Estimating the Relevance of Information in Inter-Vehicle Ad Hoc Networks*

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Abstract

This paper focuses on intelligent transportation systems. Specifically, we look at data management issues in 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. Consequently, new data management techniques adapted to this context are needed.

More precisely, we propose a new technique to estimate the relevance of data to the drivers. The originality of our proposal is that we identify and classify the different types of information that may be shared on the roads (e.g., available parking spaces, obstacles in the road, information relative to the coordination of vehicles in emergency situations, etc.). We then propose a unified solution to support all those types of information. Our experimental evaluation shows the feasibility and interest of our approach.

1 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. Despite significant efforts to reduce the number of persons dying on the road, this number remains quite high, mainly due to the human factor (e.g., accident-prone behavior or impaired reaction 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, 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.

At the same time, wireless networks have proliferated, which has made inter-vehicle communications (IVC) possible. The primary objective of IVC is to improve road safety by developing aids for drivers by exchanging information between vehicles in close proximity. For example, IVC could be used to inform drivers that an accident has occurred or that an obstacle has appeared on the road a few hundred meters ahead. As concerns data management for IVC, there is a fundamental difference with the driver assistance systems already available on the market, such as navigation systems. Indeed, navigation systems only exploit static data, such as points of interest (for users to easily locate an airport, a restaurant, etc.), stored on a memory card. Technologies such as Traffic Message Channel (TMC) [6] can be integrated directly into a navigation system to deliver non-static data such as traffic and travel information (e.g., accidents) to drivers, but IVC aims at sharing much more dynamic data between vehicles, both temporary and mobile events (emergency braking, available parking spaces, etc.).

Two communication modes are distinguished for IVC applications in the literature. The first, vehicle-to-vehicle communication (V2V), relies on spontaneous information exchanges between vehicles; the second, vehicle-to-infrastructure communication (V2I), uses a communication infrastructure to deliver information to vehicles or for vehicles to communicate information to the fixed network (e.g., in fleet tracking applications). Though such infrastructures

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were the norm in early works about communicating vehicles (e.g., the VICS project[1]), their widespread diffusion on the roadside is not to be expected in the near future, as they require an expensive infrastructure with global coverage. For this reason, the majority of existing projects focus on V2V communications. The only recent works that still rely on a communication infrastructure use V2I communication only for secondary communications – for example, to provide vehicles with Internet access [14] – and not for crucial safety purposes.

The wireless networks used for vehicles to communicate are short-range networks (about a hundred meters), which rely on standards such as IEEE 802.11 or Ultra Wide Band (UWB) [9] and provide 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. Though it is possible to use wide-range networks, like the ones used for mobile telephony (GPRS/UMTS/...), to access distant services or databases providing information on the road network, they suffer from a lack of dynamism in addition to a limited bandwidth (a few hundred Kbps). With such wide-range communication mechanisms, information about an emergency braking situation involving a preceding vehicle cannot be shared early enough to allow a following vehicle to avoid a collision. Nevertheless, they can be used to provide access to distant services, such as web services delivering information about fuel prices.

In this paper, we propose a general framework and technique to estimate the relevance of the events received by the vehicles in a network. A dynamic inter-vehicle context with a very intermittent network connectivity (e.g., two vehicles within range of each other can move at high speeds in opposite directions) creates truly interesting data management challenges. In such dynamic environments, data access depends on inter-vehicle information exchanges. Data is received from other vehicles and stored locally in a data cache. Then, query evaluation techniques can be used to sift through the stored information to determine what is relevant for that time and location, and inform the driver when necessary. In this case, query evaluation is greatly simplified since it is mainly local. However, it is difficult to determine which data is relevant. Both the spatial and temporal aspects of the information must indeed be verified. For example, in the case of information about an available parking space, an interested car must determine: 1) whether it is close enough to the reported parking space, and 2) whether the parking space became available recently enough and so it is probably still empty. The main contributions of our work are:

- Event classification – We classify the different events that may occur on the roads, taking every type of possible event into account in the same solution. Even mobile events, which are neglected in other works, such as the appearance of an emergency vehicle (e.g., a police cruiser, an ambulance, or a fire engine) requiring other vehicles on the road to give way, are considered.

- Relevance evaluation – Our technique is able to evaluate the relevance of the information exchanged between vehicles by defining four-dimension mobility and direction vectors, computed for both vehicles and events. These vectors are used to determine the probability of encounters between a vehicle and an event.

- Experimental evaluation – Our proposal has been strongly evaluated. The results are promising, as the drivers are notified in time of the interesting events.

The rest of this paper is organized as follows. Section 2 presents some related works. Section 3 describes our event classification procedure for inter-vehicle networks, including the representation of events. Section 4 explains how the encounter probability is calculated. Section 5 presents the results of our experimental evaluation. Finally, section 6 offers our conclusions and gives some ideas for future work.

2 Related Work

Inter-vehicle communication is a recent field of research. Nevertheless, some studies have already made significant contributions. In the following, we indicate some of them.

In relation to network protocols, the FleetNet project [5] (2000-2003), followed later by the NoW project[2] (finishing at the end of 2007), and CarTalk [2] (2001-2004) worked to exploit inter-vehicle communications to make driving safer. Both FleetNet and CarTalk used multi-hop communication techniques, but while FleetNet was supported by a partial fixed infrastructure [7], CarTalk used no existing infrastructure. Those are very interesting projects which focus mainly on the network level of inter-vehicle communication. They use Geocast communication protocols [3, 10], which allow to determine the geographical area where messages have to be conveyed, either through direct inter-vehicle communication or via multi-hop communication.

Recently, research has focused on data management and data dissemination rather than on specific network protocols for IVC. For example, we would like to highlight:

- In the context of the *TrafficView* system [11, 12], the authors consider vehicles moving on roads with multiple lanes on each direction. They present different dissemination protocols for periodically broadcasting the data stored in a vehicle with a single network packet,

[1] http://www.vics.or.jp/english/

[2] http://www.network-on-wheels.de/

using data aggregation techniques. In [1], the authors study how to determine the *dissemination area*, which is the area where the data should be broadcast.

- In [8], the authors explain that the network connectivity is a limiting factor for information dissemination, since chains of vehicles are needed for broadcasting and a low traffic density may become a problem. The authors so make a clear distinction between data transport via locomotion (vehicles' movements) and via wireless communications to manage such situations. This distinction is also considered in the context of multi-hop routing protocols [17] with a *carry and forward* strategy, which aims at keeping the information stored on a car until it can be transmitted to another one. In the same category of solutions, we would also like to mention [15], which exploits the mobility of vehicles to disseminate data.

- In the *Mobi-Dik* project [16], the techniques used to disseminate data do not require multi-hop communications. They are in fact much closer to the field of epidemiology. A vehicle with a certain piece of information acts as a disease carrier, and "contaminates" the nearby vehicles along its route. Once contaminated, these vehicles proceed to contaminate others. The relevance of the information is monitored (based on temporal and spatial criteria) in order to decide whether it should be stored in the cache and/or broadcast later on.

- In [13], the authors focus on how to disseminate relevant geospatial information (mainly road hazards). They propose a dissemination strategy that they say to be similar to the opportunistic exchange proposed in Mobi-Dik. They also introduce interesting metrics for efficiency such as *ignorance* (not knowing about a hazard found by the vehicle) or *redundancy* (receiving irrelevant information).

Summing up, the main goal of existing V2V communication solutions is to limit the number of messages exchanged to avoid overloading the network, which is indeed crucial if the correct functioning of the applications is to be guaranteed. The existing protocols and dissemination techniques mentioned above are interesting. Nevertheless, they only focus on how and when the information relative to events (accidents, obstacles, etc.) or resources (available parking slots, etc.) should be disseminated to other vehicles. Existing solutions are all specific to a particular type of event, presented as an application example, and thus cannot support other event types. For instance, Mobi-Dik provides a very interesting solution to the problem of information-sharing inside a restricted spatio-temporal area. Although the techniques proposed in Mobi-Dik are very well adapted for sharing information between cars about available parking spaces, they cannot be exploited to relay information about an accident or an emergency braking situation. As opposed to these works, our final goal is to be able to use a single data sharing approach valid for all types of events, in order to deploy a generic system into cars. In this paper, we focus on a key element to achieve this: how to estimate the relevance of different types of events. For the moment, we use this relevance to report the events to the interested drivers when necessary. In a future work, we will also use this relevance as a basis for data exchange between vehicles.

3 Events and Data Representation

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, since there is a lot of information that drivers may find relevant, 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[3]), to name but a few possibilities. In order to determine the relevance of events, it is first necessary to classify the different types of events. In the rest of this section, we propose a system of event classification and describe how these events are represented in our work. For simplicity, not only all kind of events but also road hazards and available resources are called *events* in the following.

3.1 Event classification

The solution that we propose in this paper not only supports stationary events, such as the presence of gas stations, but also mobile events, such as an emergency vehicle asking preceding vehicles to yield the right of way. When supporting such mobile events, the set of vehicles for which the event information is relevant evolves according to both the movements of the mobile event (in the example, the emergency vehicle) and the other vehicles involved (in the example, the preceding vehicles). None of the solutions presented in Section 2 supports mobile events. Besides, the direction of traffic is also of major importance in establishing the relevance of shared information, even for non-mobile events (e.g., consider a traffic jam affecting only the vehicles moving in one direction).

So, we classify inter-vehicle network events in four different categories: 1) *stationary, non-direction-dependent events*; 2) *stationary, direction-dependent events*; 3) *mobile,*

[3]Lack of vigilance, or hypovigilance, can be detected today with oculometers using techniques that essentially count the driver's number of eye blinks.

non-direction-dependent events; and 4) *mobile, direction-dependent events*. By *direction-dependent events* we mean events that are not relevant for all nearby vehicles, but only for the vehicles traveling in a particular direction. On the other hand, *mobile events* are (as explained before) events whose location change along time.

Let us illustrate our classification system by giving some examples. Available parking spaces correspond to stationary, non-direction-dependent events since they are static and may interest all vehicles close to that resource, regardless of the direction of movement. A warning about an accident is a stationary, direction-dependent event because its location is fixed and only those vehicles that are expected to encounter the accident will find the message relevant. The vehicles close to the accident but moving in the opposite traffic stream should ignore the message so as not to distract the driver and cause a second accident. Messages warning vehicles of the lack of vigilance of a person driving on a two-way road is a mobile, non-direction-dependent event because it concerns all vehicles likely to meet such driver, regardless of their direction of movement. Finally, an emergency vehicle broadcasting a message for other vehicles to yield the right of way is a mobile, direction-dependent event. Our goal in proposing such a classification of events is to support, in the same solution, all the types of events which can occur on the roads.

3.2 Data Representation

In the following, we describe how the events are represented when they are created[4]:

- Each event is identified by a *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 each event 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. This attribute 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; in this case, the importance field should so be set to the maximum value.
- The *CurrentPosition* attribute indicates the time and location 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 4.1), which is necessary in order to estimate the event's relevance.
- 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.

[4]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).

Notice that the type of the event (stationary or mobile, direction-dependent or not) is not explicitly represented as an attribute of the event. Indeed, the type of event can be easily deduced using some of the other message fields. Each type of event is managed in the same way when received on a vehicle. On the contrary, when an event is generated, its type has to be known in order to fill the right attributes before transmitting the information to other vehicles. More precisely, the value of the reference positions (*MobilityRefPosition* and *DirectionRefPosition* attributes) depends on the type of event considered. In fact, these positions correspond to former positions of the event and will be used to estimate its direction and speed, as we will further explain in Section 4. When dealing with a stationary object/event, the *MobilityRefPosition* will always be equal to the value of *CurrentPosition*. Similarly, for non-direction-dependent events the value of *DirectionRefPosition* will be set to null to allow the identification of such type of event. Finally, we would like to highlight that *CurrentPosition*, *DirectionRefPosition*, and *MobilityRefPosition* represent GPS statements, thus avoiding synchronisation problems between the different vehicle clocks (GPS time is used).

4 Computing the Relevance of Events

One of the major problems in V2V communications is determining the relevance of an event to a receiving vehicle. In this section, we first show how the data describing an event is exploited to compute a four-dimensional mobility vector (three dimensions for the spatial coordinates and one for the temporal dimension). Then, we introduce the notion of encounter probability, used to estimate whether a vehicle is expected to encounter an event or not in order to decide if the driver should be informed about it. We have chosen to use no navigation system or roadmap. Although this could improve the precision of our proposal, it also presents some difficulties (see Section 4.2). Thus, our main goal is to prove the usefulness of the encounter probability.

4.1 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:

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

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.

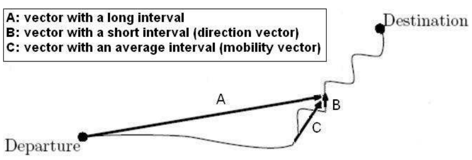

Figure 1. Mobility and direction vectors

Depending on the way we select the time interval $[t_{n-i}, t_n]$ (see Section 5), 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.

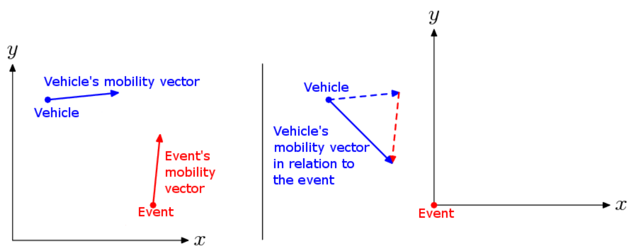

Figure 2. Change in the frame of reference

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. We so 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.

4.2 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, *expected age of the event*).
- 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 consider a stationary event, but the principle would be the same with a mobile one. In the figure, 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 the point D. Since the mobility vector $\overrightarrow{AB}$ has a temporal dimension, $|BD|$ can be converted into time to obtain Δt.

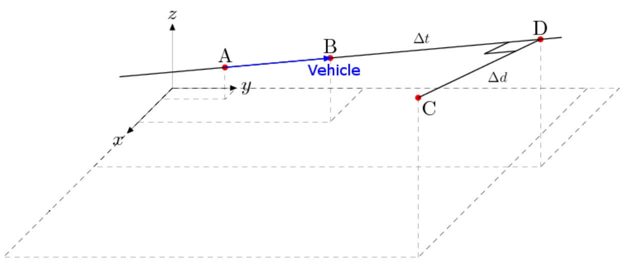

Figure 3. Representation of Δd and Δt

As explained previously, the vehicle estimates its direction vector and the event's direction vector. From these two direction vectors, a *colinearity coefficient* (c) is obtained, which is a measure of the angle formed by the 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:

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

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 valued is when computing the encounter probability. For example, the greater the α value, the shorter the spatial range where the event is relevant. β and γ are used so that only the information about events that will be encountered very rapidly and the most recent information is considered. Finally, ζ is used to weight the importance of the colinearity coefficient. Notice that if the vehicle is moving away from the event, then Δt is 0 and Δd is the current distance to the event. Therefore, the computation of the EP makes sense even in cases when an interesting event (e.g., a parking space) is behind us.

If a digital map is available and the driver's route is known, the values of Δd, Δt, Δg, and c could be computed with more precision (based on the map, the route, and a road-based distance measurement [4]). However, digital maps are not always available. Moreover, the intended route of the vehicle could be unknown. Even more importantly, in the case of mobile events, the expected route of the event will not be available, which would make the computation of the EP using the maps difficult.

The encounter probability allows to determine the relevance of an event. The greater its value, the more likely the vehicle is going to meet the event. Thus, an event will be reported to a driver if the EP exceeds a given threshold.

5 Experimental Evaluation

Due to the difficulty of testing our approach in a real environment, we analyzed several simulation tools (e.g., NS2[5], GloMoSim[6] and JiST-SWANS[7]), but it proved difficult to implement and evaluate our solutions on those sim-

[5] http://www.isi.edu/nsnam/ns/
[6] http://pcl.cs.ucla.edu/projects/glomosim/
[7] http://jist.ece.cornell.edu/

ulators. So, we finally decided to develop a new simulator adapted to our needs. Among other features, our simulator allows us to represent realistic environments, simulate different types of events, define different routes for vehicles (e.g., roads with different curve profiles), set up speeds and traffic conditions, etc. To evaluate our approach, we collect information regarding when the vehicles report the events to the drivers, and when the vehicles meet the events.

For simplicity, we assume that all the events are diffused using a flooding-based strategy. This assumption does not affect our goal, which is to prove the usefulness of the encounter probability to report the drivers about interesting events. Defining a suitable diffusion strategy (e.g., considering the computed EP and the traffic density) is out of the scope of this paper and is part of our current/future work.

Between 500 and 600 vehicles, with random trajectories, are simulated in each experiment. The speed of the vehicles varies between 90 km/h and 110 km/h, depending on the road (e.g., vehicles slow down in a curve). The results presented in this section correspond to simulations performed using two different road configurations representing highways or main roads (see Figure 4). The first one gives us a more precise view whereas the second one corresponds to a part of the route between the cities of Valenciennes and Lille (in France). We considered six different events, located in strategic places, to evaluate our solution. All the events are stationary and direction-dependent, except *event5*, which is stationary and non-direction-dependent.

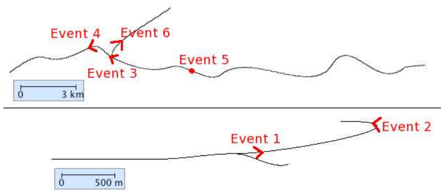

Figure 4. Itineraries and events simulated

Through experimentation, we have chosen suitable values for the penalty coefficients: α = 0.0033, β = 0.0010, $\gamma = 10^{-8}$ and ζ = 0.25. These values provide good results whatever the road configuration is. Similarly, based on experiments, we decided to compute mobility vectors using position statements performed every 500 meters, and direction vectors using position statements every 30 meters.

In the simulations, we measured the percentage of vehicles which presented a warning to the driver before meeting the event (a driver is warned if the encounter probability computed is greater than 75%). The vehicles that do not meet the event are not considered in the computation of this percentage. In Figure 5, we present the evolution of warned vehicles as a function of the reaction time available before meeting the event (no vehicle travels on the road of *event6*, and so it does not appear in the figure since – as desirable – it is never reported). We draw the following conclusions:

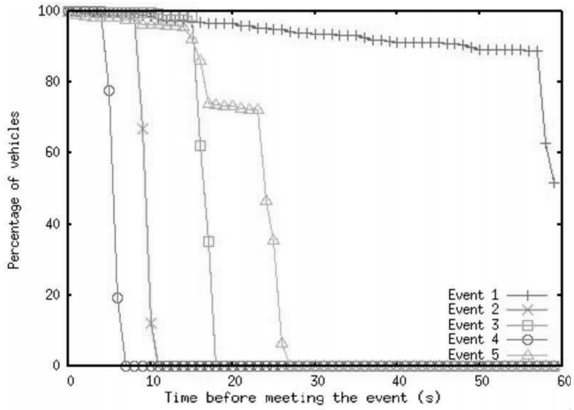

Figure 5. Percentage of vehicles informed

- For *event1*, located on a straight road just after a sliproad, all the vehicles which encountered the event presented a warning to the driver and more than 93% of them had transmitted that warning 30 seconds before meeting the event. In that configuration, many vehicles generated a warning even if they never met the event. However, this was expected. Since this event is really close to the intersection of two roads, all the vehicles which turned on the right before encountering *event1* had already generated a warning. Fortunately, those vehicles reevaluated *event1* as no more relevant very quickly after turning right (after about 2 seconds).

- *Event2* is located on a very strong curve. Despite the difficulty of this situation, the percentage of vehicles which transmitted a warning to the driver remains very high. The drivers reduce their speed in the curve, which gives them extra time to react (although the warnings are generated later than in other cases).

- The results obtained for the event *event3* confirm the good results obtained for *event1*.

- The results obtained for *event4* are not satisfactory, with a warning generated only 4 seconds before meeting the event for most vehicles. This event is located after a strong change of direction, which is a very difficult situation. Thus, the encounter probability reaches the threshold of 75% very late. Fortunately, this situation improves by using *adaptive vectors*, which implies choosing the reference positions used to compute the mobility and direction vectors according to the distance separating the vehicle and the event. This allows us to limit the impact of the direction changes by improving the accuracy of the estimated direction as the vehicle gets closer to the event. In this way, the warning is generated about 8 seconds in advance (so the drivers have more time to react). This is shown in Figure 6, where adaptive vectors are also examined for *event2* (the other event located on a strong curve). We can conclude that adaptive vectors can be very useful in situations with strong changes of direction.

- *Event5* is considered relevant earlier than *event2*, *event3*, and *event4*, as the travel direction does not penalize in the case of non-direction-dependent events.

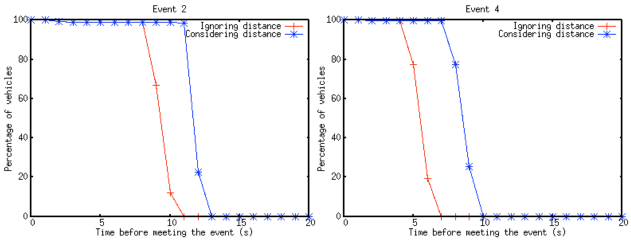

Figure 6. Benefits of adaptive vectors

To summarize, the results obtained are rather satisfactory: The vehicles present a warning to the driver in time, whatever the road configuration.

6 Conclusions

We have presented a unified approach for managing 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 really promising.

We are currently developing a robust dissemination protocol that takes the encounter probability into account and we have already obtained some encouraging results. This is indeed a crucial point since we have to guarantee the correct transportation of messages to the vehicles, whatever the traffic conditions are (number of vehicles driving, congestion, etc.). We also plan to evaluate our proposal in other scenarios and with different types of events.

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