Improvements to Location-Aided Routing through Directional Count Restrictions

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***Abstract*— We present an effective way to improve the quality of unicast routes determined by the LAR Box method. Our method uses the location information acquired by LAR itself to determine relay nodes in the forwarding zone. The improvements are two-fold: (1) shorter, more-direct routes are discovered; and (2) less overhead is needed to find those routes. Because more direct routes last longer, higher delivery ratio and lower end-to-end delays are produced by our improvements. The higher the network density, the greater the effect of our improvements.**

I. INTRODUCTION

A mobile ad hoc network (MANET) consists of a set of wireless mobile nodes (MNs) that that cooperatively form a network without specific user administration or configuration. Each MN is responsible for routing information between its neighbors, thus contributing to and maintaining connectivity of the network. By routing traffic destined for other nodes as well as itself, each MN must contribute to the network. Because of the limited reliability of wireless MAC layer, the performance of the network is increased if the data packets are routed along a specific unicast route from source to destination. Because routing has a spatial component in MANETs, the use of location information can aid the routing process. One such protocol that uses location information is Location-Aided Routing (LAR). LAR was initially proposed in [1] and shown to have good performance in [2].

Although LAR's performance is relatively good [2], we felt that there was room for improvement. Because LAR is a building block to other protocols, such as LEAP [3], any improvement to LAR can be immediately realized in several applications. The purpose of this paper is to present and quantify our optimizations of the LAR Box method. Specifically, we examine the effect of our improvements upon control packet overhead, data packet delivery ratio, and end-to-end delay. Our improvements to LAR Box consisted of reducing the number of unnecessary duplicate route formation packets, but doing so in a manner that produces more efficient routes.

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II. OVERVIEW OF LAR

LAR is an on-demand source routing protocol. When a node, S, needs a route to a destination, D, it floods a route request (RREQ) through the network attempting to find the destination. However, rebroadcasts of this RREQ message are limited to nodes within a predefined forwarding region. Each node that receives a RREQ checks to determine whether it is inside the forwarding region. If so, the node appends its (time-stamped) location and speed information to the header and then rebroadcasts the RREQ. Each node is assumed to know its location and speed from some separate location service, such as GPS. Once the RREQ is received at the destination, the destination unicasts a route reply (RREP) back along the reverse route found in the header.

When the originating node sends out a request, it starts a timer. If this timer expires without the node receiving a reply or if the node does not know any prior information about the destination, then the node rebroadcasts the request, but this time the request is flooded throughout the entire network and not just the forwarding region.

There are two basic ways that the forwarding region can be defined for LAR: LAR Box and LAR Step [1]. In both cases, the goal is to find a route from a source node, S, to a destination node D. As our improvements were directed towards LAR Box, that method will be discussed here.

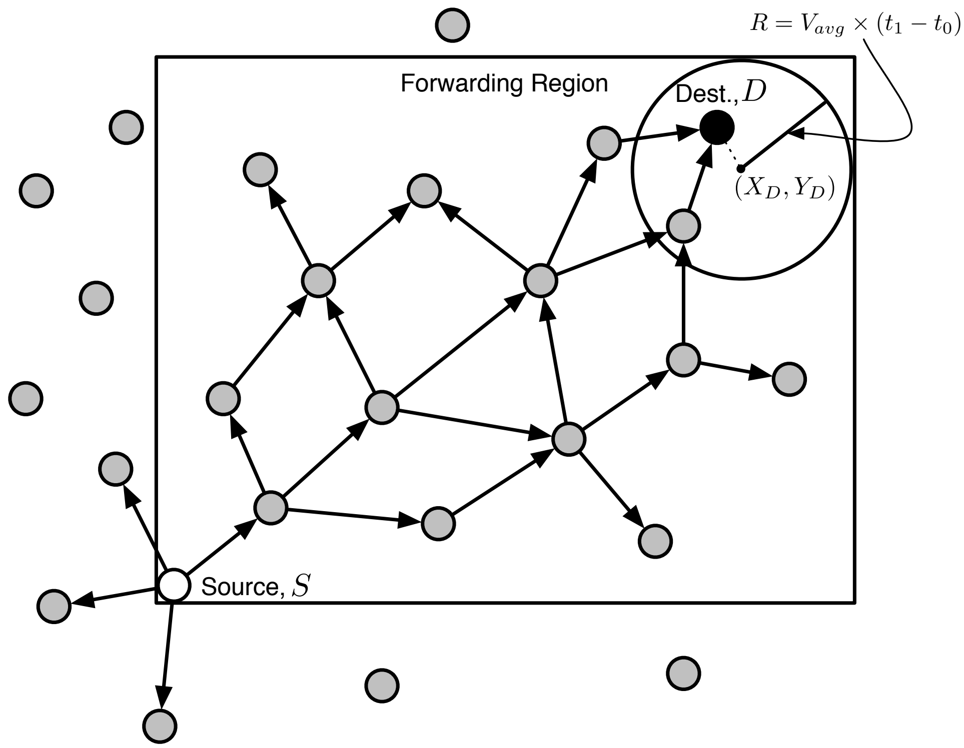

Fig. 1. Sample LAR Box forwarding region. A route between source node S and destination node D is found by flooding the forwarding region. The forwarding region is calculated based on the location of S and the last known position (X_D, Y_D) and velocity (V_{avg}) of D.

In LAR Box, a neighbor of S determines if it is within the forwarding zone by using the location of S and the expected zone for D. As shown in Fig. 1, the expected zone for D is a circular area determined by the most recent location information on D, (X_D, Y_D), the time of this location information, (t_0), the average velocity of D, (V_{avg}), and the current time, (t_1). This information creates a circle with radius $R = V_{avg} \times (t_1 - t_0)$ centered at (X_D, Y_D). The forwarding zone is a rectangle with S in one corner, (X_S, Y_S), and the circle containing D in the other corner. In addition, an error factor δ can be added to this radius to account for a increase in speed of the destination by increasing the size of the forwarding zone. With this error factor, the formula for R becomes $R = (V_{avg} \times (t_1 - t_0)) + \delta$

Both LAR Box and LAR Step include a two stage route discovery method. In the first stage, the route request packet is forwarded according to either LAR Box or LAR Step. If a route reply packet is not received within the route request timeout period, then a second route request packet is flooded through the entire MANET. If a route reply packet is (again) not received within the route request timeout period, then D is considered unreachable.

III. Improvements to LAR Box

There are two existing improvements to LAR Box already implemented and included in [2]. The first is a "zero ring search," in which a node, S, first queries its neighbors to learn if any of them has an existing route to the destination, D. The second improvement is an adaptive LAR Box. In this technique, each additional node recalculates the dimensions of the box based on its own location, placing itself in the lower left-hand corner of the box. After implementing our improvements as described below, we found that the "zero ring search" was did not perform as well in conjunction with our improvements as our improvements did by themselves. However, the adaptive box was retained and is reflected in all of our results.

Our improvements to LAR Box are based on the idea of count restriction [4] of rebroadcasts. Whenever a node receives a route request, the node first waits for an assessment delay (AD) to determine how many other nodes rebroadcast the same packet. If the number of duplicate rebroadcasts heard is below some threshold (Count Threshold), then the node will rebroadcast the route request, as shown in Fig. 2. Otherwise, the node in question just drops the packet. The purpose behind this

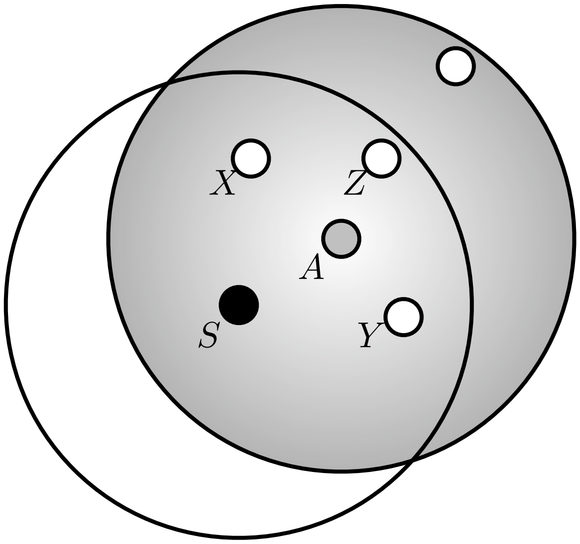

Fig. 2. Example of count restrictions. Nodes A, X, Y, and Z all receive the broadcast send by S, but only A, the node that chooses the smallest assessment delay (AD), rebroadcasts it.

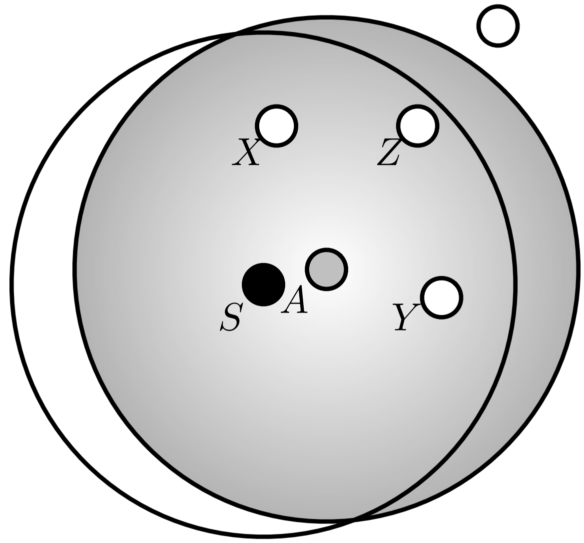

Fig. 3. An example in which count restriction with a random assessment delay fails. If the count restriction is set to 2 and A chooses the smallest AD, the route request sent by S and rebroadcasted by A will not be delivered. X, Y, and Z will not resend the request because they received two copies.

count restriction is to reduce the number of control packets by reducing the number of unnecessary rebroadcasts. In previous studies [2], the AD was chosen randomly between 0 ms and 10 ms (T_{max}). In addition, we propose a Count Threshold of 2, which means that if a node hears a single rebroadcast a given route request, then that node does not rebroadcast that route request.

Even though it is better overall, there are situations in which count restrictions negatively interfere with choosing the assessment delay randomly, as shown in Fig. 3. If a node very close to the previous broadcasting node chooses the lowest random delay, then the additional area covered by the rebroadcast will be very small, and thus no additional nodes will receive the route request.

Due to this situation where count restrictions fails with random assessment delay, we explored a more principled way to calculate assessment delay. Although basing the assessment delay on the amount of additional area covered by a rebroadcast did improve our simulation results, we devised a better metric, which we have termed the projection method.

Intuitively, we desire nodes that are closest to the destination, D, to rebroadcast sooner, and nodes that are further will have a higher assessment delay, causing them to wait longer before rebroadcasting. In a MANET, however, D could be very far away, and there is no general way to quantify *a priori* that a node is close or far. Instead, we calculate assessment delay such that it is lower if the receiving node is far from the sending node (which is bounded by the transmission range) and even lower if the receiving node is in the same direction as the destination node.

The projection method works as follows. Let the previous broadcasting node be denoted O, the destination node denoted by D, and the node receiving the broadcast as A. (Notice that O can be any intermediate node from S to D, including S itself.) Also, let the maximum range of the broadcast be defined as TX_RANGE. Then the assessment delay, AD, is defined as:

$$AD = T_{max} \times \left(1 - \frac{\overrightarrow{OD} \cdot \overrightarrow{OA}}{|\overrightarrow{OD}| \times \mathrm{TX\_RANGE}}\right) \quad (1)$$

Fig. 4 shows an example. The method forces the assessment delay to be dependent upon the projection of $\overrightarrow{OA}$ onto $\overrightarrow{OD}$. In the best case when O sends a route request to A, and A is right on the line between O and D with A being as far away from O as possible to hear the request (i.e., $|\overrightarrow{OA}| = \mathrm{TX\_RANGE}$), then $\overrightarrow{OD} \cdot \overrightarrow{OA}$ will be equal to $|\overrightarrow{OD}| \times \mathrm{TX\_RANGE}$ and the assessment delay will be zero. That is, A will not have to wait at all to retransmit in the best case. Suppose instead that A is on a line perpendicular to the destination. In this case, the dot product in equation (1) will be zero, and A will have to wait the full assessment delay, T_{max} before resending. There is an interesting third case: If a node A is in the opposite direction as the destination D, the dot product in equation (1) will be negative and A will have an assessment delay longer than T_{max}. In this case,

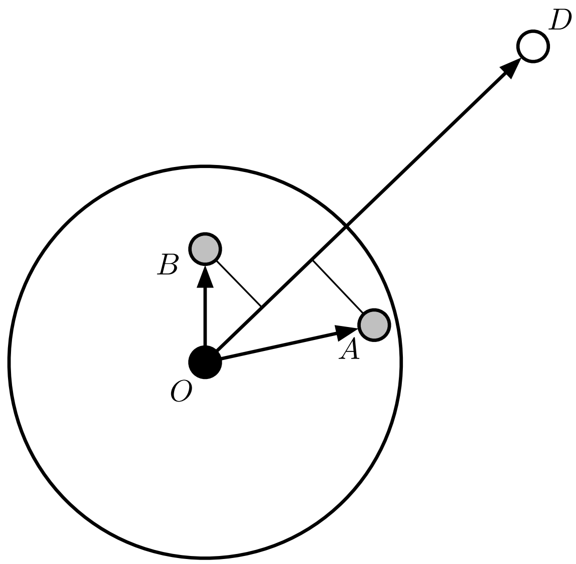

Fig. 4. Assessment delays calculated by the projection method. The assessment delay for nodes A and B are proportional to the length of the projections of $\vec{OA}$ and $\vec{OB}$ onto $\vec{OD}$. Because A's projection is longer its assessment delay is shorter, so it will broadcast first.

A will never resend O's route request. Because A is in the wrong direction, this is the correct behavior.

As a result of the use of the projection method with count restrictions, we were able to cut the number of control packets transmitted as well as find better routes that increased the data delivery ratio.

IV. Simulation Results

For our comparison of the existing LAR Box method with our improvements, we examined data delivery ratio, control packet overhead, and end-to-end delay in simulation. The data delivery ratio is defined as the number of data packets received at the destination nodes divided by the number of data packets transmitted from the source nodes [2].

All of our performance measurements were based on the average of ten different simulation trials. We also calculated a 95% confidence interval for the unknown mean, and this is also plotted on each figure. A complete list of simulation parameters can be found in Table I.

As indicated in Fig. 5, adding Count Restrictions (CR) to LAR Box significantly reduces the number of control packets transmitted, especially at higher speed. But even more important is the fact that the dot product method of calculating the assessment delay reduces the number of control packets by more than half at 20 m/s. Adding count restrictions to LAR clearly achieves the goal of reducing the overhead by eliminating (some) control packets.

Input Parameters	
Number of Nodes	50
Simulation Area Size	300 m x 600 m
Transmission Range	100 m
Simulation Duration	1000 s
Count threshold	2
Maximum assessment delay, T_{max}	10 ms
Forwarding error factor, δ	0 m
Header size with n addresses	$4n + 40$ bytes
Data payload	64 bytes
CBR sources	20
Packet rate	4 packets/s
Traffic pattern	Peer-to-peer
Derived Parameters	
Node Density	1 node per 3,600 m^2
Coverage Area	31,416 m^2
Transmission Footprint	17.45%
Maximum Path Length	671 m
Network Diameter (max. hops)	6.71 hops
Network Connectivity (node degree)	8.73 (no edge effect)
Network Connectivity (node degree)	7.76 (edge effect)
Mobility Model	
Mobility Model	Random Waypoint [5]
Mobility Speed	2, 5, 10, 15, 20 m/s $\pm 10\%$
Pause Time	10 s $\pm 10\%$
Simulator	
Simulator Used	NS-2 (version 2.1b7a)
Medium Access Protocol	IEEE 802.11
Link Bandwidth	2 Mbps
Number of Trials	10
Confidence Interval	95%

TABLE I
SIMULATION DETAILS

Adding count restrictions to LAR Box did not just reduce overhead, but it also helped create better routes. As seen in Fig. 6, the addition of count restrictions significantly increased the data delivery ratio at higher speeds, especially when the dot product assessment delay method is used. Although there is virtually no difference between the two methods at lower speeds, this can be explained by the fact that most routes do not break at lower speeds, and thus in terms of delivery, one route is virtually as good as another.

In addition, the evidence that adding count restrictions to LAR Box creates better routes is shown in that end-to-end delay increases much more gradually with speed as compared to the existing LAR Box method. In fact, at 20 m/s, the end-to-end delay drops from around 1.5 s to around 0.4 s. By any standard this is a great decrease, and

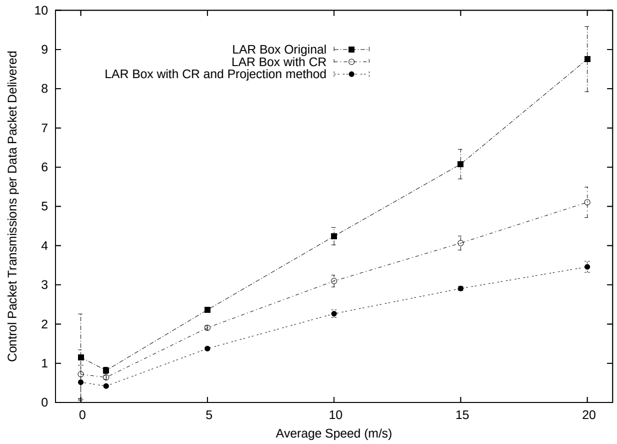

Fig. 5. Simulation results of overhead vs. speed. The projection method results in far fewer control packets sent because the route found are shorter.

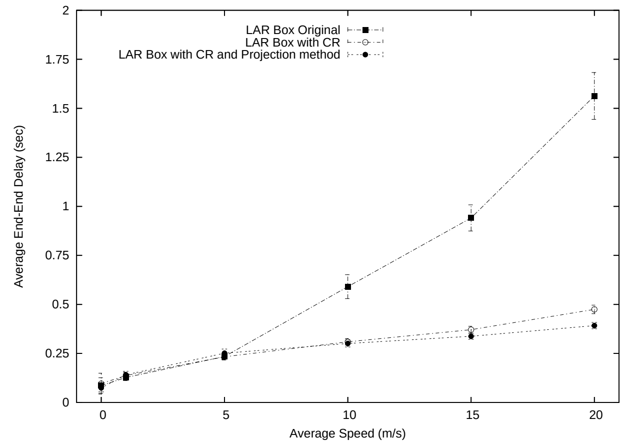

Fig. 7. End-to-end delay is reduced by the projection method because it creates shorter routes.

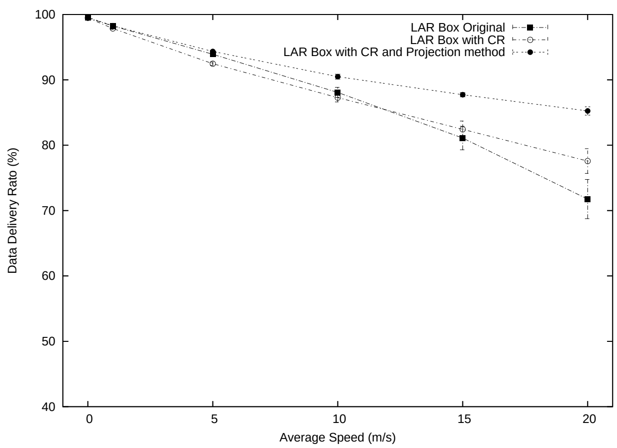

Fig. 6. Because shorter, more direct routes last longer, the projection method provides higher delivery ratio.

indicates that the routes that adding count restrictions to are more stable and longer lasting.

Ultimately, since adding count restrictions, especially with the projection method, decreased overhead and end-to-end delay, while increasing the effectiveness of the network by increasing the data delivery ratio, we are confident that our improvements to LAR Box are indeed improvements.

V. Future Work

There are a couple of areas for future work involving our improvements to LAR Box. One area in which we see the potential for even further improvement is to make this method adaptive. That is, allow each node to change the parameters by which LAR Box implements these count restrictions based upon network conditions, such as number of neighbors, congestion, velocity, etc. By adding in adaptation, this method should be able to improve LAR Box even further by allowing fine-tuning of the parameters on the fly.

The other major area of future work is to determine the versatility of this new count restriction method, by testing it under a wider variety of network conditions than has currently been done to date. Although it is known that the improvements will be more pronounced under higher density of mobile nodes, it is not known, how well this method performs under higher network load.

VI. Conclusions

The core idea of the improvement is to use the location information acquired by LAR itself to determine relay nodes in the forwarding zone. The improvements are two-fold: (1) shorter, more-direct routes are discovered, and (2) less overhead is needed to find those routes. Because more direct routes last longer, higher delivery ratio and lower end-to-end delays are produced by our improvements. Because our additions to LAR Box improved on overhead, data delivery, and end-to-end delay we are confident that these additions do indeed represent improvements to LAR Box. Basically, these improvements allow LAR Box to work faster, better, and cheaper. However, we feel that there is room for further optimization; especially if the mobile nodes are allowed to adapt the parameters of the count restriction to adjust for network conditions.

Gathering information about the network allows nodes to make better decisions about whether or not to re-broadcast. This results from decreased overhead in the network, which also improves the efficiency and ability of the network. Even without global knowledge, there is still a good deal of information that a mobile node can infer about its immediate neighborhood, which is useful for making decisions.

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