Optimizations for Location-aided Routing (LAR) in Mobile Ad Hoc Networks *
(A brief note)

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Abstract

Location-Aided Routing (LAR) [14] algorithm is an approach to utilize location information for mobile hosts, with the goal of decreasing routing-related overhead in mobile ad hoc networks. A number of optimizations are possible to improve performance of the basic LAR protocols. This paper mainly focuses how the basic operation of LAR can be improved by applying those optimization schemes.

1 Introduction

The issue of developing efficient routing algorithms is a challenging problem in the area of mobile ad hoc networking (MANET). Many different protocols have been proposed to achieve a given level of routing performance for MANET [1, 2, 4, 5, 6, 8, 9, 14, 15, 18, 19, 20, 22, 23]. Among those protocols, Location-Aided Routing (LAR) algorithms we proposed [11, 12, 14] attempt to reduce routing discovery overhead incurred with some flooding based approaches, such as Dynamic Source Routing (DSR) [9, 10] and Ad hoc On demand Distance Vector routing

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(AODV) [19]. In LAR, the use of physical location information has been suggested to reduce the search space for a desired route. The basic LAR has two different algorithms in terms of how to define the limited search space, named "request zone", as described in [11, 12, 14].

Several optimizations are possible to achieve more efficient performance of the basic LAR protocols. In [12, 14], some potential optimizations to the basic LAR algorithms have been suggested, for instance, alternative definitions of request zone or use of directional antenna, etc. This report mainly summarizes these and several other optimizations for the LAR protocols.

2 Overview of LAR

The basic idea of Location-aided Routing (LAR) is that routing-related overhead can be reduced by using the physical location information, i.e., by limiting the search space for desired route to a destination into a smaller but feasible request zone, determined based on knowledge of previous location of the destination. This approach results in lower route discovery overhead in MANET. LAR is basically the same as *flooding* algorithms, with some modifications. The modification at the source is to define a request zone so that only nodes in the request zone can be allowed to forward a route request message into their neighbors[1]. The intended destination is modified to reply with its location information so that this information can be used for a future route discovery at the source.

Two different LAR algorithms have been presented in [14]: *LAR scheme 1* and *LAR scheme 2*. LAR scheme 1 uses expected location of the destination (so-called expected zone) at the time of route discovery in order to determine the request zone. The request zone used in LAR scheme 1 is the smallest rectangle including current location of the source and the expected zone for the destination. The sides of the rectangular request zone are parallel to the X and Y axes. When a source needs a route discovery phase for a destination, it includes the four corners of the request zone with the route request message transmitted. Any intermediate nodes receiving the route request then make a decision whether to forward it or not, by using this explicitly specified request zone. Note that the request zone in the basic LAR scheme 1 is not modified by any intermediate nodes. On the other hand, LAR scheme 2 uses distance from the previous location of the destination, i.e., $DIST$, as a parameter for defining the request zone. Thus, any intermediate node J receiving the route request forwards it if J is "closer" to or "not much farther" from the destination's previous location than node I transmitting the request packet to J. Therefore, the implicit request zone of LAR scheme 2 becomes adapted as the route request packet is propagated to various nodes.

3 Optimizations of LAR

3.1 Alternative Definitions of Request Zone

As described in the previous section, in [14], there are two ways of defining a request zone. Several other alternatives may be conceived. For instance, in the rectangular request zone of

[1]Two nodes are said to be neighbors if they can communicate with each other over a wireless link.

LAR scheme 1, sender node S may be on the border of the zone. Instead, one may define a larger rectangle as the request zone. Also, in LAR scheme 1, the sides of the rectangle are always parallel to the X and Y axes. It is possible to remove this restriction when defining the rectangular region. For instance, one side of the rectangle may be made parallel to the line connecting the location of node S to previous location of D – this approach would often result in a smaller request zone (see Figure 1).

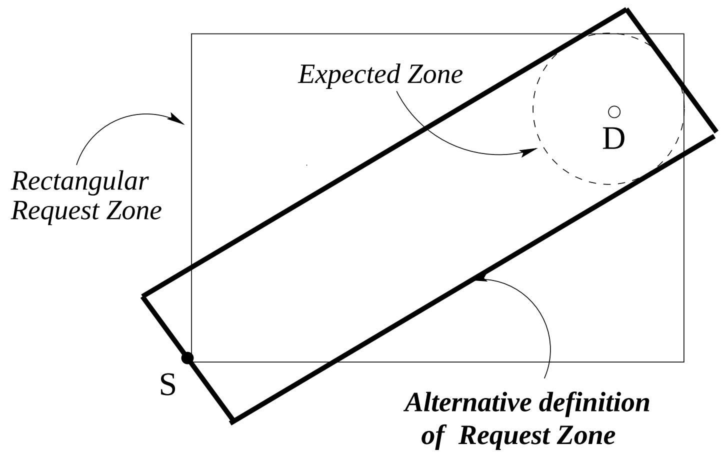


Figure 1: Alternative Definitions of Request Zone for LAR scheme 1

In our previous simulations of the two LAR schemes [11, 12, 14], the request zone is expanded to the entire network space when a sender using our algorithm fails to find the route to a destination within a timeout interval. This simple strategy of expanding the request zone causes performance degradation of LAR schemes with a smaller transmission range and number of nodes. This scheme may be improved by increasing the request zone gradually.

Definition of a request zone is also dependent on how much information regarding the mobile hosts is available. The basic LAR scheme 1 assume that only speed[2] of the nodes is known. It is interesting to consider situations wherein additional information may be available (for instance, direction of movement).

3.2 Adaptation of Request Zone

3.2.1 Adapted Request Zone by intermediate nodes

Accuracy of a request zone in LAR (i.e., probability of finding a route to the destination) can be improved by adapting the request zone, initially determined by the source node S, with up-to-date location information for destination host D, which can be acquired at some intermediate nodes. Let us consider the case that node S starts search of a destination node D within a request zone Z at time t_1, which is based on location information about D learned by S at time t_0. Let us assume that the *route request* includes the timestamp t_0, because the location of node D at time t_0 is used to determine the request zone. Also, location of node S and the time t_1

[2]In simulations presented in [13], average speed of mobile nodes is used to define the expected zone, whereas maximum speed is used in [14]. It is also possible to use some other function of the speed distribution.

when the request is originated are also included. Now suppose that some intermediate node I within Z receives the route request at time t_2, where $t_1 < t_2$. More recent location information for D may potentially be known by node I (as compared to node S), and the expected zone based on that information may be different from previous request zone Z. Therefore, request zone initially determined at a source node may be adapted at node I.

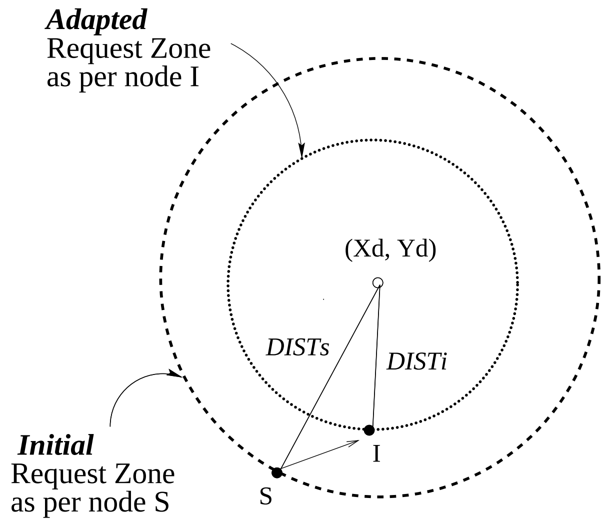
For instance, when using LAR scheme 1, node I may determine the expected zone using more recent location information for node D, and define the adapted request zone as the smallest rectangle containing node S and the new expected zone for node D. Similarly, when using LAR scheme 2, node I may calculate distance from the more recent location of destination D that it knows, and use this distance in the decision rule (to decide whether to discard a route request) of scheme 2.

3.2.2 Other ways for Request Zone Adaptation

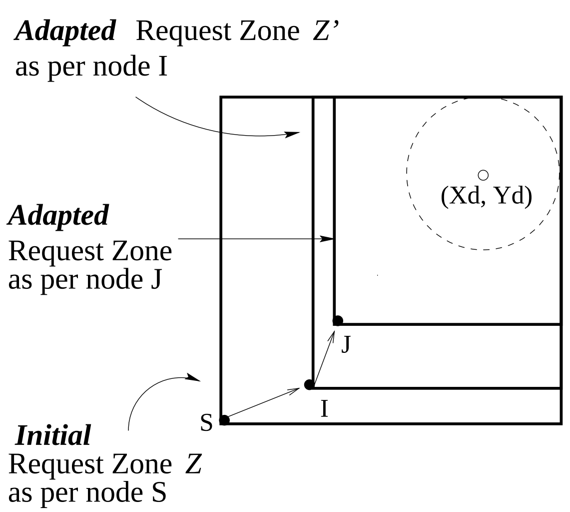
Even though the LAR scheme 2 does not explicitly specify the request zone, the request zone at node S can be thought to be implicitly defined as a circle of radius $\alpha DIST_s + \beta$[3]. As the route request packet is propagated to various nodes, this implicit request zone is adapted by an intermediate node I as a circle of radius $\alpha DIST_i + \beta$, as shown in Figure 2(a). On the other hand, in LAR scheme 1 the request zone is specified explicitly by the source S, and the request zone is not modified by any intermediate nodes. We can improve the performance of LAR scheme 1 by having the request zone be adapted at an intermediate nodes I, such that the request zone for the request propagated by node I includes the current location of I and the expected zone of the destination D. For instance, in Figure 2(b), when node I receives the route request from the source S and forwards the request to its neighbors because I is within the request zone Z (defined by S), it can replace Z by an adapted request zone Z' before forwarding the request. By applying the same reasoning when node J receives the route request message from node I, the request zone can be again adapted.

Generalizing the above idea, although a rectangular shape is used for the request zone in LAR scheme 1, any other form may also be used. For instance, Figure 2(c) shows the case when the request zone is defined as a cone rooted at node S, such that angle made by the cone is large enough to include the request zone – the angle made by the cone may be chosen by some other heuristic as well (for instance, if the angle is always chosen to be 90 degrees, this scheme would become similar to that in Figure 2(b)). Similar to adaptation of the rectangular request zone in Figure 2(b), the cone-shaped request zone may also be adapted as shown in Figure 2(c). This approach using cone-shaped region is analogous to the approach used in [1] to deliver data to a destination node. The significant difference between the two approaches is that the LAR uses the cone-shaped regions for route discovery, not for data delivery. Also, LAR schemes does not require periodic broadcast of location information, unlike [1].

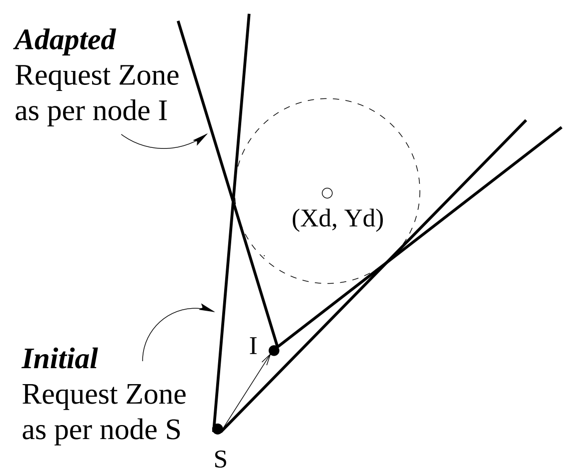
[3] Some parameters α and β are used to tune the request zone's size in [14].



(a) Adaptation of *Implicit* Request Zone for LAR scheme 2 : ***Circular Shape***



(b) Adaptation of ***Rectangular Shaped*** Request Zone



(c) Adaptation of ***Cone-Shaped*** Request Zone

Figure 2: Implicit or Explicit Adaptation of Request Zone for LAR

3.3 Local Search

In the basic LAR protocol, any intermediate node I detecting routing failure (due to a broken link) informs the source node S by sending a *route error* packet (see Figure 3(a)). Then, S initiates a new route discovery (using a request zone), to find a path to the destination D. As we have already seen, if we use location information, routing messages can be reduced by limiting propagation of route request packets to the request zone determined (implicitly or explicitly) by node S, as shown in Figure 3(b). Figure 3(c) shows how this scheme may be improved to reduce the size of request zone as well as latency of route re-determination for node D. This can be done by allowing any intermediate node I detecting route error to initiate a route discovery using a request zone based on its own location information for node D. Such a *local search* may result in a smaller request zone (as shown in Figure 3(c)) because node I may be closer to D than S. Smaller request zone could reduce routing overhead. The time to find the new path to D may also be reduced, as a smaller request zone is searched.

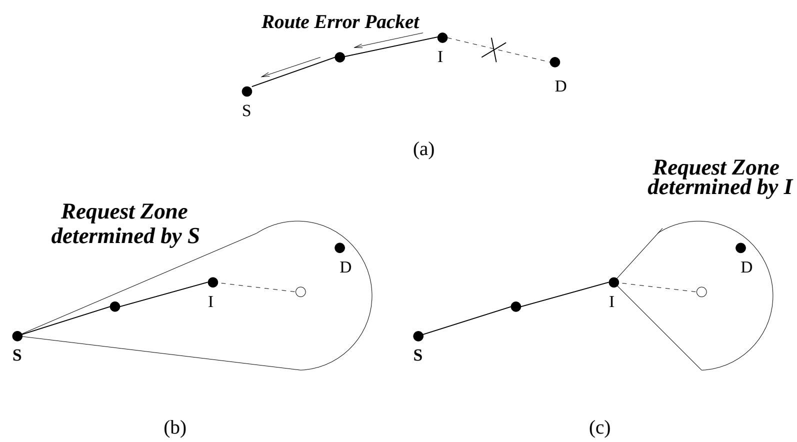


Figure 3: Local Search to Re-establish a Broken Route

3.4 Propagation of Location and Speed Information

Initially, in ad hoc network environments, a node may not know the physical location (either current or old) of other hosts. However, as time progresses, each node can get location information for many hosts either as a result of its own route discovery or as a result of message forwarding for another node's route discovery. For instance, if node S includes its current location in the route request message, and if node D includes its current location in the route reply message, then each node receiving these messages can know the locations of nodes S and D, respectively. In general, location information may be propagated by piggybacking it on any packet. Similarly, a node may propagate to other nodes its average speed (or some other measure of speed).

3.5 Combining with Time-to-Live (TTL)

In DSR [9], route discovery using expanding ring search has been suggested as one optimization over flooding. In this approach, a source initially sends a route request with setting its time-to-live (TTL) field to 1. If no route reply is received for some time, the source increases the TTL to a larger value and tries again. Although both TTL and LAR schemes limit the spread of route request messages, their behavior is quite different. In fact, the LAR protocols may also be used in combination with the TTL optimization. By setting the TTL to some reasonable number, the source can bound the number of hops the request packet will travel. Therefore, even if a node exists within the request zone defined by the LAR scheme, it will drop the packet when it is over TTL hops away from the source.

3.6 Clock Synchronization

LAR scheme 1 assumed clock synchronization between the nodes. However, this approach can be easily extended to the case when clocks are unsynchronized. When a node X receives location information for another node Y (for instance, in a route reply packet), node X would timestamp the information as per its local clock. This information can be used in a future route discovery, as described in LAR scheme 1. This approach is likely to perform as well as in the case of synchronized clocks, because message delivery delays are likely to be relatively small. LAR scheme 2 does not need synchronized clocks, which may be considered to be an advantage over scheme 1.

3.7 Use of Directional Antennas

3.7.1 Directional Antennas

A directional antenna is an antenna in which the radiation pattern is not omnidirectional. One advantage of directional antennas for mobile communication is that they reduce effects of multipath degradation [25]. Increasing the effective communication range of base station can also be considered as an advantage. On the other hand, when applying directional antennas to mobile communications, new problems occur: for instance, multiple access protocols with omnidirectional antennas should be redesigned since with directional antennas the beam can only be directed at a subset of neighbors [7].

Some researchers have already suggested use of directional antennas for a packet radio system consisting of a base station and a number of mobile users. For example, Zander [25] has proposed the use of directional antennas in slotted ALOHA multihop packet radio networks whose broadcast radio channel is shared by means of some random time division multiple access (RTDMA) scheme. More recently, a way of using adaptive directed antennas for the Mobile Broadband System (MBS) has been proposed [7]. In [7], to apply directional antennas to mobile communications, they pointed out that a mobile station's direction needs to be tracking precisely so that the base station can direct the beam at the mobile station with sufficient precision. In addition, they argued conventional multiple access protocols are not suitable with directional antennas and suggested an adaptive protocol of dynamic slot assignment (DSA) for directional antennas. Other researchers have also suggested using directional antennas for packet radio networks [16, 21, 24].

Most of previous MANET routing algorithms assume (implicitly or explicitly) use of *omnidirectional* antennas even though MANET nodes can be equipped with wireless transmitters and receivers either using omnidirectional antennas (broadcast) or using highly directional antennas (point-to-point) [3]. In fact, the main reason why those protocols usually assume omnidirectional antennas is because they cannot specify the direction in which routing request packets need to be transmitted. Clearly, in order to utilize directional antennas for the routing purpose, a source should define where to send a route request packet.

3.7.2 LAR with directional Antennas

The LAR protocol lowers routing overhead by reducing the number of nodes that will receive and forward a route request message. However, the basic LAR approach is still limited in a sense due to the broadcast propagating nature of mobile ad hoc networks. In general, MANET nodes are assumed to have *omnidirectional* antennas for wireless communication [3]. This assumption implies that any request message broadcast by a node will reach all its neighbors, even if some of these neighbors are outside the intended request zone. This may be improved upon by using directed antennas.

For instance, in Figure 4, let us assume that node S needs to determine a route to node D so it broadcasts a route request packet. Let us also assume that LAR scheme 1 is used for this route discovery phase with omnidirectional antennas. With LAR scheme 1 based on the viewpoint of S, the request zone is defined as the rectangle in which only node S, A, B and D are included. Nodes C and E do not need to receive any route request packets, because they are both outside the request zone. However, due to the broadcast transmission properties of wireless networks, node C receives a route request packet from node S whose transmission range covers C as well as A. Similarly, the request message will be forwarded to node E, via node A, unnecessarily. (In fact, when node A forwards the route request, all it neighbors B, C, E, and S, will receive the request.) This inherent limitation can be mitigated by using *directional antennas.* A directional antenna is an antenna in which the radiation pattern is not omnidirectional. LAR protocols, particularly those using the optimizations in Figure 2, make it possible to utilize directional antennas for routing in MANET.

Again, assume that node S having a directional antenna initiates a route discovery phase for node D. Based on the previous location information of D, route request packets may only be directed at a small group of mobile nodes (see Figure 4). Therefore, in this scenario, node C does not receive the request packet from S even though C is a neighbor of S. When node A forwards the route request (originated by node S), it applies a similar criteria. Continuing in this fashion, intuitively, an extension of LAR protocols with directional antennas will substantially decrease the cost of ad hoc routing. Since it can prevent unnecessary transmission of routing packets.

4 Summary

This technical report describes how the basic LAR schemes may be optimized to improve performance. Future work is needed to evaluate these optimizations.

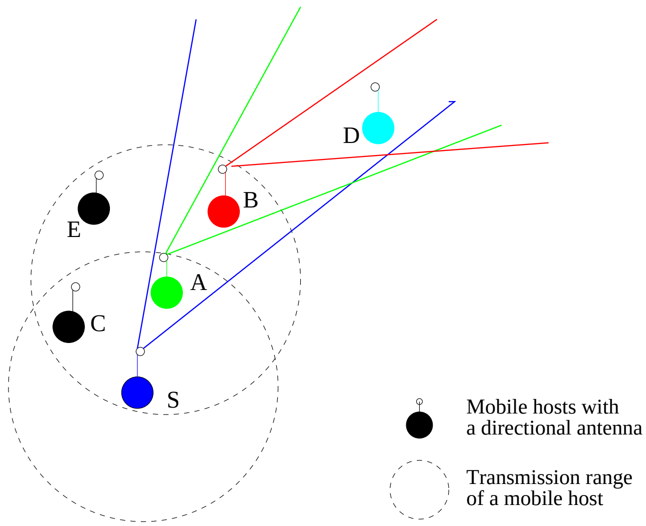


Figure 4: LAR with Directional Antennas

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