# Experimental Caracterization of V2V and I2V Communications

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***Abstract*— A key component of Intelligent Transportation Systems (ITS) is the provision of adequate network infrastructure to support vehicular communication. In this paper we present the results of an extensive measurement campaign evaluating the performance of IEEE 802.11 in different vehicular communication scenarios: vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V). We concentrate our evaluation on multi-hop communication in these two scenarios. We found that distance and line of sight communication are the two main factors affecting the network communication. The experimental results confirm also the feasibility of using ad hoc networks to extend the transmission range of the infrastructure and the connection time for cars in motion.**

***Keywords*- Vehicular ad hoc networks, IEEE 802.11, Wireless Access, Multi-hop communication, Experimental performance.**

## I. INTRODUCTION

Vehicular communication is an emerging class of wireless communication enabling mobile users in their vehicles to communicate to the road and to each other. Currently, Inter-Vehicle Communication systems (IVC) are widely discussed, attracting considerable attention from the research community as well as the automotive industry. Some of the initial efforts in this field began with the development and standardization of vehicular communication technologies. That is the case of DSRC (Dedicated Short Range Communication) in North America and Japan, as well as some European projects. Vehicular communication are expected to take place in urban zones, rural zones and highways through providing some network functionalities, protocols and integration strategies for services' delivery to users.

Three deployment alternatives (cf. Figure 1) include: i) a pure wireless Vehicle-to-Vehicle ad hoc network (V2V) allowing standalone vehicular communication with no infrastructure support, ii) an Infrastructure-to-Vehicle (I2V) architecture with wired backbone and wireless last hops, iii) and a hybrid architecture that exploits the fixed infrastructure using V2V communication.

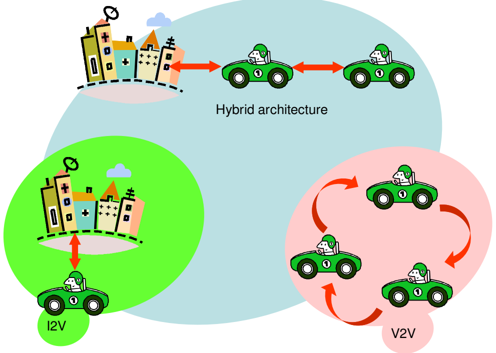


**Figure 1** - Vehicular communication architectures.

The deployment of such technologies originally intended for critical and safety application, also gave the opportunity to provide a wealth of other business driven applications. Examples include navigational driver assistance, road information services, and infotainment services for passengers (e.g. games, file downloads, video on demand, web browsing, email access, file sharing, car following). Consequently, vehicular networks are promising in providing a set of on-board potential services for drivers and passengers as well as providing different communication facilities between moving vehicles.

Vehicular networks are close examples of ad hoc networks especially due to the rapidly changing topology and the high mobility of such networks. However, their constraints and optimizations are remarkably different (mobility, power etc.) and create some challenges which can greatly impact the future deployment of these networks. Firstly, fast association and low communication latency should be satisfied between communicating vehicles in order to guarantee: i) service's reliability for safety-related applications while taking into consideration the time-sensitivity during messages' transfer, and ii) the quality and continuity of service for passenger's oriented applications.

These unique characteristics, the popularity of GPS (Global Positioning System) system, the availability of traffic data and a wide range of safety, commercial, and infotainment applications motivate new VANET characterization studies.

In this paper, we investigate the usability of providing network connectivity to mobile users in vehicles for the three architectures cited before (V2V, I2V, and hybrid).

The central question for the first architecture is: What is the expected performance of multihop routing for mobile users, particularly for users in automobiles trying to communicate in a multihop fashion (car following, games applications)? In a previous work [7], we presented extensive experimental measurements for this architecture using only two vehicles (direct communication without routing).

For the two other architectures, the question is: What is the expected performance of Wi-Fi networks for drivers/passengers as they move in urban and suburban areas where APs are currently widely deployed?

Some of the questions addressed in this paper are:

1. What is the distribution of packet loss, delay and signal quality?
2. What is the distribution of data transfer rates for the second and third architecture?
3. What is the effect of a car's speed on these metrics?
4. What is the effect of a multihop routing on these metrics?

We answer these questions by running a set of extensive experiments.

The rest of the paper is organized as follows. First, we outline related work in section 2, and then describe our experimental method in section 3. Result analysis and discussion of our findings are shown in section 4. Section 5 concludes the paper and addresses our future research directions.

## II. RELATED WORK

Some literature on VANET experiments exist. In [1], the authors present the results of a measurement study over a set of open APs deployed currently in and around the Boston metropolitan area. They measure the connection time and the upload bandwidth with nine moving cars attempting to connect to "open up" wifi access points.

Gass et al. [2] demonstrate the feasibility of using off-the-shelf IEEE 802.11b wireless networks for TCP and UDP transfers to and from a moving car. Their experiments are also conducted in a planned environment—they measure performance from an "in motion" client to a single access point in the California desert, where there are no obstacles and no interferences from other radios and vehicles. This environment allows them to measure performance in a controlled mobile setting.

Ott et al, [3] study the behavior of network connections that are initiated over an IEEE 802.11b channel from a moving car. This study describes TCP and UDP measurements between a moving car with an external antenna and an AP. Their work explores TCP and UDP traffic with the server being directly connected to the AP. The goal was to understand the impact of the car's speed, transmission rate, 802.11 bit-rate, and packet size on throughput and delay.

Bucciol et al, [4] discuss some experimental results using multimedia application in inter-vehicular ad hoc network using two vehicles equipped with IEEE 802.11b devices in only two typical driving scenarios (urban and highway). The authors come out with the following results: (i) the SNR is more important in a highway than in an urban area, (ii) the link is more available in a highway then in a city, and (iii) the optimal transmission policy varies depending on the scenario, since it is better to use large packets with a low bit rate in highways, and to use small packets with a high bit rate in urban areas.

The same results are obtained in [5] regarding to the SNR and noise level. Moreover, the authors give some other results about RTT, TCP and UDP throughput, etc. They use 3 vehicles and use a static routing. From their point of view, the deployment of multimedia applications is difficult. Their results were not that obvious to be able to come out with these clear conclusions, since there was a continuous cutting in the connection.

In [6], the authors measured the link quality while driving in highway, urban and sub-urban environments. The study results showed that the sub-urban area is the most favourable for inter-vehicle communication.

The purpose of experiments in [1, 2, 3] is to understand the performance in terms of connection time, loss packet, etc when the mobile station is attempting to connect to Access Points. While experiments in [4, 5, 6] are "Following Experiments" in different environment conditions. These experiments are simple arbitrary driving and do not consider neither all scenarios that we can find in our daily life nor the effect of certain factors on the different performance parameters. Their main objective is to have a global view of connectivity between only two vehicles while changing driving environment conditions. Moreover, they do not monitor and report all the performance metrics.

Our experimental study is unique in several ways. First, our test bed is larger using more than two vehicles. Second, we attempt to provide detail trends such as throughput, delay, and signal strength between three moving cars with no stationary node. Third, we focus on using V2V multi-hop communication to extend the operative range of Access Points.

## III. EXPERIMENTAL CHARACTERIZATION OF VANET

### A. *Equipment description and software tools*

To setup our experiments, we use laptops running Linux operating system (Redhat) and equipped with an Atheros PCMCIA 802.11b/g Orinoco cards with external antenna (Lucent Technology Omnidirectionnal Antenna, 2.5dB gain), and Holux GPSlim236 Bluetooth based . We use a modified version of Multi-band Atheros Driver for WiFi, also known as MADWIFI [8] which gives the ability to monitor the entire transmitted and received packets that reach the network card. The modified tool is developed at the University of Stanford. We use also Iperf [9] as a traffic generator. We set Iperf source traffic to send 760 packets per second with a packet size of 1.5 Kb. Fig.2 shows one of the three cars of our experimental testbed. The first car acts as the traffic receiver while the second is the traffic transmitter. A third car is used in some experiments to relay information and in others as an AP. The three vehicles operate using the 802.11b mode (DSSS at 2.4Ghz).

We developed a data analysis toolkit to analyze connectivity, signal-to-noise ratio, packet losses, delay, and throughput over different distances and speeds.

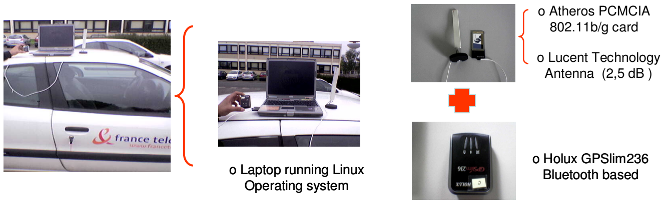


**Figure 2** - The experimental testbed.

### *B. Description of the test*

Two sets of experiments were performed:

- **V2V Experiments**

In order to evaluate the performance of multi-hop V2V communication, we conducted two experiments in two different environments in the surrounding of the city of Lannion, France.

- *Scenario 1*: Static scenario

The static scenario is conducted in a parking lot surrounding and located in between buildings using three static vehicles. The distance between each two vehicles is set at 90 meters. The route is preconfigured to go from sender to intermediate node and from the intermediate node to the receiver.

- *Scenario 2:* Following scenario

During this part of the experiment, we drove out of Lannion city, heading to Guingamp city. The 3 cars follow each other during four minutes. The sending vehicle and the receiving vehicle maintain at least 300m of distance while the intermediate vehicle is somewhere between them. Depending on the road conditions, other vehicles can get in between the three cars occasionally and we would lose line of sight communication. (cf. Fig. 3 (a))

- **I2V Experiments**

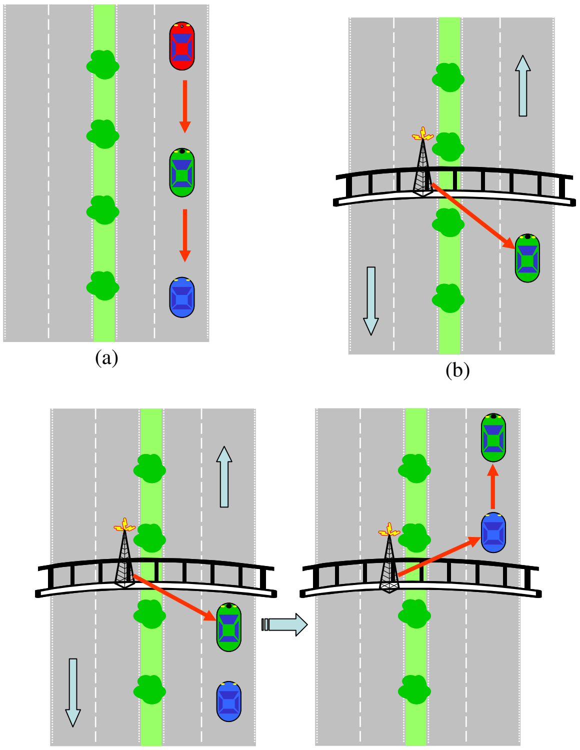
The main goal of this set of experiments is to evaluate the performance of I2V communication and to study the feasibility of using multi-hop communications to extend the range of Access Points. The infrastructure could be a hot-spot diffusing videos, music, and local news to moving cars. The test environment was a straight, two-lane road, with low level of traffic. The distance between the start and the end points of each drive was approximately 3000 meters with a car stopped on the middle (in a bridge to achieve the best possible propagation characteristics) acting as an access point (AP). It transmits data at the maximum rate (11Mbps). The end points were chosen such that the vehicle was out of wireless coverage when it reached the extremes.

- *Scenario 3:* Single vehicle/ Single AP

In this scenario, a vehicle is moving in a straight road, with low (50km/h) and high (90km/h) speeds. When it comes into range of the AP, it automatically associates and begins receiving data. (cf. Fig. 3 (b)). We focus on data downloads to cars. In any case, many of our results concern the bi-directional properties of the radio channel itself, and these findings should apply equally to both data transfer directions.

- *Scenario 4:* Two vehicles/ Single AP

The concept of this scenario is almost the same as the previous one except the fact that a second vehicle is used as a relay in order to extend connectivity with the AP. (cf. Fig. 3 (c)). The receiver starts receiving data until it leaves the wireless coverage of the AP. Then, it uses one-hop communication to continue receiving data. In other words, the following car is used ad a relay to bridge the gap between the receiving car and the AP.



(a) (b)

(c)

**Figure 3** - The experimental scenarios.

## IV. RESULTS & ANALYSIS

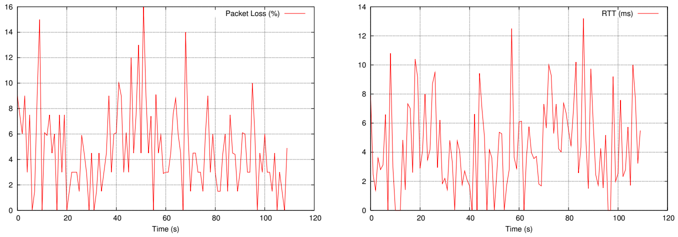
### *A. V2V Experiments*

The performance metrics used to evaluate the connectivity between cars in different performed scenarios are:

- *Packets loss:* percentage of data packets dropped due to network difficulties.

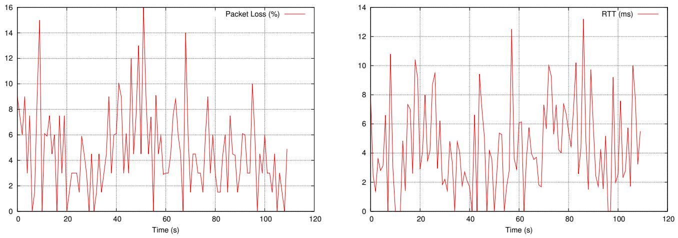
- *Round Trip Time (RTT):* is the time elapsed for a packet to a remote place and back again. It is measured in ms using the ping tool.

Figures 4(a) and 4(b) correspond to the static scenario of the V2V measurements. They depict the packets losses and RTT measured between three static cars. While figures 5(a), 5(b) and 6(a), 6(b) show the obtained results while the three cars are following each others in highway and with two predefined speeds (50 Km/h and 90 Km/h).



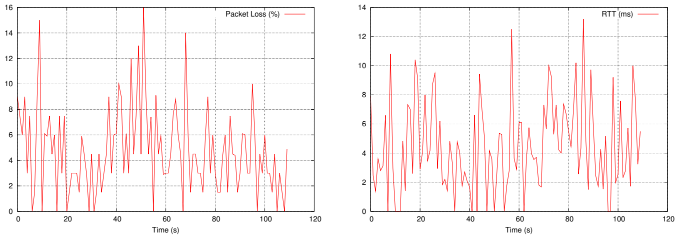
(a) (b)

**Figure 4** – Packet loss (a) and RTT (b) over time in static scenario.



(a) (b)

**Figure 5** – Packet loss (a) and RTT (b) over time in following scenario (Low Speed).



(a) (b)

**Figure 6** – Packet loss (a) and RTT (b) over time in following scenario (High Speed).

Losses in the following scenario are lower than the static scenario despite the mobility of nodes. This is due to the impact of the environment since while driving in the highway scenario, there are no obstacles and no interferences from other radios and systems.

As shown in Fig 5(b) and 6(b), the obtained RTT over time for the following scenario show much more stability compared to the static scenario (Fig 4(b)). The two major spikes are caused by the highway entrance and exit through the hilly curve ramps.

Table 1 shows statistic summary of the first set of experiments. While comparing the obtained average losses and RTT for the low and high speed, we can conclude that the speed does not affect very much performance of multi-hop V2V communications.

**Table 1 – Statistic summary for the V2V scenarios**

| | Average losses (%) | Average RTT (ms) | Average distance (m) |
|---|---|---|---|
| Static Scenario | 4,75 | 4,41 | 87,17 |
| Following Scenario (LS) | 1,99 | 1,97 | 91,39 |
| Following Scenario (HS) | 3,48 | 2,04 | 142,05 |

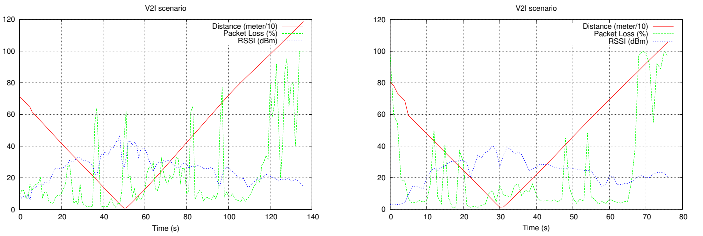
In previous work [7], we characterized one-hop V2V communication in different scenarios. Among these scenarios, there is the ‛highway following' scenario. The average losses of this later (0.36 %) are lower than those obtained for the two-hop following scenario (3.48 % for the following scenario with high speed). In other words, losses increase with increasing number of hops. This phenomenon is explained by considering the mechanism of CSMA (Carrier Sense Multiple Access).

### *B. V2I Experiments*

For this set of experiments, we measured the following metrics:

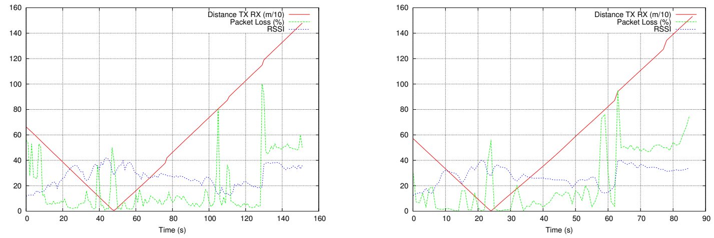
- Received Signal Strength Indication (RSSI) and Packet loss.
- the period of the car node 's connection to network
- the amount of data that the node could receive from the web server

We performed all tests several times also leading to similar results. Figure 7 represents the packet loss and RSSI (Received Signal Strength Indication) measures for scenario 3 (single vehicle/single AP). Figure 8 represents the same measures for scenario 4 (2 vehicles/single AP). The RSSI measurements over distance led to a symmetrical graph as expected. The average packet losses and RSSI still the same for the two scenarios. The impact of the bridges is clearly visible.



(a) (b)

**Figure 7** – Packet loss and RSSI for scenario 3 with (a) low and (b) high speed.



(a) (b)

**Figure 8** – Packet loss and RSSI for scenario 4 with (a) low and (b) high speed.

Table 2 shows the network connection time and the amount of transferred data for the two last scenarios 3 and 4. Note that for the scenario 4 (2 vehicles/single AP), the average connection time to the AP and the amount of data that the destination car could receive from the AP represent the sum of multihop duration and direct duration.

**Table 2 – Network connection time and amount of data for (a) scenario 3 and (b) scenario 4.**

| Network connection time | | |
|---|---|---|
| | high speed | low speed |
| **Total** | **81** | **140** |

| Amount of data | | |
|---|---|---|
| | high speed | low speed |
| **Total** | **59,195** | **98,86** |

(a)

| Network connection time | | |
|---|---|---|
| | high speed | low speed |
| direct | 66 | 143 |
| multihop | 25 | 27 |
| **Total** | **91** | **170** |

| Amount of data | | |
|---|---|---|
| | high speed | low speed |
| direct | 54,247 | 106,452 |
| multihop | 9,813 | 9,519 |
| **Total** | **64** | **116** |

(b)

The experimental results revealed the following two points about the feasibility of the ad hoc network.

- The ad hoc network enlarges the service area and the connection time for cars in motion (more than 16%).
- It increases the amount of data that the car can acquire through AP (more than 10%).

We conclude that an ad hoc network is beneficial to extend both service area and connection time of nodes on moving vehicles.

## V. CONCLUSION AND FUTURE WORK

In this work, we have presented the results of an evaluation of the performance of V2V and I2V multi-hop communication based on the IEEE 802.11b technology. We have shown that distance and line of sight communication are the two main factors affecting the network communication in our experiments. The experimental results revealed also that the ad hoc network could extend the transmission range of infrastructures and the connection time for cars in motion.

In the future, we are going to perform further experiments examining vehicle(s) to many APs scenarios. Also, we intend to extend our experiments and improve our results by building a larger network using more than three vehicles and our own multi-hop routing protocol called GyTAR (improved Greedy Traffic Aware Routing Protocol) [10].

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