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Event sharing in vehicular networks using geographic vectors and maps

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Abstract. By exchanging events in a vehicular ad hoc network (VANET), drivers can receive information that allows them to find relevant places (e.g., parking spaces) or avoid dangerous/undesirable situations (e.g., an accident or a traffic jam). However, developing this kind of information services for drivers calls for new data management approaches, such as an appropriate dissemination protocol and some mechanism to decide when a driver should be alerted.

In this paper, we present a data management solution for event exchange in vehicular networks and compare two different approaches for relevance assessment. The first approach relies on the computation of geographic vectors to estimate the relevance of events, whereas the second approach exploits digital road maps. We also describe a prototype that has allowed us to test our proposals in a real environment. Moreover, we present an exhaustive simulation-based experimental evaluation that proves the usefulness of exploiting the information stored in digital road maps for data management and sharing in vehicular networks, which is an important novelty regarding existing works. The experiments also show that the first approach can also be used with a good accuracy, although smaller in some situations, in cars where maps are not available.

Keywords: Vehicular ad hoc networks, data management, event relevance estimation

1. Introduction

In the last few years, intensive research efforts are being developed in the area of transportation, mainly motivated by safety issues and technological improvements. Besides research focusing on enhancing vehicle applications such as navigation systems for vehicles (e.g., see [4,31,40]), exchanging dynamic data (i.e., data whose relevance can change very quickly) in a vehicular network using *Inter-Vehicle Communications* (*IVC*) is a hot topic nowadays [23,32,37]. Thus, thanks to the development of wireless networks and portable computers/devices, two vehicles nearby (within communication range of each other) can exchange interesting data, such as information about both static and mobile events (e.g., an emergency braking, an available parking space, a driver exhibiting risky behavior, etc.). Other communication schemes can also be considered, based on a fixed infrastructure or mobile telephony networks (e.g., 3G). Thus, even if it may be unrealistic to assume the availability of a generalized wide-area fixed infrastructure in the next years, mobile telephony networks already offer new perspectives for the development of applications to assist drivers. Anyway, such solutions, based on a centralization of the data and decision processes, still suffer from issues such as poor scalability or low reaction time available when dealing with some events like an emergency braking. Therefore, we focus in the following on

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vehicular ad hoc networks, although it is important to emphasize that this does not prevent the possibility to benefit also from a wired backbone (when available) as proposed in [30].

As an example, *VESPA* (*Vehicular Event Sharing with a mobile P2P Architecture*) is a system developed to share information about events in inter-vehicle ad hoc networks [13]. Data are received from other vehicles and stored locally in a *data cache*. Then, query evaluation techniques are used to sift through the stored information to determine what is relevant according to that time and location, and issue a warning or transmit information to the driver when necessary. Two main challenges in VESPA, as well as in other data sharing approaches for vehicular networks [25,28], are how to decide which data are relevant to the driver and how to transmit data to potentially interested vehicles.

In this paper, we focus on the concept of Encounter Probability (EP), whose goal is to determine whether an *event* (e.g., a traffic congestion) or a *resource* (e.g., an available parking space) is relevant to a vehicle, by using both spatial and temporal criteria. Thus, the EP is a measure of the likelihood that the vehicle will meet the event in the future. Such an EP can be used to filter, among the events received, those events that are relevant to the vehicle and so may be also relevant to the driver [12]. The EP can also be used by data dissemination protocols. In [6], we introduced a dissemination protocol able to handle the diffusion of a wide variety of events in the network. This protocol relies on the assumption that an event relevant to a vehicle may also be relevant to its neighbors. The EP is then used at each hop in the network to determine the relevance of the event. Summing up, the main contributions of this paper are the following:

- *We propose a general data management architecture for vehicular networks*. The architecture proposed allows exchanging data in vehicular networks and processing the data exchanged on the vehicles. One of the important components of the architecture is an *Encounter Probability Evaluator*, which computes the EP between a vehicle and the events received.
- *We propose a method to compute the EP based on the use of geographic vectors* (approach 1). This method simply considers the Euclidean space and thus does not rely on the availability of road maps or other information about the environment.
- *We propose a method to compute the EP based on the use of digital road maps* (approach 2). This method exploits the information available in digital road maps to try to compute the EP in a way that can be used more effectively. It is important to emphasize that the use of digital road maps for relevance assessment has not been considered so far in the literature.
- *We perform an experimental evaluation to test and compare both proposals*. The experimental results show the interest of the approaches and allow us to draw conclusions about the advantages and disadvantages of each alternative.

The structure of the rest of this paper is as follows. In Section 2, we describe the basics of the data management approach that we propose, which relies on some technique to compute the EP between a vehicle and an event. In Section 3, we summarize an approach to compute the EP based on the management of geographic vectors. In Section 4, we describe a new proposal that benefits from the use of digital road maps. In Section 5, we evaluate and compare experimentally both proposals. In Section 6, we present some related works. Finally, in Section 7 we summarize our conclusions and indicate some ideas for future research.

2. General data management approach

In this section, we describe the basic aspects of the general data management approach that we propose for exchanging data in vehicular networks and processing the data exchanged on the vehicles. Firstly, in Section 2.1 we present the different types of events that we consider. Secondly, in Section 2.2 we describe the way the information about the events is represented. Thirdly, in Section 2.3 we present the general architecture proposed for data management in vehicular networks. Finally, in Section 2.4 we explain how the events are disseminated and processed once received by the vehicles.

2.1. Types of events

Based on mobility features, we distinguish different types of events: direction-dependent vs. non-direction-dependent, and mobile vs. stationary. As opposed to other proposals, our proposed system not only supports *stationary events* (e.g., the presence of available parking spaces) but also *mobile events* (e.g., 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 is relevant evolves according to both the movements of the vehicle generating the event (in the example, the emergency vehicle) and the other vehicles involved (in the example, the preceding vehicles). 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, some events are *direction-dependent events* and others are *non-direction-dependent events*.

Besides, an orthogonal classification of events, considering attraction and repulsion events, is also proposed. *Attraction events* are events that the driver would like to meet (e.g., parking spaces, petrol stations, etc.) according to her/his current interests/goals, even if this means that s/he has to change her/his current route. As an example, a driver approaching downtown for a business meeting would be interested in parking spaces nearby even if they are not just in front of her/his final destination. As another example, an unavailable taxi driver could release an event reporting other taxis about a person looking for a taxi, and this event could potentially be relevant to any taxi nearby (independently of its direction). On the contrary, *repulsion events* are events that should be avoided whenever possible because they imply driving difficulties (e.g., accidents, traffic jams, a slippery road, fire on the road, a vehicle driving in the wrong direction, etc.).

Finally, we could also distinguish between *events* and *resources*. An event and a resource differ in the sense that competition between vehicles may appear in the case of resources (e.g., parking spaces). In the rest of the paper, we will use the term event to refer to all types of events, since we do not want to focus on competition management here. The interested reader can consult [14,15] for more information about parking spaces allocation and competition management in VANETs.

2.2. Representation of events

The different types of events mentioned previously are represented uniformly in our approach. Specifically, the following attributes are used to represent the events and generate messages exchanged between vehicles to assist the drivers when necessary:

- A *Key* (composed of a unique identifier of the vehicle, such as its MAC address, plus a local event identifier) identifies the event.
- A *Version* number allows to distinguish between different updates of the same event (e.g., used to refresh the location of a mobile event or to remind that a long-lived event still exists).
- An *Importance* value helps to determine the urgency of presenting that information to the driver (e.g., an emergency braking has a higher importance than an available parking space).

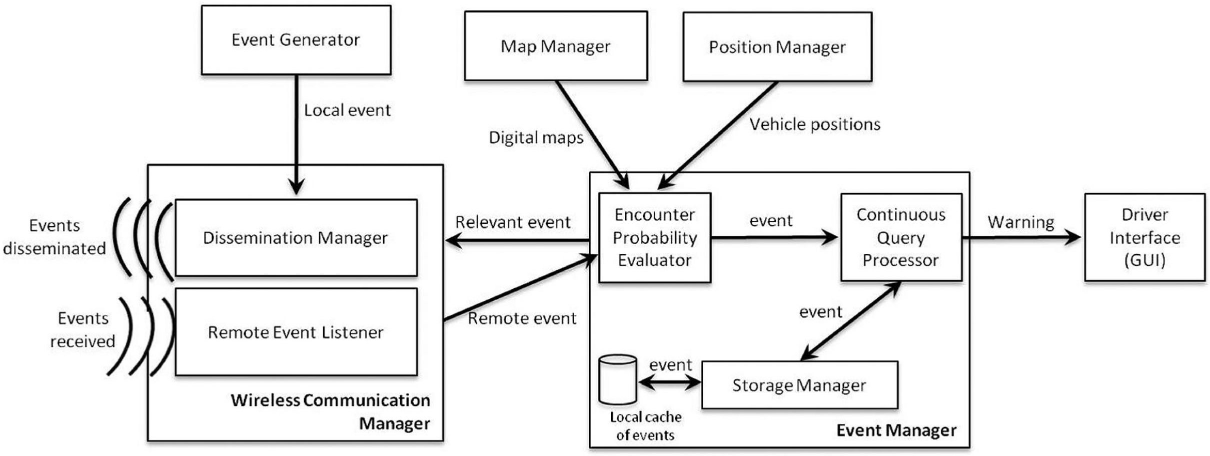

Fig. 1. General data management architecture.

- A *CurrentPosition* field indicates the time and place corresponding to the event. Using the GPS time on each vehicle allows to avoid synchronisation problems between the clocks of the different vehicles.
- A *Description* field contains further information for the driver.

Other additional attributes will be introduced throughout the paper depending on the relevance assessment approach considered. Specifically, in Section 3.2.1 we introduce the attributes *DirectionRefPosition* and *MobilityRefPosition* for the approach based on geographic vectors, and in Section 4.2 we introduce the attribute *initialTTL* for the approach based on digital road maps. All these attributes could be part of the representation of an event, which would enable vehicles to use any of the two relevance assessment approaches proposed.

It could be interesting to mention that we plan to enrich the structure of events by adding semantic information (by considering the RDF/XML exchange syntax for the Web Ontology Language OWL), which will help the vehicles to interpret unambiguously the information exchanged (e.g., the *Description* field) and could also facilitate the interoperability between different systems (e.g., developed by different car manufacturers). However, for the purposes of this paper the structure of events presented in this section is enough.

2.3. General architecture for data management in vehicular networks

The general data management architecture that we propose, which is deployed on every equipped vehicle, is presented in Fig. 1, where the following main elements can be distinguished:

- The *Wireless Communication Manager* is in charge of the reception and transmission of events. This module is composed by the *Dissemination Manager*, which allows the vehicle to broadcast events, and the *Remote Event Listener*, which is responsible for the reception of events transmitted by neighboring vehicles.
- The *Event Manager* handles the events received by the vehicle. It is composed of the *Continuous Query Processor*, which processes *active continuous queries* representing the driver's interests (e.g., a driver is informed about available parking spaces only if s/he specified her/his interest in that type of event) by using an *Encounter Probability Evaluator* (based on geographic vectors or digital road

maps, as described in Sections 3 and 4, respectively), and the *Storage Manager*, which is in charge of deciding about the storage and removal of events in a local cache.
- The *Driver Interface* is the graphical user interface used to interact with the driver (e.g., showing information about relevant events).
- The *Position Manager* interacts with the GPS receiver of the vehicle to retrieve information regarding the location of the vehicle.
- The *Map Manager* is in charge of managing digital road maps containing information about the roads in the surroundings of the vehicle. This module is only needed when the approach based on digital road maps is used to compute the *Encounter Probability* (see Section 4).
- Finally, the *Event Generator* releases events detected by the vehicle. The generation of many events could be initiated using the numerous sensors embedded in modern cars (for example, by coupling the airbag system with the creation of an event representing an accident) or via other static data sources (e.g., sensors on a road). This will prevent a driver from disseminating false information to her/his own benefit (ensuring the reliability of messages manually generated by drivers is out of the scope of this paper and considered in works such as [29]).

In the following, we explain briefly the way the different modules interact:

1. An event received by the Remote Event Listener is communicated to the Encounter Probability Evaluator. The Encounter Probability Evaluator computes the *Encounter Probability* between the vehicle and the event, which is a measure of the likelihood that the vehicle will meet the event in the future, based on information provided by the Position Manager. Additionally, the information provided by the Map Manager can also be used if the information stored in digital road maps is exploited as described in Section 4. The relevance of an event may change continuously due to the different dynamic factors affecting the computation of the Encounter Probability (such as the distance to the event), whatever the method used to compute it. Therefore, the Continuous Query Processor, using the Encounter Probability Evaluator, evaluates periodically the active continuous queries to verify which events must be reported to the driver through the Driver Interface. For this, each event for which the Encounter Probability is higher than a certain *relevance threshold* (see Section 2.4) must be checked against the set of active continuous queries. Additionally, some events representing dangers on the road (identified by a high value of the *Importance* field, described in Section 2.2) are reported to the driver immediately, even if there is no query asking for those data.
2. The Storage Manager is informed by the Query Processor about the probabilities computed by the Encounter Probability Evaluator. If the Encounter Probability of a previously stored event is smaller than a certain *storage threshold* (see Section 2.4), then the Storage Manager removes the event from the local cache. On the contrary, if the Encounter Probability of a new event is greater than the storage threshold, the event is stored.
3. For a new event received, in case its Encounter Probability is higher than a certain *diffusion threshold* (see Section 2.4), the Dissemination Manager is contacted by the Event Manager to broadcast the event and inform other vehicles.

It should be emphasized that our focus on this paper is on the software side, and more specifically on the data management issues involving the *Event Manager* component, instead of on networking aspects. However, in other previous works, we have also proposed a data dissemination approach aiming at minimizing the network overload [6].

2.4. Management of events

To share information in VANETs, different protocols have been proposed over the last years. All these protocols have to control both the number of messages exchanged and the delivery of the information to the interested vehicles. For example, in [6], we proposed a dissemination protocol whose goal is to carry different types of events in the vehicular network (e.g., available parking spaces, emergency vehicles, traffic congestions, etc.) to the potentially interested vehicles. To achieve this, it is necessary to adapt the dissemination of an event according to its type. Thus, for example, the information about an available parking space may be interesting for all vehicles around, whatever their direction. On the contrary, the information relative to an emergency braking or a traffic congestion should be delivered only to the vehicles driving towards that event. In [6], we used the concept of Encounter Probability (EP) to adapt the dissemination chain of an event according to its type. Thus, each vehicle receiving an event estimates its relevance by computing the EP and then relays it only if such event is considered relevant. In addition, we introduced in the proposed protocol features to limit the number of times a single message can be relayed, in order to avoid network flooding.

Thus, once an event is received by a vehicle, this vehicle reacts based on the comparison of its EP with three different thresholds, the *relevance threshold* (RT), the *storage threshold* (ST, with $ST \leqslant RT$), and the *diffusion threshold* (DT):

- If $EP < ST$ then the (potential) relevance of the event for the vehicle is not enough. Therefore, the event is discarded.
- If $EP \geqslant ST$ then the event is considered relevant to the vehicle and it is stored in the vehicle's data cache. Additionally, a warning will be communicated to the driver if and only if: 1) $EP \geqslant RT$ (which means that *the event is relevant to the vehicle* at that moment), and 2) either the *Importance* of the event is high (e.g., it is an accident) or the driver has specified her/his interest in that type of event (i.e., *the event is relevant to the driver*).
- Besides, if $EP \geqslant DT$ then the vehicle relays the message it received about the event. The diffusion threshold is used by the dissemination protocol proposed in [6]. The basic idea of this protocol is that a vehicle should diffuse a message about an event if it estimates it relevant enough. In that case, the probability that the event is also relevant to its neighbors is indeed high. Thus, an event will keep being disseminated to neighboring vehicles while it is considered relevant for dissemination in a particular area. Besides, this dissemination strategy relying on the EP also ensures the adaptation of the *diffusion chain* according to the type of event. For example, an event representing a traffic congestion will only be diffused to the vehicles driving towards it; on the contrary, a notification about an available parking space will be relayed to all the vehicles in the vicinity of that resource, whatever their direction.

It should be noted that a distinction between events that are *relevant to the vehicle* and events that are *relevant to the driver* is made, emphasizing the importance of cooperation between the vehicles. Moreover, an event that is initially relevant only to the vehicle could become also relevant to the driver (e.g., for parking spaces the driver may decide at any time that s/he wants to park).

3. First approach: Using geographic vectors

In this section, we focus on the approach using geographic vectors [13]. Firstly, in Section 3.1 we intuitively explain the motivation of this approach. Then, in Section 3.2 we describe how the EP is computed by using geographic vectors.

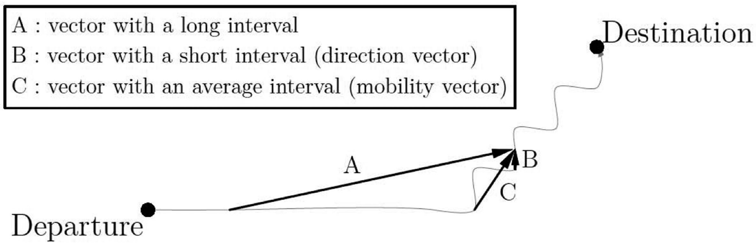

Fig. 2. Mobility and direction vectors.

3.1. *Motivation for using geographic vectors*

The main motivation for using geographic vectors to estimate the EP is that the direction of a vehicle (and/or a mobile event) can be used to predict its future positions, and so it is possible to compute a probability that estimates if the vehicle is going to meet an event.

Thus, when no digital road maps are available, the Encounter Probability between a vehicle and an event is obtained by considering the estimated future positions of the vehicle. For this purpose, two movement vectors are defined for a vehicle: the direction vector and the mobility vector (see Fig. 2). The *direction vector* allows to estimate future positions of the vehicle quite precisely on a short term, whereas the *mobility vector* captures an overall impression of the direction of the vehicle and allows to estimate future positions on the long term. Each vehicle can compute its direction vector and its mobility vector easily. Similarly, each vehicle can compute the *mobility and direction vectors of the events* it receives, since not only vehicles but also events (more specifically, *mobile events*) can move. By comparing the direction and mobility vectors of a vehicle and an event it is possible to compute the Encounter Probability, as we explain in the following. It should be noted that, as these vectors are defined in the Euclidean space, no digital road maps are needed with this approach to compute the Encounter Probability.

3.2. *EP with geographic vectors*

In this section, we explain our approach to compute the EP based on geographic vectors. First, we present the main aspects of the approach in Section 3.2.1. Then, in Section 3.2.2 we detail some ideas about the use of *penalty coefficients* to adjust the weights of the different spatio-temporal parameters involved in the computation of the EP.

3.2.1. *Computation of the EP by using geographic vectors*

As explained before, this approach for the computation of the EP is based on the *mobility and direction vectors* of vehicles and events. A vehicle can compute its mobility and direction vectors by sampling its location periodically. To allow computing the mobility and direction vectors of an event by a vehicle, we introduce two additional attributes in the event description presented in Section 2.2: the *DirectionRefPosition* and the *MobilityRefPosition*, which store two preceding reference positions (according to what is described in Section 3.1).

For each event, a *mobility vector* (*and direction vector*) *of the vehicle in relation to the event* is computed by the vehicle by changing the frame of reference. Figure 3 illustrates this change, explained in detail in [13]. The mobility vectors of one vehicle and one event are represented on the left side of the figure, and the resulting vector after the frame of reference has been changed is shown on the right

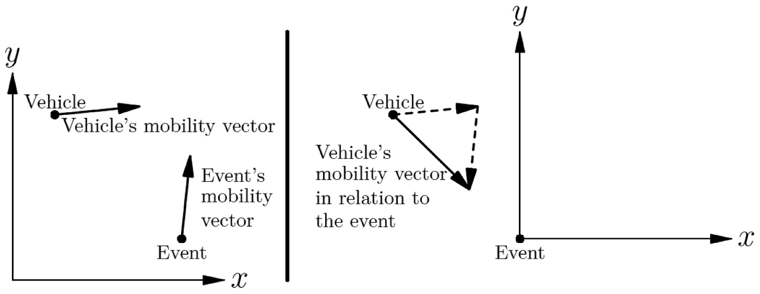

Fig. 3. Mobility vector of the vehicle in relation to the event: change of the frame of reference.

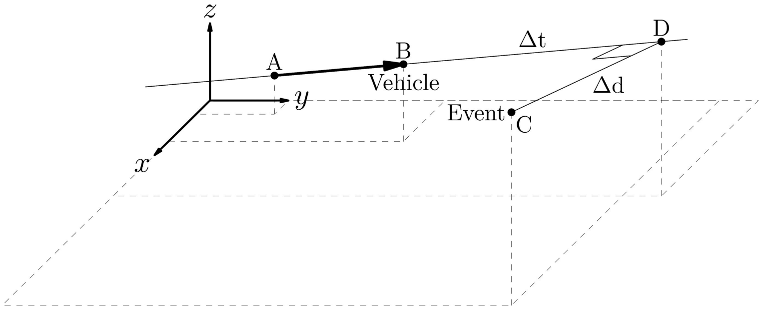

Fig. 4. Geometrical representation of Δd and Δt for a sample stationary event.

side. The change of frame of reference simplifies the computation of the EP by allowing a single vector for each couple <vehicle, event> to be managed, regardless of the type of event.

The mobility vector and direction vector of the vehicle in relation to the event are used to compute four elements (an example of the first two elements, Δd and Δt, is shown in Fig. 4, where B represents the position of the vehicle, C the position of the event, and $\overrightarrow{AB}$ is the mobility vector of the vehicle in relation to the event):

- 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 time when the event is generated and the moment when the vehicle will be closest to the event (Δg).
- The angle between the direction vector of the vehicle and the direction vector of the event (represented by a colinearity coefficient c).

Once these values have been calculated, they are used to estimate the EP (a value in the range of 0% to 100%) between the vehicle and the event:

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

where α, β, γ and ζ are *penalty coefficients* with values $\geqslant 0$. 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 EP. For example, the greater the α value, the shorter the spatial range where the event is considered relevant. β and γ are used so that only the most recent information and the information about events that will be encountered very rapidly is considered. Finally, ζ is used to weigh the importance of the colinearity coefficient. It should be noted 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 when an interesting event (e.g., a parking space) is behind the driver.

3.2.2. Use of the penalty coefficients

Considered individually, the penalty coefficients allow the definition of bounds on the relevance of events. For example, if the relevance threshold is set to 75% for the Encounter Probability, a value of $\alpha \geqslant \frac{1}{300}$ implies that if the minimum geographical distance between the vehicle and the event over time (Δd) is larger than 100 meters, then the event will be considered as not relevant whatever the values of the other parameters (i.e., Δt, Δg, and c):

$$75 \leqslant \frac{100}{(\alpha \times 100 + 1)} \Rightarrow \alpha \leqslant \frac{1}{300}$$

In the same way, β sets a maximum time interval between the current position of the vehicle and the position of the vehicle when it is expected to be at the closest location from the event; if this time interval is exceeded, the event is considered not relevant. For example, for values of $\beta \geqslant \frac{1}{900}$ an event will not be considered relevant if the time elapsed when the vehicle is at the closest distance from the event is estimated to be five minutes or more. Similarly, γ is used to penalize the relevance according to the age of the event. In practice, γ should be set according to the frequency used to generate new *versions* (see Section 2.2) of potentially long-term events (e.g., if this period is five minutes, then it is possible to set $\gamma = \frac{1}{900}$). Finally, ζ may induce a maximum tolerance on the angle formed by the direction vectors for direction-dependent events. For instance, when the vehicle is on the highway, the tolerance on the angle should be relatively low. Thus, if the tolerance is set to 45°, the value of ζ can be computed as follows:

$$75 \leqslant \frac{100}{\zeta \times 45 + 1} => \zeta \leqslant \frac{1}{135}$$

Naturally, the importance of the $\Delta d, \Delta t, \Delta g$ and c parameters depends on the event considered (e.g., traffic congestion, parking space, emergency braking, etc.). For instance, a message describing a traffic congestion should be broadcasted several kilometers away from the place where it is located, for drivers to have the opportunity to change their itinerary. The penalty on Δt should so be very low. On the other hand, when dealing with parking spaces, the penalty on Δt should be more important because a driver is only interested in finding an available parking space if it can be reached quickly. In addition, for the same type of event, the penalty coefficients may have to be modified according to the current time and date. For example, when dealing with parking spaces in urban areas, the penalty on the age (i.e., the value of γ) should be more penalizing on Saturday afternoons than on Monday nights.

The different penalty coefficients can be fine-tuned by following different guidelines, similar to the ones described in this section. For more details about the computation of the Encounter Probability, along with an evaluation of its benefits, we refer the interesting reader to [13].

4. Second approach: Using digital road maps

In this section, we propose an alternative approach where, instead of relying on the computation of geographic (mobility and direction) vectors, the underlying road network topology is considered. Firstly,

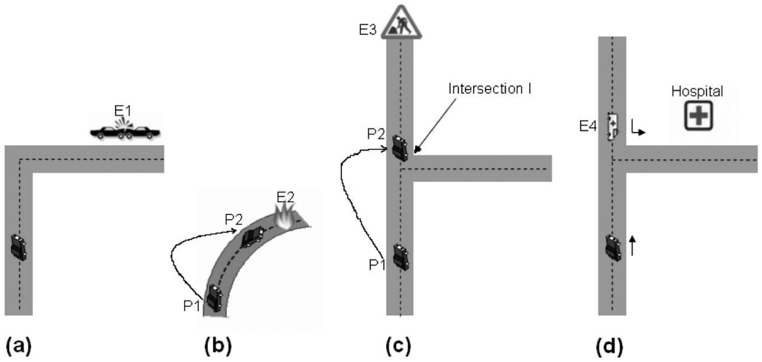

Fig. 5. Advantages of maps: sample scenarios.

in Section 4.1 we present some simple but illustrative situations where the use of digital road maps could be useful. Then, in Section 4.2 we describe how the EP is computed by exploiting the extra information provided by digital road maps.

4.1. Motivation for using digital road maps

A key idea of our general data management approach is that the relevance of an event should determine how the information about the event is disseminated and how a driver is alerted about such an event. The importance of considering the road network for this is justified by describing some simple situations where just considering the mobility and direction vectors, as described in Section 3, is not appropriate (see Fig. 5):

- In the situation shown in Fig. 5a, the car would consider the event *E1* (an accident) as not relevant since the values of Δd and c computed (see Section 3.2.1) would be too large. Intuitively, it is difficult to predict that the vehicle will meet the event unless we know that the road network will force a right turn.
- In Fig. 5b there is fire on a curve (represented by event *E2*). However, by just considering geographic vectors, *E2* is not relevant until the vehicle is at location $P2$ (at *P1* the value of the colinearity coefficient c is too large and leads to a small EP computed). By then, alerting the driver is of little use (the driver herself/himself is able to see the fire), since it may be too late to react.
- Figure 5c shows a segment of a road that is difficult to traverse due to road works (event *E3*). Although the direction and mobility vectors of the vehicle computed at location *P1* suggest that the vehicle will meet the event, the value of Δd computed renders the event as not relevant yet (the vehicle is still far away from the event and so the situation may change in the future). When the event is considered relevant (at location *P2*) it is too late for the driver to take an alternative route, as s/he just missed the last possible intersection to avoid the event.
- A similar situation is shown in Fig. 5d, where there is a mobile event *E4*: an ambulance requesting the cooperation of nearby vehicles to get through. In this case, the value of the Δd computed is small enough and the event is considered relevant to the vehicle. However, the ambulance is about to turn left towards the hospital. As a consequence, the vehicle is never going to meet the ambulance. Therefore, alerting the driver would be an unnecessary disturbance. It should be noted that, in this scenario, information about the route of the mobile event would also be necessary to benefit from the use of digital road maps.

It is important to emphasize that, even though we have presented very simple examples for illustration purposes, similar situations can be observed in reality and considering real road maps. Despite the fact that the previous scenarios suggest the need of using digital road maps, we have obtained promising experimental results with the alternative approach (see Section 3) that uses geographic vectors [6,13]. Therefore, once we design an approach based on road maps, we will need to evaluate experimentally how the use of information contained in digital road maps can actually improve the accuracy of the relevance estimation.

It should be noted that, by using maps, it is trivial to estimate whether a vehicle will encounter an event or not if we assume that the route of the driver is known in advance (the route of the event is also needed if it is a mobile event, as exemplified before in relation to Fig. 5d). However, it is not possible to constantly ask the driver about her/his destination. This is for example required for route guidance with existing navigation systems, but these are used only occasionally, when the driver does not know her/his route. On the contrary, driver assistance systems should not be intrusive in order to facilitate their everyday use transparently. Indeed, even when the driver knows her/his route perfectly (e.g., driving to the office or back home) and s/he has not introduced the route's data in a navigation system, s/he may need to be informed about some interesting events (e.g., dangers) on the roads. Therefore, the solution that we propose to compute the EP with digital road maps does not assume that routes are known in advance.

4.2. EP with digital road maps

To benefit from digital road maps, we introduce one new field in the messages describing events exchanged between vehicles (see Section 2.2). Instead of the reference positions used for the EP computation based on geographic vectors (i.e., the *DirectionRefPosition* and *MobilityRefPosition* attributes, described in Section 3.2.1), we add here an *initialTTL* field which will be used to compute the EP. The *TTL* (*Time to Live*) of an event is an estimation of the time interval during which the event will continue being valid. If the event still exists after the TTL (e.g., the event may be a traffic congestion that has not disappeared yet when expected), a *new version* of the event (with a new TTL) has to be generated. The generator of an event sets the *initialTTL* of the event, and the current value of the TTL can be obtained by considering that value and the time elapsed since the creation of the event (the event's generation time is stored in the *CurrentPosition* field, as described in Section 2.2).

In the following, we present our solution to compute an Encounter Probability using digital road maps for both attraction and repulsion events (described in Section 2.1). Firstly, in Section 4.2.1 we define the concept of *Reachability Probability* for attraction events. Secondly, in Section 4.2.2 we define the concept of *Need to Escape Probability* for repulsion events. Finally, in Section 4.2.3, we summarize the computation of the EP based on the two previous concepts.

4.2.1. Dealing with attraction events: reachability probability

For attraction events (i.e., events that the driver would like to meet, such as parking spaces), the EP is computed as the *Reachability Probability* (*ReachP*):

$$\mathit{ReachP} = \begin{cases} 100 & \text{if} \quad \mathit{TTL} > \mathit{TTR} \\ 0 & \text{otherwise} \end{cases}$$

where the TTR (*Time To Reach*) is the time needed for the vehicle to reach the event by taking the shortest path. Notice that $ReachP$ is either 0% or 100%, depending on whether it is estimated that the vehicle will be able to reach the event in time (i.e., before it disappears) or not. As there may be several attraction events relevant to the driver (i.e., with $ReachP = 100\%$), extra information is used to compute a *score* for each event and provide the driver with events of the same type ordered in a *ranked list*. For example, several reachable parking spaces are ranked according to different criteria, such as: 1) the distance to the vehicle (to minimize the time needed to reach the parking space, and therefore the probability that it becomes unavailable), 2) the probability of finding an available parking space it that area[1] (to minimize the impact of a situation where another vehicle occupies the space first), 3) the distance from that parking space to other alternative available parking spaces (to assign a higher score to a parking space if there are other events reporting available parking spaces near that space), or 4) the number of modifications in the route planned by the driver (if available) needed to meet the event.

Obviously, sharing resources such as parking spaces introduces some competition between vehicles. Indeed, only one vehicle will obtain the resource even if more than one receives a notification about it. To overcome such problems, we have proposed a complementary allocation protocol which aims at avoiding the competition between vehicles by electing, among the set of interested drivers, a single one [14,15].

4.2.2. Dealing with repulsion events: need to escape probability

In contrast to attraction events, repulsion events are events that the driver wants to avoid (e.g., traffic congestions, accidents, etc.). Dealing with such events, the EP is computed as the *Need to Escape Probability* (*NeedEsP*), which indicates the probability that the driver needs to perform some specific action to avoid the event:

$$\textit{NeedEsP} = \begin{cases} 100 & \text{if} \quad \mathrm{TTL} > \mathrm{TTE} \\ 0 & \text{otherwise} \end{cases}$$

where the *TTE* (*Time To Escape*) is the amount of time needed by the vehicle to reach the last intersection that offers the vehicle an alternative route to avoid the repulsion event (e.g., in Fig. 5c it would be the time needed to reach intersection *I*), or the *TTR* if there is no such intersection (i.e., if it is not possible to avoid the repulsion event). Therefore, by definition, it should be noted that the following always holds: $TTE \leqslant TTR$. The idea is that if the vehicle is not even able to reach that intersection before the end of the TTL of the event, then such an event is not relevant to the vehicle (it is expected to disappear before the vehicle reaches it). Otherwise, as commented before, a new version of the event will be generated if the TTL elapses and the event is still there; in this case, by having the last intersection to escape as a reference (instead of simply considering the TTL), the vehicle will still be able to avoid the event if necessary. Besides, a driver would not be alerted about a repulsion event if the route of the vehicle is known in advance and it does not pass through the event (unless the route changes in the future). However, even in this case the NeedEsP computed may be 100% (the event will be considered in this case relevant to the vehicle although not to the driver, similarly to what we discussed in Section 2.4), which implies that the vehicle will store and disseminate the event to inform other vehicles.

4.2.3. Computation of the EP by using digital road maps

According to the previous considerations, a vehicle will compute the EP for an event depending on whether the event is an attraction event or a repulsion event:

$$EP = \begin{cases} ReachP & \text{for an attraction event} \\ NeedEsP & \text{for a repulsion event} \end{cases}$$

---

[1] This knowledge can be extracted from aggregated information about events, as suggested in [11].

Fig. 6. GUI of VESPA for the GV-based approach.

By using digital road maps, the EP computed is thus either 0% or 100% (i.e., an event is either definitely relevant or irrelevant). Therefore, the specific values of the storage threshold, the relevance threshold, and the diffusion threshold (defined in Section 2.4), are not significant as long as these thresholds are higher than 0. Rankings of the attraction events (see Section 4.2.1) can be used to remove events with small scores in case of insufficient storage or to minimize the number of events disseminated. On the other hand, relevant repulsion events should be disseminated in any case, as they represent places that should be avoided and besides there will probably be a much smaller number of them.

5. Experimental evaluation

In this section, we evaluate and compare experimentally the two alternative approaches presented in this paper for data sharing in vehicular networks: using geographic vectors and exploiting the information stored in digital road maps, that we will call in the rest of this section the *GV-based approach* and the *Map-based approach*, respectively. We consider two different configurations for the approach based on geographic vectors: the GV-based configuration for both highway and urban scenarios, and the GV-based* configuration for highway scenarios. The *GV-based** configuration uses more selective penalty coefficients (e.g., the vehicle has to be closer to the event to consider it relevant), and it will be considered as an alternative to reduce the number of false warnings (i.e., irrelevant messages received by a vehicle) in a highway scenario. On the contrary, with the *GV-based* configuration the events will be disseminated far away from their location to provide drivers with more time to react (e.g., in the case of traffic congestions).

In the following, we present our experimental results. Firstly, in Section 5.1 we describe the experimental settings considered for the evaluation of our proposal. Then, we present experiments where we measure the amount of time available since a driver is notified about an event until the moment the driver meets the event (see Section 5.2), the number of irrelevant messages transmitted (see Section 5.3), and the performance of the system when dealing with mobile events (see Section 5.4).

5.1. Experimental settings

We have developed a prototype of VESPA (http://www.univ-valenciennes.fr/ROI/SID/tdelot/vespa/prototype.html), that works on mobile devices, and performed some experiments in real situations. Thus, Fig. 6 presents the graphical user interface (GUI) of VESPA for the *GV-based approach*

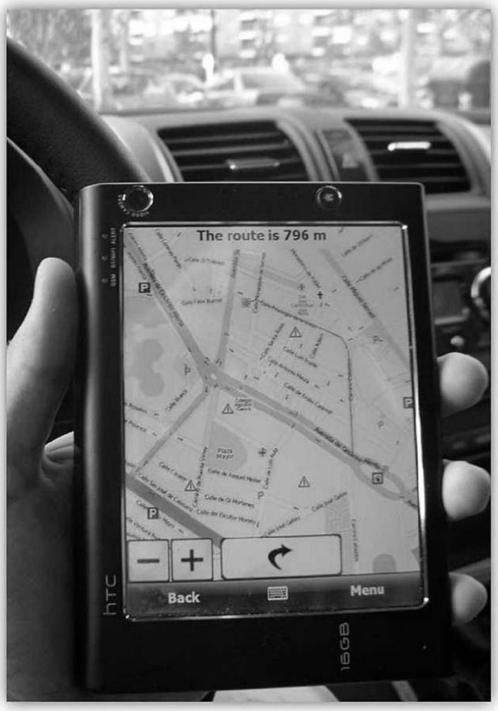

Fig. 7. GUI of VESPA for the Map-based approach.

considering an available parking space event. The GUI for the *Map-based approach* is different, as shown in Fig. 7, since the digital road maps used to evaluate the relevance of events are also exploited to show the events on a map, like navigation systems (e.g., TomTom Navigator, Navigon, Garmin, etc.) do, or to show the route needed to reach or avoid a specific event.

Despite the availability of this working prototype, due to obvious scalability reasons it is not possible to fully evaluate our approach through field tests. Thus, for example, it is difficult to obtain repeatable scenarios with a high number of vehicles in a real environment. Therefore, for experimental evaluation we use a vehicular network simulator that we have developed (http://www.univ-valenciennes.fr/ROI/SID/tdelot/vespa/simulator.html), which allows to simulate realistic contexts. Tests in a real environment are thus used mostly for verification and to calibrate our simulations.

During our experimentations, we have considered real road networks of an area of the city of Valenciennes (France) extracted from real digital road maps. The maps we used in our prototype and our simulator were provided either by *Tele Atlas* (http://www.teleatlas.com) or by *OpenStreetMap* (http://www.openstreetmap.org/). For the Map-based approach, these maps are transformed into a graph representation from which shortest paths can be computed by applying the Dijkstra algorithm [8, 41] (some additional heuristics are applied to speed up the performance of the computation of routes on the mobile device when large maps are managed). More precisely, we have considered two scenarios for evaluation:

- *Highway scenario*: a (15 Km long) segment of the highway between Valenciennes and Lille in the North of France; see Fig. 8, where different events are represented with their numbers: from *event1* to *event4*.

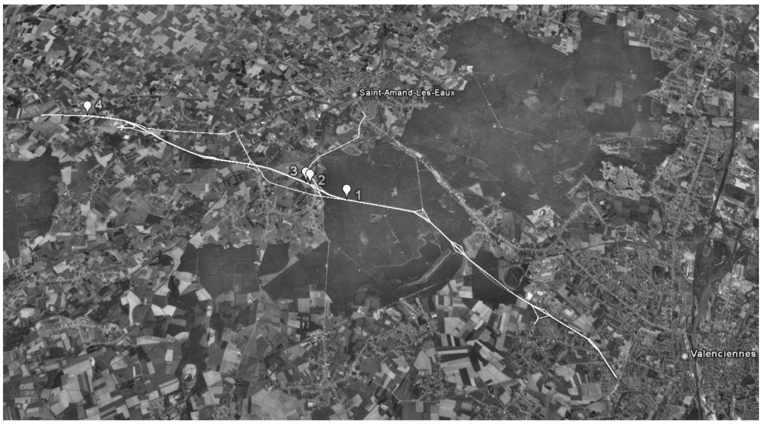

Fig. 8. Road network considered for the experimentation on the highway.

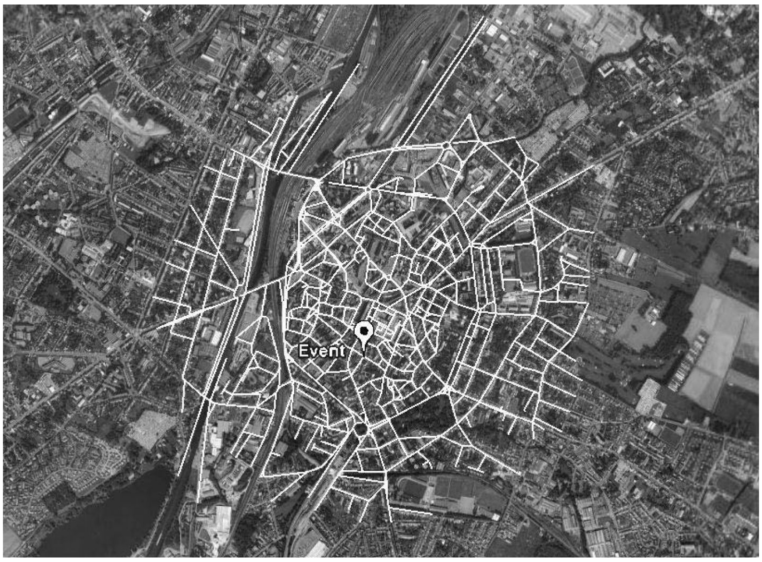

Fig. 9. Road network considered for the experimentation in an urban area.

- *Urban scenario*: the center of the city of Valenciennes in France; see Fig. 9, where a single event is marked.

On these road networks, we evaluate whether the two solutions proposed (based on geographic vectors vs. using digital road maps) allow the vehicles to exploit the information about attraction/repulsion events effectively (in order to avoid the repulsion events and meet the attraction events). The events considered for evaluation are those shown in the figures. Nevertheless, similar results have been obtained considering other maps and/or events placed at different locations.

In the simulation, vehicles are created every two seconds, with a random location, at one extreme of one of the roads considered in the scenario evaluated. Once created, vehicles follow a classical random mobility model through the road network. Their speed ranges from 20 Km/h to 130 Km/h with an average speed of 76 Km/h in the highway configuration, and varies from 15 to 60 Km/h with an average speed of 32.5 Km/h in the urban configuration. About 400 vehicles were considered during each simulation.

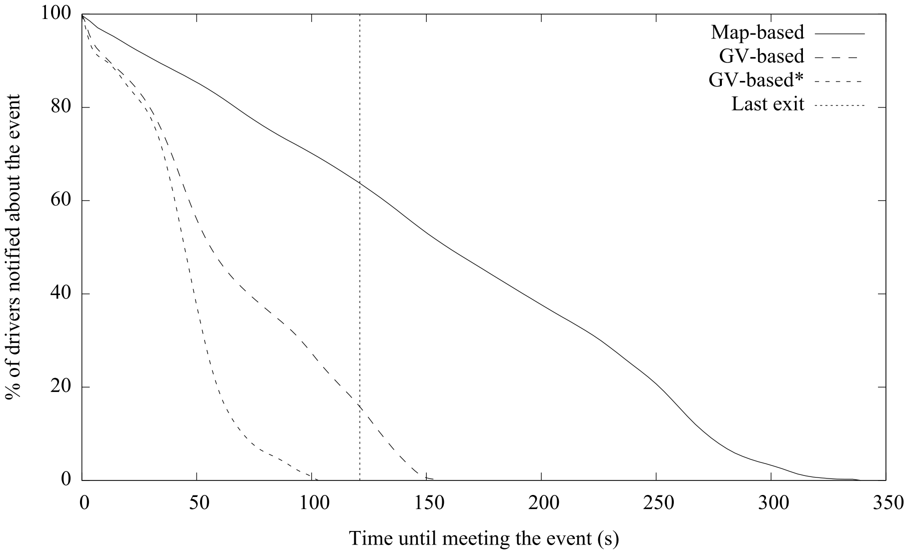

Fig. 10. Percentage of vehicles warned along time: stationary direction-dependent event on the highway.

The wireless communication range considered for each vehicle is 200 m. For each event, its time to live (TTL) is set to 500 s and the event is activated after 150 s of the start of the simulation. For the approach that computes the EP based on geographic vectors, mobility/direction vectors are obtained by using position statements performed every 500 m and every 30 m, respectively. Finally, the thresholds used to evaluate the incoming events in relation to their Encounter Probability (see Section 2.4) are set to 75%. The values used for the different parameters in the experiments, including the penalty coefficients in the GV-based approach, have been obtained through an extensive experimental evaluation; thus, we have selected values that behave well in a variety of different scenarios.

5.2. Evaluation of the reaction time available to drivers

During our simulations, we observed the vehicles which presented a warning to the driver before meeting events of different types (e.g., direction-dependent or not) located at different places on the road networks considered. More specifically, we measured the percentage of vehicles which presented a warning to the driver according to the time separating the moment when the vehicles received a warning and the moment when they would encounter the event. We expect that the greater the *accuracy* of the mechanism used to compute the Encounter Probability, the greater the amount of time available to drivers to react when events are received.

First, in Fig. 10 we focus on the event number *1* indicated in Fig. 8, that is, *event1*. This event is a repulsion, stationary, and direction-dependent event (e.g., a danger on the road or a traffic congestion) located on the highway. We first observe in Fig. 10 that 100% of the vehicles meeting *event1* inform their driver before meeting the event with both approaches. The Map-based approach significantly increases the time interval separating the moment when the vehicles warn their driver and the moment when they will actually encounter the event. By warning the drivers earlier, the probability to be able to exit the highway before meeting the event increases, which is particularly interesting for repulsion events that drivers need to avoid. For instance, the average travel time between *event1* and the last exit on the highway before *event1* is about 120 seconds; in this figure and in the upcoming figures, the *average*

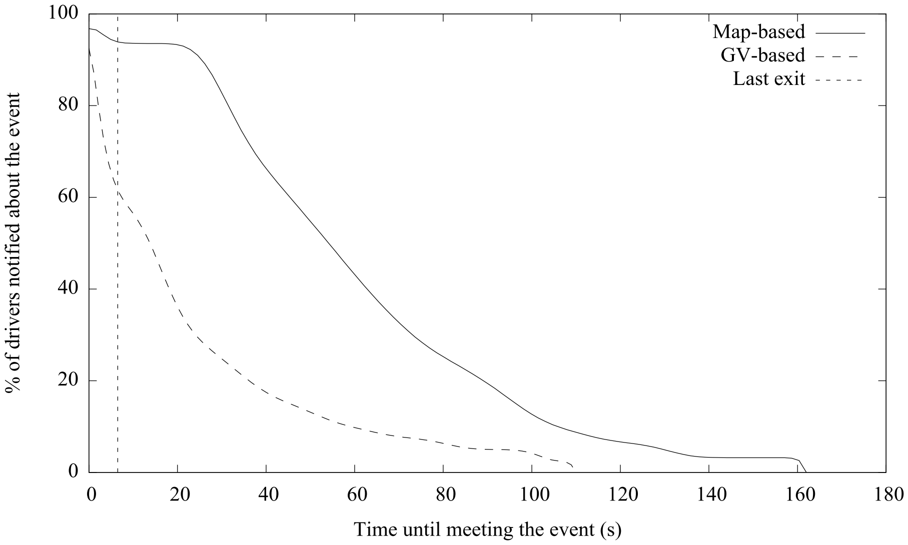

Fig. 11. Percentage of vehicles warned along time: stationary direction-dependent event in the urban scenario.

travel time from the last exit is represented by a vertical dashed line. So, the GV-based approach does not ensure that the messages describing this repulsion event are relayed far enough for drivers to have the opportunity to avoid that event. Indeed, the figure shows that only about 20% of the vehicles with the GV-based approach (and no vehicle with the GV-based* approach) had a chance to use the information received to avoid the event. Obviously, even with the Map-based approach, it is not possible to reach 100% of the vehicles informed 120 seconds before meeting the event, since some of them may be already very close to the event at the moment when the event is generated; according to our experimental results, with the Map-based approach about 70% of the vehicles received the information in time to avoid the event. Although in Fig. 10 we only show the results for *event1*, it is important to clarify that we obtained similar results for other types of events, located at different places on the highway (see Fig. 8).

During our tests, we compared the GV-based and Map-based approaches not only on highways but also in urban environments. Our goal with the evaluation in urban environments was to study the effects of frequent changes of the direction of vehicles. Figure 11 shows the moment when the vehicles are informed considering our different approaches applied on a stationary direction-dependent event located in the center of the city of Valenciennes (as shown in Fig. 9). In this scenario, the Map-based approach outperforms again the GV-based solution, although in this case the differences are reduced with respect to the highway scenario. Moreover, since the number of alternative roads is much higher here, both solutions allow a large percentage of the drivers to find an alternative route before encountering the event (about 95% with the Map-based approach and 60% with the GV-based approach), which is important in the case of repulsion events.

Finally, in Fig. 12 we present as another example the results for a stationary non-direction-dependent event in the urban scenario (located at the same location as the event considered in the previous experiment, see Fig. 9). The difference between the Map-based approach and the GV-based approach is again reduced in this case and we observe similar results for both approaches.

Before concluding this section, it is important to remind that we have evaluated also other types of events at different locations, in both urban and highway scenarios, obtaining similar results. Thus, we can conclude that the Map-based approach increases the reaction time available for drivers to avoid repulsion events, especially in scenarios where no many alternative roads exist.

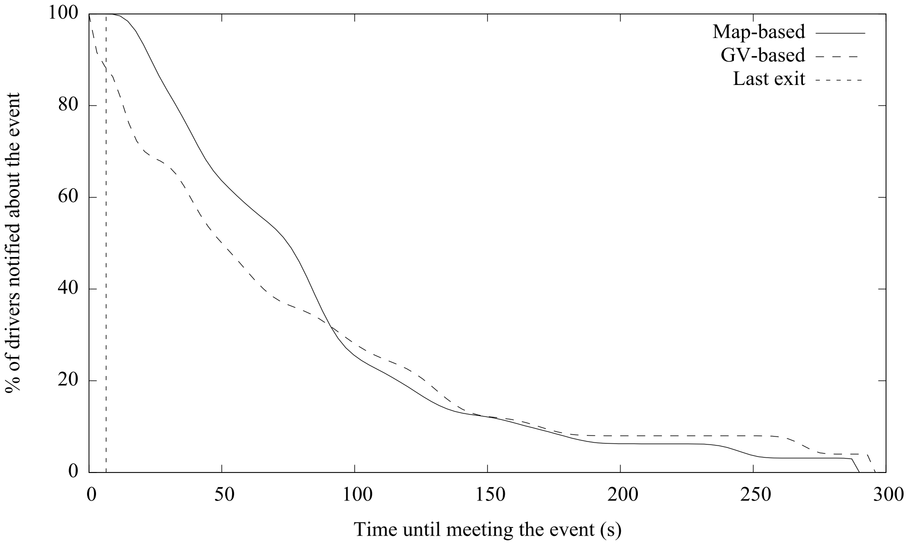

Fig. 12. Percentage of vehicles warned along time: stationary non-direction-dependent event in the urban scenario.

5.3. Evaluation of the number of irrelevant messages shown to the drivers

Obviously, the time interval available since a vehicle receives an event until it meets the event is a very important parameter, as it determines the reaction time provided to the driver by the system. However, it is not the only important one. The number of warnings about events communicated to drivers that these drivers finally did not encounter (called *false warnings* in the following) is interesting too. Indeed, while trying to communicate a piece of information to vehicles located far away from the event, it should be ensured that the information is delivered only to potentially interested drivers. Again, we expect that the greater the *accuracy* of the mechanism used to compute the Encounter Probability, the smaller the number of false warnings communicated to drivers. Of course, the existence of false warnings cannot be avoided when the final destination of the vehicles is not known. For instance, a vehicle can change its direction and finally not encounter an event that it previously estimated relevant (in that case the Continuous Query Processor, described in Section 2.3, will notify the driver that the event is not relevant anymore). Anyway, it is important not to disturb the driver with irrelevant information and the ratio of false warnings should remain limited.

Figure 13 shows the ratio of false warnings for different (direction-dependent) events considered during our tests on the highway (see Fig. 8). Since the ratio of false warnings observed strongly depends on the trajectory of the vehicles (e.g., it depends on the percentage of vehicles exiting the highway just before meeting a certain event), it is particularly important to ensure that the same trajectories are considered for the vehicles in the evaluation of all the approaches. We observe in Fig. 13 that the ratio of false warnings is quite limited with the Map-based approach whatever the location of the event. The GV-based* approach, using very penalizing coefficients, outperforms the Map-based approach for several events; however, as it was shown in Fig. 10, the GV-based* approach may leave little time for the reaction of the driver. As expected, the GV-based approach increases the number of false warnings, and the increase depends on the road configuration. For example, for *event1* we observe a very high percentage of false warnings because a high number of vehicles arriving on the highway using the road located between *event2* and *event3* in Fig. 8 consider this event relevant but finally do not meet it.

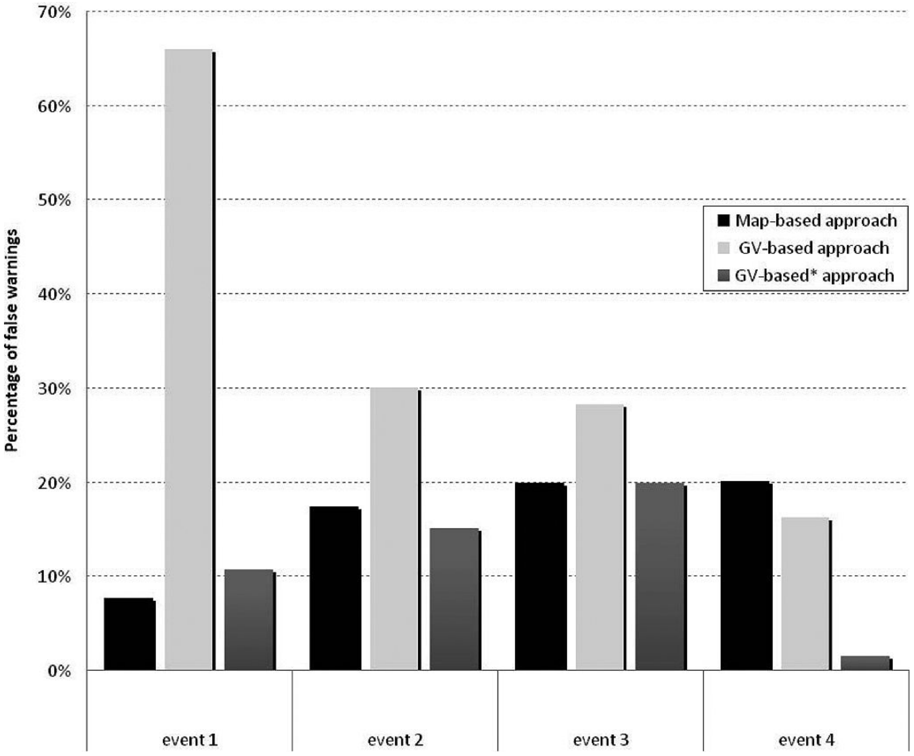

Fig. 13. Percentage of false warnings communicated to the drivers on the highway.

We also evaluated the percentage of false warnings generated for the different solutions in the urban environment. We omit the corresponding figure here because the general conclusions are similar to those observed in the previous case. Nevertheless, it should be emphasized that the ratio of false warnings in the urban scenario is always inevitably higher than in the highway configuration, since in an urban environment the vehicles keep changing their direction (due to the numerous turns and alternative routes available in urban roads) and often estimate an event as relevant at one point during their travel but it becomes irrelevant later. The percentage of false warnings about repulsion events shown to the driver is reduced with the Map-based approach, since it considers the Time to Escape to warn the driver only if s/he should react then to try to avoid the event.

5.4. Evaluation of the case of mobile events

Finally, we consider the evaluation of mobile events. Specifically, we present the reaction time available to drivers when receiving information about a mobile event corresponding to an emergency vehicle driving on the highway and asking the preceding vehicles to yield the right of way. The speed of the emergency vehicle is 163 Km/h. It moves over 9 Km, starting from the location of *event1* in Fig. 8, and generates a new version of the mobile event every two seconds to update its location. The TTL associated with each version is set to 25 seconds.

As shown in Fig. 14, similar results to those presented previously are observed. Thus, all the drivers reached by the emergency vehicle had been warned before. As in the previous cases, the vehicles are warned earlier with the Map-based approach. Anyway, with such mobile events, the GV-based approach

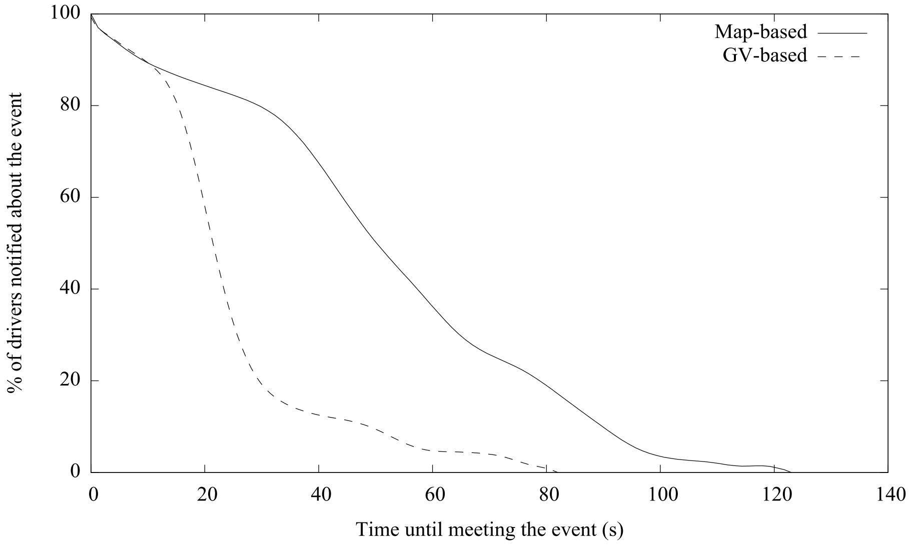

Fig. 14. Percentage of vehicles warned along time: mobile direction-dependent event on the highway.

can help to keep the diffusion area of the event limited, to avoid warning drivers too early (i.e, for vehicles still too far away from the mobile event), thus reducing the probability that the warning is unnecessary (e.g., the emergency vehicle may exit the highway before reaching the vehicle, as explained in Section 4.1).

6. Related work

Data dissemination in *Mobile Ad Hoc Networks* (*MANETs*) is an important research topic. In this area, several works have proposed broadcasting approaches to try to overcome the network congestion and other limitations of classical *flooding* (e.g., the *dynamic probabilistic flooding* approach presented in [20]). The special features of vehicular networks, which are highly dynamic MANETs, have attracted further research efforts. Thus, several previous works have addressed the problem of data management in vehicular networks [28], highlighting the importance of defining appropriate relevance measures for data exchange and query processing. As an example, we would like to highlight the following works:

- In the *Mobi-Dik* project (see, for example [39]), an *opportunistic exchange* mechanism, inspired by the field of epidemiology, is proposed for data sharing in vehicular networks. 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. This dissemination principle is accompanied by mechanisms that monitor the relevance of the information (based on temporal and spatial criteria) in order to decide whether it should be stored in a local cache in the vehicle and/or broadcasted later on. Although this mechanism is well adapted for cars to share information about available parking spaces (which is the case study for Mobi-Dik), it has not been designed to deal with other types of events (e.g., to relay information about an accident or an emergency braking situation). Another work related to this approach is [27], which focuses on road hazards and proposes a data sharing strategy that is claimed to be similar to the opportunistic exchange proposed in Mobi-Dik. It is also interesting to mention the proposal in [19], which tackles the problem of content-based communication in a MANET based on the ideas of *opportunistic networking* (temporary contacts between mobile hosts are exploited to exchange documents) and *delay-tolerant networking* (a message can be stored temporarily in a host until forwarding it is possible).

- The importance of considering the relevance of data in a data management solution for vehicular networks is also emphasized in [9], which proposes the use of a *propagation function* to decide the route that a message has to follow in order to reach a target spatial area. The originator of a message defines an appropriate propagation function (e.g., by considering traffic conditions for the current time frame), which can be interpreted as a “gravitational field" where the message is attracted towards areas of minimum potential. The route traversed by the message is thus the result of evaluating the propagation function at each routing hop. On the basis of this propagation function, different dissemination approaches (both deterministic and probabilistic) are proposed and compared. However, how to define appropriate data propagation functions for different scenarios, which is a key element for the dissemination strategy, is not studied in such paper.
- Finally, the importance of considering the relevance of events (called the *expected benefit* in [2,17]) for data sharing in VANETs, especially when the bandwidth is scarce, is also emphasized in works such as [1,3]. For example, in [1], a relevance-based dissemination approach is proposed, although it is not detailed how the values of the different relevance parameters are set. In [5], the focus is on road accidents and a zone-of-relevance is also defined.

Thus, all these previous works agree on the importance of evaluating the spatio-temporal relevance of data. However, they mostly focus on the dissemination of events, whereas our approach considers a relevance evaluation mechanism for both data sharing among vehicles and data management on the vehicles (data storage, dissemination, and reporting of events to drivers). Moreover, our approach is a general proposal for all the types of events relevant on the roads. Finally, the previous works do not exploit the information available about road networks for the evaluation of the relevance of the data.

Although the importance of considering the underlying road network has been highlighted in several works related to moving objects and location-based services (e.g., [7,16,18,36]), as far as we know the road information has not been used so far for data sharing and data management in vehicular networks. There are only some works that use road map information but focus on multi-hop data delivery [22,38, 42]. Thus [22], presents a position-based routing approach that makes use of the navigational systems of vehicles to route a message following the shortest path to a target node. In [38], the *MDDV* approach is presented, based on the observation that taking the path with the shortest distance from the source is not necessarily the best approach, as road segments with a high traffic density lead to a faster propagation. Finally [42], proposes several Vehicle-Assisted Data Delivery (*VADD*) protocols, that benefit from the predicted vehicle mobility and digital road maps to improve the basic *carry-and-forward* solutions [10].

Summing up, although the previous works show the importance of the topic studied in this paper, none of them considers the use of road maps to estimate the relevance of events or uses this relevance to decide an appropriate dissemination strategy and a suitable driver alert mechanism for different types of events. On the contrary, we propose a complete and general system for data management and sharing in vehicular networks, that is able to benefit from the information stored in digital road maps when it is available.

7. Conclusions and future work

In this paper, we have presented a general and complete data management solution for intelligent vehicles, and we have studied and evaluated two different approaches to compute an *Encounter Probability* in order to estimate the relevance of events exchanged in a vehicular ad hoc network. The first approach is based on the management of geographic vectors whereas the second one exploits digital road maps. Whatever the mechanism used to compute it, the Encounter Probability is used to decide when to alert the driver and whether the event should be rediffused or not. Up to the authors' knowledge, this is the first work that proposes to benefit from information stored in digital road maps for data management and sharing in vehicular networks.

We have implemented a working prototype of the proposed system and tested it in a real environment. Moreover, we have evaluated our approach in a larger scale by using simulations. Our experimental evaluation proves that digital road maps can increase the accuracy of the system considerably, especially when dealing with repulsion events that should be diffused far away from their initial location. However, the other alternative also provides good results and we believe that both approaches are rather complementary. Indeed, digital road maps may be unavailable (e.g., they can be expensive to buy or accessible only through the Internet when a 3G connection is available), or some elements may be missing in existing digital road maps (e.g., roads in parking lots, entrances of parking lots, etc.). So, the approach based on geographic vectors could be the only one that could be used in some situations.

As future work, we will analyze whether using information about the planned trajectories could be useful, especially in the case of a mobile event (whose expected trajectory could be stored as an attribute of the event). Besides, our current research involves studying the applicability of mobile agent technology [26,33] in vehicular networks. Thus, for example, we have proposed encapsulating environment monitoring tasks in mobile agents that hop from car to car as needed [34,35]. We are also considering using mobile agents to implement a pull-based query processing approach that supports location-dependent queries [21,24] in vehicular networks. Finally, it could be interesting to study agent-based data dissemination approaches, as proposed in [25].

Acknowledgements

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