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Localization technique in VANets using Clustering (LVC)

Nasreddine. Lagraa[1], Mohamed. Bachir. Yagoubi[1] and Sarah. Benkouider[1]

[1] Laboratory of Computer sciences and Mathematics
Computer science department; University of Laghouat, Laghouat, Algeria,

Abstract

Relative location information is an important aspect in vehicular Ad hoc networks .It helps to build vehicle topology maps, also provides location information of nearby vehicles.
Due to the characteristics of VANet, the existing relative positioning techniques developed initially for Ad hoc or sensors networks are not directly applicable to vehicular networks.
In this paper, we propose a protocol of localization in VANet when no GPS information is available, based on clustering and has the advantage to use a single coordinates system. We study its impact on the performances of the network, by using the network simulator NS-2.
Keywords: *VANets, Localization, Trilateration, clustering.*

1. Introduction

Vehicular Ad hoc Network (VANets), considered as a subclass of mobile Ad Hoc networks (MANets), is a promising approach for future Intelligent Transportation System (ITS). These networks are characterized by highly mobile nodes and potentially large network. The nodes can recharge frequently, they are constrained by the road and traffic pattern.
Many researchers consider Vehicular Ad hoc NETworks as one of the most important technologies for improving the efficiency and safety of modern transportation systems, by enabling vehicles to communicate with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Road side-to-Vehicle Communication (RVC) [1].
A plethora of applications have emerged in this domain. For example, vehicles can inform that there is traffic accident or congestion to the nearby vehicles to avoid traffic jam near the affected areas. Also, it enables vehicles to connect by Internet to obtain real time news, traffic and weather reports.
VANET also gives the enormous opportunities in online vehicle entertainments like gaming, chatting, multimedia streaming and file sharing via the Internet or the local ad hoc networks.
One of the most promising vehicular safety applications is the development of an advanced cooperative collision warning system [2]. It is envisioned that the system will use vehicle-to-vehicle radio communications to create a cooperative collision warning system, where vehicles cooperatively share information (i.e. location, speed, heading, acceleration, etc.) for collision anticipation.
Tatchitkou and al. [3] showed that sending safety warning messages containing position information can substantially reduce the probability of collision within a platoon.
The localization of a vehicle compared to an event when it's informed for the existence of an accident or an imminent danger. It's a task of great importance that can avoid pile-up of vehicles and loss of human life.
Currently, typical localization techniques integrate GPS receiver and motion sensors. However, when the vehicle passes through an environment that eclipses GPS information or creates a multipath effect, these techniques fail. Unfortunately, vehicles often travel in environments where GPS is not accessible. For these reasons, many techniques are proposed in literature to locate nodes in Ad hoc networks [4], in sensor networks [5], as well as in VANets [2, 6, 7]. Some of these techniques show how to determine the location of vehicles if only some vehicles are equipped of GPS [4], whereas others present methods to determinate position using a local and global coordinate systems which need a lot of calculates [4].
In this paper, we propose a new technique to determine the positions of nodes in a vehicular ad hoc network in the full absence of GPS information.
The proposed solution is essentially based on a technique of clustering, where a clusterhead is chosen among a group of vehicles and a technique, for the establishment of the relative positions of the nearby nodes. Every clusterhead establishes a local coordinate system and calculates the positions of all its neighbours in the group using the distances measured between vehicles. In the aim to reduce the calculate time in dangerous situation, the orientation of the coordinate system of the first clusterhead and the global system are considered the same. This new solution provides sufficient location information and accuracy to support basic network functions.
The rest of this paper will spell it out more carefully: The techniques of localization used in VANet are presented in section 2; in section 3 the relative techniques of localization are summarized; our approach is detailed in section 4.The simulation results are discussed in section 5. Finally, some concluding remarks are given.

2. Overview of localization techniques

A number of localization techniques have been proposed to determine the position of mobile nodes in classical Ad hoc. Most of them can be adapted to VANets [8]. Techniques like Map Matching, Dead Reckoning, Cellular Localization, Image/Video Processing, Localization Services, and Relative Localization are commonly discussed in VANet literature.

In this section we briefly explain each of these techniques and discuss when and how they can be used to localize vehicles in Intelligent Transport Systems.

2.1 Global Positioning System (GPS)

GPS, the Global Positioning System [9, 10], is composed of 24 satellites which can operate in orbit around the earth. Each satellite circles the earth at a height of 20.200 km and makes two complete rotations every day. The orbits have been defined in such a way, in which any region of the earth can be observed at least by four satellites.

A GPS receiver is an equipment able to receive the information constantly being sent by the satellites and using it. The GPS receiver uses the Time of Arrival technique (ToA) to estimate its distance to the four known satellites, and trilateration technique [11] to compute its position. Once these procedures have been executed, the receiver is able to know its latitude, longitude and altitude.

The main solution for VANet localization is to equip each vehicle node with a GPS receiver. This is a very reasonable solution; since the GPS receivers can be installed easily in vehicles. But as VANets advance into critical fields which are dependent on localization systems, GPS starts to show some undesirable problems such as not always available and not robust enough for critical applications.

2.2 Map matching

In the Map Matching [12] technique, several positions obtained over regular periods of time can be used to create an estimated trajectory. The estimated trajectory is then compared to the known digital map data to find the most suitable path geometry on the map that matches the trajectory. Using this technique, position information (e.g., from GPS) can be accurately depicted on the map.

2.3 Dead Reckoning

By using Dead Reckoning [13], the current position of a vehicle can be computed, based on its last known location and using such movement information as direction, speed, acceleration, distance, time, etc. The last known position, also known as a fix, can be obtained, for instance, by using GPS receivers (which are most common) or by locating a known reference (road crossing, parking lots, home, etc.) on a digital map.

Since Dead Reckoning accumulates errors rapidly over time and distance, it is considered only as a backup system for periods of GPS outage, for example, when a vehicle enters a tunnel and loses its GPS connection.

2.4 Cellular localization

Cellular localization [14] takes advantage of the mobile cellular infrastructure present in the most urban environments to estimate the position of an object. Known applications of this technology include locating mobile phones, tracking domestic animals, and vehicle localization.

In order to work properly, mobile cellular systems require the installation of a communication infrastructure composed of a number of cellular base stations distributed through the covered area.

Cellular localization is usually less precise than GPS. The accuracy depends on a number of factors such as the current urban environment, the number of base stations detecting the signal, and the positioning algorithm used, etc. Also, signals from the Cellular infrastructure have more availability in urban environments than signals from satellite (used by GPS receivers) which can be useful for indoor environments such as parking lots and even tunnels.

2.5 Image/video processing

The image and video information sources, and the data processing techniques can be used for localization purposes, especially in mobile robot guidance systems [15]. In some cases, however, cameras are already available in security systems implemented in parking lots and tunnels. Commonly, these Image/Video Processing techniques are used to feed Data Fusion algorithms to estimate and predict a vehicle's location [8]. In fact, both image and video information are actual sources from which we can compute the location parameters of a vehicle.

2.6 Localization services

A Localization Service can be implemented by using any known infrastructured localization system; such as the Cricket Location-Support System [16], RADAR [17], Ultra-Wideband Localization [18], or WiFi Localization [19]. In [20], Thangavelu and al. propose a system called "VETRAC", a vehicle tracking and location identification system designed for VANets that uses WiFi access points as a communication infrastructure. The proposed system can be used in tunnels, university campuses, airports, etc.

VANets can also use Wireless Sensor Networks (WSNs) as the base for a VANet localization infrastructure. The reason for doing this is that WSNs can also be used to monitor other road variables like movement, temperature, smoke, visibility, and noise.

Thus, these networks are ideal for monitoring critical environments, as well as for emergency operations, as shown by a number of works [21]. Also, the use of sensor networks as a roadside communication infrastructure is an envisioned scenario in many Intelligent Transportation Systems. A number of WSN features can also be used to improve the performance and accuracy of an infrastructured VANet localization system. For instance, movement sensors can be used to send localization packets only when vehicles are presented.

2.7 Relative localization

By the exchange of the estimated distances between the vehicle and its neighbors, a local relative position maps can be constructed. With this dynamic position map, a vehicle can locate itself relatively to nearby vehicles as well as locate the vehicles in its vicinity [8]. This type of relative localization has been used mostly in Ad Hoc and Sensor Networks [4, 5], but recently a number of solutions [2, 6, 7] have been proposed for VANets.

3. Overview of relative localization techniques

A number of distributed relative ad hoc localization systems have been proposed recently for Ad Hoc and Sensor networks, but only a few of these [4,5] can be applied to highly mobile and dynamic networks such as VANets.

A GPS-free positioning algorithm for ad hoc networks was proposed in [4], where each node runs a self-positioning algorithm, that computes the angles between the one-hop neighbors using the inter-node distance measurements to establish a local coordinate system. Once the local coordinate systems are established, the nodes orient their coordinate system to a common coordinate system however all nodes' x, y coordinates point in the same direction.

The GPS-free algorithm, as pointed out by Iyengar and Sikdar in [5], is expensive in terms of the number of messages that need to be exchanged between nodes. Iyengar and Sikdar derived an improved version of [4], to tackle these issues, by creating an algorithm that improves scalability and convergence times. For the formation of the local coordinate system, they use the method of triangulation as in [4]. However, to keep the system scalable as the number of nodes increases, this required the formation of local coordinates at only a small subset of the total nodes (which they called master nodes).

Kukshya and al.[7] made use of the results from [5] to create a scheme for localizing neighbouring vehicles based on radio range measurements. Their goal was to establish an accurate map of the relative positions of all neighbouring vehicles. Under the assumption when vehicle does not have access information from GPS or dead-reckoning system (e.g. operating in conditions where GPS did not have line of sight). They use trilateration [9] for estimating a vehicles position.

In [6], a distributed localization algorithm is proposed to assist GPS-unequipped vehicles in estimating their positions based on nearby GPS-equipped vehicles. To estimate a position for a vehicle not equipped with GPS, it needs to communicate with at least three GPS-equipped vehicles in its vicinity in order to estimate distances and gather their positions information. When the number of nearby GPS-equipped vehicles is less than three, the author shows how to estimate at least the direction of the vehicle and the distance from an event (an accident or a danger) based on the small amount of available information. The proposed algorithm can successfully estimate the position of vehicles not equipped with GPS, but it is hard to identify situations where vehicles have network cards to communicate with other vehicles but have no GPS equipment. Also, the direction of the cars can be easily estimated by exchanging digital compass or gyroscopes information.

In [2], another distributed VANet localization system is proposed, in which distances between vehicles are estimated using RSSI and the information is used by an optimization algorithm to improve the initial position estimation of the vehicles (obtained, for instance, via GPS). This technique is primarily intended to improve GPS's initial position estimations, but since nearby GPS receivers tend to have correlated errors, estimating distances using RSSI will hardly improve the position information. However, this solution can also be used to improve positions computed via the Dead Reckoning technique during GPS outages.

4. Our approach: Localization in VANets using Clustering (LVC)

In this paper we propose a new technique, which consists to determine the positions of nodes, in a vehicular Ad hoc NETwork when no GPS information is available. It based on the clustering technique and uses the trilateration method for the establishment of the relative positions of the nearby nodes. This solution can be executed in three phases:

Phase 1: Selection of the first clusterhead to be the center of the system and calculate the relative positions of all its neighbors in the group.

Phase 2: According to the first clusterhead selected in the previous step, we choose the other clusterheads (CH) and their coordinates in the system.

Phase 3: This step will execute only if the chain of clusterheads is broken.

4.1 Phase1

To select the first vehicle « M » which will be the center of the network, any vehicle detects that no GPS information is available), it waits for a fixed delay. If during this time receives a message from a clusterhead, it becomes a node member of the clusterhead group's. Otherwise, it sends a message to say "is there any clusterhead in the approximate?" If there is no response received, it broadcasts a message to say "I am the first clusterhead".

The selected vehicle in this phase becomes the center of the network with the position (0, 0), and the positions of the other vehicles in the network are calculated on the base of this selection.

To calculate the positions of the nearby vehicles of the vehicle « M », we choose two vehicles $A, B \in V_M$ (where V_M is the set of nearby vehicles of « M » in a group of radius R = 300m) (cf. Fig. 1) such as:

- The distance between vehicles «A» and «B» (d_{AB}) is already known, (where $A \in V_B$ *and* $B \in V_A$). The neighbors can be detected by sending periodically a beacon messages. Hence, we can calculate the distances between vehicles using the technique based radio RSSI 'Received Signal Strength Indication'. We choose RSSI because probably is the most well-known, and less expensive to implemented, since it does not require any specialized hardware.
- The node «A» must be on the positive x axis of the coordinate system.
- The node «B» has a positive B_y component on y axis (Fig. 1).

  Thus, we obtain the positions of vehicles « M », « A » and « B » as follows:

$$M_x = 0; M_y = 0$$
$$A_x = d_{MA}; A_y = 0$$
$$B_x = d_{MB}\cos\alpha; B_y = d_{MB}\sin\alpha$$

Where « α » is the angle $A\hat{M}B$ and it is calculated by the following formula:

$$\alpha = \arccos\frac{d_{MB}^2 + d_{MA}^2 - d_{AB}^2}{2 d_{MB} d_{MA}}$$

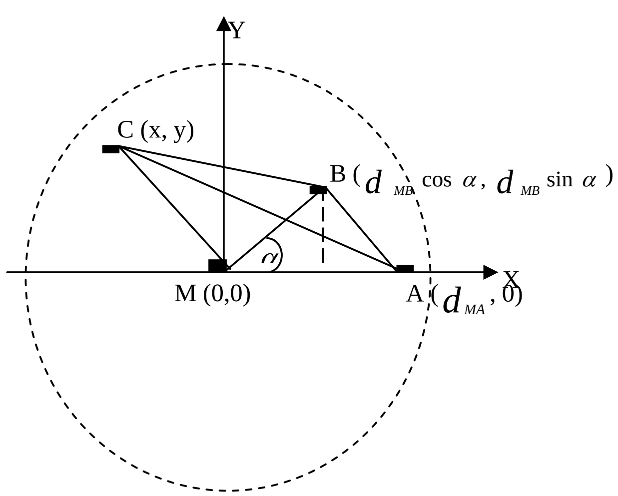

Fig.1: the calculation of the nearby positions vehicles of « M ».

To calculate the positions of the other nearby vehicles of « M » (let's take a vehicle C, $\forall C \in V_M$ *and* $C \neq A, B$) where we already know the distances d_{MC}, d_{AC} *and* d_{BC} (or $C \in V_A \cap V_B$). We use the technique of trilateration that gives the following equations:

$$x^2 + y^2 = d_{MC}^2 \ldots\ldots\ldots\ldots (1)$$
$$(d_{MA} - x)^2 + y^2 = d_{AC}^2 \ldots\ldots\ldots\ldots (2)$$
$$(d_{MB}\cos\alpha - x)^2 + (d_{MB}\sin\alpha - y)^2 = d_{BC}^2 \ldots\ldots (3)$$

$$(1) - (2) \ \Rightarrow 2 d_{MA} x - d_{MA}^2 = d_{MC}^2 - d_{AC}^2$$

$$\Rightarrow \ x = \frac{d_{MA}^2 + d_{MC}^2 - d_{AC}^2}{2 d_{MA}}$$

To determine the coordinate « y », we use the equation (1) - (3).

The calculations above show how we can calculate the position of a vehicle « C » which is a neighbor of vehicles « A » and « B». If the vehicle « C » is not a neighbor of « A » or of « B », we can calculate its position using the position of « M » and at least two other vehicles with known positions.

4.2 Phase 2

When the center of the network (vehicle « M ») builds its coordinates system and calculates the positions of all its neighbors in the group, it starts to construct the backbone formed of clusterheads. For this reason, it selects two clusterheads (CH) among the nearby vehicles. The first vehicle « M^{+1} » is for the superior level and the second vehicle « M^{-1} » is for the lower level of « M » (Fig. 2).

Both vehicles « M^{+1} » and « M^{-1} » are selected such that they verify the following conditions:

- $y_{M^{+1}} = MAX\ y_V$ *and* $D_{MV} \leq 250m$, $\forall V \in V_M$ (Due to the high mobility In VANets we choose $D_{MV} \leq 250m < R$ to avoid the fast break of the backbone)
- $y_{M^{-1}} = MIM\ y_V$ *and* $D_{MV} \leq 250m$, $\forall V \in V_M$

The two clusterheads M^{+1} and M^{-1} execute the same procedure to calculate the positions of their neighbors.

So, we use the position of M^{+1} (respectively M^{-1}) calculated by the vehicle M and at least the positions of two vehicles in the range of M and M^{+1} (respectively between M and M^{-1}) to calculate the positions of the nearby vehicles of M^{+1} (respectively M^{-1}). This gives the possibility to apply the technique of trilateration.

Finally, to calculate the positions of all the vehicles in the network, the vehicle M^{+1} (M^{-1}) must select his successor M^{+2} (his predecessor M^{-2}) (Fig. 2). The procedure will be repeated until no successor (predecessor) is found.

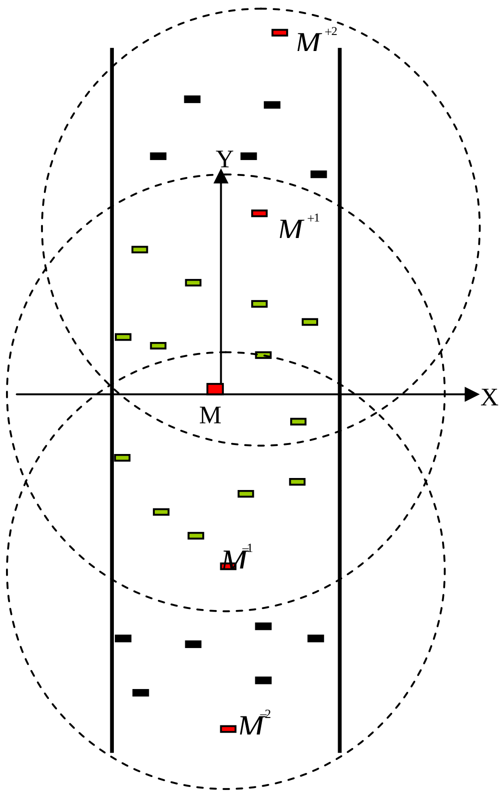

Fig. 2: The selection of master's vehicles (CHs).

4.3 Phase 3

This step can be executed in two different cases:

- As soon as the first clusterhead receives two or more than a message via the GPS, at this moment recognizes that it left the environment without GPS. Thus, it has to inform its neighbors' that it has left the tunnel (or the forest) by sending a special message. In the reception of this message, the previous clusterhead (i.e. M^{-1}) is going to take the role of the master clusterhead.
- In the second case, where the first clusterhead arrests or fails, one of its clusterhead neighbors (i.e. M^{+1} or M^{-1}) is chosen to take the role. For that purpose, each one of them starts to decrement a random timer. The vehicle sees its timer expire the first, it becomes the new center of the network.

5. Simulation results

To evaluate the performances of this technique, we use NS2 simulator [22] and the mobility generator tool IMPORTANT [23] to produce realistic mobility model.
For this reason, we have to change the number of nodes in the network (20, 30, 40, 50, and 100), and the speeds.
We also use two kinds of mobility. The first is a low mobility with a speed between 20 km/h and 50 km/h. The second is a high mobility with a speed between 80 km/h and 140 km/h.
The Fig. 3 shows for two cases of mobility: low and high, that the rate of positions calculated (RNP) is related to the numbers of nodes in the network.

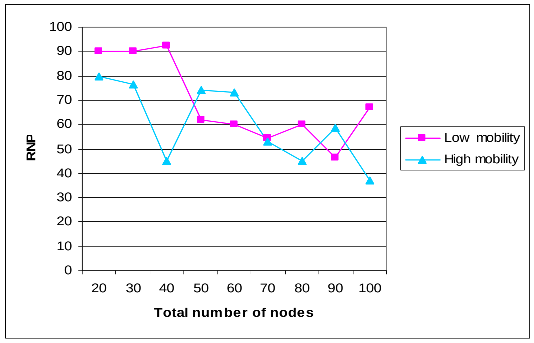

Fig. 3: Rate of positions calculated according to the total number of nodes.

For a number of nodes which varies between 20 and 40 and in the case of low mobility, we notice that RNP increases when the number of nodes increases. So, it's clear that the low variation in speed of vehicles permits the clusterhead to calculate the positions of vehicles in its domain with a low effect of the topology changes.
In the case of high mobility, the success to calculate the positions is less than the first case, due to the fast changes in topology. Generally, the rate of calculated positions decreases when the members in the group of a clusterheads change very quickly. But sometimes, we can find the opposite, for example, when the number of nodes varies between 50 and 60 the rate of success is better than a network of low mobility. We can explain that, by the fast movement of the vehicles which allows nodes to enter to another domain. Consequently, the new clusterhead can calculate their positions.
The Fig. 4 shows that RNP has an influence on the mean error and this for both cases of mobility.

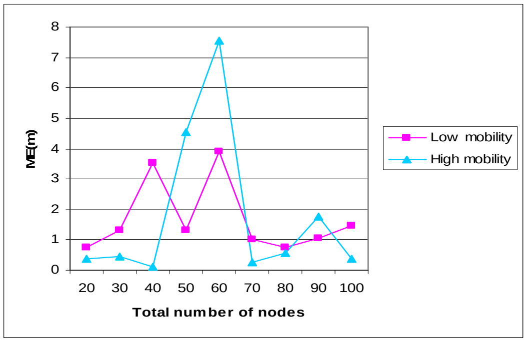

Fig. 4: Mean error according to the number of nodes.

In the case of low mobility, RNP reaches 92, 5 % with a mean error less than 4m. In the case of high mobility, the rate of positions reaches 73, 33 % with a mean error $\cong 8m$.

This can be explained by the fact that in the case of high mobility, when the clusterhead is in the process of calculating the position of a vehicle, the later moves quickly. Therefore, if we compare the position calculated by the clusterhead and the real position, we remark that errors are proportional to the speed. In the case of low mobility, vehicles move with an average speed that permits to decreasing the mean error.

The curves of the Fig. 5 show for both cases of mobility that the number of sent messages increases with the augmentation of the total number of nodes, in which confirms the smooth operation of our protocol.

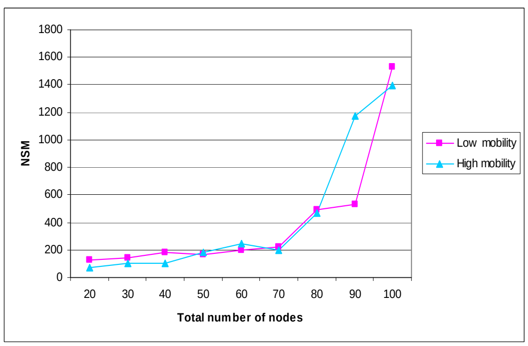

Fig. 5: Number of sent messages according to the total number of nodes.

In our algorithm, each vehicle has to broadcast a massage to calculate the distances with regarding to its neighbors. Thus, every time we increase the number of vehicles in the freeway, the number of sent messages also increases.

To evaluate the performances of LVC when the speeds change, we fixed the number of vehicles to 50 and we vary the speed between 20-40 km/h or 40-60 km/h … and 100-120 km/h.

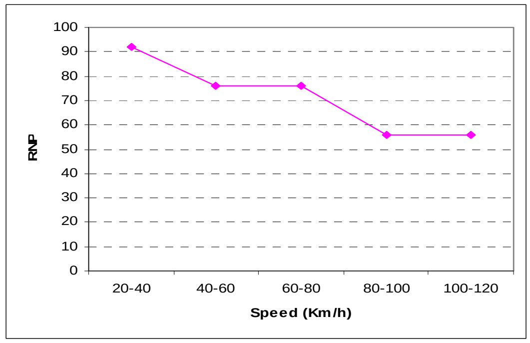

Fig. 6 Rate of positions calculated according to the speed.

According to the Fig. 6, we see that the speed of vehicles has an impact on the Rate of Nodes with Position (RNP). Thus, every time we increase the speed the RNP decreases, due to the fast change of topology. So, a vehicle being in a range of a clusterhead can leave to another range, consequently the clustehead does not calculate its position which reduces imperatively the RNP.

Finally, we compare the performances of our approach with the GPS-free positioning in mobile Ad hoc networks technique GPMAN [4]. According to this, we choose to present the rate of positions calculated (RNP) and the latency (The necessary time to calculate the positions). We remark that the obtained RNP using our method (LVC) is better than the GPMAN whatever the number of nodes (cf. Fig. 7). Also, the latency of LVC is widely better than the one obtained by GPMAN (cf. Fig. 8), due to the utilization of single global axes for the whole system which permits to avoid translations and rotations for calculating the positions of any node.

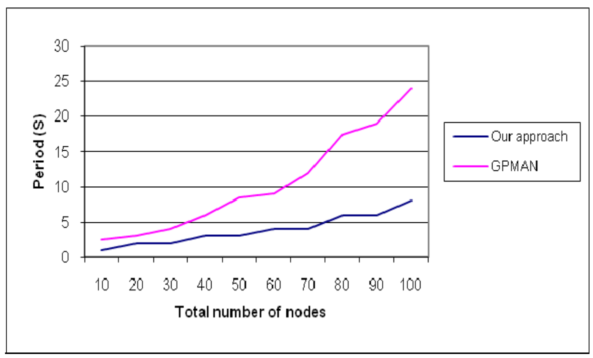

Fig. 7 Rate of positions calculated using LVC and GPMAN.

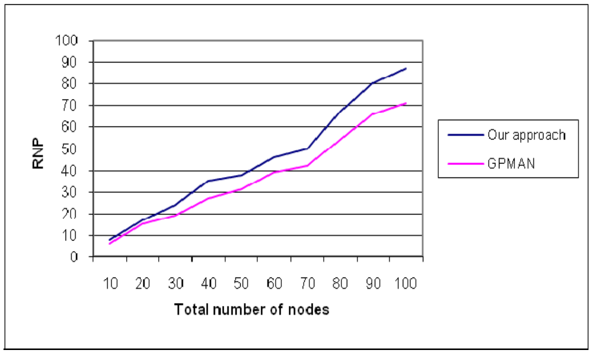

Fig. 8: The latency using LVC and GPMAN.

6. Conclusions

We have presented a novel technique of localization in vehicular networks, which permits to simplify the necessary calculations to estimate the positions of nodes.

Our solution provides certain improvements:

(i) A single coordinate system -without using the rotations and the translations of axes-, (ii) a selection of the clusterheads not random, and (iii) a technique of maintenance of the system allows changing the first clusterhead in case of failure.

We can say that the performances of our algorithm are very satisfactory and it can be useful in safety applications when GPS information is not available.

Simulation results show that the rate of calculated positions reaches at most 92,5 % with a position error does not overtake 8 m.

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