Coverage in WLAN: Optimization Model and Algorithm

S. Kouhbor, J. Ugon, M. Mammadov, A. Rubinov, A. Kruger
School of Information Technology and Mathematical Sciences
University of Ballarat, Victoria, Australia, 3353
E-mail: skouhbor@students.ballarat.edu.au

Abstract

When designing wireless communication systems, it is very important to know the optimum numbers of access points (APs) in order to provide a reliable design. In this paper we describe a mathematical model developed for finding the optimal number and location of APs. A new Global Optimization Algorithm (AGOP) is used to solve the problem. Results obtained demonstrate that the model and software are able to solve optimal coverage problems for design areas with different types of obstacles and number of users.

Keywords: WLAN, access point, design area, global optimization, shadow fading

1 Introduction

Wireless Networks offer many advantages over transitional wireline local area networks in areas such as scalability, mobility, and elimination of wiring reconfiguration. For reliability and economic reasons, APs should be strategically located so that only the desired areas of the building are covered. Finding Optimal number and placement of APs is complicated due to indoor propagation losses that are highly dependent on the type of the building and the composition of walls.

Recently, optimization techniques have attracted the researchers [1] - [15] because they allow to avoid numerous measurements and other expensive physical experiments. Some of researchers [1] - [6] used discrete optimization models to find the position of APs. In this case, the design area is divided into rectangles (grids). APs are only allowed to be placed on the points of the grid. To obtain satisfactory results, the size of the grid must be sufficiently small. However, in this case, the dimension of the problem can be very high. For this reason other authors [7] - [11] prefer continuous mathematical models posing no restrictions on the position of APs.

In the current paper we consider a problem of minimizing total path losses. The objective function is discontinuous due to the presence of obstacles. A new Global Optimization Algorithm (AGOP) [16] , [17] is used to solve the problem. AGOP does not require gradient (or gradient like) information (see [18]) and can be applied to a wide range of functions.

The paper is organized as follows: Section 2 describes optimization model, Section 3 explains methods for solving the problem at hand. Testing and results are discussed in Section 4 and 5. The final section summarizes the paper and discusses future research.

2 Optimization Model

2.1 Notations

The following notations are used in description of the optimization models:

a_j, j=$1,\dots,N$	Access point (AP)
r_i, i=$1,\dots,M$	Receiver/user
$pl(a_j, r_i)$	Path loss from user r_i to AP a_j
pl_{max}	Maximum tolerable path loss

It should be noted that a_j represents the unknown coordinates of APs. Their number N is not known either. The coordinates of users r_i are assumed to be known and these users can be distributed in design area according to the design specifications.

2.2 Model Description

The objective function in this paper is based on path losses. The path loss for each receiver should satisfy the following condition:

$$\min_{j=1,\dots,N} pl(a_j, r_i) \le pl_{max} \quad \forall i = 1, ..., M. \tag{1}$$

Constraint (1) states that path loss is evaluated against the maximum tolerable path loss pl_{max}. This ensures that the quality of coverage at each receiver location is above the given threshold. This given value, pl_{max} can be calculated by subtracting receiver threshold (R_{th}) from transmitter power (P_t).

$$pl_{max} = P_t - R_{th}. \tag{2}$$

The above inequality (1) can be expressed in the equality form as:

$$\left(\min_{j=1,\ldots,N} pl(a_j, r_i) - pl_{max} \right)^+ = 0, \tag{3}$$

where $(\alpha)^+ = max(\alpha, 0)$.

Therefore, a solution $(a_1, \ldots, a_N)$ is feasible if and only if:

$$\sum_{i=1}^{M} \left(\min_{j=1,\ldots,N} pl(a_j, r_i) - pl_{max} \right)^+ = 0 \tag{4}$$

2.3 Finding Number of APs

Initially we set the number of APs to 1:N = 1; then the necessary number of APs is found through the following steps:

1. Try to minimize the function in the left hand side of (4);
2. If the minimal value is 0, then N is the desired number;
3. Otherwise, N is increased by 1: N = N +1;
4. Go to step 1.

2.4 Path Loss Model for Obstructed Environments

The path loss function in free space at a distance, $d(a_j, r_i)$, greater than reference distance (d_0) is given by [19] - [21]:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 20 \log \left(\frac{d(a_j, r_i)}{d_0} \right). \tag{5}$$

The RF (radio frequency) path between transmitter and receiver is affected by the distance between the two terminals and the type and number of obstacles (walls, doors, windows, furniture, etc). Thus, including loss caused by partitions (fixed and moveable walls) in path loss model (5) can be written as [19] - [21]:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 20 \log \left(\frac{d(a_j, r_i)}{d_0} \right) + \sum n_{sp} l_{sp} + \sum n_{hp} l_{hp}. \tag{6}$$

where n_{sp} represents the number of soft partitions of a particular type and l_{sp} represents the loss in dB attributed to a particular soft type partitions, n_{hp} represents the number of hard partitions related to a particular type and l_{hp} represents the loss in dB associated with a particular hard type partitions.

Note that function (6) is discontinuous because of the presence of the obstacles.

2.5 Log Normal Shadowing

Formula (6) does not consider that the signal received by receiver could be different for two receivers that have the same distances from transmitter. This difference is caused by different environmental clutter that may be vastly different at two different locations having the same distance from transmitter. Formula (6) provides the mean value of the signal strength that can be expected when the distance between receiver and transmitter is d. The actual signal strength received by receiver may vary around this mean value. Measurements have shown that the path loss $pl(a_j, r_i)$, measured at any distance d at a particular location is random and distributed log-normally about the mean distance-dependent value. Taking this into account, path loss function can be written as [19]:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 20 \log \left(\frac{d(a_j, r_i)}{d_0} \right) + \sum n_{sp} l_{sp} + \sum n_{hp} l_{hp} + X_\sigma, \tag{7}$$

where X_σ is a zero mean Gaussian distributed random variable measured in dB with standard deviation σ also in dB.

This variation or loss of signal strength due to blockage or absorption in the environments from points of equal distance to transmitter is referred to as *shadow fading*. To compensate for unpredictable shadowing a Gaussian random variable is added to path loss.

3 Solution of the Model

As we aim to limit ourselves to continuous search in the design area, we will not discuss discrete optimization algorithms [5] , [6].

Direct search methods seem to be the best option for solving problem at hand [8], but these methods are suitable for continuous functions only. The problem at hand is not continuous [1] , [6] , [8]. The reason for this discontinuity is due to receive power that at a single point may exhibit discontinuities because of a tiny change in the position of users or AP that can happen.

The function in the left hand side of (4) is also nondifferentiable and nonconvex. Therefore, standard powerful optimization techniques (Newton based, quasi-Newton methods, conjugate gradient search method [7], steepest descent method [13]) cannot be applied to the problem at hand.

A few authors [14] , [15] have used genetic algorithms to solve the problem. Although they do not require the knowledge of gradients, they are highly dependent upon starting conditions and algorithm parameters. While they could be an option for smaller area, they would not be applicable to real situations since a large number of function evaluations is required.

We use the new Global Optimization Algorithm (AGOP), developed at the University of Ballarat, to solve the problem. The description of this method can be found in [16] , [17]. AGOP is designed for solving unconstrained continuous optimization problems. It can be applied to a wide range of functions, requiring only function evaluations to work. Operation of AGOP is explained in the following subsection.

3.1 Operation of AGOP

Consider the problem:

$$\text{minimize} \quad f(x) : R^n \to R, \quad \text{s.t} \quad x \in B,$$

where B is a given box constraints. AGOP must first be given an initial set of points, say $\Omega = x_1, ..., x_q \subset R^n$. A suitable choice for it can be generated from the vertices of the box B.

Suppose that $x_\star \in \Omega$ has the smallest value of the objective function, that is, $f(x_\star) \leq f(x)$ for all $x \in \Omega$. A possible approach has been developed for finding possible descent direction v at the point $x_\star$ (see [16] for details). An inexact line search along this direction provides a new point $\hat{x}_{q+1}$. A local search about $\hat{x}_{q+1}$ is then carried out. This is done using the *local variation* method. This is an efficient local optimization technique that does not explicitly use derivatives and can be applied to nonsmooth functions. Letting x_{q+1} denote the optimal solution of this local search, the set Ω is augmented to include x_{q+1}. Starting with this updated Ω, the whole process can be repeated. The process is terminated when v is approximately 0 or a prescribed bound on the number of iterations is reached. The solution returned is the current $x_\star$, that is, the point in Ω with the smallest cost.

4 Testing

We could not compare our solutions with the solutions found in all other research papers, as the details of building used for test were not available. However, we compared our solutions for two floor plans tested in [15] and [1]. Results are reported in [22].

In this paper we report the results obtained for a new building at Mount Helen Campus of the University of Ballarat that is going to be equipped with WLAN. The floor plan has dimension of 75.6 m by 23.2 m. The exterior walls are windows with metal frames. Loss associated to windows is considered to be 5 dB. The interior walls are of plaster type with metal stud. Loss associated to each wall and door is considered to be 6 dB and 3 dB respectively. Fig. 1 shows the floor plan with walls of different attenuation factor shown with lines of different thickness and position of 402 users. Specifications of one model of APs developed by Cisco (Aironet 1100 series) [23] is used to test the model. This gives us the opportunity to examine the model with wide range of values of P_t and R_{th} to find the effect of AP parameters on the number of APs.

4.1 Static APs and Mobile Users

The goal of the solution to the optimization problem is to provide coverage for demand areas, that is, wherever users need coverage. The numbers and coordinates of users in the demand areas are set by design specification while the numbers and location of APs are not known and they are to be found by the program. Once, the numbers and placement of APs are found, they are supposed to be installed permanently. We assume that after installation of APs, their numbers and placement will not change even if the numbers and coordinates of users change in any particular place. This is a good and reasonable assumption for lowering the cost of deployment. For this reason, APs will be static in their placement once they are installed. Although they are static, they have to cover the users at all times, anywhere that they move in the demand areas. This means that we add “potential users” anywhere they require coverage for conducting activities according to design specification. In the next section, an example supporting the movement of users will be given.

5 Results

AT first coverage is not provided for three laboratories because they are equipped with PCs. When P_t = 20 dBm and $R_{th} \leq$ -80 dBm, one AP can cover all users in the demand areas. Fig. 2 shows the position of APs when R_{th} = -88 dBm. In order to show the position of APs clearly, users are removed once the number and position of APs are found. When P_t is kept constant and R_{th} is increased, the number of APs required are increasing due to coverage distance that is decreasing. Fig. 3 shows the placement of APs when P_t = 20 dBm and $R_{_{th}}$ = -55 dBm. The value of P_t has effect on the number of APs when R_{th} is kept at high values. For example, when P_t = 10 dBm and R_{th} = -55 dBm, 4 APs are required to cover the users. This is shown in Fig. 4. As can be seen from the results, the model and algorithm responds to the location of users, that is, most of APs are placed where the majority of users are located in the cases where more than one AP is required. From the capacity point of view, it appears from the results that the number of APs found in each case are not sufficient for 402 users. It should be noted that the capacity is not included in the optimization model as a constraint. It is also assumed by the model that 402 users are accessing APs at once in every case. In reality, it is hard to imagine that in a small building 402 users are accessing the APs together.

5.1 Effect of Number of Users on the Number of APs

In order to investigate the effect of number of users on the number of APs, it was decided to provide coverage for the laboratories as well. As a result, the number of users were increased to 510. Conducted test indicated that when the value of P_t is high and R_{th} is low, number of APs remains the same as the result obtained for 402 users. This is due to coverage distance that is very high and not many walls with high attenuation between AP and users. However, when P_t decreases and R_{th} increases, the number of APs increases. For example, Fig. 5 shows that when P_t = 10 dBm and R_{th} = -55 dBm, 5 APs are needed to cover all users in compare to 4 APs that were needed for 402 users.

5.2 Effect of Standard Deviation on the Number of APs

The range of values of standard deviation for the path loss values predicated is 8 to 10 dB at 2.4 GHz [21]. Therefore, the value of X_σ in (7) was chosen to be 8 dB. Test was conducted for all the parameters of APs. It was found that for high values of P_t and low values of R_{th}, the number of APs obtained are the same as when shadowing was not considered. The only interest point that was observed was this that the previous placement found in subsection 4.4 does not cover the users any more due to change of path losses. When P_t = 20 dBm and R_{th} varied between -95 to -90 dBm, one AP can cover all users. When shadowing effect was not considered, the same number of AP was required when R_{th} varied between -95 and -80 dBm. As R_{th} increases from -84 to -72 dBm, the number of APs are increasing to two. Fig. 6 shows that as R_{th} increases further to -55 dBm, 4 APs are required in compare with 3 APs when shadowing was not included. When P_t decreases, again more APs are required. For example when P_t = 15 dBm and R_{th} = -60 dBm, 4 APs are required in compare with 3 APs that were required without the inclusion of shadowing. The reason for an extra AP required is that by adding the standard deviation to path loss model, the cell size or coverage distance decreases, therefore, more APs are required to cover the users. As one can notice, the capacity for users increases when shadowing effect is included in path loss.

5.3 Mobile Users

Fig. 7 shows an example where a user can move to different demand areas while its coverage is guaranteed by the nearest AP. In this particular example since P_t = 15 dBm and R_{th} = -55 dBm, the pl_{max} = 70 dB. As can be seen in this figure, user1 who is located in tutorial room is covered only by AP2 because its path loss to this AP is 68.07 dB which is less than 70 dB. Calculated path loss indicate that the coverage of this user is assured if this user moves along the path shown with solid line. It should be noted that this is not the only path that this user can move. In fact any where that the other users are located, this user can move as well. Calculated path loss shows that if this user moves along the path shown with dashed line, the coverage in some parts is not assured. For example, at position 7 (P7), the path loss from this user to AP1 is very high (81.74 dB) due to 3 walls that are between the user and AP.

5.4 Optimal Number

In order to show that the obtained number of APs is optimal, the proof for the case where P_t = 15 dBm, R_{th} = -55 dBm, and σ = 8 dB is given. Fig. 8 shows the position of APs. Path loss model (7) is used to calculate the coverage distance and path losses between users and APs. This path loss is compared with maximum path loss pl_{max} (2).

If path loss is less than or equal pl_{max}, then the user is covered. As can be seen in Fig. 8, one AP is provided for each room in the left hand side. These APs can cover the users in open space area on the left top side of the building as well. The reason for a single AP in each room is due to short coverage distance. When there is only one wall with attenuation of 6 dB between the AP and the users, the coverage distance for AP is 12.561 m. The distance between the two rooms is 15 m. Therefore, a single AP cannot cover two rooms. The AP in the large lecture theater can cover all the users. Since there are no walls between these users and AP, the coverage distance of AP is 25.06 m while the maximum width of this room is 12 m. The AP on the top right hand side is covering most of the users in the open space area. Some of the users in this area such as the one with the coordinates of x=68 and y=8 are not covered by this AP. Calculated path loss for this user to the AP is 71.83 dB which is more than pl_{max}. However, the path loss from this user to the AP in the bottom right hand side is 69.24 dB which is lower than pl_{max}. Therefore, the AP in the low right hand side of building is covering the users in the open space area, one room and some users in the open space area on the top.

6 Conclusion and Further Research

This paper investigates location problems based on minimizing a nonnegative objective function that is 0 only when the coverage of the entire area or users is assured. A new global optimization algorithm was used to solve the optimization problem. The model was tested on a building with walls of different attenuation and different values of P_t and R_{th}.

Results obtained in all cases indicate that the model and algorithm described above can be used for finding optimal number of APs for coverage. It is observed that the optimal number of APs depends on the number of users and their location, that is, most of APs are placed where the majority of users are located in cases where more than one AP is required. It was also found that the number of walls, size of building, and the values of P_t and R_{th} have effect on the number of APs.

In this paper the effect of standard deviation (σ) on the number of APs was particulary investigated. It was observed that the number of APs increased when σ was added to path loss. Path loss model was used to find the coverage distance and maximum path loss between users and AP. Using these values, we were able to validate the obtained number of APs. In order to consider the movement of users during the day, users should be placed wherever they require coverage. Results indicated that higher capacity for users can be obtained by decreasing the power of AP, as it was expected.

Through results that have been obtained so far for different types of buildings, it is clear that providing coverage for the design area/users is not sufficient in the design of WLAN. It is important to provide sufficient capacity, that is, to limit the number of users communicating with an AP at a time in order for them to be able to conduct their critical activities. Although, capacity can be obtained by lowering the power of AP and increasing receive threshold, better and more accurate results can be obtained when capacity issue is incorporated into optimization model. Therefore, further research will involve extending the optimization model for obtaining higher capacity for users. Load balancing between APs can assist in achieving capacity.

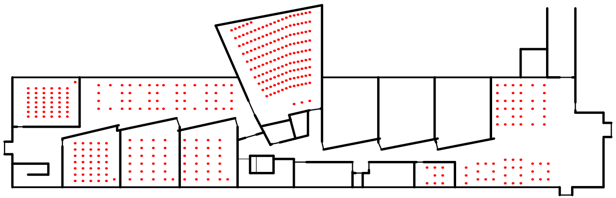

Figure 1. Layout of the floor plan

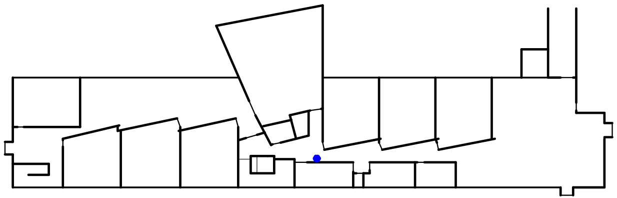

Figure 2. Position of AP when P_t=20dBm and R_{th}=-88dBm

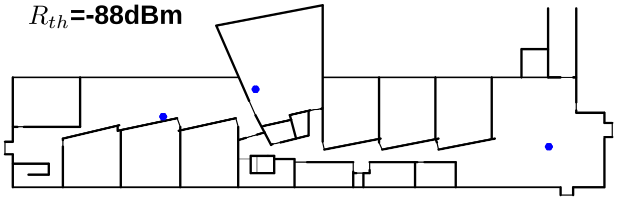

Figure 3. Number of APs when P_t=20dBm and R_{th}=-55dBm

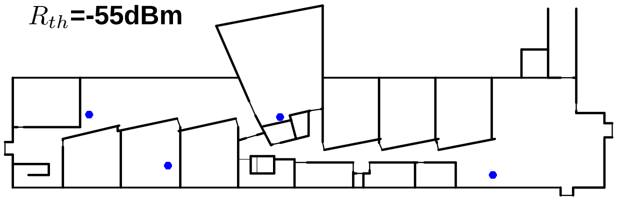

Figure 4. Number of APs when P_t=10dBm and R_{th}=-55dBm

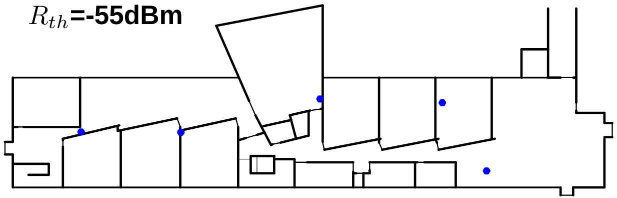

Figure 5. Number of APs for 510 users

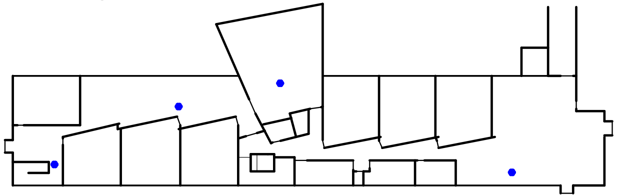

Figure 6. Number of APs when P_t=20dBm, R_{th}=-55dBm, and σ=8dB

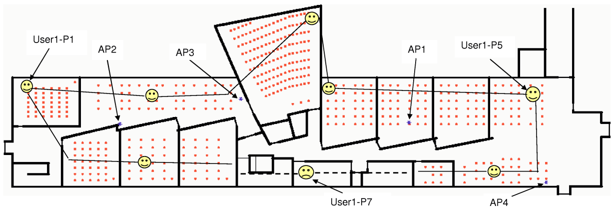

Figure 7. Coverage of mobile user

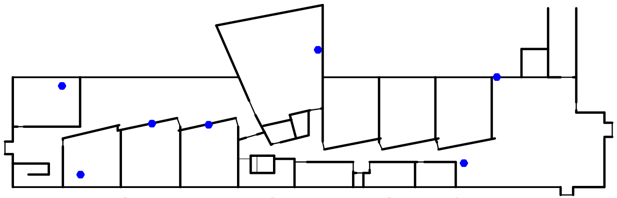

Figure 8. Optimal number of APs

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