Tgrid Location Service In Ad-Hoc Networks: Modeling & Analysis

Baktashmotlagh Farrokhlegha

Abstract*:* Geographic addresses are essential in position-based routing algorithms in mobile ad hoc networks, i.e. a node that intends to send a packet to some target node, has to know the target's current position. A distributed location service is required to provide each node's position to the other network nodes. Grid Location Service (GLS) has been known as a promising location service approach. In this paper we present a new approach called TGrid and describe the performance of a novel multi-level Tree-walk grid location management protocol for large scale ad hoc networks. We provide a qualitative comparison of GLS and TGrid using statistical analysis beyond the results of the original paper and a theoretical framework. We present analytical results with respect to three main metrics: query cost, maintenance cost, and storage cost under two traffic patterns: uniform and localized traffic pattern. The proposed approach is evaluated through mathematical analysis, and the results indicate that our protocol scales 11well with increasing of node-count, node-density and node-speed. We show that the tree Main metrics, query cost, maintenance cost, and storage cost in TGRID grows only logarithmically in the total number of nodes in a uniformly randomly distributed network.

Keywords*:* Location based routing, location service, location management, Mobile Ad Hoc Networks

1 Introduction

Routing in a mobile ad hoc network is a demanding task since the network's topology is changing frequently. In early approaches, proactive and reactive routing protocols were suggested [6],[12]. These protocols maintain information about paths in a network. This may be difficult with frequent topology changes. Position-based routing algorithms make routing decisions based only on the position of the communication partners, and offer a scalable solution to this problem [5],[10],[14]. Different position-based routing protocols have been developed for ad hoc networks. Some of these protocols assume that at least a location service exists which provides location information of all the mobile nodes in the network. Grid Location Service (GLS) is one of the methods for providing location information in an ad hoc network [1],[10]. In GLS, each mobile node periodically informs 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. GLS is a distributed location service which tracks mobile node locations. GLS combined with geographic forwarding allows the construction of ad hoc mobile networks that scale to a larger number of nodes than possible with the previous works. In this work, we propose an ad-hoc mobility management scheme. Routing is carried out in the hierarchical network structure. The location of a mobile host is defined in terms of the positional relationships between the mobile host and location server zone. In particular, we will define the location of a mobile host as the ID number of its nearest location database zone. The nodes containing the location databases can dynamically detach and re-attach to the network at any time due to mobile nodes' movement or changes in the communications environment [4]. However, the temporally interruption in a node's connectivity to the network should have minimum effect on the other nodes' communication.

This imposes great challenges in the design and operation of an ad-hoc network[4]. This paper proposes TGrid's distributed location service algorithm and compares its scalability with GLS (one of the best location services). The rest of the paper is as following. In section 2 we overview GLS algorithm. Section 3 describes the implementation of the proposed algorithm (TGrid) in detail. Section 4 describes assumptions and notations used for theoretical framework for modelings and analysis of location servers presented in [2],[11]. Section 5 analyzes Grid and TGrid's design performance and scalability using theoretical framework. Section 6 summarizes the paper's contributions and compares our scheme with some of the known schemes in location management. It also concludes the paper and suggests areas for future improvements.

2 Grid Location Service

Grid Location Service (GLS) is a hybrid location service. In GLS, physical location of network is divided into "grid squares" arranged hierarchically based on their size. The smallest grid is an order-1 square. Four order-1 grids form an order-2 grid, and so on. The various orders of an example grid are shown in Figure 1[1][15]. Each node chooses its location servers by selecting a set of nodes in each level. These location servers have the least ids greater than or equal to node's ID itself. To perform a location query, we assume node **A** needs the position of node **B**. Therefore, node A sends a request to the node that its ID is the least ID greater than or equal to **B** for which A is the location server. That node forwards the query in the same way to another node until it reaches the B's Location Server. It forwards the query to node B, and B responds the query with its most recent location [3],[14]. To update, whenever a node moves a threshold, it sends an update packet to its location servers at a rate proportional to the distance it has traveled since the last update. Due to distance effect phenomenon, faraway location servers move slowly than nearby servers, so they can be updated less frequently than the nearby ones [6],[12].

- *Ms. Baktashmotlagh farrokhlegha is currently lecturer in Technical and vocational university, Urmia , Iran Email: Baktaash@gmail.com*

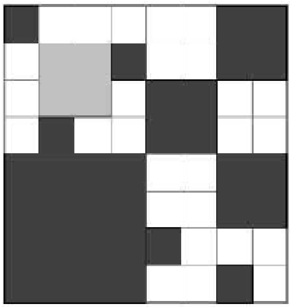

Fig.1 *various levels in Grid [3]*

3 TGrid

TGrid Location Service divides the area containing the ad hoc nodes into a hierarchical grid of squares as GLS. TGrid combines 9^i order-1 grid to form an order-i Grid ($0 \leq i \leq H$) where H is the highest level number. Each node selects the middle square in each order i region as its location server zone (Home Region). The structure of TGrid is shown in Figure 2. For a node C to be node A's location server, C must be in the middle square of nine grids in level i grid where A resides. The location server regions store multi-grained information, i.e., each level-i location server zone stores the information of which level-(i-1) zone the node is in, and only level-1 location servers store the exact location of A. Each node updates its level-1 location server zone with its exact location and updates higher level location server zone with its relative location. If the node-B needs node-A's geographic location, it sends the query to its own level-1 location server zone. If the nodes in that zone have any information about A's location, they send the answer to B, otherwise the request forwarded to higher level location server zone until it reaches the last zone (most central square in the whole area). When B gets the answer, and it's the relative location of A, the query is recursively forwarded to the closer location server zones to A until it reach the one that know the exact location of A. one of the nodes in this zone sends back the answer to B. Location Discovery and Data Transfer in TGRID is shown in figure 3.

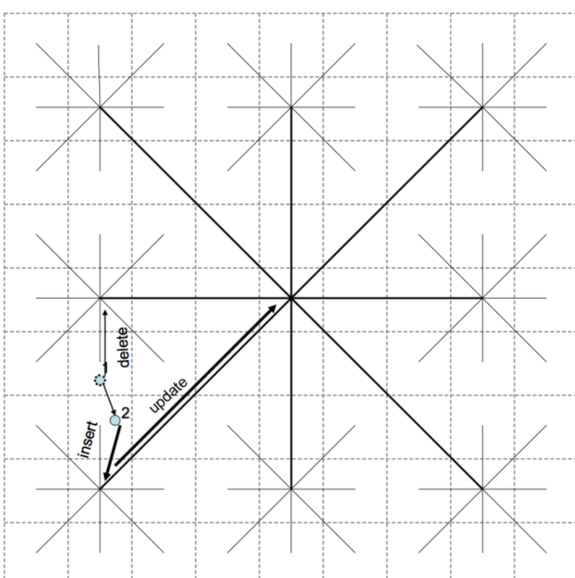

Fig.2 *Location update*

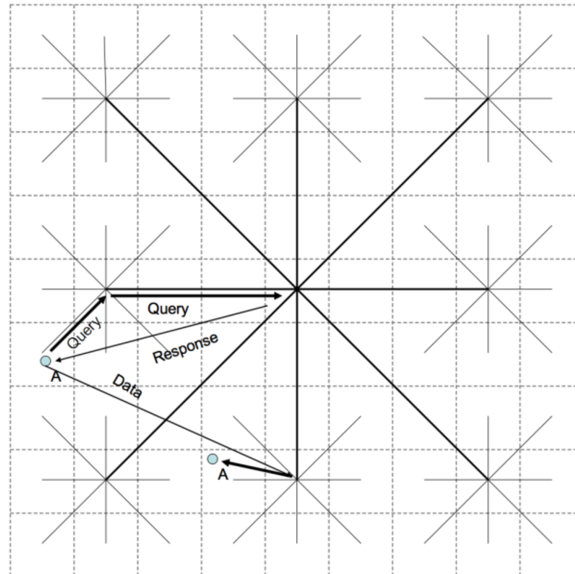

Fig.3 *Location Discovery And Data Transfer*

4 Theoretical framework for design and analysis

We use three metrics to evaluate the scalability of each scheme: location maintenance cost, location query cost and storage cost, which are formally defined as follows.

Definition 1 (Location Maintenance Cost): The location maintenance cost C_m is the number of forwarding operations each node needs to perform in a second to handle the location update/maintenance packets.

Definition 2 (Location Query Cost): The location query cost Cq the number of packet forwarding operations due to location queries each node needs to perform in a second.

Definition 3 (Storage Cost): The storage cost Cs of a location service is the number of location records a node needs to store as a location server

TABLE 1. *NOTATIONS*

The main assumptions used in this analyze is that the node density is constant, Nodes move according to a simplified random way-point mobility model and traffic pattern is either uniform traffic or localized traffic. To study the impact of different traffic patterns on scalability of location services, we use the introduced notations in [2]. For i=0, ..., H, we denote P_i as the probability that node B (the querying node) and A (the node being queried) are co-located in the same level-i square. It uses P_i^u and P_i^l to represent P_i under uniform and localized traffic patterns, respectively. Based on the size of the level-i squares of a node, P_i^u can be easily obtained as follows for grid [2],[11],

$$P_i^u = \begin{cases} \frac{3}{4^{H-1}} & if \quad 1 \leq i \leq H \\ \frac{1}{4^h} & if \quad i = 0 \end{cases}$$

And for our scheme TGrid,

C_m	location maintenance cost
C_q	location query cost
Cs	storage cost
v	node speed
Z	average progress of each forwarding hop
$\rangle_i$	level-i square boundary crossing rate
d^u	distance traveled by an update packet
d^q	Distance traveled by a query packet
n^u	number of forwarding hops of a query packet
n^q	perimeter refreshing rate
$\lfloor$	Distance threshold in perimeter refresh
K	prob. querying nodes in level-i square (uniform traffic)
P_i^u	prob. querying nodes in level-i square (localized traffic)
P_i^l	constant of random distance between squares
C_3	

$$P_i^u = \begin{cases} \frac{8}{9^{H-1}} & if \quad 1 \le i \le H \\ \frac{1}{9^h} & if \quad i = 0 \end{cases}$$

For simplicity of analysis, it considers a specific localized traffic pattern in which the probability P_i^l decreases exponentially in larger and level-i squares. Formally [2],[11],

$$P_i^l = \frac{1}{2} P_{i-1}^l, for 1 \le i \le H$$

For our scheme we define

$$P_i^l = \frac{1}{3} P_{i-1}^l, for 1 \le i \le H$$

Given that $\sum_0^H P_i^l = 1$ [2],

$$P_i^l = \frac{1}{2^{i+1}} \cdot \frac{1}{1 - \frac{1}{2^{H-1}}}, for 0 \le i \le H$$

and for our scheme,

$$P_i^l = \frac{1}{3^{i+1}} \cdot \frac{1}{1 - \frac{1}{3^{H-1}}}, for 0 \le i \le H$$

For all the schemes, the location update cost is directly related to the boundary crossing rate of a moving node. A node A generates a location update packet when it crosses some square boundaries. The following Lemma gives the boundary crossing rate.

Lemma 1 (Boundary Crossing Rate): The square boundary crossing rate of a node A is

$$\rho_0 \approx \frac{\pi v}{2R}$$

where v is the moving speed of the node A, and R is the side length of a level-0 square. The proof for this lemma is given in [2]

The boundary crossing rate ρ_i for a level-i square in multilevel hierarchical structure is

$$\rho_i \approx \rho_0 \cdot \frac{1}{2^i}, for \quad 0 \le i \le H-1$$

and for our scheme

$$\rho_i \approx \rho_0 \cdot \frac{1}{3^i}, for \quad 0 \le i \le H-1$$

5 Theoretical analysis of schemes

In this section, we employ a common theoretical framework to analyze the scalability of the 2 schemes described in section 2 and 3. We are interested in how well these schemes scale as the size of the network, denoted by the number of nodes N, increases, and the moving speed of a node, denoted as v, increases under different traffic patterns.

5.1 GLS

Assuming nodes are relatively static during the lifetime of a packet, the GLS scheme guarantees that in i steps, the location server will be reached, where i is the level of the minimal common square A and B are co-located. The following theorem about GLS is proved in [2],[12].

Theorem 1:

For GLS, location maintenance cost $E(C_m)$, location query cost $E(C_q)$ and storage cost $E(C_s)$ are:

$$E(C_m) = O(v\sqrt{N})$$

$$E(C_q) = \begin{cases} O(\sqrt{N} & for \quad uniform \quad traffic \quad pattern \\ O(\log N) & for \quad localized \quad traffic \quad pattern \end{cases}$$

$$E(C_s) = O(\log N)$$

5.2 TGrid

The TGrid scheme uses a multilevel hierarchical structure as Grid. Each node selects a home zone in level-i squares for i>0. There are some major differences between TGrid and GLS. GLS stores the exact location information on every location server. Therefore, to ensure the location information being up-to-date and to reduce the query failure rate, all location servers of a node need to be updated periodically. In TGrid when a node B intends to find the location of A, it sends a query packet towards a node in its level 1 home zone called h1. Either h1 knows the exact (relative) location of A or not. If the first case happens, h1 sends back the exact location of A to B or it forwards query to another home zone near the exact location of A. Otherwise it sends up the request toward the center of the whole region. Since the square in the middle of whole region knows all nodes relative addresses so assuming nodes are relatively static during the lifetime of a packet, in the worst case TGrid guarantees that we can find the location of the node in 2H hops where H is the level-number of the highest level.

Now we prove the following theorem about TGrid.

Theorem 2: location maintenance cost $E(C_m)$, location query cost $E(C_q)$ and storage cost $E(C_s)$ of Tgrid are:

$$E(C_m) = O(v.\log\sqrt[3]{N})$$

$$E(C_q) = \begin{Bmatrix} O(\sqrt[3]{N}) & \text{for uniform traffic pattern} \\ O(\log\sqrt[3]{N}) & \text{for localized traffic pattern} \end{Bmatrix}$$

$$E(C_s) = O(\log\sqrt[3]{N})$$

Proof: For the location maintenance cost metric C_m, Consider the expected distances the update packets travels to update the locations servers at the level-i square, denoted $E(d_i^u)$. We have

$$E(d_i^u) = c_3.3^i R$$

Where $3^i R$ is the side length of a square at level-i and c_3 is constant factor representing the average random distance between two points in two neighboring squares. Since updates are sent out at a rate of ρ we have

$$E(C_{m1}) = \sum_{i=0}^{H} \rho_i.E(n_i^u)$$
$$= \frac{\pi v c_3 H}{3z} \propto v.H$$
$$A \propto N, H \propto \log\sqrt[3]{N}, E(C_{m1}) = O(v.\log\sqrt[3]{N})$$

For $E(C_{m2})$, let λ be the perimeter refresh rate. The number of nodes around the perimeter is bounded by $\frac{\pi k^2}{\gamma}$, where k is the distance threshold. Since there are H + 1 location server zone which need to be refreshed

$$E(C_{m2}) = (H+1)\lambda.\frac{\pi k^2}{\gamma} = O(\log\sqrt[3]{N})$$

so

$$E(C_m) = E(C_{m1}) + E(C_{m2}) = O(v.\log\sqrt[3]{N})$$

Next we consider the location query cost C_q. Based on the location query procedure described above, the expected location query cost when A and B are co-located in a level-i square is

$$E(n_i^q) = \sum_{j=0}^{i} \frac{E(d_j^u)}{z} + \sum_{j=i}^{1} \frac{E(d_j^u)}{z}$$
$$= 2\sum_{j=0}^{i} \frac{c_3.3^j R}{z} - \frac{c_3.R}{z}$$
$$= (3^{i+2} - 3)c_3.\frac{R}{z}$$

For the uniform traffic pattern,

$$E(C_q) = \sum_{i=0}^{H} E(n_i^q).P_i^u$$
$$\approx \sum_{i=0}^{H} (3^{i+2} - 3).c_3 - \frac{R}{z}.\frac{8}{9^{H-i}}$$
$$\approx 3^{H+1}.c_3.\frac{R}{z}$$
$$= O(\sqrt[3]{N})$$

And for the localized traffic pattern,

$$E(C_q) = \sum_{i=0}^{H} E(n_i^q).P_i^l$$
$$\approx \sum_{i=0}^{H} (3^{i+2} - 3).c_3 - \frac{R}{z}.\frac{8}{3^{i+1}}.\frac{1}{1 - \frac{1}{3^{H-1}}}$$
$$\approx 3.c_3.\frac{R}{z}.H$$
$$= O(\log\sqrt[3]{N})$$

Finally, the storage cost is,

$$E(C_s) = \frac{N.(H+1).\frac{\pi k^2}{\gamma}}{N}$$
$$= O(\log\sqrt[3]{N})$$

The results show that our different design choices can affect the scalability of our location service, and in turn the overall scalability of location-based routing.

6 Performance Studies

We implemented the TGRID protocol as well as HGRID [7] in Glomosim [8],[13] as separate location management layers that operate in conjunction with IP. Location table and neighbor table are two Main data structures in the location management layer. If the location of the destination is unknown, Data from transport layer is queued in a buffer and a location query is sent to the destination's location server. Packet lifetime in the buffer is 4 seconds. Periodic broadcast protocol enables each node to realize its local connectivity, and records it in the neighbor table to assist in geographic routing. MFR[9] without backward progression, in which packets are dropped if no forward progress can be made, was implemented as the geographic routing algorithm. The first study fixed the simulation area to be 6750× 6750 km2 and the average node speed to be 5 m/sec while varying the total number of nodes in the network. In the second study simulation area was fixed to 2250 × 2250 km2 consisting of 320 nodes by varying the average node speed. Specific parameters for our simulations are listed in table I.

***TABLE 2** SIMULATION PARAMETERS*

Parameters	Scenario I	Scenario II
Simulation Time	300 s	300 s
Simulation Area	6750×6750 m^2	2250×2250 m^2
Unit Grid Size	250 m/s	250 m/s
Number of Nodes	720 – 2280	320
Transmission Range	350m	350m
Transmission Speed	54 m/s	54 m/s
MAC Protocol	IEEE 802.11	IEEE 802.11
Mobility Model	Random Waypoint	Random Waypoint
Maximum Speed	10 m/s	0-25 m/s
CBR Rate	1 Packet	2 Packet/s

Pause Time	0	0
Traffic Pattern	Random	Random
Buffer Size	1000 packets	1000 packets
Data Payload	512 bits	512 bits
CBR connections	1000	160

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To test the efficiency of the protocols for location discovery as well as efficient delivery of data, we initialized 1000 CBR connections, where the source and destination nodes are chosen randomly for all the scenarios. Each connection sends one data packet, randomly starts after 150 seconds into the simulation and terminates randomly at 250 seconds into the simulation.

6.1 simulation results

Figures 4 and 5 indicate the fraction of data packets successfully delivered by each protocol and the query success ratio. TGRID performs almost better than HGRID but in most of cases both protocol performs the same.

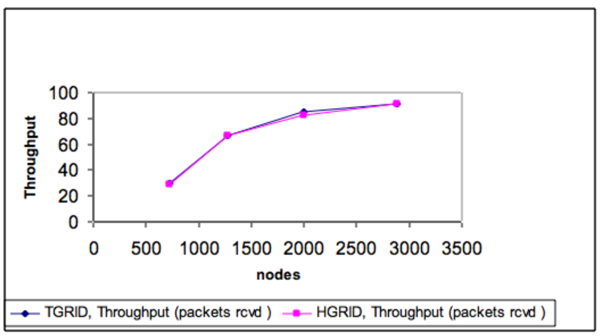

Fig.4 *Data Throughput*

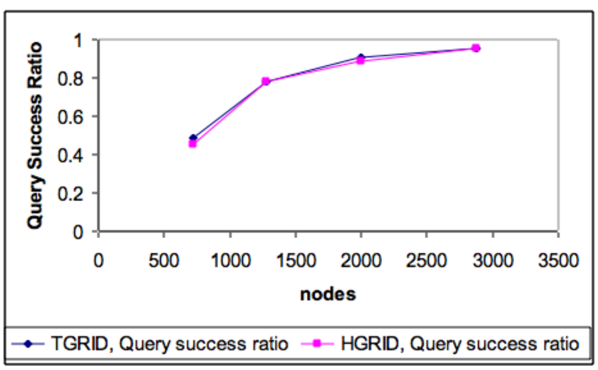

Fig.5 *Query Success Ratio*

Figure 6 and 7 shows the average control overhead for both protocols. However for both protocols the update overhead increases only logarithmically with the number of nodes, TGRID has less control overhead than HGRID. As shown in figure 6 with the packet overhead being nearly equal for both protocols, the average number of bytes being transmitted is more for HGRID (figure 7).

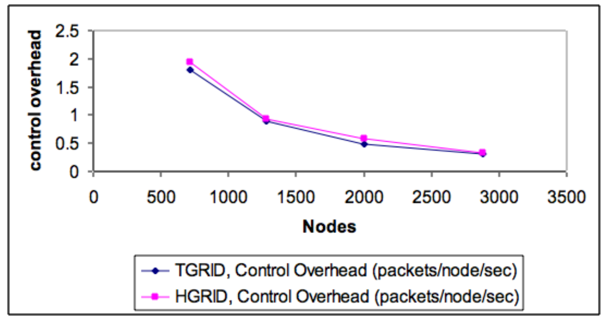

Fig .6 *Control Overhead*

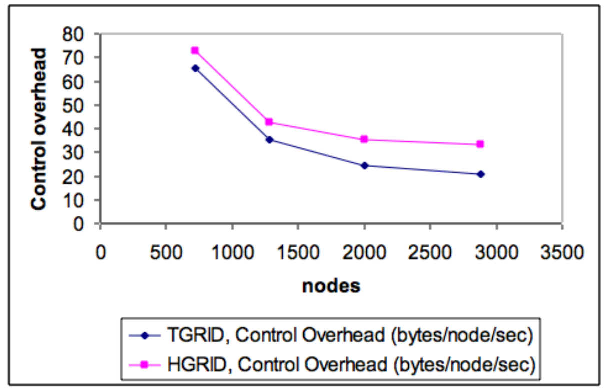

Fig.7 *Control Overhead*

Finally, figure 8 shows the increase in location database size of both protocols with increase in number of nodes. TGRID has less memory requirements than HGRID, since number of location databases are less. However, in both protocols the average of database size grows only slightly with the increase in network size and both protocols are scalable.

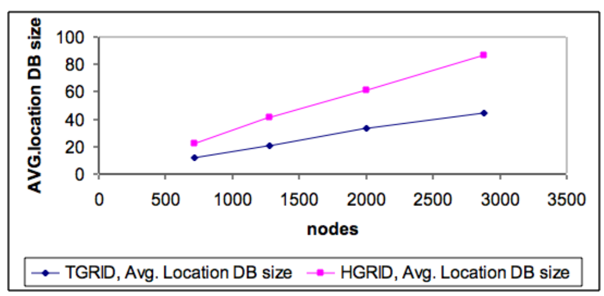

Fig.8 *Location Database Size*

Previous figures show the effect of node density on location management and how different location management protocols affect the performance of geographic routing. We also considered the effect of mobility on performance of the network and varied the maximum speed in the Random Waypoint model to change the average mobility of the nodes. An increase in mobility is proportional to the rate at which nodes cross grid boundaries and new updates sent out to location servers. Each plot point presented here is an average of seven simulation runs.

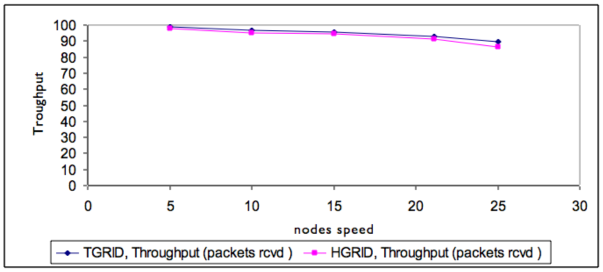

Fig.9 *Throughput*

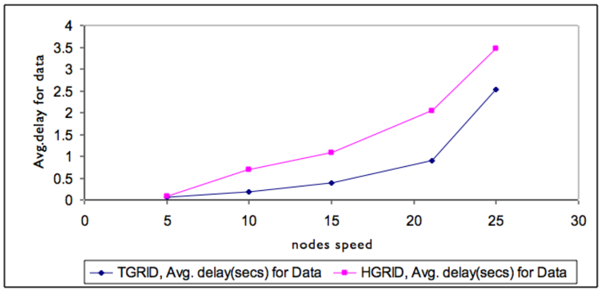

Fig.10 *Delay*

Figures 9 and 10 show the average data throughput and delay achieved by each protocol. Throughput decreases with mobility for both protocols, with TGRID being affected almost more by mobility. Packet delay increases with mobility. HGRID performs worse than TGRID, indicating that network congestion due to mobility causes network under–performance.

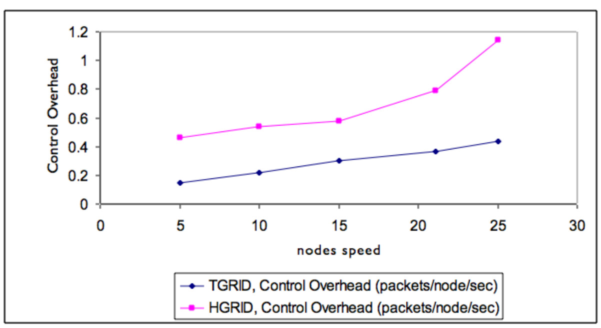

Fig.11 Control Overhead

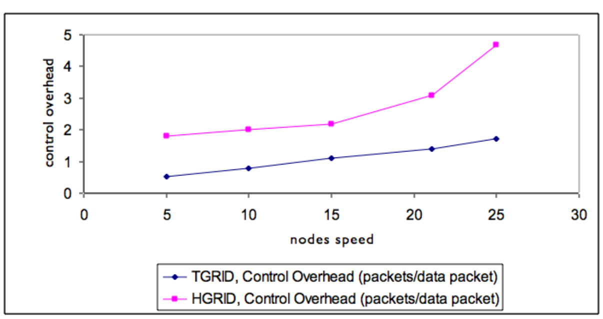

Fig.12 Control Overhead

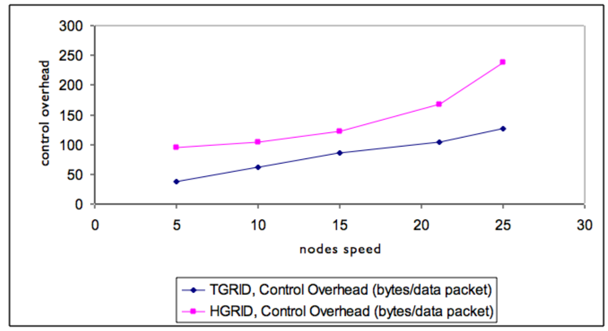

Fig. 13 *Control Overhead*

In HGRID, when a node moves in highest level boundaries, it makes more updates than TGRID, so highest server grids become points of congestion and thus the bottleneck in performance as indicated by the increase in data delay with increased mobility. Figure 14 shows the probability that a query for a destination returned successfully in TGRID is more than HGRID.

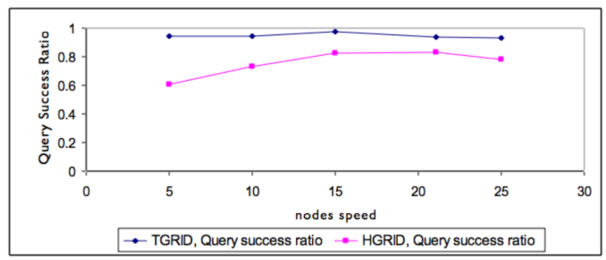

Fig.14 Query Success Ratio

7 CONCLUSIONS AND FUTURE WORKS

We have presented TGrid as a new location service scheme for mobile ad-hoc networks. We used tree metrics to compare scalability of our new scheme versus the best known scheme GLS. We used a uniform theoretical framework developed in [2] to compare the scalability of the two schemes. Our analysis shows that TGrid outperforms GLS in terms of location maintenance cost, location query Cost, and location storage cost. We have presented that query costs in both schemes are reduced in localized traffic pattern which is not surprising. But this shows the advantage of our scheme. In TGrid scheme the node that is located near the middle of the whole region has the least update and query cost, and the nodes in the middle square know the relative location of any other nodes in the network. It requires large storage in middle nodes but it can be solved by just taking 2 bits for each node and hash each node's ID to the stored table that each row just have 2 bits. These 2 bits show the next higher level location server, and must select one of the 4 location server zones that are around. In terms of the total overheads, TGrid overcomes GLS in both traffic patterns. We summarize the three performance metrics of the 3 location service schemes in Table II. TGrid Location Service scales better than Grid Location Service and HIGH-GRAGE location service scheme with respect to node density, speed and size of the area. We bring High Grade location service scheme results in Table II, because it's more similar to our scheme than GLS due to the use of multi grained location information. In High Grade, each node has one set of location servers in each level-i and only level-0 location servers store the exact location of A. You can find details about this algorithm in [2]. Finally, we point out that if nodes distributed normally, TGrid performs in its best case. The research about the TGrid Location Service is by far not complete. The location service in its base version needs to be studied further by simulating it under different scenarios.

TABLE 3 *COMPARISON OF THREE SCALABILITY METRICS FOR THREE LOCATION SERVICE SCHEMES*

	GLS	**High Grade**	**TGrid**
Location maintenance cost	$O(v\sqrt{N})$	$O(v.\log N)$	$O(v.\log\sqrt[3]{N})$
Location query cost	$O(\sqrt{N})$ (uniform) $O(\log N)$ (localized)	$O(\sqrt{N})$ (uniform) $O(\log N)$ (localized)	$O(\sqrt[3]{N})$ (uniform) $O(\log\sqrt[3]{N})$ (localized)
Storage cost	$O(\log N)$	$O(\log N)$	$O(\log\sqrt[3]{N})$

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