UMN Wireless Network: Maximum Network Coverage Problem

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Abstract: In this paper, we try to solve the problem of 'Maximum Network Coverage' for University of Minnesota wireless network domain. We propose a mathematical model, based on tree-based evolutionary genetic algorithms, that takes the dimension of a building (in UMN campus) as input and finds the optimal number of wireless access points and their corresponding positions. Placing too few access points results in coverage gaps and too many increases the deployment cost. The proposed method iterates over all the parameters and converges to an optimum solution for number and position of access points. The results obtained for the Ford Hall building indicate that we obtained the same network coverage as the current wireless access point deployment, but, with lesser number of access points.

Keywords: Maximum network Coverage, wireless access point placement, genetic algorithm, optimization

1. Introduction: In recent times, wireless local area network (WLAN) technologies have found widespread usage. This is because of the increase in mobility requirement and ease in system implementation. The IEEE 802.11 standard has been widely used because of its relevance to office and residential building space where a number of transmission rates are attainable. The primary objective of WLAN is to provide network connectivity (or network coverage) to all desired locations within the specified region. The network coverage is defined by the number and placement of access points. The distance and the obstacles between the receiver and the access point are the major causes for variation in the transmission rates. Hence, the access point locations play a critical role in the maximization of network coverage.

A well-planned infrastructure of wireless access points would result in maximization of coverage area along with high signal strength in the region. The number of parameters governing the wireless signal attenuation along with the complexity of design of a building space increases the difficulty of achieving an optimal solution for access point placement. In practice, various business organizations, like Cisco, performs a site survey to make all the necessary readings to obtain characteristics of the building space and probable user locations before the actual wireless infrastructure installation. This survey is expensive and time consuming. Needless to say, it is not optimal.

In this paper, we propose a 'genetic algorithm' based model to find the optimal number and placement of access points. The proposed model uses the concept of 'evolving graphs' to converge to an optimal solution which maximizes the network coverage for a specified region. We tested the performance of the proposed model for Ford Hall building at the UMN campus. The results are encouraging as the performance of the proposed method is nearly equal to the existing infrastructure but with less number of access points.

The paper is organized as follows: Previous research work to find optimal solution for access point placement and maximization of network coverage is discussed in Section 2.

Section 3 presents a formal definition of the problem. The proposed 'genetic algorithm' based model is presented in Section 4. The simulation results on application of the proposed approach to 'Ford Hall' building in UMN campus is presented in Section 5. We conclude with directions to future research in Section 6.

2. Related Work: The problem of access point placement has been widely studied. Quite often, researchers have treated this as either as a set cover problem or an optimization problem. Rengarajan et al. proposed a grid based approximation algorithm to compute the optimal placement of access points [1]. The algorithm minimizes the number of access points required while ensuring that the received SNR at each location is sufficient to meet the offered load at the location. The proposed algorithm does not take into account the effect of co-channel interference.

As an optimization problem, we have the luxury of either using conventional approach such as KKT conditions to obtain an optimal solution that satisfies all the constraints or employ iteration based evolutionary algorithms like genetic programming.

As an optimization problem, the offered solutions try to maximize the network coverage given multiple constraints related to signal attenuation, path loss, receiver and transmitter characteristics, presence of obstacles and building dimensions. Kouhbor et al. tried to minimize the path loss function using a global optimization algorithm [2]. The results were encouraging but their method has not been put to test in different scenarios.

The problem with such conventional approach is that there are multitudes of parameters and reaching an optimal solution might not be feasible. Due to presence of many parameters, a closed solution may not exist for the network coverage problem.

Maksuriwong et al. proposes use of a multi-objective genetic algorithm to solve access point placement problem such that the signal coverage is maximized over a well-defined area [3]. The major advantage of applying such a 'Multi-Objective Genetic Algorithm' is that multiple access points can be obtained from a single run. These set of solutions provides more alternatives to the network designer. A multi-objective genetic algorithm has been successfully used to locate solutions which are superior to the solutions generated manually [7, 8].

The superiority of iteration based genetic algorithms (GA) over conventional methods in solving optimization problems motivated us to adopt a similar GA based approach to solve the problem of maximizing network coverage in UMN wireless domain [4,5,6].

3. Problem Statement: The main objective is to find optimal number and placement of wireless access points to achieve maximum network coverage across the specified region. Maximum coverage problem in the wireless network domain integrates two sub problems –

(i) Maximize the coverage area, and
(ii) Keep the signal strength above a specified threshold.

The scope of this project is to find optimal number and position of wireless access points to maximize network coverage in

Figure 1: Heat Map - Ford Hall (floor 1) at UMN campus

any specified building inside UMN campus. University of Minnesota provides existing number, locations and network coverage for all the buildings using heat maps [10]. The heat map serves as the pictorial view of the quantitative measure of the strength of wireless network. These are generated floor wise for each building in the UMN campus. One such heat map, for floor 1 of Ford Hall, is shown in Figure. 1.

The maximum coverage problem in the domain of wireless network for UMN campus is as follow: To develop a wireless access point infrastructure for a region of dimension $L*B$, the access points are placed to cover maximum number of users within the specified region. Too few access points would result in insufficient coverage due to its limited service radius. Too many access points will significantly increase the deployment cost of such infrastructure. Hence, the design problem is to find optimal number and positions of access points which provides maximum coverage, still keeping the deployment cost low. Formal definition is given below:

Given a set of N clients, randomly distributed within the region of size $L*B$, with coordinates (X_i, Y_i), such that $X_i \leq L; Y_i \leq B$, find an optimum access point placement for a set of access points N_{AP}, where the service radius of each access point is R and deployment cost is C_{AP}.

$$\text{Minimize: } f = C_{AP} * N_{AP} \qquad (\mathbf{1})$$

To solve the given optimization problem, we employ tree based genetic algorithms, which iterates over the number of access points and their corresponding locations to converge to an optimum solution.

4. Proposed Method: We employ the concept of evolving graphs based on tree based, genetic algorithm to find the optimal access point placement in order to maximize network coverage.

Genetic Algorithm (GA) is a search heuristic that mimics the process of natural selection to solve optimization problem. It provides a set of instructions and a fitness function to measure how well a computer has performed a task. It starts from a high-level statement of 'what needs to be done' and automatically creates a computer program to solve the problem. The heuristic is routinely used to generate useful solutions to combinatorial optimization and search problems, using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover, as shown in Figure 2.

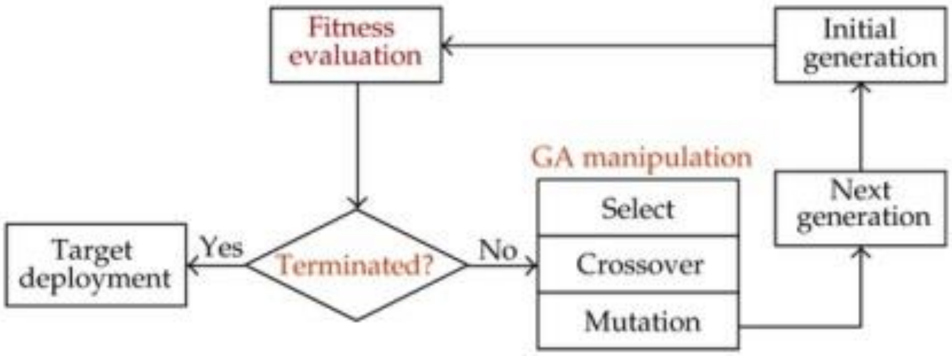


Figure 2: Pictorial representation of Genetic Algorithm [9]

In Genetic Algorithm, an initial population is randomly created. The fitness of each individual in the population then determines whether it survives. Termination criteria (such as the generation size or the fitness value exceeding the threshold) determine the target deployment to be achieved. Finally, genetic operators such as selection, crossover, and mutation identify the next generation. After meeting a number of iterations or predefined criteria, a near optimal solution is found.

GA provides approximate solutions to computationally expensive problems. Population based evolutionary algorithms are more desirable if the cost saving from global optimality is important, as computing power is cheap today. GA has been employed successfully for Non-linear optimization problems and Variable length search problems (similar to optimal access point placement problem).

Fitness Function: We define our fitness function as a weighted measure of network coverage and number of access points to be installed.

The function *'CoverFitness'* defines the network coverage achieved in terms of number of clients covered by the given access points. More the number of clients covered, more will be the value of *'CoverFitness'*.

$$CoverFitness = c1 * \frac{nClientsCovered}{nClientsCovered + nClients} \quad (2)$$

Where, *c1* is a constant, *nClientsCovered* gives the number of clients covered by the solution and *nClients* is the total number of clients.

The function *'APCostFit'* works as a check on number of wireless access points. The more the access points installed, the lesser will be the value of *'APCostFit'*.

$$APCostFit = \frac{nClients}{nClients + c2 * N_{AP}} \quad (3)$$

Where, *c2* is a constant, *nClients* is the total number of clients and N_{AP} is the number of access points.

A weighted sum of *'CoverFitness'* and *'APCostFit'* ensure that maximum network coverage is achieved with minimum number of access points. We also penalize the fitness measure of the solution for each isolated access points.

$$Total\ Fitness = p * CoverFitness + (1 - p) * APCostFit + penalty * N_{islotaed} \quad (4)$$

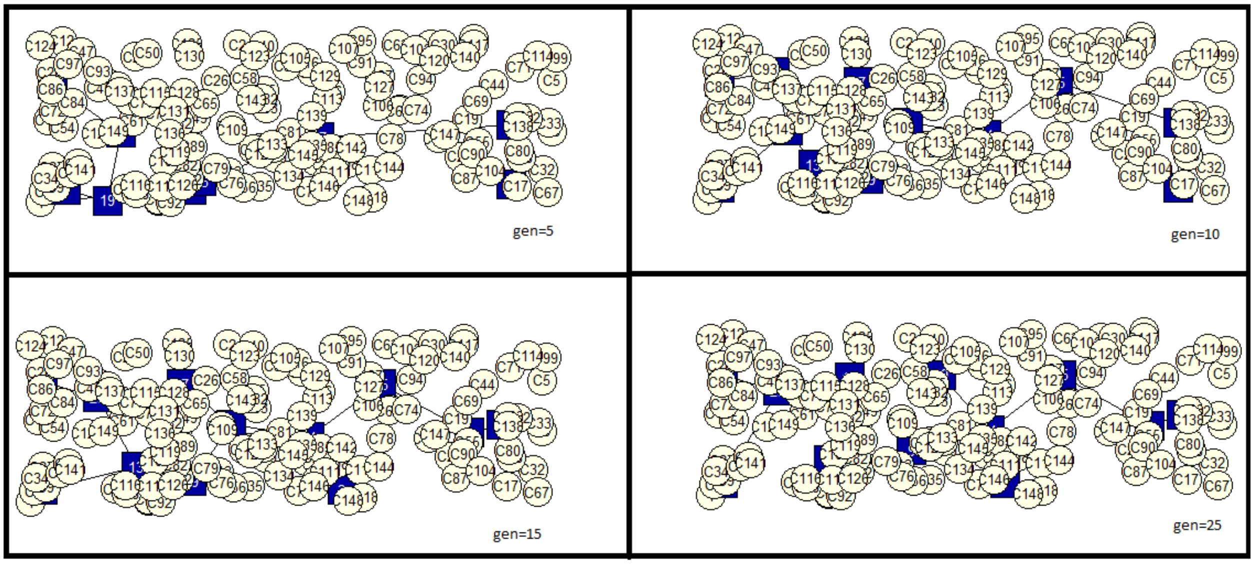


Figure 3: Access point placement at generations 5,10,15,25 (shown using LEDA software)

5. Simulations and Results: In this paper, we report the results obtained for floor 1 of Ford Hall. The heat map of the given floor is shown in Figure 1. For the performance evaluation of the proposed method, a strongly typed genetic programming library, *'lilgp'*, written in C, is used [11]. The dimension of the floor is 477 feet * 176 feet. We randomly distributed 150 clients in the given region. The solution would place the access points such that they cover as many clients as possible. The coverage radius of access points is defined to be 22 feet which corresponds to the most widely used wireless routers. The specifications for the genetic programming approach are given in Table 1.

GA Parameter	**Value**
Building Dimension	477*176
Number of Clients	150
Coverage Radius	22 feet
Population size	100
Number of Generations	100

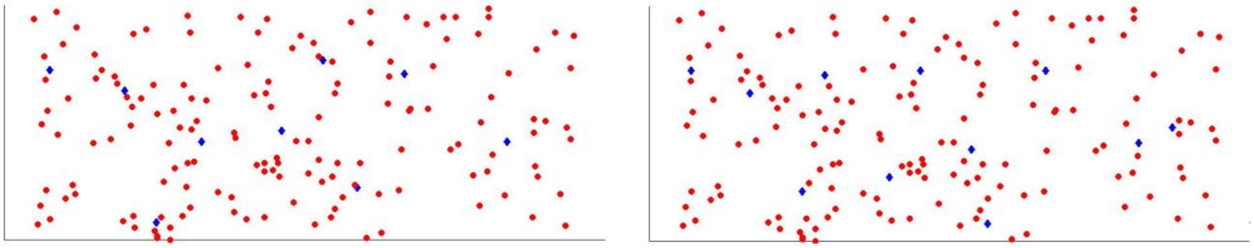
Table 1: Specifications for Genetic Programming

For the randomly distributed client population, we present the results for the evolving graph in Figure 3. These results are presented using open source LEDA software. The figure shows evolution of graphs for generation number 5, 10, 15 and 25. As evident from Figure 3, the evolution tends to focus on covering all the clients. But, the cost minimization process keeps a check on increasing number of access points, by eliminating the redundant access points to converge to an optimal topology.

In Figures 4-6, we present a performance comparison of the proposed method

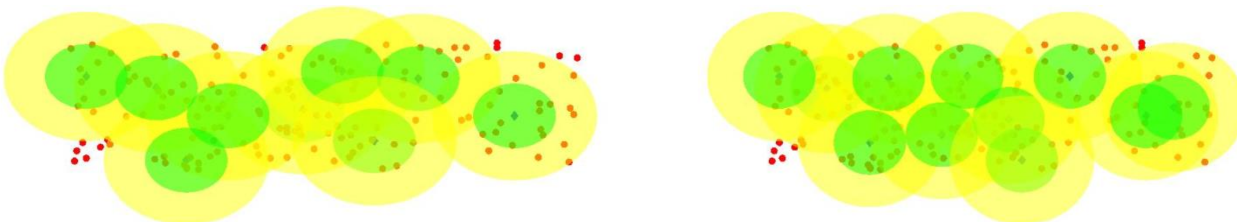
(i) using only equation (2)
(ii) using equations (2) and (3)

Figure 4 shows the access points – client distribution for the above two cases (corresponding to the two equations). Clients are shown using red and access points are shown using blue. For the above two cases, Figure 5 shows the coverage map of the optimal solution using GA approach. The green circles represent the region with 'excellent' signal strength and the yellow circles represent 'good' signal strength. Figure 6 presents a comparison of original heat maps with heat maps generated using proposed GA methodology.



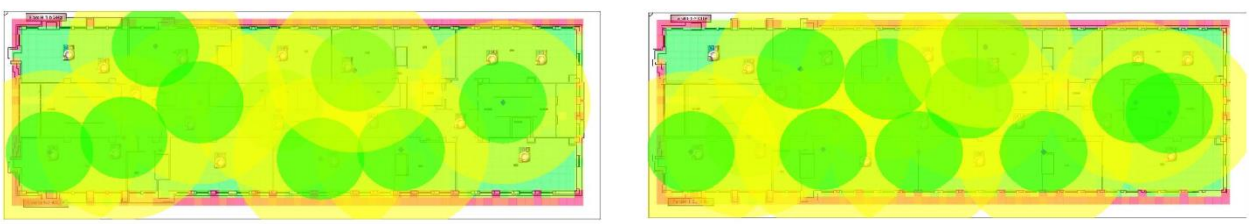
Total Fitness = CoverFitness   Total Fitness = p*CoverFitness + (1-p)*APCostFit

Figure 4: Access point and client distribution



Total Fitness = CoverFitness   Total Fitness = p*CoverFitness + (1-p)*APCostFit

Figure 5: Coverage Map for access point placement solution



Total Fitness = CoverFitness   Total Fitness = p*CoverFitness + (1-p)*APCostFit

Figure 6: Coverage Map - comparison between proposed and original heat maps

	Original	**Using Equation (2)**	**Using Both Equations (2) and (3)**
Dimension of Image	446*1200	446*1200	446*1200
White region (%)	14.34	14.34	14.34
Region considered (%)	85.66	85.66	85.66
Green region (%)	68.50	24.91	27.17
Yellow region (%)	-	38.45	36.14
Total region covered (%)	68.50	63.36	63.31
Number of Access Points	17	9	12

Table 2: Result Comparison - proposed v/s original

Table 2 gives performance comparison in terms of proportion of area covered. Green region represents the area with ‘excellent’ signal strength and yellow region represents area with ‘good’ signal strength. The last two rows of Table 2 prove that we were able to achieve nearly equal network coverage with half the number of access points.

6. Conclusion: In this paper, we proposed a genetic algorithm based evolutionary solution to find the optimal number and placement of access points. The performance evaluation of the proposed method on the floor maps for buildings in UMN campus proves that our method performs better than existing wireless access point topology. We were able to achieve nearly equal network coverage with almost half the number of access points.

For our experiments, we limited ourselves to rectangular regions. Future work will involve extending the proposed method to non-rectangular shaped regions. Also, we did not take into account, signal attenuation and path loss due to presence of obstacles like walls. An extension of this work will incorporate that information in the fitness function. In future, we would like to extend the proposed algorithm to other buildings in UMN campus.

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