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WIRELESS LAN SYSTEN DESIGN CONSIDERING AVERAGE PATH LOSS MINIMIZATION

Narongchai Ungurawanich and Naruemon Wattanapongsakorn

Department of Computer Engineering
Faculty of Engineering
King Mongkut's University of Technology Thonburi
91 Prachauthit Road, Bangmod, Thung Kharu, Bangkok 10140, Thailand

ABSTRACT

Path loss is an important issue in infrastructure-based wireless LAN design. In this paper, we consider infrastructure-based wireless LAN network design by minimizing average path loss in indoor environment service area. Path loss is an attenuation factor which is a major cause of network performance degradation. The design aims to minimize average path loss and serve all traffic demand in the service area with capacity and coverage restrictions and other requirements. The problem is formulated as a non-linear optimization problem. Genetic Algorithm (GA) is applied to solve this problem for finding appropriate access points' parameters including locations, frequency channels and power levels. GA is an effective heuristic searching algorithm suitable for various types of problem solving. The GA results are captured and evaluated with a brute-forced search approach where optimum solutions can be obtained.

1 INTRODUCTION

The improvements in wireless communication devices and related electronic appliances of wireless systems has increased and become cheaper, smaller and more powerful in the last few years. The IEEE 802.11b standard Wireless Local Area Networks (WLANs) have tremendous growth in the world market. WLANs provide consumers and businesses mobile data networking capabilities that complement the mobile voice capabilities of cellular phones. Therefore the deployment of WLANs and the growth in the number of subscribers is expected to rapidly increase. The network design is an important issue of the widespread deployment of infrastructure based WLANs.

There are many important factors which reduce the performance of WLANs network such as radio propagation, multi-path fading and path loss. Path Loss is the signal attenuation between transmitter and receiver as a function of the propagation distance and other parameters. A poor WLAN network design causes more path loss value in the service area therefore the performance of WLAN network is reduced. This paper aims to minimize path loss factor to optimize WLAN network performance in the service area.

The network design determines the number, location and configuration (e.g., frequency, power level, etc.) of WLAN access points (APs) and network capacity (aggregate bit rate) provided to a specific service area. In current practice WLANs are largely designed on basis of trial and error, measurement based approach. Specifically, one places APs in buildings at opportunistic locations, measures the received signal strength in the desired coverage areas of the building and adjusts the AP locations, power levels, frequency channel etc., based on observed coverage All of this is done manually, and is labor intensive. Such an approach is expensive and time consuming when deploying large numbers of WLAN APs.

In this paper, we present a new wireless LAN system design methodology for infrastructure based wireless LANs which minimizes the average path loss in the service area and assures sufficient data rate capacity to meet expected user demand in coverage area requirements. The design will give optimal wireless LAN network performance by determining the number of access points and access points' parameters including locations, frequency channels and power levels which will satisfy the set of constraints that include radio propagation conditions, the data rate density requirement and physical limitation like receiver sensitivity. We formulate the design problem as a non-linear programming optimization problem which is solved by Genetic Algorithm (GA) technique. GA is an efficient searching algorithm. For large search space or large problem size, GA requires less computational time with promising solutions comparing with traditional search algorithms such as integer programming, dynamic programming, branch and bound and exhaustive search algorithm (Goldberg et al 1999).

The rest of the paper is organized as follows. In the next section, we give an overview of related works in wireless LAN design. In section 3, the explanation of model formulation and objective function are given. Section 4 presents the Genetic Algorithm concept. The application of GA on solving problem is explained in section 5. Section 6 illustrates the simulation of network design results obtained with GA and discusses the results obtained with traditional method. Lastly, section 7 concludes and summarizes our research.

2 LITERATURE SURVEY

The infrastructure-based wireless LAN design problems are how to allocate access points to the service area which meets the service area requirements. There are many design purposes in previous researches. The research (Stamateos et al 1996) aims to minimize installation costs by determining the best placement of access points and frequency channel assignment for those access points. The capacity based wireless LAN design researches which assures sufficient data rate demand in coverage area are presented in (Rodriges et al 2000), (Kabara et al 2001) and (Prommak et al 2002). The research (Maksuriwong et al 2002) aims to determine access point placement for maximizing signal coverage over the interested service area.

The access points' parameters assignment problem for wireless LAN system is difficult. To determine access points' locations, a development of integer linear programming model was proposed in (Rodriges et al 2000). A greedy algorithm is one of algorithms used to place the access points and set their power levels and the channel allocations accordingly (Kabara et al 2001). A multi-objective genetic algorithm (MOGA) is used to solve a wireless LAN access point placement problem (Maksuriwong et al 2002). The research (Prommak et al 2002) used brute-force search algorithm to determine access point parameters, including locations, power levels and frequency channels.

Among these previous researches, there is one research paper (Prommak et al 2002) which considered both capacity and coverage-based design. The paper focused on assuring sufficient data rate demand capacity to meet expected user demand in coverage area and interference level requirements. It used brute-force search algorithm to determine the solutions. Although this approach satisfies the capacity and coverage requirements, it does not provide optimal solution that minimizes average path loss in the service area.

Genetic Algorithm (GA) has been used to solve many difficult engineering problems and is particularly effective for combinatorial optimization problems. GA can be used to solve optimization problems where the problem space is huge and trying all possibilities is not an option. Examples problems are component redundancy allocation in series-parallel systems (Coit et al 1996, Phengprajit et al 2002), and system reliability design considering alternative design, multiple design objectives or time-interval coefficients (Gen et al 1999).

3 MODEL FORMULATION AND OBJECTIVE FUNCTION

A discrete grid size 1m x 1m is used in our algorithm. The candidate locations which are used to install access points are represented by grid points. The grid points also specify the locations that require radio signal coverage and user's locations. In our design, we consider grid point to allow access points to be located at any intersection grid.

3.1 Model Formulation

We represent two-dimensional space with *(x, y)* coordinates. Let *A* denotes the set of *N* access points {ap_1, $ap_2 \ldots ap_n$}, *U* denotes the set of wireless users or demand nodes in the service area {$u_1, u_2, \ldots u_m$}, *GC* denote the set of grid points {$g_1, g_2, \ldots, g_c$} representing the area that requires radio coverage.

3.2 Objective Function

The main objective of this paper is to minimize average path loss in the service area with coverage and capacity constraints. The objective function is to minimize the followings.

$$\min\left(\frac{\sum_{j=1}^{n} u_{ij}\, pL_{ij}}{m}\right), \forall i \in U \tag{1}$$

where each user i has to be in set of user U and each access point j has to be in set of A, uij is a binary variable that indicates whether user i associates with access point j or not and pLij is the portion of path loss which is a function of distance between location of user i associated with access point j. In equation (1), pLij , Path loss model, is defined by

$$pL\left(f_j,(x_i,y_i),(x_j,y_j)\right) = pL(d_0) + 10n_0\log\left(d_{ij}/d_0\right) + K_\sigma \tag{2}$$

where (x_i, y_i) is user *i* coordinate, (x_j, y_j) is access point *j* coordinate, f_j is frequency channel of access point *j*, d_0 is the reference distance, d_{ij} is the distance between user *i* and access point j, n_0 is the path loss exponent which is equal to 3.02 (Prommak et al 2002), K_σ is the shadow fading margin which is equal to 10 (Prommak et al 2002). In equation (2), $pL(d_0)$, path loss value of the reference distance, is defined by.

$$pL(d_0) = 10\log\left[\left(\frac{4\pi d_0 f_j}{3\times 10^8}\right)^2\right] \quad (3)$$

We define a set of constraints which include capacity and coverage restrictions and requirements to the wireless LAN design as follows:

$$\sum_{j=1}^{n} u_{ij}\left(p_j - pL\left(f_j,(x_i,y_i),(x_j,y_j)\right)\right) \leq P_R \quad (4)$$

$$10\log\left[\sum_{\substack{k=1\\ f_k=f_j}}^{n}(1-u_{ik})\log^{-1}\left(p_k - pL\left(f_j,(x_i,y_i),(x_j,y_j)\right)\right)\right] \leq P_I \quad (5)$$

where P_R is the received signal strength threshold which is equal to -80 dBm and P_I. is the signal interference power threshold which is equal to -90 dBm. These constant values are referred from Rappaport et al 1996. In equation (4) is a constraint which states that the signal received at each wireless terminal must be greater than the receiver threshold sensitivity. In equation (5) is a constraint which specifies the interference threshold of the wireless terminal.

$$\sum_{i=1}^{m} d_i u_{ij} \leq \beta C_{ap}, \ \forall j \in A \quad (6)$$

where β, the access point effective capacity, is equal to 0.9 referred from Stamateos et al 1996, due to the content based MAC protocol, it is assumed that the access points' throughput reduces to 90% of access point full capacity and C_{ap}, an access point capacity, is equal to 11 Mbps referred from Stamateos et al 1996. They are used in equation (6) to assure that the traffic demand of wireless terminals assigned to particular AP does not exceed the data rate capacity of the AP.

$$\sum_{j=1}^{n} g_{hj} \geq 1, \ \forall h \in GC \quad (7)$$

In equation (7) is a constraint which states that the radio signal will be available across the specified coverage space. This condition allows the grid point to be able to receive radio signal from more than one access points, it allows over-lapping of the access points' coverage areas. $g_{hj} = 1$ if the received signal strength at the grid point h from the access point j is greater than P_R and associated interference level is below P_I; $g_{hj} = 0$ otherwise.

The constraints from equations (4), (5), (6) and (7) (Prommak et al 2002) include Path loss model in equation (2) and (3) (Prommak et al 2002), which may vary for different service area environments.

4 GENETIC ALGORITHMS (GA)

Genetic Algorithm (GA) was first invented by John Holland in the early 1970's (Coit et al 1996). GA is a stochastic optimization technique that uses the biological paradigm of evolution. It has a concept where good chromosome has a better potential of being carried to the next generation than the bad chromosome. It uses mathematical principle to indicate which chromosome is better or worse than the others are (Goldberg et al 1999). GA is characterized by the following steps:

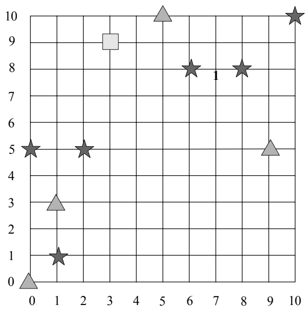
1. Encode the solutions.
2. Generate initial population
3. Select parent solutions for breeding
   - Crossover breeding operator
   - Mutation operator
4. Repeat step 3 until termination criteria is met.

An effective GA depends on complementary crossover and mutation operators. The effectiveness of the crossover operator dictates the rate of convergence, while the mutation operator prevents the algorithm from prematurely converging to local optimum. The number of children & mutants produced in each generation are tunable parameters that are held constant during a specific trial.

5 ACCESS POINTS' PARAMETERS ASSIGNMENT USING GA

In this research, the Genetic Algorithm is used to solve the access points' parameters assignment problem. The problem is to design wireless LAN network by determining number of access points and their parameters including locations, frequency channels and power levels. The assignment problem is subjected to minimum average path loss in the service area.

For example, the area 10m x 10m service area and 11 users with different locations and demands are illustrated in Figure 1.



Users locations and demand

User_no	Location (x,y)	Demand (Kbps)
1	(0,0)	250
2	(9,5)	250
3	(5,10)	250
4	(10,10)	2000
5	(1,1)	2000
6	(2,5)	2000
7	(3,9)	50
8	(0,5)	2000
9	(6,8)	2000
10	(8,8)	2000
11	(1,3)	250

Figure 1: 10 m x 10 m service area example

The service area is represented as discrete of grid size 1m x 1m. The grid points are counted from 0 and started from bottom left to top right of the service area as illustrated in Figure 1.

We classify wireless users in three categories based on typical demands in this environment. Those with handheld computers access the network at 50 kbps. The second classes of the wireless devices need a medium data rate of 250 kbps as they employ laptops to mostly read email and access some Internet sites. The third category consists of high data rate wireless terminals which employ laptops to utilize remote file systems and streaming audio/video. This classification is the same as in Prommak et al. 2002.

We apply the GA to solve the assignment problem by following these five steps:

5.1 Encoding

In this example, there are two required access points which can serve total users' traffic demands in the service area. The network design with two access points can be represented with string encoding:

$$g_1\ f_1\ p_1 \mid g_2\ f_2\ p_2 \mid \ldots \mid g_j\ f_j\ p_j$$

where g_j is selected location of access point, f_j is the selected frequency channel and p_j is selected power level for access point j.

Suppose we have m choices to allocate grid points in the area, n choices of frequency channel assignment and o choices of power level selections for each access point.

For access point j : gj can be 0..m-1, fj can be 0..n-1 and pj can be 0..o-1.

The gj, fj and pj are then encoded in binary representation which is used in crossover process. In Prommak et al.2002, the frequency channels can be 2.412, 2.437 and 2.462 GHz and the power levels can be 24, 20 and 15 dBm. These frequency channels and power levels are encoded as 0, 1 and 2 for fj and pj, respectively.

5.2 Initial Population

We set the initial population by randomly generating a set of chromosomes consisting of genes, and calculate their fitness value according to the fitness function, equation(1).

5.3 Selection

The chromosomes or population are sorted by their fitness values. The top 70% of population with high fitness values according to the objective function, are selected for the crossover process.

5.4 Crossover

We randomly select two network design patterns or chromosomes from the current population for crossover, to produce two new chromosomes (offspring). Also we randomly select a gene in a chromosome for crossover. The positions.

An Example of two possible chromosomes representing 2 APs allocation: 23 2.437 24 | 95 2.412 20
36 2.462 20 | 104 2.437 15

Apply binary encoding to each gene:
0010111 01 10 | 1011111 00 10
0100100 10 10 | 1101000 10 00

P1 and P2 are randomly selected as gene positions for crossover process. The gene positions are counted from right to left.

If P1 = 6 and P2 = 2, then

Results:
00101**0**1 01 10 | 1011111 00 **0**0
01001**1**0 10 10 | 1101000 10 **1**0

which are: **21** 2.437 24 | 95 2.412 **15**
38 2.462 20 | 104 2.437 **20**

For the next population generation, we select the top 20% of the population with the maximum fitness values from current population generation and compose with the best 70% from the crossover and mutation process, and 10% from new random population.

5.5 Mutation

Firstly, the current population generation is sorted by their fitness values. Then each chromosome in the generation except the best chromosome with highest fitness is randomly selected for mutation with probability = 0.1 (mutation rate = 10%). Only one position of the genes representing an AP location is randomly altered. The chromosomes resulted from mutation are combined and considered as the chromosomes in the current population generation.

6 SIMULATION RESULTS

A 10 m x 10 m small service area shown in Figure 1, is used as the first problem to evaluate our GA approach where the solution is compared with those obtained using a brute-force search algorithm. We run the GA for 20 generations, and found that the results from our GA are very close to the brute-force search results. Result comparison of the two algorithms is shown in Table 1.

Then, we consider a larger size of network design example, having 21 m x 35 m service area with 33 users in different locations acquiring 25.75 Mbps total bandwidth demand. Among these, there are 10 users with 2 Mbps and 23 users with 250 kbps bandwidth demands. A diagram of planning service area is displayed in Figure 2. We obtain this network design problem from (Prommak et al 2002). The parameters of access points and average path loss values are displayed in Table 2. Then, We apply our GA approach to solve this problem where the corresponding GA result is shown in Table 3.

From Tables 2 and 3, we can see that the result from our GA gives lower average path loss than the result from Prommak et al 2002 (95.39104 vs. 95.85435).

Next step, we run the GA simulation with this problem assuming 4 required access points. We obtain a better solution with lower average path loss compared with those with 3 access points (91.15715 vs. 95.39104). The result is shown in Table 4.

Figure 3 illustrates the network design with average path loss value from (Prommak et al 2002). The network design using GA with 3 and 4 required access points are illustrated in Figures 4 and 5, respectively.

Table 1: GA result compares with brute-force result

Algorithm	**Average path loss**		
	Min	**Max**	**Average**
GA	89.53809	90.98967	89.74474
Brute-Force	89.53809		

Table 2: The parameters of each access points with average path loss value (Prommak et al 2002)

No	**Location (x, y)**	**Frequency**	**Power**
1	(10,4)	2.462	15
2	(11,20)	2.437	20
3	(31,9)	2.412	24
Average path loss		95.85435	

Table 3: The parameters of each 3 access points with average path loss value applied with GA

No	**Location (x, y)**	**Frequency**	**Power**
1	(8,3)	2.462	15
2	(11,19)	2.437	20
3	(32,12)	2.412	24
Average path loss		95.39104	

Table 4: The parameters of each 4 access points with average path loss value applied with GA

No	**Location (x, y)**	**Frequency**	**Power**
1	(4,6)	2.462	15
2	(12,18)	2.437	20
3	(33,17)	2.412	15
4	(23,2)	2.437	20
Average path loss		91.15715	

7 CONCLUSION

In this paper we consider infrastructure-based wireless LAN design which minimizes average path loss and serves all traffic demands in the whole service area. The design objective together with the access points' parameters are formulated as an optimization problem where Genetic Algorithm is successfully applied to identify the optimal/ near optimal solutions.

The network design objectives are to minimize average path loss in the service area and also satisfy constraints including interference, capacity and SNR. These multiple constraints are in contrast with one another. Therefore, the degree of constraints' importance must be well aware and considered in the network design.

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AUTHOR BIOGRAPHIES

NARONGCHAI UNGURAWANICH is a graduate student in Computer Engineering at King Mongkut's University of Technology Thonburi. He received a B.Eng. degree from Mahidol University in 2000. His research interests include WLAN network design and optimization. His email address is <eawba@yahoo.com>

NARUEMON WATTANAPONGSAKORN is an assistant professor in Computer Engineering at King Mongkut's University of Technology Thonburi. She received the B.S. degree and the M.S. degree, both from The George Washington University, and Ph.D. degree in Electrical Engineering from the University of Pittsburgh, USA. Her research interests include network design and optimization, fault-tolerant technique, and reliability engineering. Her email address is <naruemon@cpe.kmutt.ac.th>

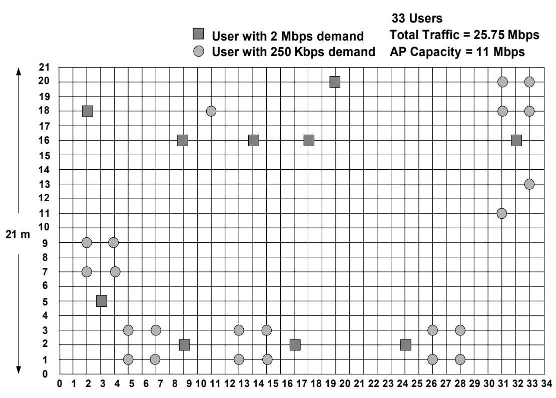

Figure 2: 21 m x 35 m service area example

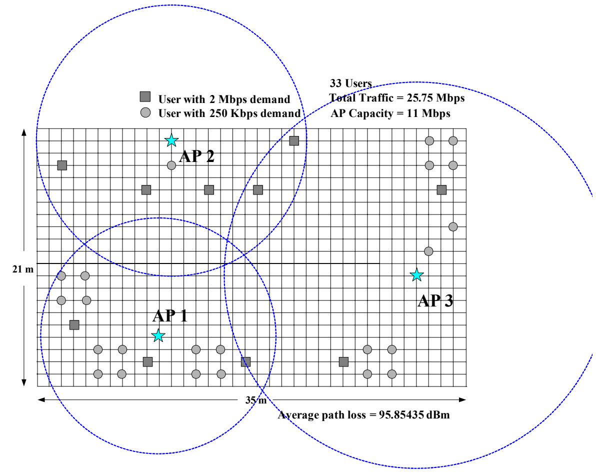

Figure 3: Network design using CSP with 3 access points

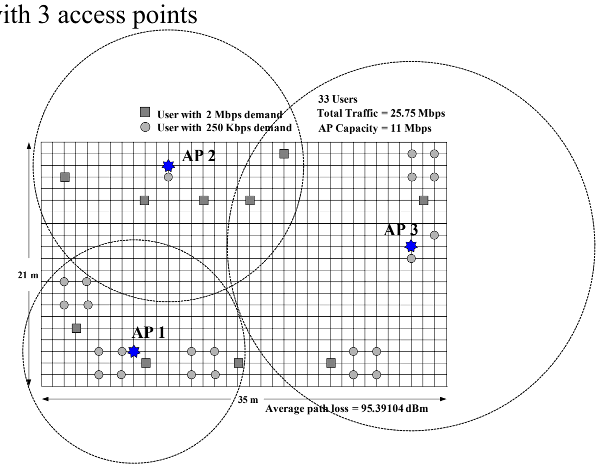

Figure 4: Simulation network design using GA with 3 access points

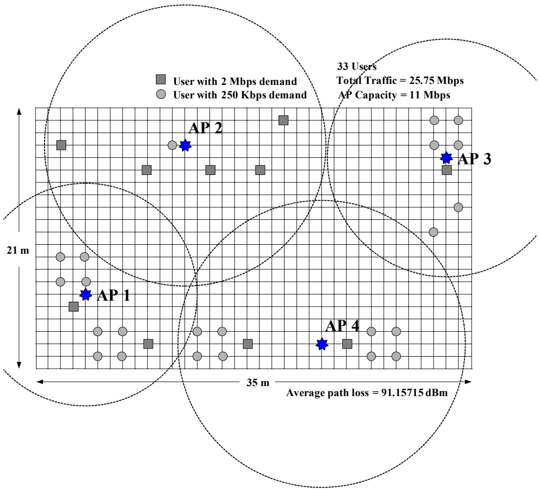

Figure 5: Simulation network design using GA with 4 access points