

Inter-vehicle Geocast Protocol Supporting Non-equipped GPS Vehicles*

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Abstract. IVG is a GPS-based Inter-Vehicle Communication protocol used for alarm message dissemination among vehicles in a highway in risk situations. It is based on the principle of wireless ad hoc networks. In this paper, we propose an improvement to IVG towards supporting its interoperability in environments where vehicles “GPS-U” without GPS devices are present. It is also the case, because of obstacles, where certain vehicles have GPS devices but cannot obtain their position via GPS. The proposed solution allows GPS-U vehicle to compute its position with the help of its neighbors that are equipped with GPS devices “GPS-E”. Analyses show that the optimal performances of IVG can be reached even when the rate of GPS-U vehicle is 40%.

1 Introduction

Intelligent transportation Systems (ITS) have been investigated for many years in Europe, Japan and North America, with the aim of providing new technologies able to improve safety and efficiency of road transport. Recently, the democratisation of GPS technology and the progress in mobile ad hoc networking have led to the appearance of new inter-vehicle communication protocols [1, 2, 3]. Based on the use of GPS devices, these protocols have been mainly designed for safety driving by the dissemination of urgent information, called alarm messages, in the case of accidents, fogs, etc, among the vehicles. In [1], the proposed solution called RBM Role Based Multicast was designed to overcome fragmentation in the ad hoc network composed by the vehicles and to reduce the number of redundant broadcasts of alarm messages. In [2], two other solutions were proposed, Track Detection (TRADE) and Distance Defer Time (DDT). In TRADE, each vehicle wanting to disseminate an alarm message has to determine positions and driving directions of its neighbors. DDT does not rely on neighbors maintenance, but inserts distance-based defer time slots for each rebroadcast alarm message. When a vehicle executing DDT receives an alarm message, it sets-up a timer in order to determine if it is useful to rebroadcast that message.

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In [3], we proposed IVG, Inter Vehicle Geocast, an inter vehicle message dissemination protocol that improves bandwidth utilization, reduce delays and packet loss since it avoids neighbors maintenance signalling, and overcomes fragmented networks by the use of dynamic relays.

Since all the previous proposed protocols are based on geographical positioning system (i.e. GPS), we analyze in this paper the possibility of the interoperability between GPS-equipped and GPS-unequipped vehicles in IVG, with the aim to give GPS-unequipped vehicles pertinent information about the accident. The solution is based on cooperation between GPS-E vehicles in order to help GPS-U vehicles to get their positions. Although the knowledge of the exact position is not always possible, the GPS-U vehicle can obtain some useful information such as driving direction and distance from the accident.

Several radiolocation systems have been proposed for locating the Mobiles Stations (MS) in cellular systems [4, 5, 6]. To do that, these systems use one or more of the following parameters: signal strength, angle of arrival, time of arrival or their combinations. Recently, a new algorithm Self-Positioning Algorithm (SPA) has been proposed for positioning mobile nodes in wireless ad hoc networks [7] without relying on GPS and not tacking into account inter-vehicle communication. In this paper, we propose another method for GPS-free positioning for IVG [3] taking care on urgent nature of communication. For example, in the case of an accident, vehicles without GPS have to be informed in the right moment. The algorithm should be lightweight and give to the vehicle enough accurate information about the accident. The suggested solution must be temporary while waiting for all the vehicles to be GPS-equipped in the future and the disappearance of GPS-unequipped ones.

The remainder of this paper is organized as follows. In section 2, we give an overview of IVG protocol. In section 3, we present our algorithm of GPS-free positioning for IVG. Section 4 presents a performance evaluation of the proposed algorithm. Finally, we give a conclusion in section 5.

2 IVG Presentation

IVG is mainly designed for effective alarm message dissemination in the ad hoc network of vehicles in a highway. IVG is based on geographical multicast, which consists in determining the multicast group according to the driving direction and the positioning of the vehicles. The multicast is restrained to the so-called risk areas. First, broken vehicle (or accident) begins to broadcast an alarm message to inform the other vehicles of the situation. Since the accident vehicle can just inform its one-hop neighbors, some other vehicles have to rebroadcast the alarm message to inform the vehicles located at more than one hop from the accident. The vehicle that performs the rebroadcast is called relay. Relays in IVG are designated in fully distributed manner. The way with which a node is designated as relay is based on distance defer time algorithm. The node that receives an alarm message does not rebroadcast it immediately but has to wait some time to take a decision about rebroadcast. When the defer time expires, if it does not receive the same alarm message from another node behind

it, it deduces that there is no relay node behind it. Thus it has to designate it self as a relay and starts to broadcast the alarm messages in order to inform the vehicles which could be behind it. The defer time of a node (x) receiving a message from another node (s) is inversely proportional to the distance separating them that is to favorite the farthest node to wait less time and to rebroadcast faster. The alarm message must contain some information such as accident position, previous and current positions of the relay from which the message is received. This information is used by the vehicle that received the alarm message in order to determine its location according the accident vehicle [3]. The message is relevant if the vehicle is located in a relevant area and it is received for the first time. When a vehicle receives the same alarm message before its defer timer expires, it concludes that there is another vehicle behind it which is broadcasting the same alarm message. In this situation, the second alarm message is not relevant because the vehicle was already informed about the accident by the first alarm message and it is useless to rebroadcast it because there is a relay behind it that is ensuring the dissemination of this alarm message.

The message dissemination in IVG depends on the rate of vehicles equipped with GPS device in the road. We believe that the success of IVG depends on its performances with GPS-unequipped vehicles. In the next section, we propose a solution that allows the well functioning of IVG even with GPS-unequipped vehicles. The performances of that solution depend on the rate of GPS-unequipped vehicles and on the density of vehicle in the highway.

3 GPS-Unequipped Algorithm

Since each vehicle executing IVG relies on the periodic computation of its driving direction (previous and current positions) some modifications have to be envisaged to make GPS-U vehicles know these positions when the communication with the GPS satellite is not possible. IVG can be executed normally if these positions are accurately known. However, this is not always possible. In some situations, GPS-U vehicles can't obtain their exact previous and current positions. In that case, these vehicles can't participate in the process of alarm message dissemination. However, they can obtain some information about the driving direction and the distance from the accident. This can help the driver to take decisions. For example, if the accident happens in the opposite driving direction according to the accident in a divided highway there will be no need to brake.

In order to obtain and refresh its position, a GPS-U vehicle, say S, periodically broadcasts a PREQ (Position Request) message to its one-hop neighbors. When a GPS-E vehicle receives a PREQ, it creates a PREP (Position Reply) message, includes its current position in that message, and sends it back to S. The knowledge of the exact position of S depends on the number and the positions (not all aligned) of neighbors sending PREP messages. S can compute its exact position if it receives at least three PREP from three different vehicles (Fig. 1).

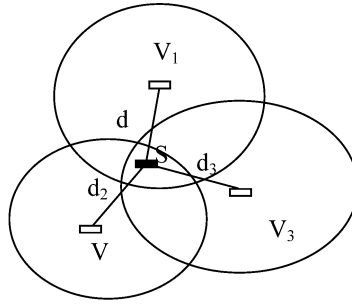


Fig. 1. Location using three non-aligned GPS-E vehicles

When S receives three PREP messages from three different vehicles, say V_1 , V_2 and V_3 , it uses a radiolocation method (i.e., signal strength) in order to determine the distances d_1 , d_2 and d_3 from V_1 , V_2 and V_3 . In this case the exact position of S can be easily calculated.

The algorithm of IVG can be executed normally if the GPS-U vehicles can compute their positions. In fact, GPS-U vehicle uses PREP messages in order to get its position instead of GPS satellite. However this is not always possible because in some cases, where the number of PREP messages is less than three, the exact position cannot be known. In what follows, we study these cases, when S receives two, one, or zero PREP.

We suppose that S receives answers when it moves from a previous position, S_p , to a current position, S_c . To allow computation of positions and driving directions of vehicles, we distinguish the following situations:

- If S has two neighbors in S_p and three neighbors in S_c , or three neighbors in S_p and two neighbors in S_c , then the exact positions can be known.
- If S has three neighbors in S_p and one neighbor in S_c , or one neighbor in S_p and three neighbors in S_c , then one exact position S_p (Resp. S_c) can be calculated. The second position, called the lacking position, is the intersection of two circles. Hence, if this intersection is in one point, the exact value of the lacking position S_c (Resp. S_p) can be known. Else, the lacking position can be one of the two points of the intersection of the two circles. In some cases, even when the exact values of previous or current positions are not accurately known, the driving direction of vehicle S can be guessed. This is the case where the two possible solutions fall in the same driving direction.

4 Simulations and Analysis

In order to evaluate the performance of the IVG-U algorithm, we model a straight road 10 km long with C lanes in each direction. Each vehicle on the road moves at a constant, randomly chosen velocity. For sake of simplicity, we do not model complex maneuvers like lane changes and overtaking. Furthermore, we uniformly distribute the number of vehicles per kilometer per lane to model the traffic density in the road.

Since the knowledge of the position of a GPS-U vehicle depends on the number of its GPS-E neighbors, we derive a formula giving the mean number of GPS-E neighbors of a GPS-U vehicle: $N(\text{GPS-E}) = \tau \cdot \left(\frac{N}{10^3 W} \right) \cdot \lceil \bar{H} - 1 \rceil$, where $\bar{H}$ is the surface covered by a GPS-U vehicle and τ is the rate of GPS-E. The mean number of vehicles per m^2 is $(N/10^3 W)$, where W is the width of the lane.

Fig. 2 shows the variation of the mean number of GPS-E neighbors of a vehicle according to the variations of the rate of GPS-E vehicles, transmission range and traffic density. We consider four situations according to the density of traffic ($N=2, 4, 6$ and 8) and four other situation according to the rate of GPS-E ($\tau = 0.2, 0.4, 0.6$ and 0.8). We remark that the mean number of GPS-E vehicles is proportional to the transmission range and the GPS-E vehicles rate. We remark that when τ is greater than 60% that the mean number of GPS-E neighbors is greater that three even with a low transmission range ($R=150$). This means that all GPS-U vehicles can obtain their positions and IVG performs well.

Two other simulations with $\tau = 60\%$ and $\tau = 40\%$ that are not included here, show that with τ around 40% and traffic density is low ($N=2$) that the mean number of GPS-E neighbors can be less than three when the transmission range is less than 250m. In this situation, the performances are not optimal since not all the GPS-U vehicles can obtain their positions. However, we can envisage that the GPS-U vehicles increase their transmission power to reach ranges more than 250m in order to get more than two GPS-E neighbors, therefore they can compute their exact positions.

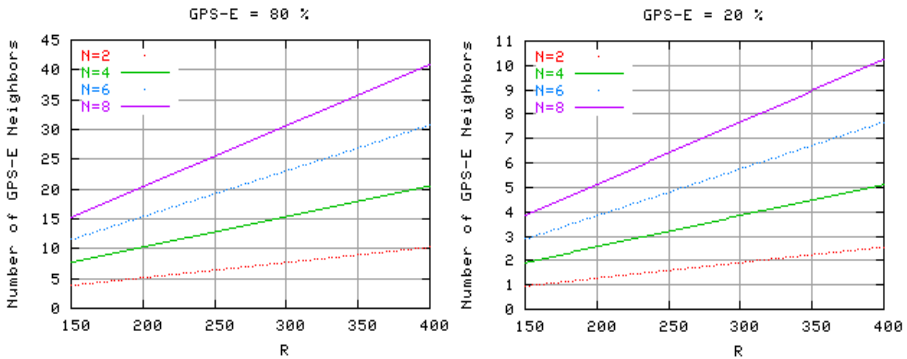


Fig. 2. The average number of GPS-E neighbors with different τ rates

For $\tau = 40\%$, curve shows that the number of GPS-E neighbors is always less than three even the transmission range is 400m when the traffic density is low ($N=2$). In this situation, not all GPS-U vehicles can compute their exact positions. Hence, these vehicles can't be relays in IVG, they are just passive elements.

5 Conclusion

In this paper, we propose an improvement to the basic IVG algorithm towards supporting its interoperability in environments where GPS-U vehicles are present. We show that the performances of IVG are optimal when a GPS-E rate is 60%. We also show that we can improve the performances of our method when GPS-E rate is 40% by the increase of the transmission range.

In some situation where GPS-E rate is less than 20%, the exact positions of such GPS-U vehicles cannot be known even with high transmission power. In that situations, we propose to let these vehicle as passive elements (they don't re-broadcast alarm messages) and we give them some information such as driving direction and distance from the accident. This information can help the driver to take decisions.

We are developing an extension to the ns-2 code of IVG in order to support the presence of GPS-U vehicles. Indeed, we believe that the performances of the proposed method are better than those presented in the mathematical analysis because in the real world some GPS-U vehicles can get their positions and help other GPS-U vehicles. This means that average number of GPS-E vehicles can be higher than the one presented in section 4. Thus the performance of IVG can be optimal even with less than 40% initially GPS-E vehicles.

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