Finding Stable Routes in Mobile Ad Hoc Networks

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Abstract

A mobile ad hoc network (MANET) is an infrastructureless and highly dynamic network. Routes in such a network may fail frequently because of node mobility or other issues. Stability therefore can be an important element in the design of routing protocols. Stable routes, also called the long-lived routes, can be discovered and used to reduce the overhead resulted from route maintenance in ad hoc networks. In this paper we propose the Long-lived Route Prediction (LRP) scheme to discover stable routes. The LRP scheme is distributed, and it predicts the long-lived routes based on the history of link lifetime. Furthermore, we apply the LRP scheme to both open area and urban area using simulation. Simulation results show that the LRP scheme can indeed discover stable routes to reduce the number of route rediscovery, and can be much more efficient and scalable.

Keywords: mobile ad hoc networks, link lifetime, routing, long-lived route, stable route.

1. Introduction

A mobile ad hoc network (MANET) is an infrastructureless network in which nodes share the radio channel to communicate with one another. Mobile nodes are free to move and can self-organize themselves to form a standalone network. Due to the limitation of radio coverage, a node can only communicate directly with these nodes that keep within its radio coverage. If not, multi-hop communication is then required. In such a way, each node acts as a candidate router for other nodes. This infrastructureless property makes the deployment of MANET easy, even in hostile environments. Besides, the supports of node mobility and multi-hop communications make MANETs more robust to node failures than infrastructure networks.

However, there are many challenges in the design of routing protocols when node mobility is considered. Many efforts are needed to find routes in MANET since nodes are mobile and the network topology changes frequently. Furthermore, scarce bandwidth resource and imperfect channel quality can even limit the number of routing information exchanged. Routing protocols for MANETs can be either *proactive* or *reactive* according to the strategy of routing table maintenance. Proactive routing protocols, such as DSDV [1] and WRP [2], tend to maintain the route information for each of other nodes in the network. On the contrary, reactive routing protocols, such as AODV [3] and DSR [4], do not attempt to maintain up-to-date routing information for each of other nodes but only discover route when needed. A detailed comparison between proactive and reactive routing protocols can be found in [5].

Radio links live as long as nodes stay close to one another. Ideally, links should hold for a long time and prevent communication from being interrupted by link failure. However, the inherent nature of node mobility in MANET greatly affects the lifetime of links. A route includes a sequence of links. Even if only one link in the sequence fails, the route no longer works. That is, route stability is heavily affected by link stability. Whenever a route fails, consequent route maintenance is trigged and thus the network throughput degrades. To reduce the overhead on route maintenance, connections should be set up using stable routes, or long-lived routes. Hence, the main goal of this paper is to provide a routing scheme for MANETs to discover stable routes. Furthermore, we run simulations considering both open and urban areas so that the results could be more realistic.

The rest of this paper is organized as follows. Section 2 summarizes related work. Section 3 introduces the LRP scheme. Results obtained from simulation are presented in section 4. Finally, we provide conclusions in section 5.

2. Related work

Links among high mobility nodes are relatively short-lived, and are less stable than those among low mobility

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nodes. The knowledge of the state of node mobility, such as location, moving speed, and moving direction, etc., can be helpful in the prediction of link lifetime. The global positioning system (GPS) is a very popular technique used to obtain the state of node mobility. There are routing protocols using the information obtained from the GPS [6]. Many researches assume an open area environment where the GPS can be simply utilized. However, in the urban area, there may be buildings, walls, and trees, etc. to form shields against the GPS signals, the use of GPS is greatly limited by shadow effect and multipath fading, and the GPS-aided routing protocols would not work well [7]. The received signal strength can be also taken as an index of link lifetime [8-12]. In the open area, the received signal strength can be an accurate index to the link lifetime. However, in the urban area, a link may fail abruptly because of shadow effect, and the prediction error may thus increase.

The Associativity-Based Routing (ABR)[13] protocol introduces the concept of *associativity* to evaluate the stability of links. In the ABR, each node periodically broadcasts a one-hop control beacon to identify itself. Links are associatively stable if and only if the number of received control beacons exceeds a threshold. Because the threshold value in the ABR depends on the moving speed of mobile nodes, some mechanisms for speed estimation are required. In [14], the authors analyzed the link lifetime distribution using different mobility models. Each node has to recognize the link lifetime distribution of current network. Thus, given a link age, the expected residual lifetime of the link can be obtained, and the route with the longest residual lifetime is preferred.

In this paper we propose the Long-lived Route Prediction (LRP) scheme to help discover long-lived routes. The LRP scheme predicts long-lived route based on the history of link lifetime. The advantage of the LRP scheme is that it does not use the GPS or the received signal strength and will not be affected by the presence of shadow effect. In an urban environment, multipath fading is another issue to wireless communication systems. However, the use of the RAKE receiver, for example, in spread spectrum systems or the antenna diversity technique can eliminate the effect of multipath fading. In this paper, we assume that all link failures are caused by node mobility and shadow effect.

3. The LRP Scheme

In this section, we describe how the LRP scheme predicts the long-lived routes. In the LRP scheme, each node maintains a record of link lifetime, which is the history of link lifetime observed by the node. Each node monitors the lifetime of links to its neighbors. To be aware of the radio link establishment and failure, each node periodically broadcasts a one-hop and ack-free hello packet to identify itself. By continuously receiving the hello packets, a node can verify the existence of its neighbors. The age and lifetime of a link can be determined by counting the number of hello packets received. Here the age of a link is the number of hello packets received from a link, and the link lifetime is the sum of hello packets received before link failure. If a neighboring node moves out of the radio coverage, the receiving of hello packets would terminate and therefore the node can recognize that a link failed. Once a link fails, the corresponding two nodes of the link would record this link failure event on their lifetime records along with the lifetime of the failure link.

In the LRP scheme, we define the *longevity factor* as an index of link stability used to predict the long-lived route. The idea behind the LRP scheme is to establish routes over stationary nodes as possible to prevent frequent route failures. The link lifetime of all links to a stationary node would tend to be longer and, in the contrast, the link lifetime of all links to a moving node would tend to be shorter. When a moving node becomes stationary, longer-lived links are emerging more likely. Thus if a link whose age is greater than the lifetime of these links being stored in the link lifetime record, this link is considered to be reliable and stable.

The use of longevity factor is described as follows. Given a node x, the link lifetime record of x is denoted as LTR_x. Let a be the age of certain link of node x. Let the indication function $I(i)$ be

$$I(i) = \begin{cases} 1, & \text{if } a < LTR_x(i) \\ 0, & otherwise \end{cases}, \text{ for } 1 \le i \le |LTR_x| \qquad (1)$$

where $|LTR_x|$ denotes the number of link lifetime entries stored in LTR_x and $LTR_x(i)$ denotes the i_{th} entry in LTR_x. Let $\sigma_a = \sum_{i=1}^{|LTR_x|} I(i)$, then the longevity factor (LF) of this link is calculated as

$$LF = 1/(\sigma_a + 1) \quad (2).$$

For example, let $LTR_x = \{3, 8, 29, 15, 77\}$, then the longevity factor of a link of age 10 is 0.25, and a link of age 90 is 1. Based on the longevity factor of a link calculated from (2), consider a route of M links, each with longevity factor l_i, $i = 1, 2, \ldots, M$, then the longevity factor of this route is given by $\prod_{i=1}^{M} l_i \Big/ M$. The size of LTR_x, which is the maximum number of entries that can be stored in LTR_x, is a design parameter. If the size of LTR_x is set to be infinite, the whole link lifetime history is referenced. However, a larger size LTR_x consumes more memory space as well as more computation power. Therefore, the LTR_x should only store the latest k link lifetime records.

The routing protocol we modified for the LRP scheme is the Ad hoc On-demand Distance Vector (AODV) [3] routing protocol that the longevity factor field is added to record the longevity factor information. When a route to a destination is needed, the source node floods a route request (RREQ) message over the network. Upon receiving the RREQ message, the destination node sends a route reply (RREP) message back to the source node. The route is setup in the routing tables of intermediate nodes during this process. The source node can start forwarding data packets to the destination node via the discovered route. If a route fails because of link failure, the upstream node of the failed link will initiate a route error (RERR) message to notify the source node. The source node will flood RREQ to the network again to discover a new route if needed.

Figure 1 gives an example of a 3-hop route to show the operations of the LRP scheme in the route discovery phase. There are a source node, two intermediate nodes, and a destination node designated as 1, 2, 3 and 4, respectively. For clarity, only the longevity factor (LF) fields are shown in the figure. When the source node initiates a RREQ message, the longevity factor is initialized to be 1 and is received by node 1. Having received the RREQ message, node 2 determines the longevity factor of the link to node 1 (denoted as l_1), and then rebroadcasts the RREQ message to node3 with an LF value of l_1. Upon receiving the RREQ message from node 2, node 3 determines the longevity factor of the link to node 2 (denoted as l_2), and then rebroadcasts the RREQ message to node 4 with an LF value of $\prod_{i=1}^{2} l_i$. When node 4 (i.e. the destination) receives the RREQ message from node 3, it determines the longevity factor of the link to node 3 (denoted as l_3), and then the longevity factor value of this route is determined as $\prod_{i=1}^{3} l_i \big/ 3$. After a period of time from the first RREQ message arrived, the destination node chooses the route with the largest route longevity factor value and sends a RREP message back to the source node along the chosen route in a reverse sequence.

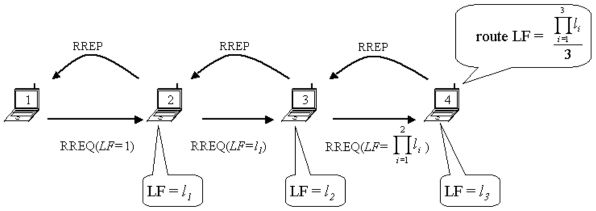
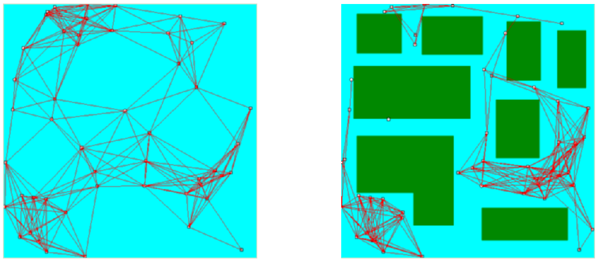


Figure 1 Determination of the longevity factor (LF)

4. Simulation

In the simulation, two different environments are considered: open area and urban area as shown in Figure 2. Both areas are of size 500m × 500m. The dark areas are obstacles to both node movement and radio propagation. The radio coverage is within 150m radius and all links are assumed to be bi-directional. Each pair of nodes can communicate directly if the two nodes are within the radio coverage. The node mobility model used here is the Random Way Point Mobility model [15]. The moving speed is uniformly distributed with a range of [0.3,2] m/s.



(a) open area (b) urban area

Figure 2 Simulation environments

50 nodes are deployed in the simulation. This high-density network can ensure that there exist several different routes between a source-destination nodes pair, and the difference of route lifetime between different routing strategies can be observed more easily. There are 50 active connections in the simulations so that as long as a connection is broken due to route failure, the source node will initiate a RREQ message immediately to discover a new route. The simulation results provided are gathered and averaged over 50 connections. The size of the lifetime record is a design parameter. We examine different lifetime record size of 5, 15, 25 and 50 in the simulations. The results show that the mean route lifetime has minor difference with respect to different lifetime record size. In this paper, we only present the results of lifetime record of size 15.

In the simulation, three routing protocols are considered: the LRP-enhanced AODV (denoted as AODV-LRP), AODV and the RABR, for the comparisons of mean route lifetime. Simulation results in open and urban areas are shown in Figures 3 and 4, respectively. In the open area, the AODV-LRP gives 8% to 19% improvement on mean route lifetime as compared with that of the AODV and at most 2.1% worse than the RABR. In the urban area, the improvement on mean route lifetime using AODV-LRP is 15.4% to 24.2% as compared with the AODV, and 5% to 14.6% as compared with the RABR. The mean hop counts of routes are shown in Figure 5, where in the open area, the mean route length of using AODV-LRP is 12% to 16.8% longer as compared with the AODV, and 2.5% to 6.2% longer as compared with the RABR. In the urban area, the mean route length of AODV-LRP is 7% to 10% longer as compared with the AODV and up to 2.7% longer than the RABR.

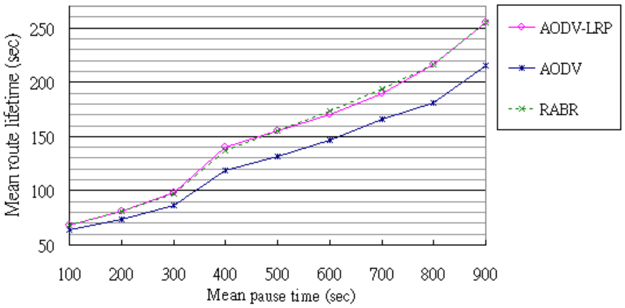


Figure 3 Simulation results in open area

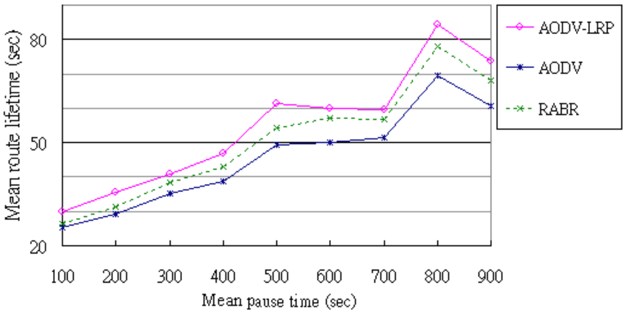


Figure 4 Simulation results in urban area

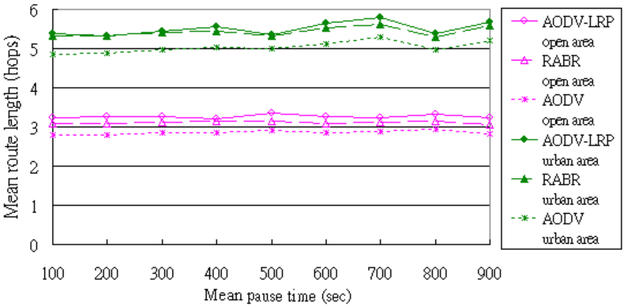


Figure 5 The mean route length

5. Conclusion

In this paper we propose the LRP scheme to discover stable routes in the MANET. The LRP scheme works using the history of the link lifetime and does not require any extra equipment such as GPS to be installed on mobile nodes. We compare the LRP-enhanced AODV (AODV-LRP), AODV and RABR routing protocols and compare the lifetime of routes among them. Simulation results show that the AODV routing protocol performs the poorest. The performances of the AODV-LRP and RABR routing protocols in open area are quite close, but in the urban area, the AODV-LRP routing protocol outperforms. Therefore, the LRP scheme can predict stable routes and is suitable for MANETs in the urban environment.

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