

# Stable Routing Algorithm for Mobile Ad Hoc Network

Youyuan Liu

School of Computer Science, Chongqing University of Arts and Science, Chongqing, China  
cqyclly@163.com

**Abstract**—Mobile Ad Hoc network is a multi-hop temporary autonomous system of mobile nodes with wireless transmitters and receivers without the aid of pre-established network infrastructure. With a great deal of different applications increasing, it needs to provide stable communication for such network. In this paper, a new routing algorithm is proposed which can dynamically estimate delay variety and calculate link stability factor. In the route discovery phase, it finds paths meeting delay requirement with greatest stable link. In the route maintenance phase, it effectively keeps monitoring network topology changes through delay prediction and performs rerouting in time. Furthermore, some enhancement strategies are adopted to control route acquisition latency and improve transmission quality. Simulation results show that it can meet with the delay requirement while decrease the routing cost. Comparing with other conventional routing algorithms, it can achieve higher packet delivery rate especially in rigorous network environment.

**Index Terms**—mobile Ad Hoc network; routing algorithm; dynamic source routing; link stability

## I. INTRODUCTION

Mobile ad hoc network (MANET) can provide temporary wireless networking capability in situations where no fixed infrastructure exists [1][2]. Such network is created spontaneously without any infrastructure. The placement of nodes, in most of the cases, is dependent upon the application and is unpredictable. The nodes are not managed or controlled by any central node. Communication among nodes, in this type of networks, can be either direct or via relaying nodes. Since the network can also dynamically change its topology, routing has a crucial impact on the network performance. Moreover, different services in MANET have raised certain research concerning routing with Quality of Service (QoS) supporting. The QoS requirement is defined as a set of constraints to be met by a network while in communication on performance metrics, such as bandwidth, delay or link state [3][4][5][6][7]. Routing algorithms with different metrics have been proposed in many literatures.

Tom Goff et al. investigate adding proactive route selection and maintenance to on-demand MANET routing algorithms. When a path is likely to be broken, a warning is sent to the source indicating the likelihood of a disconnection. The source can then initiate path discovery early, potentially avoiding the disconnection altogether

[8]. In [9], Queuing theory and communication theory are jointly applied to relate a routing metric called permissible arrival rate, which can support routing discovery under an average delay constraint. W. Zhua proposes a novel algorithm called ticket-based probing with stability estimation (TBP-SE). Models are created to estimate relative link and path stability [10]. In the context of geographic (location-based) routing, a scheme is proposed in to predict future paths before existing paths break [11][12]. This scheme can avoid path re-computation delay. But it does not reduce path breakage so that some problems such as transmission failure and huge routing message overhead still exist. In [13], Wang et al. respectively define link stable time for a link and path stable time for a path. If the stable time of a path is going to be expired, the source node will discover a new path in advance. However, no detailed method is given to estimate the link stable time. In [14], analysis and simulations show a significant network capacity gain for MANET employing multiuser detectors, compared with those using matched filter receivers, as well as very good performance even under tight delay constraints. Xie et al. propose a link reliability based hybrid routing, which is a novel hybrid protocol. Contrary to the traditional single path routing strategy, multiple paths are established between a pair of source-destination nodes. In the hybrid routing strategy, the rate of topological change provides a natural mechanism for switching dynamically between table-driven and on-demand routing [15]. A. Kherani and R. El-Khoury study the throughput of multi-hop routes and stability of forwarding queues in MANET with random access channel. Their result is characterization of stability condition and the end-to-end throughput using the balance rate. They show that as long as the intermediate queues in the network are stable, the end-to-end throughput of a connection does not depend on the load on the intermediate nodes [16].

Based on the studies mentioned above, we propose a link stable based dynamic source routing (SDSR) algorithm with delay constraints. Simulation results show that it attains improved performance comparing with the other two traditional routing algorithms. The remainder of this paper is organized as follows. In Section 2, we describe the network model and present the adaptive delay estimate method as well as link stability measure. In Section 3, we propose the routing discovery, routing maintenance and some enhancement strategies of SDSR. In Section 4, we evaluate the performance of the

proposed algorithm through simulation experiments. Finally, we provide the conclusions.

## II. PRELIMINARIES

### A. Network Model

MANET can be represented by a weighed graph  $G(V, E)$  where  $V$  is the set of nodes in the network and  $E$  is the set of links with connected nodes which are in transmission range of each other. Since  $V$  and  $E$  change with the moving, joining and leaving of nodes, MANET has a dynamic topology. Each node has a unique identification as well as one sender and one receiver at least. Assume that each node has the same transmission distance. If two nodes are within the transmission range they are regarded as neighbors and there is a link between them. Each node cyclically sends message to get its neighbor set. Adjacent nodes share the same wireless media and transmit messages through local broadcasting. Furthermore, IEEE 802.11 MAC protocol constitutes a set of standards for wireless LAN and has been popularly used as the MAC layer in MANET. In this paper, we use the control frame ACK to implement per-hop acknowledgement at MAC layer and carrier sense mechanism to monitor link state. Additionally, other mechanisms of IEEE 802.11 are used to resolve problems such as data collision and hidden terminal.

### B. Adaptive Delay Estimate

In MANET, two mobile nodes within transmission range are not enough to ensure the successfully communication, since many phenomena, such as interference, physical obstacles and power problems, may occur during the transmission and cause it to fail. By using intermediary nodes to forward the message can tackle with the problem. Many routing protocols operate on a store-carry-forward mode to take advantage of node mobility to improve node connectivity and message throughput [17].

While evaluating the end-to-end delay of such protocols is a difficult task due to the inherent complexity of MANET, particularly the random nature of both the movement of the nodes and of the traffic flow. The difference of delay is often great. In this paper we introduce a simple method similar to traditional RTT adaptive algorithm to evaluate the delay variety. The source node copies the message to all the relay nodes it meets, and in the meanwhile any node that carries the message may in turn copy the message to all the nodes it encounters, which is responsible for the end-to-end delay.

Assume that  $D_{cur}$  denotes the current delay of routing,  $D_{old}$  denotes the previous delay of routing and  $D_{new}$  denotes the future delay predicted. If  $\Delta D_{cur}$  is the current delay variety,  $\Delta D_{cur} = D_{cur} - D_{old}$ . Thus, we can calculate the future delay variety  $\Delta D_{new}$  as follows:

$$\Delta D_{new} = a \cdot \Delta D_{old} + (1 - a) \cdot \Delta D_{cur} \quad (1)$$

The predictable future delay is defined as:

$$D_{new} = D_{cur} \pm \Delta D_{new} \quad (2)$$

The equations defined above can be used to predict the dynamic delay. The value of  $a$  is between 0 and 1, which reflects the extent the previous delay variety impact on the future delay. While  $a$  is approach to 1, it means that the value of  $\Delta D_{new}$  is changing not much comparing with  $D_{old}$ . Otherwise,  $\Delta D_{new}$  depends heavily on current delay of routing. If the future delay predicted  $D_{new}$  is greater than the request delay constraint, it shows that the QoS requirement can not be met.

Since the topology in MANET often changes, the delay is also dynamic changes. Thus the bound of delay can be considered. Assume that  $D_{req}$  is the delay constraint for QoS request. We can compare  $D_{req}$  with  $b \times D_{new}$ , where  $b$  is the bound factor which will be set to 1.2 empirically. It represents the difference between the delay for QoS routing request and the future delay predicted. If  $D_{req}$  is within the scope, we consider that the delay request can be met [18].

### C. Link Stability Measure

In MANET, the network topology changes frequently because of the nodes mobility. Once the distance between two mobile nodes exceed a certain threshold, it may result in link failure and need routing rediscovering, which will inevitably decrease routing delay and packet loss ratio. In order to solve this problem, a link stability measure can be introduced into routing algorithm which is capable of predicting the duration of time routes will remain valid. Assume that the received signal strength solely depends on its distance to the transmitter. In most cases, mobile nodes installed with GPS or other location devices can easily obtain its velocity and coordinates which will be updated in a certain interval. If such parameters are known, we can determine the duration of time the two nodes will remain connected [19].

For two neighbor nodes  $i$  and  $j$ , assume that their coordinates are  $(x_i, y_i)$  and  $(x_j, y_j)$  while velocity are  $v_i$  and  $v_j$ . Furthermore, the velocity decomposition along X-axis and Y-axis of the two nodes are  $(v_{ix}, v_{iy})$  and  $(v_{jx}, v_{jy})$  respectively. While exceeding a period  $t$ , the coordinate of the two nodes are  $(x_i + t v_{ix}, y_i + t v_{iy})$  and  $(x_j + t v_{jx}, y_j + t v_{jy})$ . Let  $r$  be the maximum effective transmission distance between  $i$  and  $j$ . According to current coordinates, when the distance between two nodes reaches  $r$ , we can get following equation:

$$((x_j + t v_{jx}) - (x_i + t v_{ix}))^2 + ((y_j + t v_{jy}) - (y_i + t v_{iy}))^2 = r^2$$

Solving it we can get:

$$t = \frac{\sqrt{r^2(a^2 + b^2) - (ac - bd)^2} - (ad + bc)}{a^2 + b^2} \quad (3)$$

where

$$a = v_{jx} - v_{ix}$$

$$b = v_{jy} - v_{iy}$$

$$c = y_j - y_i$$

$$d = x_j - x_i$$

$t$  is defined as the link stability factor and it represents the time needed for two nodes reaching the maximum effective transmission distance. Once exceeding such

period, the current route will fail. Routing algorithm considering about such factor will achieve greater link stability than traditional routing algorithm. It can reduce the rerouting frequency brought by routing disconnection. Additionally, it can reduce the routing cost and increases delivery reliability for transmission.

### III. THE PROPOSED SDSR ALGORITHM

Routing protocols are used to find and maintain routes between source and destination nodes [20]. In on-demand protocols such as DSR, nodes only compute routes when they are needed. Like any source routing protocol, in DSR the source includes the full route in the packets' header. The intermediate nodes use this to forward packets towards the destination and maintain a route cache containing routes to other nodes.

#### A. Format of Control Packets

SDSR adopts source routing mechanism and extend the DSR protocol by flooding RREQ to build routes. To utilize the information obtained from the mobile prediction scheme, extra fields must be added into conventional RREQ in DSR protocol. When a source node floods RREQ, it appends its location, speed, and direction into the control packet. It sets the maximal link expiration time to the corresponding field firstly. When the relay node receives a RREQ, it will predict the link expiration time between itself and the previous hop using Eq. (3). The minimum between this value and the link expiration time recorded in the RREQ is included in the packet. Once a single link on a certain path is disconnected, the entire path is invalidated. The node need update the location and mobility information field written by the previous node with its own information. If a relay node receives multiple packets with different link expiration time, it selects the minimum value among them and sends its own routing table with the chosen link expiration time attached. When the source node receives RREP, it selects the minimum link expiration time among all the routing tables received. Then the source can build new routes by flooding a RREQ before the route breaks.

The main fields in RREQ are described as follows:

SA: the source address.

DA: the destination address.

ID: an exclusive identification produced by source node for routing request, by which a relay node can decide whether it ever received the RREQ.

LET: the link expiration time. It is set to the maximal initially and will be updated by relay nodes according to Eq. (3).

Delay: the delay constrains of the routing request.

X\_position: the X-axis coordinate of node.

Y\_position: the Y-axis coordinate of node.

V: the velocity of node.

D: the move direction of node.

A[i]: the source routing recorded in RREQ.

MRI: the Minimal refresh interval. To effectively estimate LET value, some factors need to be considered when choosing the flooding interval of RREQ. If the node mobility rate is high and the topology changes

frequently, routes will expire quickly. If the source propagates the routing request excessively, it can cause collisions and congestion, and clogs the network with control packets. Thus, the MRI should be enforced to avoid control message overflow. On the other hand, if nodes are stationary or move slowly and link connectivity remains unchanged for a long duration of time, routes will hardly expire and the source will rarely send control packets.

The main fields in RREP include SA, DA, LET and A[i] which are same as above. Furthermore, there is a field L, i.e., the last hop external.

#### B. Routing Discovery and Maintenance

SDCR includes two major phases: routing discovery and routing maintenance. Routing discovery process is to find feasible paths between source and destination node. Routing maintenance process is to monitor and predict the future information about availability of link. Link stability factor and delay constraints are taken consideration in routing discovery and maintenance.

When a source node initiates a routing request to a destination node, it first checks its routing cache. If there exists feasible paths, the source selects the most stable one to send data packets. Otherwise, it will broadcast RREQ to begin building routes.

While a relay node receives a RREQ, the process is as follows:

- Step 1** If it is not the destination, it will check its ID with those received before. Once exists same IDs, it means that the RREQ was repeatedly received and must be discarded. Otherwise, goto step 2;
- Step 2** It begins to check whether the delay constraint is met. If not satisfied, the RREQ will be discarded. Otherwise, goto step 3;
- Step 3** It begins to calculate the link stability factor. With the information of position and velocity of upstream node and itself, relay node calculates the link stability factor  $t$  according to Equ.(1);
- Step 4** If  $t < LET$ , it will be modified with  $t$  as the new LET. Otherwise, LET remains unchanged. Thus, all relay nodes along a route will stay the minimum stability factor;
- Step 5** Information about position and velocity of RREQ will be added to the corresponding fields of the relay node. In the meanwhile, their address will be added to the fields of SA and DA of RREQ. Then RREQ will be forwarded. Goto Step 1.

Once the destination node receives RREQs, it will obtain all feasible paths meeting the delay requirement. It begins to send RREP to the source and the link stability time will be copied in RREP. When the source receives RREP, it calculates the end-to-end delay of each route and stores it to routing cache. Thus each routing cache includes corresponding link stability time and delay. Finally, the source will select the best route among all feasible paths and use it to send data packets.

In routing maintenance phase, SDSR will mainly monitor the delay changes of routes. The process is as follows:

- Step 1** If source node obtains the feasible routes to destination, it can begin to send data packets;
- Step 2** While relay node receives data packets, it will check whether the current delay satisfied with delay requirement recorded in RREQ. If not satisfied, the relay node will inform source node by sending a RRER to it. Otherwise, goto step 3;
- Step 3** Relay node calculates the future delay according to Eq. (1) and (2) and judge whether it can meet the delay requirement;
- Step 4** If the delay constraint can not be satisfied, source node will be sent a RRER and it needs to reselect a new route meeting delay requirement. Otherwise, data packets will be continuously sent to downstream by relay node. Goto step 2.

Once the source node receives a RRER, it will delete the corresponding routes from its own routing cache. Then it checks whether there are other routes to destination in the routing cache. Among all of the feasible routes found, it selects the best route to send packets. Otherwise, the source node will initiates a new routing discovery.

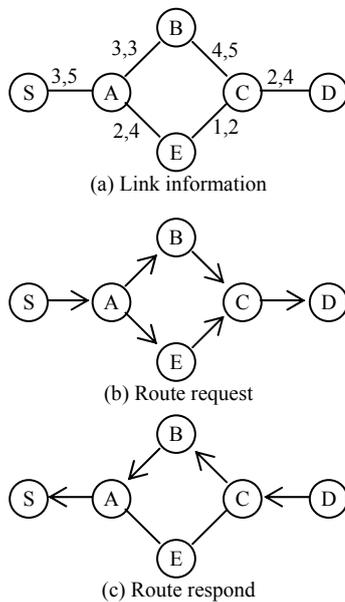


Fig. 1. Route selection example

In the traditional DSR, the destination node selects routes by the first RREQ received. A different route selection method is applied when we use the mobility prediction. In our proposed SDSR, however, instead of using the minimum delay path, we can choose a route that is the most stable, i.e., the one with the largest LET. To select the best route, the destination must wait for an appropriate amount of time after receiving the first RREQ so that all possible routes and their LETs will be obtained. The destination then chooses the most stable route and sends the RREP to the source node according to the

routing list recorded in the RREQ. Route breaks will occur less often and the packet delivery will be higher because stable routes are used. An example is shown in figure 1, the tuple represented the link delay and expiration time respectively. Assume that two routes are available from the source S to the destination D. Route 1 has a path of (S, A, B, C, D) and route 2 has a path of (S, A, E, C, D). If the minimum delay is used as the route selection metric, node D selects route 2. Route 2 has a delay of 8 while route 1 has that of 12. Since the RREQ that takes route 2 reaches D first, route 2 will be selected as the preferred route. If the stable route is selected instead, route 1 will be chosen by D. Obviously, the link expiration time of route 1 is 3 while that of route 2 is 2. Thus D will select the route with the maximum LET as the preferred route.

### C. Some Enhancement Strategies

The crucial issue of on-demand routing protocols is the delay required to build a route. This route acquisition latency makes on-demand protocols less attractive in networks where real-time traffic is exchanged [19]. In DSR, when no available route information is known by the source node, data transmission will be delayed for a certain period of time. Once the source received the RREP from destination, it can begin to send data. To effectively eliminate such delay, when a source has data to send but no route is known, it can flood the data instead of the RREQ. The periodic transmission of control packet can also be replaced by data. The control information becomes request with data payload attached. Thus, the flooding of data with control field achieves data delivery in addition to constructing and refreshing the routes. Although the size of the flooded packet is larger compared to RREQ, route acquisition latency is eliminated.

The reliable transmission of control message plays an important role in establishing and refreshing routes. The IEEE 802.11 MAC protocol adopted in our network model can perform reliable transmission by retransmitting the packet if no acknowledgment is received. However, if the packet is broadcasted, no acknowledgments or retransmissions are sent. Thus, the hop-by-hop verification of the control message delivery and the retransmission must be considered about. We can utilize the passive acknowledgment to verify the delivery of a routing table. The sources node must send active acknowledgments to the previous hops since they do not have any next hops to exchange routing information. When no acknowledgment is received within the timeout interval, the node retransmits the message. If packet delivery cannot be verified after an appropriate number of retransmissions, the node considers the route to be invalidated. The node then broadcasts a message to its neighbors specifying that the next hop to the source cannot be reached. Upon receiving this packet, each neighbor builds the routing information to its next hop if it has a route to the source node. If no route is known, it simply broadcasts the packet specifying the next hop is not available.

IV. EXPERIMENTAL RESULTS

We have evaluated the performance of three routing algorithms, i.e., standard DSR[20], DQR[21] and SDSR, through simulation experiments with different network scenes. In our experiments, networks with a specified number of nodes are randomly generated within a 1000×1000 square region. One pair of the nodes is randomly chosen to be the source and destination. The IEEE 802.11 MAC protocol is used in the network. Random way-point is selected as movement model and the CBR is used to send data. In all cases, our results are based on the performance of 20 randomly generated networks. The major experimental parameters are shown in table 1.

TABLE 1. EXPERIMENTAL PARAMETERS

Parameter	Value
Bandwidth of wireless radio	1Mb/s
Transmission radius	250m
Packet size	512bits
CBR ratio	1packet/s
<i>a</i>	0.8
<i>b</i>	1.2

A. Results for Mobility

In this scene, we generate a network with 60 nodes, and the delay request is set to 40ms. The pause time of mobile nodes varies from 0 to 150s (See Fig. 2 to Fig. 4). When the pause time of nodes decreases, which means the network topology changes frequently, the performance of both algorithms degrade. Since the establishment of unstable routes increases, it will result in high overhead for routing reconstruction. In SDSR, however, those RREQs can not meet the delay requirement will be discarded and in turn reducing the number to reconstruct routing. Once the feasible route is established, the stability of data transmission will

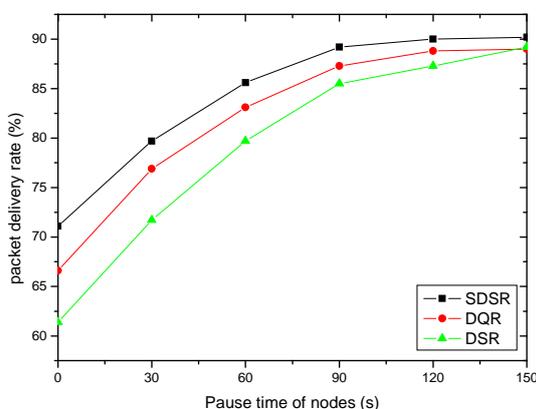


Fig.2. Result for mobility (1)

naturally increase because of its mobile prediction scheme. In the case of more static topology, the delay of SDSR is higher than that of DQR because it needs to calculate link stability factor, which will cause more latency in routing discovery process. However, the decrease of pause time of nodes will lead to more links disconnected. The routing delay can be offset in SDSR and it will get better performance because of its stability first routing scheme.

B. Results for Network Size

In this scene, the pause time of mobile nodes is set to 90s and the delay request is set to 40ms. The number of nodes in network varies from 20 to 120 (See Fig. 5 to Fig. 7). We observe that with the growing number of nodes, the performance of all algorithms gets better since the feasible routes will increase between source and destination node. By delay prediction and stable link selecting in advance, SDSR can achieve better performance. Especially in large network, the advantages of SDSR will behave more and more markedly.

C. Results for Delay Request

In this scene, we generate a network with 60 nodes, and the pause time of mobile nodes is set to 90s. The delay request varies from 40ms to 100ms (See Fig. 8 and Fig. 9). While releasing the delay constraints, more routes will be constructed in the routing discovery phase and the successful routing discovery ratio and packet delivery ratio of all algorithms increases. SDSR outperforms against the other two algorithms since it can predict the link available time according to information of nodes and select the most stable route meeting the delay requirement to send data packets. Thus it reduces the packet losses and guarantees the reliable and rapid transmission. In other words, it has high routing discovery probability and packet delivery ratio.

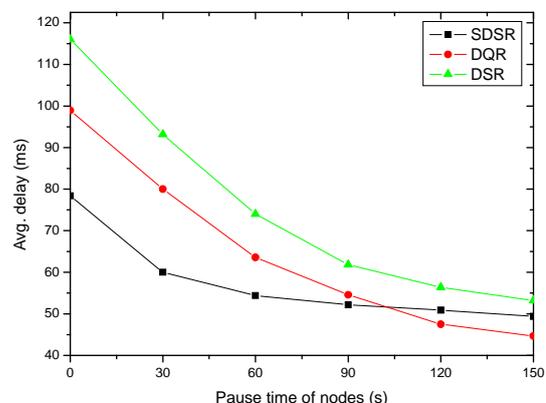


Fig.3. Result for mobility (2)

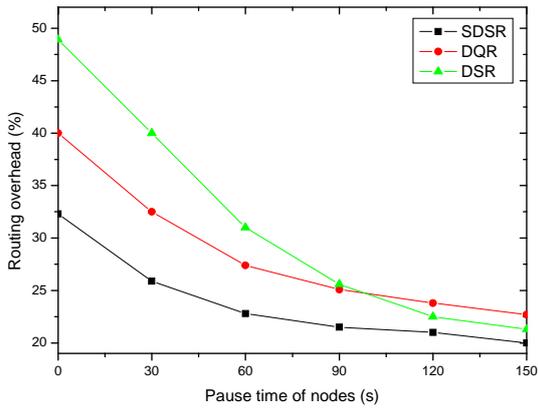


Fig.4. Result for mobility (3)

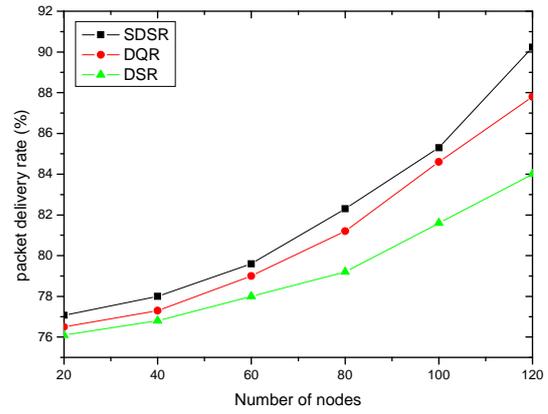


Fig.5. Result for network size (1)

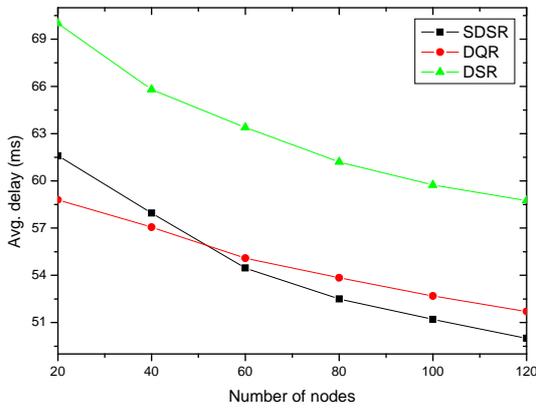


Fig.6. Result for network size (2)

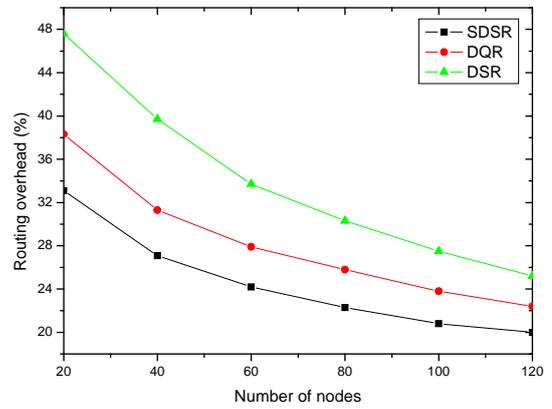


Fig.7. Result for network size (3)

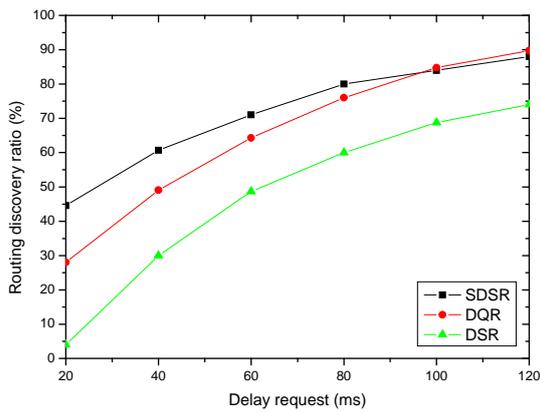


Fig.8. Result for delay request (1)

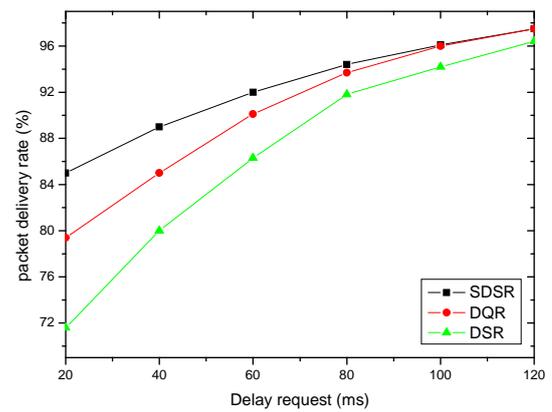


Fig.9. Result for delay request (2)

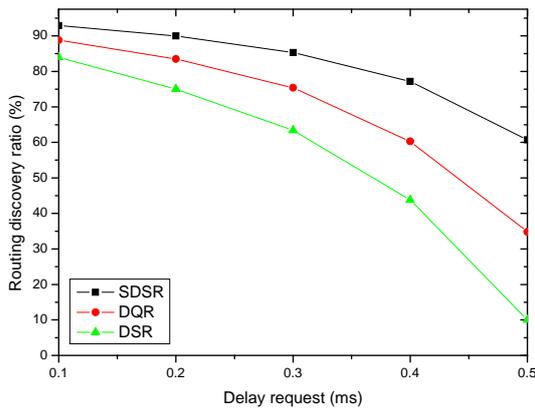


Fig.10. Result for link error rate (1)

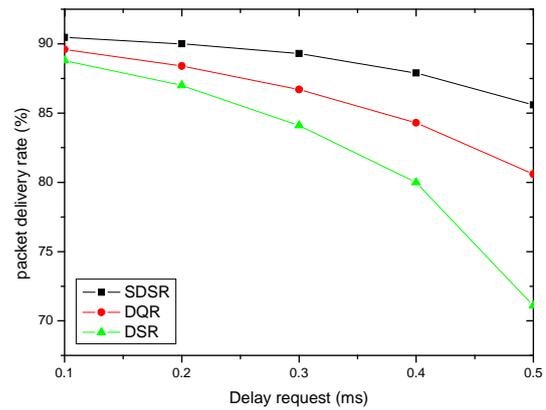


Fig.11. Result for link error rate (2)

**D. Results for Link Error Rate**

In this scene, we generate a network with 60 nodes, the delay request is set to 40ms and the pause time of mobile nodes is set to 90s. The link error rate varies from 0.1 to 0.5 (See Fig. 10 and Fig. 11). With link error rate increasing, the reliability of each path will decrease and in turn resulting in more route failure. So the packet delivery ratio and routing discovery ratio becomes lower in all routing algorithms. Since the maximal end-to-end reliable path will be considered as the routing selection metric by calculating LET for each link, SDSR can achieve better performance.

**V. CONCLUSIONS**

In this paper, we present a new stable dynamic source routing (SDSR) algorithm for MANET. SDSR can select routes according to link state and dynamic delay detection. In the route discovery phase, SDSR finds paths with the greatest link stability factor. In the route maintenance phase, it effectively keeps monitoring network topology changes by delay prediction and performs rerouting before the paths become unavailable. With some enhancement strategies, SDSR significantly improves performance of network. Experimental results show that SDSR can achieve higher packet delivery rate and routing discovery ratio comparing with DSR and DQR.

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