Front. Comput. Sci. China 2010, 4(1): 143–150
DOI 10.1007/s11704-009-0065-8

RESEARCH ARTICLE

A MANET accessing Internet routing algorithm based on dynamic gateway adaptive selection

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Abstract Based on the study on communication situation of mobile ad hoc network (MANET) accessing Internet and taking the gateway important function of accessing network into account, a MANET accessing Internet routing algorithm based on dynamic gateway adaptive selection (MRBDAS) is presented. It considers candidate gateways' connecting degree, load degree, residual energy, and movement rate synthetically and uses the idea of group decision-making method for reference. The algorithm employs the methods of multipaths and query localization technique based on old path information to maintain routing adaptively. Compared with the existing accessing routing algorithm based on dynamic gateway, the algorithm demonstrates in its simulations that by bringing dynamic gateways colony function, the MRBDAS can improve network throughput, reduce average transmission delay of data packets and routing overhead, and prolong accessing network life. The validity of MRBDAS has been proven.

Keywords routing algorithm, gateway selection, dynamic gateway, mobile ad hoc network (MANET) accessing

1 Introduction

Mobile ad hoc network (MANET) is a network without any central entity. Relying on the cooperation among nodes, it constructs a self-governing network in a mobile, complex, changeful, and wireless environment on its own account, which provides users with various services. MANET nodes enable a seamless communication without any communicating infrastructure, so MANET can receive Internet service through the Internet gateway nodes and extend the Internet service to the region without effective infrastructure. Then, how MANET achieves access to Internet becomes one of the key issues.

At present, the main idea on enabling MANET's access to the Internet is to use the gateway at home and abroad. Gateway is a kind of nodes at the edge of both MANET and Internet, so it can communicate with the nodes that lie in either MANET or Internet [1–4], which is just the basis of realizing MANET's access to Internet. Refs. [5,6] provide an accessing method. They use some fixed routers, which lie in the Internet, as static accessing gateways. MANET nodes needing to access Internet visit Internet nodes through these static gateway nodes. This method can provide more stable accessing performance but often forms a communication bottleneck at the gateway nodes. Based on this method, Refs. [7–9] provided an accessing method using MANET nodes as dynamic gateways. In this way, accessing flexibility can be improved, but it does not mention how to select gateways when there are multiple ones available.

By studying massive related references and observing actual instance of MANET accessing Internet, we find that it will affect network performance directly in choosing a reasonable gateway. However, the premise of existing studies on gateway selection is that dynamic gateways have been determined, and the nodes just need to switch among different dynamic gateways according to network conditions [10,11]. Essentially, this is a method that uses the gateway as soon as it is found. This may lead to a peak

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Received January 7, 2009; accepted October 10, 2009

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use of gateways and communication bottlenecks, which will cause the energy of these dynamic gateways exhausted rapidly and even cause communication interruption due to network division.

Considering the network architecture and characteristic of MANET accessing Internet, we propose a MANET accessing Internet routing algorithm based on dynamic gateway adaptive selection (MRBDAS). It considers candidate gateways' connecting degree, load degree, residual energy, and movement rate synthetically. The MRBDAS uses group decision-making method for reference and adopts the measures of multipaths and query localization technique based on old path information. We build the simulation platform with network simulation software NS2 and validate MRBDAS performance on this platform. We want to prove that MRBDAS is superior to existing routing algorithm in packets delivery ratio, end-to-end transmission latency, normalized network overhead, and network lifetime. The MRBDAS is expected to solve the problem of existing accessing routing algorithm unfit for a network with heavier load.

In Section 2, the MRBDAS and its realization process are described in detail. Section 3 compares and analyses MBRDAS with existing accessing routing algorithm based on dynamic gateways by simulating. Finally, conclusions are drawn in Section 4.

2 MRBDAS

2.1 MANET accessing Internet model

The MANET accessing Internet model studied in this paper is shown in Fig. 1 in terms of the features of MANET and Internet, respectively.

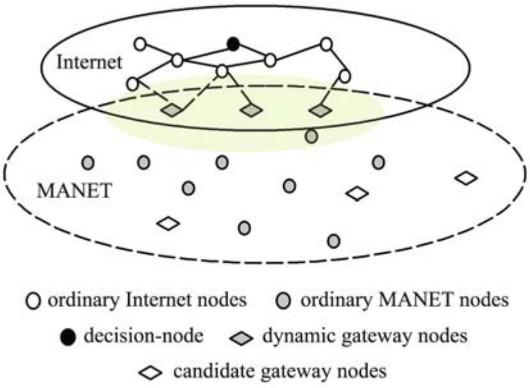

Fig. 1 MANET accessing Internet model

There are five kinds of nodes, which are ordinary Internet nodes, ordinary MANET nodes, candidate gateway nodes, dynamic gateway nodes, and decision node. Candidate gateway nodes are MANET nodes, which are set with dynamic gateway function beforehand. When these candidate gateways are selected to execute gateway function, they are called dynamic gateway nodes. The decision node is a special Internet node that can select suitable routes and gateways. When there is no communication between MANET and Internet, it will act as an ordinary Internet node. If there is communication between MANET and Internet, the destination node is just the decision node. It will choose reasonable gateways with its decision function.

In Fig. 1, we can see that this accessing network has typical hierarchical structure characteristics. In such a hierarchical structure, the source node that initiates communication lies in the undermost layer and broadcasts RREQ (route request) packet to the entire network. The gateway nodes lie in the middle layer. When candidate gateways receive RREQ, they will transmit the RREQ to the destination node in the Internet and wait for the return message from destination node. The destination node lies in the topside layer. It collects RREQ and selects appropriate routes and gateways according to content of RREQ and then returns RREP (route reply) packets. For this three-layer hierarchical network architecture, it provides better network accessing performance only when the nodes in the three layers cooperate mutually. Therefore, we adopt solution for multilayers decision-making problem [12,13] into gateway selection algorithm.

2.2 Dynamic gateway selection model

To provide a better performance of MANET accessing Internet, it is a key problem to select suitable gateways. In MRBDAS, the destination node answers for selecting dynamic gateways, so its behavior will affect accessing performance of entire network. The entire process of destination node selecting dynamic gateways is described in detail as follows.

To select dynamic gateways, we need to evaluate each candidate gateway synthetically. The impact factors taken into account for the candidate gateway mainly include the following:

- Connecting degree: the number of wired nodes, which can communicate with this candidate gateway;

- Load degree: the number of nodes, which are communicating with this candidate gateway;
- Residual energy: the node available energy, supposing that the node may pick up its own residual energy information directly;
- Movement rate: the absolute value of nodes movement speed, which is also picked up by the node itself.

Therefore, we evaluate candidate gateways with the above four parameters. The concrete gateway selection process is carried out according to the following steps.

(1) We establish an evaluation matrix.

Suppose that there are n candidate gateways that are recorded as $\{G_1, G_2, \ldots, G_n\}$. We establish the fuzzy evaluation matrix using the method of massing experts' advice in group decision-making for reference.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} \end{bmatrix}, \tag{1}$$

where n denotes the number of candidate gateways, and a_{id} ($i = 1,2,\ldots,n,\ d = 1,2,3,4$) expresses the evaluation value of the ith candidate gateway under the evaluation criterion d.

(2) We standardize the evaluation matrix.

The standardization process of the evaluation matrix can be equivalent to the process of standardizing the evaluation data. We can transform the matrix into the form as $B = (b_{id})_{n\times 4}$.

When the target needs to be "the larger the better", we use the upper limit effect measure

$$b_{id} = \frac{a_{id} - \min\{a_{id}\}}{\max\{a_{id}\} - \min\{a_{id}\}}, \ b_{id} \in [0,1]. \tag{2}$$

For example, the evaluation criteria, such as connecting degree and residual energy, are like this.

When the target needs to be "the smaller the better", we use the lower limit effect measure

$$b_{id} = \frac{\max\{a_{id}\} - a_{id}}{\max\{a_{id}\} - \min\{a_{id}\}}, \ b_{id} \in [0,1]. \tag{3}$$

For example, the evaluation criteria, such as load degree and movement rate, are like this.

When the target measures are unified, we get a new evaluation matrix

$$B = (b_{id})_{n\times 4}, \ b_{id} \in [0,1], \tag{4}$$

where b_{id} could be regarded as the key-gene subjection degree of the ith candidate gateway under the evaluation criterion d.

(3) We calculate the weight of evaluation criteria.

The blur entropy of the dth evaluation criterion can be expressed as

$$H_d = -t\sum_{i=1}^{n}[b_{id}\ln b_{id} + (1-b_{id})\ln(1-b_{id})], \tag{5}$$

where $t = 1/n$ is a constant; $d = 1, 2, 3, 4$.

The weight of evaluation criteria can be expressed as

$$\omega_d = \frac{1-H_d}{4-\sum_{d=1}^{4} H_d}. \tag{6}$$

Blur entropy is used to evaluate the blur degree: the blur entropy is bigger, the fuzziness of this evaluation criterion is bigger, and then, the weight endued to this evaluation criterion should be smaller.

(4) We confirm the integrated evaluation value of candidate gateways.

$$E = \begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{pmatrix} = B \times W, \tag{7}$$

$$W = \begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{pmatrix}, \tag{8}$$

where e_i is the integrated evaluation value of the ith candidate gateway.

(5) We select gateways according to concrete communication demand.

After the destination node computes integrated evaluation value of each candidate gateway, it will finally select communication routes and gateways according to the parameter usability of path (UoP) in RREQ and the integrated evaluation value.

We use weight algorithm to compute the UoP of path with candidate gateways (UoP'):

$$UoP' = \omega \cdot UoP + (1-\omega)\cdot e_i. \tag{9}$$

In this paper, the effect of candidate gateways to network accessing performance is considered bigger than the effect of UoP to network accessing performance, so it is supposed that $\omega = 0.4$ in simulation.

2.3 Accessing routing algorithm

MRBDAS bases on on-demand routing pattern and divides the entire routing process into two stages: routing establishment and routing maintenance. Gateway nodes and destination node get route information and select reasonable routes and gateways by adding node usability degree parameter and *UoP* parameter into the RREQ packets.

2.3.1 Routing establishment

When the source node wants to communicate with destination node in Internet and it has no available route to destination node, it will adopt reactive mechanism. The processes of routing search and establishment is described as follows.

Step 1 Source node broadcasts RREQ.

The source node adds parameters such as hops, traffic, route information, and *UoP* into RREQ.

Step 2 Middle node carries on the judgment to RREQ and makes corresponding response.

After the middle node receives RREQ, it will establish a reverse route to the upriver node automatically and check the broadcast series number in RREQ. If it has received an RREQ with the same series number and if there are same nodes in the route, it will discard this RREQ; otherwise, it will calculate its own availability value and adds it into the RREQ and then retransmit this RREQ.

Step 3 Candidate gateways receive RREQ and add relative information.

When candidate gateways receive RREQ, it will add its connecting degree, load degree, residual energy, and movement rate into the RREQ.

Step 4 Candidate gateways encapsulate the RREQ they received and send them to destination node.

As soon as the candidate gateway receives the first RREQ, it will start a timer and collect the RREQ it received. When the timer is at term, the candidate gateway will encapsulate the RREQ packet with the biggest UoP and sends it to destination in the Internet.

Step 5 Destination node receives RREQ and makes a decision.

When the destination receives RREQ, it will compute gateway scale according to the traffic information. At the same time, it will distill candidate gateway's relative information and *UoP* information from RREQ, confirm dynamic gateways and routes needed in this communication process, making use of candidate gateway selection algorithm presented above, and then tell the results to gateways.

Step 6 Dynamic gateways send RREP to the source node.

The selected gateways add the route information with biggest *UoP* into the RREP and send the RREP to the source node along with the reverse route established by them.

Step 7 Establish the forward route.

In the process of RREQ sent to source node, the nodes in this route will establish the forward route to the gateway node.

Step 8 Source node receives RREP and sends data packets.

The RREP finally arrives at the source node. The source node starts a timer and collects available routes for this communication process and then sends data packets to the destination node along with these routes. Hereunto, the procedure of routing establishment is completed.

2.3.2 Routing maintenance

When some section of the links is invalid, which is caused by nodes' migration or network congestion, it is necessary to recover the interruption route quickly. It can reduce the network overhead caused by rediscovering the route. Considering that MANET nodes have mobility, but in the usual situation, they will not move too far all of a sudden, it is feasible to make the transmission node save the route information, which can offer a small scope to the source to find the destination node. By marking the used route, when the communication is interrupted, it needs only to search new fungible route around the original route but in the entire net scope. In this way, it can control the search in a relatively small scope, and the concrete procedure is as follows:

When there are data packets transmitting, the first transmission data packet establishes the label in each repeater node. Then, their neighbors who are *n* hops away from them are also marked. If the link is invalid, the algorithm will take the node, which is its upriver node, as source node, and find the replace route to the destination node. The new RREQ will disseminate in the label region. In order to realize this method, the algorithm adds a counter to the message, which used to establish the label. When the message used for establishing label arrives at a

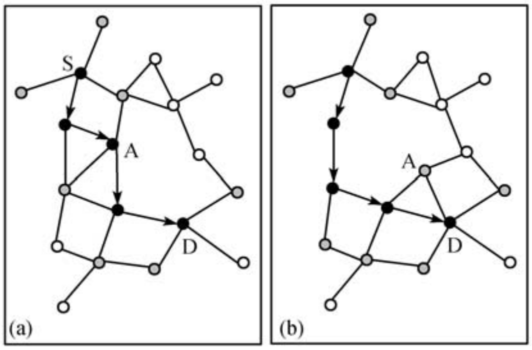

Fig. 2 Routing maintenance process when $n = 1$
(a) Before route change; (b) after route change

node without label, the counter adds 1. If the counter surpasses its threshold value n, it will stop establishing label. The routing maintenance process is shown in Fig. 2.

In Fig. 2, the black nodes denote transmission nodes, which are in the communication route, and the gray nodes denote nodes labeled. In Fig. 2, we can see that when the node A migrated, and link was interruptive. Then, the new RREQ will disseminate in black nodes and gray nodes to find replace route. This kind of inquiry localization technology reduces the message flood effectively, and the superiority will be even more remarkable as the net scale increases.

The threshold value n is mutative with the net state change. In this paper, the original value is 1, and the upper limit is 5. If the message cannot arrive at the destination node when its threshold achieves the upper limit, it will extend its flood area to the entire network. However, the nodes around the flood area do not transmit RREQ blindly; it will transmit RREQ with probability p to achieve the goal of controlling cost.

3 Performance analyses

In this paper, the open-source network simulation software NS2 is used to validate the dynamic gateway selection model and the accessing routing algorithm. The simulation results joined dynamic gateway selection model and the accessing routing algorithm or not are compared and analyzed.

3.1 Network simulation mode

(1) Node movement model

There are 100 MANET nodes and 15 Internet nodes in simulation scene, and the nodes distribute in a 1000 m × 1000 m rectangular region randomly. The mobile nodes make random motion in simulation region by maximum speed 20 m/s, and the entire simulation process continues at 1200 s.

(2) Communication model

The simulation is based on CBR (Constant Bit Rate) traffic source. The packet sending rate are respectively 10, 20, 30, 40, 50, 60, 70 and 80 packages per second (packages$\cdot$s^{-1}). The size of packet is 512 bytes. We observe the accessing network performance at different packet sending rate.

3.2 Performance evaluation parameters

The network average throughput is the ratio of packets received successfully by the destination node to the packets sent by the source node in application layer. It reflects the capacity of the network to process and transmit data. It has been a main sign to validate the reliability, integrity, effectiveness, and accuracy of the routing protocol.

The normalized network overhead is the ratio of routing control packets to the total number of data packets, that is, the average number of control packets to transmit a data packet. It is used to measure the expansibility of the routing, network performance, and efficiency in low-bandwidth or congestion circumstances.

The average end-to-end delay is the average transmission time that the packet is sent successfully from source to destination; it can reflect the network congestion situation.

3.3 Results and analysis

This paper carries out the simulation separately to three accessing situations, which are as follows:

Case 1 Use dynamic gateway to realize accessing.

In this case, using strategy of dynamic gateway is to “use dynamic gateway as soon as it is discovered.” It will not adjust dynamic gateway autoadaptively.

Case 2 Use dynamic gateway selection model to realize access.

It adjusts the adaptive use of dynamic gateway but does not maintain the adaptivity of routing.

Case 3 Add routing maintenance in the foundation of Case 2, i.e., use MRBDAS completely.

The simulation results and comparative analysis are as follows:

Figure 3 shows the network average throughput rate comparison under three conditions. In Case 1, network average throughput rate is higher in light load conditions because there is almost no congestion in dynamic gateways, and there is also less lost packet. However, with the packet sending rate increases, the network load becomes weight, and the congestion increases. The throughput rate begins to decline, and the declining trend is very clear. In Case 2, it makes a reasonable plan to use dynamic gateways and uses multipath for transmission. The network congestion level will increase with the packet sending rate increase, which will result in throughput rate drops, but the decline trend is slow. In Case 3, it reduces the rerouting phenomenon caused by the broken link, so the network average throughput rate increases slightly.

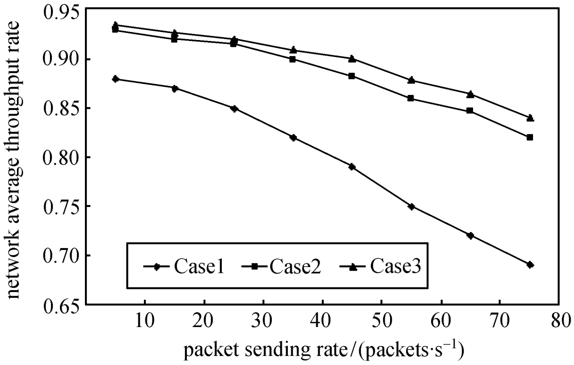

Fig. 3 Network average throughput rate comparison

Figure 4 shows that average end-to-end delay comparison under three conditions. In Case 1, it needs less time to find the route with light load, and the average path length is shorter, so the average end-to-end delay is smaller. However, with the packet sending rate increasing, the network load increases, and the time used to find routing and the path average length also increases, which lead to routing delay and transmission delay increase correspondingly. In case 2, the gateway selection is more rational and effective, but it needs time to choose gateways, so its advantages will gradually be reflected only when the network load increases. In Case 3, it will find routing in a small area when link is broken, so the time used to find routing decreases, and the average transmission delay has been slightly reduced.

Figure 5 shows the normalized network overhead comparison under three situations. In Case 1, the network congestion is smaller under the light load, and the number of control packets is relatively less. Therefore, the normalized routing overhead is little. As the network load increases, the congestion pricks up, which always leads to rerouting, caused by link brokenness, and the number of control packets and normalized routing overhead also increase. In Case 2, due to the need for collecting information of the candidate gateway nodes, it needs to inform the decision-node's decision to gateway nodes. Therefore, the number of control packets is greater, that is, one of the reasons causing large overhead under light load. However, as the network load increases, the gateway selection model will choose better gateway and better path, so the overhead declines gradually. In Case 3, it will increase the number of control packets with a label area created, so the network overhead is the largest when the load is light. However, as the network load gets heavier, the congestion gets more serious, which is resulted by increase in broken links. With the use of query localization technique, the network overhead will not change significantly with the network load increases.

Figure 6 shows the network lifetime comparison under three situations. The simulation time set in this paper is

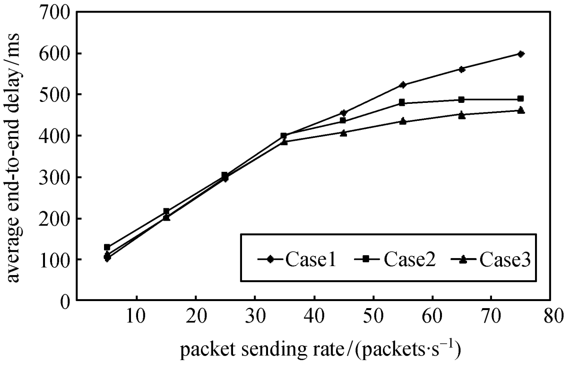

Fig. 4 Average end-to-end delay comparison

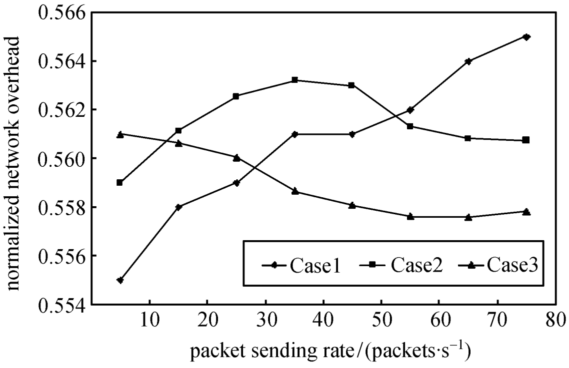

Fig. 5 Normalized network overhead comparison

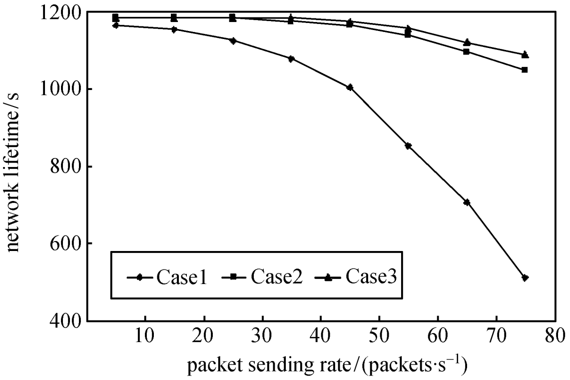

Fig. 6 Network lifetime comparison

1200 s. If the network can still provide accessing when the simulation time amounts to 1200 s, and the network lifetime in this situation is also regarded as 1200 s. In Case 1, when the packet sending rate is low and the load around gateway is light, it can provide the longer time accessing, i.e., the network lifetime is long. As the packet sending rate increases, the load around gateway gets heavier, and the energy consumed increases too. Furthermore, it does not balance the utilization to gateways, so there may be gateways taking the lead to die, and then, the other gateways must withstand heavier load. This evil circulation will lead to the network time reducing fast with the packet sending rate's increasing. In Case 2, it selects gateways dynamically, i.e., carries on adaptive adjustment to utilization of gateways. Therefore, it can balance the load around gateways and prolong the gateways' lifetime, which prolongs accessing network's lifetime naturally. In Case 3, it adopts accessing routing algorithm in the foundation of selecting gateways dynamically and maintains routing. This modus operandi cannot prolong the network lifetime on basic, but it avoids rerouting to the best of its abilities, which can reduce the nodes' energy consumption, prolong the nodes' lifetime indirectly, and prolong the network lifetime indeed.

Through the above analysis, we can conclude that after introducing MRBDAS, the performances of accessing network in average throughput, average end-to-end delay, normalized network overhead, and network lifetime have been improved with various degrees, and the model validity has been proven.

4 Conclusions

This paper studies the dynamic gateway selection and routing in MANET accessing Internet. Considering that MANET nodes have movement nimble characteristic, a MANET accessing Internet routing algorithm based on dynamic gateway adaptive selection is proposed. Through the simulation and the comparison between MRBDAS and existing accessing routing algorithm based on dynamic gateway, we have validated that the MRBDAS has a great improvement in promoting network average throughput, reducing normalized network overhead, reducing average end-to-end delay, and prolonging network lifetime compared with existing accessing routing algorithm based on dynamic gateway. The validity of MRBDAS has been proven.

Acknowledgements This research was supported by the Hi-Tech Research and Development Program of China (2006AA1453).

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