Real-world evaluation of IEEE 802.11p for vehicular networks

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ABSTRACT

This paper presents a set of experiments, performed using an IEEE 802.11p physical layer implementation based on the open-source *ath5k* driver, in both line of sight (LOS) and non-line of sight (NLOS) conditions. The results are compared against theoretical models and simulation of the same scenarios with proper propagation and channel models. The communication range in LOS can reach values larger than 1Km, while in NLOS scenarios, this communication range is decreased to the order of hundreds of meters.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Experimentation, Measurement, Performance

Keywords

VANET, Vehicle-to-Vehicle, IEEE 802.11p, Range, Propagation, Real-world experiments, Vehicular, Networks.

1. INTRODUCTION

In this work, we assess the performance of IEEE 802.11p in LOS and NLOS scenarios, such as straight roads and different types of intersections, respectively. We show that LOS communications can be performed over more than 1Km, while non-LOS communications are limited to 110m of range in intersection scenarios. Finally, we compare the experimental results with simulation using proper propagation and fading models, for LOS and NLOS scenarios. While for LOS scenarios the simulation results match the experimental results, the same is not true for NLOS communications. These results show that the available models are not able to gather the behavior of buildings, walls and other obstacles in intersections, and that research efforts are required to accurately model urban vehicular environments.

The remaining of the paper is organized as follows. Section 2 presents the system setup, while the results from both simulation and experiment campaigns are shown in Section 3. Section 4 presents our conclusions and plans for future work.

2. SYSTEM SETUP

The setup for the experiments comprised two on-board units, each composed by a Single-board Computer running Debian Linux, two wireless interfaces (IEEE 802.11b/g and IEEE 802.11p), two antennas and a GPS, using a modified version of *ath5k* [6]. The units were placed inside two vehicles with a rooftop mount antenna.

To run the experiments, we developed benchmarking applications that merge the GPS time and position, packet delivery information and Received Signal Strength Indication (RSSI) values, and return the evaluation metrics, synchronized with the position of the vehicle and universal time. This software was developed using socket programming and its main function is to send, via UDP, small packets (70 bytes) at a rate of 25 packets per second, including GPS information in the experiment logs.

3. EXPERIMENTS AND RESULTS

This section presents the scenarios and the experimental results, complemented, whenever possible, with theoretical results and NS-3 [1] simulation. Both the on-board units and the simulator were configured according to the parameters shown in Table 1. Furthermore, the Two-Ray model and a statistical model to account for multipath and other effects were used in simulation. The metrics evaluated are

Table 1: Parameters

Parameter	Value
Channel	175
Center frequency (f)	5.875 GHz
Bandwidth	10 MHz
Setup TxPower (P_{Ttheor})	23 dBm
Measured TxPower (P_{Teff})	14.58 dBm
Receiver sensitivity	-95 ± 2 dBm
Antenna Gain ($G_{t,r}$)	2 dBi

RSSI and PDR and the experimental results obtained are a moving average considering the 5 last samples (note that a RSSI of -35dBm represents 100% and a RSSI of -95dBm represents 0%). The results contain the mean of 5 runs and

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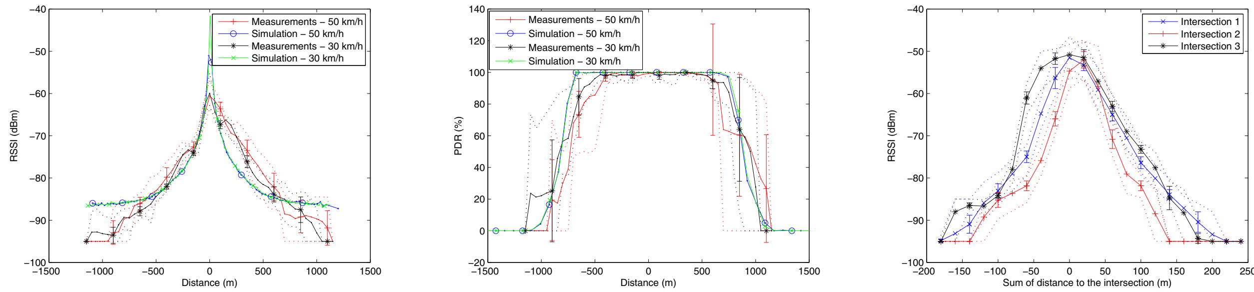

(a) RSSI in LOS (b) PDR in LOS (c) RSSI in NLOS

Figure 1: Results

the corresponding 95% confidence intervals. We also present in dashed lines, the curves of the minimum and maximum values of the experimental results.

3.1 Line of Sight Experiments

This scenario consists of two vehicles moving in opposite directions towards each other at the same speed for two different speeds: 30 km/h and 50 km/h.

The results presented in Figures 1(a) and 1(b) show that, up to 100 Km/h of relative speed, there are no significant differences between the values of RSSI and PDR at different speeds. A slight skew in RSSI is observed after the vehicles cross, which is due either to irregularities in the antenna radiation pattern or even to the fact that vehicles are not completely symmetrical. The range of communication is 950m and the simulation results are able to follow the experimental results, with small deviations in the extreme situations for the RSSI. For the PDR, the simulation proves to be in agreement with the experimental sets.

3.2 Non-Line of Sight: Intersections

The second scenario evaluates the communication near intersections. The experiment presented consists in two vehicles going at the same speed towards the intersection and starting at the same time.

In order to have a comprehensive view of different types of intersections, the measurements were performed on three distinct sites: Intersection 1 (I1) with a building at approximately 12 meters apart from the center of the road; Intersection 2 (I2) - the worst case - with a wall 3 meters high near the intersection placed about 4 meters from the center of the road and no building in front, thus having no such reflection source; Intersection 3 (I3) with a building 24 meters away from one of the legs and 5 meters from the other.

Figure 1(c) presents the RSSI as a function of the sum of the distance of both vehicles to the intersection for the three different intersections. Due to space constraints, we are not able to present the plot of the PDR for this case.

The results show that I1 and I3 have the largest communication ranges of 100m, while I2 - worst case - extends only to 60m. This proves that communication between vehicles is still possible when vehicles are far from the center of the intersection, allowing safety critical applications to operate.

Simulation of these scenarios was also carried out in NS-3 using the knife-edge and Universal Theory of Diffraction models [5]; however, the results obtained were too far from the real-world measurements: these models do not consider reflections on buildings other than those that create the obstruction, which we proved to be a source of improvement of the communication range. City-wide models [3] are not appropriate as they represent the aggregation of several empirical results, and thus are not configurable for a specific type of intersection, whereas ray-tracing models [3] could provide accurate information about propagation in these scenarios, but are very computationally intensive, thus, not suitable for network simulators.

4. CONCLUSIONS

We assessed the performance of the IEEE 802.11p in LOS and NLOS scenarios. Our results indicate that LOS communications can be achieved with more than 1Km range, while NLOS communication is limited to 100m range in the tested scenarios. In NLOS, the communication time is sufficient to enable the cooperation between vehicles for safety-critical applications to operate. Although for LOS communication it was possible to integrate a propagation and channel model in the simulator to closely match the experiment results, the available models for NLOS are not able to gather the behavior of buildings, walls and other obstacles at intersections, which make them unsuitable to be used in simulations of vehicular communications.

As current work, we are implementing the IEEE 802.11p MAC layer (WAVE) and experimentally testing different scenarios in urban and highway environments.

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