CORNER: a Realistic Urban Propagation Model for VANET

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***Abstract*—Recent advances in portable technologies suggest that ad hoc networks will finally move out from the research and military harbors to the commercial world. In particular, vehicular safety and entertainment applications are mature for the market. Several major manufacturer are considering vehicular communications as an opportunity to increase the profitability and marketability of their vehicles. In this phase, simulations are essential to evaluate the performance of protocols and applications large urban Ad Hoc and Vehicular networks. This paper tackles on the long overdue issue of an high fidelity propagation model for urban ad hoc networks. In particular, we propose CORNER a low computational cost yet accurate urban propagation prediction technique for ad hoc networks in urban scenarios. We also provide validation of the model through a side-to-side comparison of real experiments and simulations.**

***Index Terms*—Vehicular Networks, Propagation, IEEE 802.11**

I. INTRODUCTION

Urban ad hoc networks have been long studied by DARPA projects focusing on warfare and emergency scenarios such Katrina and the twin towers attack. More recently the popularity of GPS devices equipped with Wi-Fi and smart phones raised the interest in civil applications such as vehicular communications and mobile social networks.

We envision Vehicular Ad Hoc Networks (VANETs) as the first concrete case for urban ad hoc networks. In particular, we believe that WiFi enabled smart devices will provide a first platform for a field deployment of vehicular applications and protocols. Eventually, in the near future, OEM based WiFi deployments will leave the stage for a new generation of cars equipped with Dynamic Short Range Communication (DSRC) compliant with the upcoming *IEEE802.11p* standard.

In city scenarios, characterized by highly dense hotspots [1] [2], it is crucial to study scalability and performance of applications and protocols. However, the prohibitive cost of real testbeds with hundreds of vehicles forces researchers and developers to a massive use of simulation tools augmented with limited actual experiments. Simulations' fidelity is particularly important to ensure that the results are suitable for the design process. In particular, propagation and mobility are key in determining the performance of mobile networks in a city scenario; however, at the best of our knowledge, there is very limited availability of computationally efficient propagation models in today's network simulation tools. In this paper we present the CORNER urban propagation model. CORNER can be easily used in any network simulator and, in this work, we introduce a highly efficient implementation for QualNet[1] [3]. CORNER implements the propagation attenuation formulae presented in [4]. The formulae require the knowledge of the position of nodes relative to the underlying road network in order to classify the attenuation scenario in which the considered pair of nodes are in. Possible situations are: Line of Sight (LOS); Non-Line of Sight with one corner separating the two nodes (NLOS1) and Non-Line of Sight with two corners between the two nodes (NLOS2) (see figure 2). CORNER provides this classification and the geometric computations and information needed to apply the formulae. The resulting attenuation is then used by the Qualnet physical layer statistical model which determines the channel properties.

II. IMPLEMENTATION DESCRIPTION

Differently from the classical battlefield and warfare scenarios urban scenarios are characterized by buildings that constitute an obstruction to the free space radio waves propagation. In order to perform high-fidelity simulations, with a more realistic propagation, buildings simply cant' be ignored. In principle, it would be possible to compute the path loss very accurately using Ray Tracing or similar techniques [5]. However, these techniques require a very detailed information about the environment to simulate, such as a tridimensional description of the environment or the reflection index of all the surfaces in the environment [6]. Gathering information on buildings material, shape, and reflection index is a difficult task that requires a the allocation of specific resources for each building. For instance the blueprints of the buildings need to be inspected and the reflection index of each construction material needs to be experimentally studied or otherwise assessed. Thus resulting in almost impossible task especially for large urban areas. Furthermore these techniques have a very high computational cost often resulting in several months of CPU cycles. Therefore, due to resource and time constraints most of the current literature based on simulation studies assumed a *flat*

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[1] For a simulator-independent implementation of CORNER please check the page: http://cvet.cs.ucla.edu/vergilius.html. The tool produces in output a general attenuation matrix that can be plugged, virtually with no effort, in any simulator.

propagation model (e.g. the ”Two Ray” model) that does not consider the existence of buildings or other elements present in the underlying urban enviroment.

CORNER implements a light weight propagation model that only needs information about the road topology providing a good trade off between computational complexity and verisimilitude of the simulation. CORNER implements the propagation model presented in [4], that provides the Path Loss (PL) as a function of the relative position of two nodes for urban scenarios. For each couple of vehicles the model takes into account three possible cases: Line Of Sight (LOS), Non Line Of Sight with one corner along the path (NLOS1) and Non Line Of Sight with two corners along the path (NLOS2). In order to distinguish among these three possible cases we assign each road segment a width, computed as:

$$Width = (NoL * LW) + 10 \tag{1}$$

Where NoL is the number of lanes and the units are expressed in meters (N.B. the number of lanes is double if the segment is part of a two way road). LW represents the lane width, that we assume constant. In addition we consider the roads 10 meters larger to take into account the sidewalk. We then classify each node pair as follows:

a) LOS: Two vehicles are considered in line of sight if they are traveling on the same road segment. They are also considered in line of sight if they are traveling on two road segments connected by a crossroad and one of them is in the sight window of the other. The sight window of a vehicle is the portion of plain the the vehicle can see from the opening offered by the crossroad. A graphical representation of the sight window is shown in Figure 1. In addition, two vehicles could be in line of sight if they are traveling on two road segments separated by two crossroads. In this case one of the considered vehicles has two different sight windows, one per each crossroad. Let us define the two sight windows as SW_A and SW_B generated respectively by the closest and farthest crossroads. If the other vehicle is traveling inside SW_B and SW_B is fully contained into SW_A then the two vehicles are in line of sight. A graphical explanation for the latter situation is shown in Figure 2.

b) NLOS1: Two vehicles are considered in NLOS1 if they are traveling on two adjacent road segments and they are not in the sight window of each other, as shown in Figure 1. Two vehicles are also considered in NLOS1 if they are traveling on two road segments that are separated by two crossroads and one of the vehicles is in LOS with the farthest crossroad, as shown in Figure 2.

c) NLOS2: Two vehicles are considered in NLOS2 if they are traveling on two road segments separated by two crossroads and are nor in LOS or NLOS1, as shown in Figure 2.

To perform the above classification we need to determine on which road each vehicle is traveling. This requires the knowledge of the underlying road topology, that consists of a set of intersections and road segments. Each vehicle is then assumed to be traveling on the road segment to which it is closest. This assumption introduces some errors especially when vehicles are exactly at the intersection. In fact in this case the vehicle is at distance 0 from all the road segments connected to the intersection making the assignment an arbitrary choice. This arbitrary choice affects the creation of the sight window. For this reason the classification of each couple of vehicles (A, B) is performed twice, first from A to B and then from B to A, and the best case is chosen.

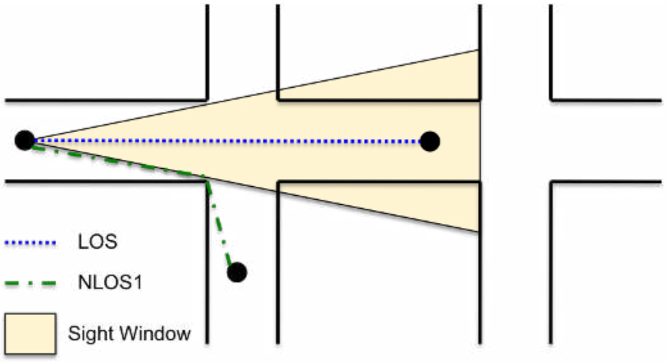

Fig. 1. Propagation: Graphical Example for vehicles traveling on adjacent road segments

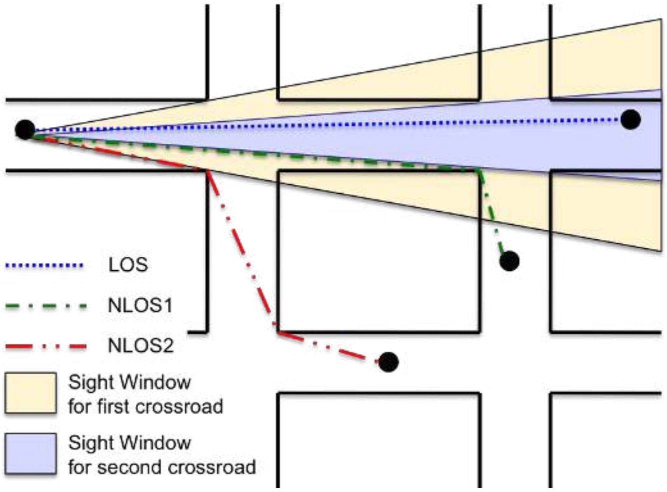

Fig. 2. Propagation: Graphical Example for vehicles traveling on road segments separated by 2 crossroads

III. Model Validation

In this section we provide the results of our validation experiments. These experiments were carried out using two cars equipped with a laptop with linux OS, a GPS receiver and a IEEE802.11b/g wireless card. The wireless card uses an Atheros chipset allowing the use of the open source driver MadWiFi [7]. To better understand the characteristics of connectivity we performed all the tests placing our application directly on top of the MAC layer. This is possible in Linux using the Ethernet raw sockets package. In other words our application sends and receives packets directly to and from the wireless card buffer, avoiding the use of IP and higher layer protocols that can be cause of connection delays. We performed two sets of experiments: one to assess the connectivity around corners, involving fixed and mobile nodes; a second set to assess the link quality around corners using fixed locations. We performed all of our experiments in a Los Angeles residential area[2]. We then reproduced the same scenarios using the QualNet [3] network simulator and compared the obtained results with the ones obtained in reality. It is important to point out that the real experiments are affected by environmental interference that can not be easily reproduced in simulation. In fact, we were able to detect 227 distinct Access Points (APs) in the area. Figure 3 shows the channel occupancy of all the detected APs. It is evident that not only the orthogonal channels 1, 6 and 11 are used. Our experiments were performed using the automatic channel detection. With this setting the wireless card scans all the band and chooses the least interfered channel to operate on. Although this setting guarantees the lowest possible level of interference, the high number of surrounding APs will affect heavily the packet reception, especially in the case of broadcast for which retransmissions are not allowed. In addition the use of non-orthogonal channels seriously affects the carrier sensing procedure. In order to reproduce this kind of interference, we would need information that is not possible to gather, such as the location of access points and the kind of data traffic that is running on them.

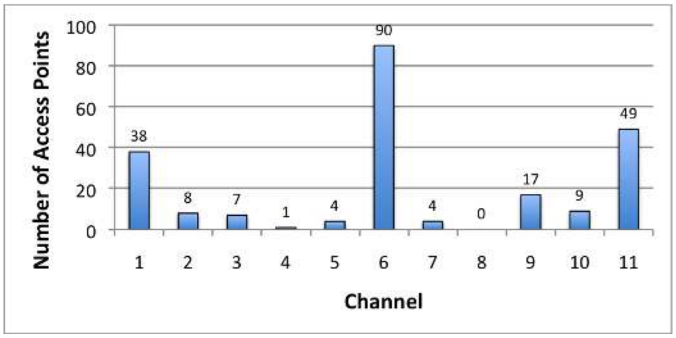

Fig. 3. Environmental Interference: Channel occupancy of APs in the area

A. Connectivity Experiments

To assess the connectivity around corners we performed both fixed-to-mobile and mobile-to-mobile experiments. In both setups the nodes are periodically broadcasting a packet containing their geographic coordinates and the GPS timestamp. The frequency of transmission has been set to 10 packets per second.

Fixed to Mobile: we performed two different tests with one car revolving around a block and the other fixed, first in the middle of the block and then placed at an intersection. In both experiments the fixed car periodically send out broadcast packets. The mobile car then saves the geographic coordinates where it received each packet. Figure 4 shows, plotted on Google Earth [8], the set of locations where packets were received both for the real test (green dots) and in simulation (yellow dots). It is evident that the simulated connectivity is very similar to the real one. In addition we can see that in simulation the number of received packets is much higher. This is a consequence of the surrounding environmental interference as discussed previously.

Fig. 4. Fixed to Mobile experiment, comparison between reality and simulation.

Fig. 5. Fixed to Mobile experiment, comparison between reality and simulation.

Mobile to Mobile: To further validate the propagation model we also ran a Mobile-to-Mobile experiment. The two involved cars were revolving around the block in opposite directions. One of the cars would store the position it received the packet at, together with the position of the other car included inside the packet. Figure 6 shows each single received packet as a red line joining the receiving and sending positions represented with blue squares. The comparison of the real experiment and the simulation is shows in Figure 6(a) and 6(b). We can observe that the model well represents the reality avoiding the transmission of packets that traverse the block.

B. Link Quality

To asses how the presence of a building affects the link quality, we performed an experiment involving propagation around a corner. We fixed a sender node at the beginning of

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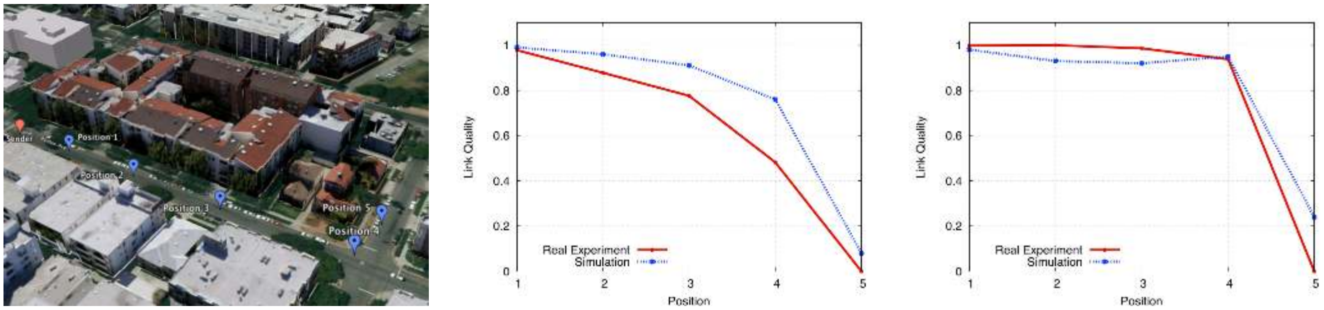
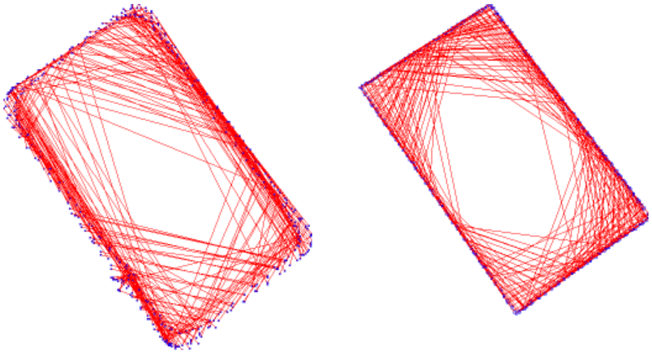
[2] LAT: 34.053397N LON: 118.442660W



(a) Experiment Setup (b) Broadcast Experiment (c) Unicast Experiment

Fig. 7. Link Quality evaluation experiment: comparison between real experiment and simulation for both broadcast and unicast packets.



(a) Real Experiment (b) Simulation

Fig. 6. Mobile to Mobile experiment: connectivity comparison between real experiment and simulation

a block and we moved the receiver in five different positions, first in line of sight and then around a corner. We sent 500 packets both in unicast and broadcast and we defined the Link Quality as the number of packet received divided by the number of packets sent. Figure 7(a) shows the experimental setup. In Figure 7(b) we present the Link Quality of the broadcast transmissions at different locations for both the real experiment and the simulation. As expected the Link Quality in reality is much lower due to the presence of environmental interference as discussed previously. Figure 7(c) shows the comparison between reality and simulation for the Link Quality of the unicast transmissions. Acknowledgement and retransmissions make unicast transmissions more robust to the environmental interference and in fact, we observe that the Link Quality in simulation is very similar to the real one.

IV. CONCLUSION

We presented CORNER: a low computational cost yet accurate propagation model. CORNER provides the propagation attenuation between node pairs taking into account the presence of buildings. CORNER takes advantage of the underlying road network to classify the relative positions of node pairs (LOS, NLOS1, NLOS2). In addition we presented an experimental validation of the model for both connectivity and link quality. Results show that CORNER well reproduces the connectivity that is achievable in reality. CORNER represents a good step towards more reliable and efficient simulation studies. Therefore we strongly encourage the use of CORNER instead of the obsolete and unrealistic *flat* propagation schemes used in the past.

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