A Scalable and Reliable Multiple Home Regions based Location Service in Mobile Ad Hoc Networks

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Abstract. Compared with topology-based routing, location-based routing scales much better in large-scale mobile ad hoc networks. Location-based routing protocols assume that a location service is available to provide location information of each node in the network. Many location service protocols have been proposed in the literature. However, either they do not scale well in large-scale network environment, or they are not reliable if the network is highly dynamic. We propose a multiple home regions based location service protocol in large-scale mobile ad hoc networks. Theoretical analysis shows that the proposed protocol outperforms existing protocols in terms of both scalability and reliability.

Keywords. Mobile ad hoc networks, location service, location-based routing, scalability, reliability

1 Introduction

In recent years the widespread usage of wireless communication and handheld devices has stimulated research on self-organizing networks. Mobile Ad hoc NETworks (MANETs) are self-organizing, rapidly deployable and dynamically reconfigurable networks, which are formed by mobile nodes with no pre-existing and fixed infrastructure. Usually, these mobile nodes function as both hosts and routers at the same time. Two mobile nodes communicate directly if they are within the radio transmission range of each other; otherwise, they reach each other via a multi-hop route. Some typical applications in MANETs include communication in battlefield and disaster relief scenarios, video conferencing and multi-party gaming in conference room or classroom settings.

To route packets is one of the fundamental tasks in MANETs, but it is very challenging because of the highly dynamic topology of the network triggered by node mobility. There are two different approaches to route packets in such a network environment, namely, topology-based routing and location-based routing [1]. Topology-based routing protocols use the information about the communication links that are available in the network to perform packet forwarding. Due to node mobility, topology-based routing protocols can not scale well in large-scale MANETs. In location-based routing, however, each node determines its own location information through the use of Global Positioning System (GPS) or some other type of positioning service. A location service, also known as mobility tracking or mobility management, is used by the sender of a packet to determine the location of the destination and to encapsulate it in the header of the packet. The routing decision at each forwarding node is then based on the locations of both the forwarding node's neighbors and the destination node. In this way, the location-based routing does not need to maintain routing tables as topology-based routing does. Therefore, location-based routing can scale quite well in large-scale MANETs [2] [3]. One of the main challenges of a location-based routing protocol is how to get the location information of a packet's destination when needed. Most of these protocols have a location service responsible for accomplishing this task. When a node does not know the location of its correspondent node, it requests the location information from a location service. Generally speaking, each node determines its own location information through the use of GPS or other techniques for finding relative coordinates based on signal strengths [4]. Since it is not necessary to maintain explicit routes in such protocols, location-based routing can scale well in large-scale MANETs even if the network is highly dynamic. This is a major advantage in MANETs where the topological change may occur frequently due to node mobility.

The rest of this paper is organized as follows. Section 2 introduces some related works. Section 3 presents our location service, which is used to update, maintain and query the location information of mobile nodes. Section 4 analyzes the scalability and reliability of the proposed protocol. Finally, we conclude this paper in Section 5.

2 Related Works

Location service is essential for designing location-based routing protocols in large-scale MANETs. Many location service protocols for MANETs have been proposed in the literature as follows.

Distance Routing Effect Algorithm for Mobility (DREAM) [5] is highly reliable and it provides localized information. The search of location of a destination requires only a simple local lookup. However, as the location information is periodically flooded into the whole network, the communication complexity is very large. DREAM thus has poor scalability and is inappropriate for large-scale MANETs.

Quorum-based approach is proposed in [6]. The key merit is the distribution of responsibility among quorums. But the quorum system has a major drawback in that it depends on a non-location-based routing protocol to maintain the integrity of the databases of the entire quorum, the implementation complexity of which is very high in MANETs. In particular, this drawback may greatly reduce the scalability.

To solve the scalability problem, the home-region based location service is proposed. In such a scheme, nodes within some geographical areas maintain the location information of other nodes which have made that area as their home region.

Similar to the Mobile-IP scheme [7], home-agent based location service (HALS) is proposed in [8]. This scheme eliminates the quorum system's major drawback. However, such a scheme is also not perfect due to the following reasons. (1) Since nodes can be hashed to any arbitrarily distant region, it may result in increased communication complexity. (2) Since nodes only store location information in the nodes that are in the home agent region, if all the nodes in a home agent region which store a particular node's location information failed or left the home agent region, then the other nodes can not obtain this node's location information. That is, such a scheme is not reliable when a home agent region becomes empty due to the fact that all the nodes in the region become faulty or move out of the region simultaneously.

To solve the problems mentioned above, another home-agent based location service called the SLURP protocol has been presented in [9]. Although SLURP handles the problem of empty home region, there are some disadvantages as follows. (1) If the distance between a source node and a destination node is very close, but the source is far away from the destination's home region, the communication complexity will be very high. (2) If a node moves out of a region and it happens to be the last node in the region, then it needs to inform all the eight neighboring regions, and the overhead of which is very high. (3) Even worse, if the last node that moves out of the region happens to become faulty, it will lose the location information which is stored in this region, thus resulting in reduced reliability. (4) There is an extreme case in MANETs that also results in reduced reliability. That is, if one region becomes empty, then the eight regions surrounding the empty region will also become empty. Such an extreme case will not occur too frequently, but it does occur sometimes. For example, a bombing in the battlefield may damage the region where it occurs, and it may also affect all its neighboring regions of the damaged region.

Although the two protocols mentioned above scale well, their reliability may not meet requirements of some applications due to the existence of empty home regions. To improve the reliability of a location service, the GRID Location Service (GLS) is proposed in [10]. GLS is a promising distributed location service. However, the behavior of GLS in a dynamic environment and in the presence of node failures is difficult to control. Moreover, its implementation complexity is very high.

The SLALoM protocol, presented in [11], is similar to GLS. It improves both the query efficiency and the reliability in the sense that the use of both the near and far home regions reduces update traffic. However, the update traffic is still too high due to the fact that so many home regions are used for each node.

In order to reduce the update traffic, especially for those nodes which are not being queried, the ADLS protocol [12] adopts an adaptive demand-driven approach. Although ADLS reduces the update traffic, it affects querying efficiency. Even worse, when the primary home region becomes empty, the location information stored in this region will be lost, resulting in the reliability problem like the SLURP protocol.

In order to maintain the location information, the GLS, SLALoM and ADLS protocols have to set a lot of home regions for each mobile node in the whole network. Generally speaking, they improve the reliability compared with the HALS and SLURP protocols, but their scalability is worse than the HALS and SLURP protocols because so many home regions are used. Moreover, these protocols are too complex to implement in the highly dynamic MANETs. In order to provide a scalable and reliable location service, we propose a new location service protocol with multiple home regions, which can be considered as a tradeoff between the home-agent based protocols such as HALS and SLURP, and the GRID-based protocols such as GLS, SLALoM, and ADLS.

3 Overview of the Proposed Protocol

We propose a scalable and reliable Multiple Home Regions based Location Service (MHRLS) protocol for location-based routing in large-scale MANETs. In MHRLS, multiple home regions are assigned to each node by mapping its node ID. And all the nodes located in these regions are responsible for maintaining the approximate location information of the node to be mapped. To send messages from a source node to a destination node, the source node first queries the current location information of the destination node by MHRLS. After getting the location information, the source node sends messages to the destination by some location-based routing protocol such as the MFR protocol [13]. In this section, we overview the proposed protocol from the following four aspects, namely, dividing the large network into small regions, assigning home regions to each mobile node, and the update, maintenance and querying of the location information when needed.

3.1 Dividing the Large Network into Small Regions

We assume that each node in MANETs is equipped with GPS to get its accurate location information. Though it brings in extra expenses, it gains more by using location information. Each node has a unique node ID. A large rectangular area is divided into small rectangular regions. Each small region is assigned a unique region ID. An example network which is divided into 6*6 small regions is shown in Figure 1. Each node in the network is aware of the information about how the network has been divided and which small region itself belongs to.

3.2 Assigning Home Regions to Each Mobile Node

Before a source node *S* sends messages to a destination node *D* using a location-based routing protocol, it has to get node *D*'s current location while the only information it knows about node *D* is its ID. To solve this problem, node *S* can either probe the information by flooding or querying some other nodes who know the location where node *D* is. Obviously, the querying scheme might be more efficient than the flooding scheme in most cases. For the querying scheme, node *D* needs to first designate some nodes, or called its location servers, and then update the location servers with its location information. In MHRLS, a hash function is used to map each node in the network to all the nodes which are located in multiple home regions as its location servers.

More specifically, the MHRLS protocol establishes *k* functions in advance, each of which can map the same node ID into a different region ID (*k* is set as a system parameter) as follows: $f_i(Node\ ID) \rightarrow Region\ ID_i$

All nodes within the node's *k* home regions should maintain the node's current location information dynamically. Take node *D* in Figure 1 as an example, its *k* home regions are region 8, region 17 and region 26 (here *k*=3).

In order to make the *k* home regions to be evenly distributed in the whole network, the function *f* needs to satisfy the following two properties:

1. Function *f* can evenly map the node ID into every region in the whole network, i.e., the probability of being a home region is the same for every region in the network.
2. Function *f* can be used in MANETs with various shapes and different coverage sizes, i.e., the function still works even when the network shape and size change.

3.3 Location Information Update

After a node moving out of the current region, it first gets its home regions by *k* functions ($f_i(ID), 0 \le i \le k-1$), then the location update message (including node ID and current region ID) is sent to the centers of these *k* home regions separately. We assume to use some routing strategy based on geographic location information such as MFR protocol [13] to forward such a message. If the node which received the update message is not in the destination home region, it will forward the message; otherwise, it will broadcast the message to the rest of nodes within the destination home region. Finally, each node has a copy of its current location information stored in all the nodes of the *k* home regions. Take node *D* in Figure 1 as an example, after moving from region 23 to region 29, it will send an update message including its node ID and region 29's region ID to region 8, region 17 and region 26, respectively.

3.4 Maintenance of the Location Information

When a node moves into a new region, the node sends a message to its neighbors requesting location information registered in this region. Any neighbor which has such location information generates a reply message to the node, and then the node uses the reply message to maintain its new location information for the new region.

3.5 Querying the Location Information

A source node computes home region IDs of a destination node and sends a query message for the destination node's location. The proposed MHRLS protocol provides two kinds of queries for the location information:

1. The source node queries all home regions of the destination node, and we call such a scheme Query-All. More specifically, the source node sends one copy of the query message to the center of each home region. The first node receiving the message in the home region sends a reply message (including ID of the region where the destination node currently locates). To prevent the source node from receiving *k* reply messages, the source node will simply discard the following reply messages associated with the same query message after receiving the first one. This scheme is easy to realize and has high reliability, but the communication overhead is relatively high.
2. The source node queries the nearest one of the *k* home regions of the destination node, which is called the Query-Nearest scheme, and sets a timeout at the same time. The first node receiving the query message in the destination region sends a reply message. If the source node does not receive any reply message after the

timeout period, it will send a query message to the nearest one out of the rest k-1 home regions of the destination node. This process continues until the source node receives a reply message. This scheme uses less query/reply messages compared with the Query-All scheme, and it is highly efficient if all the home regions are not empty and all the home regions are reachable from any node in the network at any time. However, if these conditions do not hold, the query efficiency may be degraded, and the reliability may be reduced too.

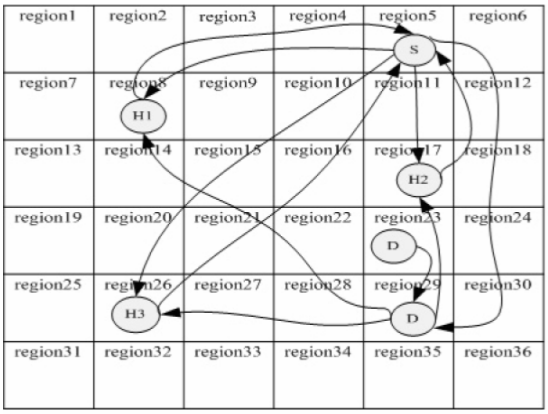

Figure 1. Location Service of MHRLS

4 Performance Analysis

In this section, we analyze the proposed MHRLS protocol in comparison with existing location service protocols in terms of scalability and reliability.

4.1 Scalability Analysis

We do the scalability analysis of our MHRLS protocol similar to the SLURP protocol in [9]. We define the scalability of a location service protocol as the cost to successfully update, maintain and query the location information. The total cost of a location service scheme can be divided into three parts: location update cost, location maintenance cost and location querying cost. In the following formulae, N stands for the number of mobile nodes in the network, and v stands for the moving speed of the mobile nodes. We derive all the formulae according to those in [9].

The location update cost of MHRLS c_u is:

$$c_u \propto kv\sqrt{N} \; ; \qquad (1)$$

The location maintenance cost of MHRLS c_m is:

$$c_m \propto vN \; ; \qquad (2)$$

The location querying cost of MHRLS c_q is:

$$c_q \propto k\sqrt{N} \quad \text{(When the Query-All scheme is adopted);} \qquad (3)$$

$$c_q \propto \sqrt{N} \quad \text{(When the Query-Nearest scheme is adopted);} \qquad (4)$$

The total cost in the Query-All scheme c is:

$$c \propto (Nkv\sqrt{N} + vN + kN\sqrt{N}) \propto kvN^{3/2}; \qquad (5)$$

The total cost in the Query-Nearest scheme is:

$$c \propto (kvN\sqrt{N} + vN + N\sqrt{N}) \propto kvN^{3/2}. \qquad (6)$$

Thus, the total cost of MHRLS is: $c \propto kvN^{3/2}$. (7)

Table 1. Scalability Comparison between MHRLS and SLURP

	SLURP	MHRLS
location update cost	$c_u \propto v\sqrt{N}$	$c_u \propto kv\sqrt{N}$
location maintenance cost	$c_m \propto vN$	$c_m \propto vN$
location querying cost	$c_1 \propto \sqrt{N}$	$c_1 \propto k\sqrt{N}$ (the Query-All scheme)
		$c_1 \propto \sqrt{N}$ (the Query-Nearest scheme)
total cost	$c \propto vN^{3/2}$	$c \propto kvN^{3/2}$

Although Table 1 shows that the total cost of the MHRLS protocol is higher than that of the SLURP protocol, both of them scale at the same level when k is small. In fact, the scalability of the SLURP protocol is not as well as that shown in Table 1 because the scalability analysis of the SLURP protocol in [9] takes no account of the possible cost for maintaining location information when some region has no nodes within. Thus, we conclude that MHRLS has comparable scalability with SLURP.

4.2 Reliability Analysis

In this subsection, we compare the reliability of the proposed protocol to existing protocols in two different situations. In this paper, we define the reliability of a location service protocol as the probability to successfully update, maintain and query the location information in a certain situation.

4.2.1 Uniform Distribution of Empty Regions

Firstly, we assume that empty regions are of uniform distribution, i.e., the probability for each region in the network to be empty is the same. And we assume that the probability of any region to be empty is equal to p, which is very small. In the HALS protocol, since location information of each node is kept in a single region which is set to be the node's home region, the reliability of the protocol is equal to 1.0-p; In the SLURP protocol, since a copy of location information of each node is kept in 9 adjacent regions, the reliability of the protocol is 1.0-p^9; In the proposed MHRLS protocol, since a copy of location information of each node is kept in k uniformly distributed regions, the reliability of the protocol is equal to 1.0-p^k, which is close to 1.0 if k is relatively large and p is very small. Therefore, the MHRLS protocol is more reliable than the HALS protocol in such situation. In addition, compared with SLURP, the MHRLS protocol achieves higher reliability if k is larger than 9; even if k is smaller than 9 (but not too small), reliability of the MHRLS protocol can be still very high even though it will be only a little lower than the SLURP protocol does. The analysis results on the reliability of the HALS, SLURP, and MHRLS protocols in the case of uniform distribution of empty regions are given in Table 2.

4.2.2 Non-Uniform Distribution of Empty Regions

In this subsection, we consider that multiple adjacent regions become empty at the same time, for example, the 9 adjacent regions in the SLURP protocol are empty. In case of uniform distribution, such a case may not occur, or occurs very rarely. That is, such a case stands for an extreme case of non-uniform distribution of empty regions. This will probably happen when group mobility is of great importance, and thus a relatively large area may become empty. For example, a bombing in the battlefield may damage the region where it occurs, and it may also affect all its neighboring regions of the damaged region. Here we consider the probability that 9 adjacent regions are empty at the same time is equal to P. In this case, reliability of the HALS protocol is equal to 1.0-P, so is the SLURP protocol. However, in the same situation, the reliability of our proposed MHRLS protocol is equal to 1.0-P^k. That is because the k home regions of each node are evenly distributed in our protocol, and they have little probability that several of them happen to locate in the same 9 adjacent regions. Then we conclude that the MHRLS protocol is more reliable than both the HALS protocol and the SLURP protocol. The analysis results on the reliability of the HALS, SLURP, and MHRLS protocols in the case of non-uniform distribution of empty regions are also given in Table 2.

Table 2. Reliability Comparison with HALS and SLURP

	HALS	SLURP	MHRLS
Uniform Distribution of Empty Regions	1.0-p	1.0-p^9	1.0-p^k
Non-Uniform Distribution of Empty Regions	1.0-P	1.0-P	1.0-P^k

4.2.3 Numerical Results

According to Table 2, numerical results about the reliability of the HALS, SLURP and MHRLS protocols are given in Figure 2 and Figure 3 for uniform and non-uniform distributions of empty regions, respectively. In both figures, R stands for the reliability in Table 2, which is a function of the protocol being investigated and the probability for a given region to be empty. For the sake of presentation, we use the value of $-\lg(1.0-R)$ as Y. So the bigger the value of Y, the higher the R is. Therefore, in both Figure 2 and Figure 3, the X-axis essentially stands for the probability for a given region to be empty, and the Y-axis essentially stands for the reliability of the protocol being investigated.

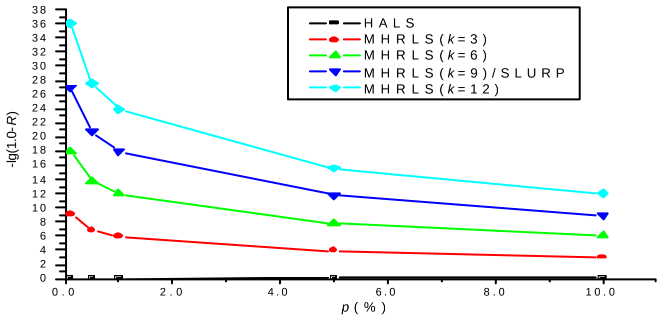

Figure 2. Numerical Results in Uniform Distribution of Empty Regions

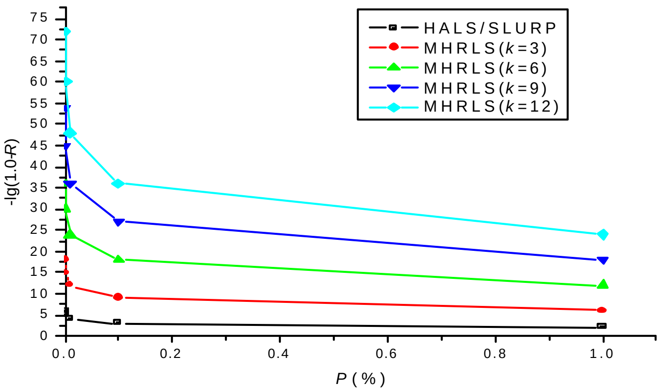

Figure 3. Numerical Results in Non-Uniform Distribution of Empty Regions

Figure 2 shows that our proposed protocol always outperforms the HALS protocol under any probability for a given region to be empty, while our proposed protocol outperforms the SLURP protocol only when the parameter k is not less than 9. In addition, Figure 3 shows that our proposed protocol always outperforms both the HALS protocol and the SLURP protocol when the parameter k is larger than 1 (we only show k = 3, 6, 9, 12, respectively).

5 Conclusions

In this paper we proposed a scalable and reliable location service protocol in large-scale MANETs. The proposed protocol uses multiple home regions to update, maintain and query the location information for each node in the network. We also presented two kinds of query strategies which can be used in different application scenarios. Theoretical analysis shows the proposed protocol has comparative scalability as that of SLURP, and the proposed protocol is more reliable than HALS and SLURP in both uniform and non-uniform distributions of empty home regions.

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