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GrLS: Group-based Location Service in Mobile Ad Hoc Networks

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Abstract: In this paper, we propose a group-based location service (GrLS) for mobile ad hoc networks (MANETs). The novelty of GrLS is in its exploitation of group mobility to improve the protocol efficiency. As an important mobility scenario, group mobility has many popular applications. GrLS provides different location management strategies for individual nodes and groups of nodes. An individual node recruits its own location servers and updates its location to them. On the other hand, in a set of nodes with group mobility, only the group leader recruits location servers and updates its location to a specific home region called group home region. Other members of the group are waived from performing network-wide location updates. Since the location update cost normally dominates other costs for all practical purposes, the overhead of location service is significantly reduced. Simulation results also show that GrLS can achieve higher location query success ratio with much lower overhead than existing protocols that do not consider group mobility.

Keywords: geographic routing, location service, group mobility, mobile ad hoc networks

1 Introduction

Recently, geographic routing has attracted a lot of interest in the research community. A challenging problem in geographic routing is how a source node can obtain the location of the destination. Clearly, it needs the support of location service. Numerous protocols for location service have been proposed, including VPDS [1], GHLS [3], GLS [5], DLM [8], and HLS [9]. They can be divided into flooding-based and rendezvous-based approaches. Generally, a rendezvous-based location service protocol works as follows. First, each mobile node recruits at least one other node as its location server. Then, whenever necessary, a mobile node will send location updates to its location servers to update its location. Once a source node wants to send messages to another node, if the location of the destination is unknown, it will send a location query to the location servers of the destination. At least one of the location servers should receive the location query and send the location reply to the source.

In recent years, group mobility [4], where mobile nodes are organized into groups to coordinate their movement, has emerged from the demand of applications where a team of users with mobile devices work together. In each group, all the group members stay closely and move together in accordance with the same mobility pattern. Since a group of nodes always move as a whole and have the similar location tracks, group mobility can be further exploited to improve the efficiency of location management. This motivates our research reported in this paper.

We propose a novel location service protocol, named GrLS. To our knowledge, it is the first location service protocol which has exploited group mobility. GrLS consists of two components: individual location management and group location management. In the protocol, the network coverage area is partitioned into equal circle-shaped regions, which are selected as home regions by nodes. For each node with individual mobility, it sends location updates to the location servers in its home region and the location server handles all the location queries for it. For nodes with group mobility, group location management is designed, which consists of micro and macro group location management. With micro group location management, each group member is aware of the locations of all other group members. With macro group location management, a designated group leader updates its location to the location servers in a specified group home region and replies all the location queries for other group members in its group. Thus, the overhead of location updates to the home regions can be saved for all the other group members.

The major contributions of this paper are listed as follows:

- A network center originated partition method is proposed to allocate the home regions for mobile nodes.
- A novel strategy of recruiting location servers for both individual nodes and group leaders is proposed.
- An effective and efficient group location management strategy is proposed.

The rest of the paper is organized as follows. Section 2 presents the design of GrLS. In Section 3, we describe the performance evaluation for GrLS and discuss the results and observations. Finally, Section 4 concludes the paper.

2 GrLS: A Group-based Location Service

Without loss of generality, we assume that all the mobile nodes are aware of their own locations and have the same radio transmission range. There are two kinds of nodes in the network: individual nodes and group nodes. An individual node moves according to its own mobility pattern. A group node has joined a group and moved according to the specified group mobility pattern. In a group, one node is the group leader and all other nodes are group members.

2.1 Geographic Area Partitioning

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The partition begins from the network center and spreads outward, as shown in Fig. 1. The area is partitioned into equal circle-shaped regions. In Fig. 1, as the dotted lines show, each circle contains a hexagon with the side length equal to the radius of the circle. These hexagons are non-overlapping but can completely cover the entire network. Each circle has six neighbour circles because a hexagon has six sides. We denote the radius of the circle as *R*, $R=\sqrt{7}/2\,r$, where *r* is the radio transmission range of mobile nodes. Thus, there is a central circle-shaped region centered at the network center and many other circle-shaped regions spread around the central region symmetrically in the network. All the regions have unique region IDs.

At startup, all nodes know the network center and the partition method. Thus, based on its location, each node can calculate the region which it is staying in. We assume that there exists a publicly known hash function that maps a node's ID to a specific region (called its home region),

$$\boldsymbol{F}(\text{Node ID}) \rightarrow \text{Region ID},$$

F is a many-to-one mapping.

The central circle-shaped region is selected as the group home region by all the group leaders. Each group leader recruits both location servers and ID servers in the group home region. All the other circle-shaped regions are selected as home regions by individual nodes. Each individual node recruits location servers in its home region. All the home regions spread around the network center, which can alleviate the drawback of flat hashing-based protocols, i.e., location servers in a home region can potentially be far away from both the source and destination nodes.

2.2 Recruiting Location Servers

A mobile node needs to determine which nodes in the home region can act as its location servers. In [1], a node functions as a location server at a probability. Clearly, it will lead to uncertainty and generate high searching overhead.

We propose a strategy, which allows us evenly distribute the load of providing location services across all the nodes in the home region. As shown in Fig. 2, we further partition a circle-shaped home region into seven circle-shaped subregions labeled by 0 to 6. A node will recruit one location server in each subregion of its home region. Each subregion is a small circle with a radius of 0.5*r*. The overlapping area of two neighboring subregions is assigned to the one with smaller subregion ID. A node can send messages to all other nodes in the same subregion. The messages may be received by nodes in neighboring subregions. Clearly, a node knows all its neighbours in the same subregion through beaconing. This is just the reason why we partition the network into circle-shaped regions with radius of $\sqrt{7}/2\,r$.

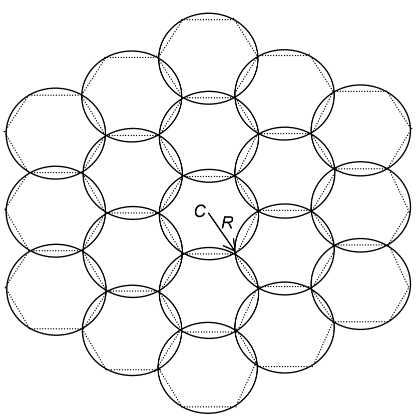

Fig. 1. Illustration of the network coverage area partition.

As above mentioned, the location servers of a node *A* will be evenly distributed in its home region. To further balance the load among the nodes in the same subregion, node *A* will recruit the node whose ID is the closest to its own ID as its location server. Hence, different nodes may recruit different location servers in the same subregion. Overall, the responsibilities of acting as location servers are evenly shared among all the nodes in a subregion. As a result, our strategy of recruiting location servers is scalable and load balanced.

2.3 Basic Location Management in GrLS

2.3.1 Adaptive Location Update

In GrLS, we adopt an adaptive location update scheme, which combines the advantages of both time-based and distance-based schemes. Initially, we set the minimum and maximum location update intervals and define the distance threshold of location update. If the distance the node has moved since last update reaches the threshold value, but the time has not exceeded the minimum location update interval, the node will not send any location update; if the time is between the minimum and the maximum interval, location update will be sent out. On the other hand, if the maximum location update interval is reached, but the distance the node has moved is less than the threshold value, the node will trigger the location update immediately. For the distance threshold of location update, according to [6], it can be approximately set as half of the radio transmission range of mobile nodes.

2.3.2 Location Query

If a source node *s* wants to query the location of a destination *d*, it will first query its own location database. If *d*'s location can be found, there is no need to trigger a location query. Otherwise, *s* sends a location query message to *d*'s home region. Since *s* knows the hash function, *d*'s ID and the network center, *s* can easily calculate the location of the center of *d*'s home region, which is just the destination of the location query message. The location query message also carries *s*'s location, which is useful when a location server sends a location reply to *s*. Since *d* may be an individual node or a group node (group member or leader), different location query strategies are proposed. Here, we describe the location query for individual nodes. The strategy

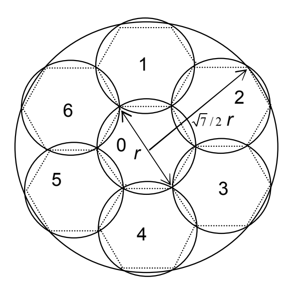

Fig. 2. The division of a home region.

for querying group nodes will be described in Section 2.4.2.

For an individual node *d*, the query for its location will be firstly received by a node in one subregion of *d*'s home region. The node then acts as a proxy in this subregion. By *d*'s ID, which is carried in the location query message, the proxy can easily determine which node is the desired location server of *d*. Then the proxy directly forwards the location query message to *d*'s location server in this subregion. Upon receiving the location query, the location server sends a location reply message to the source *s* through geographic forwarding.

2.4 Group Location Management in GrLS

The group location management consists of two parts: micro group location management which helps each member acquire the locations of all other members in the same group, and macro group location management in which only group leader updates its location to location servers and answers the location query for any node in the group.

2.4.1 Micro Group Location Management

a) Group Initialization

Once a group leader is determined, it broadcasts its ID and location information to all the group members. Then each group member is aware of its group leader. Upon receiving the announcement of the group leader, each group member makes a reply by sending its own ID and location information to the group leader. When the group leader has collected the information from all the group members, it generates a GroupView message containing both ID and location information of all the group members. The GroupView message is then broadcast to all the group members. Once a group member receives the GroupView message, it can maintain a consistent view about the group and know the locations of any other group member. Then the group initialization is completed.

b) Group Maintenance

We define a new concept- group relative location. In addition to the actual location, each group member also has a group relative location, which is the relative location of its actual location to the actual location of the group leader. Clearly, the group relative location of the group leader itself is (0, 0). Each group member periodically calculates its group relative location. Once the distance change with respect to its group relative location has reached a predefined threshold, the group member will send a location update to the group leader. In addition, when the maximum location update interval is reached, the group member also needs to send a location update to the group leader immediately.

If a group member has not updated its location for a predefined time period (i.e., the location expires), the group leader will think it has left the group and then remove its ID and location information from the database. When the group leader finds that the number of group members, whose locations have changed or expired, has reached a certain percent of the group size, it broadcasts a GroupViewChange message to all the other group members to refresh the group view. The group leader also broadcasts its own location update to all the group members, but based on the distance change of its actual location.

2.4.2 Macro Group Location Management

a) Group Home Region

In GrLS, all the group leaders share the same group home region, i.e., the central circle-shaped region. Similar to other home regions, the group home region is also divided into seven circle-shaped subregions with subregion ID ranging from 0 to 6. , In each subregion of the group home region, each group leader recruits one location server, which has the closest ID to its own ID. We let all the group leaders recruit location servers in the central region. The number of group leaders is exactly the same as the number of groups, which is intuitively small. Thus the nodes within the central region will not be overloaded. Even when we want to further reduce the load in the group home region, we can scale it to the central region plus its six neighboring regions.

b) Reactive ID Update

In each subregion of the group home region, the node with the least ID is recruited as ID server by all the group leaders. Totally, there are seven ID servers in the group home region. ID server is used for group membership management. It stores the group membership information of each group, i.e., the IDs of both group leader and all the group members.

ID update, a new type of update message, is created to update the group membership information stored in the ID server. An ID update message is generated on-demand by the group leader when a new node joins the group or a group member leaves the group. Since most groups are formed by nodes purposely, group membership does not change drastically. Hence, ID update is triggered much less than location update. The overhead incurred by ID updates is also much lower than location updates.

c) Query for Group Nodes

If *d* is a group member, its original location servers have been disabled. However, the source *s* does not know this due to distributed location service. So the location query message will still be sent to the original home region of *d*. When an original location server of *d* receives this message, it finds that the location information of *d* has been disabled. It then forwards the message toward the group home region, where the network center is the destination. Once the location query is received by a node in a subregion of the group home region, the node acts as a proxy. Since an ID server exists in each subregion, the proxy sends an ID query message to the ID server requesting the ID of *d*'s group leader. The ID server sends the requested group leader ID back to the proxy by an ID reply message. Then according to the strategy of recruiting location servers, the proxy can determine which node is the desired location server of *d*'s group leader. Then it forwards the location query message to the desired location server, which continuously forwards the message to *d*'s group leader. When *d*'s group leader receives the location query message for *d*, it sends a location reply to the source *s* directly.

If *d* is a group leader, the location query procedure is the same as other group members before the location query message arrives at one of the desired location server of *d*.

When the location server finds that it has the knowledge of *d*'s location, it directly sends a location reply to the source *s*.

No matter for individual nodes or group nodes, neither broadcasting nor flooding is used in our location query procedures. Even local flooding is unnecessary.

3 Performance Evaluation

To study the performance of GrLS, we implement it as well as geographic forwarding in the GloMoSim 2.03 [10]. For comparison purpose, we have also migrated GLS into it. Geographic forwarding adopts GPSR [7]. We use 802.11 MAC protocol with DCF and a transmission range of 250m. The network coverage area is a square of 3km x 3km, which can be partitioned into 19 full circle-shaped regions as shown in Fig. 1. In the mobility scenarios, individual nodes follow the random waypoint mobility model, where each node moves at a constant speed chosen randomly between the predefined minimum and maximum speeds. Both the minimum and maximum speeds have different values in different simulation scenarios. For group mobility, we use the RVGM model [4], where different group velocities are assigned for different groups. As mentioned in Section 2.3.1, the predefined update threshold is fixed at 125m, half of the transmission range. The minimum update interval is set to be 12.5 seconds, which is the approximate result of the update threshold divided by the average node speed (125m/10ms^{-1}). The simulation duration is 900 seconds. All these important simulation parameters are listed in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Simulation Time	900 sec
Simulation Area	3km x 3km
Transmission Range	250m
Speed Range	0 – 20ms^{-1}
MAC Protocol	IEEE 802.11
Mobility Model	Random Waypoint, RVGM
Update Threshold	125m
Minimum Update Interval	12.5 sec
Maximum Update Interval	40 sec

We assume two types of network models: quasi-static ad hoc networks and mobile ad hoc networks. In the mobility model followed by quasi-static ad hoc networks, the pause time is set to be 30 seconds and the minimum and maximum node speeds are respectively set to be 0 ms^{-1} and 5 ms^{-1}. Quasi-static ad hoc networks simulate networks where nodes stay stationary or move slowly. In the mobility model followed by mobile ad hoc networks, the pause time is 0 seconds and the minimum and maximum node speeds are respectively set to be 5 ms^{-1} and 20 ms^{-1}. We evaluate GrLS in four ad hoc network scenarios: a 450-node quasi-static, a 450-node mobile, a 900-node quasi-static, and a 900-node mobile ad hoc network.

3.1 LS Protocol Overhead

Here, we compare the LS protocol overhead of GLS [5], GrLS-, and GrLS. GrLS- represents GrLS without group location management, where all the nodes then need to send location update messages to their home regions even they have formed groups. In each of the four networks, every node initiates a location query to look up the location of a randomly chosen destination at times randomly distributed between 45 and 900 seconds. The first 45 seconds are used for nodes to send the initial location update messages to their location servers. When a node sends out a location query message, a location query timer is also set for this message. If no location reply is returned before the timer expires, the node does not re-send the location query. If a location reply is successfully received before the timer expires, the node sends a data packet of size 128 bytes to the destination using the replied location.

In each network, we count all the LS protocol messages for each location service protocol. The LS protocol messages of GrLS include location update, query, reply messages, ID update, query, reply messages, and both location and ID handoff messages. The LS protocol overhead is measured by the number of LS protocol messages transmitted, with each hop-wise transmission of the protocol message as one transmission. Then we evaluate the normalized LS protocol overhead (normalized by the number of LS protocol messages generated by GLS). Hence, the normalized LS protocol overhead of GLS is always 1.

Fig. 3 plots the normalized protocol overhead of all these three protocols. It shows that GLS always has the maximum overhead. In mobile networks, the gap between GLS and other two protocols is much larger than in static networks. GLS incurs high protocol overhead because it relies on node chain consisting of mobile nodes to update and query location information. Both GrLS- and GrLS rely on home regions with fixed locations to update and query location information. Hence, they are more robust to node mobility. In addition, only one location update message needs to be sent to its home region per location update and at most seven location servers need to be updated within the home region. So both GrLS- and GrLS generate lower protocol overhead than GLS.

Compared with GrLS-, the protocol overhead of GrLS is reduced significantly. This is because the nodes which have formed groups except the group leaders do not need to send location update messages to their home regions in GrLS. ID update, query, and reply are firstly introduced by GrLS. Since we assume relatively stable groups, the reactive ID update rarely occurs. Both ID query and ID reply are triggered only when a location query message sent for a group member has reached the group home region. Moreover, both of them are just one-hop transmission. So these three new control messages account for a small portion of the LS protocol messages. In addition, we have proved that only one handoff message is needed each time a node leaves or enters one subregion. The amount of handoff messages also depends on the node mobility. Higher node mobility leads to more handoff messages. Hence, the amount of handoff messages stays roughly the same in both GrLS- and GrLS. So the saving of location update messages contributes to the

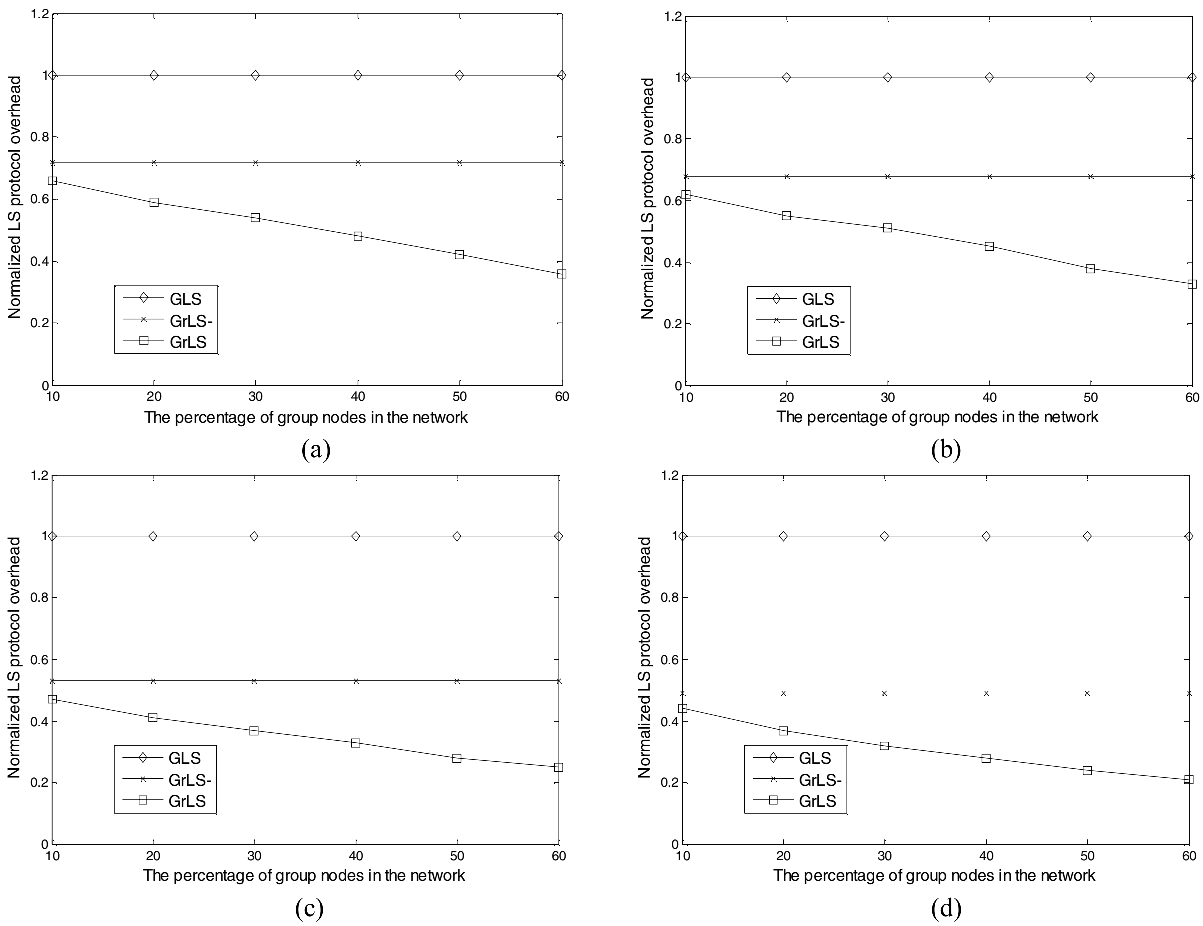

Fig. 3. Comparison of normalized LS overhead in: (a) 450 nodes quasi-static network, (b) 900 nodes quasi-static network, (c) 450 nodes mobile network, (d) 900 nodes mobile network.

reduction of protocol overhead of GrLS. As the percentage of group nodes increases in the network, more reductions in LS protocol overhead are achieved by GrLS.

3.2 Query Success Ratio

The objective of the location service is to help the source node get the location of a destination. Hence, an important metric to evaluate the location service protocol is the query success ratio. The query success ratio is the ratio of the number of location replies received by all the sources to the number of location queries initiated by all the sources. As stated in Section 3.1, each node initiates a location query to look up the location of a randomly chosen destination. If the location query fails, no retransmission is triggered. Here, we

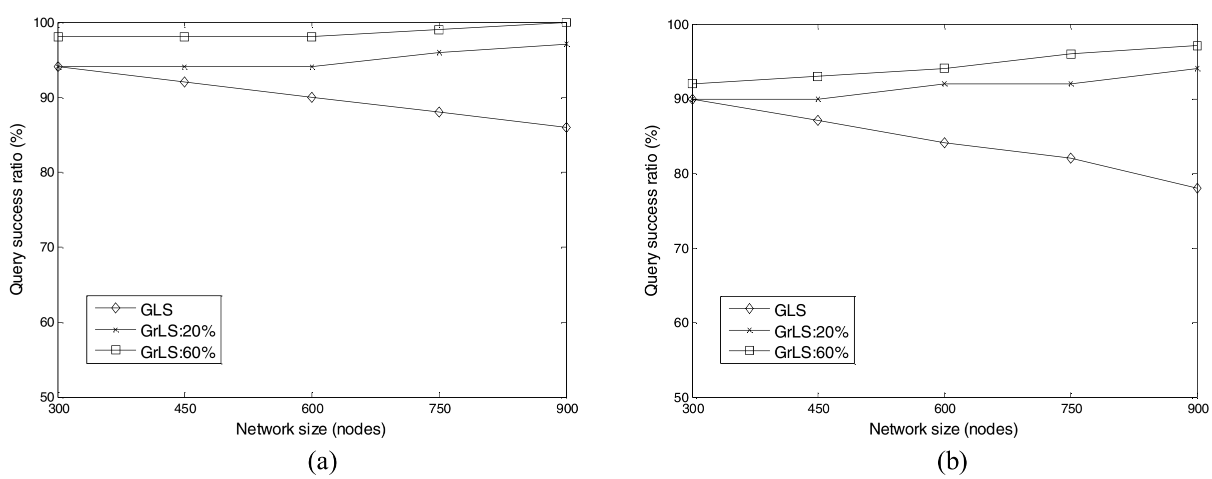

Fig. 4. Comparison of query success ratio in: (a) quasi-static networks, (b) mobile networks.

compare GrLS with GLS. To investigate the effect of group location management on GrLS, we choose two cases for evaluation: one is the percentage of group nodes is 20% in the network, and the other is 60%.

Fig. 4(a) and (b) depict the query success ratio as a function of the network size for GLS, GrLS with 20% group nodes, and GrLS with 60% group nodes. The difference between Fig. 4(a) and (b) is that the networks used in Fig. 4(a) are all quasi-static, but the networks used in Fig. 4(b) are all mobile. The results show that the query success ratio of GLS is always the lowest and drops quickly as the network size increases. Moreover, the query success ratio of GLS is much lower in the mobile networks than in the quasi-static networks. As we have explained in Section 3.1, GLS is the most susceptible to node mobility by relying on node chains. Furthermore, as the network size increases, the node chains for both location update and query become longer and weaker, which reduce the query success ratio and the location information accuracy.

With the network size increasing, the node density also becomes higher. In GrLS, more nodes can act as location servers in each home region due to high node density. Since the query success ratio is relatively high at 300 nodes for GrLS, it increases slowly when the network size goes beyond 300. In addition, as the percentage of group nodes increases from 20% to 60%, more source-destination pairs are within the same group. It increases the probability that the source node can get the location of the destination immediately, which also helps improve the query success ratio. By using group location management, GrLS has very good performance under traffic patterns with locality. Like other protocols, high node mobility also reduces the performance of GrLS as shown by the query success ratios in both Fig. 4(a) and (b).

4 Conclusions

GrLS is the first group-based location service protocol. By exploiting group mobility, GrLS provides group location management for nodes which have formed groups, thereby reducing the protocol overhead significantly. Moreover, GrLS supports seamless handoff between individual location management and group location management. Extensive simulations have been conducted to compare GrLS with GLS and GrLS-, which is GrLS without group location management. The results show that GrLS has decent load balance, low protocol overhead, and high query success ratio. The cost that GrLS pays for the performance improvement is that the average query hop length is a little larger than GrLS-. Even so, it is still smaller than GLS. A good location service protocol should be efficient, scalable, robust, load balanced, and locality aware. GrLS shows all these characteristics.

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