A Multicast Protocol in Ad hoc Networks Inter-Vehicle Geocast

Abdelmalik Bachir and Abderrahim Benslimane
Laboratoire d'Informatique d'Avignon
339 chemin des Meinajaries
BP 1228 - 84911 AVIGNON CEDEX 9
Email: {bachir|benslimane}@lia.univ-avignon.fr

Abstract— **The Intelligent Transportation Systems ITS cause a significant passion since the appearance of new Inter-Vehicles Communication mechanisms based on mobile networks. The wireless ad hoc networks, completely distributed and not depending on infrastructures, allow the fast and cheap development of such mechanisms.**

This article concerns multicast in wireless ad-hoc networks applied to ITS. We propose a new protocol called IVG Inter-Vehicles Geocast which consists in informing all the vehicles of a highway about any danger such as an accident or any other obstacle. In this case, risk areas are determined according to the driving direction and the positioning of the vehicles. These vehicles define a restricted broadcast group, so-called, multicast group. Multicast group, contrary to the classical methods, which use node identities, is defined temporally and dynamically by the location, speed and driving direction of vehicles. Some simulations thanks to Glomosim tool, for which we have defined a model for the road transport, and studies of the complexity are given. The results show that IVG is an efficient broadcast method for secure highway transportation and reduces the number of useful messages.

I. Introduction

In the context of ITS, systems based on wireless communications play a fundamental role. Indeed, their use in conjunction with a geographical positioning system like (GPS) allows to overcome limitations of traditional systems (radars, video cameras) and makes possible the realization of more advanced new services. The traditional services of guidance based on the FM radio stations should become more reliable and more accurate with the introduction of wireless communications. Cooperative driving and traffic control services should also occur. A very significant role should be played for the dependability of control. Indeed, by communicating information in current time on possible emergencies (fog, accidents...), dangers can be avoided. Cooperative driving services, based on the exchange of information between the group members, that are vehicles, guarantee more comfort and dependability. Thus, exchanged data: speed, acceleration and alignments of vehicles are used to improve the safety and efficiency of vehicle flow by keeping constant inter-vehicle secure distance in all situations (sudden change of speed, etc). These data can be treated by automatic agents and used by a self-braking mechanism or be presented to the driver in a suitable way (i.e., voice). The rigor of these applications requires the establishment of real time communication mechanisms. This requirement makes the realization of such applications increasingly difficult. Work in this domain aims to inform in real time the users of a highway in case of a possible accident. This information is communicated using a broadcast of a message, called user alarm message. Recent solutions have tendency to use communication techniques of ad hoc wireless networks. The choice of ad hoc networks, contrary to cellular networks, is justified by the fact that these networks are organized without an infrastructure which avoids the blocking and the unavailability of the network as in GSM. Moreover, the total absence of infrastructure and central equipment (like routers and multiplexes) in ad hoc networks allows faster and cheaper deployment.

This work is supported by CNRS/JemSTIC grant N SUB/2002/004/DR16.

The goal of this work is to propose a more effective and scalable dissemination of the alarm message. To be more optimal, this alarm message should be addressed only to vehicles which are in risk areas of a given accident. These well defined areas, called critical areas, define the members of a multicast group.

The rest of the paper is organized as follows. Section II gives a succinct presentation of previous works on inter-vehicle communication. Our solution, IVG allowing inter-vehicles communication, is presented in section III. The simulation behavior used and obtained results are discussed in section IV. Finally, we give some concluding remarks.

II. Overview

Traditional broadcast methods proposed in literature can't be applied directly in the context of ITS. Indeed, the mobile ad hoc network composed of vehicles in a highway contains a great number of nodes with high mobility speed. For this reason, some recent solutions [2,7] have been proposed. In [2], the proposed solution called RBM Role Based Multicast, reduces significantly the number of redundant broadcasts of alarm messages. Authors consider that the vehicle having to make the repeat broadcast must be ensured of the existence of a neighbor within its transmission range. In other words, as long as it does not have neighbors it does not broadcast the alarm message. This avoids all gratuitous alarm messages. However, this method requires that each vehicle maintains a

0-7803-7757-5/03/$17.00 ©2003 IEEE.

list of all its neighbors. The maintenance of this list generates a significant overload in the network that can delay the transmission of the alarm message and causes collisions in dense networks. Moreover, as this approach does not take into account the track detection, it presents other disadvantages. The results of simulation presented in [2] shows the collapse of this solution when the ratio of equipped vehicles with such system is between 5% and 25%.

In [7], the authors propose two other schemes, TRADE and DDT, to improve the reliability of the broadcast for inter vehicle communication. TRADE TRAck DEtection allows each vehicle wanting to disseminate an alarm message to determine the positions and the driving direction of its neighbors. Thus, each vehicle broadcasting an alarm message has to designate the vehicle that has to rebroadcast after it in order to avoid the broadcasts redundancy. However, this solution requires the maintenance of the neighbors set by all the vehicles, and thus presents the same drawbacks as Role Based Multicast. In order to cope to this problem, another algorithm, called DDT Distance Defer Time, has been proposed. DDT inserts defer time slots for each message rebroadcasting. A vehicle executing DDT determines if its alarm message rebroadcast can be dropped or not after the defer time is expired. However, this algorithm does not envisage the rebroadcast of the alarm message. Consequently, it can't overcome the fragmentation that could exist in the ad hoc network composed temporally of vehicles in highways. This remark makes DDT unsuitable for a light-crowded highways, so it can't be used in emergency situations there. Simulation results in [7] show that even for a transmission range up to $2000m$ the reliability of DDT is not perfect in rural areas where the vehicle penetration rate is low.

In order to face these problems, we combined the advantages of these solutions in a new method called IVG. IVG consists in broadcasting an alarm message in effective way to all the vehicles being in risk areas. A vehicle is in a risk area if the accident is in front of it Fig.1. These vehicles define multicast group. This multicast group, contrary to the classical methods, is defined temporally by the location, speed and the driving direction of vehicles. IVG is a solution which is not based on the maintenance of neighbors list at each vehicle in the highway. This reduces the background traffic caused by hello messages exchanged between vehicles and offers more bandwidth to the alarm message dissemination. Another feature of IVG is that it also takes into account light-crowded networks. This is achieved by the rebroadcast of the alarm message by dynamic relays. These relays are self-designated with a completely distributed manner. More details for the designation of theses dynamic relays can be found in [1].

III. Effective Broadcast with IVG

A. Description of IVG

We call relevant each message that transports a relevant information to the node receiving it i.e. when the accident occurs in front of this node, and in the same driving direction if they are in a divided highway. Grayed areas in Fig. 1. show the relevant areas for a given accident. First, broken vehicle (or accident) begins to broadcast an alarm message. We remark that if node (a) were taken as relay, node (c) could not be reached because it was out of the transmission range of node (a). Against, if node (b) were selected as relay, node (c) would have been reached and informed via (b) rebroadcast. The way with which a node is designated as relay is based on the defer time algorithm described in [6] and improved in [1] for dynamic auto-designation in the context of inter vehicle communication. The node which receives an alarm message should not rebroadcast it immediately but has to wait some time, called defer time, to take a decision about rebroadcast. When this defer time expires and if it does not receive the same alarm message from another node behind it, it deducts that there is no relay node behind it. Thus it has to designate it self as a relay and starts broadcasting alarm messages to inform the vehicles which might be behind it. The defer time of 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.

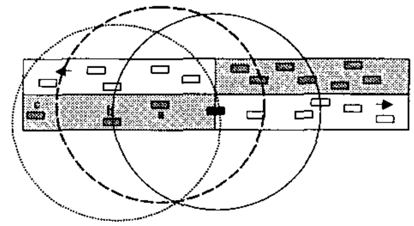

Fig. 1. Relay selection

$$defertime(x) = MaxDeferTime \cdot \frac{(R^{\epsilon} - D_{sx}^{\epsilon})}{R^{\epsilon}}$$

Where R is the transmission range and D_{sx} is the distance between the node (s) and (x). Assuming a uniform distribution of nodes over the area, the choice of $\epsilon = 2$ will set various nodes' defer times uniformly over the interval $[0, MaxDeferTime]$.

The general algorithm executed by each node receiving a broadcasted message is as follows.

when a node (x) receives a broadcasted alarm message m
  if m is not relevant
  then it is deleted
  else node (x) sets its timer according defer time algorithm
  when the timer expires it broadcasts the message if it is still relevant
  fi
end

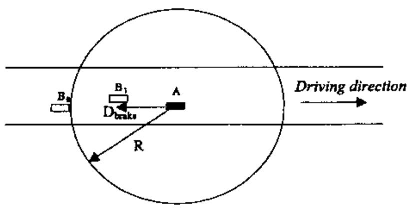

Fig. 2. $\Delta\theta$ computation

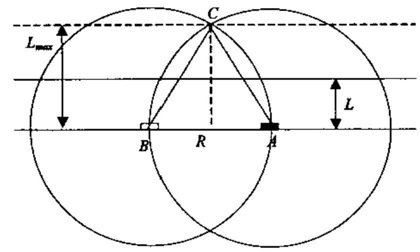

Fig. 3. Relation between R and L

For each received message, the vehicle must determine its location in report with the broken vehicle. 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 which is ensuring this alarm message dissemination.

IVG reduces the number of gratuitous alarm messages by maintaining dynamically one relay in each driving direction. In Fig.1. the relay is node (c), this relay has to overcome any fragmentation in the network by rebroadcasting periodically the alarm message. Assume that another vehicle, say (d), behind (c) receives the alarm message that (c) is broadcasting. Vehicle (d) will execute the defer time algorithm and when its timer expires it rebroadcasts this alarm message. At this time, relay (c) receives the same alarm message from (d) and stops its periodic broadcast because the relay now is (d).

In order to take into account all the cases we modelled the vehicle behaviors in a highway by a finite states machine [1]. The diagram states represent the states of vehicles (broken, waiting for time-out, etc). The transition from a state to another state is described by an event such as the arrival of an alarm message or the leaving of a risk area, etc. Moreover, the broadcast is more optimal when its period is well calculated. In order to answer the urgency of the broadcast of the messages on the one hand and to reduce the number of messages on the other hand, we have presented a technique of calculation of the rebroadcast period $\Delta\theta$ according the braking distance of vehicles. In order to determine the appropriate value of $\Delta\theta$ we need to define a region called *too much late* where the distance of a vehicle to the accident becomes less than the vehicle's braking distance. The value of $\Delta\theta$ must ensure that the vehicles are informed before penetrating in the too much late region.

we assume in Fig.2. that vehicle (B) were at the position B_0 at θ_0 and would be at the position B_1 at θ_1. The duration $\Delta\theta$ between two successive rebroadcasts must be less than $\Delta\theta_{max} = \theta_1 - \theta_0$. This is to ensure that the vehicle (B) is informed before it penetrates in the too much late region. The worst case is shown in Fig.2 where the vehicle (A) is stopped and (B) is moving with a speed V.

$$\Delta\theta_{max} = \theta_1 - \theta_0 = \frac{R - D_{brake}(V)}{V}$$

Where the $D_{brake}(V)$ is the braking distance for a vehicle moving at a speed V.

$$D_{brake}(V) = V \cdot \Delta t_{reaction} + \frac{V^2}{2 \cdot b_{max}}$$

Where $\Delta t_{reaction}$ is the reaction time of driver = $1s$. and b_{max} is the maximum deceleration = $4.4m/s^2$.

In order to make sure that the method IVG is reliable, we have checked that the broadcast covers all the space of relevance areas. For that, we established a relation between L (breadth of the road) and R (range of transmission) and checked this relation by using the values of L and R known a priori.

In the worst case (Fig.3) the vehicle (A) is broadcasting an alarm message and (B) is situated R meters far from it. The triangle ABC is equilateral. In order to guarantee that all risk area is reachable, the breadth of the highway L must be less than L_{max} where

$$L_{max} = \frac{\sqrt{3}}{2} \cdot R$$

This shows that with a transmission range $R = 150m$ we can cover a highway with a breadth L up to $129m$.

Another feature of IVG is that the length of the relevant areas behind an accident is limited to avoid infinitely dissemination of alarm messages. We believe that this way is better than the use of TTL in this situation.

B. Overhead and reliability of IVG

The goal of our method is to ensure a reliable and scalable broadcast in mobile ad hoc networks in the context of Inter-Vehicle Communication. By reliable we mean that the broadcast must cope to the defragmentation of the network so that all vehicles in risk areas are informed. To be scalable the broadcast has to be lightweight in order to reduce the network overload to disseminate the alarm messages in real time. Our method IVG achieves a reliable multicast and reduces the complexity and the overhead of methods already suggested. To compute the complexity of IVG and to compare it with the other methods, we take as metric the number of messages transmitted in the network. Regarding reliable algorithms like

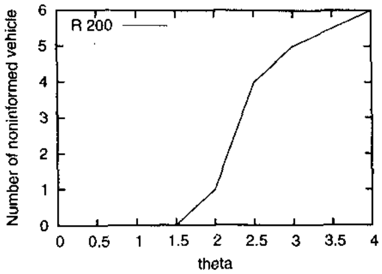

Fig. 4. The variation of $\Delta\theta$

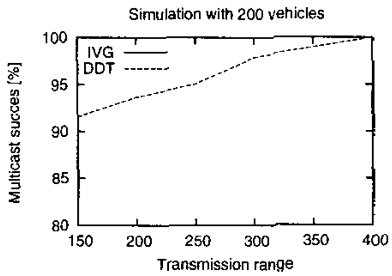

Fig. 5.

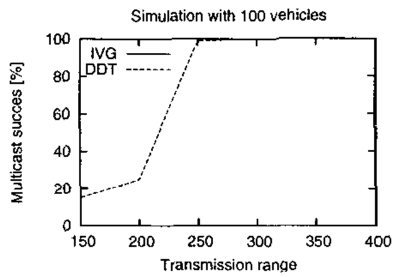

Fig. 6.

RBM and TRADE, IVG achieves the same level of reliability but it is not based on neighbors computation so all hello messages are avoided by IVG. This reduces bandwidth waste and the delay of alarm messages.

To compare our algorithm with DDT, we executed simulation tests with different penetration rates of vehicle and different transmission ranges. The results of simulations shows that DDT is not reliable in low penetration rates.

IV. Simulation

In order to evaluate the performances of the proposed method IVG, we established a model of mobility to simulate the vehicle handling in highways. We carried out series of simulations with glomosim [4]. Glomosim is a simulator of ad hoc networks developed at the university of UCLA. Results of simulations are given in [1]. We realized tests on a section of highway of a length of $10km$ and a breadth of $40m$. We used two models, one with 200 vehicle to simulate a urban highway and another with 100 vehicle to simulate a rural highway, to show the reliability of our method in both situations. We also run a simulation test to verify the appropriate value of $\Delta\theta$ given in section III. For the MAC layer we have used the IEEE 802.11. Simulations are realized in the ISM frequency band of 2.4Ghz. The size of the alarm messages used is 64 bytes and we set the maximum value of defertime MaxDeferTime to $4ms$.

In order to determine the $\Delta\theta$ value, we fixed the transmission range at $200m$, the average speed of vehicles at $125km/h$ and we varied the value of $\Delta\theta$. We measured with each $\Delta\theta$ the number of vehicles that penetrate in the too much late region before they have been informed. Results Fig.4. shows that some vehicles will penetrate in the too much late region without been informed when $\Delta\theta$ is greater than $1.5s$ which corresponds to the theoretical formula we established in section III.

We also realized another simulation series to compare the effect of the variation of the transmission range in urban and rural highways. We distributed uniformly the vehicle in highways. Vehicles move at a random speed in the interval $[V_{avg} - \epsilon, V_{avg} + \epsilon]$. V_{avg} is the average speed that we fixed at $110km/h$ and ϵ is the variation of that speed that we fixed at $15km/h$. We varied the power of transmission to obtain different transmission ranges from $150m$ up to $400m$. Simulation begins with the broadcast of an alarm message by the vehicle which makes the accident. At this moment, each vehicle being located in the multicast areas and receiving the alarm message waits during defer time period to know if it must rebroadcast the message according IVG algorithm. Simulation continues until covering all multicast areas.

We define the multicast success as the percentage of informed vehicles in the risk areas in reports to the total number of vehicles in the risk areas. We use the multicast success metric to determine the reliability of our algorithm. Fig.5 shows that when using IVG in urban highways the multicast success is 100%. This is due to the periodically rebroadcast of the alarm message by the relay. However, the DDT algorithm does not achieve the same reliability with small transmission ranges because of network fragmentation. The multicast success of DDT is less than 100% when the transmission range is less than $400m$ in urban area. This result was predictable because of the rebroadcast of the alarm messages used by IVG. The results of Fig.6 show that the use of the DDT algorithm in rural areas is dangerous especially when the transmission range is less than $250m$ and even the transmission range is greater than $250m$ the DDT does not achieve 100%. We believe that lower penetration rates exacerbate the inefficiency of DDT.

V. Conclusion

We presented in this work a new inter-vehicles communication technique for efficient alarm message dissemination based on defer time algorithm and fully distributed dynamic relay designation. With the use of GPS, IVG allows to efficiently restraint the alarm message dissemination to relevant areas. These areas define the members of the multicast group geographically. That with a double advantage, initially it enables us to avoid operations of the maintenance of the multicast tree (e.g. routing, neighbors computation, etc). These operations prove very expensive in highly dynamic environments such as transportation systems. The results of simulation obtained with Glomosim show the reliability and the scalability of IVG. We also modified the IVG to take into account vehicles without GPS equipments. Simulations are in progress and the results will be reported in a future paper. Another work in progress concerns securing communications.

REFERENCES

[1] A. Bachir and A. Benslimane, *A Multicast Protocol in Ad-hoc Networks: Inter-Vehicles Geocast*. Technical report of Computer Laboratory of Avignon, June 24th 2002.

[2] L.Briesemeister and G. Hommel.*Overcoming Fragmentation in Mobile Ad Hoc Networks*. Journal of Communications and Networks. Vol. 2, N 3. pp. 182-187, September 2000.

[3] L. Briesemeister, L. Schfers, and G. Hommel.*Disseminating Messages among Highly Mobile Hosts based on Inter-Vehicle Communication*. Proc. of the IEEE Intelligent Vehicles Symposium, pp. 522-527, October 2000.

[4] GLOMOSIM, http://pcl.cs.ucla.edu/projects/glomosim/.

[5] A. B. McDonald and T. Znati.*A Mobility-Based Framework for Adaptive Clustering in Wireless Ad-Hoc Networks*. IEEE Journal on Selected Areas in Communication, Vol. 17, N 8, August 1999.

[6] S.Y. Ni et al., *The Broadcast Storm Problem in Mobile Ad Hoc Network*. Mobicom'99 Seattle Washington USA, pp. 151-62, 1999.

[7] M. Sun et al., *GPS-based Message Broadcast for Adaptive Inter-vehicle Communications*. Proc. of IEEE VTC Fall 2000, Boston, MA, 6:2685-2692, September 2000.

[8] M. Sun, W. Feng, and T.H. Lai. *Location Aided Broadcast in Wireless Ad Hoc Networks*. Proc. IEEE GLOBECOM 2001, San Antonio, TX, pp. 2842-2846, November 2001.