

A Novel Gateway Deployment Solution for MANETs Interconnecting with Internet

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Abstract—Mobile ad hoc networks (MANETs) have recently evoked much research attention as a challenge technology that nodes are interconnected to the Internet through gateways. However, due to the limited coverage of every gateway, a gateway may not be able to provide full coverage to the whole network area. To address this problem, this paper proposes a new gateway deployment method. Firstly, the gateway deployment problem is modelled as an art gallery problem, and then a three-stage gateway deployment algorithm is proposed. The first stage is the quadrilateral division based on distribution area of mobile nodes, the second stage is a four-dye scheme based on the quadrangular division, and the third stage is the gateway location deployment, where nodes in any one of the four colours are selected as the gateway. Finally, each phase of the algorithm is analysed and proved, and the results show that the algorithm can accurately determine the upper limit of the maximum number of gateways that meet nodes coverage requirements.

Keywords— Art gallery problem, Gateway deployment, MANETs, Coverage area, Network connectivity

I. INTRODUCTION

Wireless mobile ad hoc networks (MANETs) are a kind of special network that each node in this network serves as a router or ordinary host, and can join or leave the network freely [1], attract significant attention these days. MANETs can be an independent network. However, with the development of MANETs technology, isolated MANETs can no longer meet the current growing demand for service applications [2] such as disaster recovery, search and rescue operations, military actions, and vehicular networks [3]. MANETs are connected to the Internet through gateways, as shown in Figure 1, which has become an inevitable trend of the development of wireless network technology.

Although MANETs are connected to the Internet through gateways become a promising technology, however, there are still many problems should be resolved, one of which is the limited coverage of a gateway. For this reason, it may not be able to provide full coverage to the whole network area. As a result, some nodes are not within the coverage of the gateways if there are too few gateways. But it may cause overlap of gateway coverage and waste of resources if there are too many gateways. Therefore, it is urgent and challenging to find the optimal deployment location of the gateways, so that all nodes are within

the coverage range of the gateways, while minimizing the overlapping coverage of the gateways.

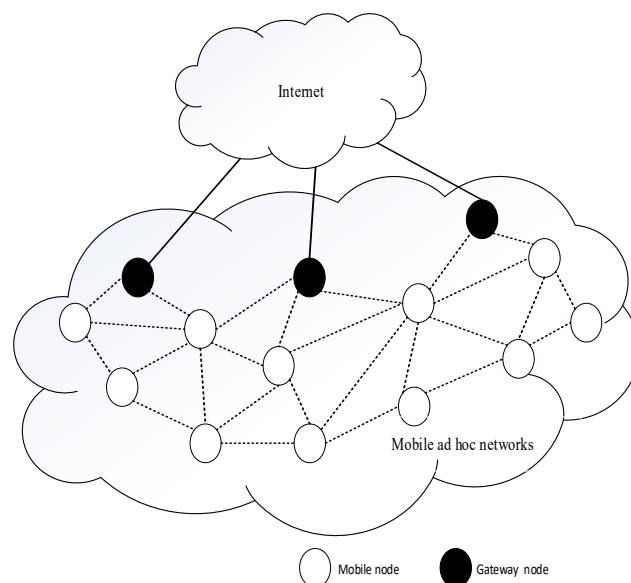


Figure 1. The connection of MANETs with the Internet

There have been a number of interesting studies [4-6] on gateway placement in MANETs, and some algorithms have been proposed. These algorithms are used to maximize the gateway coverages by increasing the number of gateways. In MANETs, increasing the number of gateways can effectively improve network connectivity, but due to the high cost of gateways, the number of gateways in the actual network needs to be controlled [7]. Therefore, in this paper, we address this issue by proposing a new method of gateway deployment that has not been mentioned before. Our work is to minimize the number of gateways while all nodes are within the coverage range of the gateways. Firstly, we model the gateway deployment problem as an art gallery problem [8], and then, a three-stage gateway deployment algorithm is proposed. The first stage is based on the quadrilateral division of the mobile node. The second stage is a four dye scheme based on quadrangular division, and the third stage is the gateway

location deployment, where nodes in any one of the four colors are selected as the gateway.

The rest of this paper is organized as follows. Section II gives a brief overview of related work. Section III defines the network model and describes the gateway placement problem. Section IV proposes a three-stage gateway deployment algorithm to find the optimal gateway location while satisfying the coverage demands and the mathematical proof is carried out for each stage. Finally, concludes the whole paper and provides the future research in section V.

II. RELATED WORK

In the previous research efforts, many approaches have been proposed to address how to improve gateway coverage from different aspects in MANETs. Handler et al [9]. first simulated the gateway deployment problem as the K -centre location problem, and then proposed to use the set coverage algorithm to obtain K covering circles, which can cover network nodes. Finally, the radius of the largest circle was adjusted as the optimization target to obtain the optimal solution, that is, the optimal location of the gateway. In [10], The authors propose a solution to the network maximum coverage and network connectivity problem using binary integer programming for gateway deployment selection at optional locations given in advance. However, how to design gateway location with large coverage and less gateway number is an interesting and challenging problem.

In recent years, some researchers [11-13] have begun to study the gateway placement problem in MANETs. They formulated the gateway placement problem as a linear program problem, and applied various heuristic algorithms to solve this problem.

In [11], The authors propose a genetic algorithm to solve the problem of deploying a minimum number of APs for service area coverage. The network deployment designed and implemented by the authors in the paper uses the minimum number of AP nodes within the required network performance parameters, and when faced with subsequent network expansion and performance optimisation aspects, the deployment conclusions designed using this algorithm need to be recalculated and considered, and the deployed network lacks scalability and has average practical performance.

Khafa et al [12]. used genetic algorithm to solve the node deployment optimization problem. The algorithm was optimized to maximize network connectivity and use coverage, and the algorithm greatly improved the solving efficiency of node location deployment optimization of WMNs router.

Wang et al. [13] proposed a heuristic deployment algorithm ILSearch, which deploys a minimum number of MR on the premise of ensuring network coverage, connectivity and user bandwidth requirements, and at the same time takes into account the multi-rate characteristics of links and link interference. ILSearch algorithm is divided into two stages: covering MR deployment and forwarding MR deployment. In the first stage, the least number of covering MR is deployed with greedy strategy to cover all terminals. In the first Phase,

deploy a minimum number of forwarding MR so that all overlaid MR nodes can multi-hop to the gateway.

In summary, the deployment of gateways based on MANETs may involve coverage, user bandwidth requirements and link interference. However, most research work on gateway layout in MANETs has focused on minimising the number of gateways while meeting coverage requirements, which is the focus of this paper.

III. SYSTEM MODEL

We consider a crowded MANET area, which contains a set of static and randomly distributed nodes. We connect the outermost nodes in the MANET area to enclose a closed network region and abstract this region as a planar polygon P containing n vertices, as shown in Figure 2. The position of a node in MANETs corresponds to a point in the polygon. In MANETs, the distance from node to gateway is generally used to judge whether the node is in the coverage of the gateways. If the distance from the node to gateway is less than the coverage radius of the gateway, the node is within the coverage of the gateway, otherwise the node is not in the coverage range of the gateway. Similarly, for any point i inside a polygon, as long as the open line segment connecting it with a point j completely falls inside the polygon, then point i can be covered by point j . In order to determine the optimal location and number of the gateways, we assume that all gateways and nodes have the same coverage area.

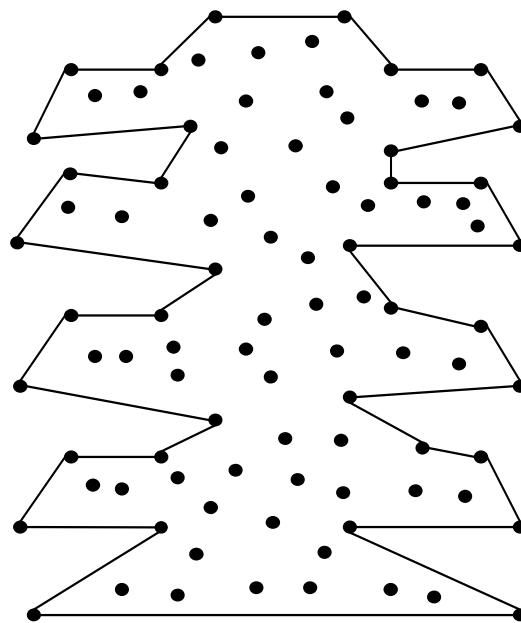


Figure 2. MANETs network model

IV. THREE-STAGE GATEWAY DEPLOYMENT ALGORITHM

Assuming that there are s nodes placed in a MANET, gateways can only be deployed in these candidate locations. The optimal solution of gateway placement can be found by a brute force search [14]. Although the brute force method is simple, its complexity suffers from exponential growth when s increases. At the same time, since gateway deployment is an

NP-hard problem, we only can find local optimal solution for gateway deployment.

In this paper, we propose a three-stage gateway deployment algorithm that finds the approximate best gateway deployment solution that meets the node coverage requirements. Here we assume that the polygon consisting of nodes is a convex polygon in order to avoid the phenomenon of voids [15]. In the first phase, we propose a quadrangular segmentation based on typical triangle segmentation in computational geometry. The second stage is a four-colour scheme based on quadrangular segmentation, and the third stage is gateway location deployment, where a node of any of the four colours is chosen as the gateway.

A. The First Stage: Quadrangular Dissection

Since our given network area is abstracted as a planar polygon P containing n vertices. Since the area of P is large, first decompose P into many sub-regions, where the "sub-regions" are quadrangles. To complete this decomposition, it is necessary to add some diagonal lines to connect certain pairs of vertices, the so-called diagonal line is an open line segment, which is connected between two vertices of P , and falls completely inside P [16]. By a great set of disjoint diagonals, a polygon can be decomposed into multiple quadrangles called the quadrangular dissection of the polygon, as shown in Figure 3.

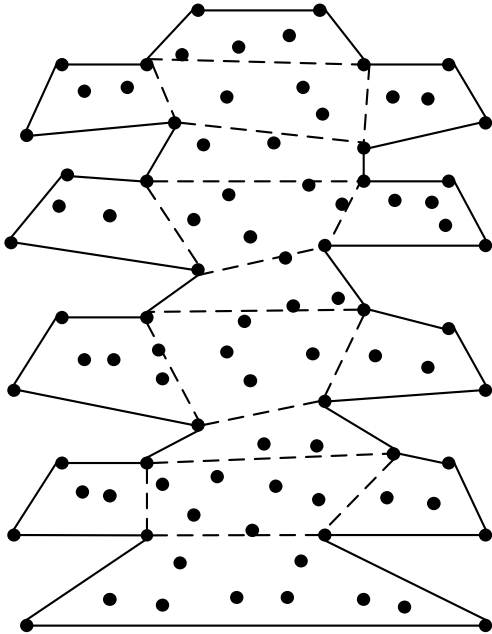


Figure 3. Quadrangular dissection

B. Proof of quadrangular dissection

We prove by induction on n :

If $n=4$, then the polygonal itself is a quadrangle, at which point it is the most mundane form of the theorem, which obviously holds.

Assume that the theorem holds for all $m > n$ when $n > 4$. Take any polygon P with n vertices, and first prove that there is at least one diagonal in P .

Let $e1$ be the vertex in the upper left corner of P . Along the boundary of P , consider the three vertices adjacent to $e1$, denoted as $e2, e3, e4$ respectively.

If the open line segment $e2e4$ falls completely inside P , it is a polyline. As shown in Figure 4: the line segment $e2e4$ falls completely in the interior of P .

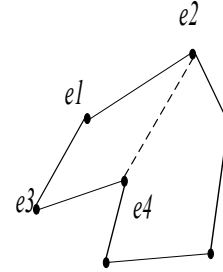


Figure 4. The line segment $e2e4$ falls completely inside

Otherwise, as shown in Figure 5., there must exist at least one vertex inside the quadrangle determined by $e1, e2, e3, e4$. Among these vertices, let $e5$ be the vertex furthest from $e2e4$. The open line segment connecting $e1e5$ cannot be connected to any edge of P , otherwise one of the two vertices in $e1e5$ must fall inside the quadrangle. The distance from the vertex $e1$ to $e2e4$ is farther than the distance from the vertex $e5$ to $e2e4$, therefore, $e1e5$ is a line diagonal.

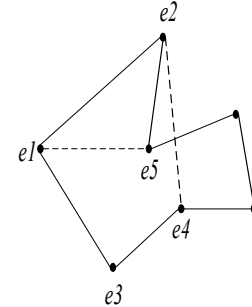


Figure 5. The line segment $e2e4$ does not fall exactly inside P

Therefore, the diagonal must exist so that such a diagonal will divide P into two sub-polygons $P1$ and $P2$ respectively. Assume that the number of vertices in $P1$ and $P2$ are $m1$ and $m2$ respectively and both less than n .

According to the induction hypothesis, $P1$ and $P2$ can be divided by four angles, so P can also be divided by four angles.

C. The Second Stage: Four Dye Scheme

Define the four-staining rule: In a convex polygon, two vertices connected by any side or diagonal cannot be dyed the same colour [17]. In this article, we use four colours of red,

yellow, blue, and green to colour the vertices. Since in the first stage, the studied network area has been divided into many quadrangles. Therefore, each quadrilateral vertex has only one red, yellow, blue, and green, as shown in Figure 6 .

D. Proof of four-dye scheme

Since the quadrilateral Q of the polygon P is a planar graph, if each small quadrangle in the quadrilateral is regarded as a point and there is an edge between two adjacent quadrilaterals, then the dual graph of the quadrilateral Q can be obtained $Q(P)$, as shown in Figure 7 . Suppose the quadrangle corresponding to vertex v is denoted as $T(v)$, and the quadrangle with vertex u is denoted as $T(u)$, if $T(v)$ and $T(u)$ share a common diagonal, an arc is set between $T(v)$ and $T(u)$, so that each arc in $Q(P)$ corresponds to each diagonal in Q . Any diagonal line will split P into two, remove any arc of $Q(P)$ and $Q(P)$ will split into two connected parts. Therefore, $Q(P)$ must be a tree, which is a trinomial tree. Each nodes has 0 , 1, 2 or 3 nodes. The left node is called the "left child", the middle node is called the "middle child" and the right node is called the "right child". There may be many results in polygon tetragonal subdivision, and the polygon can be tetragonal subdivision according to the idea of trigeminal tree. The polygon can be decomposed according to the structure of trigeminal tree to generate a trigeminal tree tetragonal net. Each polygon can be divided into four corners to get a unique trigeminal tree corresponding to it.

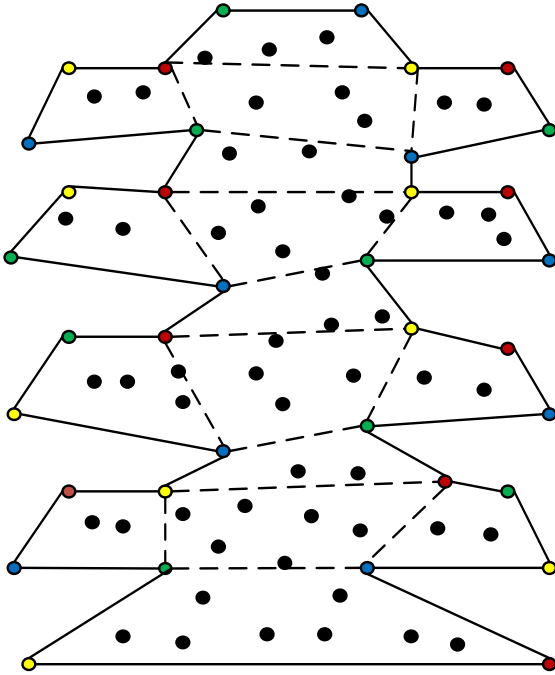


Figure 6. The four dye scheme

As long as the dual graph $Q(P)$ of polygon P is subjected to a depth-first traversal or breadth-first traversal, a four-staining scheme can be obtained. In this paper, we adopt a depth-first traversal, starting from any point of $Q(P)$, after the first quadrangle is visited, the four vertices are stained red, yellow, blue, and green (the order does not matter). Suppose that from

one vertex v of Q to another point u , there is a common line segment between $T(v)$ and $T(u)$, and since the four vertices of $T(v)$ have been coloured with mutually different colours, only two points need to be dyed and there are only two colours to choose from. So the four-dye scheme exists.

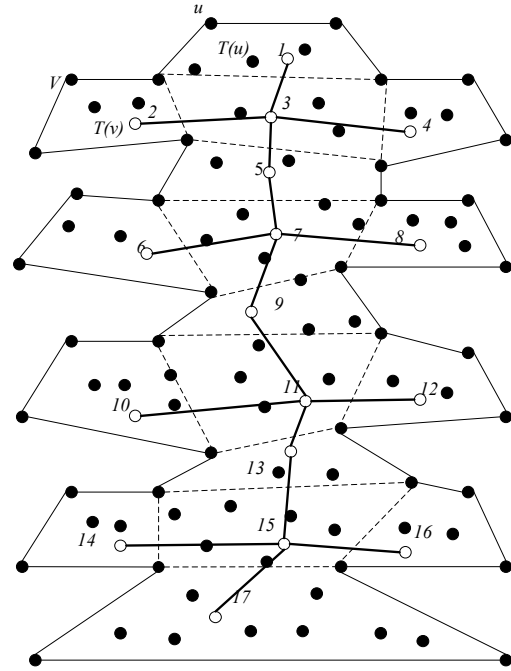


Figure 7. The four dye scheme

E. Gateway location deployment

Our goal to make each gateway cover a larger area in the region with the minimum number of gateways possible is known as the art gallery problem. Fisk concisely proved the art gallery theorem, that is, after any simple polygon is triangulated, the corresponding graph can be 3-colored, and points of the same colour can cover the entire simple polygon [18]. Similarly, we guess that by placing the gateway at the same colour position where the polygon is divided into four corners and 4-coloring, the entire area can be covered, and in the polygon P surrounded by n edge nodes, at most $\lfloor \frac{n}{4} \rfloor$ gateways are required.

F. Proof of gateway deployment

Suppose that P is a polygon with n vertices. The polygon is divided into four corners and four-colouring. The four colours are red, yellow, blue, and green. Suppose $T1$ is the set of vertices red, $T2$ is the set of vertices yellow, $T3$ is the set with blue vertices, and $T4$ is the set of vertices green. Then $T1 \leq T2 \leq T3 \leq T4$, choose $T=T1$, which means that T is less than or equal to $\lfloor \frac{n}{4} \rfloor$. For any point d in P , there is a point b in the quadrangle of P that belongs to T . Because each quadrangle in the model is a convex polygon, the wire segment bd belongs to P , that is, the gateway is placed in the same

colour position and can cover the entire area, and the upper limit of the number of gateways is $n/4$.

V. CONCLUSIONS

In this paper, we address a gateway location placement problem for MANET-based networks when connecting with Internet. We model this problem as an art gallery program and propose a three-stage gateway location placement scheme. Through the three-stage linkage, the analysis proves that the upper bound on the number of gateways required in a region enclosed by n nodes is $\lfloor n/4 \rfloor$. All the assumptions and proofs in this paper are based on the mobile nodes are static. In the future, we plan to study the deployment of gateways in dynamic networks and address this problem by incorporating Poisson distribution function.

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