A Distributed Approach for Location Lookup in Vehicular Ad Hoc Networks

Hanan Saleet, Rami Langar[‡], Otman Basir, and Raouf Boutaba
University of Waterloo ; 200 University Ave. W., Waterloo, ON, Canada
([‡]) UPMC - Paris Universitas ; LIP6, 104 av. du President Kennedy, 75016 Paris, France
E-Mail: hsaleet@uwaterloo.ca ; rami.langar@lip6.fr ; obasir@uwaterloo.ca ; rboutaba@uwaterloo.ca

***Abstract*— Efficient location management is one of the major challenges in Vehicular Ad Hoc Networks (VANETs). Due to the high mobility of vehicles and the increase in their number, the location information updating and querying messages will consume the limited bandwidth of VANETs. This involves the development of a scalable and locality-aware location service management protocol. In this paper, we propose a promising solution called the Modified Region-based Location Service Management Protocol (MRLSMP), which utilizes the existing infrastructure on the road as a location management service entity. To evaluate the efficiency of our proposal, we compare our scheme with existing solutions using both analytical and simulation approaches. Specifically, we develop analytical models to evaluate the total control overhead. Numerical and simulation results show that our protocol scales better than existing schemes, when increasing the size of VANETs which enhances the feasibility of such large scale ad hoc networks.**

***Index Terms*— VANETS, location service, communication overhead, mobility management, performance analysis.**

I. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) represent a rapidly emerging and challenging class of Mobile Ad Hoc Networks (MANETs), where vehicles and road infrastructures are equiped with wireless devices [1] – [3]. Accordingly, the vehicles, called also mobile nodes (MNs) are able to communicate with each other as well as interacting with the road infrastructure. We denote by V2V the first type of communications (i.e., vehicle-to-vehicle communications), and by V2R the communications between vehicles and Road Side Units (RSUs).

VANETs can enable a wide range of applications, e.g., emergency message dissemination, real-time traffic condition monitoring, collision avoidance and safety, where communications are exchanged in order to improve the driver's responsiveness and safety in case of road incidents. Therefore, to support the different type of applications, the network must be able to efficiently locate users. While moving, the MNs send location updates to specific regions in the network called home regions. In the same time, the nodes located in the home regions (called location servers) are responsible for replying to location queries. An efficient location service management protocol can track the locations of MNs (location updates) and reply to location queries with minimum overhead [4] [5].

Numerous proposals for location service management have been proposed for MANETs [6] – [14]. Two different approaches exist: flooding-based and quorum-based approaches. The former one involves global network flooding [6] [7], which results in severe performance degradation and scalability reduction. In the latter approach, the location servers (i.e., quorums) result from mapping the nodes' identifiers or geographical information to quorums in random or static way [8] – [14]. In view of this, XYLS [12] disseminates the location updating information in a direction such that a query can intersect an update quorum. However, this scheme assumes that every node will traverse the entire network frequently which is a rare case in VANET and will result in unnecessary use of the wireless link bandwidth. In [13], SLURP uses the concept of home region to track the MN's mobility. All nodes in this region will act as location servers for the corresponding MN. However, the main concern of such a scheme is the lack of efficient locality awareness since the MN's home region is randomly assigned. The locality awareness is defined as the ability to support effectively local traffic patterns within the network. In [14], the authors propose a distributed location service, namely HLS, in order to track the MNs position using a hierarchy of pointers. However, for a particular MN, the pointer assignment will be critically affected by the frequent crossing of the cell boundary.

To overcome these limitations, we propose in this paper a promising location service management protocol called modified region-based location service management protocol (MRLSMP). MRLSMP aims to investigate the effect of deploying a self organized framework for managing the location information using message aggregation enhanced by geographical clustering. To the best of our knowledge, MRLSMP is the first protocol that achieves both properties (i.e., scalability and locality awareness) in VANETs, while using both V2V and V2R communications.

To gauge the effectiveness of our proposal, we derive analytical expression for the total control overhead which includes both location updates and queries signaling cost. We also investigate location information updating and querying by simulations. Numerical and simulation results show that our proposal can significantly reduce location updates cost and also provide low querying overhead when compared to the most prominent existing schemes (XYLS [12], SLURP [13] and HLS [14]) under various scenarios.

The remainder of this paper is organized as follows. Section II describes our proposed protocol. Section III presents the analytical framework used to evaluate the communication overhead. In section IV, we formulate the total communication overhead as an optimization problem. In section V, a comparison between our proposal and existing solutions is drawn using both analytical and simulation results. Finally, section VI contains our concluding remarks.

978-1-4244-3435-0/09/$25.00 ©2009 IEEE

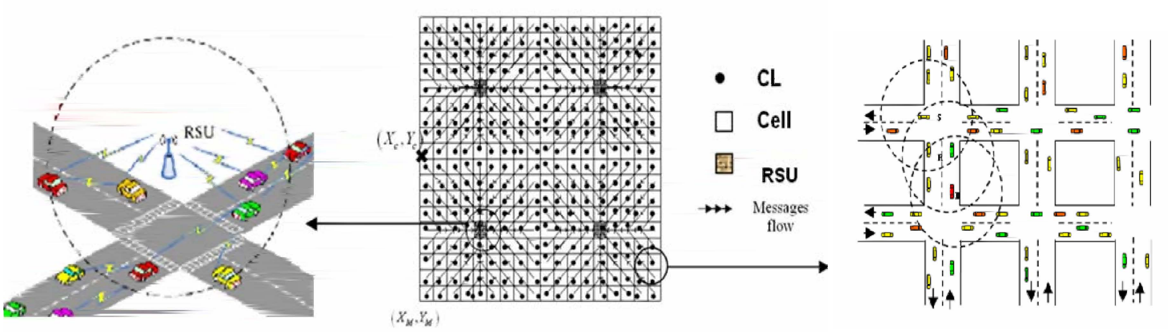


Fig. 1. System description and RSU updating process

II. MODIFIED REGION-BASED LOCATION SERVICE MANAGEMENT PROTOCOL (MRLSMP)

In this section, we describe our new scheme called MRLSMP. MRLSMP is a distributed location service management protocol for position based routing in mobile ad hoc networks. It uses the location of nodes as a criterion for building geographical clusters. That is, each vehicle automatically determines its geographical cluster while moving (by mapping its GPS location into coordinates in the network), without any additional communication or delay. Furthermore, the geographical clustering suggests the possibility of message aggregation which is essential to suppress the number of control signals in the network. In addition, MRLSMP uses the road infrastructure (i.e., RSU) as location servers.

To better understand the functionalities of our protocol, we consider the following network structure as shown in Fig. 1. The vehicles are considered as nodes of an ad hoc network, partitioned into virtual cells that form a virtual infrastructure. The nodes' mobility space is viewed as a grid (see Fig. 1). Each node is aware of the location of the grid origin (X_M, Y_M) (zero longitude and zero latitude). Also, each cell has an origin (X_c, Y_c) with respect to the grid origin. The origin of each cell gives the cell a unique identifier (ID) which identifies its location relative to the grid origin. Each cell has a particular node called Cell Leader (CL) that is responsible of aggregating the location information about all nodes within the cell. Furthermore, the grid is divided into segments, and each segment contains a number of cells. The nodes inside one segment construct one geographical cluster. Specifically, Fig. 1 shows a grid of four clusters and each cluster consists of 81 cells. Note that the central cell of each cluster is the possible position for a RSU. In our proposal, the RSU in each cluster acts as a location service management entity. Indeed, it is responsible for saving the current location of all the vehicles in that cluster as well as answering the queries about the MN's location information. The MNs are thus grouped into geographical clusters and the location information is kept locally inside one cluster. It is worth noting that in VANETs, the communication pattern is considered to be local, where the vehicles inside one geographical cluster are more likely to communicate with each other.

In addition, MRLSMP achieves scalability by the fact that location updates and querying messages are aggregated. The aggregated location information forwarded to the RSU describes a node in a specific cell instead of the detailed information about its exact location. The cell ID is used to identify the location of nodes. We believe that intelligently filtered or summarized information about the location of nodes in the network is sufficient. Therefore, it is not necessary to send the detailed information to the RSU since the desired level of detail decreases with distance and time.

In the following, we present our framework used in our analysis. The obtained results will be used, in a later stage, to derive the protocol performance metrics such as the location updating cost and querying cost.

III. FRAMEWORK FOR LOCATION MANAGEMENT ANALYSIS

In this section, we derive analytical expressions for both location updating and querying costs regarding the proposed MRLSMP scheme. Table I describes the parameters used in our analysis.

A. *Location updating cost*

In MRLSMP, the location updating cost involves two terms. The first term is regarding the messages sent by the MNs to the CL in order to update their locations within the cell. We refer to the first term as the *CL updating cost*. The second term is related to the updates sent from the CLs to the local RSU in order to update the location information of the nodes that reside in that cluster. We refer to this term as the *RSU updating cost*.

1) CL location updating cost

In our analysis, we consider a square-based two-dimensional (2-D) random walk mobility model [15] [16]. Typically, a cell with side length of l is divided into $n \times n$ square cell elements as shown in Fig.2. The side length d of each cell element is determined such that each node n_i in the cell element i can communicate directly (i.e., in one hop) with a node n_j located in the adjacent cell element j. In this case, $d = T_r/\sqrt{5}$. In addition, the MN can move to one of the neighboring cell element with equal probability p ($p = 1/4$).

From Fig. 2, we define two new terms: number of rings of cell elements (r), and number of cell rings (R). For example, the first 8 cell elements surrounding the CL are called the first ring of cell elements and the next 16 surrounding cell elements are called the second ring, and so on. In this figure, the number of cell rings R is equal to 2 and the number of rings of cell elements r is also equal to 2.

TABLE I
LIST OF PARAMETERS

Parameter	Description
A	network area
u_1	the content of the updating packet that CLs send to the local RSU
u_2	the content of the query packet
d	side length of one cell element
l	cell side length
n	cell side length multiplicity
N	number of nodes in the network
p	probability of movement to the neigboring cells
p_l	probability of local querying
r	number of rings of cell elements in one cell
R	number of rings of cells in one cluster
R_c	number of rings of clusters in the network
$X(t)$	the MN's location within the cell at time t
T_r	transmisson range
γ	the node density
z	the average progress in one hop
f_u	frequency of sending a location update
f_q	frequency of sending a location query

Let C_1 denote the cost of CL location updates. According to the node mobility, this cost can be written as follows:

$$C_1 = Cost_{intra} + Cost_{inter} \tag{1}$$

where $Cost_{intra}$ and $Cost_{inter}$ denote, respectively, the signaling cost of location updates when the MN moves within the same cell (i.e., intra-cell movement) and when the MN crosses the cell boundary (i.e., inter-cell movement).

In our analysis, the sojourn time of a MN in each cell element is assumed to be exponentially distributed. Hence, the process $X(t), t \geq 0$, where $X(t)$ represents the MN's location within the cell at time t, is Markovian. The expressions of $Cost_{intra}$ and $Cost_{inter}$ can be given as follows:

$$\begin{aligned} Cost_{intra} = & \sum_{i=1}^{r-1} 2p(2i+1)\Pi_i + \sum_{i=1}^{r-1}\sum_{j=1}^{i} 4p(i+j)\Pi_i^{(j)} \\ & + p(3r+1)\Pi_r + 2p(2r-1)\Pi_r^{(r)} \\ & + \sum_{j=1}^{r-1} p(3r+3j-1)\Pi_r^{(j)} \end{aligned} \tag{2}$$

and,

$$\begin{aligned} Cost_{inter} = & p(2r+1)(\Pi_r + \Pi_{\bar{r}}) + p(4r+1)(\Pi_r^{(r)} + \Pi_{\bar{r}}^{(r)}) \\ & + \sum_{j=1}^{r} p(2r+2j+1)(\Pi_r^{(j)} + \Pi_{\bar{r}}^{(j)}) \end{aligned} \tag{3}$$

where Π_i and Π_i^j are the stationary probability of the system. For more details, please refer to our previous work in [16].

2) RSU Updating cost

To evaluate the RSU updating cost, we consider three main factors as follows. The node density, the cluster size and the updating frequency.

Node density: The RSU updating cost is proportional to the number of nodes in one cell. Recall that in each cell, the CL is responsible of forwarding the aggregated packets of all MNs residing in the cell. Specifically, each CL stores detailed information about the MNs that it manages. This information contains node ID, X-Y coordinates of the node location, time of the last update, and velocity and direction of the node movement. At the same time the CL forwards a summarized information (node ID, cell ID and time stamp) about those nodes to the local RSU. Therefore, the RSU updating cost (measured in number of bytes) is proportional to $\gamma(nd)^2 u_1$, where u_1 is the number of bytes that represent the data about one specific node (see table II) and γ is the vehicles density measured in $nodes/km^2$.

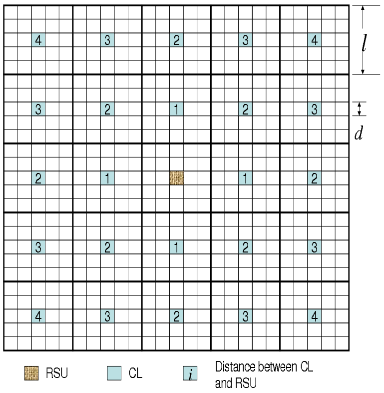


Fig. 2. The distance between the CLs and the local RSU in one cluster

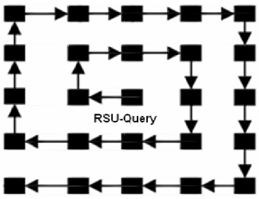


Fig. 3. Spiral shape of the location information retrieval

Cluster size: The average distance of the different CLs from the local RSU depends on the cell side length multiplicity n and the number of cell rings R around the RSU. In Fig. 2, the numbers assigned to the CL of each cell is the distance between that CL and the local RSU in terms of the cell side length l. Recall that $l = nd$. Therefore, to calculate the average distance, we use the power series as follows:

$$\begin{aligned} D_{ave} &= \frac{nd}{(2R+1)^2}\left(\sum_{i=1}^{R} 4i((2R+1)-i) + \sum_{i=1}^{R} 4i^2\right) \\ &= \frac{nd}{(2R+1)} 2R(R+1) \end{aligned} \tag{4}$$

Updating frequency: Recall that, our protocol relies on aggregating and forwarding of location updating messages. This process is achieved by all CLs residing in the cluster and must be synchronized among them. Indeed, there is a time schedule, denoted by $Time\_to\_Send$, upon which the CL should begin sending the aggregated messages towards the local RSU. More formally, the RSU updating algorithm is described by the pseudocode in Algorithm 1.

By considering the aforesaid three factors, we can formulate the RSU updating cost (measured in bytes × hops / second) as follows, where f_u is the updating frequency and z denote the average progress in one hop.

Algorithm 1 RSU Updating Algorithm

```
1:  In one Cluster do:
2:  if (Cell Leader) then
3:      Save detailed information (nodes_ID, X, Y, V, Dir) in local_table;
4:      Aggregate summarized information (nodes_ID, Cell_ID);
5:      if (packet_size $\geq$ packet_size_limit) then
6:          Go to step 13;
7:      else
8:          Continue aggregation in the same packet;
9:          if (Time_to_Send) then
10:             Go to step 13;
11:         end if
12:     end if
13:     Send the aggregated message to the next Cell Leader in the downstream direction towards the RSU;
14:     if (next Cell Leader is the RSU) then
15:         Stop;
16:     end if
17: end if
```

$$C_2 = f_u \frac{nd}{(2R+1)} \frac{2R(R+1)}{z} \gamma (nd)^2 u_1 \tag{5}$$

B. Location querying cost

The querying cost in MRLSMP consists of both a local querying, which corresponds to the queries answered by the local RSU inside one cluster, and a global querying. The latter corresponds to the queries answered by the other RSUs.

1) Local query

MRLSMP is the first protocol that uses message aggregation in location querying. When a vehicle wants to communicate with another one, it forwards a query to the cell leader which aggregates the querying messages and forwards them to the local RSU. If the queries are answered by the local RSU (i.e., both the source and destination nodes are registered in the same cluster), we refer to them as *local queries*. In this case, the overhead introduced by this kind of queries can be determined as follows.

$$C_3 = p_l f_q \frac{nd}{(2R+1)} \frac{2R(R+1)}{z} \gamma (nd)^2 u_2 \tag{6}$$

where, f_q denote the frequency of sending any type of queries. Recall that in VANETs, the traffic pattern is assumed to be local. Therefore, we assume in our analysis that the probability of querying is exponentially decaying, as shown in (7), which means that the probability of a local querying (i.e., p_l) is higher than that of the global querying (i.e., $1 - p_l$).

$$\sum_{i=1}^{2} p_i = p_l + \frac{p_l}{2} = 1 \tag{7}$$

2) Global query

If the destination is not located in the local cluster where the source node resides, the query is called *global query*. In this case, the query messages are not forwarded directly. Instead, the messages are delayed for a pre-specified time. This delay is essential for aggregating queries which are sent by vehicles residing in that cluster. The aggregated queries that are forwarded pass through the different RSUs as shown in Fig. 3. The aggregated querying messages are forwarded in a spiral around the local RSU where this spiral visits all surrounding RSUs until it finds information about locations of the destinations. The different RSUs will make use of the information stored in their own tables to find the required destinations IDs. Note that while visiting different RSUs, messages are relayed to their corresponding destination.

For simplicity, let us refer the 8 clusters which surround the local RSU, as the first cluster ring. The next 16 surrounding clusters correspond to the second cluster ring and so on. The global querying cost is affected by the following three factors: node density, network size, and global querying probability.

Node density: The global querying cost is proportional to the number of nodes in one cluster. Therefore, the global querying cost (measured in number of bytes) is proportional to $\gamma(2R+1)^2(nd)^2u_2$, where u_2 denote the average query packet size, as listed in table II.

Network size (A): The distance traveled from the local RSU to the first RSU which is located in the first cluster ring is equal to $(nd)(2R+1)$. Thus, the distance traveled to visit the ith cluster ring ($i = 0, ..., Rc$) is $8i(nd)(2R+1)$, where R_c denote the number of rings of clusters in the network. This parameter can be given as follows.

$$\frac{A}{(2R+1)^2(nd)^2} = 1 + 8 \times 0 + 8 \times 1 + 8 \times 2 + ... + 8 \times R_c$$

$$R_c = \frac{-1}{2} + \sqrt{\frac{A}{4(2R+1)^2(nd)^2}} \tag{8}$$

Querying frequency: Recall that f_q designates the frequency by which the nodes send the queries and $1-p_l$ is the probability of global query. The cost of sending the queries from the local RSU to the surrounding RSUs is given as:

$$Cost_q = (1-p_l) f_q \frac{8u_2\gamma(2R+1)^3(nd)^3}{z} \sum_{i=1}^{R_c} i$$

$$Cost_q = (1-p_l) f_q \frac{8u_2\gamma(2R+1)^3(nd)^3}{2z} R_c(R_c+1) \tag{9}$$

Hence, the global querying cost C_4 is expressed as follows.

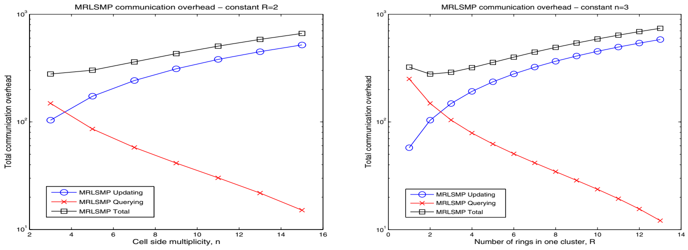
$$C_4 = \frac{(1-p_l)C_3}{p_l\gamma(nd)^2} + \frac{cost_q}{\gamma(2R+1)^2(nd)^2} \tag{10}$$

where the first term corresponds to the normalized cost related to the queries sent from the CLs to the local RSU, and the second term is the normalized cost of forwarding the queries from the local RSU to the surrounding ones.

TABLE II

DETAILS ABOUT u_1 AND u_2 IN NUMBER OF BYTES

Field type	u_1	u_2
$Node\ Identifier(ID)$	8	8
$Destination\ Identifier(ID)$	-	8
$Cell\ Identifier(ID)$	8	8
$Time\ stamp$	2	2



(a) Constant R (b) Constant n

Fig. 4. Optimal communication cost

IV. FORMULATING TOTAL CONTROL OVERHEAD AS AN OPTIMIZATION PROBLEM

In this section, we address the optimal values of the cell side length multiplicity n, and the number of rings of cells, R, in one cluster, by minimizing the total control overhead.

Based on the above analysis, this cost is defined as the sum of the total updating cost including the CL updates (i.e., C_1) and the RSU updates (i.e., C_2), and on the other hand, the total querying cost that comprises the local queries (i.e., C_3) and the global queries (i.e., C_4).

Accordingly, we formulate the problem as an optimization one with the objective function as follows:

$$\min_{n,R} \sum_{i=1}^{4} C_i$$

subject to:

$$0 \leq R \leq \sqrt{\frac{A}{(2R+1)^2 (nd)^2}} - 1$$

$$1 \leq (nd) \leq \sqrt{\frac{A}{z}}$$

The rational behind this is that, given a network of area A, the network designer can compute the optimal values of n and $R$by solving the above problem using simply the total enumeration (see Fig. 4). Doing so, the total control overhead will be minimized and an optimal network structure will be formed.

In the following section, we will examine the simulation results, and compare them with the analytical ones. In addition, we will compare the total overhead cost of MRLSMP with that of XYLS [12], SLURP [13] and HLS [14].

V. NUMERICAL AND SIMULATION RESULTS

In this section, we compare our proposal with respect to XYLS [12], SLURP [13] and HLS [14] schemes through both simulations and analytical approaches. To do so, we developed our own discrete-event simulator.

TABLE III

PARAMETER SETTINGS

Parameter	Value	Parameter	Value
t_s	1000 sec	f_u	1/60
V	10 m/s	T_r	750 m
r	1 $\sim$ 9	γ	8 nodes/km^2
f_q	1/60	N	160 $\sim$ 4000

The simulation environment consists of a large scale wireless ad hoc network. A number of N nodes are randomly generated within the network. The resulting network is considered only if all nodes maintain connectivity between them, i.e., there is at least a path that connects each pair of nodes.

In our experiments, the density γ of the nodes in the network is kept constant and equals to 8 nodes/km^2. In this case, N is varied between 160 and 4000 nodes. The mobility of nodes is simulated using a random walk model [15]. According to each location management policy, the location information updating and querying costs are calculated.

We considered several scenarios by varying the network size. The parameter settings in our experiments are listed in table III, where t_s denotes the simulation time, V is the MN's velocity. In all figures of this section, we can see that the analytical and simulation curves regarding MRLSMP coincide, which illustrates the accuracy of our study.

Fig. 5 depicts the RSU updates cost (measured in number of bytes) of all underlying protocols as a function of the network area A. In this experiment, the network size is varied from 20 to 590 km^2. We can notice that RSU updates using XYLS, SLURP and HLS is higher than that of MRLSMP. The reason is that, in SLURP, HLS and XYLS, the distance between the MN and its location servers grows dramatically with the network size since the location servers are randomly chosen in the network for the SLURP and HLS cases and along the network column for the XYLS case. This allows longer forwarding path to be formed and more byte transmissions. For HLS the updating cost is less than that of SLURP and XYLS because it does not require the MN to update the faraway home regions unless it crosses a higher level boundary.

However, in MRLSMP, the cell side length multiplicity n and the number of cell rings per cluster R used to calculate the RSU updating overhead corresponds to the output of the optimization problem given in section IV. We can notice that even if the network size increases, there is no dramatic increase in the overhead since the RSU is located at the center of the cluster, where MRLSMP employs message aggregation using a tree structure for the forwarding process with the RSU as a root. This avoids the high volume of overhead produced by each MN to update its location inside the cluster.

Fig. 6 shows the location information query of all protocols as a function of the network size. In this experiment, we also varied network size A from 20 to 590 km^2. For each value of A we used the same optimal values for n and R as in Fig. 5. We can see that MRLSMP reduces the location query cost. Specifically, in SLURP, the distance between the source and destination's location server increases with the network size since it is assumed that any two MNs in the network are equally

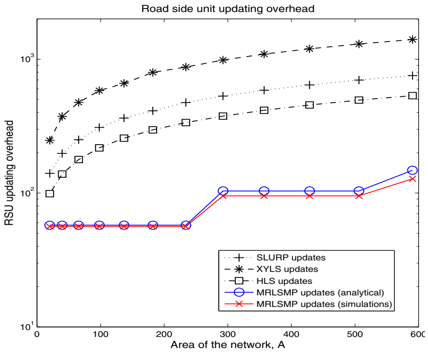


Fig. 5. RSU updates cost

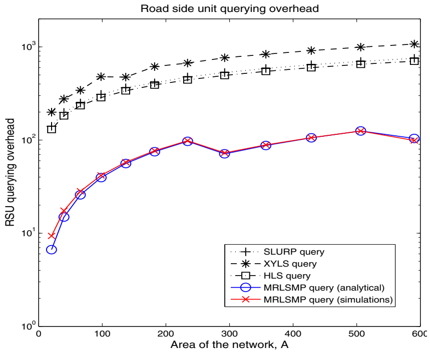


Fig. 6. Location information query cost

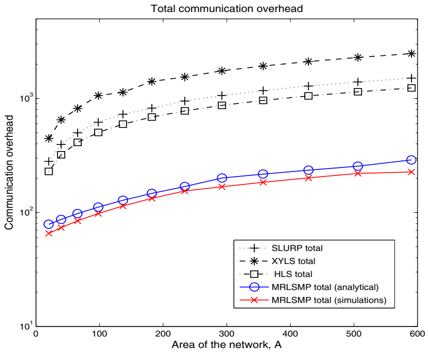


Fig. 7. Total communication overhead

likely to communicate with each other. Considering the XYLS scheme, a node can move in the whole network frequently. This results in an increase of distance between the MN and the quorum (i.e., the cell where the updating and querying intersect) when network size increases. For HLS, even though the source and destination nodes are geographically close to each other, they are considered to be located in different levels due to the virtual boundaries of the grid. This forces the query to travel to the destination pointers that are randomly located in the higher levels. As such, the querying cost of HLS increases with the network size. Note that HLS has lower querying cost than that of both SLURP and XYLS because of its hierarchical structure. Nevertheless HLS has higher cost than that of MRLSMP. It is worth noting that, MRLSMP incorporates the locality awareness by forwarding queries to the RSUs in the MN's vicinity, which results in lower querying cost.

Fig. 7 shows the total overhead of all protocols as a function of the network size. This figure summarizes the result that the total overhead of MRLSMP is the minimum compared to that of the other protocols. Therefore, MRLSMP scheme stands out as the best location service management from the communication overhead perspective. This enables MRLSMP scheme to outperform the remaining protocols although an extra time is needed to answer long distance queries due to the use of the spiral technique. In addition, note that the reduction of the number of transmissions by the in-network aggregation happens at the cost of longer delay, since packets need to be buffered and processed in the CL. However, in MRLSMP, the delay to answer a query can be reduced when the local communication pattern becomes more frequent, which is the case in VANETs.

VI. CONCLUSION

This paper described an efficient location service management protocol, called MRLSMP that supports both scalability and locality awareness in VANETs, and at the same time offers minimum overhead. Our proposal integrates the V2V and V2R communications and uses message aggregation enhanced by geographical clustering to reduce the signaling overhead in the network. It also resolves the localization of a destination node by using local search, which begins by exploring the vicinity of source nodes. Doing so, we avoid the relatively long distance signaling incurred in other protocols in both location updating and querying. Using both analytical and simulation approaches, we compared our proposed scheme with existing solutions (SLURP, HLS and XYLS). To achieve this, we developed analytical models to evaluate the total communication overhead. We found that our protocol achieves substantial communication overhead reduction and improves the locality awareness when increasing the network size. As such, our scheme stands out as a promising candidate for large scale wireless ad hoc network such as VANETs.

REFERENCES

[1] J. Zhao and G. Cao, "VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks", IEEE Trans. Vehicular Technology, Vol. 57, No. 3, May 2008.
[2] T. Arnold, W. Lloyd, J. Zhao and G. Cao, "IP Address Passing for VANETs", In Proc. of IEEE PerCom'08, Hong Kong, March 2008.
[3] A. Skordylis, N. Trigoni, "Delay-bounded routing in vehicular ad-hoc networks", ACM MOBIHOC 2008.
[4] S. Panichpapiboon, and W. Pattara-atikom, "Connectivity Requirements for Self-Organizing Traffic Information Systems", IEEE Transactions On Vehicular Technology, Vol. 57, No. 6, November 2008.
[5] J. Li, C. Blake, D. S.J. De Couto, H.I. Lee and R. Morris, "Capacity of ad hoc wireless networks", In Proc. of ACM MobiCom'01, Italy, July 2001.
[6] T. Camp, J. Boleng, and L. Wilcox, " Location information services in mobile ad hoc networks", In Proc. of IEEE ICC'01, St. Petersburg, June 2001.
[7] Y.-B. Ko and N. H. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks", in Proc. of ACM MobiCom'98, Dallas, USA, Oct. 1998.
[8] R. Flury and R. Wattenhofer, "MLS: an efficient location service for mobile ad hoc networks", In Proc. of ACM MobiHoc'06, Italy, May 2006.
[9] S. Das, H. Pucha, and Y. Hu, "Performance comparison of scalable location services for geographic ad hoc routing," in Proc. of IEEE INFOCOM, Miami, FL, USA, 2005.
[10] W. Kiess and M. Mauve, "A survey on real-world implementations of mobile ad-hoc networks", Ad Hoc Networks, vol. 5, no. 3, Apr. 2007.
[11] T. Camp, J. Boleng, and L. Wilcox, Location information services in mobile ad hoc networks", In Proc. of IEEE ICC'01, St. Petersburg, June 2001.
[12] D. Liu , I. Stojmenovic and X. Jia, "A scalable quorum based location service in ad hoc and sensor networks," in Proc. of IEEE MASS'06, Canada, Oct. 2006.
[13] S. Woo, S. Singh, "Scalable routing protocol for ad hoc networks", Wireless Networks, vol. 7, pp. 513-529, Kluwer Publishers, 2001.
[14] W. Kiess, H. Fssler, J. Widmer, M. Mauve, "Hierarchical Location Service for Mobile Ad-Hoc Networks", ACM MC2R, vol. 8, no. 4, Oct. 2004.
[15] K-H. Chiang, N. Shenoy, "A 2-D Random-Walk Mobility Model for Location-Management Studies in Wireless Networks", IEEE Trans. Vehicular Technology, Vol. 53, No. 2, pp. 413-424, Mar. 2004.
[16] H. Saleet, R. Langar, O. Basir, and R. Boutaba, "Proposal and Analysis of Regionbased Location Service Management Protocol for VANETs ", In Proc. of IEEE GLOBECOM'08, New Orleans, USA, Dec. 2008.