실내 무선 메쉬 네트워크에서의 간섭 최소화를 위한 메쉬 라우터 배치 기법
(A Mesh Router Placement Scheme for Minimizing Interference in Indoor Wireless Mesh Networks)

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요 약 무선 메쉬 네트워크는 쉬운 설치와 향상된 커버리지로 인해 많은 관심과 연구가 진행되고 있다. 예를 들면 메쉬 네트워크에서 throughput을 향상시키는 라우팅 프로토콜에 관한 연구나, 메쉬 링크의 품질을 측정하는 방법 등 다양하다. 하지만 이러한 연구들 중 대부분은 메쉬 라우터의 위치가 고정되어 있다고 가정한다. 하지만 실내 메쉬 네트워크의 경우 관리자가 메쉬 네트워크를 독점적으로 관리하기 때문에 설치 시에 메쉬 라우터를 설치할 위치를 마음대로 결정할 수 있다. 따라서 처음부터 메쉬 네트워크의 성능을 고려하여 메쉬 라우터를 설치하는 것은 성능향상에 필수적이다. 이 논문에서는 유전자 기반 최적화 알고리즘을 바탕으로 메쉬 네트워크의 특성 (간섭, 패킷 전달 토폴로지 등)을 고려한 메쉬 라우터 위치 선정 기법을 제시한다. 기존에 메쉬 네트워크는 아니지만 다양한 무선 내트워크에서 기지국이나 AP등을 설치하는 문제가 연구되었고, 메쉬 네트워크의 고정된 메쉬 라우터 집합에서 게이트웨이를 선택하는 문제 등이 연구되었지만, 메쉬 라우터의 위치를 선택하는데 있어서, 메쉬 라우터들의 위치나 메쉬 라우터 상에서의 패킷 전송 토폴로지에 의한 간섭을 고려한 연구는 없었다. 다양한 시뮬레이션을 통해 이 논문에서 제시된 기법이 랜덤 선택 기법에 비해 30-40%의 향상을 달성하였음을 보였다.

키워드 : 무선 메쉬 네트워크, 메쉬 라우터 배치, 유전자 알고리즘, 간섭, 경로 손실 모델

Abstract Due to the ease of deployment and the extended coverage, wireless mesh networks (WMNs) are gaining popularity and research focus. For example, the routing protocols that enhance the throughput on the WMNs and the link quality measurement schemes are among the popular research topics. However, most of these works assume that the locations of the mesh routers are predetermined. Since the operators in an Indoor mesh network can determine the locations of the mesh routers by themselves, it is essential to the WMN performance for the mesh routers to be initially placed by considering the performance issues. In this paper, we propose a mesh router placement scheme based on genetic algorithms by considering the characteristics of WMNs such as interference and topology. There have been many related works that solve similar problems such as base station placement in cellular networks and gateway node selection in WMNs. However, none of them actually considers the interference to the mesh clients from non-associated mesh routers in determining the locations of the mesh routers. By simulations, we show that the proposed scheme improves the performance by 30-40% compared to the random selection scheme.

Key words : wireless mesh network, mesh router placement, genetic algorithm, interference, path loss model

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1. Introduction

During the past decade, wireless mesh networks have been gaining popularity due to its extended coverage and ease of deployments. In wireless mesh networks, mobile nodes (called mesh client) communicate with mesh routers, which act similar to access points in a typical WiFi WLAN. The mesh routers communicate among themselves over wireless links and the packets are forwarded to and from a special mesh router (called gateway), which is connected to a wired network, thus to the Internet [1].

The research issues in WMNs include efficient routing protocols and link quality metrics. In these works, they assume that the locations of the mesh routers are pre-determined. This assumption is valid because many WMN testbeds are deployed by voluntary end users [2] so that the locations are not controllable by a operator. However, for some mesh networks such as Indoor WMNs, the locations of the mesh routers can be determined by the operators. So by choosing the appropriate locations of the mesh routers, we can improve the performance of WMNs. Some of the existing works try to solve problems similar to this work. For example, [3] tries to select the gateway nodes among the pre-located mesh routers. Slightly different to [3], [4] tries to select the gateway node positions in arbitrary locations not confined to the pre-located mesh routers. However, these works do not determine mesh router positions in arbitrary locations.

In this paper, we propose a mesh router placement scheme in an Indoor environment considering the interferences from the non-associated mesh routers. Placing a base station in a cellular network or an AP in WLAN [5] are similar to our work, but they are different in that they only try to make sure that the areas are covered not considering the interferences. In the proposed mesh router placement scheme, at each mesh client, we compute the signal strength from the associated mesh router and the interference from *non-associated* mesh routers to compute SINR (signal to interference and noise ratio). Then, we try to find a solution that maximizes the number of mesh clients with SINR higher than a threshold. We use a simple genetic algorithm (GA) [6] to solve this simple optimization problem.

The remainder of the paper is organized as follows. In Section 2, we introduce some existing related works and a brief description of GA. Section 3 describes our mesh router placement scheme. Preliminary simulation results are given in Section 4. We conclude the paper in Section 5.

2. Background

WMNs in an indoor environments are recently gaining popularity. [7] proposes a packet scheduling algorithm in an indoor WMN, where each mesh router has a directional antenna. Each mesh client measures the SINR values from the mesh routers for 8 possible directions. Based on the distribution of SINR values, a scheduling algorithm is proposed so that the interference among multiple transmission are reduced. [8] evaluates the feasibility of WMN in indoor environment by using a test in a multi-story office building and shows that WMN in a indoor environment is feasible. These works assume that the position of the mesh routers are fixed and given. The performance of a WMN highly depends on the interference of the environments. Thus many works on interference modeling and measurements have been proposed [9].

Genetic Algorithm (GA) is an optimization algorithm [6]. The basic idea of GA is as follows. First, a set of initial solutions are created to form the initial solution pool. Each solution contains a set of components (in our paper, the mesh router locations). At each iteration (or generation in GA jargon), the existing solutions in the pool are used to develop new solutions by using mechanisms such as *crossover* and *mutation*. In crossover, two solutions (called parents) are selected and exchange some of their components. In mutation, a solution is randomly transformed into another solution by modifying the components. The new solutions are evaluated by a fitness function and replace their parent if they are better. This process repeats till a pre-defined termination condition.

3. Mesh Router Placement Scheme

In this section, we describe the mesh router placement scheme. Basically, given the placement of mesh routers (or APs) and the positions of mesh clients, at each mesh client we compute the signal strength from its *associated* mesh router. The total interference from all the *non-associated* APs are also computed. Based on the signal strength and the total interference, we compute SINR. In this paper, the goodness (*fitness*) of a placement scheme is defined as the number of mesh clients with SINR higher than a threshold. We use the GA based optimization scheme to find an acceptable solution with the given fitness function. Measuring the signal strength and the interference is solely based on the radio path loss model adopted from [9].

3.1 Path loss model

The average path loss (in dB) at a node of distance d from the signal source in a free space is defined as follows.

$$\overline{PL(d)} = L(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) \quad (1)$$

d_0 is the reference distance and $L(d_0)$ is the reference path loss. We assume that d_0 is 1m and $L(d_0)$ is 40.04dB [5]. n is the attenuation factor subject to the environmental characteristics. We assume n=2, which represents a free space. In an environment with obstacles, the path loss is enlarged by the characteristics of the obstacles as follows [5].

$$\overline{PL(d)} = L(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + \sum_i L(O_i) \quad (2)$$

In short, the average path loss is added by the losses due to the obstacles. Depending on the characteristics of the obstacles, the actual loss values vary, but for a soft partition, the value is about 3dB and for a hard partition, the loss is about 6dB [5]. Furthermore, the path losses in (1) and (2) are the average path losses and the actual path loss follows a log-normal distribution, but we do not go into the details of the log-normal radio model.

Since the average path loss is given, we can compute the received signal strength (in dBm) at a node of distance d.

$$P(d)[dBm] = P(0)[dBm] - \overline{PL(d)}[dB] \quad (3)$$

$P(0)$ is the power level at which the source AP transmits the signal. Since the unit of $P(d)$ is dBm, the signal strength, S(d), in mW (mili Watts) is defined as follows by the definition of dBm.

$$S(d) = 10^{\frac{P(d)}{10}}\, mW \quad (4)$$

3.2 Signal to Interference Ratio

Each mesh client receives the signal from its associated mesh router, and the signals from other APs are considered as interferences. The signal strength from an AP i, whose distance is d_i. is similarly defined by (3) and (4)

$$P(d_i) = P(0) - \overline{PL(d_i)},\ S(d_i) = 10^{\frac{P(d_i)}{10}}\, mW \quad (5)$$

For a WMN with n APs, there are n-1 such interfering APs, thus the total interference, $SI(d)$, received at a node of distance d from its associated AP is as follows.

$$SI(d) = \sum_{i \neq a} S(d_i) \quad (6)$$

Here a is the associated AP d_i is the distance from the node to the AP i. It should be noted that the additive sum, (6), represents the maximum possible interference because the signals can be cancelled out by themselves and the APs are not always ON (i.e. transmitting signals). The actual "ON" probability depends on the specific MAC protocols (CSMA/CA, TDMA, etc). Thus, in this paper, instead of estimating the dynamic "ON" frequency or probability, we take a topology based approach to compute the *relative* "ON" frequency of each AP. We assume that WMNs have single gateway and the downstream traffics to each mesh client are equal.

The mesh clients associate themselves with the nearest APs (actually, the APs with the strongest signals). To compute the relative "ON" frequency, we count the number of mesh clients that each AP has. Since the actual downstream paths to the mesh clients form a tree, there is only one path from the gateway to each mesh client. Depending on the topology, some APs may forward more packets than others. Thus, we can compute the weight (or the forwarding burden) for each AP, i.e., the number of mesh clients that an AP serves for the downstream packet forwarding. Basically the number is the sum of mesh clients that the downstream APs have along the tree. For example, Fig. 1 shows a simple topology with 1 gateway, 6

APs, and 13 mesh clients. The number pair on each mesh router shows the number of mesh clients that it has and the total number of mesh clients on the subtree rooted at the mesh router. Mesh router A has 1, 6 because it has 1 mesh client directed associated with itself and is used for the packet forwarding to 6 mesh clients (1 for A, 2 for B, 3 for C).

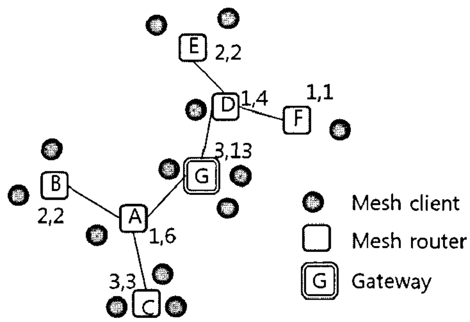

Figure 1 A Mesh Topology

The second value actually represent the relative frequency at which a mesh router is transmitting packets to its downstream nodes. To incorporate the effect of such relative frequency to (6), we compute the relative weight compared to the sum of all the weights. For example, the total weight is 31 and the relative weight of mesh router A in Fig. 1 is 6/31=0.194. Let W_i be the relative weight at a mesh router i. Note that the sum of W_i is 1. Then,

$$SI(d) = \sum_{i \neq a} W_i S(d_i),$$
$$\mathrm{I(d)[dBm]} = 10\log_{10}(SI(d)) \quad (7)$$

It should be noted that (7) is the reference average interference at which only one packet is being forwarded at the given time. Since the traffic volume varies, the actual interference can vary, but (7) accounts for the relative activities of the APs. By (3) and (7), we compute the SINR as follows.

$$SINR(d)[dB] = P(d)[dBm] - I(d)[dBm] \quad (8)$$

In SINR model, for a node at distance d to successfully receive the signal, the SINR value should be larger than a threshold and the received power itself should be larger than a threshold. Let dth be the threshold of SINR and Rth be the minimum required power. The following two conditions should be met for a signal to be successfully received.

$$SINR(d) = P(d) - I(d) \geq dth \quad (9)$$
$$P(d) \geq Rth \quad (10)$$

3.3 GA based optimization

Planning the placement of the mesh routers is done by the GA based optimization. Let N_r be the number of mesh routers. We first randomly select K initial solutions for the problem. Each solution contains the positions of the N_r mesh routers in the area. For each solution, the fitness is defined as the number of mesh clients that satisfy (9) and (10). To compute the fitness, we first choose the centroid node among the mesh routers as the gateway node. Then, we compute the downstream forwarding tree by simply applying Greedy perimeter stateless routing (geometric routing). Then, the weights of the mesh routers are computed and for each mesh client, (9) and (10) are computed. The *fitness* of a placement scheme is defined as the number of mesh clients that satisfy (9) and (10).

At each iteration, two solutions (called parents) are randomly chosen based on the ranks of the fitness values in such a way that solutions with high fitness values have high selection probability. Then, the crossover and mutation are applied to the parents to generate two child solutions. Among the two parent solutions and the two child solutions, the two best solutions replace the two parent solutions. When the number of iterations that do not improve the best fitness exceeds a certain threshold, the optimizer stops. To improve the initial fitness, we also choose the initial K solutions by running a clustering algorithm so that the positions of the mesh routers are the centroids of the N_r clusters. This refinement may produce better initial solutions.

4. Performance Evaluation

To investigate the performance of the proposed scheme, we compare our schemes (the basic scheme and the cluster based scheme) with an intuitive approach, Random scheme and Simulated Annealing (SA) optimization method. In Random scheme, we randomly generate $S*r$ solutions and choose the best one. S is the number of solutions evaluated by our GA method. Thus, Random scheme evaluates r times more solutions than our scheme does. In SA scheme, we explore the solution space starting from a randomly chosen initial solution. We choose a next solution based on the current solution by slightly modifying the current solution. For a detailed description of SA, refer to [10].

We evaluate the performance of the proposed scheme with various scenarios. In the evaluations, the default values of the parameters are N_r=20, K=30, r=1, dth=20dB, and Rth=-80dBm unless otherwise mentioned. The transmission power of each AP is 20 dBm. We randomly generate 200 mesh *clients* in an area of 200m · * 100m. In constructing the downstream tree, we only use the wireless links among the mesh routers, of which distances are less than 50m. For ease of evaluation, we assume that there is no obstacles in the area, so we use (1) instead of (2).

First, we investigate the effect of K on the optimization performance of GA algorithm. As can be seen in Fig. 2, the fitnesses of GA (basic GA algorithm) and GA-CL (GA with clustering) are higher than random methods (Ran and Ran-CL) and stable over different K values. It implies that with small number of initial solutions (like 20), GA can find a reasonably good solution. Simulated Annealing scheme (SA) shows a little worse performance than GA. The reason might be because the objective function (fitness) is not a continuous function while SA is good at continuous function optimization.

Next we look at the impact of the number of

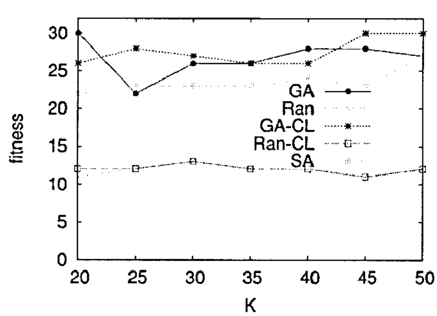

Figure 2 Fitness over the number of initial solutions, K

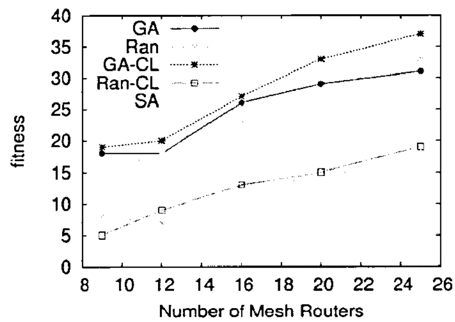

Figure 3 Fitness over the number of mesh routers, N_r

mesh routers in the network. As can be seen in Fig. 3, as the number of mesh routers increases, the number of "good" mesh clients increases because the distances to the associated mesh routers become smaller so that the signal strengths from the associated APs increase for the mesh clients.

The performance, however, is mostly affected by the threshold *dth*. As can be seen in Fig. 4, as *dth* increases, the number of "good" mesh clients decreases dramatically. This implies that new antenna technology that can capture the signal with low threshold can decrease the effect of the interferences in the WMNs.

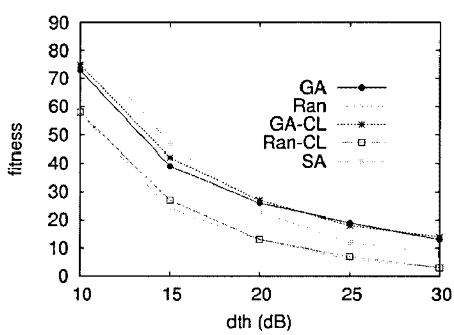

Figure 4 Fitness over *dth*

One thing to note is that the fitness of the Random scheme does not increase much as the parameter r increases. As can be seen in Fig. 5, even though 20 times more solutions are tested, the fitness of Random scheme is still much less than the fitness of GA based schemes. This clearly shows that the proposed GA based optimization scheme indeed pursues optimal solutions.

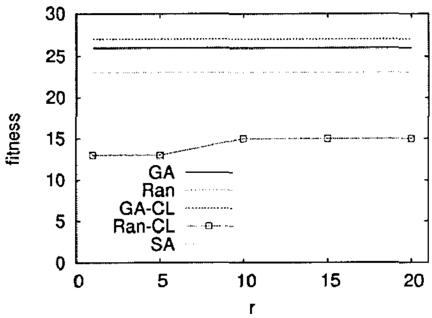

Figure 5 Fitness over *r*

5. Conclusion

In this paper, we propose a GA based optimization procedure to find the locations of mesh routers in WMNs by considering the interference among the mesh routers and the packet forwarding topology. In our preliminary evaluation, the proposed scheme outperforms the performance of the random selection schemes with high margin.

Since this paper provides only preliminary result, in the future, we apply our method to a more realistic indoor WMN environment containing obstacles. We also investigate the effect of such mesh router placements on the throughput.

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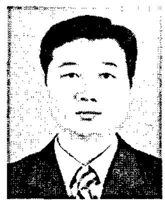

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