On the Design and Run of VANET Road Experiments

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***Abstract*—Vehicular ad hoc networks (VANETs) are an emerging area of communication that offer a wide variety of possible applications, ranging from safety to multimedia and games. In a near future, in fact, we may easily envision safety and gaming applications where the real-time video captured from a vehicle is streamed to all connected ones, within some given range. We can therefore expect that the standardization of inter-vehicular communication protocols will support the emergence of such type of new applications and that multimedia and gaming, putting to good use such technologies, will rapidly grow. However, one of the obstacles to the exploitation of such applications in the context of VANETs is given by the practical impossibility to test those solutions in real life conditions, as a great number of vehicles are required to gather any significant amount of relevant experimental data. Hence, we here present an approach that makes the practicality of field tests come true, applying a novel methodology apt to experiment with multimedia applications and games in vehicular environments, as it can cope with a very limited amount of resources. The results gained by applying this approach represent a solid leapfrog in the study of such systems. We here discuss in detail the experiments that were run on the road with such methodology and the positive implications that such results reveal for the context of VANET-based multimedia and gaming.**

I. Introduction

Vehicular networks are an emerging area of communication that offers a wide variety of possible applications: from safety to multimedia and games. Nowadays, the most common applications in this area are the safety ones; this topic clearly highlights the importance of inter–vehicular communications. We believe that once some communication standards will consolidate, new kinds of application will emerge. Among these, we are quite confident that multimedia and games will rapidly grow [1].

We can roughly divide vehicular network in two main category: with and without stationary infrastructure. The former requires expensive hardware to cover significant portions of roads, and some additional equipment to be installed on the vehicles. The latter are much more lightweight to implement while they requires common hardware to be installed on a significant percentage of vehicles. On the other hand, the software to establish vehicular communications without infrastructure is much more complex.

Due to the high costs of vehicular networks with stationary infrastructure, it is unlikely that these solutions will eventually cover all the roads. We believe that the spontaneous approach will be eventually the adopted one.

Systems based on spontaneous inter–vehicular networks, VANETs, consider a great number of involved vehicles and a large portions of covered road. Both those aspects make almost impossible live experiments of these systems.

We proposed a methodology to test spontaneous VANET into real scenarios [2], specifically, we tested a safety application. Nevertheless the methodology that we defined is general and it is well suited to implement live experiments on a great variety of VANET based protocols that rely on broadcasts.

The proposed methodology considers a platoon of vehicles that travels on a road, keeping predefined *First* and *Last* vehicles. The *First* broadcast a message backward. The broadcast is implemented by means of multi–hops. When implementing an hop, each vehicle preserves the actual direction of the broadcast. Eventually, the message reaches the *Last*, either directly or by one or more hops. The *Last*, then, bounces–back the message, *i.e.* it reverses the direction of the broadcast. Doing this re–transmission, the *Last* implements a forward hop. Analogously, when the *First* receives a copy of the message that it originally sent, it re–transmit backward the message.

Summarizing, a message is bounced back and forth at the edges of the platoon until it got lost. This technique extends the platoon of vehicles that receives the broadcast for experimental purposes. Cumulating the length of each hop that it experienced, a broadcast message could cover several kilometers from its point of origin.

The above described methodology is based on the assumption that each hop is representative of the ones that the broadcast would have encountered in real life situations. In real life, we can suppose that each message between a couple of sender–receiver traverses a wireless channel that is different from the one traversed in precedence.

An indicator of such difference is given by the *coherence time* of the wireless channel between the vehicles of the platoon, *i.e.* the time interval over which those channels are considered correlated to their previous values. At the relative speed of $1m/s$ (*i.e.* $3.6Km/h$) between a source and a receiver, the channel coherence time is approximately $125ms$ for a carrier signal at the frequency of the 802.11g. This value decreases while the relative speed increases.

Note that the same source–destination pairs could be repeated, in the worst case, every time an alert message achieves a round trip inside the platoon. We measured that a round trip requires $186ms$ on average when the platoon is made by four vehicles. Therefore, it is highly improbable that the same wireless channel conditions will reiterate between two consecutive loops inside the platoon.

In the following we will briefly sketch the presented methodology. Then we will focus on the design of such experiments, section II, its challenges and their solutions in sections III and IV. The section V discusses in detail the running of the experiments and shows some significative results. A section of conclusions ends the paper.

II. Design of experiments

The application of our methodology does not require a great number of vehicles, *i.e* circumvents the main practical obstacle to real life experiments on VANETs. Nevertheless, the experiments have to be carefully designed and implemented.

In advance to real life experimentation, it is necessary to plan an extensive set of simulations. Implementing that simulation, enforces the experimenters to focus on details that could have been neglected in the general model of the system under study. Moreover, the simulations could be drawn in such a way that a great majority of the code could be reused in the real life experiments. This code, while it has to run in the simulator, undergoes a robust debug phase.

Moreover, the results of the simulations highlight the relevant variables to measure, and their expected range of values.

The design should address the following topics.

1) What to do: given the system to test and its relevant variables to measure, it is necessary to define the best way to make these measures. It is a good approach to extend the set measures even to less important variables to double check the quality of the results. To avoid mistakes during the subsequent evaluation of the results, it is mandatory to define a complete and stable data structure to store the values. The drawback of recording a huge set of variables is that it could interfere with the regular running of the system. The position of each vehicle has to be periodically recorded to reconstruct *a posteriori* the whole experiment. The frequency of this recording depends on the nature of the system under test.

2) How to to: the correct and best way to make the measures is strictly dependent on the system under experimentation. *Where* to read the values, and *when* store them is strictly related both to the nature of the system and to its implementation. Usually, a good policy is to record the values in a plain ASCII text, formatted as CSV, and containing a *timestamp* for each recording. The CSV is highly compatible with almost all the analysis instruments that could be used lately. The weakness of this solution is that writing a text file could be very slow with respect to the responsiveness of the system under experimentation. A correct placement of the writings could be crucial to the efficacy of the experiment.

3) How to be adaptive run–time: an important task is the planning in advance of the routes, thus to test any interesting environment. During the live tests, the experimenters could have to communicate each other to take real–time decisions depending to the actual conditions. To simplify this process as much as possible, several options should be foreseen and planned to face the current circumstances.

III. Challenges

In this section, we discuss some of the most relevant challenges of the proposed methodology.

A. Clocks correspondence and Lack of 802.11p

Usually, during the experiments, there are least two sources of time for each vehicle: the GPS and the internal clock of the device that runs the experiment. The most convenient timestamp to use while recording values depends on the nature of the events; *e.g.* the positions are naturally timed by the GPS, while the sending and receiving of messages are easily associated with the internal clock of the device.

Each vehicle has its own Wi–Fi device, and therefore its internal clock, that is not synchronized with respect to the clocks of the devices onboard of the other vehicles.

A great number of systems based on VANETs considers the standard of communication the IEEE 802.11p. Unfortunately, at the moment it is not yet available a full full implementation of this protocol.

B. Runtime platoon ordering

The proposed methodology is strongly based on the relative positions between the vehicles used in the experiments. To keep the runtime management of the experiment a simple as possible, the *First* and the *Last* vehicles are designed at the beginning, an keep their roles during the whole run. The only requirement for all the other vehicles is to travel between the *First* and the *Last*. It is an easy task for the derivers to keep this configuration of the platoon. This policy excludes the constant detection of the actual *First* and *Last*. Therefore, it has a very low impact with respect to the experiment, while it do not requires neither an overhead of communication nor an agreement protocol between the participating vehicles. The relative positions of the remaining vehicles of the platoon are pointless, as long as they stay between the *First* and the *Last*.

Each vehicle can access its GPS *latitude* and *longitude* coordinates. To monitor run–time the evolution of the experiment, each vehicle broadcasts almost periodically its coordinates. These transmissions could be designed to interfere as less as possible with respect to the experiment. The policy concerning these broadcasts, *e.g.* frequency and complexity, is strictly dependent on the nature of the communication protocol under experimentation. When the *First* or the *Last* are in the its neighbor, the driver of a vehicle has to pay attention to avoid unwanted surpasses, specifically considering the traffic conditions and the lanes of the road.

Each vehicle has an updated knowledge of the latitude and longitude coordinates of each vehicle that is close to it. By means of these data, it is quite simple to compute the distance with respect to each one of the vehicles by means of the “great–circle distance” formula. The resulting distances are absolute values, without any indication on the relative positions. It is quite complex to detect if a vehicle at a known distance is traveling behind or above another one. The meanings of “frontward” and “backward” are exclusively dependent on the direction of movement onto the current road.

To detect their relative positions, the vehicles could use at least two approaches, based either on a road map or on a fixed point. The first method implies an interface to a satellite navigator system, and could be tricky or complex, the second method requires a careful choice of the fixed point. We designed a clever method based on the fixed point approach, that follows the idea of *Tom Thumb’s breadcrumbs*, and that is discussed in the next section.

IV. Solutions

In this section we analyze the solutions that we adopted to solve the above mentioned challenges.

A. Clocks correspondence and Lack of 802.11p

Usually, it is not necessary a strict synchronization between the clocks of the GPS and of the Wi–Fi device in each vehicle. A simple solution could be to put a double timestamp, from both the clocks, on the records of some events, *e.g.* the periodic storage of the position of each vehicle. This allows to piecewise continuous comparison between the two times. Any time reading, by any of the two clocks, could be easily converted by interpolation into the corresponding time of the other clock. Moreover, we could use the GPS times to further extend the time correspondence on the clocks on other vehicles. It could also be useful to timestamp any sent message.

One of the most reliable and simple way to surrogate the 802.11p protocol is to use instead an 802.11p, that is the closest one. The carrier power could be $300mw$.

B. Runtime platoon ordering

The fixed point approach is based on simple geometric considerations. We can suppose that the fixed point is behind all the vehicles. Consider a couple of vehicles, each one knowing the coordinates of both the other vehicle and the fixed point. Both the vehicles could detect their relative position with respect to the other one by comparing their distances from the fixed point: the vehicle closest to the fixed point is the back-most one. This approach requires solely to compute twice the “great–circle distance” formula: to compute the distances from the fixed point of both the vehicle itself and the other vehicle.

In several cases, the static definition of a single fixed point could lead to erroneous results. Fig. 1 shows two maps, not in the same scale, containing the same fixed point, labelled by *P*. Both the routes , that are represented in the map of Fig. 1–(A) either by solid or a segmented lines, starts at the fixed point and terminates at an intersection far away. The route that is represented in the Fig. 1–(B) as a segmented line describes a closed path around the fixed point. The leftmost route in Fig. 1–(A) is represented by a solid line. At any point of that route, the *Last* is always the closest vehicle to the fixed point. The rightmost route in the same map is represented by

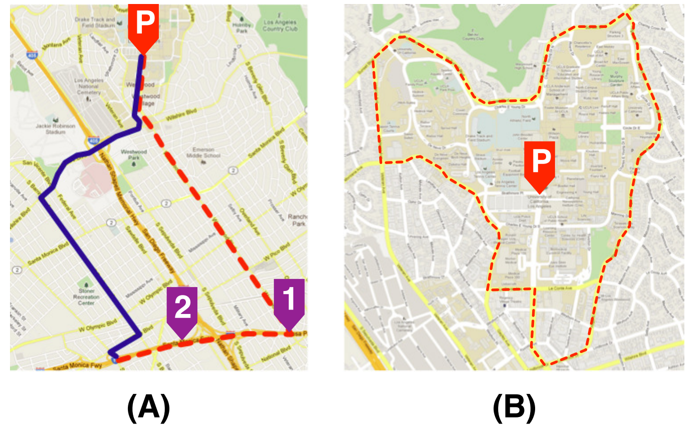

Fig. 1. Two cases of fixed point approach

a segmented line. Until reaching the point labelled by *1* the *Last* is the vehicle closest to the fixed point. On the contrary, between the points *1* and *2* the vehicle closest to the fixed point is the *First*. Passed the point labelled by *2*, the closest vehicle to the fixed point returns to be the *Last*. In this figure, two different routes, between the same points, could share the same fixed point. The situation worsen in the route depicted in Fig. 1–(B). Depending on the direction of motion, the closest vehicle to the fixed point could be any one of the platoon.

There is another problem that could arise from the position of the fixed point: the farther it lies with respect to the vehicles, the higher the risk that the errors of computation could mislead the detection of the relative positions. Summarizing, a static fixed point fits few circumstances and, in general, it is not a good choice.

To keep the simplicity of the fixed point approach and to make it more robust, we developed a technique inspired by the *Tom Thumb’s breadcrumbs* idea. The fixed point became not unique, and it is re–defined dynamically. A generic fixed point corresponds to one of the former positions of the last vehicle. Periodically, the last vehicles defines as new fixed point its current position, and broadcasts those coordinates to the whole platoon. Since each fixed point lies on the road that the platoon is traveling, the possibility of wrong detection of relative positions between the vehicles is very low. The accuracy of relative positions detection depends on both the frequency of the updates and on the curliness of the road. The drawback of this approach is that it requires to broadcast the coordinates of the updated fixed points. Sometimes this broadcast could require ad–hoc protocols, but it is very likely that the system under experimentation could be exploited to this aim by means of lightweight *piggyback*.

V. Running the Experiments

To run the experiments we implemented our methodology considering the topics discussed below. In the following we present some interesting results gained by the experiments.

A. Implementation

We relied on the Java language to implement a prototype of the system under test. Two of the main reasons for this choice are the large availability of tested libraries to manage the GPS receiver and to support low level networking operations. The major drawback of using Java is its ”slowness” with respect to other languages, such as C or C++.

The minimal equipment for each vehicle is the following:

- *Portable computer* to implement the Wi–Fi device and to monitor the ongoing experiment;
- *Roof-top wireless antenna(s)* that could be magnetic installable;
- *Wireless card adapter* inserted into the portable computer and connected by wire to the antenna(s);
- *Roof-top GPS antenna* to receive GPS signal, usually connected by USB wire to the personal computer;
- *semi-professional walkie-talkie* (up to 5Km transmission range) radio set, possibly capable of viva–voce, and its power supply, to establish one-to-all communications;
- *power supply* from vehicle’s 12v to standard outlet (beware of the consumption of the car’s accumulator) with at least two plugs (computer and walkie–talkie);
- *(optional) second portable computer* to monitor the environment; equipped with its own antennas (both GPS and wireless);
- *(optional) camera* to record the experiment and to accurately reconstruct the running scenario.

All the wires from the car roof-top will enter in the interior of the car through an almost closed window. It is important to point out that it could happen that the magnetic mounting of an antenna could fail, due to the combination of relative wind and road conditions. In that case, the antenna could fail apart. This circumstance, even if improbable, happened to us. Without any precaution, a falling antenna could drag its wiring and, possibly, the portable computer to which it is plugged.

The team of each vehicle is formed by two people, at least: a *driver* and an *experimenter*. The driver is focused solely on the driving of the vehicle, without any distraction other than some occasional indications from the experimenter. This setting ensures that the execution of the experiment does not interfere with the safety of the driving. The experimenter is the person that conducts the experiment and that communicates with the other experimenters by means of the above mentioned walkie–talkie. This kind of communication is parallel to the experiment, and does not add overhead to the resources under experimentation. Cellular phones could be a used as reliable backup communication means, while they establishes one–to–one channels.

B. Results

We run several experiments in the Los Angeles area, by means of four vehicles. To the best of our knowledge, in August 2011 we implemented the most extensive experiment on VANETs that had been published in scientific literature hitherto [3]. According with the literature, the number of hops that a message could perform following the previous approaches, was limited to a maximum of 3 [4]–[6]. In our methodology the number of hops is unlimited.

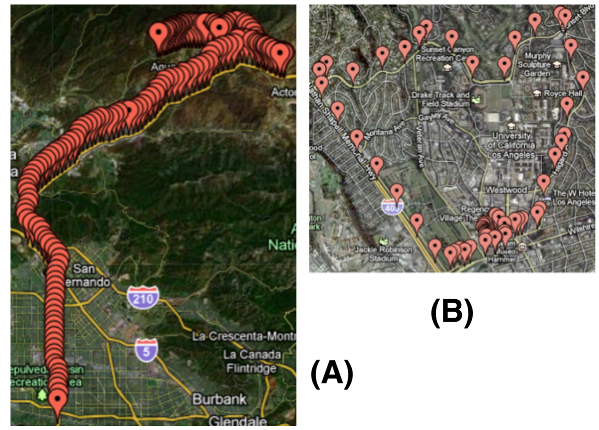

Fig. 2. Two routes: mostly on an highway (A), and on a closed path of urban roads (B)

During our experiments, the platoon of vehicles moved trough different scenarios: highways, urban and extra–urban roads. We consider that the highways were characterized by several lanes, no streetlights, and possibly a large amount of vehicles, traveling quite fast in the same direction. Urban roads had less lanes per direction, passed trough several streetlights and intersections, and the vehicles traveled at reduced speed with respect to the highways. The extra–urban roads had few lanes, intersections and streetlights; the traffic was loose and its speed was higher than in urban roads.

The experiments that we discuss below were aimed to measure a broadcast protocol that diffuses vehicular alert message by means of multiple hops [3]. The focus of this discussion is the experimental methodology, not the system under experiment, therefore we do not report on the alert system.

During the whole experiments, the *Front* remained the first vehicle of the platoon, while the *Back* was the last one. The remaining two vehicles, namely ”v1” and ”v2”, traveled following the *Front* and preceding the *Back*. The distance between the vehicles of the platoon depended on the traffic conditions, and we was able to keep the platoon connected, *i.e.* maintaining each vehicle in the reach of at least one of the others.

Hereafter we discuss two out of several experiments that we carried out by applying our methodology. Both the scenarios are shown in Fig 2. The two routes shown in the figure have been represented by pinpointing the series of consecutive positions of the *front* taken at a predefined frequency; *i.e.* the closer two consecutive points the slower the front. Even if the two figures are depicted following those criterion, they are neither in the same spatial nor temporary scales. The two figure have been made by means of the API available from *Google Maps* and the GPS readings from the experimental setting.

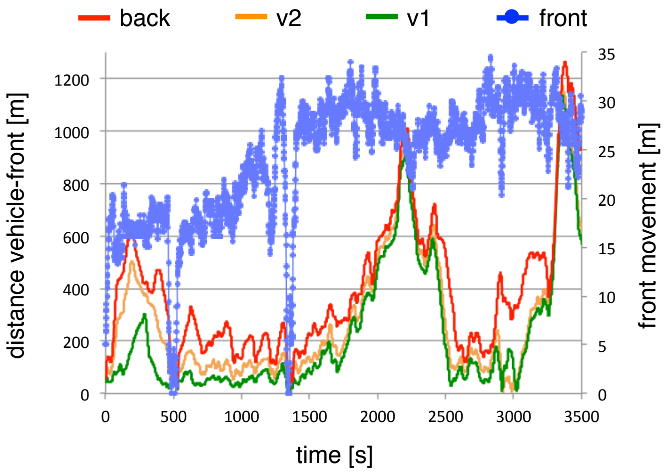

Fig. 3. Movements and distances along the first route

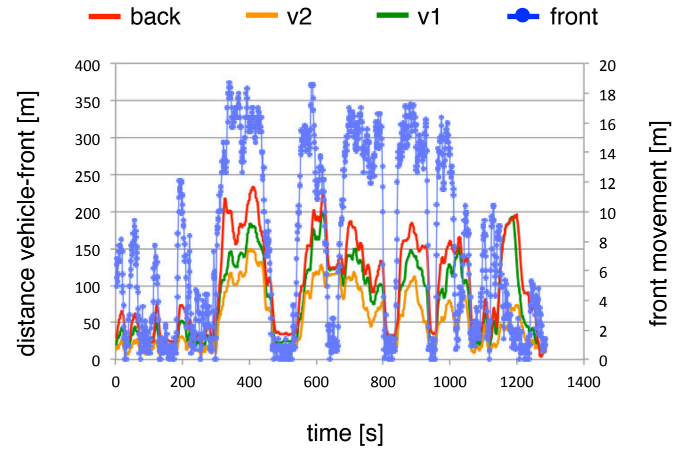

Fig. 4. Movements and distances along the second route

The route in Fig 2(A) is several kilometers long, and mainly spreads over highways. Starting from an highly populated area of Los Angeles, close to UCLA, the route forwards to a scarcely populated area in the countryside. At the starting of the route the traffic was quite heavy, but rarely affected the speed of the vehicles, and become sparse while leaving the city. The route in Fig 2(B) surrounds the campus of UCLA, it is on both urban roads and highways, and crosses numerous streetlights. The traffic was sometimes heavy, and erratic, depending on the road. Needless to say, the number of Wi–Fi networks was very high in the area of UCLA, that it is also an offices area, while was nothing in the countryside.

Each one of the double axis graphs in Figs. 3 and 4 shows both the distances of each vehicle with respect to the *Front*, and the movements of the latter. The horizontal axis shows the time, metered in seconds. The principal axis of both the figures, in the left side of the graphs, shows the distances, in meters, of each vehicle from the *Front*. The solid lines represent these distances. The secondary axes, on the right of each graph, represents the movement of the *Front* every each second, *i.e.* the displacement second by second. The dotted lines represent that movement. Note that both the scales of distance and speed are different between the two figures: as expected, they are smaller in the urban scenario.

The run of the platoon in the route Fig 2(A) is shown in Fig. 3. The speed of the front is a good outline of the whole trip of the platoon. At the beginning, the platoon is quite slow and is subject some stops and slowdowns due to few intersections and traffic jams. While approaching the country side, the traffic lightens, and the speed of the platoon increases. The platoon sometimes spans over more than a kilometer. The run of the platoon in the route Fig 2(B) is shown in Fig. 4. The effects caused by the crossed streetlights are clearly shown by the spikes in the speed of the *front*. The span of the platoon goes to a local minimum at each streetlight, and increases when the platoon is moving. Note that this span is quite small with respect to the one experienced in the previously discussed experiment.

We successfully carried out thousands experiments, measuring broadcast that spanned for several lengths of the platoon.

VI. Conclusions

The presented new approach allows for the experimentation in real life environments of protocols and systems designed for VANETs, that otherwise would have been practically impossible to carry out. Usually, the test of those systems could require hundreds of vehicles, each one equipped with specific devices. The resources to implement such experiments are practically impossible to gain due to their high costs and setting complexities.

Applying the presented approach makes possible the test on the field of protocols and system even with a very limited amount of resources. The results gained by utilizing our approach are correct and represent a solid leapfrog in the study of such systems.

The methodology that we presented is largely independent of the kind of system under test. Therefore, we believe that it could be a significative boost to the study of multimedia and entertaining systems over VANETs.

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References

[1] C. E. Palazzi; "Interactive Mobile Gaming over Heterogeneous Networks"; Proc. *5th IEEE/ITI International Conference on Information and Communications Technology (ICICT 2007)*, Cairo, Egypt, Dec 2007.

[2] A. Amoroso, G. Marfia, M. Roccetti, G. Pau; "Creative testbeds for VANET research: a new methodology"; Proc. *9th IEEE Communications and Networking Conference (CCNC 2012)*, pp. 497-501.

[3] A. Amoroso, G. Marfia, M. Roccetti, G. Pau; "To Live and Drive in L.A.: Measurements from A Real Intervehicular Accident Alert Test"; Proc. *2012 IEEE International Wireless Communications and Networking Conference (WCNC'12) - 1st IEEE Wireless Vehicular Communications and Networks Workshop*, IEEE Communications Society, April 2012.

[4] M. Moske, H. Fussler, H. Hartenstein, W. Franz; "Performance measurements of a vehicular ad hoc network"; Proc. *59th IEEE Vehicular Technology Conference (VTC 2004)*, pp. 2116-2120.

[5] J. Santa, M. Tsukada, T. Ernst, A.F. Gomez–Skarmeta; "Experimental analysis of multi-hop routing in vehicular ad–hoc networks"; Proc. *5th IEEE International Conference on Testbeds and Research Infrastructures for Development of Networks and Communities and Workshops (TridentCom 2009)*, pp. 1-8.

[6] H. Venkataraman, A. d'Ussel, T. Corre, C. H. Muntean, G. M. Muntean; "Performance analysis of real–time multimedia transmission in 802.11p based multihop hybrid vehicular networks"; Proc. *6th International Wireless Communications and Mobile Computing Conference (IWCMC 10)*, pp. 1151-1155.