Two Ray or not Two Ray this is the price to pay

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Abstract

Simulation is essential to evaluate the performance of large scale vehicular networks. It is logistically challenging (and prohibitively expensive) to run tests with more than a few dozens experimental vehicles. Given the critical role of simulation in the evaluation of VANET protocols in large scale scenarios, it is important to guarantee realism of the models. This paper focuses on the accuracy of urban propagation models and their impact on vehicular protocol results. In a city-based vehicular network we compare the predominant **Two Ray** model and a recently proposed **Corner** model. We identify a number of factors that undermine the validity of the Two Ray model, for example, the presence of buildings causing propagation disruption and the heavy weight border effects that **incorrectly** compensate for the presence of hidden terminals in the networks. The paper analyzes a small scale urban vehicular scenario which unveils the issues to be considered in large scale vehicular simulations.

***Index Terms*— Propagation, Vehicular Networks, IEEE802.11, Simulation**

I. Introduction

Vehicular ad-hoc networks are on the fast track to become a reality either by virtue of communication devices installed by car manufacturers, or by the proliferation of on board third party Wi-Fi enabled devices such as Navigation devices, PDAs, or in dash embedded computers [1]. Vehicles will be part of a network of devices aimed at providing new services and applications ranging from road safety to networked entertainment. This view is supported by market studies showing that in western Europe already one fourth of the drivers has a portable navigation device and almost 40% of European population owns a Wi-Fi enabled PDA [2], [3]. Similar trends are shared by the US market, though at slower pace. The growing interest shown by regulators, and the increasing amount of public/private research are resulting in a brand new set of applications, protocols and algorithms such as the new global vehicular standard, IEEE 802.11p, that will integrate and extend the current across-the-atlantic effort to define the future Internet [4], [5].

This paper explores the impact of propagation models in VANET's simulative studies. We focus our attention on propagation models as vehicular application and protocols will need to cope with highly dynamic channel conditions due to mobility, changes in elevation, and obstructions. In urban scenarios, for instance, it is key to account for the impact of buildings and in general of the city landscape. Figure 1 shows the delivery ratio achieved by a static vehicular ad-hoc network in small area of Los Angeles for different propagation models namely: the universally used **Two Ray** [6] model and a more recent, more accurate **Corner** [7] model for varying network loads. In particular, the chart shows the delivery ratio for an increasing number of Constant Bit Rate (CBR) flows between randomly chosen pairs of vehicles in a 59 node network. While the **Two Ray** model considers the simulation field as a ***flat*** landscape the **Corner** model takes into account the ***presence of buildings*** and estimates the signal attenuation by computing the power decay at each corner traversed by the signal. Surprisingly, this approach is computationally lightweight and ensures a high level of fidelity. It does not achieve the same realism as ray tracing propagation models such as the UDEL propagation model described in [8], [9] which in contrast requires a large amount of information (i.e. building materials), extensive computational

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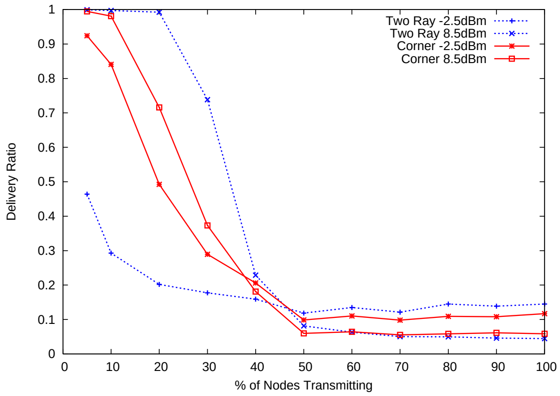

Fig. 1. Delivery Ratio as a function of increasing network load for Two Ray (dotted curves) and Corner (solid curves) propagation models

power (i.e. cloud computing), and massive storage (for the attenuation matrix). The study has been performed with different transmission powers to fully explore the design space. It is worth noting that the presence of buildings and obstructions in our experiments exposes the weaknesses of the simple Two Ray model (dotted curves on chart). At times, Two Ray is too optimistic and at times too conservative when compared to the more accurate Corner model (solid curves on chart).

In the sequel we explore design space parameters through an in depth analysis and comparison of the two propagation models using two criteria: Connectivity and Interference. We also provide details on the analysis and report interesting insights such as the role of transmit power in triggering heavy ***border effects*** on the simulation maps. Finally, we draw conclusions and chart directions for future research.

II. Practical Setup

In this section we provide details on how the reference scenario has been created. The practical setup involves two steps. First we create a realistic traffic scenario using an existing road network. This was done by using the VERGILIUS toolbox [10] and extracting a road topology from the Tiger Database [11]. The obtained cutout, a 300x300m map of the Los Angeles metropolitan area[1], was used as the underlay on which a mobility trace is created by the CORSIM traffic simulator [12]. The traffic scenario consists of 59 vehicles randomly distributed over the given road map. In our analysis we only need to consider a snapshot of the traffic (radio signals travel infinitely faster than cars). Thus, the positions of the cars are fixed. This simplifies the comparison of different propagation models. Figure 2(a) shows the snapshot used in the analysis. The second step of the experiment setup is the configuration of the simulation environment. We use version 4.5 of the QualNet Network Simulator [13]. All the simulations are based on IEEE 802.11b [14] with fixed data rate of 2 Mbps. In order to simulate the previously described traffic scenario, we use again the VERGILIUS toolbox to convert the CORSIM output into a valid QualNet input. In addition to the car position file, VERGILUS generates the pathloss matrix using the *Corner* propagation model. Next, we evaluate the drawbacks of the *flat* propagation model via analysis, using the tools provided by the VERGILIUS framework, and via simulation. The geometric analysis consists of computations performed on the snapshot only. Simulation instead takes into account also the behavior of both MAC and PHY layers of IEEE802.11. We would expect different results from analytic and simulation approaches. Instead, as we shall see in the following, the geometric analysis turns out to be a powerful (and lightweight) predictor of topology and performance properties of given mobility traces, before running the actual simulations. To reproduce the behavior of a $flat$ propagation model, like Two Ray, we consider two nodes as neighbors if the distance between them is less than a certain range. We then consider the *Corner* model. In this case, however, two nodes are considered neighbors if the signal attenuation between them is below a given threshold. In order to be consistent with the simulation results, we calibrated range and transmitted power with a simple two-node benchmark in QualNet that uses the Two Ray model. We set the transmitted power to the sum of the Receiver Sensitivity and the attenuation threshold, we then start moving one of the nodes, and we take as range the farthest distance at which the mobile node receives at least 80% of the packets transmitted by the steady node. Table I reports the correspondence between ranges and transmitted powers. It also shows the node degree (ND) and the average number of hops (AH) for increasing range and relative transmitted power obtained through the geometric analysis. As expected we observe an increasing ND and a decreasing AH for both *flat* propagation and *Corner*. It is important to note the unrealistic growth of ND and consequent drop of AH, in the case of *flat* propagation. In fact, as shown in Figure 2(b) and 2(c), with power = 1.6 dBm, i.e. transmission range = 150m (for the Two Ray model) , the network is almost fully connected. This is totally unrealistic since most links completely traverse road blocks, penetrating walls and corners!

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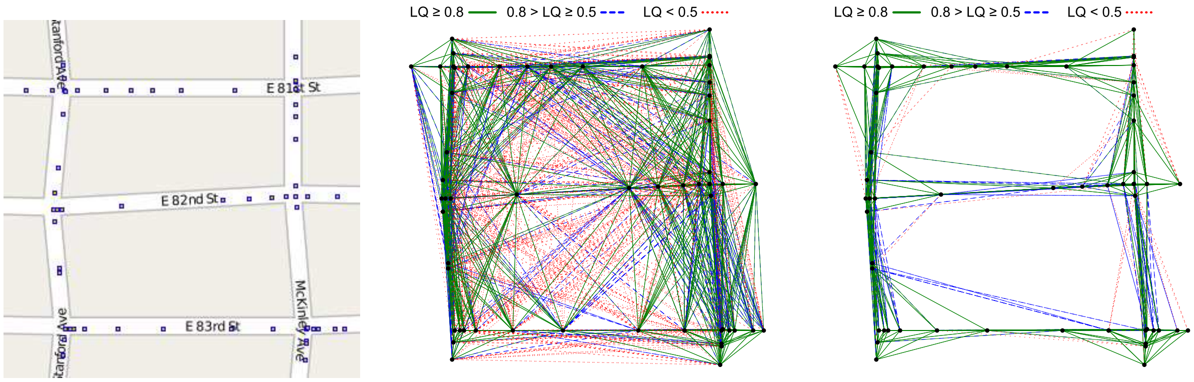
[1] LAT: 34.0683N; LON: 118.3622W



(a) Road Network - 300x300m (b) Connectivity Graph: Two Ray 1.6dBm (c) Connectivity Graph: Corner 1.6dBm

Fig. 2. Urban scenario used in simulations

III. Result and Analysis

In this section we evaluate the drawbacks of using a *flat* propagation model performing both a geometric analysis, using the tools provided with the VERGILIUS framework, and a set of simulations. The geometric analysis consists of a set of computations performed on the mobility snapshot. Simulations instead take also into account the behavior of both MAC and PHY of IEEE802.11. Therefore we would expect different results, but, as we shall see in the following, this is not the case. Indeed the geometric analysis turns out to be a powerful and lightweight tool that could be used to assess topological properties of given mobility traces, before running the actual simulations.

To resemble the behavior of a $flat$ propagation model, like Two Ray, we consider two nodes as neighbors if the distance between them is less than a certain range. As comparison we perform the same computations using the *Corner* model. In this case two nodes are considered neighbors if the signal attenuation between them is below a certain threshold. In order to be consistent with the simulation results, we matched range and transmitted power using a simple two-node simulation in QualNet that uses the Two Ray model. We set the transmitted power to the sum of the Receiver Sensitivity and the attenuation threshold, we then start moving one of the nodes, and we take as range the farthest distance at which it is capable of receiving at least 80% of the packets transmitted by the steady node. Table I reports the correspondence between ranges and transmitted powers.

A. Connectivity

We take into consideration some of the metrics introduced with the VERGILIUS framework [10] such as Node Degree (ND) and the Average Hop Count (AH). In Table I are shown the node degree and the average number of hops for increasing range and relative transmitted power obtained through the geometric analysis. As expected we observe an increasing ND and a decreasing AH for both *flat* propagation and *Corner*. It is important to note the unrealistic growth of ND and a consequent drop of AH, in the case of *flat* propagation. In fact, as shown in Figure 2(b) and 2(c), in the case of power 1.6 dBm, that for Two Ray corresponds to a transmission range of 150m, the network is almost fully connected. This is really unrealistic as most of the links completely traverse road blocks, which is very unlikely to happen in reality.

TABLE I. Node Degree and Average Hops

Range			Corner		
Range [m]	ND	AH	P_T [dBm]	ND	AH
80	10.59	2.78	-3.8	10.17	4.52
105	11.83	2.55	-1.6	14.44	2.48
120	12.29	2.50	-0.6	18.54	2.07
130	12.90	2.42	0.2	21.08	1.88
140	13.34	2.38	1	23.02	1.74
150	13.51	2.37	1.6	24.41	1.66
160	13.56	2.37	2.2	26.00	1.61
175	13.66	2.35	2.9	28.00	1.53
190	13.76	2.34	3.4	31.19	1.46
200	14.24	2.26	3.9	34.10	1.41
210	14.44	2.24	4.4	39.97	1.31
225	14.63	2.22	4.9	45.42	1.22
230	14.90	2.21	5.4	45.42	1.22
235	15.15	2.20	5.8	48.44	1.16
240	15.42	2.17	6.2	49.86	1.14
250	15.61	2.16	6.9	51.59	1.11
255	15.80	2.15	7.4	52.47	1.10

To further investigate the impact of a $flat$ propagation we also performed an analysis on link quality. In order to quantify the link quality, we used a variation of the *Expected Transmissions Count* (ETX) [15] as suggested in [16]. The basic idea behind this concept is that each node broadcasts a probe packet every second for specified

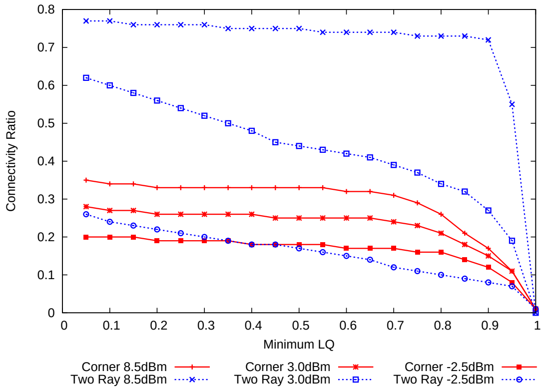


Fig. 3. Connectivity Ratio as a function of the minimum Link Quality requirement for different power levels

period of time t. Using the number of received probes n, neighboring nodes can evaluate the quality of the link between them and each prober by calculating n/t. The obtained link quality LQ is then contained in the interval $]0, 1]$, with 1 being a lossless link. Figure 2(b) and 2(c) illustrate the connectivity graph for three different LQ intervals for the case of Two Ray and Corner respectively.

Figure 3 shows the connectivity ratio ($CR(minLQ)$) as a function of increasing link quality requirements using Corner propagation model and Two Ray model respectively. We define the connectivity ratio as the number of links that fulfill a minimum link quality requirement divided by the total number of possible links:

$$CR(minLQ) = \frac{\#\, of\, links\, with\, LQ > minLQ}{N/N-1}$$

where N is the total number of nodes in the scenario. Each curve depicts a simulation when a particular transmission power is used. Obviously, for any given transmission power, we see that the connectivity ratio decreases with an increasing demand for link quality for both the Corner and two-ray propagation model. Also, for both models, connectivity ratio increases when higher transmission power cases are simulated. As Two Ray doesn't take into account environment obstructions such as building, the overall CR as opposed to Corner is much higher for every simulated power level. We can also observe that with increasing power level the connectivity ratio changes significantly for Two Ray but remains similar for Corner. This phenomenon is due to the position of the vehicles. As in our scenario all the cars are located on the roads, the network topology using Corner, as represented in Figure 2(c), matches the road network for every power level. Instead for Two Ray, a high power level allows connections from one block to another as represented in Figure 2(b). Reducing the power will automatically result in a much lower connectivity ratio, as the distance between two blocks is larger than the radio range. Finally, we observe that for high LQ requirements the connectivity ratio massively drops for the Two Ray propagation model. This is especially true for the high power scenarios. For such transmission powers, very good links are hard to achieve due to interference. As for the Corner model, the connectivity ratio is much lower for every simulated power level, the resulting interference will be lower which explains the smoother decrease of the connectivity ratio.

As a conclusion we can state that using Two Ray as propagation model for vehicular scenarios is not a realistic approach. Changing the transmission power using a *flat* propagation model will result in misleading conclusions.

B. The Hidden Terminal Problem

In this section we investigate the impact that the propagation model has on network topology focusing on the Hidden Terminal Problem. We initially perform a geometrical analysis of the mobility snapshot. For this purpose we introduce a new metric: the number of potential Hidden Nodes Situations (HN). We compute this metric by analyzing the connectivity graph. More precisely we account for a potential Hidden Node Situation when one of the neighbors of a node is not in the neighborhood of at least one of the other neighbors. In the case of a *flat* propagation model the same node placement will always lead to the same result. This is not true for propagation models that take into account obstacles.

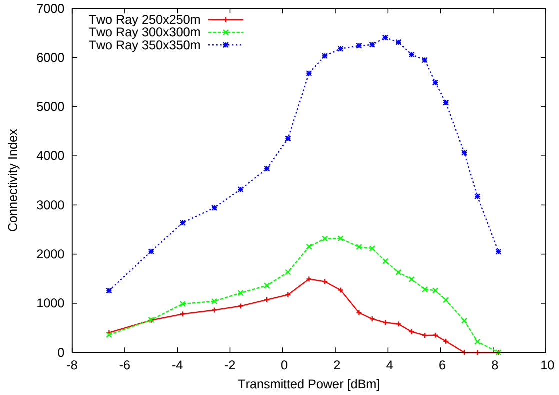


Fig. 4. Number of potential Hidden Node Situations for increasing range using scenario with different sizes for Two Ray.

Figure 4 shows HN computed with the geometric approach for increasing transmitted power in the case of a *flat* propagation. Each curve refers to a different scenario, with increasing size of the map (250x250m, 300x300m, 350x350m). The scenarios were generated using the same approach described in section II, keeping constant the node density. We can observe that for all three scenarios HN follows the same trend: an initial increase and a following descent. This trend is easily explainable; as the range increases so does the average neighborhood of each node. Consequently the number of neighbors of a node that are not in each other neighborhood also increases creating new potential Hidden Node situations. However this phenomenon stops at the point upon which the range is wide enough to cover almost the whole network causing a descent of the number of Hidden Node situations. This could be seen as a *border effect* due to the size of the map. It is interesting to note that the peak is different for each scenario. As shown in Table II, the ratio between the Range corresponding to peak and the side of the map is approximately constant. This result suggests a dependency of the network performance on the aforementioned ratio. In order to prove such dependency we then performed a set of network simulations on the three different scenarios using a setup similar to the one described in section II. In particular for this simulation set we have each node periodically broadcast a single packet. To better extract information on this matter we set the transmissions to be globally synchronized. Then in the case of a Hidden Node situation, since the 802.11 CSMA will fail, the packets will collide.

TABLE II. Relationship between the peak value of HN and size of the map.

Map Side	P_T [dBm]	Range	Ratio
250	1	140	0.56
300	2.9	175	0.58
350	3.9	200	0.57

Figure 5 shows the trend of receiving errors, i.e. collisions, with increasing transmission power using the Two Ray propagation model. Each curve represents simulations performed on the same scenarios used for the geometrical analysis. We can observe that the trend is the same as the geometrical analysis. Moreover the position of the peaks exactly matches the peaks obtained with the geometrical analysis, validating our previous hypothesis.

We finally performed the same geometrical analysis and simulation using the *Corner* model. In Figure 7 we show HN for increasing attenuation thresholds for the three different scenarios. For all scenarios we observe that HN follows an increasing trend. To explain this let us consider the scenario depicted in Figure 6. With low transmission power, the three nodes are too far away to be able to hear each other (Figure 6(a)). However with increasing transmission power since they are in Line of Sight node B eventually will hear node A and so will node C (Figure 6(b)). However node B and node C cannot hear each other as they are not in Line of Sight. This kind of situation becomes more and more likely as the transmitted power increases, justifying the growing trend of HN.

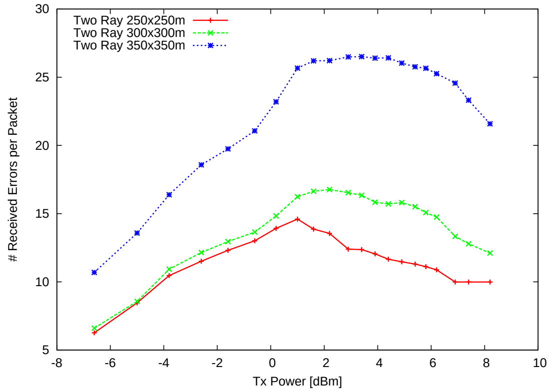
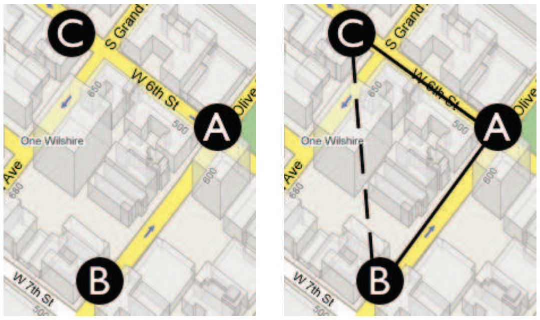


Fig. 5. Number of receiving errors per packet transmitted as a function of increasing transmitted power for different map sizes using Two Ray.



(a) (b)

Fig. 6. Practical example of a Hidden Terminal situation for Corner.

In Figure 8, we show the trend of receiving errors, i.e. collisions, with increasing transmission power using Corner propagation model. Each curve represents simulations performed on a particular sized map. For any simulation we observe that the number of received errors increases with increasing transmission power matching the results obtained with the geometrical analysis. Finally we can affirm that Two Ray not only introduces a higher level of interference, but also is affected by a *border effect* related to the size of the map considered.

IV. Conclusion

In this paper, we showed that using a *flat* propagation model such as Two Ray to perform vehicular network

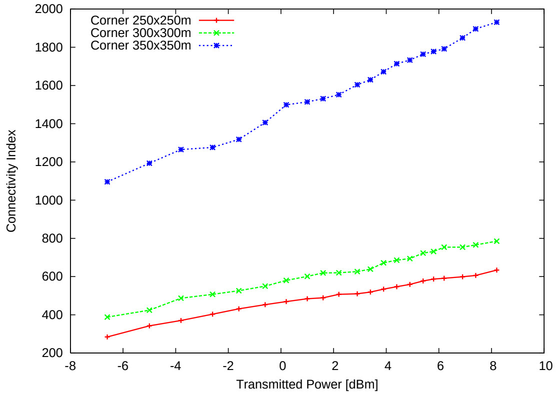


Fig. 7. Number of potential Hidden Node Situations for increasing attenuation threshold using scenario with different map sizes using Corner.

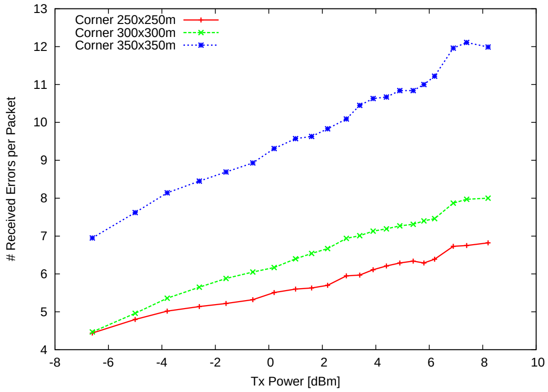


Fig. 8. Number of receiving errors per packet transmitted as a function of increasing transmitted power for different map sizes using Corner.

simulations in urban environment does not reflect reality. The propagation limitations imposed by surrounding building considerably reduces the connectivity between cars on adjacent and parallel roads. This important property is not taken into account by the Two Ray propagation model. As a result, the obtained performance metrics are often not valid in urban scenarios and vary a lot for different power levels. Another major drawback is that due to the increased connectivity, the overall interference is much higher than it would be in reality. In a simulation environment, this phenomenon causes a *border effect*, which results in incorrect interference levels.

As already shown in [7], the Corner propagation model reflects reality. The results obtained during our simulations confirmed this assertion. Since the overall performance metrics obtained using Two Ray will be strongly affected by the presented imperfections, we encourage the use of a propagation model that takes into account physical obstruction, as the resulting simulations will be much closer to reality.

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