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Data Gathering in Vehicular Networks: The VESPA experience

(Invited Paper)

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***Abstract*—The interest of intelligent transportation systems and vehicular networks is on the rise. In this paper, we present an overview of the development of VESPA, a system that we are developing for vehicles to share information (e.g., information about available parking spaces, accidents or obstacles in the road, emergency brakings, emergency vehicles asking the right of way, etc.) in inter-vehicle ad hoc networks. We summarize the research challenges that we have considered so far and the difficulties that still lie ahead. This includes the basic push-based approach used in VESPA, the resource allocation policy proposed to avoid competition in the access to scarce resources (such as parking spaces), and the development of data aggregation techniques for knowledge extraction. Besides, we also analyze our current and future work, which focuses on the exploitation of different data sources and pull-based query processing, the management of multimedia information, and the routing of query results.**

***Index Terms*—Vehicular networks, data management, data dissemination.**

I. Introduction

Advances in computing and mobile communication technologies and the increased interest in the development of *Intelligent Transportation Systems* (*ITS*) has led to an intensive research effort in *vehicular ad hoc networks* (*VANETs*) [1], [2], [3], [4], [5], [6], which are highly dynamic ad hoc networks whose nodes are vehicles. In these networks, the vehicles carry a short-range wireless communication device that they can use to directly and quickly exchange data with other vehicles (e.g., using Wi-Fi) and even to communicate queries (i.e., requests of data) in a peer-to-peer way (i.e., without the need to deploy a costly communication infrastructure). The data exchanged can be generated by sensors embedded in the vehicles (e.g., for data such as the current speed and location, the status of brakes and airbags, etc.), by other external data sources (e.g., sensors deployed along the roadside), or in some cases they could be introduced by the driver himself/herself by using an appropriate interface.

Whereas this scenario opens up a number of opportunities for the development of interesting applications and services, several difficulties also arise. Indeed, an inter-vehicle ad hoc network is a highly dynamic network subject to frequent changes in its topology. For example, two vehicles within range of each other can move at high speeds in opposite directtions, which leaves a small time window available for data exchange. This new context creates truly interesting challenges, which must be addressed to propose efficient driver assistance systems. For example, we could highlight the need of suitable techniques to perform several tasks (see Figure 1 for a general overview):

- *Determining the relevance of the information received.* When a data item is received by a vehicle, it should be able to determine whether that information is interesting or not, according to the context of the vehicle. In other words, there should be some mechanism to assess the relevance of the data [7], [8], [9], [10], [11]. The relevance of the data can be seen from a double perspective. On the one hand, it should be determined whether it is convenient to show the information received to the driver (or if, on the contrary, this could be unnecessary or disturbing for him/her). On the other hand, it has to be decided if the information received should be broadcasted to other vehicles. Several factors can affect the concept of relevance, including both temporal and spatial aspects. For example, in the case of information about an available parking space, an interested car must determine: 1) whether it is close enough to the reported parking space (spatial relevance), and 2) whether the parking space has been released recently and therefore it is probably still available (temporal relevance).
- *Disseminating the data efficiently in the network.* An efficient and effective approach is needed to make the information available to the interested vehicles with a minimum network overhead [12], [13], [14], [15], [16]. The idea of relevance, commented above, plays again a major role. Indeed, an event should be propagated to neighboring vehicles while the event is considered relevant in the area, thus leading to a dynamic dissemination area that evolves according to the relevance of the event. Besides, the dissemination protocol should

We are grateful to the colleagues who have invested their efforts in different aspects of VESPA, and also to the students that have helped in the development of the prototypes and simulation frameworks. In particular, we would like to thank the main contributors (it is not an exhaustive list!): N. Cenerario, B. Defude, T. Hien, S. Lecomte, N. Peon and D. Zekri.

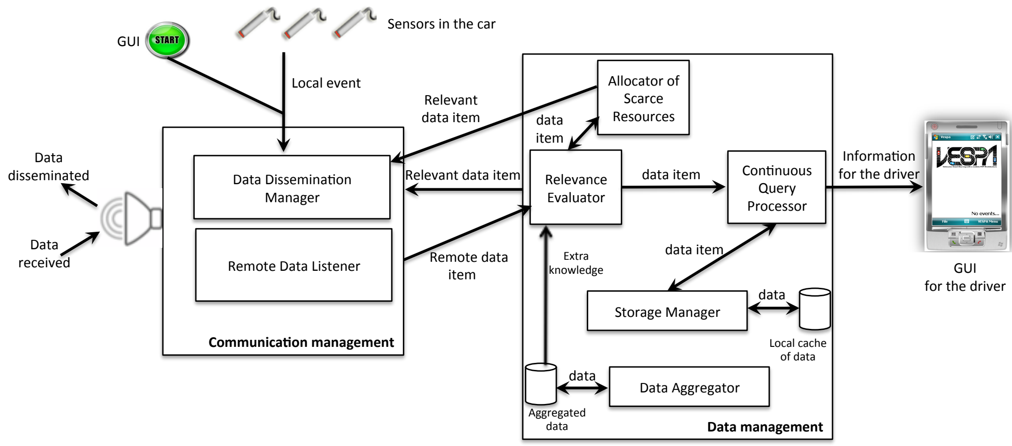

Fig. 1. General overview of the task modules

attempt to minimize the number of messages diffused. Therefore, approaches such as traditional flooding [17] are not appropriate in this context and other schemes are necessary.

- *Managing competitive resources*. The interest of peer-to-peer systems relies on the willingness of the participating nodes to cooperate and exchange information among themselves. However, providing all the interesting information to all the interested nodes may lead to problems when the information refers to scarce resources. For example, if a parking space has been released and this information is communicated to many nearby vehicles that are searching for parking, then they will engage in a fierce competition and all but one (the one eventually occupying the space successfully) will end up disappointed with the use of such a data sharing system. Similarly, if there exists a fast route and all the vehicles are informed about it, a traffic congestion could appear in that route, making it slow instead of fast. Therefore, besides relevance, some mechanism is needed to decide which information should be communicated to which drivers. In a way, this will allow "allocating" the scarce resources wisely [18], [19].
- *Aggregating data*. Obviously, not all the information received by a vehicle can be stored indefinitely on the vehicle. Even if this could be possible, it would probably be useless due to the limited temporal relevance of the events. However, the vehicle could summarize the information received, applying some data aggregation technique [20], [21], [22], [23], and then use the aggregated data to try to extract some extra knowledge that it could use in the future. For example, by receiving information about available parking spaces, a vehicle could be able to learn (given enough time) information about areas where available parking spaces are frequent. Moreover, it could exchange this information with other vehicles to help increase their knowledge too; furthermore, communicating aggregated data (instead of information about specific events) could be enough in some situations, which would reduce the network congestion and increase the scalability. The knowledge could then be exploited by drivers (e.g., to decide moving towards an area with potential available parking spaces) or by the system when evaluating the relevance of the events (e.g., by strongly penalizing the time elapsed since a parking space was released if it is located in an area where many vehicles usually search for parking, or by estimating the probability of finding an available parking space at the time of arrival [9], [24]).

In this paper, we focus on the aforementioned needed tasks by describing our experience with *VESPA* (*Vehicular Event Sharing with a mobile P2P Architecture*), a system that we are developing to support sharing information about events in inter-vehicle ad hoc networks. One of the main benefits of VESPA is that it has not been developed with a specific type of event or application scenario in mind, and therefore can deal with many types of events in a VANET (e.g., information about available parking spaces, accidents, emergency brakings, obstacles in the road, real-time traffic information, information relative to the coordination of vehicles in emergency situations, etc.). We have evaluated VESPA through simulations that have been fine-tuned based on real-world experiments in a small scale. For that purpose, a prototype of VESPA was developed (see Figure 2 and http://www.univ-valenciennes.fr/ROI/SID/tdelot/vespa/).

The contribution of this paper lies in providing an overview of the different research challenges that we have tackled and of the open issues that we plan to consider in the future. In particular, the structure of the rest of the paper is as follows. In Section II, we describe the basics of the push-based approach used in VESPA for data sharing in vehicular networks [7], [16], [13]. In Section III, we summarize our approach to deal with scarce resources that may involve a competition among vehicles [18]. In Section IV, we explain the techniques proposed to extract knowledge from the information received at the vehicles [22], [23]. In Section V, we discuss some problems that we are currently studying, regarding the use of

Fig. 2. Protoype of VESPA in action

different information sources and pull-based query processing [25], [26], management of mutimedia information [27], and routing of query results [28]. Finally, in Section VI, we present our conclusions.

II. Push-Based Data Sharing in VESPA

VESPA supports a push-based data sharing mechanism. The approach is based on the following ideas:

1) A vehicle can broadcast data about events that could be interesting for neighboring vehicles.
2) The transmitted data are received by the neighboring vehicles.
3) Each vehicle receiving an event evaluates its relevance.
4) If the relevance is higher than a certain *storage threshold*, then the event is considered to be relevant for the vehicle. Therefore, it is stored in its local data cache.
5) If the event is also higher than a certain *relevance threshold* and either the driver is interested in that kind of event or the event is assumed to be interesting for every driver (e.g., it represents an accident), then the event is considered to be relevant for the driver. Therefore, it is reported to the driver.
6) If the event is higher than a certain *diffusion threshold*, then the vehicle re-broadcasts the message so that other nearby vehicles can receive it.

So, with this approach, the data relevant for a vehicle are stored in its local data cache through a push-based model. Then, query evaluation techniques are used to process the stored information to determine what is relevant according to the context, and issue a warning or transmit information to the driver when necessary.

In VESPA, we use as a relevance measure the concept of *Encounter Probability* (*EP*) between a vehicle and an event [7]. The EP is related to the estimated likelihood that the vehicle will meet the event in the future. As explained before, the EP computed for an event received is compared with several thresholds to decide what to do with the event. In particular, the EP is used to decide whether the event should be stored, reported to the driver, and/or disseminated to other vehicles. We have proposed two alternative methods to compute the EP: one method based on geographic vectors and another one that exploits the information available in digital road maps (see Figure 3).

The first method simply considers geographic coordinates in the Euclidean space and does not require any road maps or other information about the environment. The basic idea behind the method is the possibility to predict future positions of the vehicle (and of the event, in case it is a mobile event such as an emergency vehicle asking the right of way) by considering its direction and speed, which can be determined based on previous reference positions. Then, the computation of the EP is based on four factors: 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), and the angle between the direction vector of the vehicle and the direction vector of the event (represented by a colinearity coefficient c). These elements are weighted by considering different *penalty coefficients* and aggregated to compute a value for the EP (see Figure 3, left). For more details, please see [7].

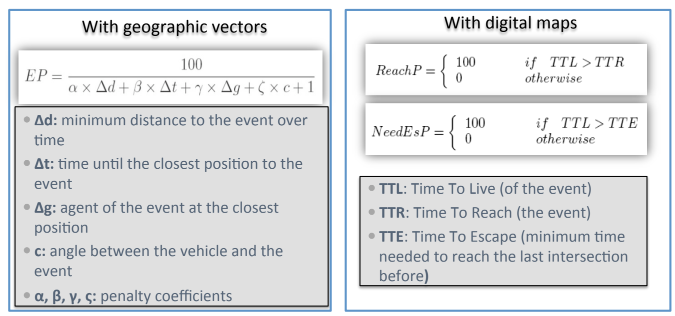

Fig. 3. Computation of the EP: using geographic vectors (left) and using digital road maps (right)

The second method computes the EP based on information available in digital road maps to try to compute the EP in a more precise way. This method is based on the estimation of the *TTL* (*Time to Live*) of an event, which is the time interval during which the event will be valid, and on the distinction of two different types of events. On the one hand, *attraction events* (see Figure 4, left) represent those that the driver would like to reach (e.g., parking spaces), and therefore we define the *Reachability Probability* based on the TTL and the time needed to reach the event by following the shortest path between the vehicle and the event. On the other hand, *repulsion events* (see Figure 4, right) are events that the driver would like to avoid (e.g., traffic congestions or accidents), and therefore we define the *Need to Escape Probability* based on the TTL and the time needed by the vehicle to reach the last intersection that offers the vehicle an alternative route to avoid the repulsion event. The value of the EP is computed depending on the type of event and considering the two probabilities mentioned (see Figure 3, right). For more details, please see [16].

Fig. 4. Reaching an attraction event (left) or avoiding a repulsion one (right)

It is important to emphasize that the dissemination protocol is not only based on the EP, as this could lead to network congestions due to a high number of redundant messages transmitted. Instead, a desynchronized rediffusion of messages is considered to limit the bandwidth used. For more information about the dissemination protocol of VESPA, the interested reader is referred to [13], where this protocol is explained in detail and evaluated experimentally.

III. Dealing with Competition in VESPA

As commented before, for some types of events exchanged between vehicles (e.g., parking spaces), it is not enough to indicate their location to the driver. Indeed, if the same information (i.e., the same available parking space) is presented to several interested drivers, this will lead to a competition between the vehicles and only one of them will be able to take that parking space. It is so important to propose a solution for scarce resources such as parking spaces to be "reserved" and so communicated to a single driver. The fully decentralized environment imposed by vehicular networks makes that reservation process particularly challenging since vehicles keep moving and no reliable link or central server can be used. Although some solutions have been proposed to disseminate information about available parking spaces using short range communications (e.g., [8]), to the best of our knowledge, no other work has tackled the problem of parking space reservation in wide areas using only vehicle-to-vehicle (V2V) communications. Thus, for example [29] considers only parking lots that are managed by Roadside Units (RSUs) and does not focus on reservation issues.

Coordinating different vehicles in vehicular ad hoc networks for them to choose one vehicle to which the parking space should be allocated is not an easy task. Indeed, no centralized server is available in such environments, where vehicles only communicate through short range communication networks. Moreover, all the vehicles have the same importance/role. In [18], we have introduced a protocol to decide to which vehicle the resource should be allocated. Our goal is to ensure that the information about a parking space is shown only to the driver of the vehicle that is chosen to occupy it, in order to minimize competition. Anyway, even if we try to help the elected vehicle to reach the parking space while it is still available, we cannot ensure that no other driver will see and use the available parking space before. This is obviously unavoidable. What our protocol eventually ensures is an effective dissemination of information about available parking spaces, without leading to a competition due to the use of the data sharing system itself. Thus, the goal is to benefit from the advantages of sharing information about available parking spaces but without incurring in the problems of sharing such information.

To avoid causing an unnecessary competition among vehicles, the reservation protocol should:

- indicate to the driver an available parking space already "reserved" for his/her vehicle (instead of a list of all the available parking spaces received by the vehicle);
- allocate the parking spaces in a way that maximizes the probability that the one assigned is still available when the driver arrives there;
- maximize the use of the resources (trying to avoid the existence of an empty parking space if there are vehicles searching in its vicinity);
- be fair to all the vehicles (i.e., ensure that a vehicle does not have a higher priority than the others);
- minimize the actions to be performed by the driver, with two goals: 1) not to disturb him/her while driving, and 2) to preserve the fairness of the protocol by not allowing the drivers to disseminate themselves misleading information that they could use to their own advantage (i.e., to obtain a parking space before the others);
- avoid network congestion.

Our solution to reserve parking spaces relies on the election of one *coordinator* per available parking space. The coordinator is a vehicle with a temporary particular role in the allocation of an available space. More specifically, it is responsible for the allocation of the parking space to a vehicle according to a predefined policy.

In the following, we summarize how our protocol works. Initially, the coordinator is the vehicle that leaves the parking space, or one of the vehicles receiving the event in case the event is generated by a fixed sensor in the parking space. The coordinator sends a message to inform the vehicles in its communication range that a parking space is available. Then, it waits for potential answers. Among the vehicles receiving the information, only those interested in the parking space send a reply to the coordinator. Each interested vehicle v_i provides to the coordinator its vehicle's identifier and the information necessary for the coordinator to choose the vehicle to which the resource has to be allocated, such as the time t_i, corresponding to the current duration of the search of a parking space for that vehicle.

The coordinator waits for potential answers during a certain period of time. Afterwards, it chooses, among the vehicles that answered, the one for which the parking space is "reserved". Different policies can be applied to make this decision; for example, the coordinator could choose the closest vehicle to the parking space, the vehicle that has been searching for the longest period of time, etc. Finally, the chosen vehicle sends a message to the coordinator to acknowledge the reception of the coordinator's message ("permission" to take the parking space) and to confirm that it will take the parking space. In case the chosen vehicle does not accept the parking space, another vehicle is chosen by the coordinator in order to ensure that the parking space will be eventually allocated. It should be noticed that if the acknowledgement is not received by the coordinator due to a communication failure, then the coordinator would repeat the allocation process and the parking space would be allocated to a second vehicle, which would generate some competition. However, this unlikely inconvenience is preferable to the possibility that the advertisement of the parking space gets lost.

In case no interested vehicle answers the coordinator, the spatial range where the available parking space is announced is extended by choosing a new coordinator. For more details about the reservation protocol of VESPA, the interested reader is referred to [18].

IV. Data Aggregation in VESPA

In VESPA, as well as in the other existing systems, messages representing events (e.g., traffic congestion, emergency braking, parking space released, etc.) are generated and exchanged between vehicles using a certain protocol, in order to warn or inform drivers. Data are considered here only as objects to be transmitted and deleted once used. From a data management point of view, such a process is unusual. Hence, we have investigated within our VESPA project how to summarize and store data about events received on each vehicle. The concept of data summarization in inter-vehicular ad hoc networks has been considered in many works as a method of compressing data to reduce bandwidth requirements (e.g., [20]). Our approach is quite different since our goal here is not only to produce instantaneous warnings to the driver, but also to extract contextual knowledge that can later be exploited to provide relevant information to the driver. For example, a summary of available parking spaces previously observed can be used to determine the area with the highest probability of having free parking places on a given day and at a certain time. In another context, thanks to the correlation of safety related messages received by a vehicle (e.g., accidents, emergency brakings, etc.), dangerous areas can be dynamically detected and indicated to the driver. Such an approach can be applied not only for the detection of permanently dangerous areas but also for the detection of those that are temporarily dangerous (due to bad weather conditions, for example).

Different spatio-temporal aggregation techniques have been proposed in the literature [30], both in the contexts of vehicular networks and wireless sensor networks (WSN). Regarding VESPA, in a preliminary work [22] we have specified a first aggregation structure based on a simple count of events in a spatio-temporal cell. Then, in [23], we have proposed a new data structure that is more efficient and able to avoid counting several times the same occurrence of an event observed by two different vehicles. Our solution is based on a simple aggregation of many events depending on both the spatial and temporal dimensions. Moreover, since all cars need to share the same spatio-temporal granularity for them to exchange information, we rely on the model illustrated in Figure 5. This model is composed of two parts:

- The *physical level*. This lowest level consists of a repository shared among all the vehicles, whose goal is to allow information exchanges without loss. The physical level is divided into fixed-size squares that form a full partition. The same idea is used for the temporal dimension. Time is so divided into temporal segments that form a full partition. We assume here that we want to emphasize the seasonal nature of the event production. We therefore propose to split time in 7 days, each sliced in 2 hours segments, providing a total of 84 time segments. The couple $\{$*square*, *time segment*$\}$ is the smallest unit that can count occurrences of events.
- The *logical level*. Based on this physical level, each vehicle can build its own logical splitting, defined as a set of rectangles (or intervals). Those rectangles are themselves sets of squares (or intervals) of the physical layer (the rectangles in Figure 5). Indeed, a driver may not be interested in the whole space but only in a subset. We impose the restriction that a physical cell must belong at most to one logical area.

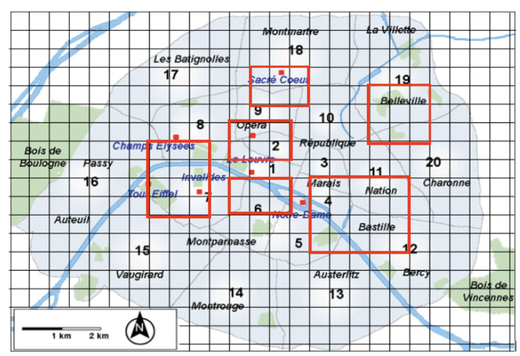

Fig. 5. Uniform division of space for the data aggregation approach

The aim of our research consists of using past collected data to estimate the probability of occurrence of an event in the absence of a recent observation. Thus the summarization process in our work implies aggregating past events to build a knowledge base that is later used to estimate whether an event might occur, even when there is no observation available. We use *Flajolet-Martin Sketches* [31], which provide a compact representation to estimate the number of occurrences of different events. This is particularly important, since the aggregation mechanism has to detect duplicates in order not to consider several times the same event when it is observed by several vehicles.

We assume that each vehicle V_i can observe a set of events E. An event e in E is characterized by several parameters. The following ones are considered in the summary (other information can be useful for managing alarms or disseminating messages):

1) ty_e: the type of event observed (e.g., an accident).
2) lo_e: the location of the event and its timestamp.
3) idf_e: the unique identifier of the event. This unique identifier is the basis for the detection of duplicates. We assume that an instance of an event always produces the same identifier on the vehicle V_i and other vehicles. Such a unique identifier can be generated by combining the current time and the GPS location of the event with a randomly-generated sequence.

As commented before, the physical space is divided into squares (cells) of size C_{NP} (*N* squares along the X axis and *P* squares along the Y axis). An *interest area* is defined as a rectangle composed of a number of physical cells. Specifically, we represent such a rectangle by considering the physical cells delimiting its boundaries: the bottom left cell with coordinates (i, j) and the upper right cell with coordinates (k, l). We assume g temporal granularities (for example ordered from Monday 0:00AM-2:00AM to Sunday 10:00PM-12:00PM). We show a summary with the data structure described in Figure 6. It consists of a set of interest areas defined by a unique identifier (idf) and two physical cells (*i*, *j*, *k*, *l*), and aggregates many types of events. A boolean indicates if the type of the event is aggregated in this area, and p is a pointer to a linked list of sketches. The table of interest areas is sorted by increasing values of *i*.

Thanks to our aggregation structure, a vehicle can store information about past events. Moreover, in order to increase the contextual knowledge exploited by each vehicle, mechanisms that allow vehicles to exchange the data they collected are needed. The two-level spatio-temporal model simplifies the exchange algorithms by creating a common repository for all vehicles. However, vehicles do not lose their autonomy while choosing their interest areas. Each vehicle decides to publish all or part of its summaries to other vehicles and can also be interested in all or part of the summaries of others. To simplify, we consider here only public publications and subscriptions (a vehicle publishes / subscribes to all the vehicles it is likely to meet). The publication process implies defining which summaries should be published (possibly aggregating them by grouping cells).

The subscription process implies defining filters specifying the event types the driver is interested in, adding appropriate spatial and temporal criteria. For example, a driver can be interested in "accidents" in "Paris" over the last month. The exchange of information between vehicles can then be done through a relay (e.g., servers located along the roads), or directly. In both cases, there is no guarantee that the exchange process will finish, in case the duration of the connection is not sufficient to allow the complete exchange of summaries. We therefore propose to use a mechanism based on priorities, which define an order based on data utility, and use this order to prioritize exchanges. Priorities are defined as a set of rules defining an order among several elements. We use as elements the different types of events, the different time granularities for the temporal dimension, and the different areas of interest for the spatial dimension.

For more details about the data aggregation process in VESPA, see [22], [23].

V. Current Work

In this section, we briefly review some other problems that we are currently studying. We first consider the possibility to exploit several information sources and pull-based query processing. Then, we highlight the importance of multimedia data in vehicular networks. Finally, we present the problem of routing query results to a moving originating vehicle.

A. Multi-Scale Query Processing

Most works on query processing on vehicular networks assume a push model where the vehicles receive information from the neighbors and then queries are executed locally based on a cache that stores the information received (like in the core VESPA approach, that we summarized in Section II). However, it would be interesting to be able to exploit during the query processing different access modes (e.g., push, pull) and several data sources (e.g., data cached locally, data stored by vehicles nearby, remote Web services, etc.).

Indeed, a push model may be suitable for many applications but becomes insufficient in some situations. Thus, only data about events that are potentially interesting for a large set of vehicles (e.g., an accident or a traffic congestion) will be diffused among the vehicles that the system estimates as potentially interested (usually based on a notion of spatio-temporal relevance). So, with only a push-based model, it will not be possible to process queries that requires access to other type of information. For example, a driver will not be able to query about available parking spaces near the target destination if he/she is still far from it. A pure push model may also be insufficient to build vehicular social networks that require exchanges within a group of vehicles (not necessarily located near each other).

So, we have initiated a research on *multi-scale query processing* for vehicular networks [25], which implies exploiting the available data sources whatever the access mode (e.g., push or pull). Regarding this issue, we are also evaluating the potential of mobile agent technology [32] for query processing in vehicular networks [26]; in [33] we presented an approach for the use of this technology for environmental monitoring using vehicles.

B. Management of Multimedia Data

Communicating multimedia data can be very interesting for a variety of applications. For example, when a vehicle receives information about an accident it may be very useful to show some pictures or videos to the driver, so that he/she can more

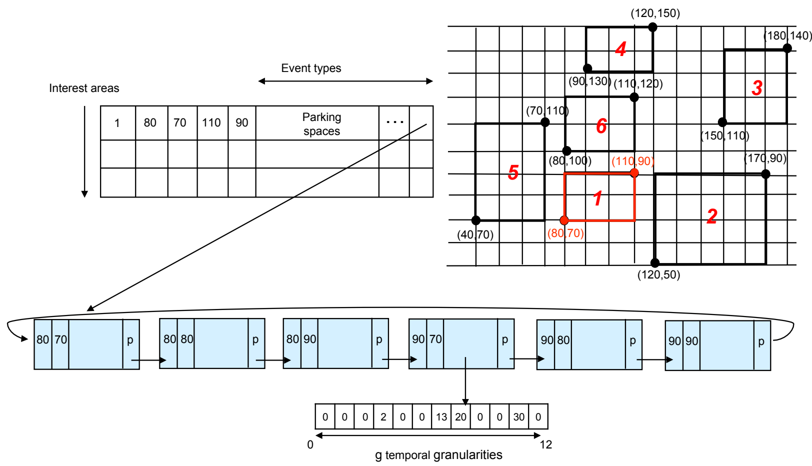

Fig. 6. Data structure

easily assess the impact of the accident. Similarly, if the driver has received information about an available parking space, a picture would help him/her determine whether that parking space is interesting for him/her (e.g., if there is enough space for the vehicle, if the surroundings look nice, etc.), as shown in Figure 7. As an example of the interest of multimedia data for vehicles, in the literature, the use of multimedia clips is proposed in [34] to provide drivers with information about real-time traffic conditions on road segments ahead; an extended version of that paper appeared in [35].

Fig. 7. Using multimedia information for an available parking space

Regarding VESPA, in [27] we presented a preliminary work proposing the use of multimedia content to describe events, but this has to be studied in more detail in order to propose a complete solution.

C. Routing Data/Query Results Towards a Moving Object

An important problem when applying pull models in a VANET is the difficulty to return the results of the disseminated query back to the query originator, which is usually a moving vehicle. In [28], we have tackled this problem by proposing *GeoVanet*, a DHT-based geographic routing protocol based on the use of *mailboxes*. The DHT-based model identifies a fixed geographical location where a mailbox is dedicated to the query to allow the user to retrieve his/her results in a bounded time.

We are currently extending the experimental work performed in [28] and we plan to enhance our initial proposal in several directions. Specifically, an interesting avenue for future research is to study the use of mailboxes in more detail and determine if it is possible to propose a solution that does not require mailboxes.

VI. Conclusions and Future Work

Vehicular networks offer many opportunities for the development of interesting services and applications for drivers, but they also pose important challenges from a data management perspective (that is the focus of this paper) and other related aspects (e.g., networking [5], security [36], trust [37], etc.). In this paper, we have presented an overview of our experience with the development of VESPA, a system for vehicles to share information in inter-vehicle ad hoc networks. We have summarized the issues tackled so far and the main lines of our current and future work.

More efforts need to be invested to fully exploit the possibilities of vehicular networks and make them a reality. Most vehicles are expected to be equipped in a near future with wireless communication devices, and technologies such as IEEE 802.11p, to enable *Wireless Access in Vehicular Environments* (*WAVE*), will soon become a reality. Therefore, researchers must get ready for this situation, collaborate with each other according to their areas of expertise, and put together the pieces to drive a new generation of services for vehicular networks.

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