Dissemination of information in inter-vehicle ad hoc networks

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***Abstract*— This paper focuses on intelligent transportation systems and more precisely on inter-vehicle ad hoc networks. Such networks are highly dynamic due to the movements of the vehicles and the short range of the wireless communications. Thus, for example, we can only rely on short interactions between the vehicles to exchange data about relevant events.**

We propose a new dissemination technique for vehicles to share information using V2V communications. Our goal is to make possible the exchange of information between vehicles when they encounter each other, taking into account the relevance of the data to the drivers. The originality of our proposal is that it relies on an encounter probability to disseminate data about any type of event (e.g., available parking spaces, obstacles in the road, information relative to the coordination of vehicles in emergency situations, etc.) in the network.

I. INTRODUCTION

Today, the car is indisputably the most heavily used mode of transportation. Unfortunately, its popularity has been accompanied by numerous problems, for example, in the areas of safety and the environment. In spite of significant efforts to reduce the number of persons dying on the roads, this number remains quite high, mainly due to the human factor (e.g., accident-prone behavior or low response time). To reduce the number of accidents, a variety of programs, generally involving "Intelligent Transport Systems", have been initiated in Japan, Europe and the United States, attracting the interest of researchers both in academia and in industry. Thanks to the resulting research, Advanced Driver Assistance Systems (ADAS) were born. Some ADAS are already available on the market (e.g., navigation systems, or warning systems to alert the driver when s/he is about to fall asleep in order to prevent her/him from crossing the center line), and many others are under development.

The wireless networks used for V2V (vehicle-to-vehicle communication) are short-range networks (a few hundred meters), which rely on standards such as IEEE 802.11 or Ultra Wide Band (UWB) [1] and provide a bandwidth in the range of Mbps. Using such communication networks, a car can receive information – for example, about accidents, traffic congestion or available parking spaces – from its neighbors. Exchanging relevant data among vehicles is an important challenge and data dissemination strategies are being studied. In [2], [3] it is claimed that neither the size and shape of the dissemination area nor the message lifetime (amount of time that the message is kept alive in the network) should be set by the vehicle generating the event; instead, it should be adaptively determined (e.g., considering the current traffic pattern) using a distributed approach. The importance of considering the relevance of events (the expected benefit in [4], [5]), especially when the bandwidth is scarce, is also mentioned. In [6], the focus is on road accidents and a zone-of-relevance is also defined.

In this paper, we propose a new dissemination technique to share information between vehicles. Other data dissemination protocols specific to V2V are being proposed (e.g., [7], [8], [9]). In [7], three dissemination protocols are studied: the *flooding* strategy (communicate all the known events to all the peers within communication range, which is a protocol with important disadvantages [8]), the *epidemic* strategy (only inform a certain number of peers), and 3) the *proximity* strategy (inform only the peers within a certain distance of the location of the event). Within the *TrafficView* project, three dissemination protocols for highway scenarios are evaluated in [9]: 1) dissemination by vehicles circulating in the same direction (*same-dir*), 2) dissemination by vehicles moving in the opposite direction (*opp-dir*), and 3) dissemination by vehicles moving in both directions (*bi-dir*). In the *Mobi-Dik* project (see, for example, [10]), an *opportunistic exchange* mechanism is proposed: a vehicle acts as a "disease carrier" and "contaminates" other vehicles with relevant data (based on temporal and spatial criteria).

Regarding the different data dissemination protocols proposed for vehicular networks, the approach presented in this paper has the following advantages: 1) it considers different types of events (e.g., mobile events, which have not been considered in other works); 2) it is a general approach (not focused only on highways or urban areas); and 3) it considers the relevance of events. Thus, for example, the dissemination strategies proposed in [7] may be suited to specific events (mainly, road hazards), but the features of different types of events (e.g., mobile events) are not considered. The work presented in [9] focuses only on highway scenarios, does not take the relevance of data into account, and does not consider different types of events. Finally, although [10] is well adapted for cars to share information about available parking spaces (which is their case study), it has not been designed to deal with other types of events (e.g., to relay information about an accident or an emergency braking).

Thus, the originality of our solution resides in the ability to disseminate any type of event. Since different events may require different dissemination mechanisms, in principle, an interesting solution for one type of event may be not useful for another type. For instance, some events have to be disseminated in a spatio-temporal area (e.g., parking spaces) because they are relevant to all the vehicles driving in that area, whereas diffusion chains have to be established for other types of events (e.g., accidents) since the direction of the vehicles has then to be considered. A major concern of our work is also to avoid flooding to ensure the correct transmission of the messages in the inter-vehicle network.

The rest of this paper is organized as follows. Section II describes the representation of events in our solution. Section III explains how the encounter probability, a key element in our approach, is calculated. Section IV presents our dissemination technique and some experimental evaluations. Finally, Section V offers our conclusions and gives some ideas for prospective research.

II. Representation of Events

To date, existing V2V solutions have considered only a small subset of the possible types of events, primarily focusing on stationary events. However, numerous types of events –both mobile and stationary– are possible in the context of inter-vehicle communication, since there is a lot of information that drivers may find relevant; for example, about accidents, traffic congestion, emergency braking situations, fuel prices, available parking spaces, emergency vehicles such as ambulances, obstacles in the road, or the behavior of drivers (e.g., strange maneuvers due to intoxication or lack of vigilance), to name but a few possibilities. Data about the events occurring on the road or available resources such as parking spaces have to be communicated to a potentially large set of vehicles, depending on the relevance of the data to the drivers. For simplicity, not only all kinds of events but also road hazards and available resources are called *events* in this paper. In the following, we describe how the events are represented when they are created[1]:

- Each event is first characterized by a unique *Key*, generated by concatenating a unique vehicle identifier (for example, its MAC address) with a locally unique event identifier.
- A *Version* number is also attached to distinguish between different updates of the same event. Once generated, an event is disseminated among a set of potentially interested vehicles. To update the information transmitted to other vehicles, for example because a mobile event has moved, the vehicle which created the event may produce a new version of the event.
- An *Importance* is associated to each event, which helps to determine whether the information should be presented to the driver or not. For example, if a vehicle approaches an available parking space, the driver is informed only if such information has been requested. On the contrary, if a vehicle receives a message indicating an accident a few hundred meters ahead in the direction of travel, it is essential to warn the driver, and so the importance field should so be set to the maximum value.
- The *CurrentPosition* attribute indicates the time and place corresponding to the generation of the event.
- Two different preceding reference positions and their timestamps (*DirectionRefPosition* and *MobilityRefPosition*) are also stored. These markers allow each vehicle to receive information to evaluate the mobility and direction of an event (see Section III-A), which is necessary in order to estimate the event's relevance.
- The *LastDiffuserPosition* contains the position of the last vehicle which relayed the message. It is used by the dissemination protocol (see Section IV).
- The *HopNumber* attribute indicates the number of rediffusions of the message (see Section IV).
- Finally, a *Description* field describes more precisely the represented event (e.g., accident, emergency braking, etc.). This field is used to transmit concrete information to drivers when they need to be warned.

The value of the reference positions (*MobilityRefPosition* and *DirectionRefPosition* attributes) correspond to former positions of the event. They are used to estimate its direction and speed, as we will further explain in Section III. When dealing with a stationary event, the *MobilityRefPosition* will always be equal to the value of the *CurrentPosition* attribute. Similarly, for non-direction-dependent events the value of *DirectionRefPosition* will be set to null to allow the identification of such a type of event. All the position attributes (*CurrentPosition*, *DirectionRefPosition*, and *MobilityRefPosition*) are GPS statements, which avoids synchronisation problems between the vehicle clocks (GPS time is used).

III. Computing the Relevance of Events

One of the major problems in V2V communications is determining the relevance of an event to a specific receiving vehicle. In this section, we first show how the data describing an event is exploited to compute a four-dimensional mobility vector (3 dimensions for spatial coordinates and one for the temporal dimension). Then, we introduce the notion of encounter probability, which is used to estimate whether or not a vehicle is expected to encounter an event, in order to decide if the event needs to be considered.

A. Mobility & Direction Vectors

To estimate the direction of a moving object, we use vectors that run between a preceding position (called the "reference position") and the object's current position. These vectors are used to situate vehicles as well as mobile events. First, the position of object A at time t is expressed as:

[1]We do not consider Human Machine Interface (HMI) aspects in this paper. The creation of the events may be initiated by devices embedded in the vehicles (for example, by coupling the airbag system with the creation of an event representing an accident).

$$P_A(t) = \begin{pmatrix} x_{A_t} \\ y_{A_t} \\ z_{A_t} \\ t \end{pmatrix}$$

where x_{A_t}, y_{A_t} and z_{A_t} are the geographical coordinates of object A at time t. The mobility vector for object A between t_1 and t_2 is thus defined as:

$$V_A(t_1, t_2) = P_A(t_2) - P_A(t_1) = \begin{pmatrix} x_{A_{t_2}} - x_{A_{t_1}} \\ y_{A_{t_2}} - y_{A_{t_1}} \\ z_{A_{t_2}} - z_{A_{t_1}} \\ t_2 - t_1 \end{pmatrix}$$

Each vehicle is able to compute its own mobility vector. By applying this vector to the current vehicle position, an estimation of its future position is obtained:

$$P_A(t_{n+i}) = P_A(t_n) + V_A(t_{n-i}, t_n)$$

The estimated future position is highly dependent on the time interval selected between two position statements. Thus, if t_n and t_{n-i} are far away, the estimation of the future position is not precise but provides an overall impression of the object's direction. If the time interval is shorter, then the estimation is much more precise on the short term but no global view of the displacement can be observed. As an example, see arrows A and B in Figure 1.

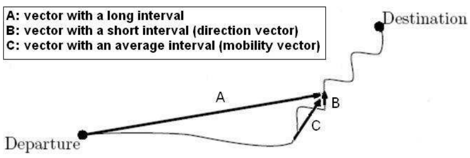

Fig. 1. Mobility and direction vectors

Depending on the way we select the time interval $[t_{n-i}, t_n]$, we distinguish:

- The *mobility vector*, whose role is to provide an overall impression of the object's movement in addition to a good estimated future position. To achieve a good compromise between the previous two cases (arrows A and B in Figure 1), an "average" interval must be used to compute it (see arrow C in Figure 1).
- The *direction vector*, which is computed with a short interval. It provides a quite precise estimated future position but only in the very short term.

Similarly, each vehicle can compute the *mobility and direction vectors of the events* it receives. For that purpose, it uses the data associated to the events, and more precisely the *CurrentPosition* attribute and either the *DirectionRefPosition* or the *MobilityRefPosition* attribute, respectively.

For each event, the *vehicle's mobility vector in relation to the event* is computed by changing the frame of reference (see Figure 2). The mobility vectors of one vehicle and one event are represented on the left side of the figure, and the mobility vector after the frame of reference has been changed is shown on the right side. With the change of reference, the computation of the encounter probability is simplified since a single vector needs to be managed for each couple <vehicle, event>, regardless of the type of event.

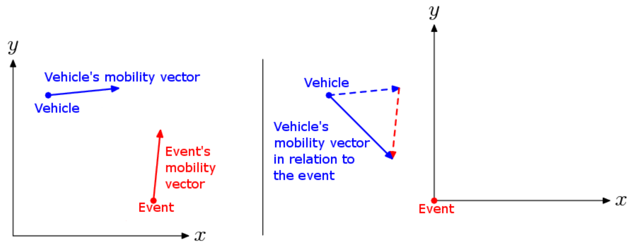

Fig. 2. Change in the frame of reference

To explain how this change of reference is computed, let us consider the mobility vectors of a vehicle A between t_{A_1} and t_{A_2} and of an event B between t_{B_1} and t_{B_2}:

$$V_A(t_{A_1}, t_{A_2}) = \begin{pmatrix} x_A \\ y_A \\ z_A \\ \Delta t_A \end{pmatrix}, V_B(t_{B_1}, t_{B_2}) = \begin{pmatrix} x_B \\ y_B \\ z_B \\ \Delta t_B \end{pmatrix}$$

The first step is to modify the mobility vectors in order to manage the same time basis (fourth dimension) for both vectors. So, we obtain the following vectors:

$$V'_A(t_{A_1}, t_{A_2}) = V_A(t_{A_1}, t_{A_2}) \times \Delta t_B$$

$$V'_B(t_{B_1}, t_{B_2}) = V_B(t_{B_1}, t_{B_2}) \times \Delta t_A$$

Then, we subtract the two vectors to obtain the mobility vector of vehicle A in relation to event B:

$$V_{AB}(t_{A_1}, t_{A_2}, t_{B_1}, t_{B_2}) = \begin{pmatrix} (x_A \times \Delta t_B) - (x_B \times \Delta t_A) \\ (y_A \times \Delta t_B) - (y_B \times \Delta t_A) \\ (z_A \times \Delta t_B) - (z_B \times \Delta t_A) \\ \Delta t_A \times \Delta t_B \end{pmatrix}$$

In the case of a stationary event, the mobility vector of the event is the null vector (whatever the time basis is):

$$V_{AB}(t_{A_1}, t_{A_2}, t_{B_1}, t_{B_2}) = \begin{pmatrix} x_A - 0 \\ y_A - 0 \\ z_A - 0 \\ \Delta t_A \end{pmatrix} = V_A(t_{A_1}, t_{A_2})$$

These vectors can then be used to compute an encounter probability to determine whether a vehicle will meet or not an event, as we describe in the following.

B. Encounter Probability

Using the mobility vector of the vehicle in relation to the event, the position of the vehicle, and the position of the event, we can deduce four elements which have an influence on the encounter probability:

- The minimal geographical distance between the vehicle and the event over time (Δd).
- The difference between the current time and the time when the vehicle will be closest to the event (Δt).
- The difference between the event's generation time (stored in *CurrentPosition*) and the moment when the vehicle will be closest to it (Δg, *event's expected age*).
- The angle between the direction vectors of the vehicle and the event (denoted by a colinearity coefficient c).

As an example, Figure 3 shows the geometrical representation of Δd and Δt in a certain scenario. To facilitate the graphical representation of the mobility vector in relation to the event, we have chosen to consider a stationary event in the example, but the principle would be the same with a mobile one. In figure 3, B represents the vehicle position, C the event position, and $\overrightarrow{AB}$ is the mobility vector of the vehicle in relation to the event. Point D can then be determined, which allows a right-angled triangle to be constructed in D with $[BC]$ as hypotenuse. D is the closest point to C on the straight line between A and B. $|DC|$ (= Δd) represents the minimal geographical distance between the vehicle and the event over time. $|BD|$ is the distance between the vehicle and point D. As the mobility vector $\overrightarrow{AB}$ has a temporal dimension, Δt can be obtained from $|BD|$.

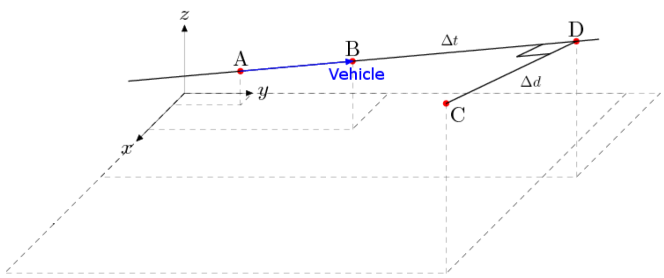

Fig. 3. Geometrical representation of Δd and Δt

Finally, as mentioned previously, the vehicle is able to estimate its direction vector and the event's direction vector. These two direction vectors produce a *colinearity coefficient* (c), which is a measure of the angle formed by these vectors. For direction-dependent events, this allows us to determine whether the directions of the vehicle and the event match. For non-direction-dependent events (identified because the *DirectionRefPosition* attribute is null), c is set to 0.

Once these Δd, Δt, Δg, and c values have been calculated, they are used to estimate an "encounter probability" between a vehicle and an event. The encounter probability (EP) is a value between 0% and 100%. It is computed, based on the previous values, using the following function:

$$EP = \frac{100}{\alpha \times \Delta d + \beta \times \Delta t + \gamma \times \Delta g + \zeta \times c + 1}$$

where α, β, γ and ζ are penalty coefficients with values ≥ 0. They are used to balance the relative importance of the Δd, Δt, Δg, and c values. The bigger the coefficient is, the more penalized the associated value is when computing the encounter probability. For example, the greater the α value, the shorter the spatial range where the event is relevant. Coefficients β and γ are used so that only the most recent information and the information about events that will be encountered in a short time is considered. Finally, ζ is used to weight the importance of the colinearity coefficient.

The encounter probability allows us to determine the relevance of an event. The greater the probability, the more likely the vehicle is going to encounter the event. In the following section, we show how the encounter probability can be used to adapt the events broadcast between vehicles.

IV. Dissemination Protocol

We have primarily designed the encounter probability to determine whether an information contained in a message received on a vehicle should produce a warning for the driver. In this paper, we do not consider the moment when the warnings have to be produced but rather want to demonstrate that the EP can also be used to disseminate information between vehicles. Our objective as concerns the dissemination protocol is to ensure that each vehicle for which an information is interesting will receive it. In the following, we first highlight the advantages of our dissemination solution, and then we evaluate experimentally these benefits.

A. Adaptive Dissemination Area

One of our main objectives is to disseminate different types of events (accidents, emergency brakings, available parking slots, etc.) in the inter-vehicle network. Thus, we have to support different dissemination modes. For example:

- An accident has to be diffused only to the vehicles driving in its direction.
- An emergency braking, like the accident, has to be diffused to the vehicles driving in a particular direction. Nevertheless, whereas the information should be relayed far away from the place where the accident took place in the first case, it should only be relayed a few hundred meters away in the case of an emergency braking.
- An available parking slot has to be transmitted to all close vehicles, whatever their direction, as it may interest them.

The use of the EP to determine the vehicles which have to rediffuse an information they received allows to diffuse the messages in the right direction, that is, towards the vehicles for which these messages may be relevant. This also ensures that the information about an event is maintained close enough to be relevant during the dissemination phase. For instance, the information about an available parking space would not be interesting for the persons driving several kilometers away from it. Therefore, in our dissemination solution, each time a vehicle receives a message, it computes the EP for the corresponding event. If the value obtained is bigger than a certain *diffusion threshold*, it has to rediffuse the message. Otherwise, it does not consider the message. Thus, while the event is considered relevant by a vehicle in a particular area, it is relayed to the neighboring vehicles.

Besides, the EP also avoids the dissemination of obsolete events. The information diffused for the events evaluated in this paper (parking space, emergency braking, etc.) is only relevant for a short period of time. So, we focus our description on the way to reach the interested vehicles that must be informed about the event, rather than on the problem of trying to keep an information in the network during a given period of time. For events with a longer lifetime (e.g., an accident), it is possible to adapt the value of the corresponding penalty coefficient γ in order not to penalize too much the EP with the age of the event. Anyway, for long-duration events, new versions of the same event have to be produced to continue informing the arriving vehicles. Thus, messages to indicate the termination of events are not required.

B. Limited Bandwidth Use

To avoid flooding, our solution aims at desynchronizing the rediffusions. Since the value of the EP may be greater than the diffusion threshold used for many vehicles, it is necessary to limit the number of diffusions of a single message. Therefore, each vehicle will wait for a period t before rediffusing the message. The length of that period depends on the distance between the receiving vehicle and the one which sent the message. The intuition behind this is to choose, among the neighbors which received the message, the farthest neighbor from the sender to relay the message. Indeed, this farthest neighbor may have the greatest number of neighboring vehicles not yet informed about the event being transmitted. It is so the best candidate to try to broadcast the message to all concerned vehicles as quickly as possible. Each vehicle determines the value of t as follows:

$$t = D \times (1 - \frac{d}{r})$$

where D is the maximum time to wait before rediffusing, r is the communication range of the wireless network used by the vehicles to communicate (e.g., 200-400 meters), and d corresponds to the distance between the receiving and the diffusing vehicle. The value of d is computed using the *LastDiffuserPosition* attribute stored in the message. Since d may vary from 0 to r, t is between 0 and D.

This approach allows a message to propagate far from the origin (if needed) and, at the same time, minimizes the number of duplicated messages received by the vehicles. An alternative where the sending vehicle decides which neighbor should rediffuse would be unrealistic, as this would require that the vehicles track the locations of their neighbors

It should be noted that, upon reception of a message, a vehicle has to avoid rediffusing such a message if it has rediffused it already before. It may happen also that none of the vehicles receiving a message about an event determines it relevant enough, after computation of the EP, to rediffuse it. Similarly, it may occur that there is no vehicle receiving the message because no vehicle is within range of the sending vehicle. To overcome these situations we use the following approach. Each time a vehicle diffuses a message, it waits during D seconds. Then, if it did not receive the message during that interval, it will periodically resend it until another vehicle estimates the event relevant and so diffuses it also. The *HopNumber* attribute (see Section II) is increased every time a vehicle relays a message, and it is used to determine if a message received is actually a rediffusion. In that case, it should not be rediffused again.

C. Experimental Evaluation

Due to the difficulty of testing in a real environment, we chose to evaluate our solution on a simulator. Choosing which simulator to use was a big challenge. It had to allow us to represent the environment, to define different routes for vehicles, to integrate various speeds and traffic conditions, and to collect all the information we need to evaluate our proposal. We studied the various simulators available (e.g., NS2[2], GloMoSim[3] and JiST-SWANS[4]), but it proved difficult to implement and evaluate our solutions on those simulators. In the end, we chose to develop our own simulator.

In our experiments, we used 1 second for D, 75% as diffusion threshold, and a communication range r of 200 m. Through experimentations, we chose values for the penalty coefficients that provide good results for different road configurations (inspired by real maps of Valenciennes, in France): α = 0,0033, β = 0,0010, $\gamma = 10^{-8}$ and ζ = 0,25.

Thanks to the results of our simulations, we could first observe that all the vehicles received the relevant events before meeting them, whatever the position of the event (straight line, curve, etc.). However, in this paper we focus on the evaluation of the efficiency of the dissemination protocol. Thus, our goal is to evaluate the number of messages emitted using our solution, to ensure that a message is not lost during its dissemination, even if there are not many vehicles driving. Moreover, we also want to evaluate the time needed to deliver a message to a vehicle with our approach. In the following, we compare our solution with two others. The first one is based on a flooding technique. The second one performs a periodic flooding, motivated by the fact that some messages are lost with a traditional flooding when the traffic density is low (as we will indicate later). With periodic flooding, the messages are so rediffused periodically.

We consider a single event and evaluate the different aforementioned dissemination strategies. In Figure 4, we present the total number of messages diffused at each second since the generation of the event in a scenario with low traffic density (about 1 vehicle every 100 meters). In Figure 5 we consider a scenario with high traffic density (about 1 vehicle every 10 meters). We can observe the following:

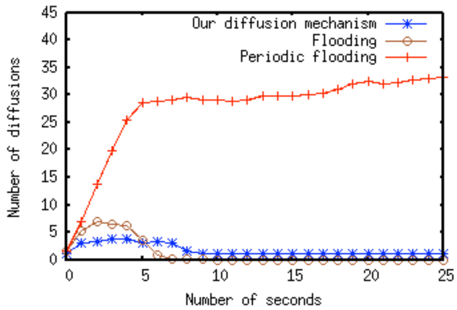

Fig. 4. Evolution of the messages exchanged in low traffic conditions

- Even with only one event, our dissemination solution strongly limits the number of messages exchanged.
- With our dissemination mechanism and traditional flooding, the number of messages decreases after a few

[2]http://www.isi.edu/nsnam/ns/
[3]http://pcl.cs.ucla.edu/projects/glomosim/
[4]http://jist.ece.cornell.edu/

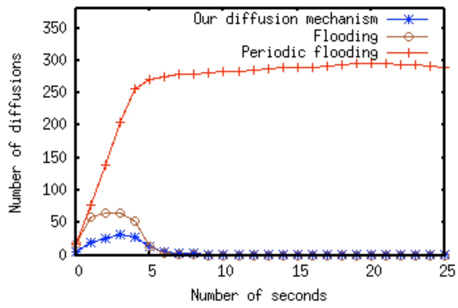

Fig. 5. Evolution of the messages exchanged in high traffic conditions

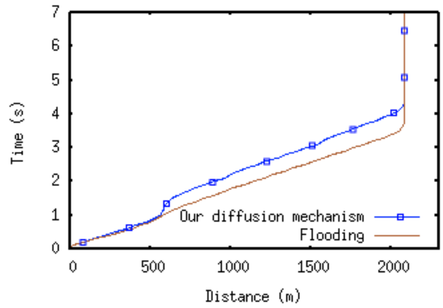

Fig. 7. Time needed to receive a message in high traffic conditions

seconds because the tail of the diffusion chain has been reached (the event is not considered relevant enough by the farthest vehicles to be rediffused).

- With the approach based on traditional flooding, the number of messages reaches 0 after a few seconds, and so the information about the event stops propagating. Therefore, a periodic flooding would be required.
- With our dissemination approach, the rediffusion of the message continues at the tail of the diffusion chain[5] as long as the EP is enough (according to the age penalty coefficient associated to the event). Therefore, the previous problem is solved by our approach.

Since our solution may introduce waiting times at each hop of the dissemination process, we also wanted to evaluate this additional cost. Thus, Figure 6 (for low traffic density) and Figure 7 (for high traffic density) show, for the different dissemination approaches, the times needed for the vehicles to receive the information according to the distance separating those vehicles from the event. Using our dissemination mechanism, the vehicles receive the information about the event a little more late. Nevertheless, the additional cost is limited, even in the worst case (i.e. when the traffic is low), and enough time remains available for the driver to react according to the information transmitted to her/him.

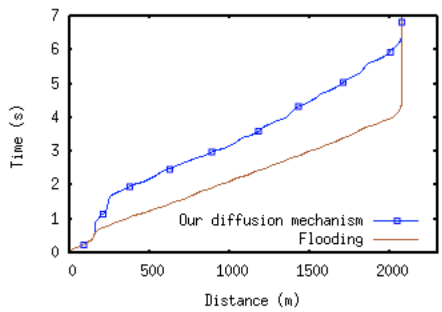

Fig. 6. Time needed to receive a message in low traffic conditions

V. Conclusions & Perspectives

We have presented a unified approach for disseminating data about different types of events in a vehicle network. Our proposal is based on the concept of encounter probability, which is computed to estimate the relevance of the events. As far as we know, this is the first proposal that does not focus only on a particular type of event. Moreover, our experimental results are promising, as they show that the drivers receive the interesting events early enough and, at the same time, the cost of the dissemination protocol is limited.

We are currently testing adaptive penalty coefficients to allow a wide-range dissemination (e.g., information about an accident, to allow other vehicles to change their itinerary).

Acknowledgements

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[5]Even if it does not appear clearly in figure 5 due to the scale, a few messages are still diffused after 10 seconds.

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