A Comparison of Reactive, Grid and Hierarchical Location-based Services for VANETs

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***Abstract*—VANETs (Vehicular Ad-hoc NETworks) are a special case of MANETs (Mobile Ad-hoc NETworks). Their main feature is the high mobility range of nodes, which causes topology changes and frequent disconnections. Topology-based routing protocols have weak performances in such networks. This is why a new set of routing protocols, designated as *geographic routing protocols*, were designed to enhance performances and ensure a better scalability. These geographic protocols assume on one hand that all nodes must be aware about their position (by using a positioning system like GPS). On the other hand they also assume a certain knowledge about the position of the destination node and the position of their neighbors thanks to *Location-based Services*.**

In this paper, we compare three location-based services: Reactive Location Service (RLS), Grid Location Service (GLS) and Hierarchical Location Service (HLS) while coupled to the well known geographic routing protocol Greedy Perimeter Stateless Routing (GPSR). As far as we know, our work is the first that targets the performance evaluation of location-based services while coupled with a routing protocol. The simulations were performed using the NS-2 simulator on a realistic map about the city of Reims (France). Besides, a scalability study of GLS and HLS is presented. This study is based on three qualitative metrics (the location maintenance cost, the location query cost and the storage cost).

***Index Terms*—VANETs; Location-based Services; Routing Protocols.**

INTRODUCTION

Geographic routing protocols in VANETs are one of the most promising solutions to avoid topology-based routing protocols drawbacks such as frequent topology changes due to high mobility. These routing protocols, which may use the greedy forwarding principle or not, always need the location information knowledge about the targeted node, neighbors and third parties. The location information are given and maintained by what we know as a Location-based Service. Therefore, any research work on geographic routing should absolutely consider the existence of a location-based service. However, in the literature, this preliminary step is often considered ideal and its impact on the performances of the whole location and routing process is not taken into account.

Our study is organized as follow: the first part defines a location-based service taxonomy. The second part presents a comparison between reactive and hierarchical location-based service mechanisms using simulations. Then, the third part details a scalability comparison between GLS and HLS. Finally, the last part concludes the paper and draws the outlooks on this study.

I. A LOCATION-BASED SERVICE OVERVIEW

The location-based service (in the context of VANETs) is a distributed service without infrastructure in general. It has to answer to a location query such as:"Where is the node with id X?".

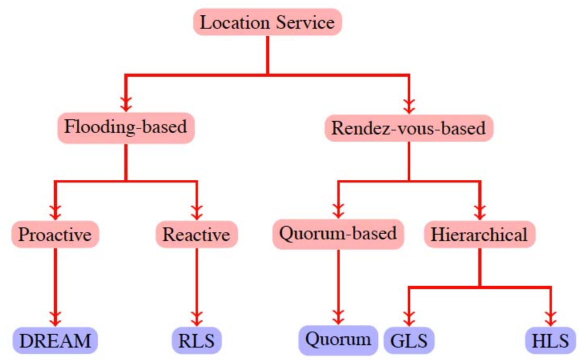

Figure 1. Location-based services Taxonomy

The location-based services can be classified according to Fig. 1 into two classes: "Flooding-based" and "Rendez-vous-based". The first class is composed of reactive and proactive services. In the proactive flooding-based location service, every node floods its geographic information through the whole network periodically. Thus, all nodes are able to update their location tables. An example of proactive flooding-based location service is the Distance Routing Effect Algorithm for Mobility (DREAM)[1]. Behind DREAM there are two ideas. the first one is: if a node is far, it appears as moving slower than a neighbor having the same speed. Therefore, the update frequency decreases with the distance to the node. The second idea is: a node with a high mobility sends more update location packets. As a result, there are less packets than a simple flooding scheme without affecting the network performances. For the second group (i.e the reactive flooding-based location service), the location response is sent when receiving a location request. This avoids the overhead of useless location information. However, it adds high latencies

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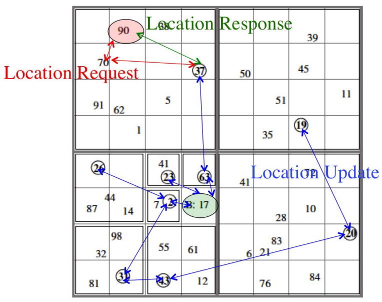
not suitable in VANETs. An example is Reactive Location Service (RLS) [2].

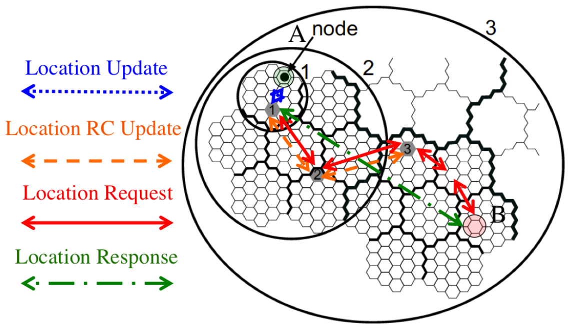
In the second class (rendez-vous-based location service), all the nodes agree on a unique mapping of a node to other specific nodes. The geographic information are disseminated through the elected nodes called the "location servers". Thus, the location-based services consists of two components:

1) Location Update : A node has to recruit location servers and, then, needs to update its location through theses servers.
2) Location Request: A node, seeking the location information of another node, broadcasts a location request. The location server will replay as soon as it receives this request.

There are two major approaches for the rendez-vous-based location services. The first approach, the quorum-based approach, as in [3], the location update is sent to a group of nodes (update quorum). The location query is sent to a different group (query quorum). These two groups are not necessarily disjoint. The challenge is then to choose how to generate the query system, as discussed in [3]. The second approach is the hierarchical approach. In this approach, the network is divided into several levels. At each level, a node recruits location servers. The location query is forwarded up and down in the hierarchy. This limits the forwarded packets and avoids flooding. Two major hierarchical examples are discussed here, the Grid Location Service (GLS) [4] and the Hierarchical Location Service (HLS) [5].



(a) GLS network partition



(b) HLS network partition

Figure 2. Hierarchical network partition

An example of location updates and queries using GLS is represented by Fig. 2.(a). GLS subdivides the region into four squares which are separated into four smaller squares and so on. The four smallest squares are called the order-1 level in the hierarchy. This hierarchy is the same for all network nodes. Fig. 2.(a) shows a three levels hierarchy. At each square in any level, a node selects a location server with the smallest ID greater than the node ID itself (if it exists). In our example, the node B with ID 17 chooses the nodes with IDs 2, 23 and 63 at the order-1; the nodes with IDs 26, 31 and 43 at order-2; and the nodes with IDs 19, 20 and 37 at order-3; as location servers. Knowing its location servers, a node shares its location information through location update messages. When the node 90, for example, needs to send data to the node B:17, it broadcasts a location query to the order-1 squares if the targeted node is not in the same square. The location is forwarded in the next order to the node with the smallest ID greater than the targeted node's ID (17) until reaching a location server (in our example the node 37), which replies with location response packet indicating the location information received from the last update.

HLS also shares the network into regions, which are subdivided in hexagonal cells. Neighboring regions are grouped into region levels. This partition is fixed and known by all the participating nodes. An example of the network partition in three region levels is shown on Fig. 2.(b). Unlike GLS, a hashing function depending not only on the ID but also on the current position of the node is used to choose the responsible cell (where a node must select its location servers) at each region level. There are two different update methods:

- The direct method: to update its location information, a node frequently sends packets to the responsible cells of the first level. A responsible cell may contain more than one location server. This is the case only for neighboring location servers (at the same region level). For other location servers, the second method is used.
- The indirect method: to reduce the traffic, only the level N-1 responsible cell's location is sent to the level N region. Consequently, the traffic congestion generated by the node's movement is local at the first level and a few multi-hop long-distance packets are sent to the top levels.

If a node A needs to send data to a node B, A broadcasts a query location. Since this location reaches B's responsible cell, the location server forwards the packet to B's responsible cell in the lower level and so on until reaching the first level responsible cell. The latter generates a reply packet and sends it to node A.

II. Hierarchical and Reactive Location-based Services Comparison using Simulations

Since the proactive flooding-based location service is not efficient (lack of scalability and risks of congestion), we choose to compare a reactive service, RLS, and two hierarchical services, GLS and HLS.

The simulations were performed using the ns-2 simulator 2.33 [6]. The geographic routing protocol used is the Greedy Perimeter Stateless Routing (GPSR) [7].

The area chosen is a 2x2 km^2 of a real map representing part of the French city "Reims". This area is extracted from Open Street Map [8]. The MAC layer used is 802.11p [9]. The simulation is run 5 times for more accurate results.

At each simulation, several random test queries are launched. A test query is a node looking for a location information of another node. The query can be replied by the cache stored or sent as a request location, which may be replied by the targeted node. To avoid the side-effects of application packet exchange, only test queries are exchanged during the simulations.

The most important simulation result is the "Query Success Rate" (QSR) shown in Fig. 3. This one represents the ratio of the queries answered from all those sent with valid location information (a maximum distance error defined as the transmission range, of 250m here, is allowed).

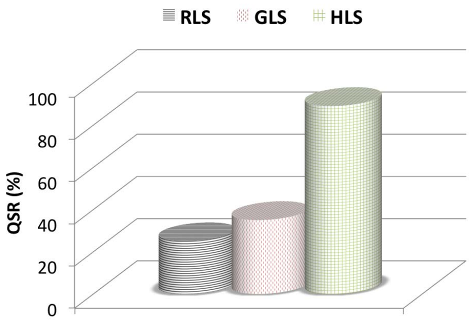


Figure 3. Query Success Rate

As depicted by Fig. 3, HLS performs more than four times better than GLS and RLS. This shows that the mechanism which keeps the location information in the responsible cells works well even for fast moving nodes. The weak GLS success rate is partly affected by its aggressive caching. The location information given by the cache becomes quickly wrong in high mobility networks. The RLS success rate is the lowest one due to the time spent by the reply to travel through the network. When the reply reaches the destination, the location information may change importantly relatively to the authorized error margin.

We studied also the overhead induced by the location-based services. The overhead here is measured as the number of packets sent and forwarded during the location updates, queries and replies (Fig. 4). RLS don't use the update mechanism but the queries are flooded all over the network. This creates an important overhead traffic overloading the network. Hence, RLS has the highest overhead among the three location-based services. GLS has a heavy update mechanism compared to HLS (+326%). This is due to the fact that the update in GLS is global for all the location servers in the network. However, it is mainly local in HLS on the first responsible cell. The overhead of the location queries and the location replies are almost equivalent (-6% for the queries in GLS compared to HLS and -33% for the replies). As a result, HLS has the lowest overhead in general, it generates 30% less overhead compared to RLS and 44% compared to GLS.

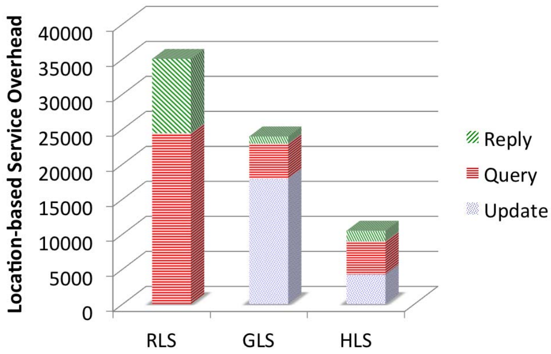


Figure 4. Location-based Service Overhead

Since RLS has the worst performances and the highest overhead, it will not be considered in the next simulation results. Another important issue in the location-based services is the "Request Travel Time" (RTT) shown in Fig. 5. In fact, the location request must be not only positively answered, but must also be received by the targeted node as soon as possible in order to be quickly handled (i.e. replied). Indeed, the reply in GLS and HLS approaches are forwarded in the same way using the greedy forwarding of the GPSR routing protocol. Thus, the RTT is seen here as an effective response time indicator. The more rapid requests are received, the faster replies are returned.

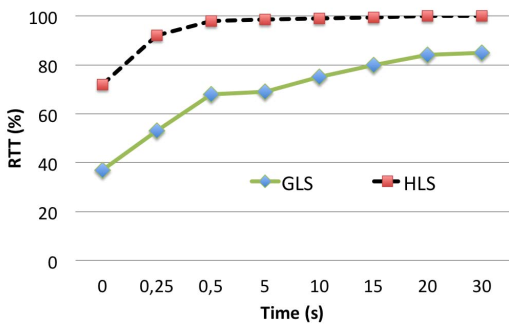


Figure 5. Request Travel Time

From Fig. 5, we see that using GLS, only 68% of the requests arrives to the targeted node after 0,5s from their sending while almost all requests (97%) are received during the same time interval for HLS. Moreover, more than 15% of GLS requests arrive after 15s against 2% in HLS. Therefore, the responsible cell mechanism in HLS helps in the request delivery with low latencies. Also, transporting requests through regions in HLS takes less time than sending it through location servers into each level in GLS.

In the next simulation, the number of nodes is variable (50, 100, 200 and 400 nodes). The aim is to observe its impact on the hierarchical location-based service's performances. The results are shown in Fig. 6.

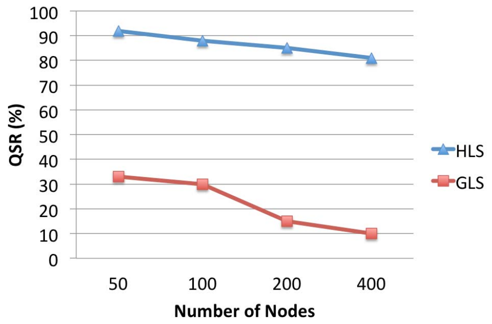


Figure 6. Query Success Rate GLS Vs. HLS

The QSR decreases due to the raising number of nodes and therefore the number of requests sent. This overloads the network especially if update queries are frequent as in GLS. The drop in performance in terms of QSR is only about 11% for HLS, when the number of nodes increases from 50 to 400 nodes, while it represents 23% for GLS.

As a result, we conclude that the rendez-vous based mechanism in the location-based service works better than the reactive flooding mechanism. Also, the HLS approach is quicker and more powerful than the GLS one.

Another useful performance criterion in the location-based service is the network scalability. The next section details our contribution about scalability performances study of both GLS and HLS. Specifically, what happens if the number of nodes increases? The study will focus on three qualitative metrics: the location maintenance cost, the location query cost and the storage cost.

III. GLS and HLS Scalability Issues

A system is scalable according to a metric, if and only if the order of the metric (the location maintenance cost, the location query cost or the storage cost) grows smaller than the order of the system's parameter (number of the nodes). In order to analyze the scalability, we used the framework presented in [10]. The notations are summarized in Tab. I. Two assumptions are considered here:

- The network area grows linearly with the number of nodes ($A \propto N$). As a direct consequence, the node density remains constant.
- The probability of initiating a packet between any two pairs of nodes is constant.

In [10], the authors evaluate the complexity of the location maintenance cost, the location query cost and the storage cost for GLS. Their main conclusion is:

$$E(C_m) = O(v\sqrt{N}) \quad (1)$$
$$E(C_q) = O(\sqrt{N}) \quad (2)$$
$$E(C_s) = O(\log N) \quad (3)$$

Parameters	Significance
A	Network area
H	Maximum level
N	Number of nodes
R	Side length of level-0 smaller squares
v	Node speed
z	Average progress in each forwarding hop
d	Average distance traveled by a node
d_i	Distance traveled at level i
ρ_i	Boundary crossing rate for level i square
c	Random distance within a square
n_i	Number of forwarding hops at a level i
P_i	Probability of querying a node at level i
C_m	Location maintenance cost
C_q	Location query cost
C_s	Storage cost

Table I
The Parameters Notifications

In the rest of the paper, we will try to evaluate these metrics for HLS. This will allow us to better compare the scalability between GLS and HLS.

A. Location Maintenance Cost

The location maintenance cost is defined as the number of packets forwarded by each node per second to update the location information within the location servers:

$$E(C_m) = \sum_{i=0}^{H} \rho_i E(n_i) \quad (4)$$

Since the node's density is fixed and the vehicles are moving randomly, the crossing rate is four times smaller at level i than at level i-1 (each level i square is divided into four levels i-1 squares). Which gives:

$$\rho_i = \frac{1}{4}\rho_{i-1} \; Then \; \rho_i = \frac{1}{4^i}\rho_0 \; \forall \; i \; 1 \le i \le H \quad (5)$$

Also, the boundary crossing rate of the level-0 square is estimated as the ratio of the speed by the average distance traveled by a node d in a circle with R as a diameter given by:

$$d = \frac{\int_0^{\pi/2} R\cos\theta d\theta}{\pi/2} = \frac{2R}{\pi}. \quad (6)$$

This gives ρ_i:

$$\rho_i = \frac{1}{4^i}\frac{v\pi}{2R} \; \forall \; i \; 0 \le i \le H \quad (7)$$

The average number of forwarding hops at level i $E(n_i)$ is defined as the ratio of the average distance traveled by a packet at level i $E(d_i)$ by the average progress performed by a packet at level i z. This latter is constant because it depends on the radio transmission and network density. $E(n_i)$ is thus obtained by:

$$E(n_i) = \frac{E(d_i)}{z}, \; where \; E(d_i) = 4^i Rc, \; \forall \; i \; 0 \le i \le H \quad (8)$$

The constant c represents the average distance between two points in a square of side 1 estimated in [11] as:

$$\begin{aligned} c &\approx \frac{2+5\sqrt{2}\ln(\sqrt{2+1})+2\sqrt{2}}{30}\sqrt{2} \\ c &\approx 0,36869\sqrt{2} \approx 0,5214 \end{aligned} \tag{9}$$

From equations (4), (7) and (8):

$$E(C_m) = \frac{v\pi c H}{2z} = O(vH) \tag{10}$$

However as:

$$H = \frac{\log(\frac{1}{2}\frac{\sqrt{A}}{R})}{\log(2)} + 1 = O(\log\sqrt{A}) \tag{11}$$

combining the equations (10), (11) and considering $A \propto N$ (the density is fixed), we obtain the location maintenance cost:

$$E(C_m) = O(v\log\sqrt{N}) \tag{12}$$

B. Location Query Cost

The location query cost is the number of packets forwarded by each node in a second when asking for location information. It depends on if the request is satisfied in the same level i or not:

$$E(C_q) = \sum_{i=0}^{H} P_i E(n_i) \tag{13}$$

As mentioned above, the traffic pattern used is uniform which means:

$$P_i = \frac{3}{4^{H-i}}\ \forall\ i\ 1 \leq i \leq H\ and\ P_0 = \frac{1}{4^H} \tag{14}$$

From the equations (8), (13) and (14) the location query cost is estimated:

$$E(C_q) = \frac{RC}{z4^H}[1+\frac{16}{5}(4^{2H}-1)] \approx \frac{3RC4^H}{z} \tag{15}$$

Combining (11) and (15) gives:

$$E(C_q) = O(\sqrt{N}) \tag{16}$$

C. Storage Cost

The storage cost is the number of location information records in a location server. Since the network density is constant, the distribution of the location servers must be uniform. Therefore, the storage cost could be deduced directly:

$$E(C_s) = H + 1 \tag{17}$$

Finally, with (11) and (17), we obtain:

$$E(C_s) = O(\log N) \tag{18}$$

D. Discussion

By comparing (1) with (12), (2) with (16) and (3) with (18): the conclusion is that GLS and HLS are scalable according to the three qualitative metrics. Therefore, HLS scales better especially for the location maintenance cost. This is due to the difference in the update mechanism. In GLS, all location servers store the position of the node. However in HLS, the location servers at a level i store the position of the responsible cell at the level i-1 which has to be updated less frequently. Those qualitative metrics confirm that HLS scales better than GLS (in addition to the fact that it has better performances than RLS and GLS, as shown in Section II).

IV. Conclusion & Future Works

This paper presents a location-based service taxonomy. We compared two classes: the reactive flooding class and the hierarchical rendez-vous based class. The comparison shows that the hierarchical mechanisms are more suitable for VANETs with high mobility and frequent topology changes. The most promising hierarchical location-based service is the Hierarchical Location Service (HLS), which when combined to the Greedy Perimeter Stateless Routing (GPSR) gives satisfactory results. As we believe that HLS performances may become even better if it is associated to mobility prediction of the targeted nodes (thanks to additional information such as speed, direction), we intend to investigate this issue in our future works.

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