Application and Research of Gateway Deployment Solving Model and Algorithm in the Wireless Mesh Network

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Abstract: In order to solve gateway deployment of geometry K center in the wireless network and improve the service quality of network. This paper puts forward the gateway deployment solving model and algorithm. This paper transforms center problem of the geometric K into center problem of node K and solves problem. This paper proposes a gateway node alternative selection algorithm combination of network topology properties and maximum cover area related theory, and according to the relevant features select an alternative area, each alternative area abstract for a virtual node and is inserted into the original network topology structure, thus forming the new network topology. Solving new problem of the network topology and looking for the optimal deployment scheme use the improved genetic algorithm. The experimental results show that the model and algorithm proposed in this paper can well solve the wireless network gateway deployment problem of geometric K center and improve the network service quality.

Keywords: Network Node; The Network Diagram; Binary Code; Crossover and Mutation

1. Introduction

With the continuous development and popularization of wireless network applications, it has become a widespread and pressing need to provide ubiquitous wireless broadband access for users. Wireless Mesh networks (WMN) has advantages of high bandwidth, high reliability, wide coverage, low deployment cost and convenient access, and will have broad prospect of application. Wireless Mesh network is a new type of broadband wireless access networks. It combines the advantages of wireless local area network (LAN) and ad-hoc network, has the character of self-organization and multiple hops, and can realize effective integration of heterogeneous network. It has become the hot spot in the next generation in the study of wireless broadband technology and the mobile Internet.

Gateway deployment problem is select the minimum number MR as gateway and optimize the network topology in order to meet user requirements of bandwidth and network performance in WMN backbone topology, and under the premise of the identified MR number and position. At present, few scholars have conducted research on the gateway deployment, described the gateway deployment problem as a joint optimization problem and is formalized by their integer linear programming, put forward some heuristic gateway deployment algorithm. There are also some solutions based on intelligent algorithm (genetic algorithm and particle swarm optimization algorithm, etc.). Choose the gateway from the given WMN backbone topology is a complicated problem, in addition to the deployment cost and user bandwidth requirements, there are many factors to consider, such as load balancing, transmission link interference between the gateways, the node load capacity, the length of the transmission path (hop count) and so on. However, the existing researches seldom consider these factors.

The gateway deployment of geometric K center problem requirements according to certain requirements to deploy some of the new node as a gateway within the given plane, to meet the needs at the same time try to improve the quality of service, this way is more complicated than the former way. Because the center problem of node K can be summarized as discrete location problem, and the center problem of geometric K is a continuous region location problems. Processing the problem is more complex, and related research work is less, especially there is little study of the problem in domestic. The foreign research has a certain study on the issue, such as Megiddo N; study the center problems of geometry K from the perspective of graph theory, and research and analysis on the computation complexity for K centers of graph.

This paper mainly studies the K WMN gateway deployment solution of the geometric K center; transformed center problem of the geometric K into center problem of node K to solve problem. This paper proposes a gateway node alternative selection algorithm combination of network topology properties and maximum cover area related theory, and according to the relevant features select an alternative area, each alternative area abstract for a virtual node and is inserted into the original network topology structure, thus forming the new network topology. Using the improved genetic algorithm to solve new problem of the network topology, to look for the optimal deployment scheme, and compared the effect and the applicable scope of genetic algorithm and Kmeans algorithm.

2. Network Model and Great Alternative Area

2.1. Network Model

As shown in figure 1, double layer structure of WMN consists of MR, IGW Internet backbone layer and MR, client Internet access layer, available undirected graph $G=(V,E)$ represents, among them, $V=\{v_1, v_2,\ldots, v_n\}$ is node set composed of n MR and IGW in the network, $E=\{e_1, e_2,\ldots, e_t\}$ represents two nodes on the communication links of same channel in the transmission range of each other. In n nodes, there are m configured to IGW and Internet access, the rest is MR constitutes the backbone. $CH=\{1,2,\ldots, k\}$ represents K orthogonal channel in wireless communication, data rate on channel $I\in CH$ expressed as wibit/s. Every node v_i has $\rho(v_i)$ wireless interface, $1\le\rho(vi)\le k$. In WMN, each MR has function that gathered flow from its mobile client, the flow of MR is mainly flow IGW or from the IGW. For a MR node, the flow generally contains two parts: from mobile client flow in its own service area $T_l(v_i)$ and transmission flow $T_r(v_i)$ for other MR relay.

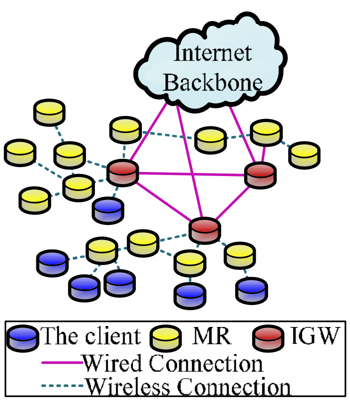

Figure 1. Network Model

2.2. Node Deployment

Node location had a greater influence on the performance of WMN; generally there are three metrics, namely: the client is Coverage (Coverage), backbone layer connectivity rate, network capacity, can be used to assess node deployment in WMN's impact on network performance. Several kinds of network topology deployment situations found: in terms of coverage, more rules topology (such as triangle, lattice) better than the random topology, and the node arrangement chaos of right level in the lattice have less effect on the coverage; Backbone layer connectivity mainly depends on the density of MR and has small relationship with specific deployment topology; And network capacity has more to do with the topological factors include cable gateway distribution density and lattice configuration.

2.3. Great Alternative Areas

The point set $\{v_1,v_2,\ldots,v_m\}$ of any alternative area $\langle v_1,v_2,\ldots,v_m\rangle$ must have an edge l_{ij}, makes $r<l_{ij}<2r$, At the same time, it can't have an edge l_{ij} larger than $2r$. Set gateway at any position inside the alternative area, its connection effect is consistent; the optional area can be abstracted as a virtual node.

Between networks nodes may result in multiple alternative areas, but most of the area function is the same, and some of the alternative regional contains other optional features. Therefore, it is necessary to reduce the redundant alternative area to reduce the time complexity.

When coverage area of three node v_i, v_j and v_z interactive overlap, as shown in figure 2, can produce a number of alternatives areas: A1 is expressed as the $<v_i,v_z>$, A2 for $<v_i,v_z>$, A3 for $<v_i,v_j>$, B for $<v_i,v_j,v_z>$. Obviously, the location of the optional area B for intersection of A1, A2 and A3, area B connectivity for connection performance of A1, A2 and A3, deployed gateway in the area B can connect directly to the three nodes. So in alternative area selection can ignore A1, A2 and A3, only consider area B, in order to reduce the number of optional area.

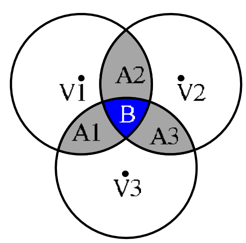

Figure 2. Great Alternative Regional Maps of Three Nodes

Thus promoted to the general situation, namely, we assume that all alternative areas in the plane R2 are $A_1,A_2,A_3,\ldots,A_m$, we can derive the concept of great alternative area: if there is no alternative area A_p, make A_p for proper subset of A_k, optional area A_k is called a great alternative area of the plane.

Thus, location of gateway nodes can be deployed is network actual nodes in all plane and corresponding virtual node in all great alternative areas. It can be known by concept that on connection function, greatly alternative areas can cover other optional area, therefore, select a alternative area has great significance in simplifying the research question and solving the WMN gateway deployment problem of geometric K center.

It can be known from alternative regional nature; setting gateway node at any position in the optional region can effectively connect all of its nodes. Using 3 (a) and figure 3 (b) as an example, the shaded area for great alternative area $\langle v_1,v_2,v_3,v_4\rangle$, generated by the node v_1,v_2,v_3,v_4 , in this great alternative area, any one of three gateway nodes o_1,o_2,o_3 can connect four network nodes.

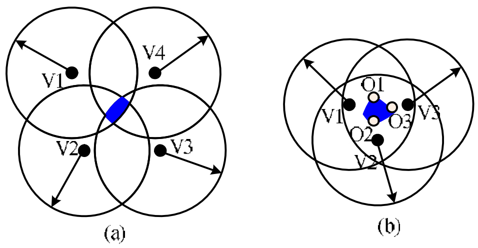

Figure 3. Signal Cover Diagram of Great Alternative Area

Gateway nodes deployed in the area of the alternative, the communication coverage is a circle with a radius r, can cover all network nodes which generate the alternative area. We call center is located in the alternative region can cover all of its nodes, circle of radius r is covering circle.

It will have at least a circle border through two network nodes of the alternative area in numerous covers round, as shown in figure 3 (b), covering round o2 passes through v1 and v4, namely the o2's center on mid perpendicular of v1 and v4, and the distance between o2 and two points is r, we call round o2 is determined by point v1 and v4. In the formation point set of alternative area, not circle determined by arbitrary two points is covered circle, but there will always two points meet the condition. As shown in figure 4, in the formation point set of alternative area $\langle v_1,v_2,...,v_7\rangle$, circle o_2 determined by node v_3 and v_4 cannot cover v_1 , v_2 , v_5 . Circle o_2 determined by node v_1 and v_2 can cover all the nodes and become covered circle. In conclusion, in the alternative region $\langle v_1,v_2,...,v_m\rangle$ will inevitably exist two nodes, the two nodes can determine a round cover, to determine an alternative area.

In order to further explain the concept of covering circle, this paper first introduces the concept of boundary points and boundary string. We can determine two points of alternative area, two points which the distance is less than 2r is the boundary point, and the connection line between two points is called boundary string.

Any two boundary point can generate two covered circle symmetrical about boundary string, namely the potential alternative areas. Boundary string in complex communication network has huge size, need to make sure that a large number of optional areas and covers round. So it is necessary to select all of the great alternative areas in the optional area, to merge the original alternative area, in order to reduce the complexity of the problem.

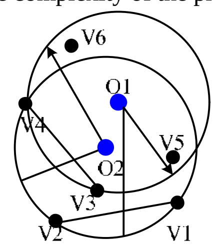

Figure 4. Determinations of Point and Chord in Alternative Region

2.4. Filter Algorithm in Great Alternative

In the network topology, using boundary string and boundary point will produce many optional areas which do not conform to the requirements, in order to reduce the time of algorithm, it needs to eliminate some optional area, and then select great alternative area.

Rule1. A boundary string and its two alternative areas generated by boundary point, if a alternative area is subset of another alternative, chose the big optional area as alternative area of the boundary string.

Rule2. If the boundary string length is less than r, and the determined two alternative areas do not contain any other node, other than the boundary point, the boundary string does not produce alternative areas.

As shown in figure 5, the two covering circles o1 and o2 which determined by boundary point v1 and v2, round o1 determines alternate area $\langle v_1,v_2,v_3,v_4\rangle$, while covering round o_2 determine alternate area $\langle v_1,v_2,v_5\rangle$, the two alternative area are not for each other's subset, hence are two different great alternative area. If the plane does not exist node v_5 , then alternative area produced by covering round o_2 is a subset of alternative areas generated by o_1 , alternative areas generated by o_2 can be deleted at this time.

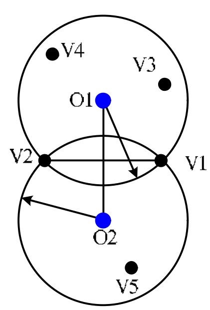

Figure 5. Two Alternative Area Determined by Boundary String

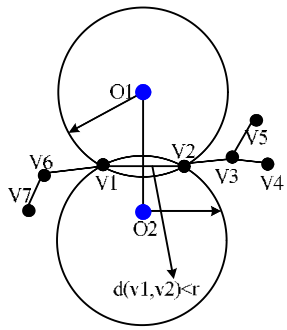

Figure 6. Invalid Candidate Areas

In figure 6, the two circles o_1 and o_2 with radius r which determined by boundary point v_1 and v_2 doesn't contain anything except boundary point, the only alternative area $\langle v_1, v_2 \rangle$ generated according to the rule 1. Due to the distance between the v_1 and v_2 is less than communication radius r, the optional area can be replaced by node v_1 and v_2.

Using rules 1 and 2 reduced the number of optional area. Great alternative filter algorithm steps as follows: looking for boundary string to generate and modify alternative areas, screening great alternative area.

2.4.1. To Find Boundary String

The distance between the node v_i and v_j is less than 2 r, where $l_{ij} < 2r$, connecting edge of node v_i and v_j will be filtered as boundary string; And when $l_{ij} \le r$, boundary string may not produce alternative area, so to distinguish mark the boundary string of the different length.

2.4.2. Generate Alternative Areas

The key step to generate the great alternative area is to produce two circles with radius r according to the boundary string, calculate the number of nodes in the circle, and generate alternative area. According to the rules 1 and 2, design alternatives generation algorithm, the description of the specific algorithm is shown below.

Algorithm 1. Gateway node generation algorithm in alternative region based on coverage Circle

Input: network parameters and network nodes coordinate

Output: Node alternative region

1. traverse the entire network

/ * For boundary string less than r processing * /

2.if (if the distance between node vi node and node vj is less than or equal to r)

3.According to the coverage radius r and node coordinates, generating two alternative region o1 and o2

4 Executing rules 1 and 2 alternative in o1 and o2 area

* / Conducting boundary string which is larger than r and less than 2r. * /

5.else if (distance between node vi and node vj is greater than r, or less than or equal to 2r)

6 Generating two alternative region o1 and o2

7 for the alternative region o1 and o2 the rule 1 is implemented

/ * Data output stage * /

8. Recording the generated alternative region.

This paper uses a 0-1 matrix $C = \{cij\} m*n$ to record generated optional area, where n represents the number of real node, m represents the total number of generated optional area in the whole network, usually have $m \le n(n-1)$. When generating the i alternative region contains the node j, $c_{ij} = 1$, otherwise $c_{ij} = 0$, all of node which the value is 1 in the first i line do constitute the i alternative area.

2.4.3. The Screening of Great Alternative Area

The row vector c_i of matrix C as formation point set of an alternative area, according to the definition of great alternative area, looking for alternative area formation point set c_i, so that they don't become a proper subset of other alternative area formation point set, the c_i is the formation point set of great alternative area.

According to the algorithm above, number the great alternative areas after getting the greatly alternative areas. Then, abstract for the virtual node and add to the network diagram to form a new network diagram.

3. Gateway Deployment to the Solve Model and Algorithm

The introduction of great alternative area above can change the geometric K center problem into center problem of node K, greatly reduced the complexity of choosing the gateway deployment location in the continuous surface, the continuous location problem into a discrete location. In order to express the unity and concise, the great alternative area represented by network node and virtual node is known as node, use symbol v_i represents. $d(v_i, v_j)$ represents the shortest distance between node v_i and v_j, identified as d_{ij}, $D = \{d_{ij}\} n \times n$ is called the shortest path matrix.

3.1. Models

Type (1) represents the distance from node v_i to its recent gateway nodes u_j, namely the nearest gateway nodes u_j is the service gateway of node vi. If there is multiple gateway nodes have the same distance to the v_i, select the gateway node with the least number of service node number u_j as service gateway of the v_i. If still unable to screen out the only gateway node on the basis of this, choose a node with minimum subscript as the service gateway v_i. The distance between the node and the node represents with the hop count, namely, when the distance between two nodes is less than or equal to signal coverage radius and the distance between them for a jump. Between each node v_i and its service gateway has a minimum hop distance, the maximum value of all the minimum hop distance is type (2)

$$\min_{u_j \in U}\left\{d(v_i,u_j)\right\} \tag{1}$$

$$h(\Theta)=\max_{v_i \in V}\left\{\min_{u_j \in U}\left\{d(v_i,u_j)\right\}\right\} \tag{2}$$

Θ is defined as a network node distribution scheme, h (Θ) is the maximum distance of distribution plans, also known as the largest hop count. The greater the H (Θ) means, the poorer the service effect of distribution scheme Θ is.

Therefore, this paper seek to find gateway deployment scheme which minimize the h (Θ), the optimal target for establishing a model is the minimum value of maximum hop count. Assuming that number of gateway needs to be deployed is k, model is described below

$$\begin{aligned} &\min\ h(\Theta) \\ &s.t.\ |U|=k \end{aligned} \tag{3}$$

When solving, it needs to conduct specific function design and the constraints of the model. Set x_{ij} were 0-1 variables, X is the binary encoding matrix:

$$x_{ij}=\begin{cases}1, \text{ represent node j is under the jurisdiction of node i} \\ 0, \text{ represent node j is not under the jurisdiction of node i}\end{cases} \tag{4}$$

The minimum value of maximize hop count as the objective function, objective function is design for the

$$G(X)=\max_{j=1,\dots,n}\left\{\min_{i=1,\dots,n}(di_j x_{ij})\right\} \tag{5}$$

Satisfy the constraint conditions for
each node only managed by a gateway

$$\sum_{i=1}^{n} x_{ij}=1 \tag{6}$$

Setting up k gateway in n network node, $\max_{j=1,\dots,n}(xij)$ represents I node set to the gateway, meet the constraints

$$\sum_{i=1}^{n}\max_{j=1,\dots,n}(x_{ij})=k \tag{7}$$

Genetic algorithm model is as follows

$$\begin{aligned} &\min\ \ G(X) \\ &s.t.\ \sum_{i=1}^{n} x_{ij}=1; \\ &\sum_{i=1}^{n}\max_{j=1,\dots,n}(x_{ij})=k \end{aligned} \tag{8}$$

3.2. Algorithm Design

Through the research above, we will change WMN gateway deployment issues into traditional node K center problem to solve the problem; the solution is a hard problem of NP. Aiming at the wireless gateway deployment problems, this paper uses genetic algorithm to solve. In order to improve the efficiency and accuracy of model, this paper improved the genetic algorithm. Through the use of special chromosome repair strategy, choice strategy of random traversal and inserting mechanism, form strategy, the algorithm can search the global optimal solution quickly. The key step design of genetic algorithm is as follows:

Special chromosome repair strategy. When the genetic algorithm is solving the problem, conduct unconstrained processing to two constraints of the model. The first constraint satisfies its natural operation process in turmoil function; Second constraint for the fixed number of gateway k, satisfies the constraint through legitimacy repair. Repair method is to make each chromosome only have k genes which value is 1. If the genetic number of chromosome which value is 1 is more than k, the randomly selected k location in these genes, retain its value is 1, the other is set to 0; If the number of gene which value is 1 is less than k, the randomly generated a certain number of position, make the chromosome has k numbers which value is 1. This is a special kind of repair strategies, each generation can produce excellent chromosomes, improve the speed of convergence.

Random traversal selection strategy and setup of heavy insert mechanism. Chromosome selection method uses a random traversal sampling strategy, complete random traversal sampling table by getting fitness vector accumulation. Then select the corresponding fitness value according to the index. The selected individual indexes are determined by comparing the size of the sum of generated random number and vector accumulation. The probability of an individual is selected for

$$P(X_i)=\frac{F(X_i)}{\sum_{i=1}^{N}F(X_i)} \tag{9}$$

Here, F (Xi) for adaptive value of individual Xi, P (Xi) as the probability that the individual is selected. In addition, use the heavy insertion mechanism, two generations population set generation gap according to fixed proportion, so as to keep good individual of parent. The combination of random traversal sampling selection strategy and inserted into the mechanism effectively solves premature convergence and low searching efficiency of the genetic algorithm.

Record Settings. Set a record, store the optimal value and chromosome generate in iteration to avoid the most excellent individuals to be eliminated, make the solving result close to the optimum value. When the algorithm iteration reached the maximum number of iterations GEN, algorithm terminated and the output results.

Other steps design. Chromosome adopt binary code, and the generation of initial population satisfy model's all constraints, in order to improve the algorithm convergence speed. The aim of crossover and mutation operation is to maintain the population diversity and avoid solving process into local optimum. In this paper, crossover operator uses double cross point of tangency which is to reduce the agent. Every time will produce a new individual. probability is set a smaller value by Mutation operator, when the probability p is greater than the setting probability of the mutation operator, the corresponding chromosomal genes will mutate. In addition, the objective function is mapped to that function, adopt dynamic calibration for

$$F(X) = G(X)_{\max} - G(X) + \xi' \quad (10)$$

Among them, $G(X)$ is objective function, t is the number of iterations, $G(X)_{\max}$ is the maximum value of objective function for each iteration, ξ is the positive factor less than 1.

4. Experiment Simulation and Analysis

4.1. The Experimental Environment and Settings

Randomly generated network diagram of 100 nodes in planar region of 5 x5 per unit area, randomly generated network topology diagram as shown in figure 7, graphic scale is 1:100, the abscissa and ordinate range of the area is 100 m ~ 600 m, the region's actual size is 500 m by 500 m. When the randomly generated network node position is too concentrated, the theoretical results are good, but this kind of network diagram does not accord with actual situation, can't test model's effect in the real application. The generated network diagram requests each node can connect to a node, at least not appear isolated point. Therefore, randomly generated node should be distributed diffuse and uniformly, and reduce the number of isolated and dense points. Therefore, makes the best communication transmission radius r of the node is 60 m, the average degree of random graph node is no more than 4, the most magnanimous of nodes are no more than 6.

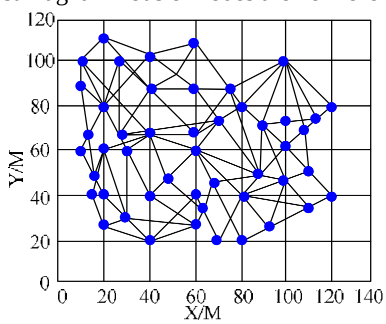

Figure 7. Network Random Graph

Using Matlab genetic toolbox to carry out simulation on the model. The computer is ordinary PC, CPU is Intel3 processor, 2GB memory. The minimum value of maximum hop count as the objective function, use the improved genetic algorithm for solving model. When using the genetic algorithm, the parameter settings are as follows: initial population scale NP = 400, the number of iterations GEN = 200, crossover rate and mutation rate are 0.9 and 0.05 respectively, the generation GAP is set to 0.8.

4.2. Result Analysis

The minimum value of maximum hop count h (Θ) as the optimization goal, using the improved genetic algorithm, a run result is shown in Table 1.

When set the number of gateway to eight, each location of gateway, the number of each gateway management network node and the formation area point set of virtual node location at this time as shown in Table 1. Among them, the position numbers less than or equal to 100 points is real node, real node is the node randomly generated by original network diagram. More than 100 points for the virtual node, represents great alternative area generated by some real virtual node, namely it can deploy a new gateway node in the region.

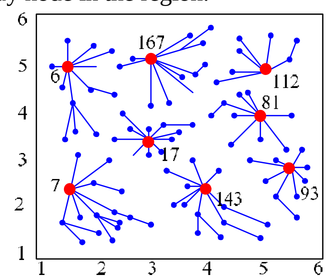

Figure 8. Gateway Deployment and Node Jurisdiction

As shown in Figure 8: number 112 virtual nodes represent a great candidate area, generated by the real node 64, 70, 73, 75, 76,77, 81, 85, 87, 89, 92.

In addition, in order to compare the results of different algorithms, solve gateway deployment issues using Kmeans clustering algorithm.

Randomly generating 100 network nodes random network diagram, use the minimum and maximum hop count as the optimization goal, with maximum and average hop count as the measurement index for the algorithm. Comparison of 100 times running results of the improved genetic algorithm GA and the classic Kmeans algorithm are shown in Figure 9 and figure 10.

Table 1. Kmeans Algorithm to Solve Problem

gateway number	Maximum Hop Count	run time	average hop count
5	4	4.302	1.60
6	2	4.723	1.22
7	2	4.466	1.19
8	2	4.447	1.17
9	2	5.474	1.13
10	2	6.287	1.13

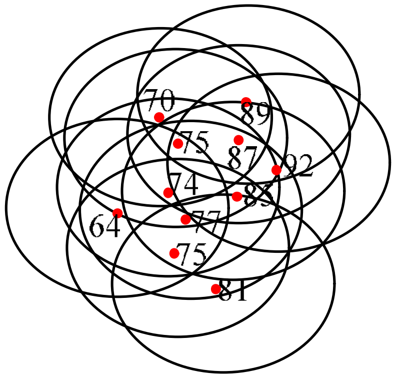

Figure 9. A Great Candidate Area of Virtual Node 112

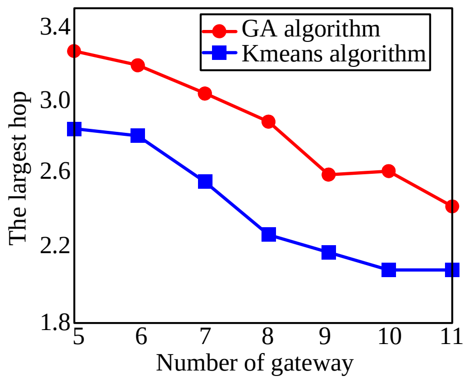

Figure 10. Algorithm Maximum Hop Count Contrast

Analyzing from the algorithm theory, time complexity of Kmeans algorithm for $O(nkt)$, the upper bound of the time complexity of genetic algorithm for $O((n-k)2kt, NP)$, among them, n represents the number of network nodes, k represents the number of the gateway deployment, t represents the number of iterations of the algorithm and NP represents population size of genetic algorithm. Solving k center problem using Kmeans algorithm, it has high operation efficiency, but it is easy to premature convergence. And using genetic algorithm, it is not easy to fall into local optimum. It can search the global optimal solution.

5. Conclusion

In order to solve gateway deployment of the wireless network geometry K center and improve the service quality of network. This paper puts forward the gateway deployment solving model and algorithm. According to the topology nature of network, the surface area of the node is divided into different optional area in accordance with the connection performance differences. The center problem of the geometry K changed into the center problem of traditional node K. Using the improved genetic algorithm to solve the problem.

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