

Research on backbone node deployment for Wireless Mesh Networks in dynamic environments

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Abstract. Wireless Mesh Network is a type of wireless networks in which demands of bandwidth for users has mobility. The backbone node placement of wireless mesh networks in a dynamic scenario is investigated, and the TSDPSO algorithm is used to adapt the dynamic environment, which updates node deployment location to adapt to changes in demand if it detects environmental changes at the beginning of the cycle time. In order to meet the demands of bandwidth for users and network connectivity, particle swarm optimization algorithm is employed to select the gateway location, then nodes to the backbone network is added constantly until all requirement is covered. The experimental results show that algorithm could get effective solution in dynamic environment.

1. Introduction

Wireless Mesh Network (WMN) is a type of multi-hop wireless network, which is different from traditional wireless network. In the era of wireless network, it has received the attention of a large number of researchers at home and abroad. Mesh Router (MR), Mesh Gateway (MG) and Mesh Client (MC) constitute the basic framework of WMN. MR has access and forwarding function in the network, it provides network services for MC within the coverage, and forwards data to MG for other MR in multi-hop networks. MG is a special kind of MR, it not only has the function of MR in wireless Mesh network, also assume the connection task with Internet by wired connection. MC is the terminal device that accessing network by MR, such as notebooks, mobile phones, etc. The backbone node deployment for WMN in dynamic environment is mainly introduced.

The literature [2] proposes a WMN router deployment greedy algorithm named NF-Greedy, which is based on network flow. In order to minimize the number of deployed MR, the algorithm selects the node with the largest weight in the MR candidate location set by iterative method, and uses the network flow method to solve the problem. In the literature [3], the problem of WMN gateway node placement is abstracted as the problem of geometric K- center, and an adaptive particle swarm optimization algorithm is proposed to solve the problem of gateway node deployment in order to minimize the path length between nodes and gateways. The literature [4] is for the WMN backbone network deployment optimization problems, in order to meet the condition of the minimum number of MR users which network bandwidth



demand as the goal, reference MG and MR separately position deployment plan, proposed in MG and MR solution in the condition of mutual influence.

At present, the approach of finding the optimal solution to WMN backbone network node deployment problem in the static environment has been relatively mature. But in real life, WMN is always in a dynamic environment, MR and MC has mobility. Therefore, the deployment of WMN backbone network nodes in dynamic environment is more meaningful. In order to meet the requirement of network connection and coverage in the dynamic environment, a particle swarm optimization algorithm is proposed to implement the deployment of MR by the literature [5]. However, the study assumes that the deployment location of MR can be moved freely, which is too costly to implement in real life. A new research to solve the deployment problem of WMN backbone nodes in dynamic environment should be proposed.

2. Problem Definition

In real life, WMN is in a dynamic environment. And in different time, MC will be in different requirements and geographical location. After the change, the user demand is stable. Therefore, when the demand changes are detected, the location of the backbone nodes is adjusted to meet the demand changes. The environment will be detected when the new cycle begins. The deployment of the backbone node location can be seen as the deployment of nodes in a two-dimensional plan. It is assume that there are enough suitable backbone node deployment locations, and the user's demand for the network has been discretized into the user needs.

2.1. Definitions and Variables

It is assumed that the wireless network communication is reliable, and the communication between nodes does not interfere with each other, then set the following variables.

R_c : Node coverage radius. A circular region centered on the node with R_c radius. The node can provide services for MC in this area.

R_c : Node communication radius. A circular region centered on the node with R_c radius. The node can communicate with other nodes in this area.

Cap : Node access capacity, Refer to that the node provides the maximum access bandwidth for the MC covered by it.

H : Maximum hop. Refer to that to ensure the quality of communication, the maximum number of hops to the gateway communication path.

T :Cyc. Refer to that the cycle which be seted by the actual situation.

In the two-dimensional plane, WMN corresponds to a topological graph $G=(V,E)$, where $V=\{v_1, v_2, \dots, v_n\}$ represents a set of nodes in the network, Adjacency matrix $E=\{e_{i,j}|i, j \in \{1,2, \dots, n\}\}$ represents the relationship between nodes. MR Candidate (MRC), refers to the pre-selected candidate positions to deploy MR in the two-dimensional plan.

- User Demand Node (UDN), refers to user demand point after the user's bandwidth demand has been discretized, reflect the distribution of user demand in the deployment area.
- Actual coverage radius, refers to the maximum distance that a backbone node can actually provide for its coverage UDN.
- Environmental change times, refers to the number of cycles that are currently running time, i.e. the number of environmental changes.

2.2. Mathematical Model

Based on the above definitions and variables, a formal description of the problem has been presented. Optimization goal as follow.

$$\min \sum_{i=1}^n x_{i,t} \quad (1)$$

It is meant to minimize the number of deployed MR after each environmental change which on the premise of satisfying the user's bandwidth requirement and network connectivity. Constraint condition as follow.

$$\sum_{k=1}^n e_{i,k} \neq 0, \forall x_{i,t} = 1, \forall i \in \{1, 2, \dots, n\} \quad (2)$$

$$\sum_{j=1}^m d_{i,j} \neq 0, \forall x_{i,t} = 1, \forall i \in \{1, 2, \dots, n\} \quad (3)$$

$$d_{i,j} = 1, \forall y_{i,j} \neq 0, \forall i \in \{1, 2, \dots, n\}, \forall j \in \{1, 2, \dots, m\} \quad (4)$$

$$x_{i,t} = 1, \forall y_{i,j} \neq 0, \forall i \in \{1, 2, \dots, n\}, \forall j \in \{1, 2, \dots, m\} \quad (5)$$

$$\sum_{i=1}^n y_{i,j} = b_{j,t}, \forall j \in \{1, 2, \dots, m\} \quad (6)$$

$$r_{i,t} \geq 0, \forall i \in \{1, 2, \dots, n\} \quad (7)$$

$$h_{i,t} \leq H, \forall i \in \{1, 2, \dots, n\} \wedge x_{i,t} = 1 \quad (8)$$

$$p_{i,j}^k \leq x_{i,t}, \forall i, j, k \in \{1, 2, \dots, n\} \quad (9)$$

$$p_{i,j}^k \leq x_{j,t}, \forall i, j, k \in \{1, 2, \dots, n\} \quad (10)$$

$$p_{i,j}^k \leq e_{i,j}, \forall i, j, k \in \{1, 2, \dots, n\} \quad (11)$$

$$\sum_{i=1}^n p_{i,j}^k = x_{k,t}, \sum_{j=1}^n p_{i,j}^k = 0, \forall k \in \{1, 2, \dots, n\} \quad (12)$$

$$\sum_{i=1}^n p_{i,j}^k - \sum_{j=1}^n p_{i,j}^k = 0, \forall k \in \{1, 2, \dots, n\}, i \in \{1, 2, \dots, n\} \setminus \{k\} \quad (13)$$

$$\sum_{j=1}^n p_{i,j}^k \leq x_{k,t}, \forall k \in \{1, 2, \dots, n\}, i \in \{1, 2, \dots, n\} \setminus \{k\} \quad (14)$$

$$\sum_{i=1}^n \sum_{j=1}^n p_{i,j}^k = x_{k,t}, \sum_{i=1}^n \sum_{j=1}^n p_{j,i}^k = 0, \forall k \in \{1, 2, \dots, n\} \quad (15)$$

The formula (2) indicates that the selected MRC must be able to connect to the gateway via a multi hop network. Formula (3) indicates that a UDN must be present in the selected MRC coverage area. Formula (4) and (5) show that MRC provides network services for UDN if and only if UDN is within MRC coverage and MRC has deployed MR. Formula (6) indicates that all user requirements in the entire network must be satisfied. Formula (7) shows that each backbone node for its coverage of the bandwidth of the UDN cannot exceed its access capacity. The formula (8) shows that the minimum hop number of each backbone node connected to the MG through the multi hop network cannot exceed the maximum hop count. The formula (9), (10) and (11) indicate that the nodes can be connected to each other only if the nodes and nodes are selected to deploy MR and the two can communicate with each other through the path to the MG. The formula (12), (13), (14) and (15) indicate that the node must satisfy the current conditions in order to have a multi hop path connected to the MG.

3. Backbone Node Deployment Algorithm in Dynamic Environment

3.1. Backbone Node Deployment Algorithm

The deployment of MR approach is that after determining the location of MG, The node is added to the backbone network node collection from the deployable MRC collection in an iterative manner. The deployment status will be updated until all UDN bandwidth requirements have been met. According to this method, the key point is how to deploy the MR from the deployable MRC collection. In each iteration, the neighbor nodes of the current backbone network will be selected from the non-deployed MRC collection, according to the principle of maximum coverage and minimum coverage radius, the node is added to the backbone network. In order to improve the efficiency of the algorithm, cross linked list is used to store data. The steps are as follows.

Step 1. Initializes the deployed MR, the covered the UDN and other placement variables, according to the UDN and MRC coordinates to compute the demand coverage table, then update the MG collection.

Step 2. Update the deployed MR, the covered the UDN and demand association tables, calculate the maximum bandwidth requirement of the current network, determine whether the current network is equal to the total flow of traffic, if it is equal to the total flow then go to step 5.

Step 3. Compute node residual bandwidth and the minimum hop that from deployed MR to MG, then update the shortest path of backbone node and node coverage requirements table. Add node to backbone network according to above method, update available MRC collection.

Step 4. Select a node with the largest weight in the adjacent MRC collection and add it to the deployed MR collection. If there is no available adjacent MRC, select the path with the largest weight, then go to step 2.

Step 5. Evaluate deployment results, end algorithm.

The above MR deployment method is deployed at the MG location, but the location of the MG and MR is mutually affected. BPSO algorithm is used to solve the problem of MG deployment, initialize a particle swarm composed of particles, searching extreme value in D dimensional binary space. According to the optimal solution and the global optimal solution, the particle swarm is modified to obtain the optimal solution. The formula for update velocity and position of particle swarm as follow.

$$v_i^{k+1} = wv_{i,d}^k + c_1r_1(x_{pbest,d}^k - x_{i,d}^k) + c_2r_2(x_{gbest,d}^k - x_{i,d}^k) \quad (16)$$

$$z_i^{k+1} = \begin{cases} 1 & \rho < Sigmoid(v_i^{k+1}) \\ 0 & Others \end{cases} \quad (17)$$

$$\text{Sigmoid}(v_i^k) = \frac{1}{1 + \exp(-v_i^k)} \quad (18)$$

$$\text{Fitness}(Z_i) = \frac{1}{\sum_{i=1}^n x_i} \quad (19)$$

According to formula (17), when v_i^{k+1} becomes closer to v_{\max} , it is more likely for c_i to be chosen as MG. According to the formula (16) to update the particle velocity and position, the results will not meet the constraints of the number of MG. Make improvements that updating the location by the stability of sorting, which means to start the update from the candidate position the lowest stability, if the position change, delete the candidate position from the sequence, or skip the candidate position, repeat the operation until the number of MG meet the target number. To sum up, the algorithm steps are as follows.

Step 1. Randomly generate a particle size of $PopSize$, initialize the position and velocity of discrete particles.

Step 2. Deployment of MR based on MR deployment algorithm, according to formula (19) to calculate the fitness of the particle swarm.

Step 3. If there is a better fitness value, update the best location and the best position.

Step 4. Update particle velocity and position according to formula (16).

Step 5. To determine whether the maximum number of iterations, or whether the results meet the requirements, if not go to step 2.

Step 6. Output particle swarm optimal results (MG, MR position and number).

3.2. TSDPSO Algorithm in Dynamic Environment

In order to solve the problem in dynamic environment, TSDPSO algorithm has been presented. The current deployment solution will be checked that whether it can meet the network connectivity and user needs after the cycle. In the D dimension space, $pbest$ represents the particle's current optimal solution, $gbest$ represents the optimal solution of the particle in the population, x_i represents the position vector of the particle itself, and v_i represents the velocity vector of the particle itself. At the beginning of the algorithm, the population is divided into two parts, core-subgroup update the velocity and position of the particle according to the speed and position evolution formula (20) and formula (21) of the standard PSO algorithm. In order to maintain the exploration ability of the population, the differential evolution strategy is applied to the aux-subgroup, and the aux-subgroup is updated according to the following formula (21) and formula (22).

$$v_{i,d}^{t+1} = wv_{i,d}^t + c_1r_1(x_{pbest,d}^t - x_{i,d}^t) + c_2r_2(x_{gbest,d}^t - x_{i,d}^t) \quad (20)$$

$$x_{i,d}^{t+1} = x_{i,d}^t + v_{i,d}^{t+1} \quad (21)$$

$$v_{i,d}^{t+1} = wv_{i,d}^t + \text{sgn}(\text{rand}() - 0.5)(c_1r_1(x_{pbest,d}^t - x_{i,d}^t) + c_2r_2(x_{gbest,d}^t - x_{i,d}^t)) \quad (22)$$

$$\text{sgn} = \begin{cases} -1 & t < 0 \\ 0 & t = 0 \\ 1 & t > 0 \end{cases} \quad (23)$$

In the evolutionary process, the particle of core-subgroup always attracted by the global optimal particle, the aux-subgroup of the differential evolution strategy is adopted to keep the attraction and repulsion of each particle with the probability of 50%.

The current deployment plan will be evaluated after environmental changes, determine whether the deployment plan to meet the network connectivity, MR can be calculated to meet the user's bandwidth demand, If the target is not met, reset deployment plan with symmetric displacement mapping strategy. Symmetric displacement mapping strategy steps are as follows.

Step 1. The difference between the particle position and the local optimal position is calculated on every dimension.

Step 2. Count the number of positive and negative values of the position difference in each dimension, positive number is denoted as $n_{1d}(d=1,2,\dots,D)$, negative number is denoted as $n_{2d}(d=1,2,\dots,D)$.

Step 3. On the one side of a large number of particles, the $\text{int}\left(\frac{|n_{1d}-n_{2d}|}{2}\right)$ particles are selected from the position of the local optimum particle.

Step 4. The one side of a less number of particles update particle positions in accordance with the one side of a large number of particles by the formula (24), update the particle position.

$$x_{ijnew} = \begin{cases} g_p + |x_{ij} - g_p| & x_{ij} - g_p < 0 \\ g_p - |x_{ij} - g_p| & x_{ij} - g_p > 0 \end{cases} \quad (24)$$

So the algorithm is as follows.

Step 1. Randomly initialize the particle swarm, the particle swarm is divided into two sub groups, initialize particle velocity and location.

Step 2. Deploy backbone nodes according to the method described before, the current optimal solution and the global optimal solution are evaluated by comparing the fitness values of the main and auxiliary subgroups.

Step 3. Update the velocity and position of main and auxiliary subgroups.

Step 4. To determine whether the environment changes after the cycle, evaluate whether the current deployment solution can meet the network connectivity and user requirements, if not go to step 2 after core-group take the space of symmetric displacement mapping.

Step 5. To determine whether the algorithm to achieve the number of times, if not go to step 2.

Step 6. The end of the algorithm, record the output value.

4. The Analysis of Simulation and Experimental Results

According to the network parameters of Roofnet experimental network platform built by Massachusetts Institute of Technology, Set the node coverage radius to 150, the node communication radius to 250, node access capacity to 54, UDN bandwidth demand to 10, the maximum number of hops to the gateway to 4, simulation user demand set of real population distribution which meet the normal distribution. Set the cycle to 15 minutes, the number of UDN changes in each environmental change is a random integer between 0 and udn-count/8. The coordinates of each UDN move randomly in the scene. The results of static and dynamic deployment in normal distribution are shown in table 1.

Table 1. Static and dynamic deployment results in a normal distribution scenario

Scene	Static and dynamic deployment results in a normal distribution scenario		
	<i>Scene Establishment</i>	<i>Static deployment results</i>	<i>Dynamic deployment results</i>
1	200*200,10,1,15	2.00	2.21
2	300*300,20,1,25	4.00	4.59
3	400*400,40,2,45	7.00	7.31
4	600*600,80,3,80	12.50	14.70
5	800*800,150,4,110	17.05	19.12
6	1000*1000,200,8,140	20.55	24.25
7	2000*2000,450,16,360	68.15	69.10

The results of static and dynamic deployment in the average distribution are shown in table 2.

Table 2. Static and Dynamic Deployment Results in an Average Distribution Scenario

Scene	Static and dynamic deployment results in an average distribution scenario		
	<i>Scene Establishment</i>	<i>Static deployment results</i>	<i>Dynamic deployment results</i>
1	200*200,10,1,15	2.00	2.38
2	300*300,20,1,25	4.00	4.24
3	400*400,40,2,45	7.00	7.60
4	600*600,80,3,80	12.80	14.42
5	800*800,150,4,110	18.05	19.00
6	1000*1000,200,8,140	21.55	23.50
7	2000*2000,450,16,360	69.80	70.05

The experimental results show that this algorithm in uniform distribution and normal distribution, the number of MR deployments in the MR deployment scheme that in dynamic environment is close to the static deployment results, which proves the effectiveness of the proposed algorithm.

5. Acknowledgment

In this work we propose an optimal algorithm for the deployment of backbone nodes in wireless Mesh networks. In order to meet the user bandwidth requirement and the network connectivity, using particle swarm optimization algorithm to select gateway location, then to minimize the number of routers as the goal to gradually add the maximum weight of the adjacent nodes to complete the deployment. This paper, using TSDPSO algorithm to adapt to dynamic environment. At the beginning of each new cycle, the algorithm detects the change of the environment, and updates the location of the deployment of the nodes to meet the demand changes. The experimental results show that the algorithm can get an effective deployment plan in a dynamic environment.

6. References

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