Optimal Access Point Selection and Traffic Allocation in IEEE 802.11 Networks

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ABSTRACT

We design an optimal access point (AP) selection and traffic allocation algorithm for IEEE 802.11 networks. Coverage and capacity are some key issues when selecting APs in a demand area. APs need to cover all users, i.e., a user is considered covered if the power received from its corresponding AP is greater than a given threshold. Moreover, from a capacity standpoint, APs need to provide certain minimum bandwidth to users located in the coverage area. Our optimization balances the load on the entire network whereby demand clusters will not necessarily select the closest AP that has the largest signal level but one that can still service the demand cluster and provide ample bandwidth.

Keywords: WiFi, Access Point, Wireless Networks, Optimization.

1. INTRODUCTION

IEEE 802.11 wireless networks offer performance nearly comparable to that of Ethernet [1]. In addition, they provide scalability and relative ease of integrating wireless access. Wireless LANs support user demand for seamless connectivity, flexibility, and mobility [2]. The most prominent differences between wireless LANs and wired LANs are transmission medium and speed.

Designing IEEE 802.11 wireless networks [3] includes two major components: placement of access points (APs) in the demand areas and assignment of radio frequencies to each AP. Coverage and capacity are some key issues when placing APs in a demand area. APs need to cover all users. A user is considered covered if the power received from its corresponding AP is greater than a given threshold. Moreover, from a capacity standpoint, APs need to provide certain minimum bandwidth to users located in the coverage area.

In [4], the authors use a divide-and-conquer algorithm to select APs. The algorithm divides the total service area into equally sized squares. The problem is then solved in each of these divisions by exhaustive search. In [5], the authors formulate an integer linear programming problem for optimizing AP placement. The algorithm maximizes the throughput by considering load balancing among APs. The optimization objective is to minimize the maximum of channel utilization of the hot spot service area. In [6], the authors formulate different optimization problems with various objective functions. The considered variables are positions of APs, their heights, their transmission power levels, and antenna sectorization. The optimization problems maximize the number of covered demand nodes while penalizing multiple coverage of demand nodes. In [7], the authors use techniques for placement of base stations in an outdoor environment for building an indoor wireless network. The algorithm minimizes the number of APs, that cover a desired service area. In [8], the authors use a greedy algorithm to solve the AP placement problem. The algorithm begins with a set of potential locations for APs. In each iteration, a new AP is greedily picked from the set that covers the maximum number of uncovered demand nodes. This algorithm assumes that if an AP covers the most demand nodes, it is more desirable to select it.

In this paper, we design our AP selection algorithm by balancing traffic load. We formulate an optimization problem that minimizes heavy congestion. As a result, APs in wireless LANs will have well distributed traffic loads, which maximizes the throughput of the network.

The remainder of this paper is organized as follows. In section 2, we describe our network design procedure. In section 3, we present our AP selection and traffic allocation optimization algorithm. In section 4, numerical results are presented. Finally, the conclusions drawn from this paper are summarized in section 5.

2. NETWORK DESIGN PROCEDURE

APs should be placed so that there are no coverage gaps in the service areas. In addition, the coverage overlap among APs should be minimized to avoid interference and achieve better throughput. If too many APs are used, the cost of equipment and installation will be higher than necessary.

Some important issues when placing APs are coverage of service areas and throughput requirements. Our approach for designing 802.11 wireless LANs is composed of the following steps:

1. Creation of a service area map: A service area map will be divided into smaller demand clusters where the number of users or traffic requirements of each demand cluster is given.
2. Placement of candidate APs: Candidate APs must be placed taking into account the connection to the wired LANs, power supply needs, and installation costs.

3. Creation of a signal level map: A signal level map is either measured or estimated using a radio propagation model. Signal levels at demand clusters should be greater than a given threshold in order to provide an adequate signal-to-noise ratio.
4. Selection of the APs from among a set of candidate locations: Using the service area map and the signal level map, we can calculate the best locations of APs from among possible candidate locations to satisfy traffic demands and capacity requests. Balancing traffic loads will be crucial to avoid and minimize bottleneck APs, which increases network throughput.

3. OPTIMAL ACCESS POINT SELECTION AND TRAFFIC ALLOCATION

Assumptions

The following assumptions are made to aid in the placement problem.

- L is the total number of demand clusters. Demand clusters are defined as the locations of high traffic loads in the service area.
- M is the total number of candidate APs. The APs are chosen such that every demand cluster must be connected to at least one candidate AP.
- S_{ij} is the signal level at demand cluster i of AP j.
- D_i is the location of a demand cluster i.
- T_i is the average traffic load of demand cluster i. Traffic requests from a demand cluster i will be assigned to only one AP.
- Candidate AP assignment graph, $G = (N, E)$:
  - Nodes (N) consist of a set of demand cluster and a set of candidate APs.
  - Edge (E) exists between a demand cluster i, D_i, and a candidate AP j if the signal level, S_{ij}, is greater than a given threshold.

The Access Point Selection Optimization Problem

Load balancing is crucial when APs are chosen because distributing user traffic demands to APs results in higher throughput. We formulate the problem of AP selection and traffic allocation by minimizing the congestion of the most heavily loaded APs. By minimizing the bottleneck APs, we can get better bandwidth utilization for the whole network, which will result in higher throughput.

We formulate an integer optimization problem [9]. The following variables are defined.

- x_{ij} is a binary variable that is 1 when demand cluster i is assigned to AP j and 0 otherwise.
- B_i is the maximum bandwidth of AP i.
- C_i is the congestion factor of AP i.

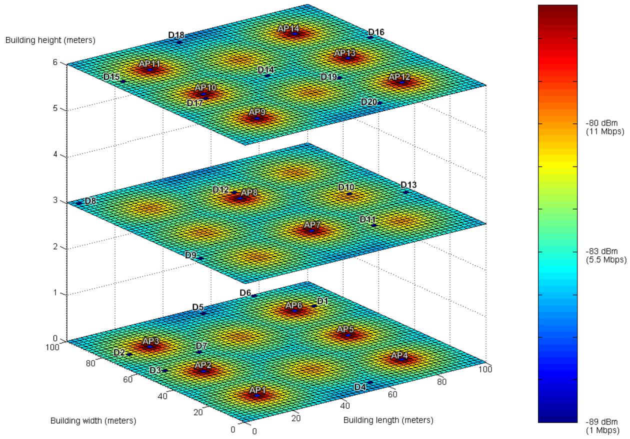

Fig. 1. The signal level map for a three story building with 14 APs and 20 demand clusters.

The optimal AP selection and traffic allocation problem is given as:

$$\begin{aligned} \min_{x_{ij},\quad 1\le i\le L,\quad 1\le j\le M} \quad & \max\{C_1, C_2, ..., C_M\}, \quad (1.1) \\ \text{subject to} \quad & \sum_{i=1}^{L} x_{ij} \le 1, \quad (1.2) \\ & C_j = \frac{1}{B_j} \sum_{i=1}^{L} T_i \cdot x_{ij}, \quad (1.3) \\ & \text{for} \quad j = 1, ..., M. \end{aligned} \tag{1}$$

Objective (1.1) minimizes the maximum congestion of chosen APs. Constraint (1.2) states that each demand cluster should be assigned to only one AP. Constraint (1.3) defines the congestion factor of the APs. The solution to the above optimization problem yields the number of APs that are selected from the candidate APs. If C_i = 0 for an AP i, then AP i is not selected.

The solution to (1) yields the AP that a demand cluster needs to connect to. A demand cluster could be a conference room, a classroom, an auditorium, or any high demand area. The system administrator would thus, set the AP that all the stations would connect to as specified by the algorithm, or the users in that cluster would be asked to connect to a specific AP. That is how the solution would be implemented in a real setting.

4. NUMERICAL RESULTS

The following results have been obtained for a three story building with 100 meters in length and 100 meters in width. Each story is 3 meters high.

First, we created a service area map with 20 demand clusters, and we generated a signal level map of 14 candidate APs. The service area map with the signal level map for the three story building is shown in Fig. 1.

The number of users per demand cluster is uniformly distributed between 1 and 10. The averagee traffic demand per user is assumed to be 200 Kbps, and each AP provides

TABLE I

THE AVERAGE TRAFFIC LOAD, T_i (KBPS), AT DEMAND CLUSTER i.

T_1	1,600	T_{11}	1,400
T_2	2,000	T_{12}	2,000
T_3	800	T_{13}	1,800
T_4	1,800	T_{14}	400
T_5	1,200	T_{15}	400
T_6	400	T_{16}	2,000
T_7	800	T_{17}	200
T_8	400	T_{18}	800
T_9	1,800	T_{19}	800
T_{10}	1,600	T_{20}	400

a maximum bandwidth of 11 Mbps in 802.11b. The average traffic load of a demand cluster i, T_i, can be calculated as the number of users at demand cluster i multiplied by the average traffic demand per user. The average traffic load used in the analysis is given in Table I.

We generated a candidate AP assignment graph from our service area map and signal level map. As shown in Table II, a demand cluster i, D_i, may be connected to multiple APs if the signal level, S_{ij}, of an AP j at D_i is greater than a given threshold, which we set to -80 dBm. For instance, D_2 is connected to AP 2 and AP 3 while D_1 is connected to AP 6 only. Also, demand clusters, D_8 through D_{13} located on the second floor, are connected to more APs than demand clusters located on other floors since ample signals can be received from both the first and third floors.

We used LINGO [10] to solve the optimization problem given in (1). The results of our optimization showed that our algorithm selected all APs among the candidate APs, as given in Table III. This table confirms that each demand cluster is assigned to only one AP which is the first constraint of our optimization problem. Our analysis also yielded that the congestion of APs is distributed throughout the network to avoid bottleneck APs, as given in Table IV. The congestion factor, C_i, would be zero if AP i is not selected by our optimization algorithm.

The AP selection derived from Table III is shown in Fig. 2. The demand cluster 17, D_{17}, selected AP 9 instead of AP 10, which is closer, since AP 10 already has been selected by D_{14} and D_{15}. By having D_{17} select AP 9, it reduces the congestion at AP 10 while it still receives ample service from AP 9. D_{15} selected AP 10 instead of AP 11, which is closer, since D_{18}, which has double the traffic demand of D_{15}, selected AP 11. Therefore, D_{15} selecting AP 10, reduces the congestion at AP 11.

As has been demonstrated in our analysis, a demand cluster will not necessarily select the closest AP that has the largest signal level. Our optimization balances the load on the entire network such that demand clusters might select APs which have slightly lower signal levels but still can service the demand clusters and provide ample bandwidth.

We randomly generated (using a uniform distribution) the locations of 15, 20, 25, and 30 demand clusters in our three story building. The results are given in Fig. 3. The congestion factor, C_i, increases, as expected, as the number of demand clusters increases. However, the load remains

TABLE II

A CANDIDATE AP ASSIGNMENT GRAPH WITH 14 APS AND 20 DEMAND CLUSTERS. AN EDGE EXISTS BETWEEN D_i AND AP j IF THE VALUE IS 1. A DEMAND CLUSTER MAY BE CONNECTED TO MULTIPLE APS IF IT IS WITHIN THE SIGNAL LEVEL THRESHOLD.

E	AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7
D_1	0	0	0	0	0	1	0
D_2	0	1	1	0	0	0	0
D_3	0	1	1	0	0	0	0
D_4	0	0	0	1	0	0	1
D_5	0	0	0	0	0	0	0
D_6	0	0	0	0	0	1	0
D_7	0	1	1	0	0	0	0
D_8	0	0	1	0	0	0	0
D_9	1	1	0	0	0	0	0
D_{10}	0	0	0	0	1	1	0
D_{11}	0	0	0	1	0	0	1
D_{12}	0	0	0	0	0	1	0
D_{13}	0	0	0	1	1	0	0
D_{14}	0	0	0	0	0	0	1
D_{15}	0	0	0	0	0	0	0
D_{16}	0	0	0	0	0	0	0
D_{17}	0	0	0	0	0	0	0
D_{18}	0	0	0	0	0	0	0
D_{19}	0	0	0	0	0	0	1
D_{20}	0	0	0	0	0	0	1

E	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
D_1	0	0	0	0	0	0	0
D_2	0	0	0	0	0	0	0
D_3	0	0	0	0	0	0	0
D_4	0	0	0	0	0	0	0
D_5 0	1	0	0	0	0	0	0
D_6	0	0	0	0	0	0	0
D_7	1	0	0	0	0	0	0
D_8	0	0	0	1	0	0	0
D_9	0	1	1	0	0	0	0
D_{10}	0	0	0	0	0	1	1
D_{11}	0	0	0	0	1	0	0
D_{12}	1	0	0	0	0	0	1
D_{13}	0	0	0	0	1	1	0
D_{14}	1	0	1	0	0	0	0
D_{15}	0	0	1	1	0	0	0
D_{16}	0	0	0	0	0	1	1
D_{17}	0	1	1	0	0	0	0
D_{18}	1	0	0	1	0	0	0
D_{19}	0	0	0	0	1	1	0
D_{20}	0	0	0	0	1	0	0

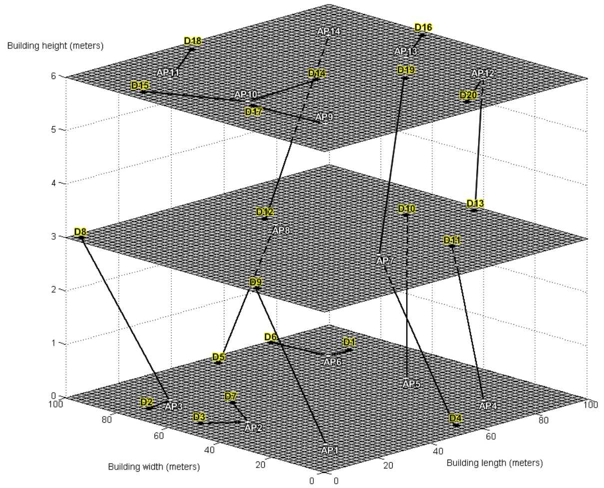

Fig. 2. Optimal AP selection and traffic distribution for 14 APs and 20 demand clusters.

TABLE III

THE SOLUTION TO OUR AP SELECTION OPTIMIZATION PROBLEM (1) YIELDED THE FOLLOWING VALUES FOR x_{ij}. EVERY DEMAND CLUSTER IS ASSIGNED TO ONLY ONE AP.

x_{ij}	AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7
D_1	0	0	0	0	0	1	0
D_2	0	0	1	0	0	0	0
D_3	0	1	0	0	0	0	0
D_4	0	0	0	0	0	0	1
D_5	0	0	0	0	0	0	0
D_6	0	0	0	0	0	1	0
D_7	0	1	0	0	0	0	0
D_8	0	0	1	0	0	0	0
D_9	1	0	0	0	0	0	0
D_{10}	0	0	0	0	1	0	0
D_{11}	0	0	0	1	0	0	0
D_{12}	0	0	0	0	0	0	0
D_{13}	0	0	0	0	0	0	0
D_{14}	0	0	0	0	0	0	0
D_{15}	0	0	0	0	0	0	0
D_{16}	0	0	0	0	0	0	0
D_{17}	0	0	0	0	0	0	0
D_{18}	0	0	0	0	0	0	0
D_{19}	0	0	0	0	0	0	1
D_{20}	0	0	0	0	0	0	0

x_{ij}	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
D_1	0	0	0	0	0	0	0
D_2	0	0	0	0	0	0	0
D_3	0	0	0	0	0	0	0
D_4	0	0	0	0	0	0	0
D_5	1	0	0	0	0	0	0
D_6	0	0	0	0	0	0	0
D_7	0	0	0	0	0	0	0
D_8	0	0	0	0	0	0	0
D_9	0	0	0	0	0	0	0
D_{10}	0	0	0	0	0	0	0
D_{11}	0	0	0	0	0	0	0
D_{12}	0	0	0	0	0	0	1
D_{13}	0	0	0	0	1	0	0
D_{14}	0	0	1	0	0	0	0
D_{15}	0	0	1	0	0	0	0
D_{16}	0	0	0	0	0	1	0
D_{17}	0	1	0	0	0	0	0
D_{18}	0	0	0	1	0	0	0
D_{19}	0	0	0	0	0	0	0
D_{20}	0	0	0	0	1	0	0

balanced across the networks. Fig. 4 shows the average congestion across the network as we vary the number of APs and the number of demand clusters.

5. CONCLUSIONS

We proposed an optimal AP selection and traffic allocation algorithm by formulating a constrained optimization problem. By minimizing heavy congestion, APs in WLANs will have well distributed traffic loads. We analyzed a three story building with 14 APs and 20 demand clusters. A demand cluster will not necessarily select the closest AP that has the largest signal level. Our optimization balances the load on the entire network such that demand clusters might select APs which have slightly lower signal levels but still can service the demand clusters and provide ample bandwidth.

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TABLE IV

THE SOLUTION TO OUR AP SELECTION OPTIMIZATION PROBLEM (1) YIELDED THE FOLLOWING VALUES FOR THE CONGESTION FACTOR, C_i, OF THE 14 APS.

C_1	0.164	C_8	0.109
C_2	0.145	C_9	0.018
C_3	0.218	C_{10}	0.073
C_4	0.127	C_{11}	0.073
C_5	0.145	C_{12}	0.2
C_6	0.182	C_{13}	0.182
C_7	0.236	C_{14}	0.182

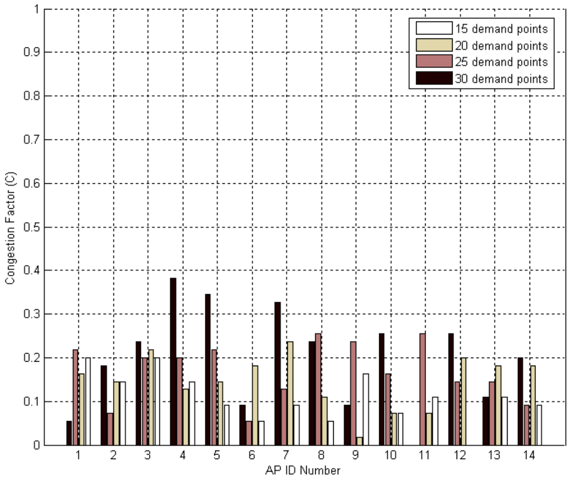

Fig. 3. Congestion factor of 14 APs with 15, 20, 25, and 30 demand clusters.

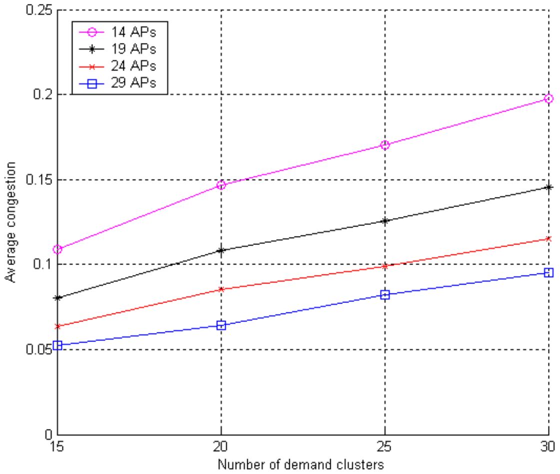

Fig. 4. Average congestion across the network decreases as the number of APs is increased.

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