THE EFFECT OF RADIO MODELS ON VEHICLE NETWORK SIMULATIONS

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ABSTRACT

One emerging type of ad-hoc network is the Vehicular Ad-Hoc Network (VANET), in which vehicles constitute the mobile nodes in the network. Due to the prohibitive cost of deploying and implementing such a system in real world, most research in VANET relies on simulations for evaluation. A key component for VANET simulations is a realistic radio propagation model that ensures conclusions drawn from simulation experiments will carry through to real deployments. Prior work has shown that the idealized perfect-within-range models commonly used in network simulation tools can be misleading. In this paper, we set out to study the effect of radio models on the simulations of vehicle communication. We first conduct measurements of the received signal strength between moving vehicles. The data obtained from these experiments are then used to develop an empirical radio propagation model. Finally, we evaluate the effect of our trace-driven model on several routing protocols in the popular network simulator NS2.

I INTRODUCTION

The rapid evolution of wireless data communication technologies in recent years has created a tremendous opportunity for the use of these technologies in support of vehicular applications. The use of wireless communications offers the capability of direct exchange of safety-related information between vehicles. The IEEE is currently developing the Dedicated Short Range Communication (DSRC) standard [1], which is being optimized for inter-vehicular communication. Planned applications include collision avoidance, road hazard notification, trip planning and infotainment. A number of mobile ad hoc network (MANET) routing protocols have been proposed to support multi-hop communication between vehicles over wide area. Although experiments are the best way to test and to validate the communication protocols, it is often impractical to conduct experiments when there are a large number of nodes under investigation. The most popular method for evaluating the characteristics of wireless routing protocol is through the use of simulation. Simulation provides researchers with a number of significant benefits, including repeatable scenarios, isolation of parameters, scalability and exploration of a variety of metrics.

The radio propagation model used in wireless simulations plays an important role in the performance of the protocol under study. Currently, however, analytical and simulation research in wireless networks typically uses simplified assumptions that all radios have a circular communication range, have perfect coverage in that range, and travel on a two-dimensional plane. Simulation results obtained with unrealistic radio propagation models may not correctly reflect the true performance of the protocols under study. Nevertheless, most of all published MANET articles used unrealistic radio propagation model. Therefore, the results from these papers might not fully be trusted. Indeed, Kotz et al warned: "Many reviewers and readers of such articles treat these simulation results with less than full respect" [2].

Therefore, realistic radio propagation models that truly represent the real behavior of radio communication are essential to make the simulator useful for researchers. In this work, we set out to study the effect of radio propagation models on the simulation of vehicle communication. We first conduct measurements of signal strength between two moving vehicles. The data obtained from these experiments are then used to develop an empirical radio propagation model. Finally, we evaluate the effect of our trace-driven model on several MANET routing protocols in the popular network simulator NS2.

The rest of the paper is structured as follows. In Section II, we briefly discussed related work. The experiment set up and procedures are discussed in Section III. The results of this experiment are discussed in Section IV. Available radio models in NS2 and our realistic propagation model are discussed in Section V. In Section VI, a new propagation model based on the experiments is presented. Section VII evaluates the effects of our realistic propagation model on several routing protocols. Finally, Section VIII presents concluding remarks.

II RELATED WORK

Kotz et al [2] surveyed radio propagation models used in a set of proceedings from 1995 through 2002. In this literature, they categorized the propagation models in three groups based on the realistic nature of the model: "*flat earth*", "*simple*", and "*good*". They concluded that most of the papers published used either the *simple* or *flat earth* model. Moreover, in their work they used several set of axioms to prove that the *simple* radio model is completely wrong. One of the axioms is: "Signal strength is a simple function of distance". By conducting experiments with 802.11b wireless cards they have demonstrated that *flat earth* or *simple* models cannot model the radio propagation of real-world wireless devices. Therefore, they conclude that a realistic propagation model, which they refer to as the *good* radio model, is necessary for accurate simulations.

Eude et al. [3] conducted experiments on car-to car basis. There are two contributions they made to improve the simulations run on NS2. Firstly, they added an algorithm to handle automatic data rate switching. This algorithm simulates the automatic mode in 802.11b wireless cards, wherein the transmission rate is decreased when the signal quality is worsening. Secondly, they created a radio model based on experimental data and fed back into the NS2. For validation, they ran the simulations with the same scenario as their experiment. They showed that the throughput behavior between the two cars in the experiment can be reproduced in the simulation using their empirical model. Our work is complementary to theirs. In this paper, we show that a realistic radio propagation model can have a significant impact on the evaluation of routing protocols for vehicle-to-vehicle communication.

Singh et al. [4] studied the performance of 802.11b compliant under varied stress conditions in vehicular traffic scenarios. From the experiments, they found that the signal strength varies with different traffic conditions and locations. The link quality measurements indicate that suburban environment is more favorable and urban driving conditions are less friendly while the freeway environment lies in between. Their result justifies the needs of separate radio model for different environments. However, they did not attempt to mathematically model their experimental results.

In [5] Camp et al. presented a measurement driven deployment strategy for wireless mesh networks. As a first step towards their goal, the authors conducted experiments with wireless mesh boxes and developed a data-driven radio propagation model for a densely populated urban environment. We have a similar objective, albeit for a completely different environment, a vehicular network.

III EXPERIMENTAL SETUP

Our experiment was conducted on moving vehicles. The objective of the experiment is to create an empirical propagation model based on experimental results.

To carry out the experiment we used two cars, each equipped with:

- Laptop under Linux (Mandrake 9.2)
- Intel Pro/Wireless 2200BG (internal 802.11b wireless card) [6]
- Garmin GPS [7]

Our experiment measured the distance between the vehicles and the signal strength on the receiver side. The exact position of the moving vehicle was recorded using a GPS receiver connected to the laptop. GPS Manager v6.2.1 [8] was used to acquire the exact positions of moving vehicles over the elapse of time. Wireless Tools [9] was used to measure signal strength at every second.

For each measurement, we managed to maintain a line of sight between the two moving vehicles. The range of distance and signal strength were measured in this experiment with distance increased by 10-meter intervals until there was no connectivity between the two cars. To get legitimate and accurate results, the experiment was repeated at least three times for different speed, transmission power, and transmission rate. For the signal strength, its values obtained from specific speed, transmission rate, and transmission power were averaged for every meter.

IV EXPERIMENTAL RESULT

In this section, various parameters that affect the measured signal strength are investigated. In particular, we investigated speed of the cars, vehicle location and wireless card transmission power level. It was found that location had the most significant effect on the measured signal strength.

A. Speed

To investigate the effect of speed on signal strength reception, we measured signal strength while driving at different speeds, namely 20 km/h and 60 km/h, in the same suburban location. Since the area is restricted to a maximum speed limit of 60 km/h, it was impractical to conduct the experiment at a faster speed. Fig. 1 shows the effect of different speeds on the signal strength for 30 mW transmission power level. Based on our observations, we found that there are no significant differences in the received signal strength.

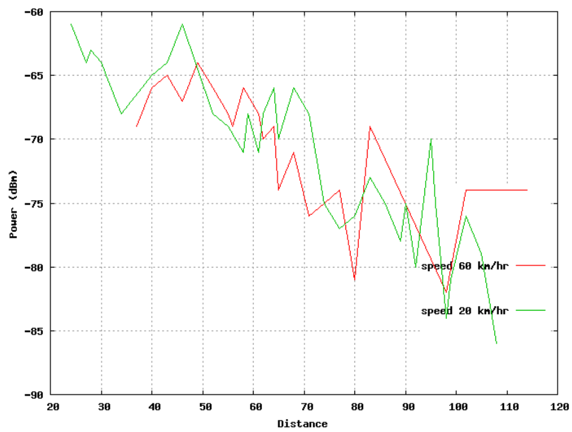

Fig. 1: The effect of speed variation on signal strength at suburban area using 30 mW power level and 1 Mbps transmission rate.

B. Location

To investigate the effect of environmental location, we performed tests in areas with the following environmental characteristics:

- Suburban: The suburban scenario must have a vehicular maximum speed limit of around 60 km/h, and a combination of trees, houses and parked cars on the side of the road.
- Highway: The highway was a flat open environment with scarce roadside vegetation and a maximum speed limit of 80 km/h.

Fig. 2 shows the relationship between distance and signal strength on suburban and highway areas. Our results show that our highway scenario produces better signal strength than suburban area. Inspection of this figure reveals that our highway scenario gives, on average, a signal strength of 5 dBm higher than the suburban scenario. Furthermore, the maximum range of connectivity between the two vehicles is increased from 110 m in a suburban area to almost 140 m on a highway.

The possible reason that the signal strength in suburban area is generally lower than in highway areas is because suburban areas might have higher diffraction, reflection, and scattering effects compare to highway area. In our suburban scenario, reflection and diffraction can occur from houses, high rise structures and cars parked on the side of the road while in highway areas these objects rarely exist. This result shows that highway environment is more favorable for radio transmission as compared to suburban areas.

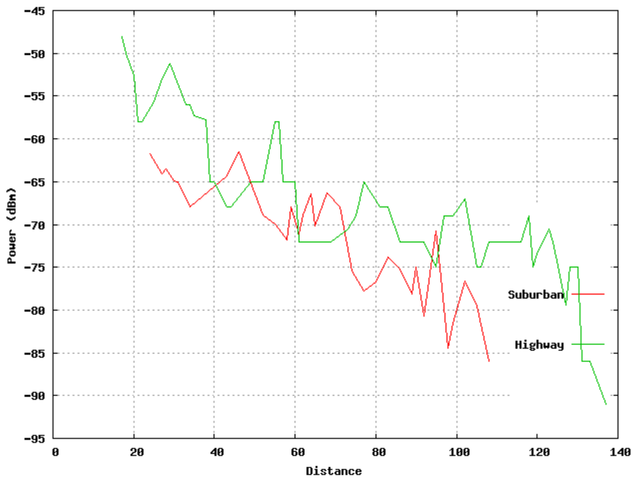

Fig. 2: The effect of location variation on signal strength using 30 mW power level and 1 Mbps transmission rate.

C. Transmission Power Level

Most of the propagation models use the fact that the signal strength fades with the distance according to the free space equation [10]. To evaluate the practicality of such models in a real environment we vary the power level of the wireless cards. The selected experimental results presented here were carried out in a suburban area. Fig. 3 shows the relationship between signal strength and the distance between two vehicles for different power level on suburban area.

As shown in fig. 3, the average signal strength across distance for 30 mW power level is higher than for 10 mW as it intuitively should. Furthermore, the maximum distance where the connectivity can still be maintained was decreasing with decreased power. For 10 mW power level, the link was dropped when it reached 100 m. The connectivity distance range was increased to 140 m when power level of 30 mW was used.

V RADIO MODEL

The results discussed in previous section shows that power level and location played a significant role in obtaining the received signal strength. It was found that speed factor is insignificant in our scenarios. Therefore in this work we focus on the following parameters: transmission power, distance, and location when developing our empirical models. There are three propagations models used in the popular network simulator NS2: free space, two ray ground and shadowing with Gaussian distribution. We first provide a brief overview of available propagation models in NS2. We then show their fallacies when they are specifically used for VANET simulation. Finally, we found that the fluctuation caused by the fading effect can better be modeled by using the deviation of signal strength from the experimental data.

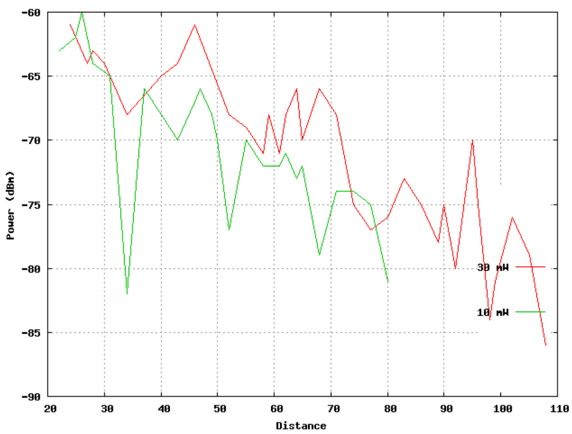

Figure 3: The effect of power variation on signal strength at suburban area using 1 Mbps transmission rate.

A. Free Space Model

The free space model predicts that the received power decays off as the square of the distance between two vehicles increases [10]. This model is used to predict the strength of the received signal when the transmitter and receiver have a clear, unobstructed line-of-sight. Satellite communication system typically undergo free space propagation model. Friss proposed the following equation to calculate the received signal power in free space at distance d from the transmitter [10].

$$P_r(d) = \frac{P_t * G_t * G_r * \lambda^2}{(4\pi)^2 * d^2 * L} \quad \text{(Equation 1)}$$

where, Pt is the transmitted power, Pr(d) is the received power which is a function of distance between transmitter and receiver (T-R), Gt, and Gr denotes the transmitted and receiver antenna gain respectively. Finally, L is the system loss factor not related to propagation. L equals to one (L = 1) indicates no loss in the system hardware [10]. Figure 7 and 8 shows that the signal strength predicted by free space propagation model is way too high as compared to experimental results.

B. Two-Ray Model

The two-ray ground reflection model is argued to be more realistic than free space model. This model is based on geometric optics, and considers both the direct path and a ground reflected rays between transmitter and receiver (Equation 2).

$$\Pr(d) = \frac{PtGtGrht^2hr^2}{d^4L} \quad \text{(Equation 2)}$$

The additional parameter included in this model is antenna height of the two nodes. This model is only relatively accurate for predicting large scale signal over distances of several kilometers for cellular telephony systems using tall towers (height above 50 m) [10]. Moreover, this model still assumes the earth is flat and no obstruction between two nodes. Therefore, this model is not practicable to be used for VANET where vehicles are generally surrounded by obstructions. Figures 7 and 8 show that the signal strength predicted by the two-ray model is higher compared to free space and experimental results.

C. Log normal shadowing

Log normal shadowing is more realistic propagation model compared to free space or two-ray propagation models since it is derived using a combination of analytical and empirical methods. The first part is the model of signal strength that fades with the distance according to power law function and the second part reflects the variations of the received power at given distance [10]. This can be shown by the following model:

$$\frac{\Pr(d)}{\Pr(do)} = -10n\log(d/d0) + X_{db}\, gaussian$$

(Equation 3)

where Pr(d0) denotes power at reference distance d_0, and n denotes path loss exponent. The reference distance is calculated by using the free space equation (Equation 1) or through extensive measurement [10]. Since the maximum radio range in our experiment and most VANET application was less than 1 km, reference distance of 1 m is used [10]. The value of n (path loss) indicates the rate at which the power decreases with distance. The deviation σ is based on Gaussian (normal) distribution. The value of path loss *n* and deviation *σ* varies on different environment as shown in Table 1 and Table 2.

Environment	*n*
Outdoor Free Space	2
Outdoor shadowed urban area	2.7 to 5
In building line of sight	1.6 to 1.8
In building obstructed	4 to 6

Table I: Some typical values of path loss n [10]

Environment	**σ dB**
Outdoor	4 to 12
Office, hard partition	7
Office, soft partition	9.6
Factory, line of sight	3 to 6
Factory, obstructed	6.8

Table 2: Some typical values of shadowing deviation [10]

D. Proposed Model

As shown in Fig. 2, we noticed a difference in signal power for the same distance in different area. The signal power in suburban area is lower than in highway area. This might be due to higher fading effects in suburban area as compared to highway area. Therefore, we develop two versions of radio propagation models for these experimental data and add them to ns2. Our proposed model is based on log normal shadowing. However, instead of using *n* (path loss exponent) and **σ dB** deviation from Tables 1 and 2 respectively, we determined those values from our experimental data. The improvement can be modeled by the following equation:

$$\frac{\Pr(d)}{\Pr(do)} = -10n\log\left(d/d0\right) + X_{db}\,Experiment$$

(Equation 4)

The values of *n* and σ dB are computed from measured data, using linear regression such that the difference between the measured and estimated signal power is minimized in a mean square error. Fig. 4 and 5 illustrate actual measured data and equation of linear regression for suburban and highway area respectively. Table 3 tabulates the value of *n* from our experiment. Fig. 7 and 8 compare the signal strength of experimental results with log normal shadowing that use n from our experiment for suburban and highway environments respectively.

Log normal shadowing (Eq 3) uses deviation with Gaussian distribution. However, the deviation from our experimental data did not pass Kolmogorov Smirnov Goodness-of-Fit Test [11] with Gaussian distribution. The test always failed when the values of Confidence interval were more than 1%. (0% is no correlation, 100 % is perfect correlation). Therefore, based on this result, we decided to construct our own distribution based on the experimental results. Our model made use of the CDF of signal strength deviation from the experimental data. Fig. 6 shows comparison of CDF between Gaussian and experimental deviation.

Environment	***n***
Suburban area	2.567
Highway area	2.295

Table 3: *Value of path loss (n) from experiments with different environments.*

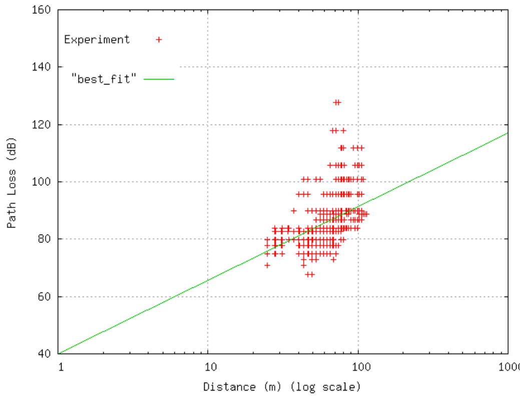

*Fig. 4 Path Loss against distance for suburban area with line of best fit of PL = 10*2.566903837*log10(d)+40.04*

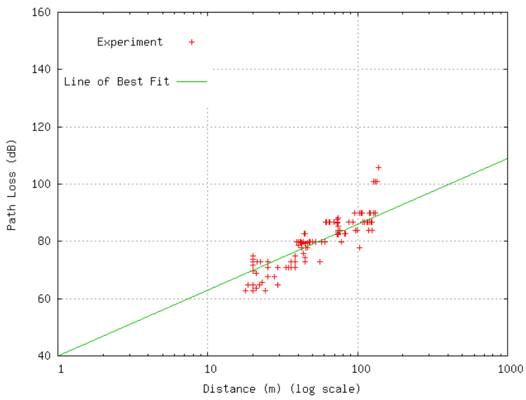

*Fig. 5 Path Loss against distance for highway area with line of best fit of PL = 10*2.294766030*log10(d)+40.04*

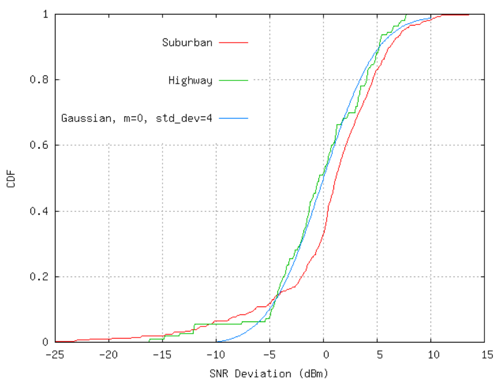

Fig. 6 *CDF of gaussian distribution with mean = 0 and σ = 4; and experimental distributions.*

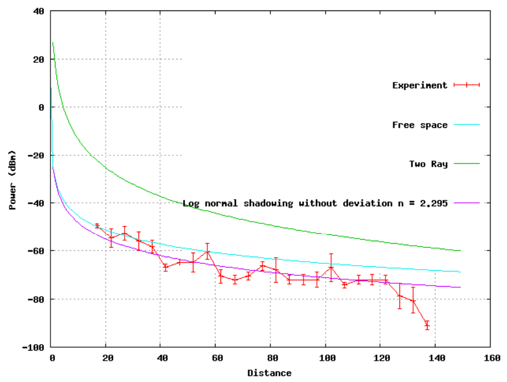

Fig. 7 *Comparison between several radio propagation models with Experimental result at Highway area.*

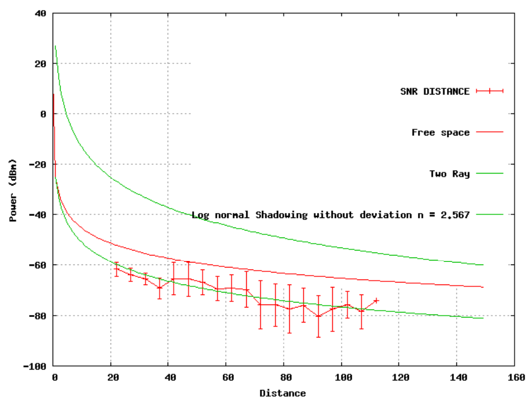

Fig. 8 *Comparison between several radio propagation models with Experimental result at Suburban area.*

VI RADIO PROPAGATION MODEL IMPLEMENTATION IN NS2

At the physical layer of each wireless node, there are two receiving threshold RXThresh (Receiving Threshold) and CSThresh (Carrier Threshold) [2]. To know if a packet is received correctly, NS2 compares the power of the packet with the thresholds. If the received power is higher than then the RXThresh, the packet can be considered received correctly. When the power is between RXThresh and CSThresh, the packet can be detected but it contains error that can not be understood. Lastly, if the power is lower than CSThresh, the message is not detected at all. In NS2, the value of RXThresh and CSThresh are dependent on the value of communication range. Therefore different radio propagation model used will give different value of RXThresh and CSThresh. To make our simulation results comparable to the experimental data, we choose the RXThresh and CSThresh based on the specification of wireless cards we used. In our simulations, RXThresh and CSThresh value are set to -91 dBm and -89 dBm respectively.

As discussed in the previous section, our proposed model is based on the log normal shadowing model, but with the value of path loss exponent (n) and deviation determined from the experiment data. The value of path loss is selected based on Table 3. Fig. 6 shows the CDFs of signal strength variation for our experimental data and the Gaussian distribution. We compute the fading component of our model based on the deviation of signal strength data.

VII ROUTING PROTOCOL COMPARISON WITH REALISTIC AND NON REALISTIC PROPAGATION MODELS

To understand how these different radio models affect the performance of network, we compare three routing protocols (DSR, AODV, GPSR) over several radio models, including Two Ray Ground model, Log-Normal Shadowing model, and our model based on experiment in suburban and highway area. In order to achieve a more realistic result, we model the vehicle mobility with real world traces, which are generated from the actual movement of buses in Seattle, Washington area King County Metro bus system. The properties of these vehicular networks have been well studied in our previous work [12]. We recommend in [12] that 1 km of radio range can assure the good connectivity of the vehicular networks. However, given that in our experiments the wireless cards can only reach around 120 m, to ensure that the connectivity is maintained throughout the simulations, we shrink the size of our vehicular network by 10 times, which means all the positions and speeds of the vehicles were divided by 10. Consequently, the relative distances and movements of vehicles are still the same as the original vehicular network used in [12].

We vary data traffic loads over the vehicular network in all comparisons. The pairs of source and destination are randomly selected from 50 nodes. The sources send four CBR packets per second and the packet size was 64 bytes. The number of data flows is varied from 5 to 25 to generate different traffic load. For each traffic load, we run six different traffic patterns with our modified vehicular network. Therefore, each presented simulation result is the mean value of six runs.

We compared five different radio models: two-ray ground, log-normal models with different path loss n that match suburban and highway environments, and our empirical models for suburban and highway. The metrics used for comparing performance include packet delivery rate and routing overhead. Packet delivery rate is the ratio of data packets delivered to destinations to those generated by senders. Routing overhead is the total number of routing packets transmitted during the simulation.

Among the five radio models, two-ray ground always gives the highest packet delivery rate, which is not surprising though. In addition, we find that our empirical model for highway produces pretty similar results for packet delivery rate as two-ray ground model.

The packet delivery rate for suburban models, either with Gaussian and our empirical, decreases as the number of nodes increase. Moreover, the results using Gaussian models are significantly different from the empirical model. These observations are consistent throughout the simulations for all three routing protocols as shown in Fig. 9-11.

As shown in Fig. 12-14, for AODV and DSR, two-way model has the lowest routing overhead while highway models always have lower routing overhead than suburban models. However, the results for GPSR simulations are the other way around, where the two-ray ground model has the highest routing overhead.

The main cause of differences in routing protocol performance with different radio models used might be because of the different radio ranges that it can reach. In our simulation, the received power threshold is 3e-13W. This value is acquired from the lowest possible power received in the experiment. At such a power level, the original shadowing and the suburban shadowing can reach 120 m, and the highway shadowing can reach 200 m. Two Ray Ground can reach the longest radio range, which is about 470 m. The longer the radio range might suggest the better connectivity can be achieved.

The other cause is due to the difference in the probability distribution functions used for different models. As depicted in Fig. 6, there is about 50 % probability that Gaussian distribution will give us a signal strength deviation less than 0 dBm. On the other hand, there is only a 30 % chance that the distribution from our empirical distribution will give the same deviation range. Therefore, the empirical models tend to produce a higher packet delivery rate and lower routing overhead as compared to the analytical models.

Note that highway models produce similar results as the Two-Ray Ground model even though the effective radio range of the highway models is shorter. This might be because the radio range of the highway model (200 m) is enough to form a well-connected network.

Figures 11 and 14 shows that DSR performs poorly with the use of log-normal shadowing models (either with Gaussian or empirical data). This is because the log-normal shadowing model creates a quite dynamical topology in our simulations. As DSR relies heavily on the cached routes, it is more likely to use the obsolete route information, which results huge routing overhead and poor packet delivery rates.

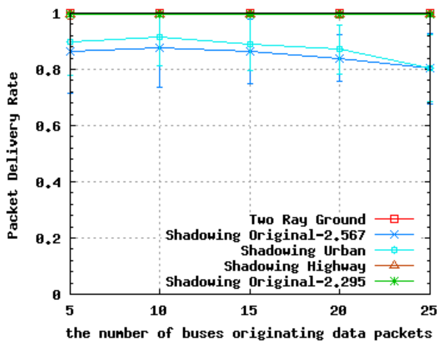

Fig. 9 Packet delivery rate for AODV

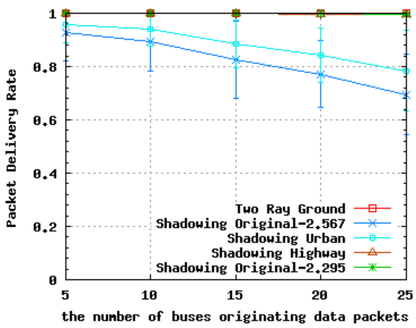

Fig. 10 Packet delivery rate for GPSR

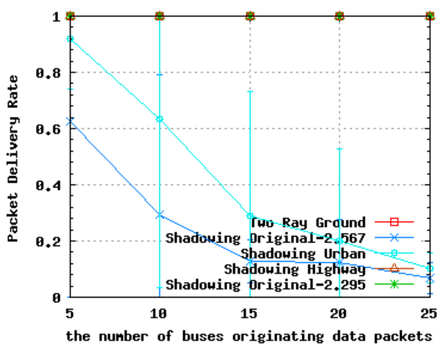

Fig. 11 Packet delivery rate for DSR

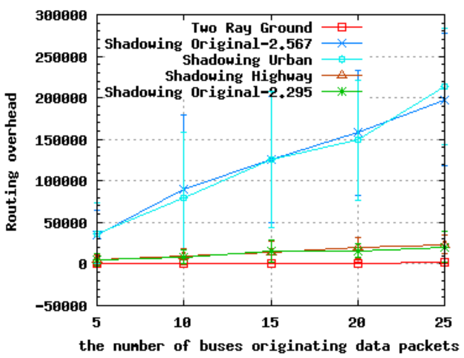

Fig. 12 Overhead AODV

VII CONCLUSION AND FUTURE WORK

Using real world measurement data, we found that transmission power and environment play a significant role on the received signal strength. However, the speed factor is considered insignificant in our scenarios. We manage to fit our empirical data into a theoretical model and studied the effect of different radio models on the performance of routing protocols in a realistic simulation environment.

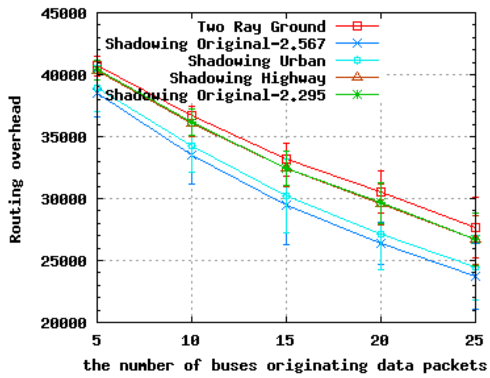

Fig. 13 Overhead GPSR

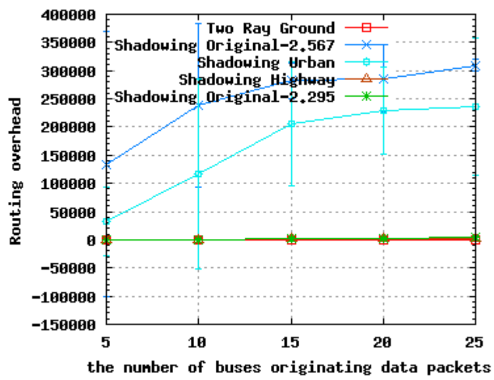

Fig. 14 Overhead DSR

We compare the performance of three routing protocols (GPSR, DSR and AODV) using two-ray ground, log-normal shadowing and our empirical models. In terms of packet delivery rate, two-ray ground model consistently produces better results than the other models for all routing protocols. Moreover, we find that when there is a good line-of-sight condition between vehicles such as in a highway environment, the results using two-way ground model are pretty close to results using log-normal shadowing models. In addition, we observe our empirical models produce significantly different results as compared to theoretical model in our simulations. Finally, we find that the use of different radio models can have varying effects for different routing protocols. The two-way ground model produces the best results for AODV and DSR, but the worst results for GPSR.

Several recent empirical studies [13 - 15] have shown the existence of three distinct reception regions in a wireless link: connected, transitional, and disconnected. The transitional region is often quite significant in size and often characterized by high-variance in reception rates. As a future work, we plan to study the effect of this transitional region on VANET simulation using our empirical data.

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