Mobility-adaptive Routing for Stable Transmission in Mobile Ad Hoc Networks

Xi Hu
College of Information Science and Engineering, Northeastern University, Shenyang, China
Email: huxi214@gmail.com

Jinkuan Wang, Cuirong Wang
College of Information Science and Engineering, Northeastern University, Shenyang, China
Email: {wjk, wangcr}@mail.neuq.edu.cn

***Abstract*—In mobile ad hoc networks (MANETs), node mobility causes network topologies to change dynamically over time, which complicated important tasks such as routing. The previous stability-oriented routing algorithms usually focus on how to discover a stable route, but rarely consider the adaptability of constructed route to the change of node's motion. In this paper, a mobility-adaptive routing for stable transmission is proposed. In the proposed routing algorithm, no information about neighborhood needed to maintain by nodes, and the link expiration time (LET), which is used to assess the stability of link, is calculated accurately in company with the discovery of some available stable routes in reactive manner. Then the asynchronous mobility information mechanism is introduced to make the stability of current route can adapts to node's motion. Based on the updated RET, the discovery of alternative stable route is determined by the critical LET zone, which can ensure the continuous transmission of data. Simulation results indicate that the proposed mobility-adaptive routing scheme can improve network performance effectively.**

***Index Terms*—MANETs, routing algorithm, stability-oriented, mobility-adaptive**

I. Introduction

MANETs consist of mobile nodes that function as both routers and hosts. These nodes form wireless links with each other. Communication is through direct links if they are neighbors or, if they are out of direct communication range, through intermediate nodes that relay packets. However, node mobility can cause the network topology to change unpredictably over time. This constant change is the main challenge to MANETs and is especially acute when mobility is high.

Numerous routing protocols to support QoS have been developed for MANETs [1, 2]. One category of these protocols, named "stability-oriented routing protocol", is presented for enhancing the stability and the continuity of the data transmission, which makes efforts to decrease the impact of node's motion to routes. The basic idea of the stability-oriented routing protocol is that the route is established with a series of adjacent nodes which can communicate as much time as they can with each other. Two essential components of the stability-oriented routing protocol are the evaluation of the stability and the maintenance of route, the former is characteristic of the stability-oriented routing protocol which is the basic of establishing stable route, and the latter is common in routing protocols, which is used to ensure that there are available routes for data transmission after the current used route is down.

There are some issues about the two afore mentioned essential components of the stability-oriented routing still should be considered. Firstly, the periodic message exchange is used by some stability evaluation methods to obtain necessary information about the neighborhood of nodes. However, an appropriate exchange interval is hard to set. When the interval is long and node mobility is high, the route exchanges cannot reflect topology changes; when the interval is short, the routing overhead will consume too much network capacity. Furthermore, this periodic exchange, which involves all nodes in whole network, can be a large consumption of network resources and increase the opportunity of collision. Secondly, the parameter for evaluation and the stability evaluation method itself determine the accuracy of the stability evaluated. Thirdly, the stability-oriented routing algorithm usually adopts reactive manner, which has a general routing cycle: route discovery; route maintenance and route rediscovery. Although the stable routes for data transmission are established in route discovery process, it should alert the change of the stability of routes which caused by node's motion during the transmission of data, since it turns to impact the route rediscovery process. Route rediscovery usually occurs when a routing algorithm fails to maintain a valid route for an ongoing traffic flow. The flow is interrupted while a new route is found, which leads to unacceptable traffic delivery gaps for real-time applications. To enable the mobile ad hoc network to carry as many applications as traditional networks do, the stability-oriented routing algorithm needs to provide continuous valid routes for ongoing flows in high-mobility scenarios. Finally, the routing overhead should be adaptive, so that the amount of routing overhead is consistent with the topology and traffic demands.

Manuscript received April 10, 2010; revised November 15, 2010; accepted January 21, 2011.

doi:10.4304/jcm.6.1.79-86

In order to limit the network overhead efficiently and adaptively, keep track of the varying topology and provide continuous and valid routes for the data stable delivery, a mobility-adaptive routing algorithm is proposed. The algorithm consists of the following phases: (1) Link expiration time (LET) calculation through the route request and route reply packets based on the GPS information, (2) Establishing an available route with stable links, (3) Updating the RET when node's motion change, (4) Maintaining route.

Our contributions in this paper are as follows: (1) Asynchronous mobility information and LET update when node's motion change, (2) The mobility information and the LET update involve only nodes on route to reduce control overhead, (3) Critical LET zone (CL-zone) for alternative route discovery, (4) Analyzing the performance of the proposed mobility-adaptive routing algorithm with simulations.

The rest of the paper is organized as follows. In section 2, we give a brief survey on some of the existing stability-oriented routing algorithms and some backup route mechanisms in MANETs. Section 3 describes the proposed mobility-adaptive routing algorithm in detail. Simulation results and performance analyses are presented in section 4. Finally, section 5 concludes this paper.

II. Related Work

Over the past years, the stability of network and communication structures in mobile networks has been subject to several research activities. The systems proposed in literature primarily differ in the kind of information they use to assess the stability [3-11, 14-17]. Neighbor Stability Routing (NSR) [4] algorithm selects the most historically and accumulatively stable mobile nodes to form a path between the source node and destination node. The relative stability is then propagated from the collective data by all the nodes along a path. The cumulative collective data, or stability factor, reflects the historical neighborhood stability among neighbors. When a node or segment on the path is down, NSR will dynamically find an alternative most stable path. Papers [5-8] use LET [9] to assess the stability of link which is based on GPS information, and the route expiration time is the minimum LET on the route. These routing protocols integrate the evaluation of LET into on-demand routing algorithms, such as DSR [12] or AODV [13], for discovering stable route. For every node can obtain GPS information by itself, no periodic message exchange needed, which can reduce much control overhead. In [14], a self-adaptive and mobility-aware path selection in mobile ad-hoc networks is proposed. To aware mobility of node, Doppler value is calculated based on the Doppler shift which can be obtained through the forwarding of route request packet like DSR for assessing the stability. In [15], it use the Newton interpolation polynomial to gain all the received signal strength within the whole sample domain based on only several sampling points, and then finds appropriate reference points to complete the whole prediction of stability. Due to the means to evaluate the stability is different, some of the evaluations [4, 16, 17] need periodic message exchange for collecting useful information, and some [5-8] don't need. All afore mentioned stability evaluations are used to establish stable route with an on-demand route discovery manner, which base on the assume that nodes will keep their current motion within the duration that the link used isn't down, so they rarely consider how to maintain the continuity of data transmission after nodes changed their motions.

DBR2P [18] is an on-demand routing protocol. After the destination node replies a path back to the source node as the current route for sending data packet, some backup routes are established and stored in the backup nodes. When a link failure is detected, a node in the route from the source to the destination cannot continue to transmit the data packet. That node will pass a "Link_Fail_Message" to an upstream node until the message reaches a backup node. After the backup node receives the Link_Fail_Message, the backup route cached is fetched to replace the route behind the backup node, and the source node S is informed to change the route. Then, S sends packets along the new route. In [19], bypass routing performs on-demand route recovery utilizing both route caches and local error recovery. Essentially, to recover from a route failure, a node first salvages a route by searching its route cache for an alternate route to the destination (if the node caches multiple routes). If a route exists, the node patches the broken route with the alternate route. If the node is not able to repair the route from its route cache, it initiates bypass recovery by querying its neighbors to see if they have a link to any nodes on the downstream route to the destination (e.g., the next hop, or all downstream nodes in case of source routes). As replies arrive, the node repairs the routes affected by the link failure with the received connectivity information. When those packets reach the destination, the new route information is added to an enhanced route error packet and sent back to the source to inform it about the broken link and successful route change. In [20], the authors propose two schemes: AODV-ABR and AODV-ABL to increase the adaptation of routing protocols to topology changes by modifying AODV-BR [21]. In AODV-ABR, in addition to constructing alternate routes by overhearing RREP packet, the mesh structure also can be created by overhearing the data packets transmitted from neighbor nodes. In this way, we can increase the adaptation of routing protocol to topology changes without transmitting many extra control messages. Then combining AODV-ABR with the local repair algorithm, AODV-ABL is proposed.

III. Mobility-Adaptive Routing (MAR) Algorithm

This section describes the work of proposed mobility-adaptive routing scheme. When there is a data transmission request, a route discovery process is triggered, and with the help of route request (RREQ) and route reply (RREP) packets, the LET is calculated by nodes and a stable route is established. Then nodes use mobility information to update the LET of link on route in real time, and an adaptive maintenance ensures the continuity of data transmission.

Details on the key design and distinct features that are incorporated in each element of the proposed routing scheme are described below.

A. Reactive calculation of LET

The calculation of LET is done with the transmission of RREQ and RREP simultaneously, so it also reacts to the demand of data transmission as other reactive routing schemes. The reactive calculation of LET can be divided into two processes: forward calculation of LET and backward information of RET, which is the route expiration time and is defined by the minimum LET on route.

The details are described via Fig. 1 as following. Firstly, three fields are added into RREQ to record the motion information (location, velocity and direction), the minimum LET on passed path and the timestamp of this minimum LET calculated respectively. When the source node S constructs a RREQ, it added its motion information into the RREQ and sets the minimum LET and the timestamp to zero. On receiving the RREQ, node A calculates the LET of its upstream link 1. Then it refreshes the RREQ with its own motion information and records the minimum LET and the timestamp in RREQ. Then it broadcasts the RREQ to its neighbor node B. When the destination node D receives the RREQ, it gets an available route (A→B→C→D) and the RET of this route; Secondly, when the destination node D constructs a RREP, it added the RET and corresponding timestamp into the RREP. On receiving the RREP, node C records the route, the RET and the timestamp for destination node D. Then it forwards the RREP to node B. So when the source node receives the RREP, nodes {C, B, A, S} have obtained the available route, the RET and the timestamp for destination node D respectively.

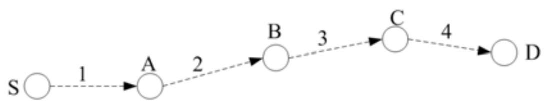

Figure 1. A route for example

B. Asynchronous mobility information and LET update

Usually the bidirectional periodic message exchange, which needs global synchronized in whole network, is used for informing motion state between neighbor nodes in stability-oriented routing protocols. But it is hard to determine the interval for different network dynamics. Furthermore, it can consume much extra network resources.

In the proposed routing scheme, an asynchronous mobility information mechanism is used to substitute the periodic message change. The asynchronous mobility information is triggered by the change of node’s motion, it means only when some node changes its motion denoted by a binary group (velocity, direction), a unidirectional information is sent to its neighbors from this node. Actually, only the nodes that are on current routes should be considered, since their motion changes can affect the stability of current routes only. So, only when the nodes on current used routes occur motion changes, it is necessary to send information to their neighbors. Furthermore, when neighbors have received the information, only the neighbors on current used route are necessary to update the relative status information. As shown in Fig. 2, nodes {7, 12} all change their motions, but only node 7 which is on the current used route (15→8 → 7 → 6 → 13) informs to its neighbors. Then the neighbors {3, 4, 5, 6, 8} of node 7 can receive the information, but only neighbors {8, 6} update their status information recorded respectively, for only these two nodes are on current used route (15→8→7→6→13).

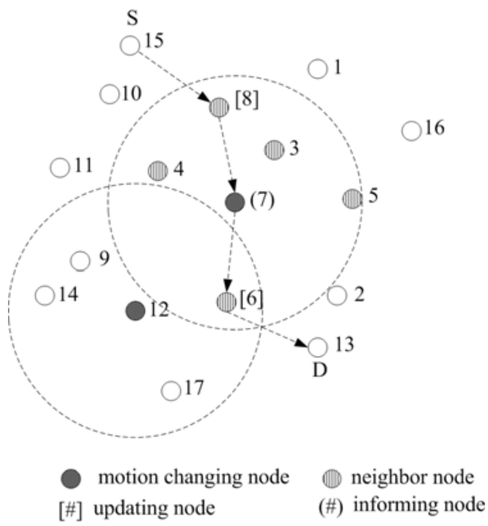

Figure 2. Asynchronous mobility information and LET update

If only the updated LET of node 8 is less than the RET, it will send an information to the source to updates the RET recorded by the source. If the updated LET of node 6 is also less than the RET simultaneously, it also sends an information to the source. But if the updated LET of node 6 is bigger than that of node 8, when node 8 receives the information sent by node 6, it will be dropped. Moreover, any nodes receiving the information will update the RET recorded.

C. Critical LET Zone for alternative route discovery

It is common that more than one route can be discovered in route discovery process, and then the optimal one is selected as the primary route and the others as the backup route. So, once the primary route is down, one backup route can substitute it immediately. But for stability-oriented routing scheme, since the primary route generally has the longest lifetime, there will be no available backup routes with afore mentioned scheme when the primary route is down.

Therefore, the critical LET zone (CL-zone) is introduced for discovering alternative route in our proposed routing protocol. The basic idea is that once the source node finds the RET recorded dropping into the CL-zone which is denoted by an interval [LET_{min}, LET_{max}], it will pre-discovery an alternative route. One situation must be considered is that the RET of some route may have been smaller than $LET_{\max}$, when the route is just established. For this situation makes no alternative route will be discovered.

Under the condition that the nodes on route keep their current motions, the RET, which is bigger than $LET_{\max}$ normally, will change gradually into the CL-zone. But if any one changes its motion, the change of RET may not be gradual anymore. One circumstance is that the RET may reduce to a small value, so the remaining lifetime of route is not enough for pre-discovering an alternative route. Therefore, we set $LET_{\min}$, and then if the updated RET of source is smaller than $LET_{\min}$, no pre-discovery will be triggered.

D. Description of MAR algorithm

The MAR algorithm is a reactive routing algorithm, which contains two essential processes: route discovery and route maintenance.

1) Route discovery

The requesting node broadcasts a RREQ to all neighbor nodes within its communication range. The RET of passed path is recorded in RREQ. So the destination node will receive several RREQs from different paths, then it selects the path with the biggest RET to send RREP. When the RREP is received by the source node, an available route is obtained.

The details of route discovery are shown in Fig. 3.

```
Algorithm 1. Route Discovery
Precondition:
   Neighborhood set of node i: N_i
   Route expiration time recorded in RREQ: RET
   Minimum LET recorded by node: min_LET
   Waiting timer for RREQ: RQ_Timer
BEGIN:
 The source node s broadcasts a RREQ
 IF node n (n∈N_m) receives the RREQ from node m THEN
    calculates LET_mn
    RET = min(RET, LET_mn)
    IF the RREQ is a duplicate packet
    AND RET ≤ min_LET THEN
       drops the RREQ
       return
    ELSE
       min_LET = RET
    ENDIF
    IF n is the destination node THEN
       IF RQ_Timer is time out THEN
          replies RREP
       ELSE
          waits RREQ
       ENDIF
    ELSE
       broadcasts the RREQ
    ENDIF
 ENDIF
 IF a node j (j∈N_i) receives the RREP from node i THEN
    IF j is the source node THEN
       gets an available route
    ELSE
       records the route, the RET and the timestamp
       forwards the RREP
    ENDIF
 ENDIF
END
```

Figure 3. The details of route discovery

2) Route maintenance

During the transmission of data, the source node will check the RET recorded periodically. Once the RET drops into the CL-zone, it will discover an alternative route for the primary route in advance. But when there is a sudden broken link, the node that first notices this break will perform a recovery procedure to handle the sudden broken.

The details of route maintenance are shown in Fig. 4.

```
Algorithm 2. Route Maintenance
Precondition:
   Neighborhood set of node i: N_i
   A communication pair of nodes: s-d
   Critical LET zone: [LET_min, LET_max]
BEGIN
// asynchronous mobility information and LET update
 IF node n change its motion AND it is on current
  used route THEN
     broadcasts MOTION_CH
 ENDIF
 IF node m (m∈N_n) receives the MOTION_CH
  AND it is on current used route THEN
    updates LET_nm
    IF LET_nm ≤ RET THEN
       updates its recorded RET
       sends an information to s which records the LET_nm
    ENDIF
 ENDIF
 IF any node receives the information THEN
    IF LET_nm ≤ RET THEN
       updates its recorded RET
       forwards the information to the source
    ELSE
       drops the information and return
    ENDIF
 ENDIF
//alternative route pre-discovery*/
 source s checks the RET recorded periodically
 IF the RET ∈ [LET_min, LET_max] THEN
    pre-discovers an alternative route
 ENDIF
// there is a sudden broken link, and node h notices this break
 IF Distance(h, d) < Distance(h, s) THEN
    /*local repaire*/
    broadcasts a RREQ to d with TTL = Distance(h, d)
 ELSE
    send RRER to s
 ENDIF
 IF node j receives the RRER THEN
    deletes the route which contains the broken link
    in its route cache
    IF j≠s THEN
       forwards the RRER to s
    ELSE
       discovers an new route
    ENDIF
 ENDIF
END
```

Figure 4. The details of route maintenance

IV. Performance Evaluation

In this section, ns-2.29 is used as the simulation tool to evaluate the performance of the MAR. The main objective of these simulations is to study the performance of MAR and the impacts of the proposed mobility-adaptive mechanisms. In the subsequent discussions, LOR which is realized according to [7] indicates the basic stability-oriented routing algorithm based on LET. LOR-p indicates LOR plus the periodic message exchange (the period is set 0.5 s in our simulations) mechanism which is used to exchange neighbor information and assess LET, LOR-1 indicates LOR plus the reactive LET calculation mechanism, LOR-2 indicates LOR-1 plus the alternative route pre-discovery mechanism (the CL-zone is set [1.5 s, 2.5 s] in our simulations), and MAR is the mobility-adaptive routing algorithm proposed in this paper.

Furthermore, we evaluate the performance of the proposed MAR algorithm with two simulations. In the first simulation, we place 50 nodes in the scene of the simulation, and increase the maximum speed of nodes from 10 m/s to 50 m/s with the step 10 m/s gradually. The random waypoint (RWP) mobility model is used to simulate the motions of nodes. In RWP mobility model, the motions of a node are divided into several sessions during the whole simulation. When a node reaches the destination of a session, it picks up a new speed and direction in the sequent session. Therefore with the gradual increasing of speed, nodes will change their motions more frequently. In the second simulation, we fix the maximum speed of node to 50 m/s, and increase the number of nodes from 40 to 80 with the step 10..

The IEEE 802.11 medium access control (MAC) distributed coordination function (DCF) protocol is used in our simulations and table 1 shows the simulation parameters. Considering the problem revealed in [22], the minimum speed is set to 1m/s, since by doing so the simulation results quickly converge to a constant and stable level. The final results are the average of ten simulations.

TABLE I.
SIMULATION PARAMETERS

Parameter	Value
Scene size	2000×500 m^2
Number of nodes	40 - 80
Radio Propagation Model	Two-ray ground reflection
Transmission range	250 m
Minimum velocity	1 m/s
Maximum velocity	10 m/s - 50 m/s
Mobility model	Random Waypoint
Data	CBR, 512 Bytes/packet
Flow	10 connects, 4 packets/s
Simulation time	600 s

A. Performance metrics

We study the following performance metrics:

(1) Packet delivery ratio – ratio of the number of data packets successfully delivered to the destination to that of the total number of data packets originating at the source.

(2) Number of control packets – sum of control packets used by routing algorithm during simulation. The control packets consist of RREQ, RREP, RRER and other control packets for maintenance.

(3) End-to-end delay per packet – average of the delay incurred by all data packets that originate at the source and are delivered at the destination.

B. Analysis of packet delivery ratio

Fig. 5 shows all of the packet delivery ratios decrease

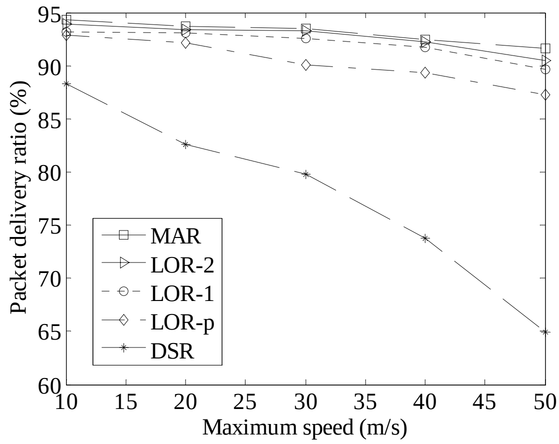

Figure 5. Packet delivery ratio vs. Maximum speed

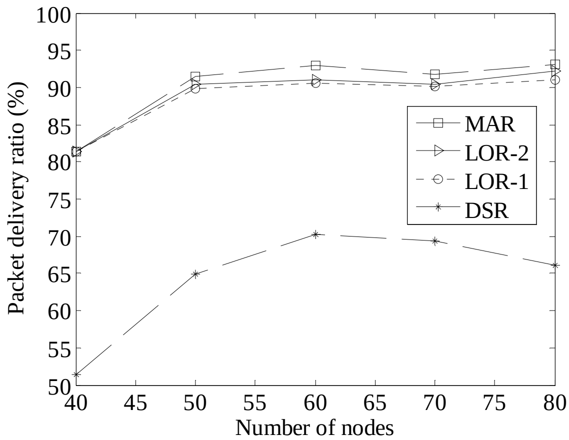

Figure 6. Packet delivery ratio vs. Number of nodes

with gradually increasing maximum speed of nodes. But we can see a clear ranking in Fig. 5, DSR shows the worst packet delivery ratio and a sharp dropping compared to the other stability-oriented routing algorithms. Among the stability-oriented routing algorithms, LOR-p has the worst packet delivery ratio compared to others. It is because that LOR-p uses periodic message exchange to calculate LET, which in turn consumes more resource and leads to many collisions among nodes. Furthermore, the fixed exchange period cannot adapt to different motion circumstances, especially when nodes move fast, so the packet delivery ratio decreases fast. Although LOR-1 only substitutes the periodic message exchange with reactive LET calculation mechanism, its packet delivery ratio is improved significantly compared to LOR-p. The alternative route pre-discovery mechanism based on the CL-zone makes the packet delivery ratio of LOR-2 is better than that of LOR-1. But the updated LET may increase after motion change, which actually covers the effect of the mobility-adaptive mechanisms, so the improvement is weakened. Even so, MAR shows the best packet delivery ratio, and the improvement is more significant when node's speed is high. Fig. 6 shows the changes of the packet delivery ratio with increasing node densities. It is clearly that DSR has the worst packet delivery ratio, and gets the maximum when then number of nodes equals 60. For all simulated stability-oriented routing algorithms, it is clear that the sparse node placement worsen the packet delivery ratio seriously. It also shows that a sharp elevation from 40 nodes to 50 nodes in our simulation scene, but a moderate undulation from 50 nodes to 80 nodes. Then it reveals that the moderate node density is essential for a better packet delivery ratio, and the packet delivery ratio will reach a steady stage within a moderate extent of node density. A clear ranking is also shown in Fig. 6 with different node densities. LOR-1 is worse than LOR-2, which is worse than MAR.

From Fig. 5 and Fig. 6, we can conclude that the proposed mobility-adaptive mechanisms can improve the packet delivery ratio effectively.

C. Analysis of control overhead

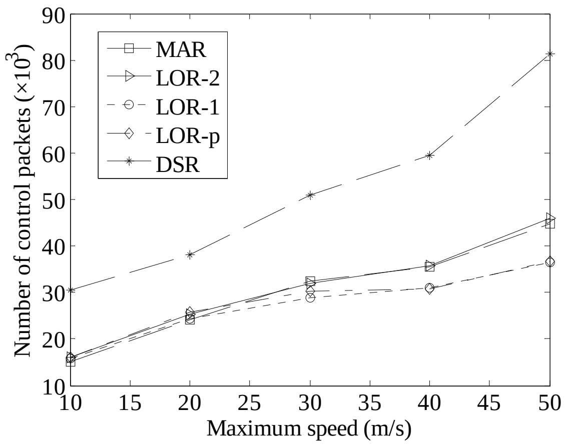

Figure 7. Number of control packets vs. Maximum speed

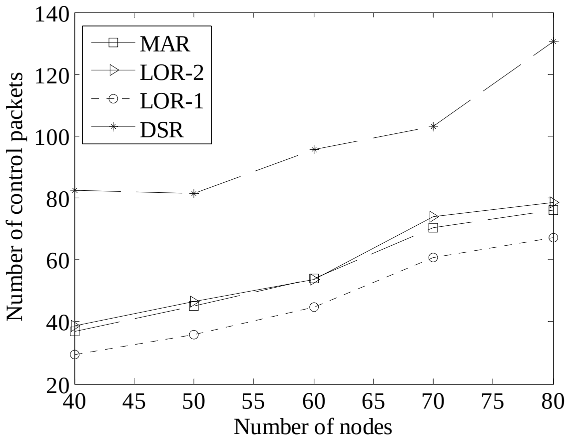

Figure 8. Number of control packets vs. Number of nodes

Fig. 7 and Fig. 8 show the control overheads increase with the increasing maximum speed and the increasing number of nodes respectively for all simulation routing algorithms. It clearly shows that DSR has the highest control overhead. But to the stability-oriented routing algorithms, Fig. 7 shows that the control overheads of all routing algorithms are similar when the maximum speed changes from 10 m/s to 20 m/s, but when the maximum speed is bigger than 25 m/s, the control overheads of LOR-2 and MAR is bigger than that of LOR-1 and LOR-p. The reason is that, although the extra mobility-adaptive mechanisms used in MAR and LOR-2 can improve the packet delivery ratio, the improvement lies in enhancing the continuity of data transmission, which actually doesn't decrease the control overhead for the maintenance of routes. Furthermore they also introduce many extra control packets for adapting to mobility, which increase with the increasing maximum speed. The same result can be drawn from Fig. 8, in which the maximum speed is set 50 m/s. Fig. 8 also shows that with the increasing number of nodes, the control overhead increases gradually since more nodes are involved in routing process. Moreover, Fig. 7 and Fig. 8 show that the control overhead of LOR-2 is bigger than MAR, which is regardless of the increasing maximum speed or the increasing number of nodes.

D. Analysis of delay per packet

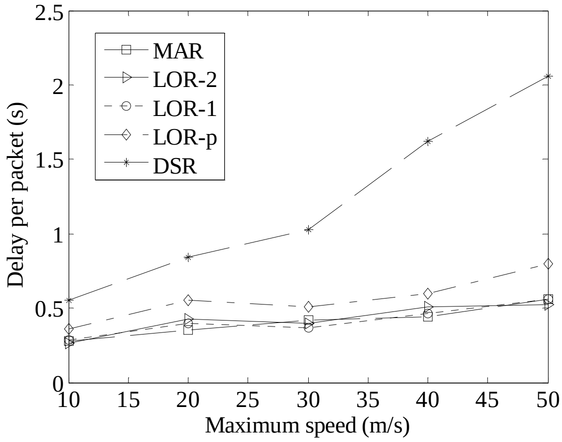

Figure 9. Delay per packet vs. Maximum speed

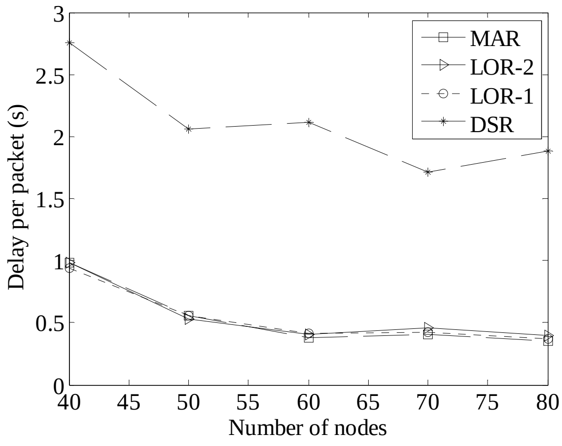

Figure 10. Delay per packet vs. Number of nodes

As shown in Fig. 9 and Fig. 10, compared to the stability-oriented routing algorithms, DSR has the biggest delay regardless the speed of nodes or the number of nodes in network. To the stability-oriented routing algorithms, Fig. 9 shows the delay increases with the increasing maximum speed. LOR-p has the longest delay in four simulated routing algorithms. The differences of delay are smaller among LOR-1, LOR-2 and MAR compared to LOR-p. In Fig. 10, it shows the delay decreases with the increasing number of nodes, and there is a sharp drop from 40 nodes to 50 nodes since the place of nodes is sparse which makes the routing algorithms need more time to discover an available route. But from 50 nodes to 80 nodes, the decrease of delay slows down gradually. Furthermore, with the increasing number of nodes, MAR shows the smallest delay.

V. Conclusion

In this paper, we introduced a routing algorithm which enhances the stability and the continuity of communications in MANETs. Communication stability is ensured by choosing the most stable route which bases on the computation of the LET. The route with the longest LET is considered as the most stable. Then the reactive calculation of LET, asynchronous mobility information and LET update, and alternative route pre-discovery based on the CL-zone are proposed to further enhance the adaptability of stability-oriented routing to the dynamic of network and ensure the continuity of communications. The performance of the routing algorithm is evaluated through computer simulations. Simulation results show the mobility-adaptive routing algorithm based on the LET can be able to provide good network performance in mobile network environments.

References

[1] L. Hanzo, R. Tafazolli, A survey of QoS routing solutions for mobile ad hoc networks, IEEE Communications Surveys & Tutorials, vol. 2, no. 9, pp. 50-70, 2007.

[2] L. Chen, W.B. Heinzelman, A survey of routing protocols that support QoS in mobile ad hoc networks, IEEE Network, vol. 6, no. 21, pp. 30-38, 2007.

[3] R. Chellappa Doss, A. Jennings, N. Shenoy, A review of current mobility prediction techniques for ad hoc networks, in: The Fourth IASTED International Multi-Conference, Banff, Canada, pp. 536-542, 2004.

[4] L. Chen, C.-W. Lee, Neighbor stability routing in MANETs, in: The WCNC, New Orleans, LA, USA, vol. 4, pp. 1964-1969, 2005.

[5] P. Yang, B. Huang, QoS routing protocol based on link stability with dynamic delay prediction in MANETs, in: IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application, Wuhan, China, vol. 1, pp. 515-518, 2008.

[6] N.-C. Wang, Y.-F. Huang, J.-C. Chen, A stable weight-based on-demand routing protocol for mobile ad hoc networks, Information Sciences, vol. 24, no. 177, pp. 5522-5537, 2007.

[7] T. Taleb, E. Sakhaee, A. Jamalipour, et al., A Novel Scheme to Reduce Control Overhead and Increase Link Duration in Highly Mobile Ad Hoc Networks, in: The IEEE Wireless Communications and Networking Conference (WCNC'07), Kowloon, pp. 3972-3977, 2007.

[8] N.-C. Wang, S.-W. Chang, A reliable on-demand routing protocol for mobile ad hoc networks with mobility prediction, Computer Communications, vol. 29, pp. 123-135, 2005.

[9] S. William, G. Mario, IPv6 flow handoff in ad hoc wireless networks using mobility prediction, in: The IEEE Global Telecommunications Conference (GLOBECOM'09), pp. 271–275, 1999.

[10] M. Al-Akaidi, M. Alchaita, Link stability and mobility in ad hoc wireless networks, IET Communications, vol. 2, no. 1(2), pp. 173-178, 2007.

[11] W.Y. Zhu, M. Song, S. Olariu, Integrating stability estimation into quality of service routing in mobile ad-hoc networks, in: The 14th IEEE International Workshop on Quality of Service, New Haven, CT, USA, pp. 122-129, 2006.

[12] D. B. Johnson, D. A. Maltz, J. Broch, DSR: The Dynamic Source Routing Protocol for Multi-hop Wireless Ad hoc Networks, in: C.E. Perkins, Ad hoc Networking, Addison Wesley, pp. 139-172, 2001.

[13] C. Perkins, E. Belding-Royer, S. Das, Ad Hoc On-Demand Distance Vector (AODV) Routing, IETF Mobile Ad Hoc Networks Working Group, IETF RFC 3561, 2003, http://www.ietf.org/rfc/rfc3561.txt.

[14] E. Sakhaee, K. Leibnitz, N. Wakamiya, etc., Self-Adaptive and Mobility-Aware Path Selection in Mobile Ad-Hoc Networks, in: The 1st International Workshop on Technologies for Ambient Information Society, Hyogo, Japan, 2008.

[15] D.P. Wu, Y. Zhen, C.X. Xu, etc., On-demand reliable routing mechanism for MANETs based on link lifetime predicting, in: The WiCOM, Dalian, China, pp. 1-4, 2008.

[16] S. Agarwal, A. Ahuja, J.P. Singh, etc., Route-life time assessment based routing (RABR) protocol for mobile ad hoc networks, in: The IEEE ICC, New Orleans, USA, vol. 3, pp. 1697-1701, 2000.

[17] C.-K. Toh, Associativity-Based Routing for Ad hoc Mobile Networks, IEEE Personal Communications, vol. 2, no. 4, pp. 103-139, 1997.

[18] Y.-H. Wang, C.-F. Chao, Dynamic backup routes routing protocol for mobile ad hoc networks, Information Sciences, vol. 2, no. 176, pp. 161-185, 2006.

[19] C. Sengul, R. Kravets, Bypass routing: An on-demand local recovery protocol for ad hoc networks, Ad Hoc Networks, vol. 3, no. 4, pp. 380-397, 2006.

[20] W.K. Lai, S.-Y. Hsiao, Y.-C. Lin, Adaptive backup routing for ad-hoc networks, Computer Communications, vol. 2, no. 30, pp. 453-464, 2007.

[21] S.J. Lee, M. Gerla, AODV-BR: Backup routing in Ad Hoc networks, in: The IEEE WCNC, Chicago, IL, USA, vol. 3, pp. 1311-1316, 2000.

[22] J. Yoon, M. Liu, B. Noble, Random Waypoint Considered Harmful, in: The IEEE INFOCOM, San Francisco, California, USA, vol. 2, pp. 1312-1321, 2003.

Xi Hu received a M.S. degree in Communication and Information System from Northeastern University in 2007. Now he is a Ph.D. candidate in Department of Information Science and Engineering at Northeastern University, China. His current research interests lie in the areas of quality of service (QoS) and reliability for mobile ad hoc networks, and efficient discovery strategies for mobile ad hoc networks.

Jinkuan Wang received the the Ph.D. degree from the University of Electro-Communications, Japan, in 1993. He is currently a professor in Department of Information Science and Engineering at Northeastern University, China, since 1998. As a special member, he joined the Institute of Space and Astronautical Science, Japan, in 1990. And he worked as a engineer in Research Department of COSEL company, Japan, in 1994. His research interesting includes array signal processing and applications, cognitive radar, software radio.

Cuirong Wang received the PhD degree in Software and Theory from Northeastern University, China in 2004. Now she is a professor in Department of Computer Engineering at Northeastern University at Qinhuangdao, China. She is a senior member of China Computer Federation. Her research interests include Routing Protocol, Network Security, Sensor Networks and network virtualization.