Location Information Services in Mobile Ad Hoc Networks

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***Abstract*—In recent years, many location based routing protocols have been developed for ad hoc networks. Some of these protocols assume a location service exists which provides location information on all the mobile nodes in the network. In this paper, we evaluate three location service alternatives. One is a reactive protocol; the other two are proactive protocols. Of the proactive protocols, one sends location tables to neighbors and the other sends location information to all nodes. In our evaluation, one proactive protocol proved to have the best performance overall. Thus, we also evaluate the main input parameter associated with this protocol for optimal performance.**

I. INTRODUCTION

An ad hoc network is a set of wireless mobile nodes that cooperatively form a network without specific user administration or configuration. Each node in an ad hoc network is in charge of routing information between its neighbors, thus contributing to and maintaining connectivity of the network. Many unicast routing protocols have been proposed for ad hoc networks; a performance comparison for a few of the protocols are in [1] and [2].

In order to improve the routing performance of unicast communication, a number of unicast routing protocols for an ad hoc network use location information. Four of these protocols are the Location-Aided Routing (LAR) algorithm [3], the Distance Routing Effect Algorithm for Mobility (DREAM) [4], the Greedy Perimeter Stateless Routing (GPSR) algorithm [5], and the Geographical Routing Algorithm (GRA) [6].

Each of these location aided routing algorithms approach the availability of mobile nodes' location information differently. For example, knowledge about the location of a destination node is assumed available in GPSR. In fact, in the simulation results presented in [5], location information is provided to all mobile nodes without cost. DREAM, on the other hand, includes the exchange of location information as a part of its protocol. Thus, protocol overhead in simulation results on DREAM are much higher than GPSR because DREAM includes the task of maintaining location information on destination nodes.

One method to provide location information in an ad hoc network is via the Grid Location Service (GLS) [7]. In GLS, each mobile node periodically updates a set of location servers with its current location. The set of location servers chosen is determined by a predefined geographic grid and a predefined ordering of mobile node identifiers in the ad hoc network.

The demonstrated success of using location information for routing in an ad hoc network (see [3] and [8]) has led us to develop and evaluate the performance of three location services: the Simple Location Service (SLS), the DREAM Location Service (DLS), and the Reactive Location Service (RLS). SLS and DLS are both proactive location services; thus, nodes exchange location information periodically in both of these protocols. The difference between SLS and DLS is in the type of information exchanged and the distance the information is propagated. Specifically, SLS transmits tables containing multiple node locations to neighbors; DLS transmits individual node locations to neighbors or to every node in the ad hoc network. RLS is a reactive location service that queries location information on an as needed basis. Each node in RLS maintains a location table; entries in the location table of a node are purged periodically based on the age of the location information. Complete details of each protocol are included in the following section.

II. LOCATION SERVICES STUDIED

To maintain location information on other nodes in the network, each mobile node maintains a location table. This table contains an entry on every node in the network whose location information is known, including the node's own location information. A table entry contains node identification, the coordinates of the node's location based on some reference system, the current speed of the node, and the time this location information was obtained from the node. As mentioned, we have developed and evaluated three location services which maintain these location tables. In all three location services, when a location request occurs, a node will first look in its location table for the information. If the information is not available in the table, the node will flood a location request packet. Nodes that hear a reply to a location request update their table in a promiscuous manner.

A. DREAM Location Service (DLS)

Protocol Description:

We call this location service the DREAM Location Service (DLS) since it is similar to a location service proposed by the authors of DREAM [4]. Each location packet (LP), which updates location tables, contains the coordinates of the source node based on some reference system, the source node's speed, and the time the LP was transmitted. Each mobile node in the ad hoc network transmits an LP to nearby nodes at a given rate and to faraway nodes at another lower rate. The

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rate a mobile node transmits LPs adapts according to when the mobile node has moved a specified distance from its last update location. Since faraway nodes *appear* to move more slowly than nearby mobile nodes, it is not necessary for a mobile node to maintain up-to-date location information on faraway nodes. Thus, by differentiating between nearby and faraway nodes, the overhead of location packets is limited.

Details on implementing the proposed location service are lacking in [4]; we have tried to ensure that DLS follows what the authors intended. (See [8] for full details on our implementation of DREAM in NS-2 [9].) Our solution for the transmission of LPs is:

$$\begin{array}{ll} \text{transmit nearby LP:} & (\frac{T_{range}}{\alpha}) * (\frac{1}{\nu}) = \frac{T_{range}}{\alpha\nu} \\ \text{transmit faraway LP:} & \text{one for every } X \text{ nearby LPs} \\ & \qquad\qquad\text{or} \\ & \text{at least every } Y \text{ seconds,} \end{array}$$

where T_{range} is the transmission range of the mobile node, ν is the average velocity of the mobile node, and α is a scaling factor. We note that LPs to faraway nodes update all nodes in the network, including nearby nodes.

There are some similarities of DLS to the Internet standard Open Shortest Path First (OSPF) [10]. Specifically, both transmit information concerning the local environment to all nodes in the network on a periodic basis. There are, however, three significant differences between these two protocols. First, DLS differentiates between nearby nodes and faraway nodes; OSPF has no such differentiation. Second, a node using DLS will transmit its location information; a node using OSPF will transmit its neighbor information. Lastly, OSPF was not developed for an ad hoc network environment; thus, the rate of OSPF update packets is only based on time not on distance moved.

Implementation Decisions:

For the transmission of nearby/faraway LPs, we set α to 4, X to 13, and Y to 23 seconds. (We optimized these three values via numerous simulation trials.) To avoid LPs being transmitted by neighboring nodes at the same time (and, thus, colliding), each mobile node offsets the transmission of their LPs with a random jitter. In the location service proposed by the authors of DREAM, nearby mobile nodes are categorized by distance. A variation of the protocol is to specify nearby mobile nodes as being within a given number of hops. We compared the performance of defining a nearby mobile node as being within a specified distance (e.g., 100 meters) versus being within one hop and discovered one hop slightly improves the results of the location service. Lastly, if a location table entry in DLS is older than 46 seconds, the information in the entry is considered *outdated* and deleted. If a node receives a location request packet addressed to itself, then the node will reply with an LP containing its location information.

B. *Simple Location Service (SLS)*

Protocol Description:

A node using the Simple Location Service (SLS) will transmit a location packet (LP) to its neighbors at a given rate. The rate a mobile node transmits LPs adapts according to location change, via a similar procedure used for nearby nodes in DLS:

$$\begin{array}{ll} \text{transmit LP:} & (\frac{T_{range}}{\alpha}) * (\frac{1}{\nu}) = \frac{T_{range}}{\alpha\nu} \\ & \qquad\qquad\text{or} \\ & \text{at least every } Z \text{ seconds.} \end{array}$$

Each LP in SLS contains up to E entries from the node's location table; the E entries are chosen from the table in a round robin fashion. In other words, each LP transmission shares location information on other nodes in the ad hoc network with the node's neighbors. As multiple LPs are transmitted, all the location information a node knows will be shared with its neighbors.

A node using SLS will also periodically receive a location packet from one of its neighbors. The node will then update its location table based on the received table entries, such that each location information with the most recent time (between the node's own table and the received table) is maintained.

There are some similarities of SLS to the Internet standard Routing Information Protocol (RIP) [11]. Specifically, both transmit tables to neighbors on a periodic basis. Differences between these two protocols include the following: SLS sends partial location tables compared to the total routing tables sent by RIP and, unlike RIP, a node using SLS will utilize its current location table in the calculation of its new location table. Lastly, RIP was not developed for an ad hoc network environment. Thus, SLS shares its tables with different neighbors as the network topology changes and, like OSPF, the rate of RIP update packets is only based on time not on distance moved.

Implementation Decisions:

For the transmission of location packets, we set α to 4, Z to 13, and E to 25. As in DLS, to avoid LPs being transmitted by neighboring nodes at the same time (and, thus, colliding), each mobile node offsets the transmission of their LPs with a random jitter. If a location table entry in SLS is older than 46 seconds, the information in the entry is considered *outdated* and deleted. If a node receives a location request packet addressed to itself, then the node will reply with an LP containing up to E entries from the node's location table (including its own location). We discuss the effect of different values for E in Section IV.

C. *Reactive Location Service (RLS)*

Protocol Description:

In the Reactive Location Service (RLS), when a mobile node requires a location for another node and the location information is either unknown or expired, the requesting node will first ask its neighbors for the requested location information (i.e., the time-to-live, or TTL, of the packet is set to zero). If the node's neighbors do not respond to the requested location information within a timeout period, then the node will flood a location request packet in the entire network.

When a node receives a location request packet and does not know the requested location information, the node propagates the flooded location request. If, however, a node receives a location request packet and the node's location table contains the requested location information, the node returns a location reply packet via the reverse source route obtained in the location request packet. In other words, each location request packet carries the full route (a sequenced list of nodes) that a location reply packet should be able to traverse in its header. Since IEEE 802.11 requires bi-directional links in the delivery of all non-broadcast packets, we assume bi-directional links in RLS. If bi-directional links are not available, this requirement can be removed via the manner proposed in the Dynamic Source Routing (DSR) protocol [1].

If feasible, each node using RLS should update its location table when a new location packet is overheard/received. In other words, we suggest promiscuous mode operation is used by all RLS nodes. (As noted in [2], promiscuous mode operation is power consuming.) Lastly, entries in the location table are aged as the node associated with the entry moves; that is, an entry associated with a node that is moving quickly will age more quickly.

There are some similarities of RLS to LAR [3] and DSR [1], two unicast routing protocols developed for a mobile ad hoc network. Specifically, all three protocols are reactive protocols that try to discover the required information on demand. In addition, all three protocols use the reverse source route to respond to a request for information. One significant difference between these three protocols is the following: RLS attempts to determine location information, while LAR and DSR attempt to determine full routes. Lastly, requesting desired information from neighbors first and allowing intermediate nodes to reply to a request are two features that both RLS and DSR have. Although not mentioned in LAR [3], we evaluate the usefulness of these features for LAR in [8].

Implementation Decisions:

A node using RLS will remove *outdated* entries from its location table if the node in the entry is believed to have moved more than one transmission distance (100m) since the last location information was received from that node. An entry also becomes outdated in the same manner as SLS and DLS; specifically, if a location table entry in RLS is older than 46 seconds, the information in the entry is deleted. In addition, similar to SLS and DLS, each node offsets its transmission of location packets with random jitter in order to avoid collisions. Lastly, the timeout for a one hop location information request is 30 ms.

III. SIMULATION ENVIRONMENT

Each location service was implemented according to the above protocol descriptions in the network simulator NS-2 [9]. The performance of each location service was tested in a network of 50 mobile nodes. Each node generates two location requests per second; the 100 location requests per second are generated for 100 randomly selected nodes in the network. Table I details the simulation environment.

Derived parameters are calculated from the simulation input parameters [12]. Node density is the number of nodes divided by the total simulation area. Coverage area is the area of the circle whose radius is the transmission distance. The transmission footprint of a node is the percentage of the simulation area covered by a node's transmission; it is derived from the transmission range of the node and the size of the simulation area. The maximum path length is the distance from the lower left corner to the upper right corner in the simulation area. The network diameter is the maximum path length divided by the transmission range. Finally, the network connectivity indicates the number of one hop neighbors a node will have. The value labeled "no edge affect" is calculated by dividing the coverage area by the node density. The value labeled "edge affect" takes into account the fact that nodes near the edges do not have neighbors on all sides.

Input Parameters	
Number of Nodes	50
Simulation Area Size	300m x 600m
Transmission Range	100m
Simulation Duration	2000 seconds, location requests generated 1000-2000 seconds
Derived Parameters	
Node Density	1 node per 3,600 m^2
Coverage Area	31,416 m^2
Transmission Footprint	17.45%
Maximum Path Length	671m
Network Diameter (max. hops)	6.71 hops
Network Connectivity (node degree)	8.73 (no edge affect)
Network Connectivity (node degree)	7.76 (edge affect)
Mobility Model	
Mobility Model	Random Waypoint
Mobility Speed	1, 3, 5, 10, 15, 20 ±10%
Pause Time	10 ±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

IV. SIMULATION RESULTS

We evaluate DLS, SLS, and RLS in both performance areas (e.g., the percentage of location requests that are answered) and overhead areas (e.g., the number of location packets transmitted per location request answered) in the following two subsections. All the performance results presented are an average of 10 different simulation trials. We calculate a 95% confidence interval for the unknown mean, and we plot these confidence intervals on the figures. Since most of the confidence intervals are quite small, we are convinced that our simulation results precisely represent the unknown mean.

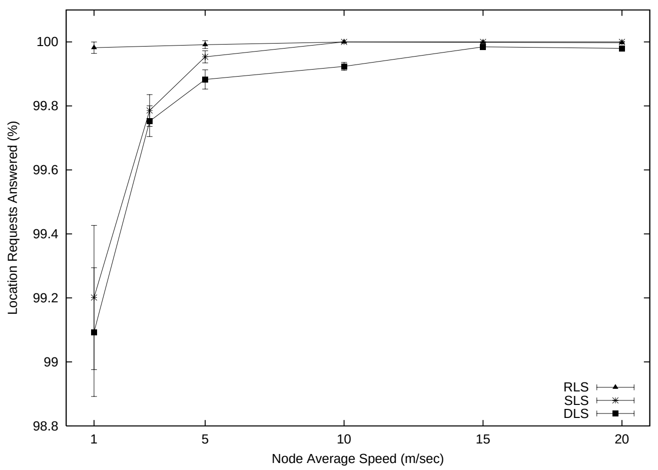

Fig. 1. Location requests answered vs. speed.

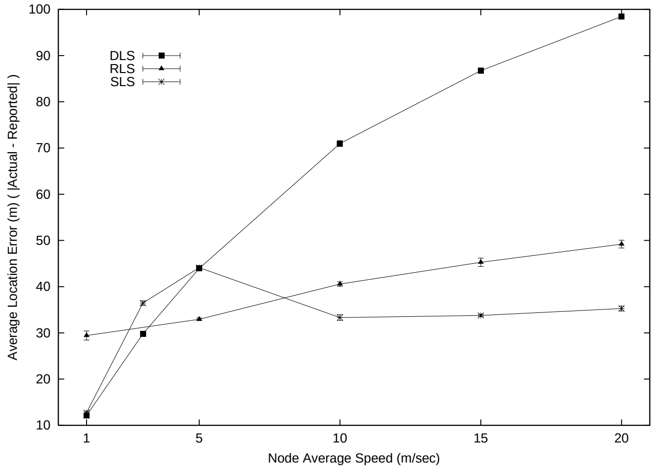

Fig. 2. Error of location responses vs. speed.

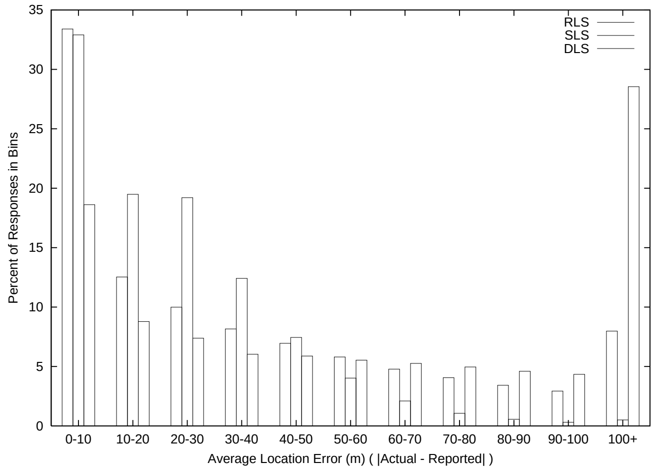

Fig. 3. Histogram of location error in location responses.

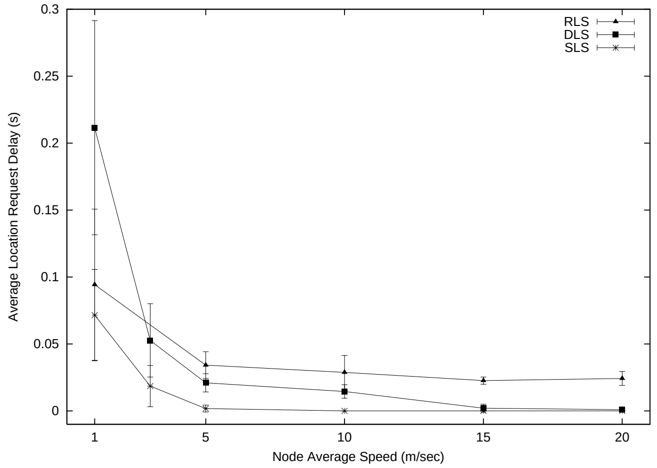

Fig. 4. End-to-end Delay for location request vs. speed.

A. Performance

The percentage of location requests that are answered versus speed is shown in Figure 1. We note that the results for all three protocols range between 99% and 100%. In other words, all three protocols provide location information on a given node almost all of the time. DLS and SLS do not perform as well as RLS at low speeds, since location packets in both of these protocols are transmitted more often at higher speeds. While Figure 1 gives us an indication of available location information on a given node, it does not answer the question of how valid the information is.

Figure 2 plots the average location error (in meters) of the protocols versus speed. The average location error is the actual location of the mobile node (at time t) minus the location of the mobile node provided by the location service (at time t). As shown, DLS and SLS provide similar accuracy at slow speeds. However, SLS provides the most accurate location information at higher speeds. That is, SLS benefits from higher speeds, since a mobile node will share its location table entries with more nodes when the mobile node is moving quickly. Similar to SLS, a node using DLS will transmit more location packets at higher speeds. Unlike SLS, however, the location packets (LPs) of DLS are flooded in the network. Due to contention issues from the flooding of LPs, the location information provided by DLS is less accurate. Lastly, the location error provided by RLS increases as speed increases. Overall, the average location error provided by our reactive protocol (RLS) is similar to the average location error provided by one of our proactive protocols (SLS).

We evaluate the location error of each protocol more closely in Figure 3. This figure gives a histogram of the location error provided by each protocol when speed is 10 m/sec. We define a location information response *invalid* if the error on the location information is greater than the transmission range. Thus, the percentage of location errors that are invalid for each protocol is shown in bin 100+. We note that over 25% of the location responses returned by DLS are invalid. As discussed in Figure 2, the *average* location errors of RLS and SLS are similar at 10 m/sec. Figure 3 illustrates, however, that RLS (unlike SLS) returns location responses that are *invalid* almost 10% of the time.

Both Figure 4 and Figure 5 concern the amount of delay in obtaining a response to a location request. Figure 4 plots the average end-to-end delay on a response to a location re-

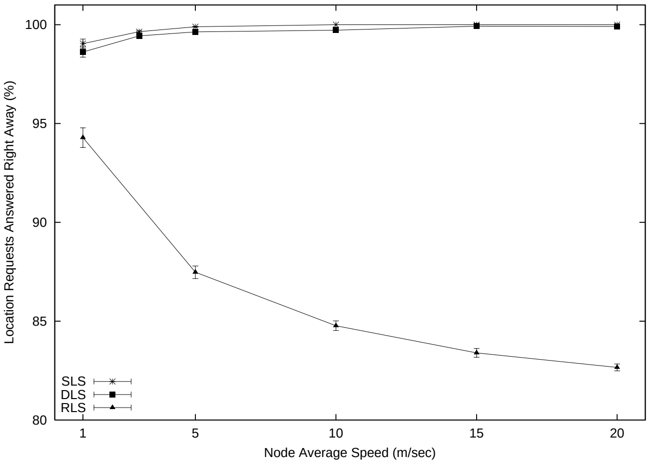

Fig. 5. Location answers available in location table vs. speed.

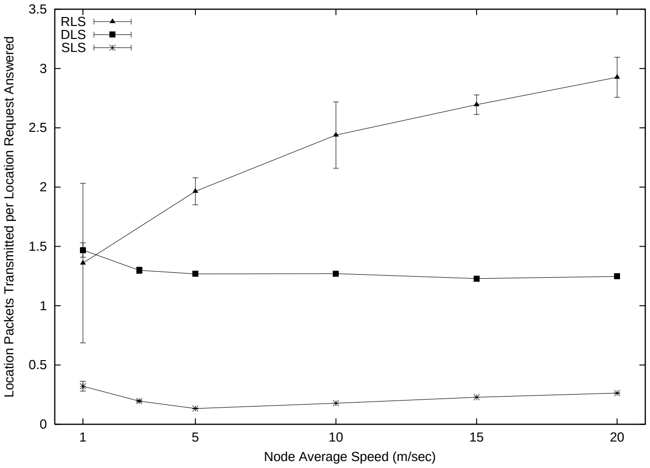

Fig. 6. Location packet overhead vs. speed.

quest versus speed. Figure 5 plots the percentage of location requests that are answered by the requesting node via its location table; in other words, this figure indicates the number of location table entries that exist in each of the protocols over the number of nodes in the network. As shown, the delay for SLS is the lowest of the three protocols (see Figure 4) since SLS has the largest percentage of location requests provided by the requesting node (see Figure 5). As expected, RLS, a protocol that obtains location information on an as needed basis, has the lowest percentage of location requests answered right away.

B. Overhead

Figures 6 and 7 illustrate the overhead that each location service requires. Figure 6 shows the number of location packet transmissions for each location request provided as speed increases. This figure helps capture the power overhead requirements of each protocol. All three protocols have a flooding component. Flooding in DLS is one of the proactive tasks in the protocol. Flooding in SLS, on the other hand, only occurs when the requested location information is not available in the location table; thus, the number of packets transmitted for each location request answered in SLS is quite small. RLS also floods only when the requested location information is not available in the location table; however, since RLS is not a proactive protocol, RLS is more likely than SLS to flood location requests. Furthermore, this task is more likely to occur at higher speeds.

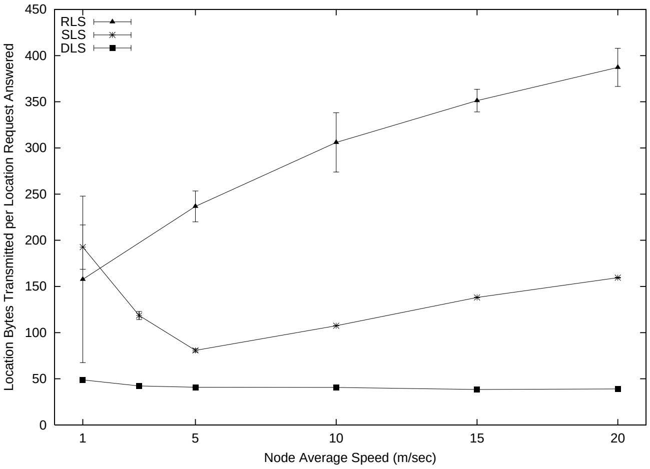

Fig. 7. Location byte overhead vs. speed.

Figure 7 illustrates the number of location byte transmissions for each location request answered as speed increases. This figure helps capture the bandwidth requirement of each protocol. The bandwidth requirement of DLS is minimally affected by speed due to the nature of its proactive element. The bandwidth requirement of RLS increases as speed increases, which corresponds to the increase in Figure 6. In other words, at low speeds, location information only expires due to the timer; at higher speeds location information expires more frequently, which generates more location requests and more overhead. Lastly, let us evaluate the bandwidth requirement of SLS. As speed increases from 1 m/sec to 5 m/sec, the bandwidth requirement of SLS decreases. At 1 m/sec, SLS is slightly more likely to reactively flood a location request than at 5 m/sec (see Figure 5). Since SLS does not have a proactive flooding component, these flooded location requests substantially affect the byte overhead. As speed increases from 5 m/sec, SLS is more likely to transmit location packets to neighbors. Compared to DLS, there are fewer, but larger, location packets in SLS. Higher byte overhead for SLS is acceptable if the performance of SLS is also higher. Figures 2 and 3 validate that the SLS error on location information is substantially less than the errors provided by DLS.

Overall, SLS offers higher performance (see Figures 2 and 3) and lower overhead (see Figure 6) than RLS and DLS. Since SLS is preferred over both RLS and DLS, we evaluate the main input parameter associated with SLS. Specifically, a smaller (larger) SLS update table size should decrease (increase) both overhead and performance. We evaluate this trade off in the next section.

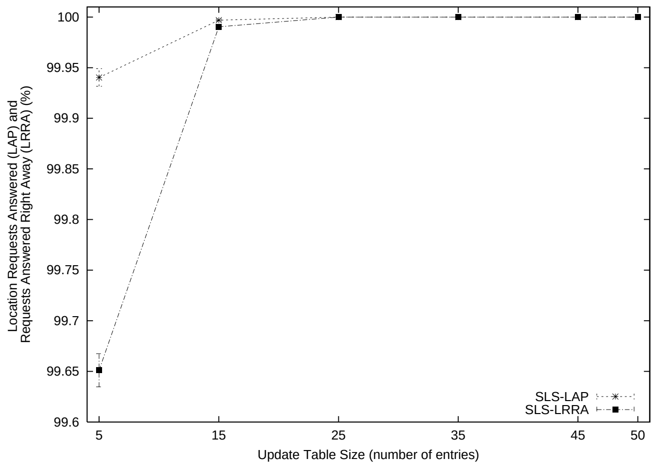

Fig. 8. Percent of location requests answered and in table vs. SLS LP table size.

C. SLS Table Size Evaluation

In this section, we investigate a desired value for E, the number of location table entries that are transmitted in each location packet, when the speed of mobile nodes is 10 m/sec. Figure 8 combines the y-axes of Figure 1 and Figure 5 with an x-axis representing E. As shown, the performance of SLS increases as the number of location table entries increases in the location packets. In addition, since location information is often immediately available (i.e., in the node's cache), the average location request delay is always low. Specifically, the average location request delay decreases from 0.015 to 0.001 as the number of location table entries in a location packet increases from 5 to 25. Lastly, while Figure 8 illustrates that location information is (almost) always available, it does not answer the question of how valid the information is.

Figure 9 shows the accuracy of the location information provided by the mobile nodes. Figure 9 plots the average location error (in meters) of SLS as the number of location table entries increases. As in Figure 2, the average location error is the actual location of the mobile node (at time t) minus the location of the mobile node provided by the location service (at time t). As expected, the average location error decreases as the number of location table entries increases. Furthermore, even when E is small, the average location error is competitive with the average location error provided by DLS at 10 m/sec; i.e., compare the results of Figure 9 with the results of Figure 2 at 10 m/sec.

Table II illustrates the overhead changes as the number of location table entries changes in each location packet. The column labeled packets (bytes) is the number of location packet (byte) transmissions for each location request provided. As expected, the overhead, in terms of bytes, increases as the number of location table entries increases in each location packet. The overhead, in terms of packets, initially decreases (as one would expect) as the number of location table entries increases. The overhead, in terms of packets, remains constant as the number of location table entries increases from 25 to 50.

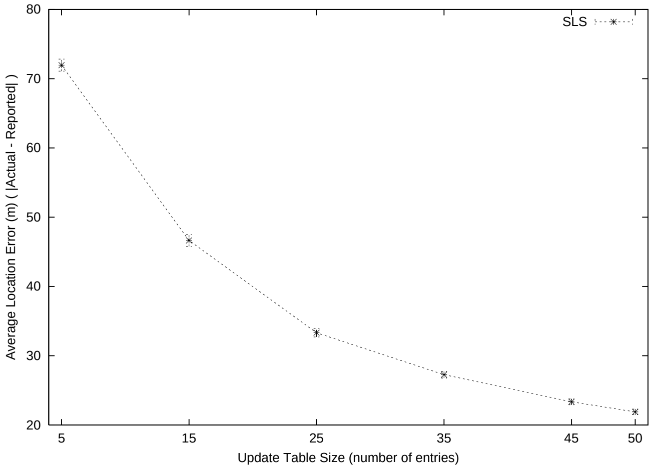

Fig. 9. Error of location responses vs. SLS LP table size.

table size	**packets**	**bytes**
5	0.460	60.209
15	0.183	67.394
25	0.177	107.462
35	0.177	149.881
45	0.177	192.254
50	0.177	213.394

TABLE II
SLS LP Table Size

Based on the results in Table II and Figures 8 and 9, a desired number of location table entries in a location packet is between 15 and 25 for the simulation environment we evaluated. Increasing the number of location table entries higher than 25 increases overhead (in terms of bytes) with no associated increase in the percentage of location requests that are answered and little associated increase in the accuracy of location information provided. In our simulation environment, 50 mobile nodes exist. Thus, a guideline for SLS is to set E to 30-50% of the mobile nodes in the ad hoc network.

V. CONCLUSIONS

In this paper, we have proposed and evaluated (via simulation) three location services for an ad hoc network. One of the three protocols evaluated is a reactive protocol. The other two protocols evaluated proactively transmit either location tables to neighbors or location information to everyone. An effective location service can be used to improve the performance and scalability of a routing protocol that requires location information (e.g., GPSR [5]).

Figures 2 and 3 illustrate that DLS, a proactive protocol that periodically floods location information, is unable to provide accurate location information (especially at high speeds). On the other hand, a proactive protocol that periodically shares location table entries with neighbors (such as SLS) offers advantages over DLS in terms of simplicity, fewer packet transmissions (see Figure 6), and higher performance.

When the proactive SLS protocol is compared with the reactive RLS protocol, we discover that the flooding requirements of RLS are much more costly in terms of both packets and bytes transmitted (see Figures 6 and 7). In addition, while the average location error of the two protocols is similar (see Figure 2), the percentage of *invalid* location responses provided by RLS is much higher than SLS (see Figure 3). We, therefore, conclude that our Simple Location Service is preferred over both our Reactive Location Service and DREAM's Location Service.

One avenue of future work is to evaluate whether SLS can improve the performance of the DREAM routing protocol [4]. In addition, RLS, DLS, and SLS should be compared with a hierarchical location service, such as the one provided by GLS [7]. While GLS has been simulated in NS-2, the version used is only ns-2.1b1; all of our simulations have been developed in ns-2.1b7, which are incompatible with the GLS simulations developed in ns-2.1b1. Thus, we are unable to compare our three location services with GLS at this time.

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