Studying the impact of the corner propagation model on VANET routing in urban environments

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Abstract

Accurate modelling of the radio channel is often the most difficult aspect of a Vehicular Ad Hoc Network (VANET) simulation due to the large variability present in vehicular terrain. CORNER is a propagation model that calculates path-loss in an urban terrain with a large concentration of buildings, based on the position of the transmitter and receiver on a street map. This paper proposes additions to the CORNER propagation model to take selective multi-path fading into account and investigates the performance of the GPSR routing protocol under the CORNER propagation model in a realistic city environment.

Keywords

impact, environments, routing, vanet, model, propagation, studying, corner, urban

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Studying the Impact of the CORNER Propagation Model on VANET Routing in Urban Environments

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***Abstract*—Accurate modelling of the radio channel is often the most difficult aspect of a Vehicular Ad Hoc Network (VANET) simulation due to the large variability present in vehicular terrain. CORNER is a propagation model that calculates path-loss in an urban terrain with a large concentration of buildings, based on the position of the transmitter and receiver on a street map. This paper proposes additions to the CORNER propagation model to take selective multi-path fading into account and investigates the performance of the GPSR routing protocol under the CORNER propagation model in a realistic city environment.**

I. Introduction

Accurate simulation of the physical layer of VANETs is a challenging problem due to the extraordinarily large variation in terrain across different vehicular environments. For example, an urban central business district (CBD) exhibits very different radio channel characteristics to a sparse country town or a highway.

The urban environment is often the most challenging to simulate due to the presence of dense narrow streets and multiple obstructions. There exist very few models which accurately simulate path-loss in such cases. Ray-tracing is the most accurate means of simulating deterministic path-loss in an urban environment; however, it is also very computationally intensive and requires extensive information on the exact position of buildings and the materials of which they are composed [1]. There also exist several statistical propagation models such as the Okumura-Hata model [2], which are aimed at modelling propagation of frequencies in the range of 100Mhz to 1.9Ghz through an urban environment. They are also targeted mainly at cellular networks and are thus unsuitable for VANETs.

A recently proposed alternative is the CORNER model, which classifies vehicles based on their positions relative to each other and uses different deterministic path-loss formulae based on whether the vehicles are in direct line of sight, or indirectly visible around one or two corners [3]. While it does provide a computationally simple and reasonably accurate path-loss model, CORNER currently does not consider interactions between multiple reflected signals which are common in an urban environment. To improve its accuracy in situations with a high degree of signal reflection, it would therefore be desirable to selectively incorporate probabilistic fading models such as Rayleigh and Rician fading for the non-line-of-sight (NLOS) and line of sight (LOS) situations respectively.

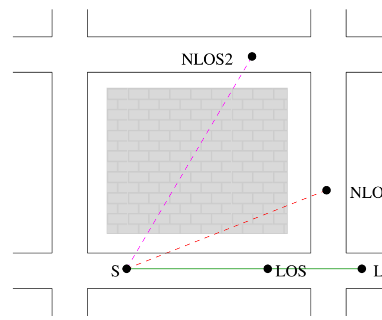

Fig. 1. Path-loss scenarios under CORNER

This suggestion is also noted by the authors of the original CORNER paper in [4].

This paper implements a version of CORNER which selectively applies Rayleigh or Rician fading to the calculated path-loss and analyses the impact of these additions on CORNER. The effects of the Rician K-factor on the packet delivery rates (PDR) are also studied. The greedy perimeter stateless routing (GPSR) protocol is used since it is a simple geographical routing protocol [5]. The impact of node density and data traffic density on PDR is also studied. Section II of this paper analyses the CORNER propagation model. Section III lists the additions made to the model in this paper. Sections IV and V detail the simulation environment and present simulation results comparing the old and new models respectively.

II. An Analysis of the CORNER Propagation Model

The CORNER propagation model is used to simulate the presence of buildings on a city map, such as that shown in Figure 1. CORNER assumes that any closed polygonal regions between adjacent intersections is occupied by a tall building, and it adapts the path-loss formulae presented in [6] to determine the path loss for three different scenarios. The three scenarios, which are illustrated in Figure 1, are:

- Direct line of sight (LOS);
- One corner (NLOS1); and
- Two corners (NLOS2).

The authors of CORNER also validated their model with experimental data gathered from vehicles at different points

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around a single city block. Their experiments measured connectivity between these points, and the experimental results closely matched corresponding simulation results obtained using the CORNER model for this specific scenario.

Path-loss expressions for the following situations are incorporated into the model [6]:

- PL_D: diffraction around a corner;
- PL_R: reflection around a corner;
- PL_{DD}: diffraction around a corner followed by diffraction around another corner;
- PL_{DR}: diffraction around a corner followed by reflection around another corner; and
- PL_{RD}: reflection around a corner followed by diffraction around another corner.

CORNER assumes that if two nodes are in direct line of sight, signal propagation follows a free-space path-loss model, for which the path-loss (in dB) is calculated as

$$PL = 20\log_{10}\left(\frac{\lambda}{4\pi d}\right). \tag{1}$$

If two nodes are *not* in direct line of sight, but are separated by one corner, the path-loss is calculated as

$$PL = 10\log_{10}\left(10^{\frac{PL_D}{10}} + 10^{\frac{PL_R}{10}}\right). \tag{2}$$

Similarly, if two nodes are separated by *two* corners, the path-loss is calculated as

$$PL = 10\log_{10}\left(10^{\frac{PL_{DD}}{10}} + 10^{\frac{PL_{DR}}{10}} + 10^{\frac{PL_{RD}}{10}} + 10^{\frac{PL_R}{10}}\right). \tag{3}$$

III. ADDITIONS TO CORNER

The CORNER model assumes that transmissions between vehicles with a direct line of sight to each other follow a simple free-space path-loss model. However, in a city environment, there are multiple reflections from surrounding buildings and the road which may interfere either constructively or destructively with the dominant signal. Similarly, in the NLOS1 and NLOS2 situations, CORNER assumes the presence of a reflected path and a diffracted path only, without considering the impact of multiple reflections.

It is well documented in the literature that fading in a densely-built city area such as Manhattan can be approximated using a Rayleigh distribution [7]. Therefore, it is proposed to modify CORNER so that signals without direct line of sight, such as those received in the NLOS1 or NLOS2 situations, follow a Rayleigh distribution. When a significant direct line of sight signal is present, such as in the LOS case, a Rician distribution can be used instead. The addition of these selective fading models will significantly improve the accuracy of the CORNER propagation model.

The implementation of Rayleigh and Rician fading in this paper uses an approximation of Clarke's model [8], which is based on samples from a standard normal distribution. Clarke's model for Rayleigh fading [9] is

$$g(t) = \frac{1}{\sqrt{N}}\sum_{n=1}^{N} e^{j(\omega_d t\cos\theta_n + \phi_n)}, \tag{4}$$

where N is the number of reflections, ω_d is the maximum radian Doppler frequency and θ_n and ϕ_n are the angle of arrival and initial phase of the n^{th} propagation path.

This equation can be broken down into its real and imaginary components, $g_c(t)$ and $g_s(t)$ respectively.

The path-loss due to Rayleigh fading in dB is calculated as [10]

$$Rayleigh_{dB} = 10\log_{10}\left(\frac{[g_c(t)]^2 + [g_s(t)]^2}{2}\right). \tag{5}$$

The Rician fading model is obtained by adding a dominant signal to Clarke's model. The ratio of the power of the dominant signal to that of the sum of the reflected signals is represented by the Rician parameter K. The path-loss due to Rician fading in dB is calculated as [9]

$$Rician_{dB} = 10\log_{10}\left(\frac{[g_c(t) + \sqrt{2K}]^2 + [g_s(t)]^2}{2(K+1)}\right). \tag{6}$$

For the purposes of this simulation, it is assumed that N is large, i.e. there are a large number of reflected signals in an urban environment. Thus, from the central limit theorem, both $g_c(t)$ and $g_s(t)$ can be approximated as Gaussian-distributed random variables.

In this paper, Rayleigh fading is applied to NLOS situations and Rician fading is applied to LOS situations in CORNER.

IV. SIMULATION ENVIRONMENT

All the simulations in this paper were performed using the Qualnet network simulator. The vehicular mobility traces are generated using the SUMO traffic generator and subsequently fed into Qualnet. Each set of simulations is run with 20 different seeds and performance measurements are averaged. The focus of the experiments is to measure the impact of the propagation model on routing protocol performance, measured in terms of packet delivery ratio (PDR). All nodes have identical receiver sensitivity (-89.0 dBm), transmission power (15 dBm), omnidirectional antennas (efficiency of 0.8), antenna height (0.6 m) and cable losses (0.5 dB).

A. Road Networks

The road network used for simulations is based on a 1.5 km^2 sub-section of a map of Manhattan, which is highlighted in Figure 2.

B. Street Mobility Model

The street mobility model developed for this simulation is a street-constrained version of the random-waypoint mobility model. Mobility patterns are generated using the SUMO micro-traffic simulator. Each vehicle randomly selects source and destination nodes on the map and calculates a route using the Dijkstra shortest-path algorithm. Once all the vehicles

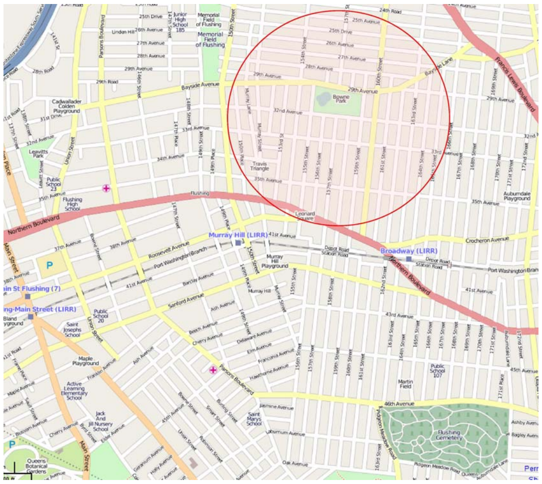
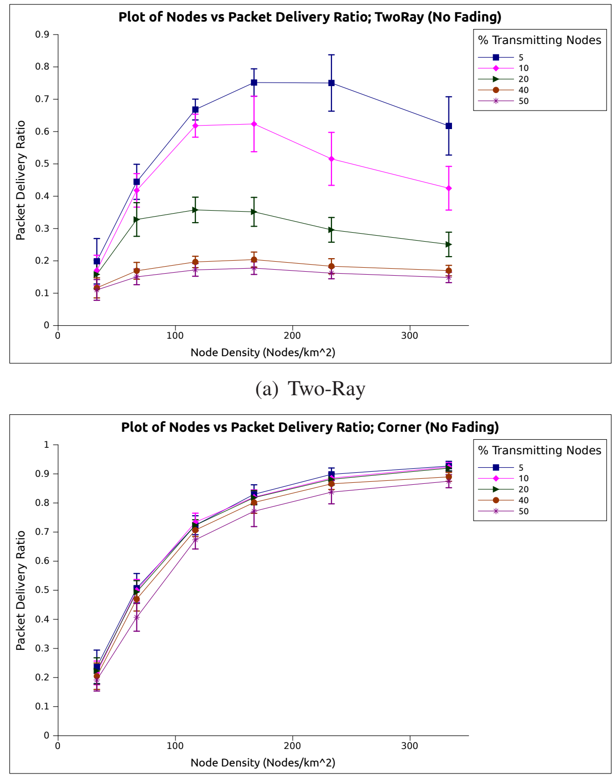


Fig. 2. Area of Manhattan (circled) used for the vehicular mobility simulation

Propagation Frequency	2.4 GHz
Mac Protocol	802.11b
Simulation Time	300 s
Number of Seeds	20
CBR Packet Size	250 bytes
CBR Data Packet Intensity	10, 20, 30, 40 and 50% of nodes
CBR Sending Rate	1 packet/s
Number of Nodes	50, 100, 175, 250, 350, 500
GPSR Beacon Interval	U[250,750] ms
Rician K-Factors for LOS	$-\infty$, 0, 10, 20, 30, 40 dB

TABLE I
SIMULATION PARAMETERS



(a) Two-Ray

(b) CORNER

Fig. 3. Impact of the propagation model on packet delivery ratios

choose a path, the simulation is run in SUMO. Any vehicles that reach their destination before the end of the simulation randomly select a new destination on the map and are rerouted there by SUMO. The resulting mobility traces are then fed into the Qualnet Network Simulator as the node locations.

C. Network Simulator

Version 5.1 of the Qualnet Network Simulator is used for the simulations presented in this paper. The CORNER implementation for Qualnet is based on an updated version of the code published on the CORNER authors' website. This implementation has been modified to selectively apply Rayleigh and Rician fading to the NLOS and LOS situations respectively. The widely-used vehicular routing algorithm GPSR is used as the routing protocol in this paper. GPSR is a stateless geographically greedy routing protocol and it provides a useful base-line for position-based VANET protocols [5].

D. Simulation Parameters

The simulation parameters used for this experiment are shown in Table I. The CBR source density is represented as the percentage of nodes transmitting packets at any given time. The GPSR beacon interval is a uniformly distributed random variable between 250 and 750 ms (in order to prevent beacon synchronisation).

V. RESULTS

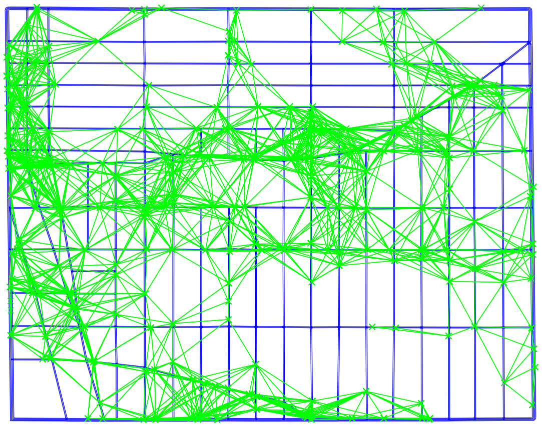
The following conventions are used in this section:

- Data traffic intensity: % of total nodes transmitting CBR packets at any given instant of the simulation
- Node density: Total number of vehicles per square Km in the simulation
- Packet Delivery Ratio (PDR): Ratio of number of CBR packets received to the number of CBR packets sent

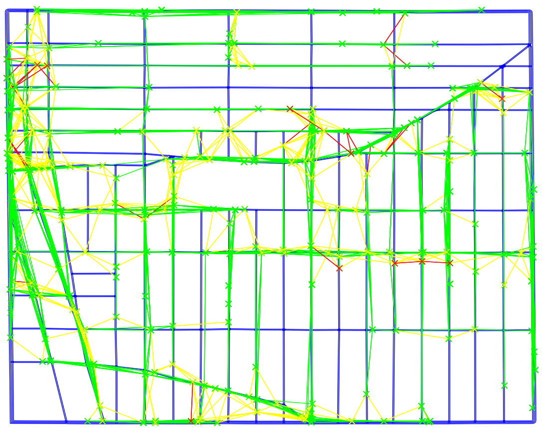
A. Impact of the Propagation Model

At present, the two-ray ground reflection model is the most widely used propagation model for simulation of VANETs. It is thus useful to compare it with CORNER and measure the tangible impact on VANET performance. Figure 3 shows the mean packet delivery ratios (PDRs) obtained with the two-ray and CORNER propagation models with identical sets of vehicular traffic patterns in the Manhattan map area. The differences between two-ray and CORNER become more pronounced as network traffic and vehicular traffic increase.

At low vehicular traffic densities, packets are frequently dropped due to the sparsity of the network. At higher vehicular densities, the likelihood of the network becoming partitioned into disjoint subsets becomes very low due to the high density of nodes. At this point, the data traffic load starts to impact upon the PDR, since a higher network load leads to a higher rate of packet collisions, causing packets to be dropped as a result.



(a) Two-Ray

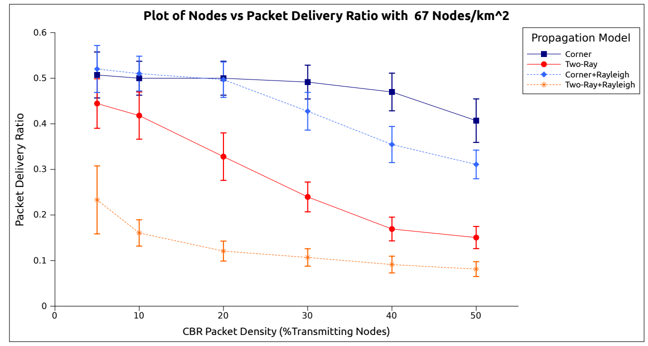


(b) CORNER

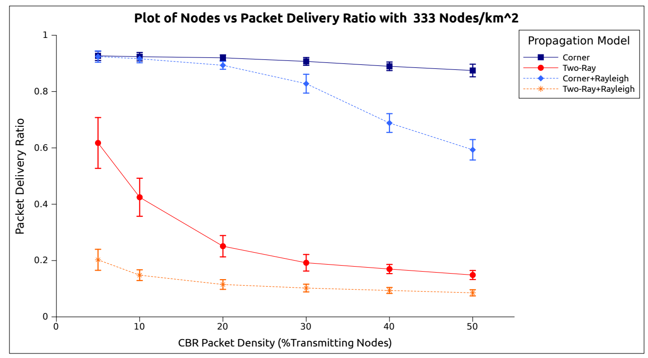
Fig. 4. Inter-node connectivity on the Manhattan map

This behaviour is much more evident with the two-ray model than for CORNER. For two-ray, the PDR remains very low at high data traffic loads at all levels of node spatial density. At lower data traffic loads (i.e. a low proportion of nodes in the network which are actively originating data flows), the PDR increases with load until the data traffic density reaches the point at which packet collisions start to occur. By contrast, when the CORNER model is used, PDR continues to increase with node spatial density since although there are more nodes in the map, their mutual visibility is more strongly restricted by the presence of obstacles (based on the LOS, NLOS1 and NLOS2 situations). Application of the CORNER propagation model results in an almost negligible drop in packet delivery ratio as the data traffic load increases, over a wide range of node spatial densities.

Figure 4 is a snapshot from a 250-node simulation which illustrates all possible connections between nodes at the same instant in time for both CORNER and two-ray propagation models. Figure 4(a) shows that even moderate data traffic load can lead to unrealistic network congestion with the two-ray model, specifically due to the formation of links across several buildings. Figure 4(b) is colour-coded to distinguish between LOS (green), NLOS1 (yellow) and NLOS2 (red) situations.



(a) PDR for 67 nodes/km^2



(b) PDR for 333 nodes/km^2

Fig. 5. Impact of Rayleigh Fading at different data traffic intensities

B. Addition of the Fading Model

The addition of the fading model is the key change to CORNER in this paper. As observed in the previous section, PDRs for GPSR running in a CORNER-based network are not significantly impacted by an increase in network data traffic. Figure 5 illustrates the impact of adding a statistical fading model to CORNER. In this case, the Rician K-Factor for LOS situations is set to $-\infty dB$, resulting in Rayleigh fading in both LOS and NLOS situations.

The impact of Rayleigh fading on the two-ray model is clearly visible at all data traffic intensities for both low and high node densities. Conversely, the CORNER model is not adversely impacted by the addition of fading at lower data traffic intensities. Starting at a data traffic intensity of 30%, the CORNER model exhibits an increasing loss in PDR corresponding to an increase in data traffic intensity. This is likely due to the removal of several NLOS connections due to fading, which leads the routing protocol to re-route packets along the LOS connections, the impact of which is not seen until packet collisions start to occur at higher data packet intensities. This is illustrated in Figure 6, which shows all possible connections between nodes for the CORNER model with fading for the same instant in time as Figure 4(b).

The addition of the fading models also has a varying impact on the performance of the CORNER model. Tests showed as little as a 5% increase in simulation time at low data packet intensities (5-10%) and as much as a 40% increase in simulation time at very high data packet intensities (50%).

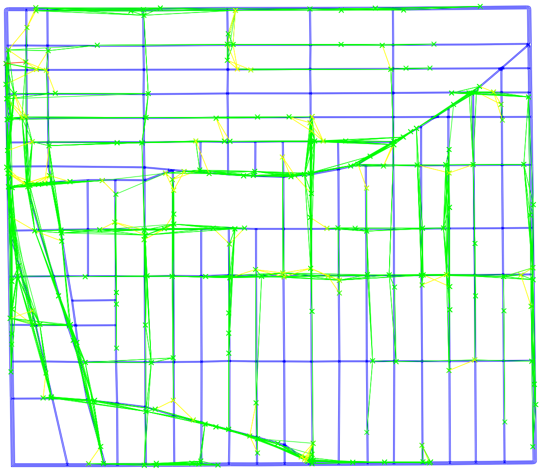


Fig. 6. CORNER connectivity map with Rayleigh fading

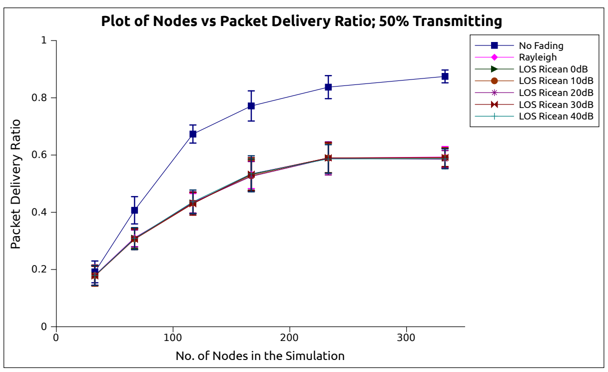


Fig. 7. Impact of the Rician K-Factor on PDR

C. *Rician Fading and the Impact of the K-Factor*

The graph in Figure 7 demonstrates that the Rician K-factor has a negligible influence on PDR in this simulation scenario. With some analysis, it was determined that the result is due to an issue in the CORNER classifier which lists any nodes greater than 2 intersections apart as disconnected. To illustrate this in further detail, the maximum propagation distance in the LOS situation must be determined.

The free-space path-loss equation is [10]:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L} \tag{7}$$

where, $\lambda = 0.125$, $G_t = G_r = 1$, $P_t = 15\ dBm = 31.623\ mW$ and $L = 3.82$. L is determined using Qualnet's radio_range function. The minimum signal which can be received by a node in the simulation is $-89\ dBm = 1.2589 \times 10^{-9}\ mW$.

Substituting in the aforementioned values into equation 7 results in a value of $d = 806.63\ m$, which represents the maximum communication distance between nodes in an LOS situation. On the simulated Manhattan map seen in Figure 2, the average distance at which CORNER determines 2 LOS nodes to be out of communications range is 260 m. Due to this limited communications range, the received signal at that distance is not significantly impacted by a small-scale fading model such as Rician fading.

VI. Conclusions and Future Work

This paper presented the addition of a fading model to CORNER and measured its impact on the performance of a well-known routing protocol in a realistic city environment. Rayleigh fading was applied in NLOS situations and Rician fading in LOS situations. The simulation results show a significant reduction in packet delivery ratios due to fading, which becomes more pronounced as the data traffic intensity increases. Furthermore, the impact of the Rician K-factor on PDR and GPSR average end-to-end hop count has been evaluated and shown to be negligible in this scenario, mainly due to an issue identified in the CORNER classifier.

Future work includes an improved situation profiler to identify LOS situations for nodes which are further than two intersections apart. The impact of the Rician K-factor should be re-tested with the improved profiler. If found to be significant, a means of estimating the K-factor for any LOS situation will be valuable in improving the accuracy of simulations.

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