

A Content-Based Dissemination Protocol for VANETs: Exploiting the Encounter Probability

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Abstract—This article focuses on intelligent transportation systems and more precisely on inter-vehicle ad hoc networks. A vehicular ad hoc network (VANET) is a highly dynamic network, as the vehicles communicate using short range wireless communications and can move very quickly. Thus, for example, we can only rely on short interactions between the vehicles to exchange information about relevant events.

In this article, we describe in detail a dissemination protocol that vehicles can use to share information by using vehicle-to-vehicle communications. The dissemination approach considers the relevance of the data, represented by what we call the encounter probability, to decide when a rediffusion is needed. The protocol is able to disseminate data about any type of event in the network (e.g., available parking spaces, accidents or obstacles in the road, information about moving objects such as emergency vehicles that should get the right of way, etc.) by setting appropriate weights for the different factors that affect the computation of the encounter probability. An extensive experimental evaluation with different types of events shows the interest of the proposal: the vehicles receive the relevant messages in time and the network overload is limited.

I. INTRODUCTION

In the last decade, a number of small-sized wireless devices (e.g., PDAs and laptops) with increasing computing capabilities have appeared in the market at very affordable costs. These devices have started to be embedded into modern cars in the form of on-board computers, GPS navigators, or even multimedia centers. This has led to the emergence of vehicular ad hoc networks (VANETs) [1], [2]. In this kind of networks, cars traveling along a road can exchange information with other nearby cars by using inter-vehicle communications (IVC) [3], which are based on short-range wireless technologies. Nevertheless, a piece of information can be disseminated and reach a far distance by using moving cars as intermediates, following multi-hop routing protocols [4].

Existing vehicle-to-vehicle dissemination approaches have considered only some of the possible types of events that may

be interesting for drivers, primarily focusing on static (i.e., non-mobile) events. However, numerous types of events are possible, since there is a wide range of information that drivers may find relevant. Some events are direction-dependent (e.g., an accident, a traffic congestion, an emergency braking, an obstacle in the road) and others are non-direction-dependent (e.g., a parking space), depending on whether the specific direction of the vehicle on a road is important to determine whether the event is relevant or not for that vehicle. Besides, while most events are probably static, some interesting events may be mobile (e.g., a vehicle driving with non-functioning brake-lights, a driver in state of lack of vigilance, an emergency vehicle asking the right of way, etc.). In [5], [6], we have proposed a classification of events and the concept of encounter probability to determine their relevance.

In this article, we focus on the dissemination protocol that is needed to inform vehicles about interesting events. The originality of our solution resides in the ability to disseminate any type of event. Other existing dissemination protocols are dedicated to the dissemination of only a particular type of event. Since different events may require different dissemination mechanisms, an interesting solution for one type of event may be not effective for another type. For instance, some events have to be disseminated in a spatio-temporal area (e.g., parking spaces) because they are relevant to all the vehicles driving in that area (during a certain period), whereas diffusion chains have to be established for other types of events (e.g., accidents) since the direction of the vehicles has then to be considered. Furthermore, another major concern of our work is to avoid the need of flooding to ensure the correct transmission of the messages in the inter-vehicle network. So, our contribution in this article resides in a dissemination technique that considers the constraints mentioned above. The proposal uses the concept of *encounter probability* (an estimation of the likelihood that a vehicle will meet an event) to determine whether an event is relevant enough to be rediffused or not.

The rest of this article is organized as follows. In Section II, we describe some related works. In Section III, we present the main idea of our dissemination protocol, which uses the concept of encounter probability to dynamically adapt the dissemination area. In Section IV, we explain how the proposed protocol minimizes the bandwidth used. In Section V, we present experimental results that show the interest of our approach. Finally, we offer our conclusions and give some ideas for prospective research in Section VI.

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II. RELATED WORK

In this section, we provide an overview of some works that tackle the problem of data dissemination in vehicular networks. The motivation to develop specific dissemination protocols in this area is that traditional approaches for general mobile ad hoc networks (MANETs) are not suitable in such a highly dynamic environment [7]. Thus, geographic addressing and routing protocols specific for vehicular networks are being proposed (e.g., see <http://www.geonet-project.eu/>), as well as other data dissemination approaches.

Several works have emphasized different aspects that should be considered when designing a suitable dissemination strategy. For example, [8] highlights three elements: the time elapsed since new data are available until the network stabilizes, the best distribution area around the event originator, and the lifetime of the data. In [9] they claim that the size/shape of the dissemination area and the message lifetime (amount of time that the message is kept alive in the network) should not be set by the vehicle that generates the event; instead, it should be adaptively determined (e.g., based on the current traffic conditions) using a distributed approach. The dissemination strategy should also attempt to optimize metrics such as the number of messages transmitted (*network overhead*) or the *broadcast utilization* [10] (percentage of new area covered by a broadcast), the number of vehicles not informed about important events (called *ignorance* in [8]), the number of vehicles receiving irrelevant information (called *redundancy* in [8]) or the *utilization rate* [10] (proportion of useful information received by the vehicles), the percentage of messages that are successfully propagated (called *delivery ratio* in [7]), and the time needed to propagate data between two vehicles separated a certain distance (called *dissemination latency* in [10]). Besides, the *relevance* of an event (the expected benefit in [11]) should play a key role in a data dissemination strategy, as supported by many existing works. For example, in [12], [13] spatial and temporal criteria are considered in order to decide whether an event should be stored and/or broadcasted.

Based on the previous considerations, several specific dissemination protocols have been proposed. For example, [12] develops an *opportunistic exchange* mechanism, inspired by the field of epidemiology, where vehicles with a certain piece of information act as “disease carriers” by “contaminating” (i.e., transmitting that information to) the nearby vehicles along their routes. In [8], three dissemination strategies for geospatial information are evaluated: the *flooding* strategy (communicate all the known events to all the peers within communication range), the *epidemic* strategy (only inform a certain number of peers), and the *proximity* strategy (inform only the peers within a certain distance of the location of the event); this last strategy seems to achieve a good trade-off, but the authors emphasize the need of more experiments. Three dissemination protocols for highway scenarios are considered and compared analytically and experimentally within the *TrafficView* project [10]: dissemination by vehicles circulating in the same direction (*same-dir*), in the opposite direction (*opp-dir*), and in both directions (*bi-dir*); the authors indicate that

the *opp-dir* model is usually the most efficient, except when the traffic in the opposite direction is sparse, in which case the *bi-dir* model should be used. As a final example, [14] proposes a segment-oriented data abstraction and dissemination (SODAD) approach for comfort applications, where the broadcast interval is dynamically adapted to avoid overloading and favor the propagation of significant changes.

Data sharing approaches for vehicular ad hoc networks may require an important percentage of appropriately equipped vehicles to work. Therefore, several proposals have explicitly considered the problem of market penetration. For example, [15] emphasizes the problem of lack of network connectivity that may occur when the density of equipped vehicles in an area is low, and advocates the use of *Stationary Supporting Units (SSUs)*, called *Road-Side Units (RSUs)* in other works [13], to alleviate this problem (different heuristics are proposed to decide the best locations to place the SSUs). In [16] adding static nodes at intersections to assist data delivery is also proposed. The potential sparsity of the vehicular network has to be considered also when designing a dissemination protocol. For example, in some occasions some vehicles will need to carry data to areas where they can be disseminated (data transportation via locomotion vs. data transportation via wireless communications) [15], which is usually called *carry-and-forward*, *store-and-forward* [17], or *vehicle-assisted data delivery* [18]. Besides, works such as [7], [10], [13], [17] indicate the importance of the direction of vehicles in the dissemination protocol, acknowledging that vehicles moving in the opposite direction could be required to collaborate in the data dissemination even if they are not really concerned about a particular event.

It is also interesting to emphasize that many existing works focus on specific types of events, use cases and scenarios. For example, [12] focuses on parking spaces, [13] on road hazards, [14] on comfort applications, [15] on urban environments, [7] on highways, etc. Nevertheless, in [19] a general inter-vehicle communication architecture is proposed and evaluated with two very different case studies (related to safety and entertainment, respectively). This last work does not study issues related to the determination of the target dissemination area, as it assumes the existence of a certain *car platoon* (group of vehicles) where the messages should be transmitted.

Regarding the different data dissemination protocols proposed for vehicular networks, the approach presented in this article has the following advantages: 1) it does not focus on a specific scenario (like most of the previous works) but considers different types of events (e.g., mobile events, which have not been considered before); 2) it is a general approach (not focused only on highways or urban areas); and 3) it considers different aspects determining the relevance of events.

III. DYNAMIC DISSEMINATION AREA

One of our main objectives is that the dissemination protocol proposed should be able to disseminate different types of events (an accident, an emergency braking, an available parking slot, etc.) in the inter-vehicle network. Therefore, we have to support different dissemination modes. For example:

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

Our approach to maintain a suitable dynamic dissemination area is based on a concept of what we call the *Encounter Probability* (EP), which represents the probability that a vehicle meets a certain event. If the EP of an event for a certain vehicle is high, then the event could be considered particularly relevant for the vehicle because it is likely that the vehicle will encounter that event. Based on this idea, we propose a dissemination protocol by which each vehicle could decide dynamically if it should rediffuse the information about an event received or not. The main objective is to ensure that each vehicle for which an information is interesting will receive it.

Thus, the use of the EP to determine the vehicles which have to rediffuse an information they received allows to diffuse the messages towards the vehicles for which such messages may be relevant. This also guarantees that the information about an event is maintained close enough to be relevant during the dissemination phase. For instance, the information about an available parking space has a limited spatial relevance (it would not be interesting for drivers located very far from it). So, in the proposed dissemination protocol, when a vehicle receives a message, it computes the EP for the event received. If the EP computed is bigger than a certain *diffusion threshold*, the message is relevant enough to be rediffused by the receiving vehicle. Otherwise, the message is ignored. Therefore, an event is propagated to the neighboring vehicles while the event is considered relevant in the area, and so on. In this paper, we propose to compute the EP based on geographic vectors, but in a complementary work (not focused on the dissemination protocol) we also show that computing the EP by exploiting the information available in road maps (when available) could improve the estimation of the relevance of events in some scenarios [20].

In the rest of this section, we first explain how a vehicle can estimate the relation between its movement and an event that it receives, by defining mobility and direction vectors. Then, we describe a mechanism used to compute an EP based on those geographic vectors. Next, we describe in more detail the impact of the different penalty coefficients and some strategies to fine-tune them. Finally, we show the advantages of the proposed EP-based approach regarding an alternative where a fixed dissemination area is determined in advance.

A. Estimating the Relation between the Movement of the Vehicle and an Event

To estimate the direction of a moving object (a vehicle or a mobile event), we use vectors that run between a previous

location (called the *reference position*) and the object's current location. These vectors are used to situate vehicles and mobile events. In the following, we explain how the mobility and direction vectors are calculated.

The location of object A at time t is expressed as $\vec{P}_A(t) = (x_{A_t}, y_{A_t}, z_{A_t}, t)$, 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 $\vec{V}_A(t_1, t_2) = \vec{P}_A(t_2) - \vec{P}_A(t_1) = (x_{A_{t_2}} - x_{A_{t_1}}, y_{A_{t_2}} - y_{A_{t_1}}, z_{A_{t_2}} - z_{A_{t_1}}, t_2 - t_1)$. Using that expression, each vehicle is able to compute its own mobility vector. By applying this vector to the current position of the vehicle, an estimation of its future position is obtained: $\vec{P}_A(t_{n+i}) = \vec{P}_A(t_n) + \vec{V}_A(t_{n-i}, t_n)$.

The estimated future position is highly dependent on the time interval $[t_{n-i}, t_n]$ selected between two position statements. So, we distinguish two vectors with different purpose:

- The *direction vector*, which is computed with a short $[t_{n-i}, t_n]$ interval. This vector so provides a good estimated future location but only in the very short term (there is no global view of the displacement).
- The *mobility vector*, whose role is to provide an overall view of the object's movement as well as a good estimated future position. For that purpose, an "average" $[t_{n-i}, t_n]$ interval is used to compute the mobility vector.

Each vehicle can compute the *mobility and direction vectors of the events* it receives. For that, it uses some data associated to the events exchanged in a vehicular network. In particular, to compute these vectors, we propose to associate to each event communicated in the network the following attributes: *CurrentPosition*, *DirectionRefPosition*, and *MobilityRefPosition*. These attributes correspond to GPS statements, which contain 3-dimensional coordinates as well as the GPS time¹. The *CurrentPosition* attribute indicates the time and place corresponding to the generation of the event. The value of the reference positions (*MobilityRefPosition* and *DirectionRefPosition* attributes) correspond to former positions of the event and are used by the vehicle receiving the event to compute the mobility and direction of the event. More specifically, the positions used to compute the direction vector of the event are the *DirectionRefPosition* and the *CurrentPosition*. Similarly, to compute the mobility vector of the event, the *MobilityRefPosition* and the *CurrentPosition* are used. When dealing with a static event, the *MobilityRefPosition* will always be equal to the value of the *CurrentPosition* attribute. Similarly, for non-direction-dependent events the value of *DirectionRefPosition* will be set to null to allow the identification of such a type of event.

For each event, the *vehicle's mobility vector in relation to the event* is computed. Let us consider the mobility vector of a vehicle A between t_{A_1} and t_{A_2} and that of an event B between t_{B_1} and t_{B_2} : $\vec{V}_A(t_{A_1}, t_{A_2}) = (x_A, y_A, z_A, \Delta t_A)$, $\vec{V}_B(t_{B_1}, t_{B_2}) = (x_B, y_B, z_B, \Delta t_B)$. First, the mobility vectors are modified in order to manage the same time basis (fourth dimension) for both vectors. We so obtain the following vectors: $\vec{V}'_A(t_{A_1}, t_{A_2}) = \vec{V}_A(t_{A_1}, t_{A_2}) \times \Delta t_B$, $\vec{V}'_B(t_{B_1}, t_{B_2}) =$

¹Using the GPS time avoids synchronisation problems between the internal clock of the vehicles.

$$\vec{V}_B(t_{B_1}, t_{B_2}) \times \Delta t_A.$$

Once we have the same time basis for both vectors, we compute the subtraction between the two vectors. So, the mobility vector of vehicle A in relation to event B is given by $\vec{V}_{AB}(t_{A_1}, t_{A_2}, t_{B_1}, t_{B_2}) = (x_A \times \Delta t_B - x_B \times \Delta t_A, y_A \times \Delta t_B - y_B \times \Delta t_A, z_A \times \Delta t_B - z_B \times \Delta t_A, \Delta t_A \times \Delta t_B)$.

B. EP-based Computation of the Relevance of an Event

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 geographical distance between the vehicle and the event when the vehicle is expected to be at the closest distance (Δd). The value of Δd can be computed as $\sqrt{|vehicle_event|^2 - |vehicle_Nevent|^2}$, where $vehicle_event$ is a segment linking the location of the vehicle and the location of the event and $vehicle_Nevent$ is a segment linking the location of the vehicle and the closest point to the event regarding the direction marked by the mobility vector of the vehicle in relation to the event.
- The difference between the current time and the time when the vehicle will be closest to the event (Δt). The value of Δt can be computed by considering the distance between the vehicle and the closest point to the event and taking into account the temporal dimension of the mobility vector of the vehicle in relation to the event.
- The difference between the time when the event is generated and the moment when the vehicle will be closest to the event (Δg). This information is obtained from the message received (considering the event's generation time stored in the *CurrentPosition* attribute) and the Δt previously computed.
- The angle between the vehicle's direction vector and the event's direction vector (represented by a colinearity coefficient c). 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* (EP) between a vehicle and an event. Thus, the higher the value of EP, the higher the likelihood that the vehicle will meet the event. The encounter probability is a value between 0 and 1, although in some occasions we may express it as a percentage (i.e., a value between 0 and 100) for convenience. When a vehicle receives an event, we can model what may happen with the event received as a random variable with two possible values: "meet" and "not meet", where "meet" indicates that the vehicle eventually meets the event and "not meet" indicates that the vehicle does not meet the event. This can be seen as a Bernoulli distribution which takes the value "meet" with probability EP and the value "not meet" with probability 1-EP. Specifically, the EP is computed using the following function, which depends on the four previous values:

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

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. In practical cases, it holds that $\alpha + \beta + \gamma + \zeta > 0$, as otherwise the EP would be always 1, which means that the event can always be potentially met by any vehicle because it is not subject to temporal, spatial or direction constraints. The bigger a coefficient is, the more penalized the associated value is when computing the encounter probability. For example, the greater the α value, the shorter the spatial range where the event is relevant. Coefficients β and γ are used so that only the most recent information and the information about events that will be encountered in a short time is considered. Finally, ζ is used to weigh the importance of the colinearity coefficient. The different values affecting the encounter probability are related through an addition operation (denominator of the previous formula); the reason is that all these values contribute independently (with a certain weight) to the final value computed for the EP. Weighted sums have been also used in other contexts to weigh the importance of different parameters (e.g., [21]).

The EP is an estimation used to compute the relevance of events in order to decide whether they should be rediffused in the dissemination protocol or not. However, even if a vehicle computes a high value for the EP, it cannot be guaranteed that the vehicle will actually meet the event. Indeed, if the event represents a dangerous situation, the driver will try to avoid it when he/she is informed about it. Moreover, even if the event does not represent a problem, since our proposal does not force the drivers to systematically provide their intended destination/route, it is still possible that the driver (by following his/her intended route) changes its direction before meeting the event. Even in the situations mentioned, it is highly probable that the vehicle computing a high EP will have neighbors driving towards the event and going to meet it. So, the vehicle has to participate in the dissemination process so that those neighbors can be informed.

C. Fine-Tuning the Relevance Estimation Mechanism: Penalty Coefficients

The α , β , γ and ζ penalty coefficients are used to balance the relative importance of the Δd , Δt , Δg and c parameters. So, considered individually, they allow to define upper bounds for the different factors affecting the computation of the EP. For example, if the diffusion threshold is set to 75% for the encounter probability, a value of $\alpha \geq \frac{1}{300}$ implies that if the minimum geographical distance between the vehicle and the event over time (Δd) is bigger than 100 meters (Δd^{max}), then the event will be considered as not relevant independently of the values of the other parameters (i.e., Δt , Δg and c): $75 \leq 100 / (\alpha \times 100 + 1) \Rightarrow \alpha \leq 1/300$.

Similarly, β sets a maximum time interval between the current position of the vehicle and the position of the vehicle when it is closest to the event (Δt^{max}); if this time interval is exceeded, the event is considered irrelevant. For example,

for values of $\beta \geq \frac{1}{900}$ an event will not be considered relevant if the time elapsed when the vehicle is at the closest distance from the event is 5 minutes or more (Δg^{max}). The penalty coefficient 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 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 (c^{max}).

In Figure 1 we show some examples of the impact of setting values for certain penalty coefficients. To generate the figure, we have considered vehicles moving at 50 Km/h, a 75% diffusion threshold, and penalty coefficients computed according to the following bounds: $\Delta d^{max} = 300$ meters, $\Delta t^{max} = 120$ seconds, $\Delta g^{max} = 60$ seconds, and $c^{max} = 4 * \pi/3$ degrees. In the figures, there is a non-direction-dependent event at the location (0,0) and each point at a given location (x, y) indicates a value computed for the EP (its color changes according to the EP value, as shown in the legends on the right). For simplicity of representation all the vehicles move upwards in the example. Moreover, we indicate with dashed lines the area where the EP is higher than the diffusion threshold (outside that area the event is not disseminated). In Figure 1.a we represent a situation where all the penalty coefficients are set to 0, and therefore the EP computed would be 1 for all the vehicles. In Figure 1.b we represent a situation where only the penalty coefficient Δd is different from 0, and so the EP is higher near the location of the event (and independently of the direction of the vehicles). In Figure 1.c we represent a situation where only the penalty coefficient Δt is used to penalize the computation of the EP. Finally, in Figure 1.d all the penalty coefficients have been set, and so we can observe a combination of the previous three situations; indeed, as mentioned in Section III-B the contributions of the different factors in the weighted sum used to compute the EP are independent. The bounds established for the different factors relevant for the EP can be seen in the figures. For example, the dissemination area in Figure 1.b is 300 meters away on the right and on the left of the event. Similarly, in Figure 1.c the bounds are at 1 666 meters, as this is the distance traveled in two minutes when moving at 50 Km/h. In several videos available at <http://www.univ-valenciennes.fr/ROI/SID/tdelot/vespa/epPCoeff/>, we illustrate this with different variations of the penalty coefficients.

Naturally, the importance of the Δd , Δt , Δg and c parameters depends on the type of event considered. 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 a close available parking space.

Besides, for the same type of event, the penalty coefficients could be modified according to the current time and date. For example, for parking spaces in urban areas, the penalty on the age (i.e., γ) should probably be larger on Saturday afternoons

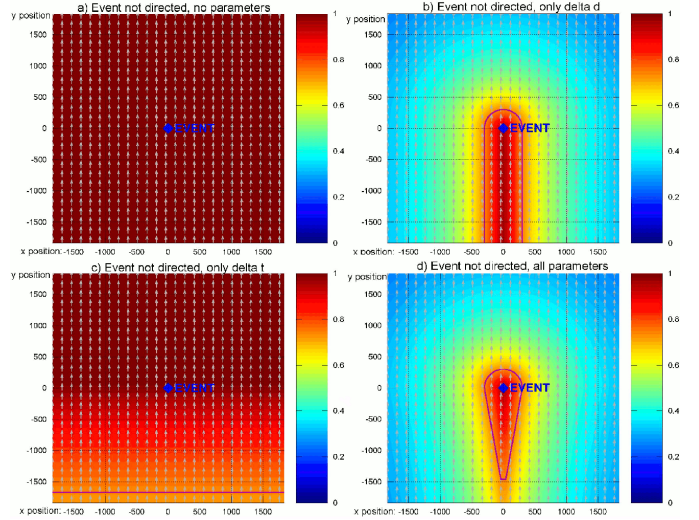


Fig. 1. Example showing the impact of the penalty coefficients

(since the lifetime of the event is then shorter).

Finally, we would like to emphasize that by setting properly the penalty coefficient γ , the proposed dissemination protocol can avoid the need to disseminate information about obsolete events (revocation messages). For events with a long lifetime (e.g., an accident), it is possible to adjust the value of γ in order not to penalize too much the EP with the age of the event. Nevertheless, for long-duration events, new versions of the same event have to be produced to continue informing the arriving vehicles. Several versions of the same event may be generated also in order to update the information associated to the event. So, for example, if the car of a sleepy driver is blocked due to a traffic congestion, the new versions of the generated mobile non-direction-dependent event (warning about her/his lack of vigilance) would indicate the speed reduction. If the car of that driver should stop for a while for the same reason, then the new versions of the event would include two reference positions equal to the current position and so represent a temporary static event. Thus, our dissemination solution does not require any message to indicate the end of an event; instead, the vehicles themselves can decide when the event needs to be removed because it is not relevant anymore (e.g., due to an excessive age).

The proposal in the paper does not require that all the vehicles use the same penalty coefficients, even though it is reasonable that the values of the penalty coefficients will depend mainly on the type of event considered. Choosing good values of the penalty coefficients for a specific type of event could be done heuristically (based on common sense) or by performing an extensive experimental evaluation in a variety of scenarios.

D. Comparison with an Approach Using a Predefined Dissemination Area

Based on the EP, the proposed dissemination protocol follows a *forward-if-relevant* principle by which each vehicle receiving the event decides whether the event should be further disseminated. The decision is based on the value of the

EP computed by the vehicle for that event². Therefore, the dissemination area is adaptive (i.e., determined dynamically), as the message propagates through the vehicular network while it is still considered relevant. This provides several benefits, as we explain on the following.

On the one hand, the approach proposed in this paper is quite general. The penalty coefficients and the diffusion threshold used in the vehicles are a way of fixing the dissemination area in a dynamic way. By setting appropriate penalty coefficients, we can set dissemination areas that may appear in a typical practical scenario. For example, if a vehicle breaks sharply, then the event should be communicated to the vehicles following it on the same road. This can be achieved with our approach by just setting all the penalty coefficients to 0 except Δd (to limit the distance) and c (to consider only the vehicles moving in the direction towards the braking event). As another example, the information about a parking space should probably be disseminated in the vicinity of that parking space, which can be achieved in our approach by just setting a value for Δd (to fix a spatial relevant area around the parking space). Moreover, with the EP-based approach it is possible to consider also elements different from spatial conditions, if necessary; for example, in the second case the penalty coefficient Δt can also be set to penalize the age of the event, as an available parking space could be quickly occupied by another vehicle.

On the other hand, the EP-based approach is also more flexible. Thus, it allows the vehicles to take decisions dynamically regarding the dissemination process. For example, some vehicles could use a higher diffusion threshold if they use energy-constrained devices for communication and need to avoid releasing many events. In general, the EP-based solution could accommodate vehicles with different degrees of cooperation/involvement in the system. Similarly, the diffusion threshold could be lowered in areas with low traffic density, to try to maximize the probability that the message is suitably disseminated.

Moreover, in some cases it could be difficult to set a suitable dissemination area in advance, as it is also emphasized in [11]. For example, when a vehicle leaves a parking space, it has no information about the number of vehicles searching for a parking space and their distances. If the vehicle generating the event chooses a too small area to inform only close vehicles, then it could happen that no interested vehicle receives the event. If, on the contrary, it chooses a larger area, then many interested vehicles could receive the event and engage in a competition to take the parking space. Similarly, it may be quite difficult to define an appropriate dissemination area for a mobile event, as it is itself moving. Therefore, an approach where each vehicle decides whether a message has to be forwarded or not can adapt more easily to the current situation and lead to dynamic dissemination areas. Other works such as [9], [11], also indicate that the dissemination areas should be dynamic.

²It would be possible to base the decision on the EP of the neighboring vehicles instead, but this would introduce an important overhead in the dissemination protocol, as the vehicles would need to keep track of the current and previous locations of their neighbors to be able to compute their EP.

IV. LIMITING THE BANDWIDTH USED BY THE DISSEMINATION PROTOCOL

A dissemination protocol where each vehicle simply considers the EP of the events it receives to decide if it should rediffuse the events or not would lead to network overloading (in a given area, many vehicles could rediffuse the same event unnecessarily). To avoid flooding, and so network congestions, the proposed solution aims at desynchronizing the rediffusions, similarly to other approaches such as the basic scheme for contention-based forwarding proposed in [22] for unicast message delivery in vehicular networks. It is necessary to limit the number of diffusions of a single message, since the value of the EP may be greater than the diffusion threshold used for many vehicles. Therefore, each vehicle will wait for a period t before rediffusing the message. The size of that period depends on the distance between the receiving vehicle and the vehicle which sent the message. The intuitive idea behind this is to choose, among all the neighbors that received the message, the farthest one from the sender to relay the message, as also considered in [19]. Thus, such a vehicle may have the greatest number of neighbors not yet informed about the event being transmitted. So, it is the best candidate to quickly broadcast the message to all concerned vehicles. The value of t is determined by each vehicle as follows:

$$t = D \times \left(1 - \frac{d}{r}\right) \quad (2)$$

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

This approach allows a message to propagate where it is relevant (if needed, far from the origin) but also minimizes the number of duplicated messages received by the vehicles. An alternative where the sending vehicle has to decide which neighbor should rediffuse would be unrealistic, as such an approach would require that the vehicles track the locations of their neighbors

It should be noted that, upon reception of a message, in general a vehicle has to avoid rediffusing such a message if it was the one that rediffused it before. It could also happen that none of the vehicles receiving a message about an event determines it relevant enough, based on the EP computed, to rediffuse it. Similarly, it may occur that there is no vehicle receiving the message because no vehicle is within range of the sending vehicle. To overcome these situations we use the following approach. Each time a vehicle diffuses a message, it waits D' seconds. Then, if it did not receive the message during that interval, it will periodically resend it (according to this period D') until another vehicle estimates the event relevant and so diffuses it also. Thus, D is used as the maximum waiting time for a vehicle to decide to rediffuse a message and D' is used as the time to wait for an acknowledgement

that the message that it sent previously was received by some other vehicle. D' is not necessarily equal to D , but the same value could be assigned for D and D' . Indeed, if $D' < D$ then a rediffusion may take place before a vehicle located far had the chance to rediffuse the message received. On the contrary, if $D' > D$ then vehicles will have more time to rediffuse but unnecessary waiting times may be introduced.

Besides, we propose to associate to each event communicated in the vehicular network a *HopNumber* attribute to indicate the number of rediffusions of the message. The value of this attribute is increased every time a vehicle relays a message, and is used to determine if a message received is actually a rediffusion. Indeed, if two vehicles are very close, they could both relay a message at the same time and a neighboring vehicle receiving the message twice should not interpret the second message as the acknowledgement in that case. Finally, it is interesting to mention that the value of D and D' could be fine-tuned by considering the trade-off between latency and network congestion: a high value minimizes the number of rediffusions but implies an increase in the latency (i.e., the dissemination is slower).

V. EXPERIMENTAL EVALUATION

We have implemented the proposed dissemination protocol in the VESPA system [5], [6], [23], which applies data management techniques to allow data sharing among vehicles in a vehicular network. Our implementation allowed us to perform some experiments in a real scenario to evaluate our dissemination protocol. However, due to scalability reasons (it is difficult to perform repeatable scenarios with a high number of vehicles in a real environment), we use a simulator to evaluate our solution. Tests in a real environment are thus used mostly for verification and to calibrate our simulations.

Choosing which simulator to use was a big challenge. It had to allow us to represent the environment, to define different routes for vehicles, to integrate various speeds and traffic conditions, and to collect all the information we need to evaluate our proposal. We studied the various simulators available (e.g., NS2³, GloMoSim⁴ and JiST-SWANS⁵), but it proved difficult to implement and evaluate our solutions on those simulators. One of the important difficulties was how to integrate VESPA with an existing simulator, which is necessary because the reception of certain events should affect the behavior of the vehicles (e.g., if a vehicle is trying to park and receives an event reporting an available parking space in its vicinity, the vehicle should move towards that location). So, in the end, we chose to develop our own simulator, which allows us to simulate realistic contexts.

A. Experimental Settings

During our experimentations, we have considered real road networks of an area of the city of Valenciennes (France), by using digital maps provided by Tele Atlas (<http://www.teleatlas.com>). More precisely, in the experiments presented

in this paper we have considered a (15 km long) segment of the highway between Valenciennes and Lille in the North of France⁶, which is shown in Figure 2.

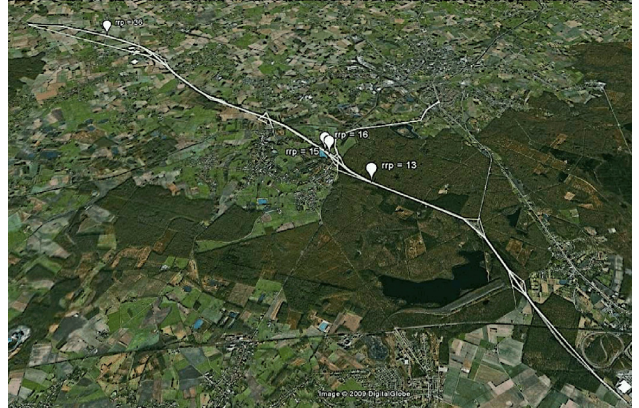


Fig. 2. Road network considered for the experimentation on highways

In Figure 3, we show the graphical user interface of our simulator when events are diffused on the highway, which is very helpful to detect possible anomalies in their dissemination. The most recent diffusions appear with large red circles in the interface. Those circles then remain visible to observe the evolution of the dissemination chain over time but their color turns to grey and their size is reduced to better distinguish the most recent ones.

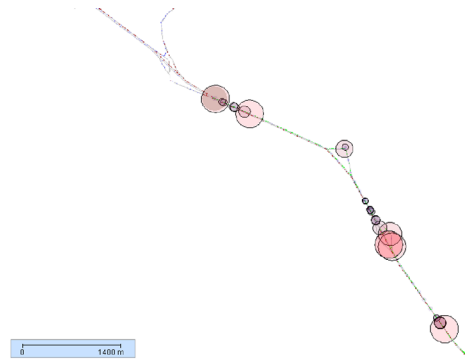


Fig. 3. Dissemination of events on the highway

In our experiments, we used 1 second for D and D' , 75% as diffusion threshold, and a communication range r of 200 m. Based on an extensive experimental evaluation in a variety of scenarios and considering real road networks, we decided to compute mobility vectors by using position statements performed every 500 m and direction vectors by using position statements measured every 30 m: these values lead to good results in a variety of scenarios. Vehicles are created every two seconds on the simulator with a random location (at one extreme of one of the roads in the considered configuration) and a certain speed (whose value is between 90 km/h and 110 km/h along the simulation). The trajectories of the vehicles for the simulations are the shortest

³<http://www.isi.edu/nsnam/ns/>

⁴<http://pcl.cs.ucla.edu/projects/glomosim/>

⁵<http://jist.ece.cornell.edu/>

⁶We have performed more experiments in other scenarios (not reported in this paper), such as urban areas, that lead to similar conclusions.

paths to random target locations. Thus, we perform a traffic simulation similar to the one proposed in [24]. On the road networks, we generate different direction-dependent and non-direction-dependent static and mobile events (parking spaces, traffic jams, accidents, obstacles, emergency vehicles, etc.) in various road segments. To calibrate the parameters related to the use of wireless networks in our simulator (e.g., time needed to receive data broadcasted in the wireless network), we extracted values from the OPNET (<http://www.opnet.com/>) network simulator. Our experiments were repeated ten times to measure the average values (no significant differences were found among the different repetitions).

B. Effectiveness of the Dissemination Protocol

First, we evaluate the global effectiveness of our solution. We consider that the dissemination protocol is effective if it is able to deliver the information about the events to all the relevant vehicles in time. With this purpose, Figure 4 shows the evolution of the percentage of vehicles which present a warning to their driver (Y-axis) according to the time remaining until the moment they meet the event (X-axis). As shown in the figure, we have evaluated the effectiveness of our approach for different types of events: static non-direction-dependent events (available parking spaces), static direction-dependent events (obstacles in the road affecting one direction of movement), mobile non-direction-dependent events (vehicles performing strange maneuvers), and mobile direction-dependent events (emergency vehicles asking the right of way). For each type of event, we considered different combinations of values of the penalty coefficients, that we intuitively represent as “restricted area”, “medium area” and “large area”. The specific values considered for the penalty coefficients in each of these cases have been determined by setting upper bounds for the Δd , Δt , Δg and c parameters (as explained in Section III-C) and a diffusion threshold of 75%. These combinations are shown in Table I; for each value of the penalty coefficient, the upper bound considered is in brackets. Higher values of the penalty coefficients means that the corresponding factors are penalized more, and therefore the spatio-temporal dissemination area is more restrictive.

Penalty coefficient	restricted area	medium area	large area
α	1/90 (30 m)	1/1500 (500 m)	1/3000 (1000 m)
β	1/90 (30 s)	1/180 (60 s)	1/900 (300 s)
γ	1/180 (60 s)	1/360 (120 s)	1/1800 (600 s)
ζ	1/180 (60°)	1/270 (90°)	1/360 (120°)

TABLE I
COMBINATIONS OF PENALTY COEFFICIENTS

As shown in the figure, unless the dissemination area is very restrictive, all the vehicles are informed before encountering the event and most of them have enough time to react to the event received. The figure also shows that the information about events that change their location (mobile events) is usually received by the vehicles later. In other words, for mobile events it is much more difficult to warn a driver located far away. This is because the probability that two moving objects will meet cannot be very high a long time in advance.

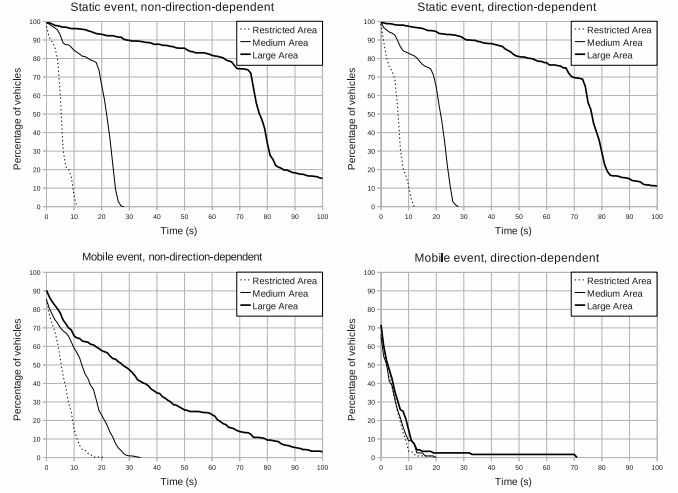


Fig. 4. Percentage of vehicles which presented a warning to their driver

So, the vehicle and the mobile event must be quite close so that it becomes possible to estimate that they will meet. On the contrary, for static events the encounter probability only depends on the itinerary of the vehicle (the location of the event does not change), and therefore it is easier to determine whether the vehicle is going toward the event.

For the rest of the experiments presented in this section, we consider different types of events mixed and penalty coefficients for a “large area” (see Table I).

C. Efficiency of the Dissemination Protocol: Overload

The proposed dissemination protocol should minimize the number of message transmissions in the network, as a high number of transmissions would imply a high cost and may lead to overloading the network. However, it is also important to ensure that a message is not lost during the dissemination. With this in mind, in the following we compare our solution with two other alternatives. The first one is traditional flooding. The second one performs a periodic flooding, where the messages are rediffused periodically, motivated by the fact that some messages are lost with a traditional flooding when the traffic density is low (as we will explain later).

In the simulated scenario we consider different types of events mixed (i.e., the different types of events considered in Section V-B occur) and we evaluate the aforementioned dissemination strategies. In Figure 5, we present the total number of messages diffused (Y-axis) at each second since the generation of the event (X-axis) in a scenario with low traffic density (about one vehicle every 100 meters), high traffic density (about one vehicle every 10 meters), and also medium traffic density (about one vehicle every 50 meters). Two phases can be observed during the dissemination. In an initial dissemination phase, the information is relayed towards the end of the dissemination chain. Once the end of the dissemination chain is reached, a maintenance phase keeps the information alive in the network while it is relevant (through periodic rediffusions).

As shown in the figure, our dissemination approach strongly limits the number of messages exchanged, providing better

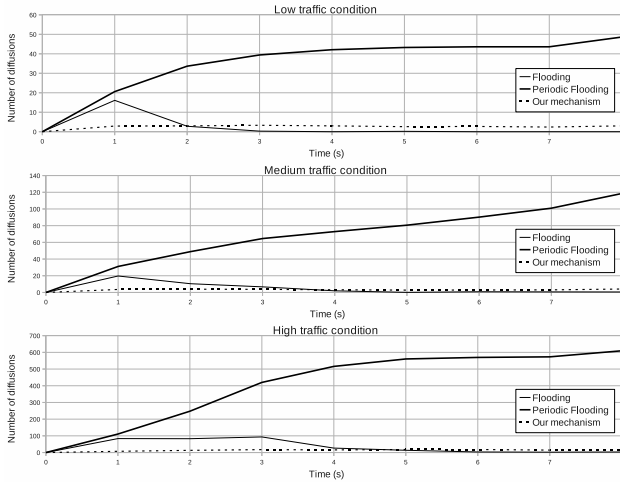


Fig. 5. Evolution of the messages exchanged

results than traditional flooding and periodic flooding. With our dissemination mechanism and traditional flooding, the number of messages decreases after a few seconds because the tail of the diffusion chain is reached (the event is not considered relevant enough by the farthest vehicles to be rediffused). Nevertheless, with our dissemination approach, the rediffusion of the message still continues at the tail of the diffusion chain (even though it could be difficult to see it in the figure due to the scale) as long as the EP is enough (the EP decreases according to the age penalty coefficient associated to the event). On the contrary, with traditional flooding, the number of messages reaches 0 after a few seconds, and so the information about the event stops propagating. Therefore, the flooding should be repeated periodically (periodic flooding). Both periodic flooding and our approach are able to keep the information alive, but periodic flooding imposes a serious overhead.

In conclusion, the dissemination protocol proposed in this paper limits the number of message transmissions and is also able to keep in the network the information about an event until the event becomes irrelevant.

D. Efficiency of the Dissemination Protocol: Latency

In this section, we evaluate the time needed to deliver a message to a vehicle with our approach. In order to avoid overloading the network with unnecessary retransmissions, the proposed dissemination protocol introduces waiting times at each hop of the dissemination process (see Section IV), and so it is important to check that this does not have an important negative effect on the latency of the messages.

As a baseline for our evaluation, we also consider flooding (traditional flooding and periodic flooding) as an alternative approach because such a dissemination protocol is expected to minimize latency (at the expense of overloading the network, as seen in Section V-C). Thus, Figure 6 shows, for the different dissemination approaches, the time needed for the vehicles to receive the information (Y-axis) depending on the distance between those vehicles and the event (X-axis). As expected, using our dissemination mechanism the vehicles receive the

information about the event a little more late than using flooding (i.e., periodic flooding and flooding are faster than our protocol). Nevertheless, the additional cost is limited – even in worst case situations (i.e., when the traffic is low) – and there is enough time for the driver to react according to the information received. We can notice that flooding stops before periodic flooding, which confirms that traditional flooding is not able to keep the information alive after a while.

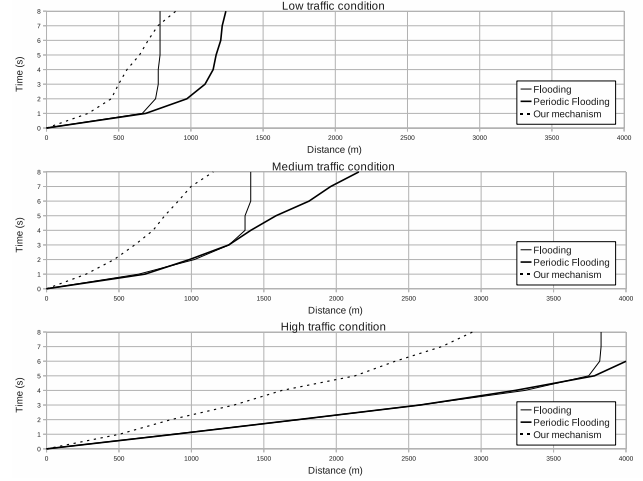


Fig. 6. Time needed to receive a message

VI. CONCLUSIONS AND PERSPECTIVES

In this paper, we have presented a content-based dissemination protocol to exchange information about events in a vehicular ad hoc network. The main features of our approach are:

- 1) It has not been designed with a specific type of events in mind. Instead, it allows the dissemination of different types of events occurring in a vehicular network. Both static and mobile events are supported seamlessly.
- 2) It uses the concept of *Encounter Probability* to dynamically adapt the dissemination area as needed, by considering the relevance of the events for the vehicles. This ensures an effective dissemination of the information about the events to all the interested vehicles.
- 3) It minimizes the network usage, by avoiding rediffusions of messages that are not really necessary to reach all the intended vehicles.
- 4) It is generic, not only applicable to a specific vehicular application, and could be deployed into any vehicular network as long as a few attributes (CurrentPosition, DirectionRefPosition, MobilityRefPosition, lastDiffuserPosition, and HopNumber) are communicated as part of the information of the events. These attributes can be easily set and take only a few bytes.
- 5) It has been implemented in the context of the VESPA system. The experimental results presented show the interest of the approach. On the one hand, the vehicles receive the interesting events with enough time before meeting the event. On the other hand, the overhead of the dissemination protocol is limited.

So far, we have evaluated our approach using a simulator. Field tests with real vehicles communicating have also been performed but only in simple scenarios. While it is challenging to set up a real scenario with a high number of cars (in terms of human and economic effort), we would like also to perform some real test in more complex scenarios. We also plan to study how the dissemination protocol could be coupled with compression and knowledge extraction mechanisms that may help to reduce the number of communications and provide aggregate information to the drivers. Moreover, we also plan to extend the proposal to benefit from support communication infrastructures when they are available.

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