LABAR: Location Area Based Ad Hoc Routing for GPS-Scarce Wide-Area Ad Hoc Networks

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Abstract

Wireless ad hoc networks are becoming increasingly important in today's world. The most challenging problem in conjunction with ad hoc networks is routing, i.e., the procedure in charge of determining the trajectory of packets traveling over the network. For large-scale ad hoc networks scalability of the routing approach is extremely important. One of the approaches to scale up ad hoc routing is geographical location based routing, which usually requires all nodes to be aware of their exact locations. In this paper, a new routing algorithm is proposed which requires only a subset of nodes to know their exact location forming *location areas* around these nodes. This paper outlines the LABAR (Location Area Based Ad Hoc Routing) routing protocol and provides with simulation measurements on its average routing distance compared to the optimum shortest path.

1. Introduction

A key feature of future mobile wireless networks is the ability to adapt and exist even without a fixed infrastructure. An ad hoc network is a collection of possibly mobile devices or nodes that can establish communications, without a fixed infrastructure or central administration. Ad hoc networking is expected to help fulfill the dream of a seamless network architecture and to play an important role in next generation wireless networks and services.

Owing to the constantly varying network topology of ad hoc networks, it is quite difficult to maintain the entire network routing information accurately and to guarantee message delivery. Multihop paths need to be constructed to route messages exploiting the cooperation of nodes. In routing using multihop paths, there are important issues to be seriously considered, e.g., routing performance, resource usage, and network scalability. Since all nodes need to exchange control information continuously with other nodes to keep up with the dynamics of the network, routing overhead is induced to the network requiring additional bandwidth, memory, space and computational resources from the nodes in the network The usage of these resources should be reduced as much as possible while maintaining a high routing performance to reduce the burden on the mobile devices. Furthermore, nodes may delay or drop packets until they acquire the routing information to the respective destinations, which can result in low performance of packet delivery. These two challenges become more critical as the network size grows; thus network scalability cannot be ignored in a routing protocol for ad hoc wireless networks.

Existing routing schemes can be broadly categorized into *proactive* and *reactive* protocols [8]. Proactive protocols (also called table-driven protocols), offer routing information on the spot by exchanging routing information about all the nodes continuously. As examples, the Destination-Sequenced Distance Vector (DSDV) [8], and the Wireless Routing Protocol (WRP) [9] belong to the class of proactive protocols. On the other hand, reactive protocols, (also called source-initiated or on-demand protocols), offer routing information with some latency since they launch the route discovery process on demand, i.e., the first time the respective destination is addressed. For example, the Ad hoc On Demand Distance Vector (AODV) [10], the Temporally-Ordered Routing Algorithm (TORA) [11], and the Dynamic Source Routing (DSR) [12] protocols belong to the class of reactive protocols.

Compared to reactive protocols, proactive protocols have less latency in sending out packets due to maintaining an up-to-date view of the network; but on the downside, they may use up more resources since they need to periodically broadcast routing information about all nodes in the network. The overhead in bandwidth for proactive protocols is proportional to the size of the network. In order to trade-off between the latency and overhead burdens of proactive and reactive protocols, hybrid and geographical routing protocols have been introduced. Hybrid protocols combine both proactive and reactive routing approaches, using the proactive scheme for the local area

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routing and the reactive scheme for remote area routing. An example hybrid protocol is the Zone Routing Protocol (ZRP) [15]. Geographical routing protocols utilize geographical location information of the nodes in the network to find the route or to forward the message. Geographical routing protocols are represented by, e.g., the Distance Routing Effect Algorithm for Mobility (DREAM) [3], the Greedy Perimeter Stateless Routing (GPSR) [14], and the Location-Aided Routing (LAR) [13] protocols.

Geographical ad hoc routing protocols are heavily dependent on the existence of scalable location management services, which are able to provide the location of any host at any time throughout the entire network. The most common way to enable nodes of knowing their location is by equipping them with GPS (Global Positioning System) [16] receivers. Yet, GPS can significantly increase the cost and power consumption of small mobile nodes while requiring a considerable spatial footprint.

Virtual backbone routing protocols [2] make advantage of the fact that it is easier to only manage a small subset of the connections in a highly mobile network. The smallest subset of links that keeps the network connected spawns a tree over the connectivity graph. With virtual backbones, routing information does not need to be flooded over the entire network but relayed only using the backbone links, thus significantly reducing overhead [2].

This paper proposes a new hybrid virtual backbone and geographical location area based ad hoc routing (LABAR) protocol, relaxing the need of GPS receiver availability at each node in the ad hoc network. In LABAR, nodes that are enabled with GPS equipment are referred to as G-nodes. G-nodes are interconnected into a virtual backbone structure to enable efficient exchange of information for the mapping of IP addresses to locations. Thus, LABAR is a combination of proactive and reactive protocols, since a virtual backbone structure is used to disseminate and update location information between G-nodes (in a proactive manner), while user packets are relayed using directional routing towards the direction zone (or area) of the destination.

We believe LABAR is well-suited for deployment in large-scale sensor ad hoc networks, where a set of sensors relies on the position information gathered by a single location-sensor thus reducing the overall cost of the network. Additionally, since with LABAR a virtual tree-like backbone is established for maintaining the ad hoc network, Bluetooth technology could be exploited. Nodes could establish a Bluetooth based tree, such as the one presented in [17], to reduce the number of overall roles in the network. Directional routing then requires neighboring nodes to establish piconets among themselves for the duration of the data transfer. Since synchronization information could be relayed over the backbone, piconet establishment and tear-down would be accelerated thus dynamically creating scatternets to relay the data.

The rest of the paper is organized as follows: Section 2 defines LABAR and its methodology. Section 3 presents some preliminary results on the hop overhead of LABAR. Section 4 concludes the paper, outlining future research directions.

2. LABAR

Let us consider an ad hoc network with two different types of nodes: G-nodes and S-nodes. We assume that the only difference between G- and S-nodes is that G-nodes are aware of their precise location. To provide with easy to obtain location for the S-nodes, S-nodes will assume the position of a nearby G-node. The following methodology and notations will be used in describing LABAR[1]:

- *Zone*: each S-node belongs to a location area or "zone" of a nearby G-node either one- or several hops away. Each S-node will assume that its geographical position is the same as that of its G-node. A set of nodes assuming the same position information is said to form a location area or zone (i.e., a zone consists of only one G-node and some S-nodes).
- *Adjacent zone*: is defined as the set of zones, which are connected to current zone through G- or S-nodes, i.e., zones that have members that are in the transmission range of any member of the current zone. *Adjacent-Zone* is a list of zones maintained by each G-node, containing the location of adjacent zones.
- N, n_i, z_j: N denotes the population of nodes, n_i is used to denote node i, while z_j denotes zone j.
- source, destination: denote the source and destination nodes of a packet respectively.
- source G-node: the G-node to which the source belongs to. The S-node to G-node mapping is obtained during zone formation process.

2.1 Zone Formation

The first step of LABAR deals with forming the zones, i.e., making the decision on which S-nodes should belong to which G-nodes. Similar steps can also be found in ad hoc clustering approaches. For the sake of simplicity, here we assume that all G-nodes start the zone formation algorithm at the same time to acquire S-nodes that have not yet been captured by any other zones. If an S-node has already been allotted to a G-node then the request message to be attached to the zone is ignored by the S-node. An S-node that has already been included in a zone initiates the zone formation algorithm on its own to draw more S-nodes form its neighborhood into its zone. By the end of the zone formation phase, all S-nodes will belong to a G-node (or to a zone around a G-node), and G-nodes will know the IDs of their zone's S-nodes.

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[1] Due to space constraints, pseudo-codes for LABAR are omitted in this paper, but can be found in [18].

2.2 Virtual Backbone Formation

Creating an easy to manage virtual backbone for relaying position information of nodes is the second step of LABAR. G-nodes in the virtual backbone are responsible for resolving the IP addresses into geographical locations.

To connect zones and get the virtual backbone to function, a G-node called the "root" initiates the backbone formation as outlined in Figure 1. The root sends connect messages to its adjacent zones. If the particular adjacent zone is not connected yet to the backbone yet, then it will be added to the backbone. If a zone is already added to the backbone, the connect message is ignored by the zone to avoid cycles in the backbone. At the end of the virtual backbone formation phase, G-node have an easy-to-maintain structure to exchange control information such as IP address to location mapping.

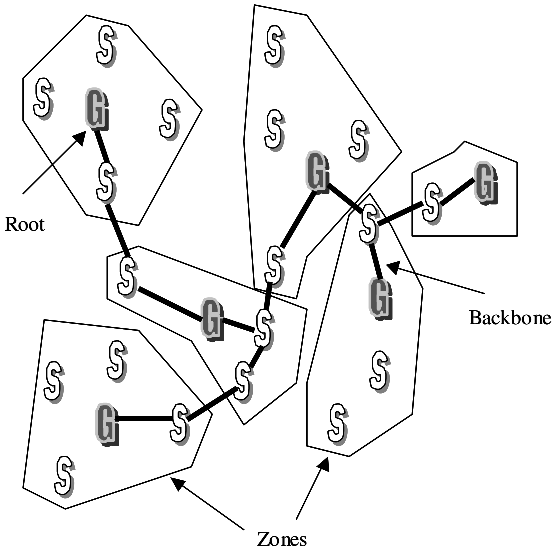

Figure 1. Virtual backbone of LABAR.

2.3 Directional Routing

Routing packets between nodes in the network involves identification of the destination node's zone to route the data in the direction of the destination zone; the IP address to geographical location mapping is done by the G-nodes using the virtual backbone. The source node queries the source G-node node to map the destination IP address into the geographical location area of the destination. Then the source G-node determines the vector pointing from its own location to the destination's location. The resulting vector's direction is compared to each of the adjacent zones' direction and distance to determine which neighboring zone should be used in relaying the data to the destination. After determining the next zone, the source G-node will instruct the source node (if different from the G-node) on how to route the packet inside the zone to reach the next zone with the least number of hops. Once a packet has left the source zone and entered an intermediate zone, the node that received the packet in the intermediate zone will be responsible to route the packet to the next intermediate (or final) zone by consulting its zone's G-node about the best directionally matching adjacent zone. In the case of a failure in the directional route (determined for example through expired hop counters, i.e., using the Time to Live-TTL field), the source zone will be informed about the failure and the virtual backbone will be used to relay the packets. A sample route is depicted in Figure 2.

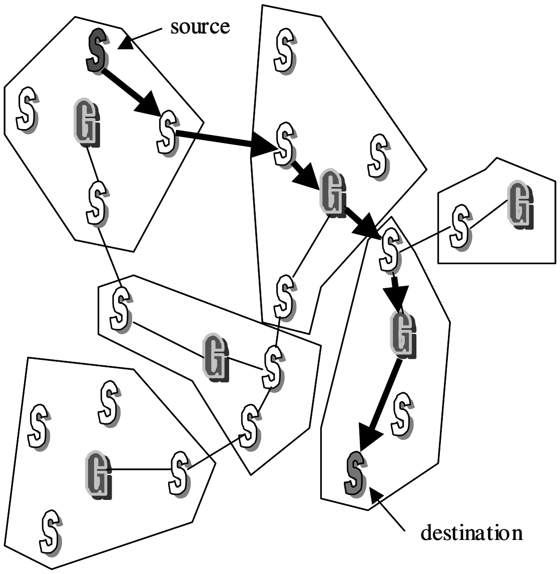

Figure 2. Routing in LABAR.

3. Hop Performance of LABAR

One of the most important metrics of ad hoc routing protocols is their effectiveness in finding the minimum distance between source and destination nodes. By evaluating routing protocols via Monte-Carlo simulations it is relatively easy to determine the shortest distance between two nodes. Such simulations can make use of the global knowledge of the connectivity graph evaluating also the lower bound, e.g., by running Dijkstra's shortest path algorithm on this graph. In this section we will provide preliminary results on how much worse LABAR's routing hop distance is compared to the shortest possible path and also compared to the route distance of the underlying virtual backbone. The hop distance of shortest path routing will be taken as a benchmark when evaluating LABAR's routing hop distance. We have investigated the effect of different node populations *N* and different network densities (given by the average nodal degree) *D*, and with a varying ratio *q* of the G-nodes to the population on LABAR's hop distance by three different sets of experiments.

During our simulations we have assumed an open propagation environment, where each node has the same transmission/reception radius *r*. Thus when the population is increased while keeping the average node degree a constant, the area the nodes are located has to be increased proportionally. The area sizes mapping *N* to *D* with a fixed *r* have been determined by preliminary simulations with a 95% confidence that the error in the area is less than 5%.

In our first set of experiments we have fixed *q* to 10%, changing the values of *N* and *D*. Figures 3 and 4 depict the minimum average, LABAR's, and the underlying virtual backbone's routing distance for Degrees 7, and 20 respectively. Since the average degree is kept constant in each of the figures, the number of hops required to reach the destination increases because of the addition of extra hops to connect the additional nodes with the existing ones. We conclude, that the rate of increase in the average routing distance is less in shortest path and location based routing when compared with rate of increase in virtual backbone based routing.

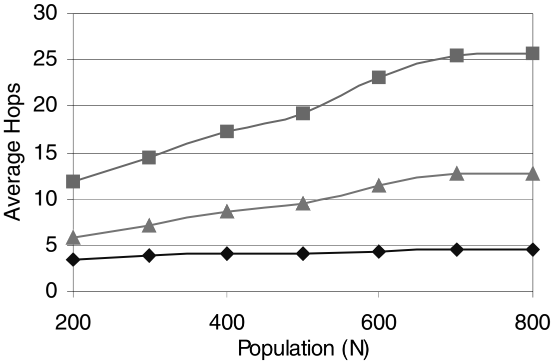

Figure 3. Varying *N* (*D*=7, *q*=10%).

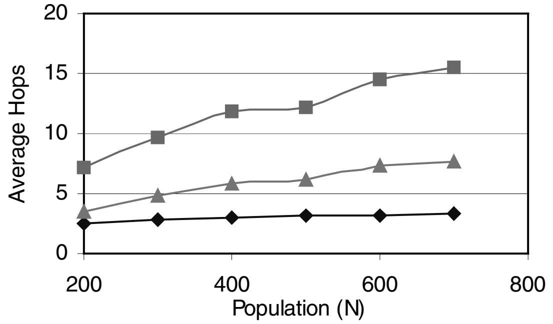

Figure 4. Varying *N* (*D*=20, *q*=10%).

In the second set of experiments, we measured the change in the routing distance when node populations are kept constant while average degrees are increased. Figures 5 and 6 show the results for populations of 200 and 700 nodes respectively. It can be observed that the rate of decrease in average hops in shortest path routing decreases as the population size increases. Similar behavior is observed in LABAR in contrast to a constant rate of decrease with virtual backbone routing.

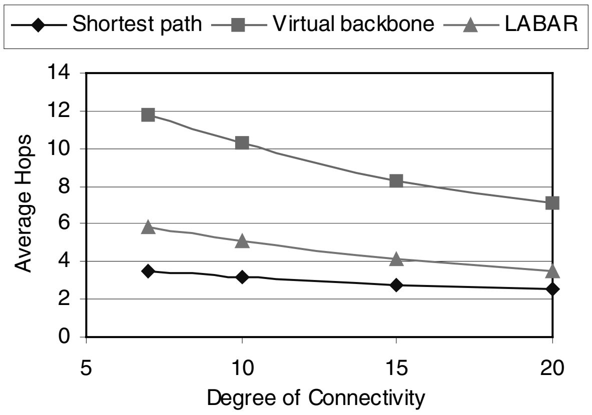

Figure 5. Varying *D* (*q*=10%, *N*=200).

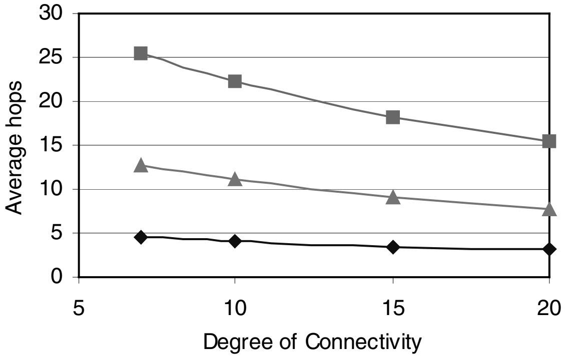

Figure 6. Varying *D* (*q*=10%, *N*=70).

Figure 7 depicts LABAR's routing distance performance in function of the population of nodes and the average degree of nodes. As expected, both the population and the average degree have a linear effect on the routing distance thus LABAR scales linearly with network population and density.

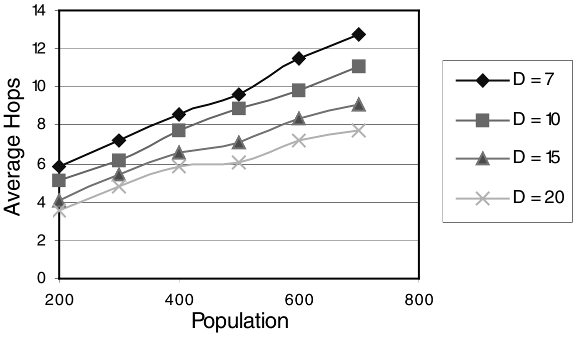

Figure 7. Varying *N* (*q*=10%).

In the third sets of experiments, the effect of a varying *q* was investigated for given populations and densities. The two *q* values chosen were 10% and 2% corresponding to situations where every 10th and every 50th node in the network is a G-node. Figure 8 shows the results in the average routing distance with an average density of 7 outlining that by decreasing the number of G-nodes, the average routing distance does not significantly decrease.

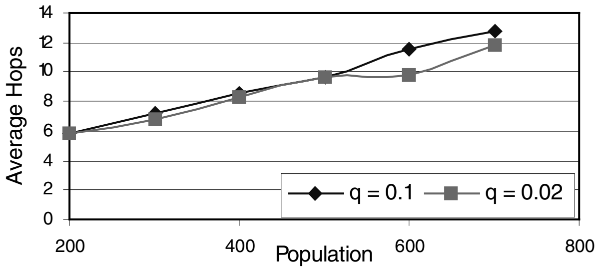

Figure 8. Varying *q* (*D*=7).

4. Conclusions

This paper presented LABAR a novel ad hoc routing approach for large-scale ad hoc networks using a combination of virtual backbone and directional routing approaches. LABAR does not require all nodes in the ad hoc network to be precisely aware of their geographical location, i.e., to be equipped with GPS receivers, it is sufficient if only a subset of the nodes is enabled to determine their location. We have outlined how routing is accomplished in LABAR. To evaluate the performance, a Monte-Carlo simulation tool was developed to determine the average routing distance of LABAR, comparing it with the optimal-shortest path. From our initial experiments we have found that LABAR scales well with the population and density of the network and that limiting the set of nodes equipped by position sensors does not significantly alter the routing distance.

Ongoing work on LABAR includes the development of an ns2 simulation model to compare other performance metrics of LABAR to similar ad hoc routing protocols.

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