Research and Application of Heuristic Algorithm in Mesh Network

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Abstract: In order to solve issues of Mesh network as a broadband wireless access network, such as high data transmission rate and long-distance signal coverage and so on, this paper proposes two heuristic algorithms with O(m3) time complexity, based on the user neighbors information and location information. The algorithm will meet transferring the minimum relay deployment problem required by users into the minimum clique partition problem of adjacency graph and gives specific algorithm steps. Experimental results show that: the proposed algorithm ensures network performance and reduces network cost.

Keywords: Data Transmission; Station; Inspire; Approximation

1. Introduction

WIMAX Mesh network as a broadband wireless access network, has the characteristics such as low cost, high data transfer rates and long-distance signal coverage. However, when the base station's transmission power is constant, the noise ratio of the received signal will exponentially decrease as the distance from the base station increases, the obtained data transfer rate decreases [1-7]; If WIMAX cell radius is too large, since the wireless signal has propagational characteristics like sight transmission and attenuation, users in the shaded area in the building and at the edge of base station coverage usually get low signal noise ratio. Therefore, the user terminal access to mobile wireless broadband's data rate is limited, affecting the quality and development of mobile Internet application and service [7-15].

In order to solve the above problem, IEEE802.16j standard combines multi-hop relay technology with the Mesh network mode, and adopts tree topology. The WIMAX network increases relays in the propagation path, forming a access link (Access Link) from users to the relay and the relay access link (Relay Link) from users to the base station, which has advantages with low cost, high bandwidth, wide coverage, and it is a new direction in technical aspects of the 802.16 standard [5-7].

2. Model and Problem Description

In this paper, WIMAX Mesh network's static multi-hop relay deployment issues are studied, the ultimate optimizing goal is to ensure users' transmission rate. Because when the number of channels is fixed, the user receiving data transmission rate is proportional to reception channel capacity, while in the WIMAX network with massive long signal communication, generally adopts Two-ray Ground Loss model, according to Shannon's theorem, channel capacity D is expressed as:

$$D = j\log\left(1+TRE_i\right) \qquad (1)$$

Wherein, j is the channel bandwidth, TRE_i is the signal noise ratio, according to the Two-ray Ground Loss model,

$$TRE_i = \frac{G_i D_i D_y k_i^2 k_i^s d^a}{R_0} \qquad (2)$$

Where, Pt is the transmission power, D_i / D_y and k_i / k_y h, respectively, for transmitting / receiving antenna gain and height, R_0 is the thermal noise, usually, these parameters are constants. Thus, by the formula (1), (2), when the transmission power is constant, the channel capacity is decided by the physical distance between reception side and the transmission side. Based on the above analysis, the user's data rate depends on the distance from the user to the relay, inverse relationship between the two. That is, assuming in order to ensure the transmission rate of the user a minimum k, the required maximum physical distance to relay is D meters, then the "relay deployment for ensuring the transmission rate of the user " problem is equivalent to the "in the user-centric area with d radius , at least deploy one relay" problem.

Therefore, when the base station transmit power and number of channels reaches a certain level, "to ensure transmission rate of users " is equivalent to" to ensure distance requirements of users to the relay".

2.1. Related definitions

Definition 1 Distance circle

For user m_i, its user distance requirement is c_i, the distance circle of user m_i takes the location of m_i as the center, the perfect circle with g_i radius is denoted by e_i.

Definition 2 User adjacency graph

User adjacency graph is a graph $g(T,e)$, where T is the set of vertexes, there is one-to-one correspondence between each vertex and the users in S, unless otherwise specified below, a vertex represents a user; E is the set of edges, for vertexes T_i and T_j in T, there is an edge $g_{ij}(T_i,T_j)$ in E if and only if the distance circle between T_i and T_j has non-empty intersection. In particular, when $g(T,e)$ has only one vertex T_i, that is, G has isolated pole, let $T=\{e_{12}(T_i,T_j)\}$.

Definition 3 Reliable coverage

If the distance circle e_i of T_i has at least one repeater or base station, then vi is called reliable coverage.

Definition 4 Complete graph

Given a graph $g(T,e)$, if there is edge between any pair of vertexes, then we say this graph is a complete graph.

2.2. Description

The least relay deployment which ensures transfer rate issue (Distance-Aware Relay Placement in WIMAX Mesh Networks, DARP): In a WIMAX Mesh network, given one base station BS and the user set $w=\{w_1,w_2,...w_R\}$, the distance set corresponding to the user data rate requirement is $D=\{D_1,D_2,...D_R\}$, deploy minimum relay R_w, makes that

(1) For $\forall w_i \subseteq w$, in the area with w_i as the center and with a radius d_i, there should be at least one repeater or base station, that is in the user-to-relay layer, deploying least relay to guarantee reliable coverage for each user (Lower -tier Relay Coverage, LORC);

(2) Each relay RS can communicate with the base station with the required data rate, i,e. in the "relay-to-base station" layer, deploy the least relay to ensure relay can communicate with the base station with the desired rate.

Among them, the second sub-problem takes the deployed relay of LORC as the leaf node, and the base station as the root, to build side-constrained Euclidean Steiner tree (MUST), so the optimization key of DARP is the solving of the LORC problem.

3. Heuristic Algorithm

First, changes LORC problem into the smallest group partitioning problem in user adjacency graph(Minimum Clique Partition), and then proposes two heuristic algorithms, finally analyzes the algorithm's time complexity.

Theorem 1. In non-empty user adjacency graph $g(T,e)$, let a vertex's minimum distance requirement as $d_{\min}$, $g(T',e')$ is one of the groups in $g(T,e)$, $|T'|$ is the number of vertexes within the group.

(1) If $0 \mathbf{p} |T'| \mathbf{p} 3$, then only one relay can ensure the reliable coverage of all vertexes in the group .

(2) If $|T'|\geq 3$ and the distance between any two vertexes in the group is not more than $|T'|\geq 3$, then only one relay can ensure the reliable coverage of all vertexes in the group.

Proof. Let $g(T',e')$ as a group in the user adjacency graph $g(T,e)$, if the distance between any two vertexes in the group is not more than $d_{\min}$,

$$\exists e_{i,j} \in E', S_i \cap S_j \neq \varnothing,\ \overline{T_iT_j} \leq \sqrt{3}\, d_{\min}, \text{ so} \tag{3}$$

$$\bigcap_{s_i \in s'} S_j \neq \varnothing \tag{4}$$

Using contradiction, assume $|T'|=s+1$, the original proposition is not true, that is, for all the $(s+1)$ vertexes in a group $g(T',e')$, at least need to deploy two relays to ensure their reliable coverage, these two relays are marked as R1 and R2.

Since in $g(T',e')$, even remove a vertex and the corresponding edge, it is still a group, denoted by $g^*(T^*,e^*)$, without loss of generality, so let the vertex as $|T'|=s+1$, $|T^*=T'/\{T_k+1\}|=k$, so in g^* all vertexes just a relay to ensure the reliable coverage. We may assume that R1 provides reliable coverage for k vertexes in T^*, there is intersection between these s vertexes' distance circle $s_1 \cap s_2 ... \cap s_k \neq \varnothing$. Then the reliable coverage provided by R2 is divided into the following two situations:

(1) R2 provides reliable coverage for T_k+1 and other vertexes in group g^*, namely in $\{s_i, i=1,2,...,k\}$ there is at least one $s_j\ (1\leq j\leq k)$.

$$g^*\begin{cases} s_{k+1} \cap s_j \neq \varnothing \\ \{s_i\}/s_j \cap s_{k+1} \neq \varnothing \end{cases}, 1\leq i\leq k \tag{5}$$

Wherein formula (5) and T' is a group contradiction, so assumption does not hold.

(2) R2 only provides reliable coverage for $Ts+1$,

$$\left\{\bigcap_{i=1}^{k} s_i\right\} \cap s_{k+1} \neq \varnothing \tag{6}$$

Formula (6) and g' is a group contradiction, the assumption is not true.

Therefore, when $|T'|=s+1$ the proposition is also true

Based on the above three steps of the proof, according to mathematical induction, this theorem is proved. QED.

Since WIMAX network users generally distribute in places with high population density, the maximum distance between users is usually less than 100m, while the average user distance requirement is 100m ~ 150m. Therefore, according to theorem 1, in general WIMAX network, we conduct the least group partition according to the user adjacent diagram. After division, place a relay at any point in the intersection area of all users' distance circles in each group, to ensure reliable coverage of users in the regiment. Therefore, LORC problem can be transformed into minium clique partition problem of user adjacency graph.

As minimum clique partition problem (Minimum Clique Parti-tion problem, MCP) is NP-complete, Under normal circumstances, the design of MCP approximation algorithm is conducted in exceptional figure for the high complexity and time limitation , for example Unit Disk Graph (UDG) and penny graph. In this paper's studied LORC problem, the distance requirement of users is far greater than 1 and different from each other , therefore the distance circle figure is not diagram UDG; Because users distribute randomly in the circle and the circles will intersect, so it not Penny Graph either, so the existing MCP algorithm can not solve the LORC problem. Based on the user's neighbor information and user location information, the paper designs minimum clique partition heuristic algorithm.

3.1. MAXDCP heuristic algorithm

The basic idea is to divide a group that contains the most vertexes from the user adjacency graph, and remove the regiment from the adjacency graph, and then in the rest of the adjacency graph continue to divide groups according to the greedy rule, until every vertex in the user adjacency graph is included in a group.

Finding "group that contains the most vertexes" is the problem of find the maximum clique, it is NP-complete, usually finding for the largest group is difficult. Given that the more the user neighbors are, the more vertexes in the group, so start from the maximum vertex $V_{\max}$ of user adjacency graph to find all the groups that contains it, then carve out the group $CQ_{\max}$ with most vertexes. In this way, until all the vertexes in user adjacency graph are included in a group. The clique partition algorithm based on the maximum degree of vertex is described as below, Figure 2 shows all steps of MAXDCP.

MAX Degree based Clique Partition Algorithm

Input: $s=\{(s_i\_x, s_i\_y), i=1,...,m\}$, $D=\{d_i, i=1,...,m\}$

Output: $SG, count$

1){ $SG \leftarrow \varnothing$

2) $count \leftarrow 0$

3) While $SG \leftarrow \varnothing$

4) SS and D generate the user adjacency graph G;

5)Find all the groups in G;

6)Find the vertex $T_{\max}$ with the largest degree in graph G;

7)Find all groups $\{CQ\}$ where $T_{\max}$ is in;

8)From all groups in G, find the group $CQ_{\max}$ with the largest vertexes;

9) $count = count + 1$;

10)Find all vertexes $\langle s_i \rangle$ of $CQ_{\max}$;

11) $SG_{count} \leftarrow \{s_i\}$;

12) $S \leftarrow S / \{s_i\}; D \leftarrow / \{d_i\}$;

13) }

14)return

15) }

Figure 1. MAXDCP algorithm

Since in practice, the base station location is known, so there are two possible methods about the process on the base station: The first method is to deploy relays in the case that the base station does not exist, when the relay deployment is complete, each user at least covered by one relay reliable coverage. Doing so, for users whose distance to the base station is smaller than the required distance, they could not only be covered by reliable relay coverage, but also can be covered by the base station's reliable relay coverage. These users can randomly select base station or a relay to transmit data. The second method firstly takes a base station with known location as a deployed relay and remove the users who have been covered by base station's reliable coverage from the user set, and then execute algorithm to handle the rest of the user. The second method will first known location of a base station has been deployed as repeaters and base stations have been reliable coverage of the collection is removed from the current user out, and then execute algorithms handle the rest of the user. Thus, in MAXDCP algorithm design, we take the first method for the base station.

Figure 3 (a) is a distance circle of user and its corresponding vertex, Fig 3 (b) is user adjacent graph, and Fig 3 (c) is a simple example of MAXDCP algorithm. As figure 3 (c) shows, MAXDCP starts from the maximum degree vertex (the 4th vertex) in the adjacency graph to search the group with the most vertexes to divide. However, since the divided group has the most vertexes in the current adjacency graph, all the edges which are connected with the vertex in the group are removed from the adjacency graph, So if the group is in the center of the adjacency graph, the maximum group division will break down other groups in the adjacency graph, so that the number of groups increase, increasing the scale of the problem, which is not conducive to minimizing the number of relay. In order to improve quality, we further consider the user position information in the area, propose algorithm GEOCP (GEO graphic information-based Clique Partition algorithm).

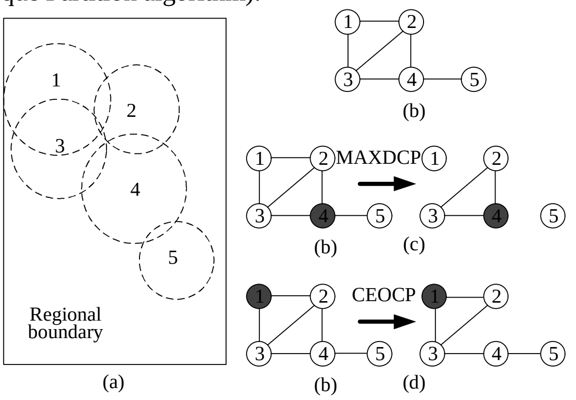


Figure 2. User adjacency graph and algorithm's clique partition example based on MAXDCP, GEOCP

3.2. GEOCP heuristic algorithm

The basic idea is, to identify the vertex where the boundary user locates from the adjacency graph, remove the maximum group which contains this boundary vertex from the adjacency graph, then in the rest of the adjacency graph continue to divide groups according to the greedy rule, until every vertex in the user adjacency graph is included in a group. Advantages to proceed from the boundary vertex to divide groups in the user adjacency graph are: each clique partition will not affect other groups' structure, there for it will not increase the number of groups in the adjacent figure. GEOCP algorithm is described in Figure 4:

GEOCP graphic information based Clique Partition Algorithm

Input:

$s=\{(s_i\_x, s_i\_y), i=1,...,m\}\%m$, which is the set of m users

$D=\{d_i, i=1,2,...,a\}\%$,the required distance between the corresponding user transmission rate

$Boundary=\{t_i, i=1,2,...,a\}\%$,area boundaries agenda, a is the number of boundary output: $SG, count$

Output: $SG, count$

1) { $SG \leftarrow \varnothing$
2) $count \leftarrow 0$
3) While $S \neq \varnothing$
4) { SS and D generate the user adjacency graph G;
5)Find all the groups in G;
6)Find the vertex $T_{\max}$ with the largest degree in graph G;
7)Mark the corresponding set $T\_boundary$ of $SS\_boundary$ vertexes in G, find the largest vertex $T_{\max\_boundary}$ of $T\_boundary$;
8)From all groups in G, find the group which contains the largest vertexes of $T_{\max\_boundary}$;
9) $count = count + 1$;
10) Identify all the vertexes $\langle s_i \rangle$ in $T_{\max\_boundary}$;
11) $SG_{count} \leftarrow \{s_i\}$;
12) $S \leftarrow S / \{s_i\}; D \leftarrow / \{d_i\}$;
13) } % end of while
14)return SG, count
15) }
Function (Boundary, S)
1) { $SS\_boundary \leftarrow \varnothing$;
2) For each $T_i \in Boundary$
3) { for each $S_i \in S$
4) {Calculate the distance from border S_i to i , denoted as $distance(S_i, f_i)$;
5) $SS\_boundary \leftarrow S*$
6) }
7) Return $SS\_boundary$
8) }

Figure 3. GEOCP algorithm

4. Simulation and Analysis

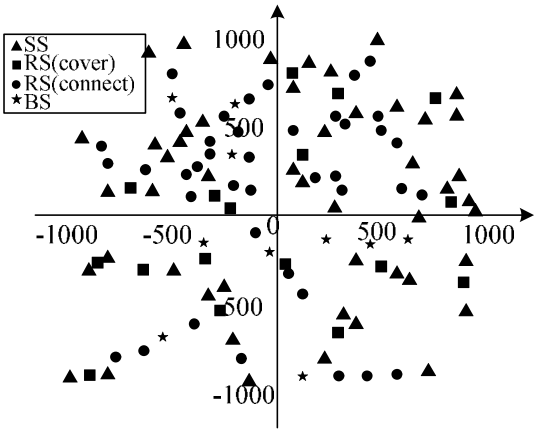
This section compares MAXDCP, GEOCP, MIS and HS's effect through simulation. Assuming in a 1200m × 1200m square area, one base station locates in the center of this area, the user are randomly distributed in the region, the user required distance is selected randomly within [100, 150] . Simulation is conducted in a PC with the Intel Pentium Dual-Core 2.5GHz CPU, 32-bit Windows operating systems, the simulation tool is MATLAB 2010a.

4.1. Network topology

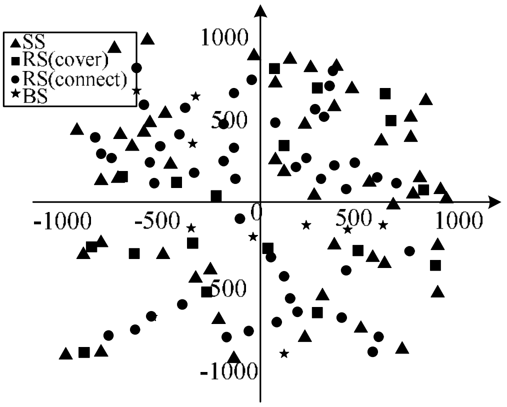
Simulate that 50 users are randomly distributed in the region, based on WIMAX Mesh network topology for relay deployment of MAXDCP algorithm and GEOCP algorithm. Respectively make MAXDCP algorithm and GEOCP algorithm deploy relay to ensure reliable coverage of the user, and then make MUST algorithm deploy the relay, so to ensure relay with reliable coverage can connect with the base station, Figure 4 shows the deployment of the relay based on different algorithms.

Among them, the 21 deployment coverage relays, 83 connected relays, MAXDCP + MUST totally deploy 104 relays. As every time MAXDCP selects the user group with the largest degree, i,e with maximum number of neighbors to conduct division, So if this user's group just in the area where users are dense, the division of the largest group will lead to other groups' decomposition, so need to deploy more relay.

Figure 4 (b) based on the GEOCP algorithm. Among them, 20 deployment coverage relays, 62 connected relays, GEOCP + MUST totally deploys 82 relays. As GEOCP combines user's location information and MAXDCP idea on the user partition, ensure that each division will not cause other user groups divide into smaller, more numerous groups, reducing the number of deployment relays.



(a)MAXDCP+MUS



(b)GEOCP+MUST

Figure 4. Relay deployment with a 1200m × 1200m area, one base station and 50 users

4.2. Comparison of the number of deployed relays

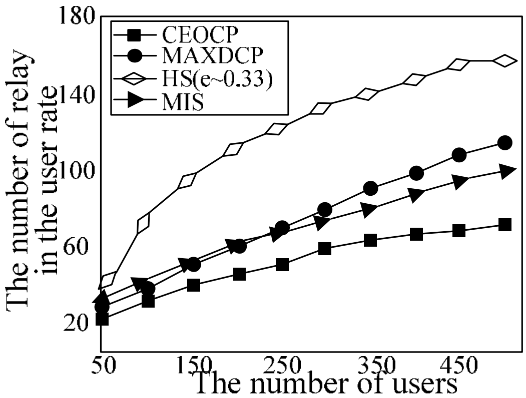
To measure the effect of MAXDCP algorithm and GEOCP algorithm, we compare them with deployed relay's number of existing algorithms MIS and HS, and compare the total running time. Field is set to a 1200m × 1200m square region, one base station in the center of the region, the number of users increase from 52 to 500 with increment of 52, the user distance requirement is taken randomly from [100, 155] , data shown are the average results after the algorithm performs 20 times .

As figure 4 (a) shows, in order to ensure the user's reliable coverage, the number of deployed relays of MAXDCP algorithm is reduced by about 35% than MIS; the number of deployed relays of GEOCP algorithm is reduced by about 56% than MIS, reduced by approximately 21% than HS, and the rate of increase in the number of relay of GEOCP is significantly lower than the other three algorithms. This is because MAXDCP and GEOCP only deploy the relays to users within a group, and within a group just one relay can ensure reliable coverage for all users in the group; the algorithm guarantees to minimize the number of divided groups so to minimize the number of deployed relays. Although MIS also generates user adjacency graph, but it selects one of the 6 vertexes around the user which with the minimum distance requirement to place relay , if the minimum distance of relay on one vertex covers other users, then place one relay . In the area with dense users, MIS algorithm will result in one user covered by several relays, the extent of this redundancy will increase as the user density becomes large. The HS algorithm is based on the minimum Hitting set, it deploy relays in intersection of distance circles. In this way, the more intensive the user, the more intersections of distance circles, which not only cause coverage redundancy on users but also increases algorithm's time complexity.

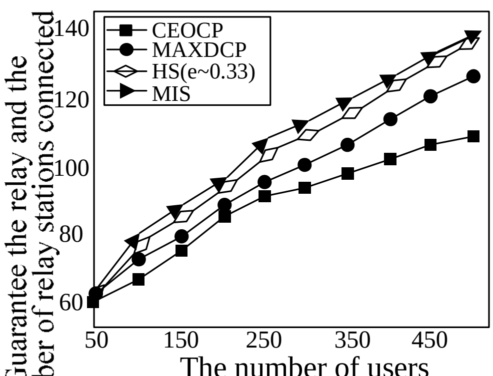
MAXDCP, GEOCP, MIS and HS deploy relays to ensure reliable coverage for users to solve the sub-problem LORC of DARP problem, then based on the location of reliable relay coverage, just need to deploy least relay to ensure multi-hop connectivity with the base station, to make MUST achieve connection between relay and the base station. The basic idea of MUST algorithm is base station as the root, relay provided reliable coverage as the leaf node to generate European Steiner tree with limited length. Wherein, relays with reliable coverage generate from the above four different algorithms. Figure 5 (b) shows comparison about the number of relays which ensure communication, as shown in the figure. The number of connectivity relays of MAXDCP + MUST is less about 8% than MIS + MUST, the number of connectivity relays of GEOCP + MU ST is less 17 percent than MIS+MUST and it is closed to the number of HS + MUST relay. This is because when the user distribution is the same, the number of reliable coverage relay which as the leaf nodes determines the number of relays that MUST requires, But when the distance between the relays that provide reliable coverage is far, it needs more relays to ensure connectivity between these relays and between relays and the base station.

Figure 5 (c) shows comparison of the total number of all the relays that MAXDCP, GEOCP, MIS, and the HS's DARP problem needs. The total number of relays based on MAXDCP decrease 23.9% compared with MIS, the total number of relays based on GEOCP reduces by 35% than MIS, decreases 18.5% compared with HS.

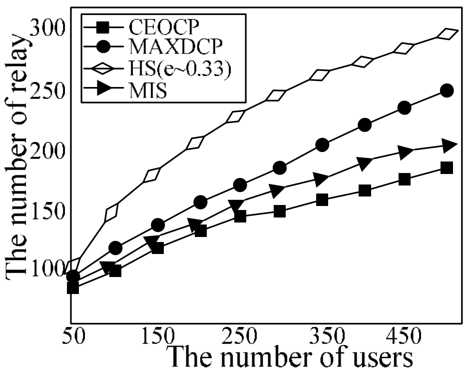
Figure 5 (d) shows the machine time that algorithm MAXDCP, GEOCP, MIS and HS respectively needs to solve the problem DARP. We note that, compared with the other three algorithms, the running time of HS + MUST algorithm apparently increases as the user density increases, This is because the HS bases on the minimum Hitting set, it selects deployment relays at the intersection of the distance circle of all vertexes, the user density increases, resulting in the number of intersections increases sharply, making the size of calculation of HS increases sharply. In contrast, GEOCP + MUST achieves the relay deployment which is similar to that of HS + MUST, by a lower run-time.



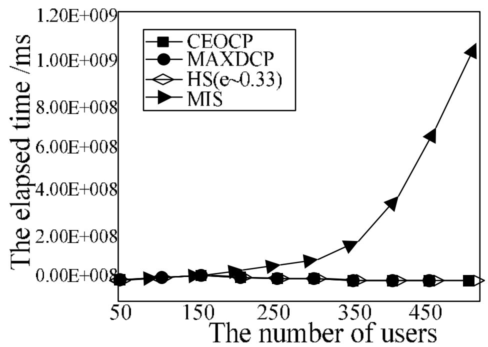
(a)Ensure the user the number of relay in the cover



(b)Guarantee the relay and the number of relay stations connected



(c)The total number of relay



(d)The elapsed time

Figure 5. Contrast of the number of deployed relays between the proposed algorithm and algorithm MIS and HS (1200m × 1200m area)

From the above simulation results it can be concluded, MAXDCP and GEOCP algorithm which based on group division can achieve a known-distance relay deployment with less time and lower time complexity, ensures the required transmission rate for access link, reducing the cost of networking.

5. Conclusion

This paper studies the WIMAX Mesh network's least relay deployment to meet the user's reliable coverage LORC, firstly proves that LORC issue is equivalent to solving problems of minimum clique partition in the user adjacency graph, the problem is NP-complete. Then, based on user neighbor information and user location information, proposes greedy heuristics MAXDCP and GEOCP. The simulation results show that: the proposed algorithm guarantees the user's distance requirements, compared with existing algorithms, it has advantages such as with fewer deployed relays and lower time complexity.

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