Experimental demonstration of the viability of IEEE 802.11b based inter-vehicle communications

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ABSTRACT

This paper demonstrates experimentally the viability of the wireless technology IEEE 802.11b for inter-vehicle communications. Although IEEE802.11b was designed for low-mobility, indoor scenarios, we demonstrate that is possible to use it in high-mobility, outdoor scenarios where vehicles reach relative speeds of 260 km/h. For the first time, this demonstration takes into account both the speed and the presence/absence of line-of-sight in the IEEE 802.11b communication link. These are key aspects to the most aggressive vehicular scenarios for VANET communications, such as urban streets where the surrounding buildings produce constant signal reflections or high-speed freeways. The results obtained are part of the Virtual Sub-Centre developed in the European COM2REACT project, which is a novel building block to manage efficiently moving groups of vehicles in close proximity.

Categories and Subject Descriptors

C.2.1 (Wireless communication)

General Terms

Experimentation

Keywords

Inter-vehicular communications, experimental demonstration, IEEE 802.11b.

1. INTRODUCTION

Vehicular Ad-hoc Networks (VANET) are a specialisation of mobile ad-hoc networks focused on vehicular environments. These networks have no fixed infrastructure and rely on the network nodes to provide network functionality. In the last years, much effort is being put in the research of this network paradigm. Most of these efforts rely on simulators to assess the goodness of research results. However, simulations usually make simplifications on the network model in order to achieve acceptable simulation times. These simplifications result in models that differ from reality, and in some cases the gap is considerable [1]. Hence, there is a strong need to study how VANET networks behave in the "real world" [2].

Because of the nature of vehicular environments, VANET communications must face additional challenges that are not present in other mobile communication technologies [3]. There are two major challenges: speed and loss of Line Of Sight (LOS). Mobile nodes (vehicles) can move at high speeds, which in relative measures are well above 120Km/h. For example, when two vehicles moving in opposite directions in a highway communicate with one another, the communication module may face relative speeds of 240Km/h. On the other hand, some situations result in non-LOS. The lack of LOS produces degradation in the quality of the communication, i.e., service quality, which could lead to burst errors or even to the complete loss of the communication. Moreover, in urban scenarios, the buildings surrounding the roads produce signal reflections that harm the communication quality because they result in burst errors that may lead to packet losses.

For these reasons, new technologies are being standardized for vehicular communications. The most outstanding is IEEE 802.11p, also known as Wireless Access in Vehicular Environments (WAVE), which will be the new IEEE standard for VANET communications. However, WAVE is still in a development phase. Therefore, while new vehicular networking concepts are developed, other mobile and wireless technologies shall be used for VANET communications. A widespread example of these technologies is IEEE 802.11b, which is commonly known as belonging to the WiFi family of standards. Although IEEE 802.11b was initially designed for low-mobility, indoor wireless scenarios, nowadays it is one of the most commonly used technologies for the experimentation of VANET communications. 802.11b has been selected because has shown a more stable communication in initial tests performed compared with 802.11g that showed higher transmission rates but also lower ranges (also seen in [12]). For the scope of COM2REACT it was not necessary to provide higher bandwidths than 1 Mbps. Although 802.11a is similar in someway to the future 802.11p, we considered that due to

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802.11a works in the 5GHz IMS band, in NLOS scenarios its performance would be worse because of its lower penetration rate.

There are not many studies on the behaviour of Inter-Vehicle Communications (IVC) using IEEE 802.11b, particularly in high-speed scenarios. There is also little work on the behaviour of IVCs in urban scenarios where a high amount of signal reflections degrade the communication performance. For these reasons, in this paper we perform an experimental demonstration of the viability of IVCs using IEEE 802.11b technology in both high-speed (interurban freeway) and signal-degrading (urban) scenarios.

This experimental study is part of the European project COM2REACT (FP6-2004-IST-4-027071). COM2REACT's aim is to establish and test a scalable, cooperative, multi-level road transport supporting system involving two-way IVCs based on IEEE 802.11b and vehicle-to-infrastructure communications based on GPRS. The COM2REACT system incorporates the innovative Virtual Sub-Centre (VSC) concept for local, short-term traffic control. The COM2REACT system concept shall provide significant improvement in the flow of information acquired by moving vehicles and in its quality and reliability, thereby enhancing road efficiency and traffic safety on urban, intercity arterials and rural roads.

The remainder of the paper is organised as follows: Section II describes the field trial used for the experimental study and relates it to other testbeds in the literature. In Section III, we describe and discuss the results obtained from the real measurements. Finally, in section IV we draw conclusions and outline future work.

2. DESCRIPTION OF THE FIELD TRIALS

In order to study the viability of IEEE 802.11b for IVCs and the impact of speed and non-LOS situations in VANET communication links, we have created two typical scenarios in which VANETs usually operate. The first one is an interurban freeway scenario. Here, the vehicles achieve high speeds that difficult the communications. The second scenario is an urban environment where the buildings reflect the signal causing interferences that affect negatively to the communications. In both scenarios, two vehicles communicate in a single hop. Note that we assess the viability of IEEE 802.11b, and hence networking aspects such as routing are out of scope of this experimental study.

2.1 Related Work

Being IEEE 802.11b a technology designed for low-mobility scenarios, a key aspect of our study is speed. There are some studies in the literature that demonstrate IEEE 802.11b based IVCs for two to several vehicles [4-7]. However, none of them considers high speeds. On the other hand, there are hardly experimental studies on how IEEE 802.11b based IVCs perform in urban scenarios, where it is common to lose the LOS because of buildings.

Concerning experimental setups, we may fin some IEEE 802.11b based testbeds and field trials in the literature. In [4], the authors focus on railway communications using IEEE 802.11b/g for vehicle-to-infrastructure communications, in which one of the nodes (the infrastructure) is static and the other node (the train) moves at a maximum speed of 88 km/h. In [5], the authors perform vehicle-to-road and single- to multi-hop IEEE 802.11b based IVC tests in a real environment. The vehicles reach a relative speed of 108 km/h but the influence of this speed is not measured. Another IEEE 802.11b IVC testbed is [6], which studies the performance of static one- and three-hop communications and three-hop mobile communications. This testbed provides physical and data-link layer performance parameters, such as received signal power, delivery ratio or throughput. Again, the influence of speed is not measured. Finally, in [7] several 802.11b/g based IVC scenarios are characterized experimentally. In the interurban scenario, where two vehicles are moving in opposite directions, the authors measure the influence of speed in the communication performance up to an inter-vehicle speed of 50 km/h.

2.2 Equipment

The equipment used in this experimental study consists of an 802.11b-compliant wireless interface card, an embedded communication platform (Routerboard) and a 9dBi omni-directional antenna, which incremented the communication range thanks to its high gain. The antenna has a magnetic base for rooftop placing during the tests, and a 1.5-meter pigtail with a MMCX connector for the wireless card (Fig. 1).

The wireless interface card chosen is the Ubiquiti Super Range 2 [8] because it allows for the extension of the standard capabilities of IEEE 802.11b hardware. This card provides enhanced output power (up to 26 dBm) and sensitivity (-97 dBm) over standard wireless cards. These values allow increasing the communication range. We configured this interface as ad-hoc and forced it to operate in the IEEE 802.11b mode. By default, the card driver has Request to Send/Clear to Send (RTS/CTS) disabled, and it allows a maximum of 7 retransmissions at the medium access control layer before the sent packets are discarded if no acknowledgement is received. For these tests we didn't consider to activate RTS/CTS, because the studied scenarios are not dense traffic networks (where RTS/CTS is useful) and one of the objectives was to measure the maximum bandwidth (RTS/CTS produces a small bandwidth reduction). A 2.4-GHz IEEE 802.11b/g mini-PCI module is directly plugged into the Routerboard.

The wireless interface was set up at its maximum power emission (26 dBm) because one of the requirements was to provide the maximum range in inter-urban scenarios. This power emission could affect to the communication in urban scenarios, but this has not been measured. In future studies this is one of the issues to be studied, including the solutions to adapt the power emission to the different situations.

The Routerboard used is an embedded PC designed as a communications platform (532A from Microtik [9]). The Routerboard's 266MHz microprocessor uses a MIPS architecture, which makes it compatible with Linux kernels. We used a tiny Linux distribution through the compact flash slot provided by the Routerboard. Additionally, the board provides two mini-PCI slots where the Ubiquiti wireless card was connected (Fig. 1), three 10/100 Ethernet interfaces and a DB9

RS-232C asynchronous serial port. The Routerboard is powered using the vehicle's lighter power source (12V).

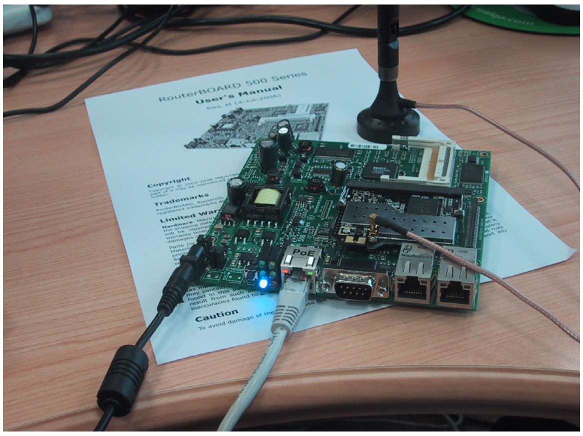

Figure 1. COM2REACT's communication module.

The devices described above form the communications module used for IVCs in the COM2REACT project, whose architecture is illustrated in Fig. 2. Additionally, a laptop was used to monitor the communications module and to collect the results of the experimental tests. This laptop was connected to one of the 10/100 Ethernet interfaces of the Routerboard. Finally, a Global Positioning System (GPS) receiver was used in each car during the experimental tests [10]. Every second, the GPS device transmitted the vehicle's position in NMEA format to the Routerboard's serial port. The GPS was also used to calculate total and relative car speeds. The complete scheme of communications devices is shown in Fig. 2.

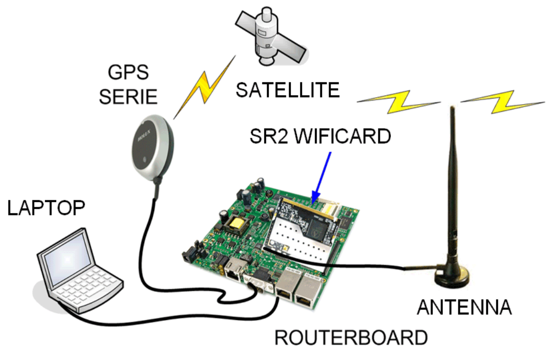

Figure 2. Communications module diagram.

We chose two typical vehicular environments, that is, an interurban freeway scenario, where vehicles move at high speeds, and an urban scenario where vehicles move more slowly but the communication is affected by signal interferences due the signal reflections produced by buildings.

The interurban freeway scenario (Fig. 3) is a secondary road in the outskirts of the Spanish city of Huesca. For safety reasons during the tests, the road chosen was not a freeway but a far less transited road with the characteristics of a freeway: a 4 Km straight road. The road is surrounded by trees and only a few buildings. In Fig. 3 we may observe that the road is not flat. This fact is important because in some places along the road there is non-LOS (NLOS) between the vehicles. This scenario was used to study the impact of high speeds on IEEE802.11b based inter-vehicle communications and also to asses the impact of NLOS in the communication.

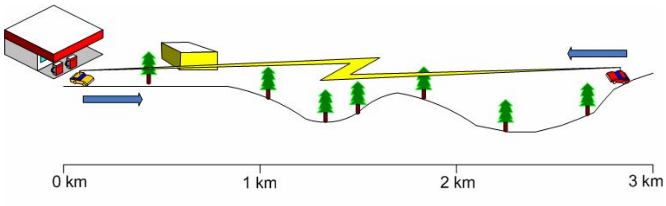

Figure 3. Cross-section of the interurban scenario.

The urban scenario is an avenue located in the city of Huesca. This site is suited for testing IVCs in urban environments because it is located in a neighbourhood with many building. Hence, in this scenario the cars were surrounded by buildings that caused reflections and multipath propagation. This scenario was used to evaluate the influence of surroundings in an urban environment with obstacles (cars, buildings, trees) between the two vehicles in LOS and NLOS situations. Fig. 4 depicts the LOS part of the urban scenario, while Fig. 5 illustrates the NLOS urban scenario. Note that the difference between these figures is the start and end points of the communication; along the avenue for LOS (Fig. 4) and around three blocks for NLOS (Fig. 5).

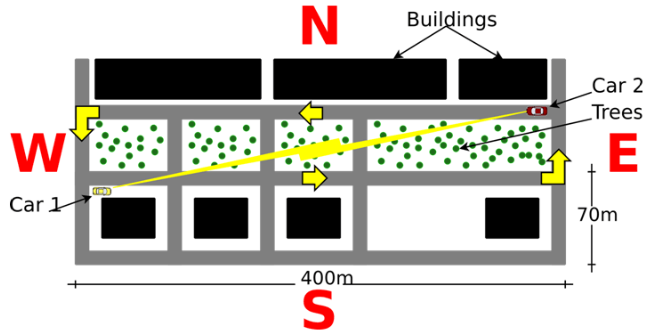

Figure 4. Urban scenario with LOS variation (LOSUS).

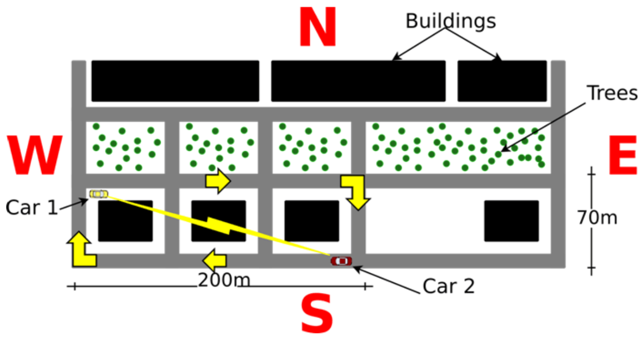

Figure 5. Urban scenario with NLOS variation (NLOSUS).

2.3 Experimental Setup

As described before, this experimental study is part of the COM2REACT project, which provides the traffic model and packet sizes for the IEEE 802.11b based IVC. These were derived from the virtual traffic control sub-centre (VSC), which manages a moving group of vehicles in close proximity. The

VSC operates locally via IVCs; it obtains and processes data acquired by the vehicles and provides instructions related to local traffic and safety situations in a timely manner. By means of the vehicle-to-infrastructure communication, the VSC also transmits selective data to a central control centre and receives, in return, instructions to distribute to the vehicles. COM2REACT's VSC communications are based on the User Datagram Protocol (UDP) and have a packet size of 1460 bytes. The communications module of the VSC is as described in Section 2.B; ad-hoc, based on IEEE802.11b, without RTS/CTS and with up to 7 packet retransmissions.

Since the VSC communication is at the network layer, we measured packet metrics. To perform these measurements, we integrated the Iperf [11] and ping tools into the Linux-based Routerboards (with 2.6 kernel) described in Section 2.C. The Iperf tool generated traffic according to the VSC characteristics and provided the throughput, packet lose ratio and jitter measures. The ping tool provided the Round Trip Time (RTT) measures for 1460-byte-long packets.

In the interurban scenario, each vehicle began the test in a side of the road. When the test starts, each vehicle starts moving at a high speed towards the other vehicle (opposite side). This way the relative speeds are maximized; the maximum relative speed reached in this scenario was 260 km/h (130 km/h each car). From the start of the test, one of the vehicles starts communicating data to the other using the Iperf or the ping tool.

The urban scenario has two different variations. In the first one (Fig. 4), the vehicles establish communication with LOS. In this variation, one of the vehicles remains stopped (Car 1) while the other one (Car 2) moves following the E-W-E path (see Fig. 4). In the second variation, there are buildings between the cars along part of the communication. One of the vehicles remains stopped (Car 1) while the other (Car 2) moves following the North-East-South-West (N-E-S-W) faces of the block (see Fig. 5). During the test, one of the vehicles communicates with the other with the Iperf or the ping tool. During these tests, the speed of the moving car is about 40 km/h (it depended on the external traffic and the route characteristics). Due to the difficulties to prepare and carry out methodical tests in real urban scenarios (where external the traffic can' t be controlled), we decided to maintain one of the cars stopped, although we still consider V2V communication (with low relative speeds V2V and V2I performances are similar).

3. RESULTS AND DISCUSSION

The figures of merit of one-hop IVCs in our study are the throughput (in bits per second), the two-way packet delay (RTT, in seconds), the packet jitter and the Packet Loss Ratio (PLR, in %). Throughput measurements indicate how much data can be delivered over an IEEE 802.11b IVC link according to the setup and traffic characteristics described in Section II. Packet metrics (RTT and jitter) provide qualitative results of service quality and show how critical could be the delivered data. For example, high delays would make IEEE 802.11b unsuitable for real-time services. Note that the IEEE 802.11b based IVC is used in the COM2REACT project by the VSC members to exchange VSC-compliant data.

3.1 Throughput

For the throughput measurements, 10 iterations were done to obtain average results with statistical constraints. Since this performance parameter is the key to our study because it shows the suitability of IEEE 802.11b based IVCs in aggressive vehicular scenarios, at the following we describe these exhaustive results grouped into interurban and urban scenarios.

3.1.1 Interurban Scenario

Figs. 6 and 7 show throughput and relative speed as a function of distance in the interurban scenario. The 0-meter distance is the point where vehicles cross each other. The communication distance reaches 3 km. From these figures, it can be observed that IEEE 802.11b shows strong dependence on the road environment (low peaks in the figures marked with blue circles). Also, it can be appreciated that fadings occur in symmetric points, produced where the vehicles lose LOS due to the slopes seen in the figure 3 (both vehicles cross the two slopes). In these points, the received throughout decreases dramatically, and the PLR is considerably increased. To overcome this, in such situations the IEEE802.11b interfaces must switch to slower but more robust modulations.

Although these figures seem to be symmetric around the place where vehicles cross (0 m), there is a difference between the approaching phase (positive distances) and the moving away phase (negative distances). For example, at -3000 m the throughput is low while at +3000m the throughput is still high. The wireless interface card's autorate selection algorithm's resistance to change the modulation produces this hysteresis effect. The rate changes only when the bit error rate overcomes a certain threshold, which depends on each modulation. In the approaching phase, the throughput grows but the autorate algorithm shows some resistance to change the modulation. Once the bit error rate is less than a certain threshold, the autorate algorithm changes the modulation allowing the system to communicate with higher throughput.

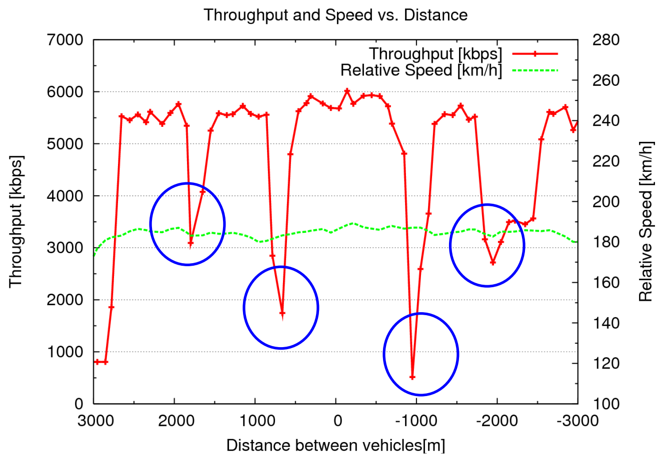

Figure 6. Throughput for the interurban scenario (180 Km/h).

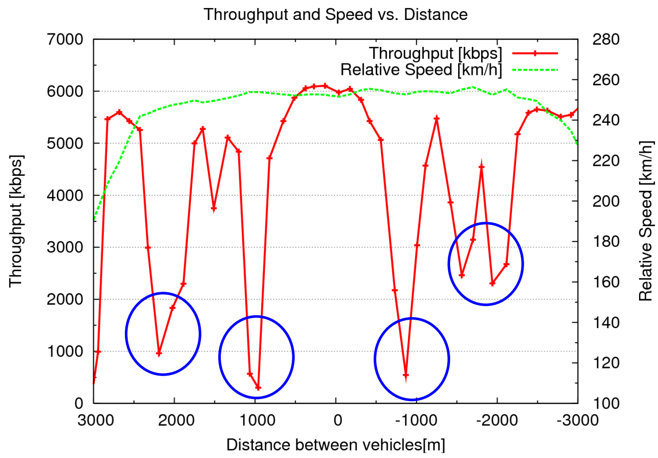

Figure 7. Throughput for the interurban scenario (260 km/h).

From these results, it can be concluded that the IEEE 802.11b technology with the selected hardware configuration (Section II. B) allows the communication between vehicles travelling with relative speeds up to 260 km/h and with distances up to 3 km in LOS situations. As illustrated in Table 1, the average throughput ranges from 3.98 to 4.54 Mbps. The typical deviation is negligible in the measurements performed.

Table 1. Throughput in the interurban scenario.

Speed (Km/h)	Avg. Throughput (Kbps)	Max. Throughput (Kbps)
140	4543	5851
160	4565	5927
180	4530	6015
200	4529	6145
220	4575	6127
240	4330	6024
260	3986	6033

3.1.2 Urban Scenario

As described in Section II.C, the urban scenario is divided into the Line Of Sight Urban Scenario (LOSUS, Fig. 4) and the Non Line Of Sight Urban Scenario (NLOSUS, Fig. 5). The results of LOSUS are shown in Figs. 8 and 9. These figures show throughput and PLR as a function of the distance between the two vehicles. In summary, the obtained throughput is well above our expectations given the great hostility of the urban scenario with respect to IVCs. The communication distance is around 350 meters (bandwidth greater than 1Mbps), which we consider enough for a urban environment where the vehicle density is high. Larger distances could be achieved but would result in worse system operation because of the interference generated between the vehicles. In that case, the available bandwidth would be significantly reduced (Notice that 0-m distance is set in point where the Car 1 is stopped. , for this reason, in Fig. 9 distance starts at 400m).

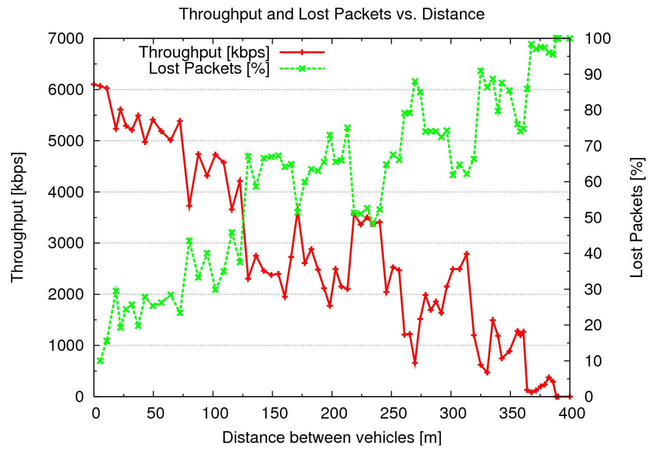

Figure 8. Urban Scenario (LOS) Throughput. W-E Path.

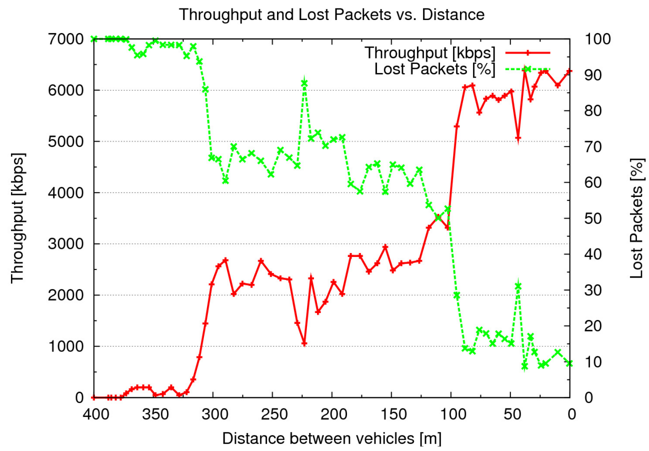

Figure 9. Urban Scenario (LOS) Throughput. E-W Path.

The Figure 9 is not exactly the inverse of the Figure 8, because we appreciate again the hysteresis effect described before.

NLOSUS results are depicted in Figs. 10 to 13 and summarized in terms of average values in Table 2. Again, these figures show throughput and PLR as a function of vehicles distance. Each figure presents a different road section (North, East, South and West) of the scenario, which is illustrated in Fig. 5, and clearly shows the influence of distance and LOS/NLOS in the communication.

Table 2. Urban Scenario (NLOS) Throughput.

Section	Avg. Throughput (Kbps)
North	4260
East	194
South	1768
West	5454

As shown in the figures, the IVC communication is continuous despite the NLOS. However, in the *East* section (Figure 11), the throughput is much lower (lower than 300 Kbps). This section corresponds to the most unfavorable situation, where cars are distant from each other and there is no direct visibility.

However, in the *South* section (Figure 12), where there is no direct visibility but the distance is lower, the throughput starts to grow. The maximum communication distance in NLOS situation with greater bandwidth than 1Mbps is 120m. For this reason we consider that it is not possible to ensure a good communication in this NLOS scenario with higher distances than 100 meters. 802.11b performance depends with the environment, and in theses cases the buildings materials influence extremely it.

Figure 10 corresponds to the North face, which is the same route presented in the Figure 8 from 0 to 200 meters, so it is a LOS situation

The West face is presented in the Figure 13, as it was supposed to be in this LOS situation, the communication performance is good due to the proximity of both cars (less than 60 meters).

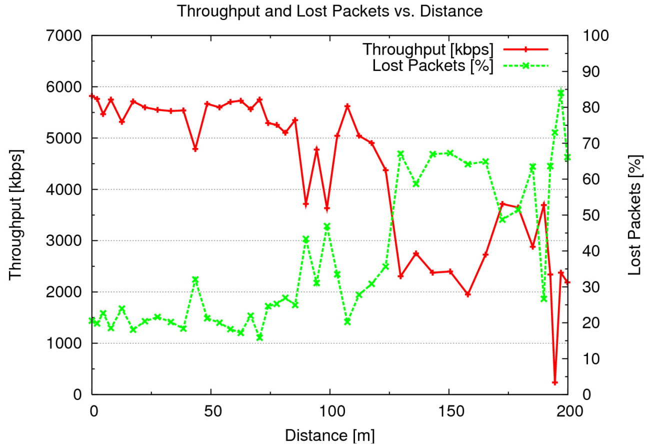

Figure 10. Urban Scenario (NLOS) throughput. North Face.

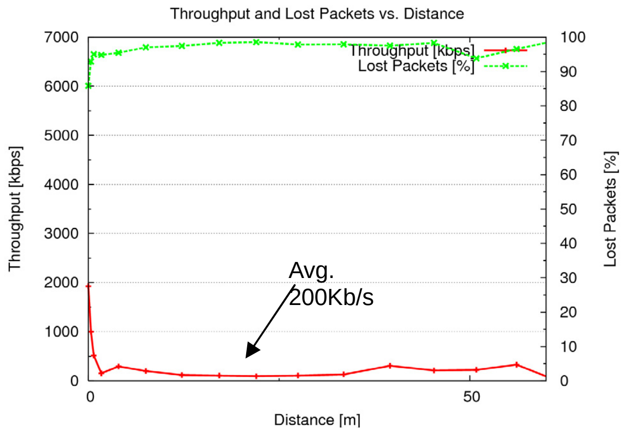

Figure 11. Urban Scenario (NLOS) throughput. East face.

3.2 Packet Metrics

As for the throughput and PLR measures, 10 iterations were done to obtain suitable average RTT and jitter values. These average results are summarized in Tables 3 and 4. As in the previous section, we group the results into the interurban an urban (LOSUS and NLOSUS) scenarios.

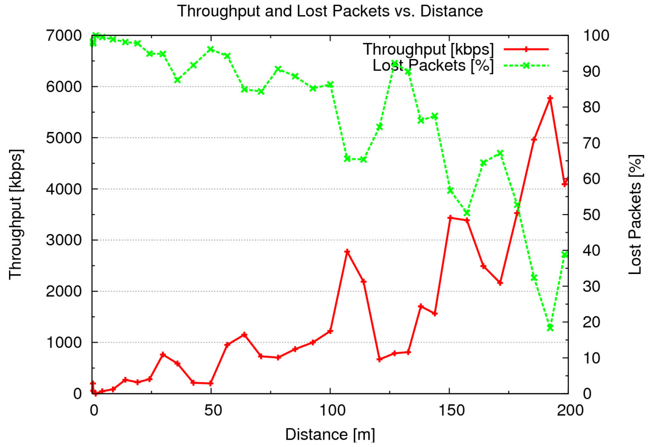

Figure 12. Urban Scenario (NLOS) throughput. South face.

3.2.1 Interurban Scenario

Table 3 shows average RTT and jitter results for the interurban scenario. We may observe that there is a constant growth of the RTT as the vehicle speed increases. The main growth of RTT starts at 240 km/h. The rationale behind this lied on the fact that at these speeds, the PLR is higher and there are more packet retransmissions, which increases the packet delay. Despite this, the jitter remains almost constant for all measured speeds.

Table 3 Delay and jitter for the interurban scenario.

Speed (Km/h)	Avg. RTT (ms.)	Avg. Jitter (ms.)
140	8.3	8.31
160	8	7.115
180	14.95	7.425
200	20	8.425
220	20.8	10.22
240	37.52	9.75
260	102.76	9.15

3.2.2 Urban Scenario

In the LOSUS scenario, the obtained average RTT is 21 ms both in W-E and in E-W sections (Fig. 4). This high RTT is due to the wrong frame reception, which produces several retransmissions. Moreover, the jitter is high because of the effect of reflections and the high variability of the environment. In the NLOSUS scenario, the average results are shown in Table 4, and they endorse all the conclusions explained before for this context, i.e, the RTT and jitter reflect the difficulties in NLOS communication, with a high and variable delay, especially in the *East* and *South* sections (Fig. 5).

3.2.3 Influence of the environment

In the interurban scenario, we observed that there is no significant influence of the vehicle speed in the communication throughput until the relative speed reaches 220 km/h. However, we observed an increment of the communication delay as the vehicle speed is increased. This increment is more noticeable at higher speeds. It seems that there are more lost packets at high speeds (higher PLR). This produces more retransmissions that increase the delay. Despite this, the jitter is little affected by the vehicles speed. In the interurban scenario, we observed the strong need of maintaining the LOS in IEEE 802.11b communications. Every slop in the road produces a peak of low connectivity where many packets are lost.

Table 4. Urban Scenario (NLOS) delay and jitter.

Section	Avg. RTT(ms)	Avg. Jitter(ms)
North	16.38	2.8
East	80.35	75.29
South	42.46	30.86
West	10.86	1.11

In the urban scenario, high influence of the environment is observed. The numerous buildings that surround the road produced several signal reflections that increased the packet error rate. This produces an important decrease on the received throughput and the communication distance. Moreover, an important increase on the delay and jitter is produced. Finally, in NLOS urban situations, the communication could be barely maintained. Despite signal reflections allow the communication, throughput is low and delay and jitter high.

4. CONCLUSIONS AND FUTURE WORK

In this paper we evaluated experimentally the performance of a one-hop VANET communication in different environment conditions. In summary, the 802.11b technology is suitable for suburban and urban scenarios with increased transmitted power. 802.11b allows for IVCs in high-mobility scenarios, where vehicles reach relative speeds up to 260 km/h. However, 802.11b is highly influenced by the environment (LOS/NLOS). The loss of LOS produces burst errors and may lead to the loss of the connection if the loss lasts long. Urban scenarios seem to be the most aggressive for IEEE 802.11b IVCs. In these scenarios, the reflections produced by the surrounding buildings increase the PLR and force numerous retransmissions. Since our study has been focused on the IEEE 802.11b link, future work involves extending the field trial to multi-hop communications to evaluate the performance of different routing protocols over IEEE 802.11b based IVCs.

5. ACKNOWLEDGMENTS

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