LAKER: Location Aided Knowledge Extraction Routing for Mobile Ad Hoc Networks

Jian Li and Prasant Mohapatra
Department of Computer Science
University of California, Davis
Davis, CA 95616
Email: {lijian, prasant}@cs.ucdavis.edu

***Abstract*— In this paper we present a Location Aided Knowledge Extraction Routing (LAKER) protocol for MANETs, which utilizes a combination of caching strategy in Dynamic Source Routing (DSR) and limited flooding area in Location Aided Routing (LAR) protocol. The key novelty of LAKER is that it can gradually discover knowledge of topological characteristics such as population density distribution of the network. This knowledge can be organized in the form of a set of *guiding_routes*, which includes a chain of important positions between a pair of source and destination locations. The *guiding_route* information is learned during the route discovery phase, and it can be used to guide future route discovery process in a more efficient manner. LAKER is especially suitable for mobility models where nodes are not uniformly distributed. LAKER can exploit the topological characteristics in these models and limit the search space in route discovery process in a more refined granularity. Simulations results show that LAKER outperforms LAR and DSR in term of routing overhead, saving up to 30% broadcast routing messages compared to the LAR approach.**

I. INTRODUCTION

Mobile ad hoc network (MANET) is an infrastructureless network formed by a set of wireless nodes that are capable of moving around freely. There is no fixed infrastructure such as basestations. Each mobile node acts as an end-system and a router. Two mobile nodes within transmission range of each other can communicate directly via the ad hoc wireless link. A multihop route is needed when the destination is beyond the coverage of the sender. Hence routing is a key component of MANET performance. A number of routing protocols have been proposed for MANETs during the recent years[1], [2]. Most of these routing protocols can be classified into two categories: proactive protocols and reactive(on-demand) protocols. In proactive approaches, each node will maintain routing information to all possible destinations irrespective of its usage. In on-demand approaches, a node performs route discovery and maintenance only when needed. Due to the nodal mobility and fast changing topology, on demand protocols generally outperform purely proactive protocols.

On-demand protocols, such as Dynamic Source Routing (DSR)[4] and Ad hoc On demand Distance Vector (AODV) routing[5], often use flooding techniques to search for a new route. Flooding based route discovery works as follows. When a node S has some data to send to node D but has no existing route to the destination, it will initiate a route discovery process by broadcasting a route-request packet. An intermediate node I, upon receiving the route-request packet for the first time, will rebroadcast the route-request again if it does not know a route to the destination node D. Finally, when the route-request packet reaches a node(which may be the destination node D itself) that has a route to node D, a route-reply packet is sent back to the sender node S.

To reduce the flooding overhead, a variety of optimizations have been developed. For example, DSR aggressively utilizes route caching strategy to reduce the number of route-request messages. As the route-reply message propagates back to the requester, all neighboring nodes along the route can listen to the route information in a promiscuous way and store the route information in its cache. Later, when a new route-request message is propagating in the network, an intermediate node that has a cached route to the destination can reply to the requester without relaying the route-request message. So the total routing overhead can be reduced. The disadvantage of caching route is that these cached routes may be obsolete by the time it is used, especially under relatively high mobility. Our idea is that it will be more desirable to cache some longer-lived properties of the network other than the to-be-broken routes. In real mobility patterns, nodal density may not be uniform across the network. Some parts of the network may cluster many nodes, while some other parts may have sparse nodes. We believe it is useful to cache this kind of nodal distribution information and later use it to guide the route discovery process.

Another technique to reduce flooding overhead is using geographical location to limit the flooding area. This approach is used in some protocols such as LAR[6] and DREAM[7]. According to both the sender and the receiver's locations, a reduced flooding sub-region can be defined instead of flooding the entire network. For example, in LAR the geographical location information is carried with the route-request messages. Upon receiving a route-request message, an intermediate node will determine if it is in the reduced flooding area. Only those nodes in the limited area rebroadcast the route-request message, hence the number of routing messages is reduced. In some cases, however, this method of defining the flooding area solely by the source and destination locations is too coarse in granularity. In other cases, it may not be able to overcome the "void" area in the network and has to resort to flooding the entire network(discussed later in Section II-B).

This research was supported in part by the National Science Foundation through the grants CCR-0296070 and ANI-0296034.

In this paper, we introduce a new approach to reduce the flooding overhead in route discovery. During a route discovery process, our approach attempts to extract knowledge of the nodal density distribution of the network, and remember the series of locations along the route where there are many nodes around. We called the series of "important" locations as *guiding_route*. The motivation behind *guiding_routes* is that we believe that, in many situations, even individual nodes move fast, the population density distribution of the network is not changing so rapidly. Using this kind of guiding information, we can further narrow the search space in the route discovery process and overcome the problem of "void" area in the network. Simulation results show that LAKER can save up to 30% broadcast control messages compared to the LAR approach, while achieving high delivery ratio and almost similar end-to-end delay.

The rest of this paper is organized as follows. The design of LAKER protocol is described in Section II. Performance evaluation of LAKER based on simulation is presented in Section III. Section IV talks about related works of our proposal. The paper is then concluded in Section V.

II. LAKER Protocol

In this section, we describe our proposal – a Location Aided Knowledge Extraction Routing (LAKER) protocol for MANETs. LAKER inherits the route caching strategy from DSR. In addition to caching *forwarding_routes* as DSR does, LAKER also attempts to cache a new kind of information about the network topology – *guiding_routes*. A *forwarding_route* is a series of node IDs which connect the source to the destination hop by hop. A *guiding_route* is a series of locations along a *forwarding_route* where there seems to be many nodes clustered together. Although individual nodes come and go fast, the structure of these clustered places is not expected to change as rapidly. So it is possible to discover and cache this kind of guiding information during the route discovery process. In the next round of route discovery process, we can utilize this information to guide the route discovery direction and narrow the search space, even finer compared to the LAR approach.

The assumptions we make for LAKER are as follows.

- Each node knows its current location, for example, by means of Global Positioning System (GPS).
- Each node keeps track of the number of neighbors it has. This can be achieved, for example, by means of periodic beaconing message on the network layer, or with assistance from the data link layer.
- Each node has an End-system Unique Identifier (EUI).
- There exists a geographical location service(for example, see [9]). When node S has data to send to node D, S can look up the location service to obtain D's up-to-date location.

The *guiding_routes* – which have the knowledge of the population density distribution of the network – play an important role in LAKER's route discovery process. Existing knowledge can be used to guide the flooding, and new knowledge may be discovered in the course of route discovery. The idea of caching *guiding_routes* in LAKER is to exploit topological characteristics of the network, hence the mobility model used in study will have great impact on our algorithm. We will discuss this issue in Section II-A, followed by two important functionalities of LAKER: knowledge guided route discovery in Section II-B and knowledge extraction in Section II-C.

A. Mobility Modeling

In current literature of mobile ad hoc networks, the "Random Waypoint"[10] mobility model is widely used in simulations. In this model, initially all the mobile nodes are uniformly distributed in the simulation area. When the simulation starts, each node stays at its initial position for a specific duration called *pausetime*, and then randomly selects a destination within the simulation area, and starts moving towards this destination with a stable speed, which is randomly chosen from a predefined range. When the mobile node arrives at the destination, it will stay there for *pausetime* seconds, then chooses another destination and new speed and continues to move, and so on.

The "Random Waypoint" mobility model does not capture the mobility and topological characteristics in the cases where nodes may cluster at some sub-regions of interest instead of randomly moving around. For example, there are several events occurring at different places on a large campus, mobile users roam from one event location to another, pausing for a certain period of time at each location. We believe this is more realistic than randomly choosing destination. Another example is that there is an obstacle region(like a lake) within the simulation area and the mobile users are restricted from entering these regions. In order to capture this kind of mobility patterns, a recent work[12] proposed the "Restricted Random Waypoint" model. In this new mobility model, a mobile node will randomly choose a destination only from a set of sub-regions, which are separated as small parts of the whole simulation area. A similar mobility model was used in [13].

In this paper, we adopt the "Restricted Random Waypoint" mobility model. The design of LAKER is aimed at taking advantage of topological characteristics(population density distribution) of the network.

B. Knowledge Guided Route Discovery

LAKER is a descendant of DSR and LAR, and thus uses an on-demand request-reply mechanism in route discovery. When a node S needs a route to node D, a route-request message will be broadcasted. The route-request packet contains these fields: *source_EUI*, *destination_EUI*, *traversed_forwarding_route*, *source_location, destination_location*, *guiding_route*, *traversed_guiding_route*. The first three items are standard contents in a DSR route-request message. As the name indicates, *traversed_forwarding_route* stores the chain of nodal EUIs along the partial path traversed so far. The next two items, *source_location* and *destination_location,* are introduced in LAR to define the request zone, which may be chosen as a rectangular shape. The last two items are newly introduced in LAKER. The field *guiding_route* stores some guiding information(initially this field may be empty if the source node does not have any *guiding_route* to the destination location; as the route-request message propagates in the network, intermediate nodes may fill in the guiding information). The field *traversed_guiding_route* stores the newly discovered guiding information as the route-request message propagates in the network.

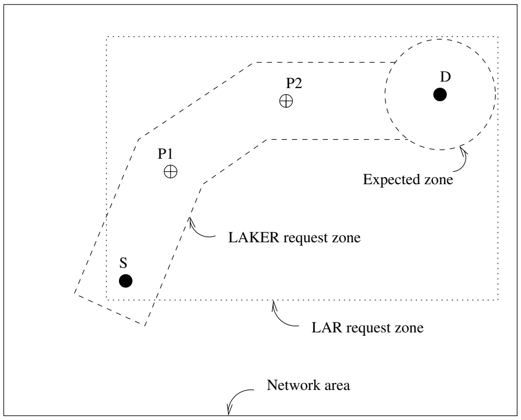

Fig. 1. Request zone: LAKER v.s. LAR

There are two major advantages of using *guiding_route* in the route discovery process. First, it can guide the route discovery direction more precisely and further narrow the search space even compared to the LAR approach. An example is illustrated in Figure 1. P1 and P2 are two guiding positions along the *guiding_route*. The request zone of LAKER is defined by the location of the source node S, the guiding positions, and the "expected zone", which is the estimated region where the destination node is currently located. As discussed earlier, the population density is not uniformly distributed in the network area. There are some sub-regions with higher population density. In route discovery phase, it is very likely to find a feasible route by limiting the search space along this chain of “hot spots”. Only nodes in this narrow band will participate in the route discovery process. Since the search area is further reduced, LAKER is expected to incur less routing overhead than LAR approach.

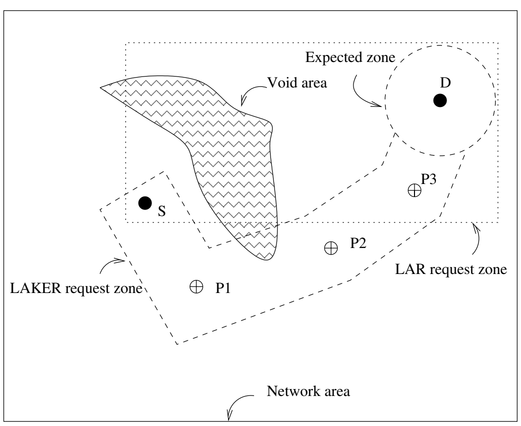

Fig. 2. Route discovery with void area in the network

The second advantage of using guiding information is that the route-request message can smartly pass around some "void" area that exists in the network, as illustrated in Figure 2. Note that there is a void area(may be a lake) in the simulation area. If using LAR’s rectangular request zone, it will fail in searching a feasible route to the destination and have to repeat with an expanded request zone up to the whole network. If the source node S has related *guiding_route* in cache, it can use the guiding information to direct the route discovery to pass around the void area without flooding the entire network.

Algorithm 1 Route discovery in LAKER

```
when intermediate node X gets RREQ from node S to node D :
if node X is located in an important position
    add X's position to traversed_guiding_route in RREQ
endif
if node X has forwarding_route to the destination D
    send RREP back to the source S
else
    if node X has newer guiding_route to the destination D
        update guiding_route in RREQ
    endif
    if guiding_route exists in RREQ
        if node X in the LAKER request zone
            rebroadcast RREQ
        else
            drop RREQ silently
        endif
    else
        rebroadcast RREQ
    endif
endif
```

The LAKER route discovery algorithm is shown in Algorithm 1. RREQ stands for a route-request message, and RREP for a route-reply message. Upon receiving RREQ, intermediate node X first adds its own location to the *traversed_guiding_route* field in RREQ if it thinks its location is an important guiding position(this will be further discussed in Section II-C). Node X then decides if it is within the request zone based on the guiding information carried in RREQ, and processes RREQ accordingly, that is, rebroadcasts or drops it. During this process, intermediate nodes can update the *guiding_route* field in RREQ if they have newer guiding information towards the destination location.

This algorithm is executed at intermediate nodes, hop by hop, until the route-request message reaches a node that has a forwarding route to the destination, or reaches the destination node itself. One or multiple route-reply messages will get back to the source node.

C. Knowledge Extraction

In the route discovery phase, our design allows mobile nodes to extract partial knowledge of the topological characteristics in the network. So, in the route discovery phase, not only can it be thought of as searching for a *forwarding_route* to a node with the requested EUI, but also searching for a *guiding_route* towards a geographical location in the network. In particular, it attempts to remember those important locations in terms of metrics of interest. One of such metrics may be the population density, i.e., try to remember those places with more mobile nodes around.

Each node keeps track of the number of its direct neighbors. If the number of neighbors exceeds a certain level, *guide_pos_nb_num*, the node will consider itself located in an important position in term of population density. When relaying a route-request packet, such an intermediate node will append its location information to the *traversed_guiding_route* field in the route-request packet. As the route-reply packet propagates back to the source node, it contains both *forwarding_route* and *guiding_route* information between the source and destination pair. We assume that each mobile node operates in a promiscuous mode, so it can snoop the *guiding_route* as well as the *forwarding_route* information from all routing packets it hears.

When the route-reply message gets back to the source node, it will cache both the *guiding_route* as well as the *forwarding_route* information, and starts sending data packet using the newly obtained *forwarding_route*. After some time, the *forwarding_route* in use may be broken. The source node will initiate a new route discovery process with a *guiding_route* from its cache.

III. Performance Evaluation

In this section, we evaluate the performance of LAKER protocol through simulations using the *ns-2* simulator[14]. The Monarch Group's mobility extension[15] to the *ns-2* simulator provides detailed implementation of IEEE 802.11 radio and MAC specifications. In order to compare the results of the LAKER approach and the LAR approach, we utilize the codebase of DSR in the *ns-2* simulator and integrate LAR and LAKER algorithms into DSR.

The simulation area is 1200×1200 square meters. A node's speed is uniformly distributed in the range of (0, 10) meters per second, and the wireless transmission range is 250 meters. We use a 150 node network in simulation. There are 12 constant-bit-rate (CBR) connections, each of which randomly starts during the first 100 seconds and has a bit rate of 2 packets per second. Each simulation runs for 300 seconds of simulation time. Mobile nodes move within the simulation area according to the "Restricted Random Waypoint" mobility model. The parameter *pausetime* reflects the degree of mobility. For different mobility degree, we use different *pausetimes* of 0, 30, 60, 120, 180, 240 and 300 seconds. When *pausetime* is 0 seconds, it means that all nodes are moving all the time and the MANET has a high degree of mobility. When *pausetime* is 300 seconds, it means that all nodes are stationary during the simulation.

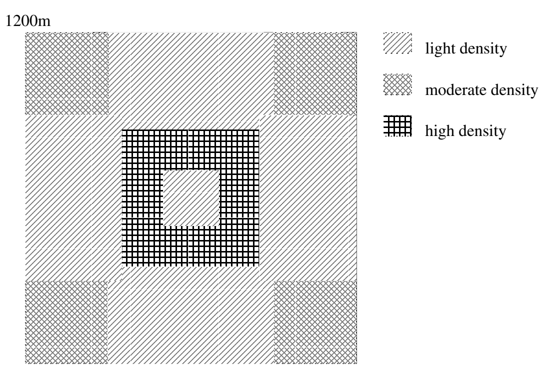

Fig. 3. Simulation mobility model

As discussed in Section II-A, mobility modeling will have great impact on the performance of routing protocols. To show LAKER's ability in exploiting the topological characteristics of the network, we use a more or less artificial model in simulation as shown in Figure 3. Note that population density is not uniform in different parts of the network. Connections take place between mobile nodes located in the diagonal "corner" parts of the network.

To evaluate the performance of LAKER, we consider three metrics: the number of routing messages, the packet delivery ratio, and the end-to-end delay. For each *pausetime*(i.e., each point of the curves), we run multiple rounds of simulations using different moving patterns and then obtain the average results. We compare the results of DSR, LAR, and LAKER protocols as follows.

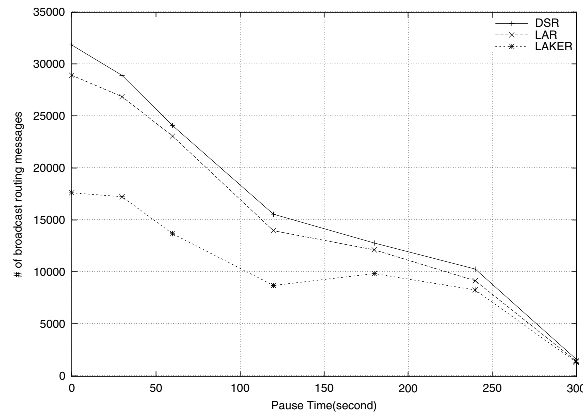

Fig. 4. Number of broadcast routing messages

First, the routing overhead is shown in Figure 4. We can observe that LAKER can greatly reduce the number of broadcast routing messages, compared to both DSR and LAR. LAKER protocol can discover topological characteristics of the network and use this information to guide its route discovery in a more efficient manner. In average, LAKER can save up to 30% broadcast control message compared to LAR. As the *pausetime* increases, the difference between routing overhead in LAKER, LAR and DSR reduces. This is because the mobility of the network reduces as *pausetime* increases, and routing activities become less and less. Note that the number of broadcast routing messages in LAR is just a little less than that of DSR in our simulation, which is natural because communicating nodes are in the four corners and connections take place between nodes in the diagonal corners, and thus the LAR request zone is often comparable to the entire network area.

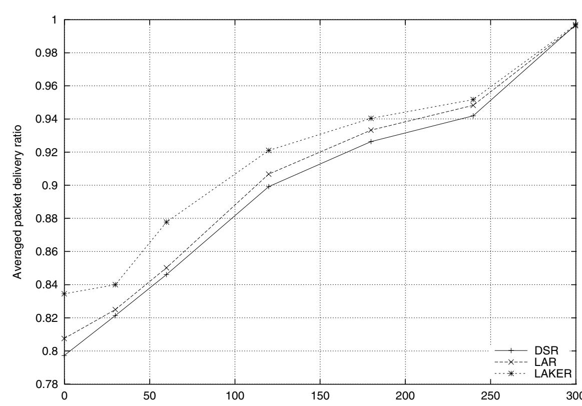

Fig. 5. Delivery ratio

Second, Figure 5 shows the end-to-end delivery ratio.

LAKER can achieve a little higher delivery ratio than LAR and DSR. We believe this is because of the fact that LAKER can reduce the number of broadcasting messages, which leads to fewer packet collisions. The delivery ratios in all three protocols increase as the *pausetime* increases, because the network topology becomes more stable.

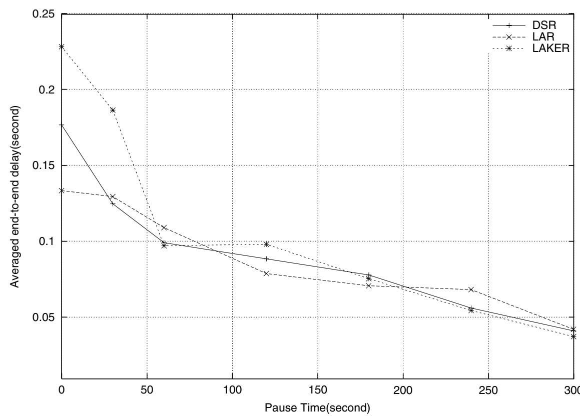

Fig. 6. End to end delay

Third, let us observe the end-to-end delay shown in Figure 6. Except for some cases at small *pausetime*s(such as 0 and 30 seconds), LAKER can achieve almost the same delay as LAR and DSR. The reason that LAKER has higher end-to-end delay at low *pausetime*s is because LAKER attempts to search for new routes in a very limited space, which may lead to the discovery of fragile routes, which in turn will incur more delay to packet delivery.

IV. Related works

Mobility modeling and location guided routing have gained much attention from researchers recently. A survey on mobility models in ad hoc networks can be found in [3], and a number of position based routing protocols are summarized in [2]. Here we only talk about a few works that are closely related to our work.

LANMAR routing protocol[11] attempts to exploit the network characteristics aiming at addressing the scalability problem. The protocol adopts a "Reference Point Group Mobility" model and attempts to keep track of logical subnets in which the members have a commonality of interests and are likely to move as a "group". LAKER is different from LANMAR in that it attempts to keep track of the population density distribution of the network, aiming at reducing routing overhead by means of better guidance in route discovery.

The restricted random waypoint mobility model we adopt in this paper was proposed in [12]. The authors of [12] also propose an "Anchored Geodesic Packet Forwarding" approach to solve the problem of "void" area in the network. As proposed in [12], the knowledge of "anchored path" is generated with assistance from a set of friend nodes in the network, or based on a predefined map of population density. When forwarding data packet, "anchored path" is used as loose source routing information. Our notion of "guiding_route" is similar to the idea of "anchored path". Our work is different from [12] in the sense that we use a different way to generate and utilize this kind of guiding information. In particular, LAKER can gradually learn of partial knowledge of the network characteristics and use this information to guide future flooding-based route discovery.

GPSR routing protocol[8] aggressively uses geographical location information in making routing decision. When an intermediate node receives a packet, it will greedily forward this packet to one of its neighbors, which can mostly reduce the distance towards the destination node. When a packet is stuck at some intermediate node due to the existence of "void" area in the network, a perimeter routing technique is applied to find a bypassing route towards the destination.

V. Conclusion

In this paper we presented a Location Aided Knowledge Extraction Routing (LAKER) protocol for MANETs. Under mobility models where nodes are not uniformly distributed, LAKER can gradually learn of the topological characteristics of the network, such as population density distribution, during the route discovery process. This kind of knowledge can be organized in the form of a set of *guiding_route*, and can be used to guide future route discovery processes more precisely and more efficiently. Simulation results show that LAKER can save up to 30% broadcast control messages compared LAR approach, while achieving better delivery ratio and almost the same end-to-end delay.

References

[1] E.M. Royer and C.-K. Toh. A Review of Current Routing Protocols for Ad-hoc Mobile Wireless Networks. IEEE Personal Communications, Apr.1999, pp.46-55.

[2] M. Mauve, J. Widmer, and H. Hartenstein. A Survey on Position-based Routing in Mobile Ad hoc Networks. IEEE Network Magazine, 15(6):30-39, November 2001.

[3] T. Camp, J. Boleng, and V. Davies. Mobility Models for Ad Hoc Network Simulations. Wireless Communication & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications, 2002.

[4] D.B. Johnson, D.A. Maltz, and J. Broch. DSR: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks. Ad Hoc Networking, edited by C. E. Perkins, Addison-Wesley, 2001.

[5] C.E. Perkins and E. M. Royer. Ad hoc On-Demand Distance Vector Routing. Ad Hoc Networking, edited by C. E. Perkins, Addison-Wesley, 2001.

[6] Y-B Ko and N. H. Vaidya. Location-Aided Routing(LAR) in Mobile Ad Hoc Networks. ACM/Baltzer Wireless Networks (WINET) journal, Vol.6-4, 2000.

[7] S. Basagni, I. Chlamtac, V.R. Syrotiuk, and B.A. Woodward. A Distance Routing Effect Algorithm for Mobility(DREAM). Proc. of ACM MOBICOM'98, pp. 76-84.

[8] B. Karp and H. T. Kung. GPSR: Greedy Perimeter Stateless Routing for Wireless Networks. Proc. of ACM MOBICOM 2000, pp.243-254.

[9] J. Li, J. Jannotti, D. Decouto, D. Karger, and R. Morris. A Scalable Location Service for Geographic Ad-hoc Routing. Proc. ACM MOBICOM 2000.

[10] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva. A Performance Comparison of Multi-hop Wireless Ad-hoc Network Routing Protocols. Proc. ACM MOBICOM '98, pp. 85-97, October 1998.

[11] M. Gerla, X. Hong, and G. Pei. Landmark Routing for Large Ad Hoc Wireless Networks. Proc. IEEE GLOBECOM 2000.

[12] L. Blazevic, S. Giordano, and J. L. Boudec. Self Organized Routing in Wide Area Mobile Ad-Hoc Networks. IEEE GLOBECOM 2001.

[13] E. Elmallah, H. Hassanein, and H. AboElFotoh. Supporting QoS Routing in Mobile Ad Hoc Networks using Probabilistic Locality and Load Balancing. IEEE GLOBECOM 2001.

[14] The Network Simulator *ns-2*, available online at http://www.isi.edu/nsnam/ns/.

[15] The Monarch Group at Rice University, project website http://www.monarch.cs.rice.edu/.