Using Hitchhiker Mobile Agents for Environment Monitoring

Oscar Urra, Sergio Ilarri, Eduardo Mena and Thierry Delot

Abstract Recently, there has been a great interest in the development of protocols and data management techniques for vehicular networks (VANETs). In a VANET, the vehicles form a wireless ad hoc network where different types of useful data can be exchanged by using the dynamic links that a vehicle can establish with its neighboring vehicles. While this offers opportunities to develop useful applications, many research challenges arise from the point of view of data management.

In this paper, we propose the use of cars equipped with sensors in a VANET for environment monitoring. Our approach is based on mobile agents, which jump from car to car as necessary to reach the area of interest and keep themselves in that area. Thus, relying on an expensive fixed infrastructure of sensors is avoided. Instead, any area can be monitored with low cost as long as there are enough vehicles traversing it. We present experiments that compare different traveling strategies for the agents.

1 Introduction

Vehicular ad hoc networks (VANETs) are attracting a great interest, both in research and in industry. One of the most interesting features is the possibility to use a spontaneous and inexpensive wireless ad hoc network between the vehicles to exchange interesting information (e.g., to warn the driver of an accident or a danger).

On the other hand, the relevance of environmental issues has grown considerably, and there are many areas of study on this subject. In many of them, it is important to have environmental data collected in the field, such as CO_2 or other gas con-

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centration levels, the presence of harmful substances, or meteorological parameters such as the temperature, the humidity, and many others. The usual way of collecting these measures may be problematic. Thus, fixed measurement instruments can be expensive to maintain and they require an infrastructure to operate them, a protected location, power, and communication lines. An alternative could be the use of mobile equipment operated by a person who travels in the area of interest while sampling the required environment parameters, which is also a slow and expensive process. To avoid these drawbacks, we can benefit from regular vehicles traveling along the roads within the geographical area of interest, as long as those vehicles are equipped with the appropriate measurement device; to encourage participation in the monitoring among sensor-enabled vehicles, different techniques can be applied (e.g., based on the concept of *virtual currency*, as in [1]).

In this paper, we advocate the use of mobile agent technology [8, 2] (programs that can move between computers) as the ideal candidate to implement such a system in an efficient and flexible manner. In our proposal, mobile agents jump from vehicle to vehicle as necessary to reach the area of interest and keep themselves within that area. As each vehicle follows its own route, which may be different from the optimal route or even be unsuitable for the monitoring task, the mobile agents may need to change to a different vehicle frequently. Thus, we can compare a monitoring mobile agent in our proposal with a hitchhiker, who may use several vehicles to reach the intended destination. The main difference is that a monitoring mobile agent cannot live outside the execution environment provided by the cars (i.e., outside a mobile agent platform, as explained in Section 3); therefore, once the agent arrives in the area to be monitored, it must jump from car to car to keep itself within such area. With a mobile agent-based strategy, the required environment data can be collected quickly on a wide area (as long as there are enough vehicles). Moreover, the cost of a support infrastructure is avoided, as the idle resources of regular vehicles are used instead.

As far as we know, no other work proposes taking advantage of mobile agents' features to perform monitoring tasks in a vehicular network. Indeed, [3] is the only work that uses this technology in a vehicular field; however, its goal is different (traffic control and management) and it does not face the research issues appearing in our context (agents that must move from car to car to perform the monitoring and transferring data without the need of a dedicated network). Other works that focus on monitoring using vehicles are MobEyes [4] and CarTel [5]. In MobEyes it is not possible to define specific monitoring tasks; instead, the vehicles diffuse data summaries, which are collected by nearby vehicles such as police patrols. CarTel assumes the existence of open Wi-Fi access points to send the sensor readings directly to a central server. Neither of these works benefit from mobile agents to perform a flexible and inexpensive monitoring.

The rest of this paper is structured as follows. In Section 2, we describe how a VANET can be used for environment monitoring. Based on that general proposal, in Section 3 we describe our monitoring approach based on the use of mobile agents. In Section 4, we present some tests that compare different *hitchhiking strategies* for the agents. Finally, in Section 5 we summarize our conclusions and present some lines of future work.

2 Using VANETs for Monitoring

A *Vehicular Ad hoc Network* (VANET) is a mobile, ad hoc, communication network which is dynamically established between vehicles traveling along roads in a geographical area. The vehicles use only short-range networks (100-200 meters), like IEEE 802.11 or based on Ultra Wide Band (UWB) standards, in order to establish temporary communication links to exchange information between vehicles in a mobile P2P fashion [6]. Hence, it is possible that there exists no direct connection between two vehicles in the network, in which case the use of some multi-hop communication protocol [7] is necessary. These protocols are usually complex and it is difficult to limit the maximum time needed to deliver a message to a recipient, due to the fact that the existing links change constantly. However, using short-range networks has three important advantages: 1) there is no need of a dedicated support infrastructure (expensive to deploy and maintain), 2) the users do not need to pay for the use of these networks, and 3) it allows a very quick exchange of information between two vehicles that are within range of each other. Moreover, many application scenarios do not need to communicate with a specific target vehicle but with all the vehicles within a certain area. Although we do not rely on a fixed network infrastructure, we can benefit from the existence of some *relaying devices* on the roads: static devices, deployed along the roadside, which provide Internet-wide coverage to nearby vehicles by using a fixed network (thus enabling vehicle-to-infrastructure communications).

We argue in this paper that a VANET can be used for monitoring purposes. Thus, vehicles can measure certain environmental parameters in a specific area by means of different types of sensors installed on the vehicles. For example, we may think of devices that measure the CO_2 or the pollen concentration, the temperature, or even the coverage level of a cell phone company. As another example, monitoring data such as the number of available parking spaces or the average speed of vehicles in an area are also interesting to provide useful information to drivers. Using a VANET for monitoring implies a process of five steps:

1. *Determining the goal of the monitoring task.* The coordinates of the *monitored area*, the environmental parameter to measure and the monitoring period.
2. *Allocating vehicles for the monitoring.* Vehicles equipped with the required sensors must be assigned the task to measure the required environmental parameter.
3. *Collecting the data of interest.* The data sources will be sensors installed on the vehicles, which measure the required parameters from the environment.
4. *Routing the collected data.* The acquired data are sent to a predefined place using on-board short-range wireless devices to transfer the data to other nearby cars.
5. *Processing the data retrieved.* The collected information is gathered and stored in an information system for later analysis and processing.

In the next section, we describe the mobile agent-based approach that we propose to perform the monitoring indicating how these steps are realized with mobile agents.

3 Environment Monitoring Using Mobile Agents

Mobile agents are software components that run on an execution environment (traditionally called *place*) provided by a certain *mobile agent platform*, and can autonomously travel from *place* to *place* (within the same computer or between different computers) [8, 2]. A mobile agent platform provides services such as transportation of agents to other computers, communication with other agents, security, etc., in a transparent way to the programmer. Mobile agents provide some benefits (e.g., autonomy, flexibility, and effective usage of the network [8]) that make them very attractive for distributed computing and wireless environments (e.g., see [9]).

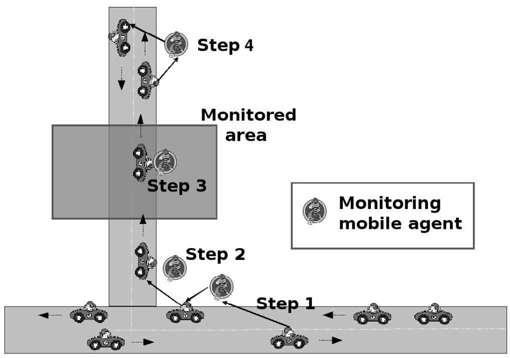
A mobile agent can be seen as a program that has the ability to pause its execution, move to another *place*, and resume its execution there, maintaining the values of its data structures (the state of the agent). Thanks to this capability, it is easy to build complex distributed applications that are at the same time flexible: If the task executed by an agent must be changed in the future, a new version of the agent (a new agent implementation) can be delivered. Thus, there is no need to keep specialized software installed on the computers/devices composing the distributed system: Only the generic mobile agent platform software is needed and an agent implementing the required behavior can be sent there at any time.

Mobile agent systems and monitoring VANETs bear several similarities. Thus, in a monitoring VANET there are many vehicles, distributed on a wide geographic area, that obtain data (measured by sensors) which must be moved from vehicle to vehicle based on certain conditions (e.g., location and direction) to try to reach their target. The existing similarity with a situation where some software agents move from one computer/device to another makes mobile agents a very suitable option to implement a monitoring solution for VANETs. The five steps of the monitoring process described in Section 2 can be implemented using mobile agents as follows:

1. *Determining the goal of the monitoring task*. A number of monitoring parameters must be provided to a mobile agent implementation, such as: the type of environmental parameter to measure, a definition of the monitored area (e.g. given by the GPS coordinates of its perimeter), the monitoring precision required (see step 3), and the monitoring period (given by a time limit after which the agent will end the monitoring task and will return the collected data). All these parameters are determined before the monitoring agent deployment, which is initiated from the agent platform hosted on a *monitoring computer*.
2. *Allocating vehicles for the monitoring*. The monitoring agent moves to the *relaying device* (see Section 2) that is the closest to the area of interest. Once there, the agent waits for a suitable car passing by and hops there. Then, as it travels in the car, the agent will constantly assess the possibility to jump to a different car if it considers that it may be a better alternative to reach the target area.

3. *Collecting the data of interest*. The target area may be too large to be monitored by a single agent. Thus, we divide the area in sub-areas (cells), according to the monitoring precision required (the larger the number of cells the higher the precision, as samples in more locations within the area will be taken), and allocate one clone of the agent (a *cell monitoring agent*) to each sub-area. They will need to move to a different car whenever its current car leaves the cell, or if the required sensor type is not available. When the agent reaches its cell in a car with suitable sensors, it will take data samples and store them in its data structures. This process is performed autonomously by each agent, without the collaboration of any other agent.
4. *Routing the collected data*. Once the monitoring period has elapsed, the cell monitoring agents return to the monitoring computer with the collected data. If the monitoring computer is attached to the fixed network, they jump from car to car trying to reach the closest relaying device from which they travel to the monitoring computer directly (using the fixed network). However, some application scenarios require the monitoring computer to be mobile. For example, the driver of a car could automatically receive information about the traffic ahead or about the availability of parking spaces in areas near his/her destination. In this case, the agent jumps from car to car to reach the area where the monitoring device is (this area can be computed from the initial location of the device, its maximum speed, and the time elapsed), and then it broadcasts itself within that area.
5. *Processing the data retrieved*. The monitoring computer gathers the data transported by the incoming agents and stores these data (e.g., in a relational database) for further processing. The arriving agents can then finish their execution.

Figure 1 shows a scenario where an agent reaches the monitored area and later has to "come back" with another vehicle because its current vehicle leaves the area.



Steps in the sample scenario	
Steps 1-2:	The agent tries to reach the target area by *hitchhiking* (jumping from car to car).
Step 3:	The agent takes samples in the monitored area.
Step 4:	The agent tries to come back to the monitored area.

Fig. 1 Example scenario: a hitchhiker agent in action

In the rest of this section, we first describe the technology required to implement the proposed approach. Then, we emphasize the benefits of this approach based on mobile agents. Finally, we enumerate some difficulties and how we solve them.

3.1 Technological elements

Apart from the existence of certain relaying devices on the roads (as mentioned at the end of the first paragraph in Section 2), vehicles taking part in the approach described are required to be equipped with several hardware components and run certain software:

- They must be equipped with *sensors* that measure values of the type required in the monitoring task. Different vehicles with different types of sensors may participate in different monitoring tasks. These sensors will probably not be installed by car manufacturers but by voluntary users willing to take part in the distributed monitoring. Since these devices usually operate in a passive and non-intrusive way, the users' driving experience will not be altered.
- They must have a *computing device* with enough resources to execute an agent platform and manage the sensors (e.g., a PDA or an ultra mobile PC). This computing device must provide:

  – A *wireless communication device*, that allows the vehicle to communicate with its neighbors.
  – A *GPS receiver*, which can be queried by the monitoring agents to know if they are within the intended geographic area.

  In this sense, any wireless-enabled PDA with a working navigation system (e.g., TomTom, see `http://www.tomtom.com`) would be enough.
- They must execute a (lightweight) *mobile agent platform* that offers suitable services to the monitoring agents, such as a wireless transportation service to other devices and an interface to query the available sensors and the GPS receiver.

It should be noted that most of the elements indicated above are interesting for a variety of applications, not only for our monitoring purposes. Thus, for example, many vehicles will have a GPS receiver as part of a navigation system. Moreover, we can envision that a wide variety of applications could be deployed in a VANET if the vehicles execute a mobile agent platform. Cars not providing the features described simply cannot cooperate in the monitoring task.

3.2 Benefits of Using Mobile Agents in Monitoring VANETs

The use of mobile agents for environment monitoring in vehicular networks has a number of advantages, such as:

- *Flexibility regarding how the monitoring task is deployed and performed*. A VANET can be very heterogeneous and dynamic. Thus, there are different types of sensors that may be available on the vehicles, very different road infrastructures (e.g., urban/rural roads or highways) with different traffic density, etc. Depending on the context, different traveling strategies could be considered by the agents. Thanks to the flexibility provided by an approach based on mobile agents, if a better *traveling strategy* is found or a new class of sensors is introduced, a new version of the monitoring agents with the needed enhancements can be deployed in the network without altering the ongoing VANET operations: A mobile agent can implement the behavior required and carry it to any vehicle which hosts a mobile agent platform (without any extra software installation in the vehicle).

- *Cost minimization*. As sensors in vehicles are constantly "moving", a small number of them are needed to cover a certain area. Instead of deploying an expensive fixed infrastructure of static sensors, an approach based on agents that travel in a vehicular network benefit from existing resources available on regular vehicles.
- *Global coverage*. Any geographic area can be monitored, as long as there are suitable vehicles traveling nearby. Mobile agents carry the monitoring task wherever it is needed. For example, if there is a traffic accident involving a lorry carrying dangerous substances, mobile agents can travel there to monitor the scene.
- *Good performance*. Mobile agents exhibit a good performance in comparison with other alternative approaches, such as traditional client/server architectures (e.g., [9] is one of several studies showing this).
- *Natural implementation*. Routing the collected data between the vehicles can be implemented naturally using mobile agents. In general, mobile agents allow a convenient implementation of the monitoring steps described in Section 2.

For all the above reasons, mobile agents are a suitable technology for monitoring in VANETs.

3.3 Challenges and Solutions

However, there are some challenges to consider to perform an efficient monitoring:

- *Size of the monitored area*. The monitored area could be very large, and so using a single monitoring agent would be inefficient. Thus, the agent should move within the area to sample the environmental data at several locations within the area, making it very difficult to obtain all the samples of the data with a high sampling frequency. Instead, as mentioned in the description of step 3 in Section 3, we propose to divide the monitored area in several sub-areas (*cells*) and allocating a different *cell monitoring agent* to each of those cells.
- *Routing the monitoring agent to the target area*. To reach the target area, a monitoring agent must jump from car to car[1] until it finds one car that moves into that area (see steps 1-2 in Figure 1). For this, the agent tries to find a suitable vehicle that can physically transport it closer to the area that must be monitored.
- *Keeping an agent within its assigned cell*. Another important question is how to keep an agent inside its cell while it is collecting data. Thus, if the vehicle

[1] The *target car* could move out of range at any time. A mobile agent platform ensures the reliability of agents' movements: Either a trip succeeds or the agent has the opportunity to re-try (traveling to the same car or to a different car).

carrying the agent leaves the cell, then the agent will need to come back (using a different vehicle) to continue the monitoring task (e.g., see step 4 in Figure 1).

- *Returning to the monitoring computer.* Once the monitoring task has finished, the agent must return to the monitoring computer (probably via a relaying device).

Regarding the last three issues, different traveling strategies (that an agent can apply to try to reach a certain location, such as the center of its target cell) can be considered, such as:

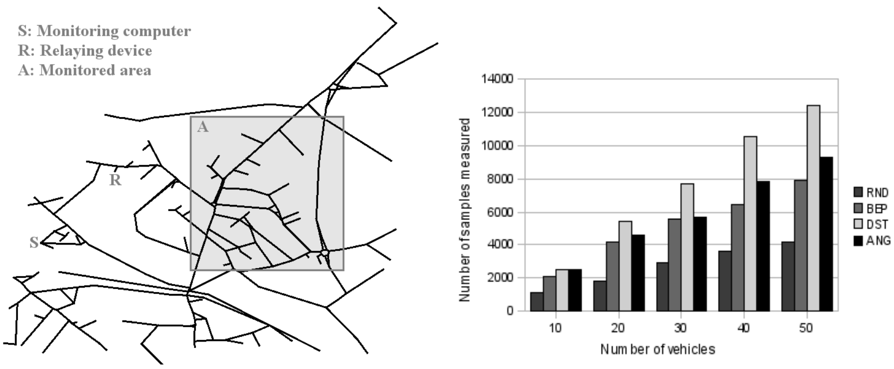
- *Random jump (RND)*. The agent jumps to another car with a 50% probability.
- *Basic Encounter Probability (BEP)*[2]. The angle between the movement vector of the vehicle and a straight line to the destination is considered, in order to estimate the probability that the vehicle will move towards the destination. The agent jumps if, by jumping, its BEP increases.
- *Distance (DST)*. The agent jumps whenever the distance between the target car and the agent's destination decreases along time.
- *Frontal angle (ANG)*. The angle of direction of the target car regarding the agent's target location is considered. The agent jumps if this angle is less than 90°. The difference with the BEP strategy is that the decision is taken independently of the status of the current vehicle carrying the agent.

With some of these strategies the decision is based on information that must be obtained by querying the target car. Therefore, a traveling protocol for mobile agents where a trip succeeds only if certain conditions hold at the destination would be useful. These strategies will be evaluated experimentally in the next section.

4 Experimental Evaluation

As stated in the previous section, defining a suitable hitchhiking strategy for the agents is an important issue. Therefore, we have evaluated the four strategies proposed by simulating vehicles moving within a graph network. The simulation is run on a road network represented by the graph shown in Figure 2.a, extracted from a real map, which corresponds to an area of four squared kilometers in the region of Valenciennes (France). The area to monitor is divided in six cells. A monitoring agent is created on a fixed computer at node S, and then this agent travels to a relaying device R. When a suitable vehicle passes within range of R, the agent jumps in the vehicle to try to reach the target area. Once in the target area, this agent transforms itself into six cell monitoring agents, one for each cell within the monitored area. The simulated vehicles move along the edges of the graph with (random) speeds between 50 and 100 km/h, taking a random turn at each intersection. The range of the wireless communications is between 140 and 200 meters, and each agent takes one second to perform a jump to another car within range.

[2] This measure is inspired by the concept of *Encounter Probability (EP)* presented in [10], that estimates the probability that a vehicle will meet an *event* (e.g., an accident) on a road.



(a) (b)

Fig. 2 Comparing traveling strategies: (a) scenario for evaluation and (b) samples measured

To compare the different traveling strategies, we measure the total number of samples taken by the agents during a 50-minute monitoring task with each strategy: The longer an agent is able to remain within its cell, the higher the number of samples it will be able to take and, therefore, the monitoring will be more accurate. Each test is repeated 10 times and the average results are reported in Figure 2.b, for scenarios with different numbers of vehicles. As expected, the worst strategy is RND because with this strategy the status of the cars is not considered in the decision process. The best strategy is DST, which is also quite simple and intuitive. Next in performance is ANG, and then BEP. These last two strategies are similar but the second one takes into account both the current and the potential target car; as a consequence, the number of jumps performed by the agents with the second strategy is smaller. As shown in the figure, all the proposed strategies behave better with a higher number of vehicles, as this offers the agents more transportation means and alternative paths to reach their target areas. Moreover, with enough vehicles, a sufficiently high sampling frequency can be maintained (e.g., about 40 samples per minute and cell with the DST strategy in a scenario with 50 vehicles). It is expected that the best strategy will depend on a number of factors, such as the traffic density or the speed of the vehicles. We plan to perform more experiments in a wide variety of scenarios.

5 Conclusions and Future Work

In this paper, we have presented a novel approach that combines vehicular networks with mobile agent technology for environment monitoring. In our approach, the mobile agents jump from car to car to arrive to the target geographic area and to keep themselves there to perform the monitoring task. We have analyzed different research issues and proposed and evaluated different routing strategies for the agents. Our initial experimental results are promising. However, there are some factors that can challenge the system, such as a low number of equipped vehicles or the existence of poor wireless communications. More work is needed to analyze the limitations of our current proposal in those circumstances.

As future work, we plan to perform more experiments in other scenarios and with different experimental settings. We will also study other strategies (e.g., using replicas of the monitoring agents as a form of redundancy to perform the monitoring). Finally, we will also analyze the suitability (and perform some adaptations) of the mobile agent platform SPRINGS [2] to implement a prototype; some experiments with this platform have already been performed in wireless environments [11].

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