Extensive Experimental Characterization of Communications in Vehicular Ad Hoc Networks within Different Environments

Moez Jerbi, Sidi-Mohammed Senouci, and Mahmoud Al Haj
France Telecom R&D
2 Avenue Pierre Marzin, 22307 Lannion Cedex, France
{moez.jerbi, sidimohammed.senouci, mahmoud.alhaj}@orange-ftgroup.com

***Abstract*— Test-bed based research is an important aspect in Mobile Ad hoc Networks (MANETs) and especially in Vehicular Ad hoc Networks (VANETs). However because of the high associated cost, we do not see as many high quality experiment studies as simulation or analysis ones. In this paper, we present extensive experimental measurements of vehicle-to-vehicle communication on several typical scenarios in order to study the critical factors that affect multimedia applications over an IEEE 802.11 VANET. Unlike [1], we proof that in addition to short message transfer, the deployment of multimedia applications is also feasible. We found that network performances are clearly different according to the environment (city, highway, etc.), the distance between vehicles and the vehicles speed.**

***Keywords*- Vehicular ad hoc networks, IEEE 802.11, SNR, pathloss, video transmission.**

I. INTRODUCTION

During the last century, wireless communication technologies have enabled many conveniences to our lives and raised our daily productivity. One area where there is more potential for wireless technologies to make a real tremendous impact, that could change the face of life, is the area of inter-vehicular communications (IVC). IVC is also known as vehicle-to-vehicle communications (vehicle-to-vehicle) and vehicular ad hoc networks (VANET).

VANETs share some common characteristics with general MANETs. These two spontaneous networks are characterized by the movement and self-organization of their nodes. They are also different in some ways. In VANET, driver behaviour, mobility constrained by the road and traffic, powerful and rechargeable source of energy in vehicles, highly mobile nodes and potentially large network create unique characteristics and special features. These characteristics have important implications on protocol design in these networks. Thus, numerous research challenges need to be addressed for inter-vehicular communications to be widely deployed. 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, the performance of a video transmission is evaluated in different driving scenarios. We aim to see the effect of both distance and speed on the quality of the received traffic which emulates a video transmission. This characterization will help researchers to conceive new solutions and proposals for VANET networks. Our goal is to prove that vehicle-to-vehicle communications is a feasible concept, and to find out the critical factors that affect the quality of a video transmission over a vehicular ad hoc network in different scenarios.

The rest of the paper is organized as follows. In section 2, we explore the literature on the characterization of VANET.. Section 3 describes the test set up and test environments. Result analysis and inferences of our study are shown in section 4. Section 5 concludes the paper and addresses our future research directions.

II. RELATED WORK

A few experimental studies on VANET have been reported in the literature. 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.

Bucciol et al, [3] 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 [4] 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 multi-media 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 [5], 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] 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 [3, 4, 5] 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 while changing driving environment conditions. Moreover, they do not monitor and report all the performance metrics. In our work, we consider different scenarios and different metrics. Our aim is to answer questions like: What happened in some specific communication scenarios (crossing, passing, etc) and how speed and distance affect the network performance.

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 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 [6] 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 [7] as a traffic generator. To emulate a video transmission, we set Iperf source traffic to send 200 packets per second with a packet size of 1.5 Kb [8]. Fig.1 shows our experimental testbed. The first car acts as the traffic receiver while the second is the traffic transmitter. Both vehicles operate using the 802.11 ad hoc mode, i.e. without relaying on any access point. The monitoring tool (MadWifi) is installed on the two cars.

We developed a data analysis toolkit to analyze connectivity, signal-to-noise ratio, packet losses, Jitter, and throughput over different distances, and speeds. A comparison of logged packets transmitted combined with the GPS data from both nodes, allows a detailed statistical analysis. In order to measure the distance between the two vehicles (V1 and V2) based on the vehicles position we use the following formula [9]:

$$Dist\ (V1,\ V2) = R \times acos(sin(lat1) \times sin(lat2) + cos(lat1) \times cos(lat2) \times cos(lon2 - lon1)) \quad \textbf{(1)}$$

Where R is the radius of the earth (6378.7 Km).

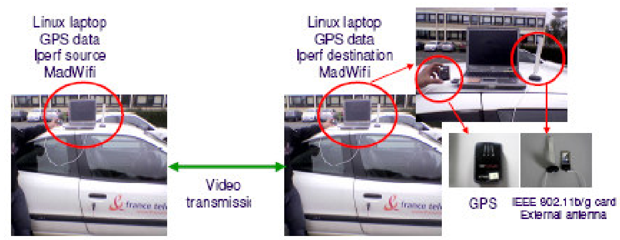

Figure 1 - The experimental testbed.

B. Description of the test

Two sets of experiments were performed:

❖ **<u>Long Duration Experiments:</u>**

In order to study the effects of the environment on wireless network performance and have a global view of connectivity while changing driving environment conditions, we conducted two experiments:

<u>*Scenario 1*: One vehicle following the other in a city</u>

This scenario corresponds to Fig.2 (a). The drivers drive the cars following each other during 10 minutes. Depending on the road conditions, other vehicles can get in between the two cars occasionally and we would lose line-of-sight communication.

In the city scenario, the average speed is low, less than 50 km/h. Stops caused by traffic jams, traffic lights and roundabouts are frequent, while the distance between the two cars is on average smaller than in a highway. In this part of the experiment we drove downtown Lannion city. City environments have certain unique characteristics: (1) many tall buildings obstructing and interfering the transmission signals, (2) vehicles are closer together than in the highway scenario, thus create interference if transmission range is large.

<u>*Scenario 2* : One vehicle following the other in a highway</u>

In the highway scenario, the speed is greater than the city scenario and limited to 90km/h. During this part of the experiment, we drove out of Lannion city, heading to Guingamp city. The drivers drive the cars following each other during 10 minutes. There are no stops, no traffic lights and no roundabouts.

❖ **<u>Short Duration Experiments:</u>**

In those set of experiments, we conducted some real short scenarios to understand VANET behaviour in more details. Here, the focus is on the impact of relative speed and distance between the two wireless nodes in some specific cases (crossing, passing, roundabout)

As we mentioned before, we used many real scenarios:

- *Scenario 3*: A vehicle passes beside another static vehicle, with low (30km/h) and high (50km/h) speeds, and exchange data with that vehicle (cf. Fig. 2 (b)),

- *Scenario 4*: Two vehicles moving in opposite directions at predefined speeds (low: 30km/h, and high: 50km/h) (cf. Fig. 2 (c)),
- *Scenario 5*: A moving vehicle turns around a static one. We vary, the distance between the two vehicles (small: 12m, and big: 33m) and the mean speed of the moving vehicle (low: 16Km/h, and high: 33Km/h). We also consider when the vehicle varies its speed progressively from 0km/h to 45km/h and then decelerates rapidly from 45Km/h to 0Km/h. Finally, we consider when a person walks around the static vehicle as in MANET (cf. Fig. 2 (d)).

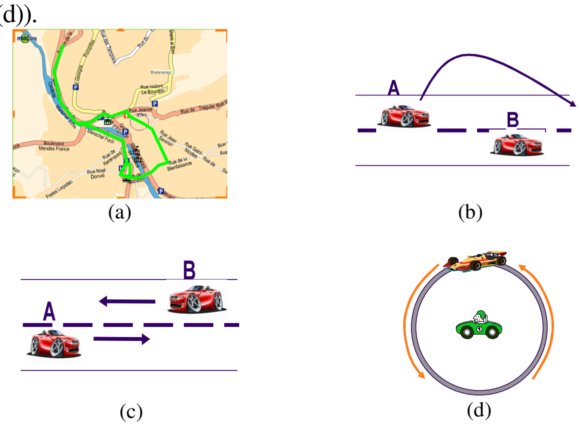

Figure 2 - The experimental scenarios.

IV. Results & Analysis

The performance metrics used to evaluate the connectivity and the quality of video transmission between two moving cars are:

- *Signal-to-Noise Ratio*, often written S/N or SNR, is a measure of signal strength relative to background noise. The ratio is usually measured in decibels (dB).
- *Pathloss*: is measured by the ratio of the signal's power at the transmitter's output to its power at the receiver's input. This ratio usually is expressed as logarithm and measured in decibels.
- *Jitter:* is the variation in time between packets sent and packets arriving caused by network difficulties such as route changes, congestion, packet loss, traffic regulators etc., It is usually measured in ms.
- *Packets loss:* percentage of data packets dropped due to network difficulties.

Referring to [10], they specified the following boundaries for the video quality grades:

- *Good*: Jitter values (0-20 ms) and losses from (0-0.5%)
- *Acceptable*: Jitter values (20 – 50 ms) and losses from (0.5 – 1.5 %)
- *Poor*: Jitter values (> 50 ms) and losses from (>1.5%)

Figures 3(a) and 3(b) show the SNR and pathloss measured between two moving cars in the city scenario and highway scenario respectively. The obtained SNR for both scenarios is good. This is expected, since the distance between the sender and the receiver is small (less than 50 m). Pathloss is less in a city than in a highway due to the closer distance in the city scenario and also the constructive effect of multipath fading. Note that the city scenario has a slightly better overall SNR.

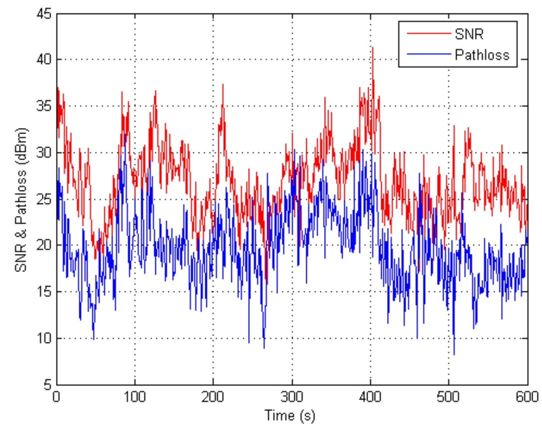

Figure 3(a) - SNR & Pathloss in City scenario

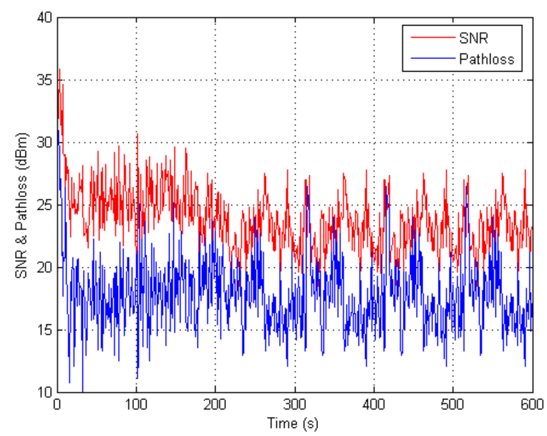

Figure 3(b) - SNR & Pathloss in Highway scenario

As shown in Figures 4, we find that the noise level is about the same for both city and highway and it remains at the same level regardless of the distance or speed variation. Thus, the decrease in signal strength is the main cause for the decrease of SNR.

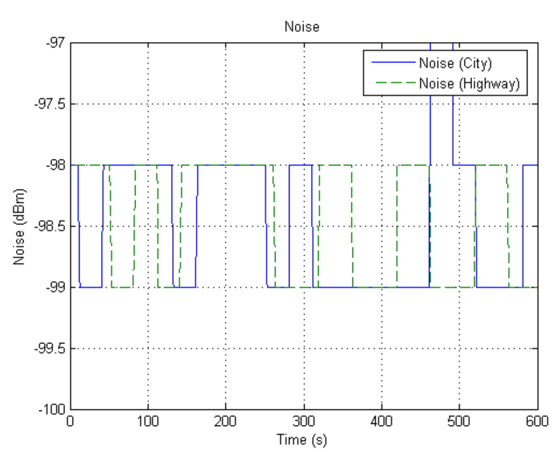

Figure 4 - Noise in City & Highway scenario

We note that the decrease in the signal strength for the suburban scenario is caused by the loss of line-of-sight communication in road curves and also because the city scenario contains more ups and downs because of the frequent stop signs and buildings. For the highway scenario, this decrease is caused by the highway entrance and exit through the hilly curve ramps.

The other experimental results are summarized in the following table:

TABLE 1: Experimental results

	Pathloss (dB)	Jitter (ms)	Packet Losses (%)	Average Distance	Average ΔSpeed	Video quality
City	26,77	0,177	1,08		4,20	A
Highway	23,72	0,152	0,29	59	5,21	G

(G = good, A=acceptable, P = poor) [10].

Figures 5(a), 5(b) and 6(a), 6(b) correspond to *the short duration experiments*.

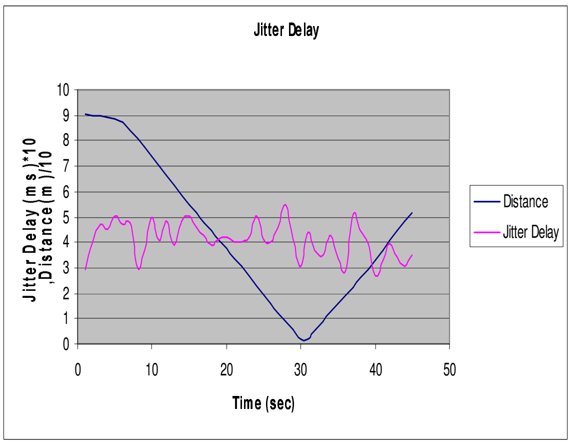

Figure 5(a) – Jitter Vs Distance in Passing Scenario

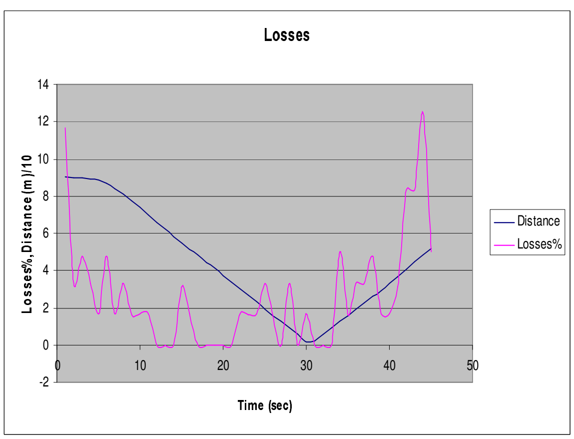

Figure 5(b) – Losses Vs Distance in passing scenario

Figures 5(a) and 5(b) depict the jitter and packet loss variation with distance between the two vehicles for the overtaking scenario with low speed (30Km/h). Here in this scenario we can see that the jitter delay stays approximately constant during the experiment duration but it's higher than the other scenarios (city, highway). Losses are also slightly higher and decreases as the cars get closer and increases as they fall further apart.

Figures 6(a) and 6(b) show the jitter delay and packet loss variation with relative velocity between the vehicles for the crossing scenario with high speed (50Km/h). As in the previous scenario, we can see that Packet loss behaves according to the distance. Also we can see that the jitter delay behaves according to the difference between the speeds of the two vehicles (ΔSpeed) which means that the jitter delays increases as ΔSpeed increases.

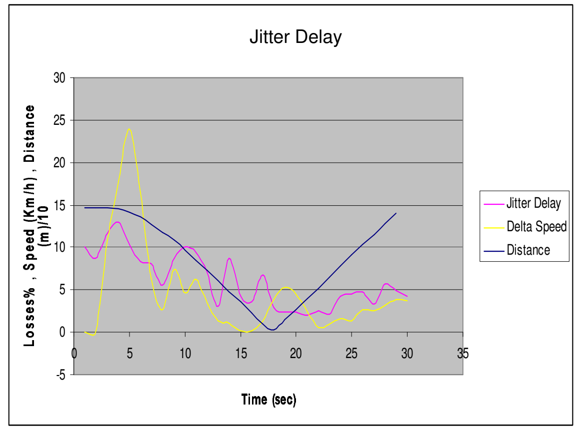

Figure 6(a) – Jitter Vs Distance & ΔSpeed in Crossing Scenario

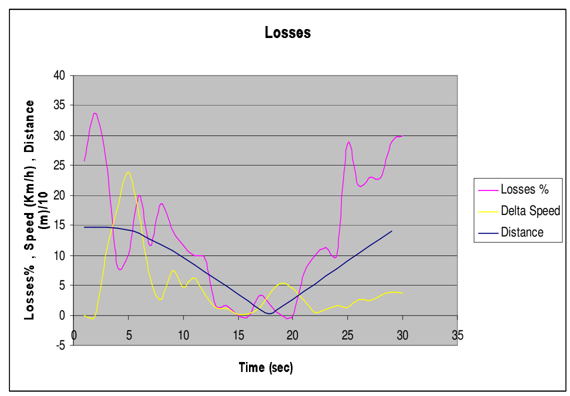

Figure 6(b) – Losses Vs Distance & ΔSpeed in Crossing Scenario

The other experimental results for these two scenarios and those of the round about scenario are summarized in the following table:

TABLE 2: Experimental results

	Jitter (ms)	Packet Losses (%)	Average Distance	Average ΔSpeed	Video quality
Passing with high speed	0,332	3,88	100	37,32	P
Passing with low speed	0,409	2,62	100	24,75	P
Crossing with high speed	0,554	13,33	150	4,66	P
Crossing with low speed	0,463	11,57	150	3,64	P
Round about big with high speed	0,145	1,04	33	33,10	A
Round about big with low speed	0,157	5,59	33	16,16	A-P
Round about small with high speed	0,149	5,31	12	32,10	A-P
Round about small with low speed	0,148	4,80	12	16,43	A-P
Round about big with variable speed	0,152	0,59	33	22,48	G
Round about small by walk	0,163	5,83	12	7,65	A-P

(G = good , A=acceptable , P = poor) [10]

The main objective of the round about scenario was to have a constant distance between the two vehicles. Hence, we can see through results the impact of the two parameters (distance and speed) separately. However, the obtained measurements show that while the mobile station is moving around the circumference with constant speed, the signal quality and network performance varies randomly. We assign this unexpected phenomenon to the antenna patterns (cf. Fig. 7 below). In case of small round about, the antenna pattern affects the losses, thus, regardless of the driving speed, the car falls in the low gain area all the time, whereas in the big round about scenario, the moving vehicle alternates between low and high gain regions.

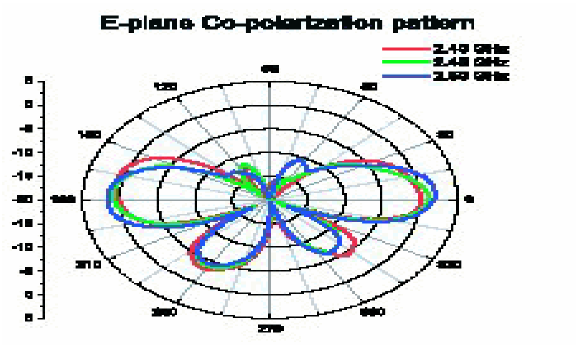

Figure 7 – Antenna patterns

V. Conclusion and Future Work

In this work, we have presented extensive experimental measurements of inter-vehicle communications. The goal of these experiments was to see the effect of wireless channel and environment on delivering multimedia applications in highly mobile networks as VANETs. Obtained results demonstrated the feasibility of such applications in various driving conditions. We found that both signal quality and network performance varies greatly depending on the distance and speed. In the future, we are going to explore the effects of other parameters such us the packet size, the transmission rate, directional antennas. Also, we intend to extend our experiments and improve our results by building a larger network using more than two vehicles using our own multi-hop routing protocol called GyTAR (improved Greedy Traffic Aware Routing Protocol) [11].

VI. References

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