550 m. The average traffic demand per user is assumed as 200 Kbps, and the number of users per demand point is randomly distributed between 1 and 10. The traffic demand at a demand point is given by the number of users × the average traffic demand per user.

B. Case Study of an Example Network

On the sample network example in Fig. 1, we found a set of selected APs and their channels with the objectives of minimizing the maximum of channel utilization and the number of APs.

In Table I, it is shown that the maximum of channel utilization is 1.64 with five selected APs with the objective of minimizing α. However, the number of APs is reduced to four by using the objective of minimizing the number of APs with the increase of α (2.36). If the x_{ij} variable is real, that is, every mobile host at a demand point may choose different AP and thereby traffic demand is optimally assigned to APs, the maximum of channel utilization (1.36) can be reduced.



(a) Demand and AP candidate points (b) AP assignment graph, G (c) Channel assignment graph, G_{α}

Fig. 1. Graph model of demand points and AP candidate points

TABLE I

THE RESULT OF THE EXAMPLE NETWORK ((*) SHOWS THE RESULT WITH THE REAL VALUE OF x_{ij})

Objective	α	Number of APs
α	1.64 (1.36)	2.36 (2.36)
Number of selected APs	5 (5)	4 (4)

C. *Random Topology*

As it is difficult to get all the information about the large-sale WLAN service area environments such as demand points, user popularity, signal measurement, and traffic demand estimation, we use a general network topology for the verification of the proposed method. To investigate performance on the general network topology, we randomly generated demand points and candidate AP points on the grid plane of 200 × 200 where each grid represents $10 \times 10\, m^2$ square unit.

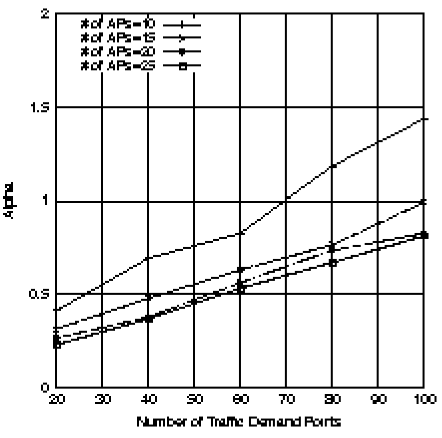


Fig. 2. α according to the growth of traffic demand

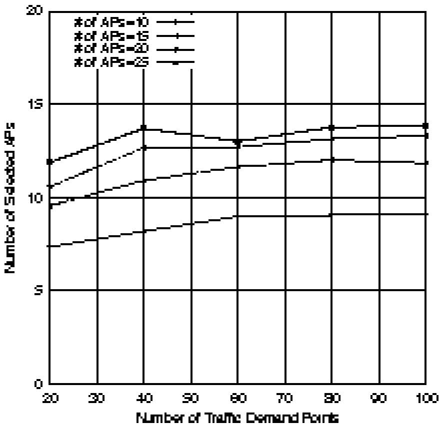


Fig. 3. Number of selected APs according to the growth of traffic demand

In Fig. 2, we can see that α is reduced by increasing the number of candidate APs as the number of traffic demand points increases. However, Fig. 3 shows that the size of the best AP set do not increase even if traffic demand becomes high, because of the channel interference condition. For example, the required number of APs is about 13 for the traffic demand points are greater than 40. Therefore, it will save the installation and administration costs for ISPs to choosing the optimal AP location by the proposed method.

D. *Considering Automatic Rate Fallback Distances*

If the WLAN topology is supposed to provide high bit rate (e.g., 11 or 5.5 Mbps) connections to mobile hosts, candidate APs should be located such that every mobile host, with the maximum signal power and within the short distance between APs and mobile hosts, is connected in high bit rate to at least one candidate AP on the AP assignment graph. Hence, if we solve the same WLAN service design problem after adding more candidate APs whose distance to mobile hosts is short enough to provide high bit rate connections, mobile hosts get more increased bandwidth. For example, for a set of 20 candidate AP location points, which can connect mobile hosts of 40 demand points to APs in the bandwidth of at least 1 Mbps, the optimization problem finds an α of 0.4 with 11 APs. In the same environment, if we increase the number of candidate AP location points to 40 such that at least 5.5 Mbps connections are provided, 19 APs are selected to reduce α to 0.35. Therefore, for a given WLAN network, we can get a solution of selected APs that increases the end host throughput, after putting more candidate APs which provide high bit rate connections. However, adding more candidate APs increases the administrative cost and the computation complexity, because the channel interference condition must be resolved among all the neighboring APs.

IV. RECONFIGURATION

In general, the traffic demand pattern of the wireless LAN will be more dynamic due to the user mobility than that of the wired LAN. Therefore, after wireless LAN APs are installed throughout the service area, it is necessary that APs should be efficiently reconfigured under dynamically changing traffic demand. During the reconfiguration process, APs and their channels may be changed, which will cause user traffic disruption. In this section, we propose an AP reconfiguration method with the objective of minimizing the amount of traffic demand disruption due to new assignment of APs to demand points, while it maintains α less than that of the original AP configuration.

The problem solving procedure of reconfiguration is shown in Fig. 4. When the original traffic matrix $\{\overline{T_i}\}$ is changed to $\{T_i\}$, we first solve the problem for the new traffic demand matrix $\{T_i\}$ to get the optimal value of α. Then, we find the solution for the new traffic demand matrix, $\{T_i\}$ that is a set of AP and demand point associations which minimizes the amount of changed traffic flows, while the maximum of channel utilization is less than α.

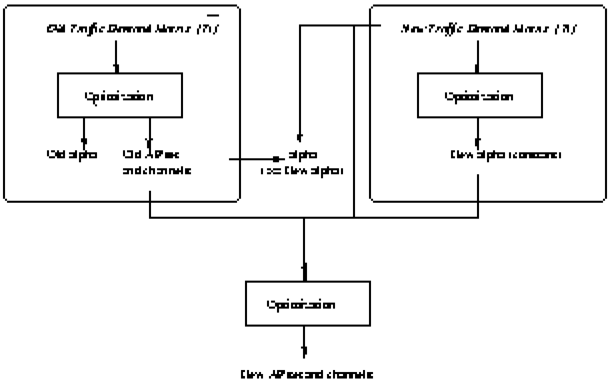


Fig. 4. The Problem Solving Procedure of Reconfiguration

Let Δ_{ij}^{+} denote the amount of added traffic flows at demand point i assigned to AP j, and Δ_{ij}^{-} the amount of traffic to be subtracted at the demand point and AP association, (i, j). The reconfiguration problem formulation is given as follows.

$$Minimize \quad \sum_{i,j} \Delta_{ij}^{+} \tag{7}$$

subject to

$$\sum_{j \in N_a} x_{ij} = 1, \quad \forall i \in N_d \tag{8}$$

$$\sum_{i \in N_d} T_i \cdot x_{ij} \leq \alpha \cdot B_j, \quad \forall j \in N_a \tag{9}$$

$$T_i \cdot x_{ij} - \overline{T_i} \cdot \overline{x_{ij}} = \Delta_{ij}^{+} + \Delta_{ij}^{-}, \forall i \in N_d, j \in N_a \tag{10}$$

$$x_{ij} \leq a_j, \quad \forall i, j \tag{11}$$

$$a_j \leq \sum_{k \in K} c_{kj}, \quad \forall j \in N_a \tag{12}$$

$$c_{ki} + \sum_{l \in \{\{k-d+1,\ldots,k+d-1\} | (k-d+1 \geq 1) \wedge (k+d-1 \leq |K|)\}} c_{lj} \leq 1, \\ \forall k \in K, \forall i \in N_a, \forall (i,j) \in G_a \tag{13}$$

$$\Delta_{ij}^{+} \geq 0, \Delta_{ij}^{-} \leq 0 \tag{14}$$

The objective (7) is to minimize the amount of changed traffic flows due to new assignments of AP to demand points. In constraint (9), α is set to a constant value of the maximum of channel utilization for the new traffic demand. Constraint (10) describes the differences between new AP assignment variables and old ones.

For instance[1], when the traffic demand matrix is randomly changed within the maximum variation value of 100 %, the optimal α for the new traffic demand matrix is 0.86. However, if AP configuration for the old traffic demand matrix is used, α becomes 1.07. Then, through the optimization step of minimizing the amount of changed traffic flows (=2.9), we can find the AP and demand point associations satisfying α of 0.86.

V. CONCLUSION

In this paper, we proposed an optimization method of AP placement and channel assignment to minimize the maximum of channel utilization in ILP problem formulations. By using a simple model of demand point and channel assignment graphs, the WLAN service design process can be easily performed. The proposed method finds the best set of AP locations for load balancing by considering user traffic demands. From the simulation results, it is seen that the maximum of channel utilization or the number of selected APs is minimized. In this paper, we assumed that constant bandwidth is provided by a channel at an AP regardless of active users and connection bit rates.

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[1] 200×200 grid topology, 15 candidate APs, and 50 demand points

However, in order to perform complete capacity planning, the dynamic AP capacity function of the number of users and their bit rates should be considered. In addition, a real WLAN service environment will be considered to experimentally test the proposed WLAN design method

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