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Research Article

Blind Corner Propagation Model for IEEE 802.11p Communication in Network Simulators

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Vehicular Ad Hoc Network (VANET) has been developed to enhance quality of road transportation. The development of safety applications could reduce number of road accidents. IEEE 802.11p is a promising standard for intervehicular communication, which would enable the connected-vehicle applications. However, in the well-known network simulators such as NS3 and Omnet, there is no propagation model that can simulate the IEEE 802.11p communication at blind corner realistically. Thus, in this paper, we conducted the real-world experiments of IEEE 802.11p in order to construct the model to describe the characteristics of the IEEE 802.11p communication at the blind corners. According to the experimental results, we observe that the minimum distance between the vehicle and the corner can effectively be represented as the key parameter in the model. Moreover, we have a variable parameter for adjusting the impact of the obstruction which could be different at each type of blind corners. The simulation results using our proposed model are compared with those using the existing obstacle model. The results showed that our proposed model is much more closely aligned with the real experimental results.

1. Introduction

World Health Organization (WHO) reported that 1.2 million people from all over the world die and 20 to 50 million people suffer from injuries because of road accidents each year [1]. According to [2], a lot of accidents occurred at the intersections. Blind corner is one type of the intersections where the accidents occur easily. This is because one vehicle from one side of the corner cannot see the other vehicles from the other side of the corner. We consider the blind corners as the corners with obstacles and they rarely have space for sidewalk. The blind corners can be generally found in many locations, for example, in the cities of Asian countries, in small alley, in local way, and inside the organization area. These locations are surrounded by buildings that obstruct the driver's line of sight as shown in Figure 1. Not only can the buildings cause the blind corner, but also walls, trees, and construction sites can also cause the blind corner. Furthermore, the traffic lights are rarely found in such locations. That is why the accidents could occur easily at the blind corners.

Even though the line of sight of the driver at the blind corners is blocked by the obstacles, wireless communication can partially pass through the obstacles. As a result, the vehicles can sense other vehicles around. The wireless communication network among vehicles is introduced as Vehicular Ad Hoc Network (VANET). VANET has been developed to enhance the quality of road transportation and Intelligent Transportation System (ITS). VANET consists of 2 types of communications: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). One of the major ITS applications is the safety application, in which some warning signals can be sent to other vehicles in case there are vehicles or pedestrians nearby. By receiving the signals, the intelligent vehicle can decide if it can move on or it needs to brake. This could reduce the number of accidents.

The IEEE developed the 802.11p Wireless Access for Vehicular Environment (WAVE) standard as a support for VANET applications [3]. The IEEE 802.11p has the communication range up to 1,000 m if the vehicle speed is less than 200 km/h. As the blind corner is one of the critical locations where the accidents can occur easily, the VANET

Figure 1: Sample building that causes blind corner.

communication could help notify the driver. Nevertheless, the obstacles at the blind corner not only obstruct the sight of the driver but also obstruct the wave propagation signal. Consequently, the communication could fail easily. In other words, the performance of IEEE 802.11p can be degraded when the communication occurs at the blind corner. This is one of the vulnerabilities of IEEE 802.11p communications for safety applications [4].

The effect of the obstruction leads to the decreased communication range of IEEE 802.11p and the performance degradation of the protocols and applications that rely on VANET. To consider this issue, researchers and developers evaluate their work using both real-world experiment and simulation. The real-world experiment is the evaluation method that uses real equipment running in real scenarios. Although this method provides the testing performance accurately, it is time-consuming, expensive, and difficult to reproduce the test cases and it is difficult to scale to large scenarios. Thus, the simulation is an alternative method for performance evaluation.

To enable realistic simulation, the propagation models are applied to the nodes in the simulation. Recently, there have been researches about the propagation models for each kind of obstructions such as vehicle obstruction [5, 6] and building obstruction [7–12]. These models have been evaluated by comparison to the results from the real experiments. As the models are applied, the simulation results can become more realistic in each specific scenario. However, to the best of our knowledge, the existing models are not suitable for applying in blind corner scenario.

In our previous works, we conducted the real-world experiment to study the performance of IEEE 802.11p in blind corner scenario [12]. The experiment was conducted using Denso Wireless Safety Unit (WSU), which is IEEE 802.11p communication module. Each vehicle was equipped with the WSU module. The results showed that two vehicles at different sides of the corner can communicate with each other when the minimum distance between the vehicle and the corner is less than 60 m. The results emphasized that the performance at the blind corner should be taken into a serious consideration when developing any safety applications.

In this paper, our contribution is twofold. The first contribution is that we extend our previous work to cover more blind corners in order to investigate and generalize the characteristics of the blind corners regardless of the specific corners. The second contribution is that we propose a novel blind corner model, which is implemented as an extension of the well-known models in the network simulators. This model can represent the characteristics of IEEE 802.11p communication at blind corners realistically.

There are two methods to construct a new model which are ray tracing method and flat propagation method [10]. The ray tracing method has a complex computation, consumes a lot of resources and time, and is difficult to parameterize the parameters. On the other hand, the flat propagation method normally calculates some values and uses some probabilistic functions to represent signal propagation loss. Our design concern is that the model has to be simple in order to consume less time when it is applied in the simulation. Therefore, we use the flat propagation method. Our model can be implemented as an extension of the two-ray ground model and the Nakagami model, the well-known propagation models in the network simulators, so it is easily applied to any network simulators. The network simulator that we use in this work is NS-3 [13], which is open source software for network simulation and is very popular as a network platform in research and education. For performance evaluation, we conduct extensive real-world experiments and compare the results from the experiments to the results from our proposed model.

The following of this paper is organized as follows: the background knowledge and related works about propagation models are described in Section 2. Then, our field experiment settings and results are shown in Section 3. In Section 4, our model is elaborated. The discussion and comparison with other related works are shown in Section 5. Finally, Section 6 concludes our work.

2. Background Knowledge and Related Works

The blind corner is a critical scenario for the safety applications, so the performance of the safety application should be considered. Although we can install the infrastructure such as Roadside Unit (RSU) at the corner to improve the communication performance, it consumes a lot of cost for deployment. Moreover, it is not cost-effective to deploy the RSUs at all corners in the city because there are too many blind corners in most of the countries, especially the countries in Asia. Therefore, the scenario where the communication occurs at the blind corners without any additional infrastructures should be taken into consideration. Such scenario can be considered as beneficial to the safety applications because it can help reduce the accidents at any corners.

One method that can help simulate the communication effectively is to add the propagation loss models or signal attenuation models. There are two methods to construct propagation models, which are ray tracing method [14, 15] and flat propagation method [8–11]. The ray tracing method traces the signal from source to destination using the characteristics of signals like reflection, diffraction, and interference. Then, the loss of the signal is calculated. Although this

Table 1: Comparison of the models.

Issue	Obstacle model [8, 9]	CORNER model [10, 11]	Blind corner model (our model)
(i) Signal attenuation	√	√	√
(ii) Simulator used	NS-3, Omnet	QualNet	NS-3
(iii) Communication module used in the real experiments	IEEE 802.11p	IEEE 802.11b/g	IEEE 802.11p
(iv) Characteristics of the corner used in the experiment	Not blind corner	Not blind corner	Blind corner (the corner with no space for side walk or the side walk less than 1 m)
(v) Parameters used in path loss calculation approach	Number of walls penetrated	Wave characteristics parameter	Minimum distance

method can give an accurate signal strength at the destination as an output of the model, it is not widely used because the obstacle topologies and the signal attenuation characteristics for each obstacle have to be collected and set in advance. Moreover, it consumes a lot of resource and simulation time.

Researchers mostly use the flat propagation method instead of the ray tracing method. The flat propagation method utilizes values that can be obtained from the topology easily as inputs for the formula. The formula will give a result as attenuated signal strength. The most common value that is used as an input is distance. This method consumes less resource and simulation time. The examples of the models using this method are two-ray ground model and Nakagami model. These two models are embedded into most of the network simulators. However, many researchers still introduce new models based on the flat propagation method for more realistic simulation in some specific scenarios.

The obstacle model [8, 9] uses number of walls where the signal has to penetrate as a main variable for formula calculation. As a result, the obstruction amount of the signal depends on number of walls the signal is passing through. This model focuses mainly on building obstacles, while the CORNER model [10, 11] uses the wave characteristics such as reflection and diffraction as a main variable for formula calculation. The CORNER model classifies the scenarios into 3 categories: line of sight (LOS), non-line of sight with 1 corner (NLOS1), and non-line of sight with 2 corners (NLOS2).

Our work focuses on blind corners, which are the corners that have no space for sidewalk or the corner with the sidewalk less than 1 meter. At the corner with no space for sidewalk, the signal from the transmission node will penetrate to the wall, leading to more signal obstruction. Our model is different from the obstacle model and the CORNER model in that we use the minimum distance between the vehicles to the corner as the main parameter to calculate in our formula. We explain the rationale behind our design in Section 4.

Our model, the obstacle model, and the CORNER model are compared as shown in Table 1. All of the models perform signal attenuation when the transmitted signal travels through the obstacles. In order to calculate the path loss, the obstacle model uses number of walls penetrated, the CORNER model uses wave characteristics such as reflection and diffraction effects, and our model uses the minimum distance as the main parameter. The obstacle model and our model are implemented in the NS-3 simulator, whereas the CORNER model is implemented in the QualNet simulator. The obstacle model is also embedded in Veins framework based on Omnet simulator [16]. For the communication module used in the real experiments, IEEE 802.11p is used in our model and the obstacle model, whereas IEEE 802.11b/g is used for the CORNER model.

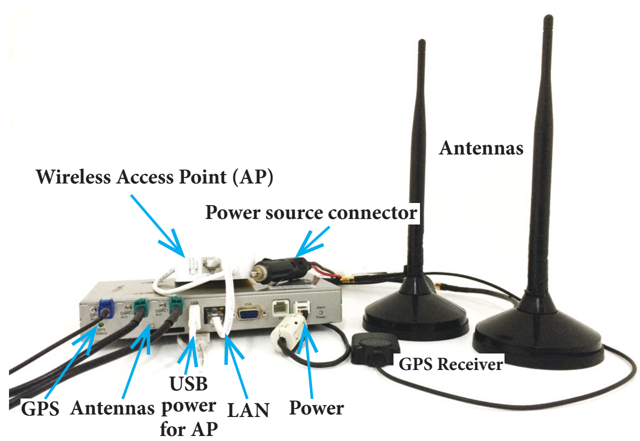
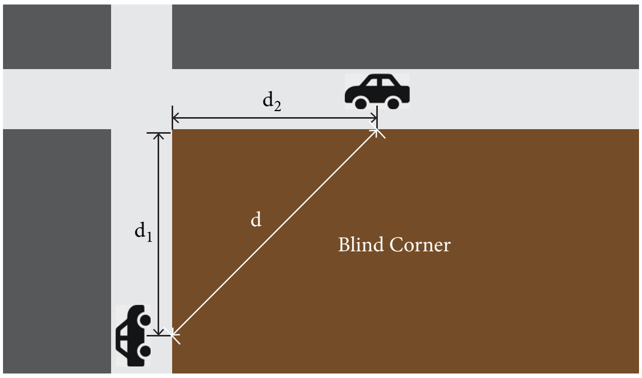


Figure 2: Denso WSU experiment set.

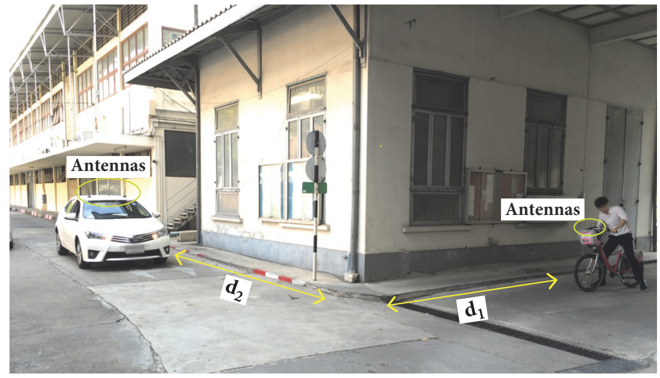
3. Field Experiment

We set up field experiment to study the characteristics of real IEEE 802.11p communication devices in blind corner scenario [12]. Our previous work reveals the performance of IEEE 802.11p where the communication range among 2 vehicles in blind corner scenario is less than 6% of full specification of IEEE 802.11p, which is 1,000 m. In order to investigate the performance in more details, we extend the experiment to cover more samples of blind corners and propose the model for using in the simulators.

3.1. Field Experiment Settings. We set up the experiment scenario using 2 vehicles on different side of the blind corner. Each vehicle is equipped with Denso Wireless Safety Unit (WSU), which is connected to 2 external antennas (see Figure 2). The antennas are placed at 1.2 m from ground. IEEE



(a) Bird's eye view



(b) Perspective view

FIGURE 3: The experiment scenario: (a) bird view and (b) perspective view.

TABLE 2: The experiment settings.

Settings	Values
(i) Data transmission device	Denso WSU 5001-T
(ii) Antennas	2 external antennas at 1.2 m from ground
(iii) Transmission power	20 dBm
(iv) Beacon interval	10 Hz
(v) Total number of packets sent each experiment case	Approximately 100 beacons
(vi) Number of experiments	4 blind corners

FIGURE 4: Electrical Engineering Lab.

FIGURE 5: Mechanical Engineering Lab.

802.11p is used as a communication module in Denso WSU. Because GPS does not provide accurate position information, we have measured and recorded the location manually with a standard measuring wheel. As a result, we can obtain an accurate position of the vehicle which leads to more accurate result.

The network traffic generated in the experiment is 10 Hz beacon, which is the minimum transmission frequency required for safety applications [17]. The attached antennas transmit the signal with 20 dBm power. In each experiment case, one vehicle is fixed at distance d_1 on one side of the blind corner. The other vehicle is moving between $d_2 - 1$ m and $d_2 + 1$ m on the other side of the blind corner. Then, we calculate the average value of the results for that point. We send approximately 100 beacons for each case and calculate the packet delivery ratio and average RSSI. The experiment scenario is depicted in Figure 3 and the settings are summarized in Table 2.

We did experiments at 4 blind corners: Electrical Engineering Lab (see Figure 4), Mechanical Engineering Lab (see Figure 5), Civil Engineering Lab (see Figure 6), and Centennial Building (see Figure 7) in Faculty of Engineering, Chulalongkorn University. These 4 blind corners represent different types of blind corners. We divide the blind corners into 2 types, which are the corner with large obstruction (Electrical Engineering Lab and Mechanical Engineering Lab) and the corner with small obstruction (Civil Engineering Lab and Centennial Building). The corner with large obstructions is the corner with concrete building, which has a lot of large machines made of metal inside. The corner with small obstruction is the corner with concrete building which has a wide free space inside and mostly contains tables and chairs. The locations of all blind corners in our experiment are shown in bird's eye view in Figure 8. Because the range of each corner is different, the maximum distance between the vehicles and the corner is differently set for each blind corner. The range for each experiment is shown in Table 3. We conducted extensive experiments and found out that the results have the same trend regardless of the day of the experiment and distance step. In order to conduct the experiment with less time, we increase the distance step in our later experiments.

Table 3: Experiment distance for each blind corner.

Location	Vehicle 1 distance (d_1)	Vehicle 2 distance (d_2)
Electrical Engineering Lab	0, 5, 10, 15, 20, 30, 40 m	1 – 55 m (step every 2 m)
Mechanical Engineering Lab	0, 5, 10, 15, 20, 30, 40 m	1 – 30 m (step every 3 m) 30 – 58 m (step every 4 m)
Civil Engineering Lab	0, 5, 10, 15, 20, 30, 40 m	1 – 15 m (step every 2 m) 15 – 39 m (step every 3 m) 39 – 55 (step every 4 m)
Centennial Building	0, 5, 10, 20, 30 m	1 – 30 m (step every 3 m) 30 – 42 m (step every 4 m)

Figure 6: Civil Engineering Lab.

Figure 7: Centennial Building.

Figure 8: The bird's eye view of the blind corners in our experiment. (1) Electrical Engineering lab. (2) Mechanical Engineering Lab. (3) Civil Engineering Lab. (4) Centennial Building.

3.2. Field Experimental Results. Packet delivery ratio (PDR) and average Received Signal Strength Indicator (RSSI) are our evaluation metrics. The PDR is calculated from the ratio between number of packets received at the destination node and number of packets sent by the source node. The average RSSI is calculated by averaging RSSI of all the received packets at the destination node. The results for each blind corner are shown in 3-dimensional graph. For the PDR, the 3 dimensions are the distance between the first vehicle and the corner, the distance between the second vehicle and the corner, and PDR. For the average RSSI, the 3 dimensions are the distance between the first vehicle and the corner, the distance between the second vehicle and the corner, and the average RSSI.

Figure 9 shows the real experimental results for all blind corners. Figures 9(a) and 9(b) show PDR and RSSI results of the first blind corner (Electrical Engineering Lab). Figures 9(c) and 9(d) show PDR and RSSI results of the second blind corner (Mechanical Engineering Lab). Figures 9(e) and 9(f) show PDR and RSSI results of the third blind corner (Civil Engineering Lab). Figures 9(g) and 9(h) show PDR and RSSI results of the fourth blind corner (Centennial Building). As can be seen from the results, both PDR and RSSI are an inverse variation to the distance from the corner.

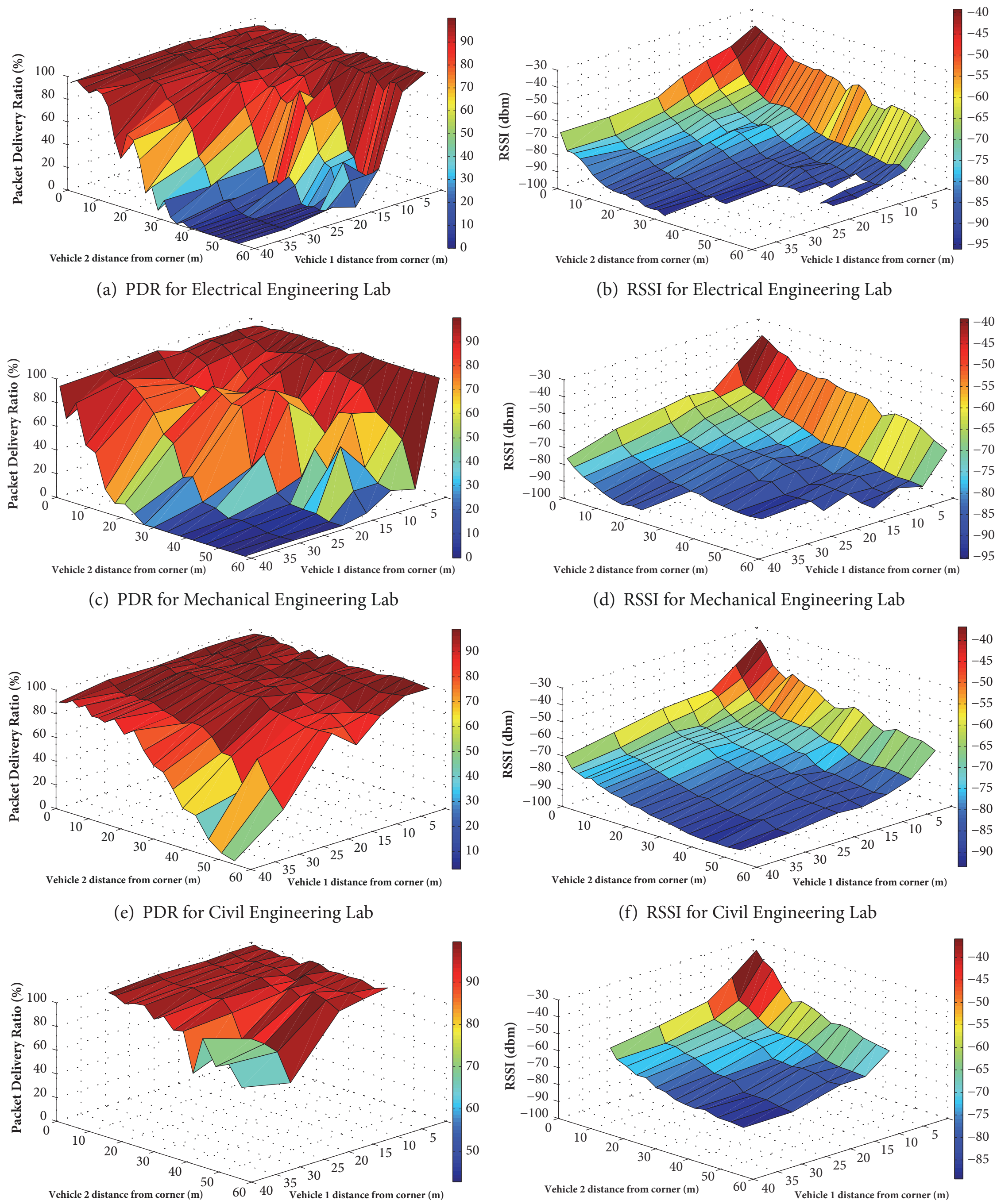
According to the results from 4 blind corners, we can divide the blind corners into 2 types which are the corner with large obstruction (the first and the second blind corners) and the corner with small obstruction (the third and the fourth blind corners). The first and the second blind corners are concrete buildings with a lot of large machines inside, leading to a lot of signal attenuations, while the third and the fourth blind corners are concrete buildings with a wide free space inside, leading to less signal attenuation.

Moreover, it can be noticed that all the results shown in the graphs are quite symmetric. Therefore, PDR and the average RSSI are associated with the minimum distance between the vehicles and the corner. This is because the closer the vehicle to the corner is, the smaller effect of blind corner the communication experiences. More discussion can be found in our previous work [12].

From the experimental results, we also observe the latency of the transmission between 2 nodes. The latency is around 89-95 ms for all distances at all blind corners. This latency value can be considered as a parameter in the simulation setup.

4. Blind Corner Propagation Loss Model

4.1. Study of NS-3 Propagation Model. Network simulator is a tool that is very popular in education and research field. The network simulator allows researchers to simulate various kinds of networks and various kinds of scenarios



(a) PDR for Electrical Engineering Lab

(b) RSSI for Electrical Engineering Lab

(c) PDR for Mechanical Engineering Lab

(d) RSSI for Mechanical Engineering Lab

(e) PDR for Civil Engineering Lab

(f) RSSI for Civil Engineering Lab

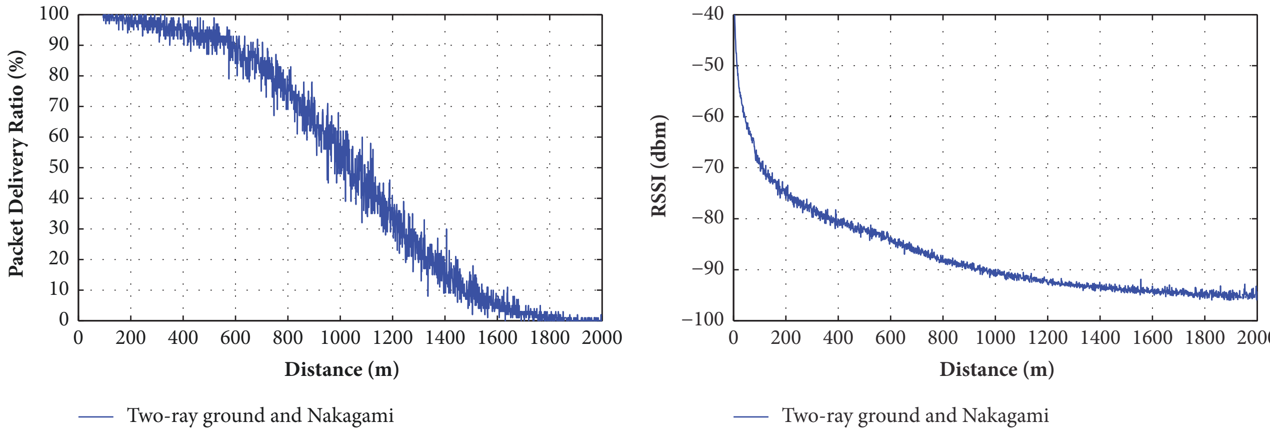
(g) PDR for Centennial Building

(h) RSSI for Centennial Building

FIGURE 9: Results from real experiments. (a) PDR for Electrical Engineering Lab. (b) RSSI for Electrical Engineering Lab. (c) PDR for Mechanical Engineering Lab. (d) RSSI for Mechanical Engineering Lab. (e) PDR for Civil Engineering Lab. (f) RSSI for Civil Engineering Lab. (g) PDR for Centennial Building. (h) RSSI for Centennial Building.

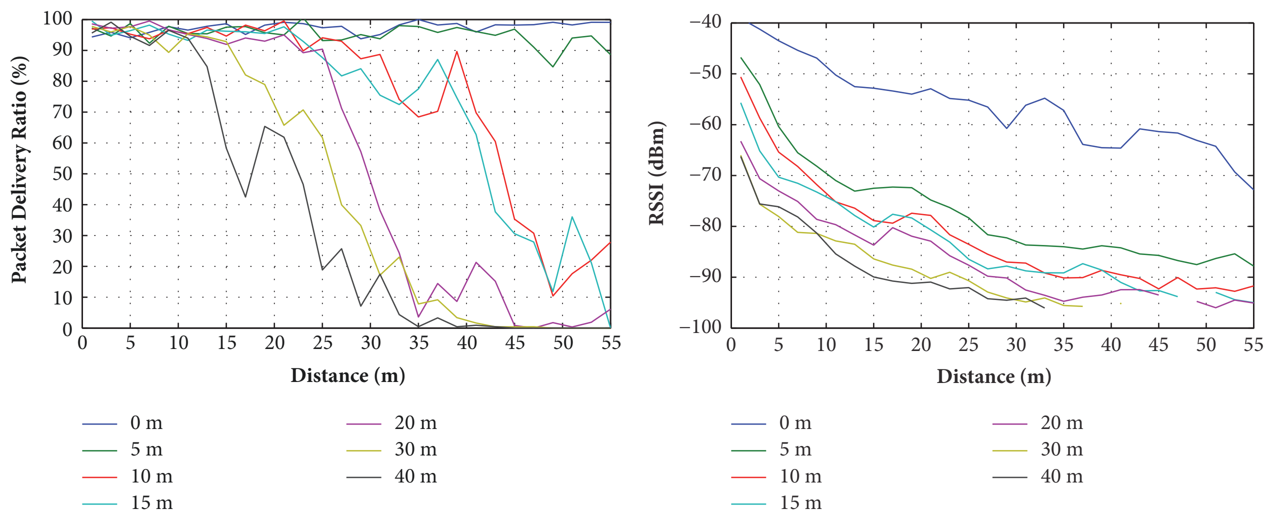
which are convenient for simulating a large-scale network. One of the most popular network simulators is NS-3, which is open-sourced software. Moreover, NS-3 also supports simulation over vehicular network that uses IEEE 802.11p as wireless interface. Using the simulator, we have to consider which propagation model is suitable to simulate packet loss.

Normally, for vehicular network, the well-known propagation model setting is to use two-ray ground model coupled with Nakagami model. These two models result from the Euclidean distance between transmission node and receive node. By using NS-3, the results of PDR and the average RSSI when applying these models are shown in Figure 10. We observe that the graph characteristics of the simulation results



(a) PDR (b) RSSI

Figure 10: Simulation results when applying two-ray ground model coupled with Nakagami model. (a) PDR. (b) RSSI.



(a) PDR (b) RSSI

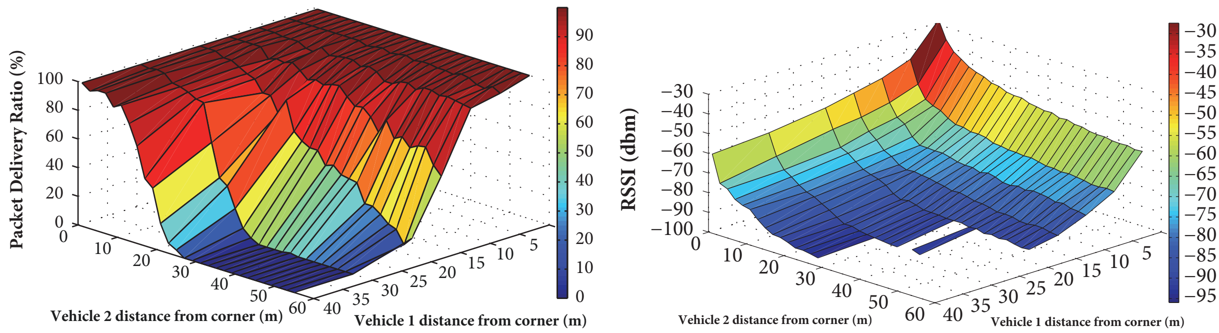
Figure 11: Results from real experiments for Electrical Engineering Lab. (a) PDR. (b) RSSI.

are similar to the results from real blind corner experiments. For more clarification, we simplify the result from real experiments in Figures 9(a) and 9(b) to 2-dimensional graph as shown in Figures 11(a) and 11(b). Each graph shows the result for different distances of vehicle 1. As can be seen, all the graphs have the same trend, similarly to S-shaped curve. Each point in the real experiment result in Figure 11 can be mapped to the result in Figure 10 by increasing the distance. On the other words, the signal characteristics when travelling through the blind corner behave the same as the signal when the vehicles are in line of sight at longer distance. As a result, we modify the distance calculation when the signals travel through blind corner. Since distance is the most important factor for calculation in the propagation models, modifying distance calculation is like modifying the characteristics of the models applied. This can represent characteristics of the communication at blind corners.

Referring to the variables depicted in Figure 3, we modify the distance calculation and use the summation of distances between the vehicles and the corner ($d_1 + d_2$) instead of using the Euclidean distance (d). This is because in the case of the blind corner this summation represents the distance the signal really travels. Moreover, as we discussed that the minimum distance is associated with the result, we add the minimum distance factor to the distance calculation. This factor represents that the closer the vehicle to the corner is, the smaller effect of blind corner the communication experiences. This leads to the higher PDR. As a result, the estimated distance is formulated as shown in the following equation:

$$\text{Estimated Distance} = (d_1 + d_2) \times \min(d_1, d_2) \qquad (1)$$

In order to investigate the PDR and RSSI results when applying our estimated distance equation, we set up the simulation scenario the same as the real experiment scenario which is shown in Table 2. There are 2 vehicles on different side of blind corners. The 2 vehicles are transmitting and



(a) PDR (b) RSSI

Figure 12: Results for preliminary simulation. (a) PDR. (b) RSSI.

Input: Location of vehicle V_1 and V_2, Obstacles list, α
Output: Distance
(1) Distance = UNKNOWN
(2) if there are obstacles between V_1 and V_2 then
(3) d_1 = Distance of V_1 from corner
(4) d_2 = Distance of V_2 from corner
(5) Distance = $(d_1 + d_2) \times \min(d_1, d_2) \times \alpha$
(6) else do
(7) Distance = Distance between V_1 and V_2
(8) end if
(9) return Distance

Algorithm 1: Blind corner model.

receiving IEEE 802.11p signal. The transmitted signal strength is 20 dBm. The traffic generated is 10 Hz beacon.

The result from the preliminary simulation is shown in Figure 12. As can be seen, the graph characteristics in Figure 12 are similar to the results from real experiments shown in Figure 9. The packet delivery ratio and the average RSSI have inverse variation to the distance. So we consider this method to be used in our model.

4.2. Proposed Blind Corner Model. From the experimental results in Figure 9, each type of blind corners does not obstruct the transmitted signal equally. The PDR ratio and the average RSSI are not the same for all blind corners. According to this reason, it can be seen that only the minimum distance is not enough for the model. Therefore, we add a parameter α in order to adjust the degree of the obstruction. Equation (2) formulates the modified version of the estimated distance from (1).

$$\text{Estimated Distance} = (d_1 + d_2) \times \min(d_1, d_2) \times \alpha \quad (2)$$

The parameter α is used to adjust the degree of the obstruction, which represents low obstruction to high obstruction. α must be greater than or equal to 0.4. If α is less than 0.4, it cannot be used because it makes the estimated distance lower than the real Euclidean distance. This will lead to nonrealistic simulation result.

The distance calculation can be divided into 2 cases: (1) line of sight and (2) non-line of sight. If the vehicles are in line of sight, it is not necessary to use our distance calculation model. The real Euclidean distance can be used as an input in Nakagami or two-ray ground models. However, if the vehicles are in non-line of sight, our distance calculation model is useful. The estimated distance calculated according to (2) can be used as an input in Nakagami or two-ray ground models instead. The algorithm that describes our distance calculation is shown in Algorithm 1.

5. Results and Discussion

In this section, we show the results from the simulation using our model and suggest the appropriate range of the parameter α. We simulate the scenarios using the simulation setting as shown in Table 2, so that all the settings will be the same as the real experiments. Then, we vary the value of α. We compare the results from the simulation and those from the real experiments for each blind corner. We calculate the root-mean-square error (RMSE) between the results from the simulation and those from the real experiments using (3). Equation (3) shows RMSE calculation, where i is the distance between the first vehicle and the corner, j is the distance between the second vehicle and the corner, $x_{i,j}$ is the PDR of the distance pair i, j from the real experiment, $s_{i,j}$ is the PDR from the simulation, and n is number of distance pairs. The RMSE for each α and each blind corner are shown in Figure 13.

$$\text{RMSE} = \sqrt{\frac{\sum_{\text{Each pair of distance } i,j} \left(x_{i,j} - s_{i,j}\right)^2}{n}} \quad (3)$$

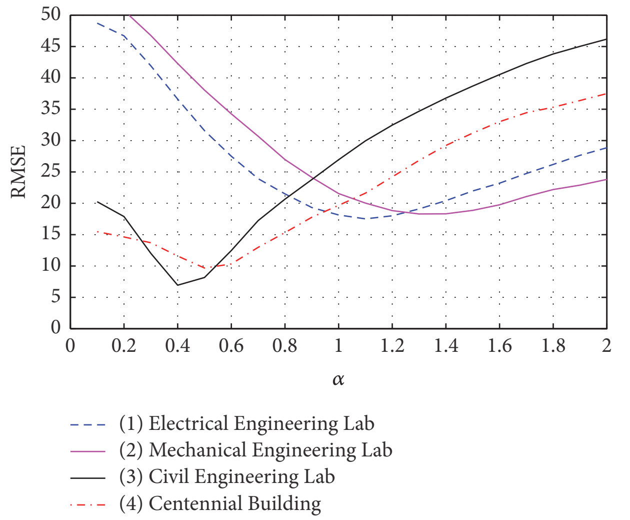
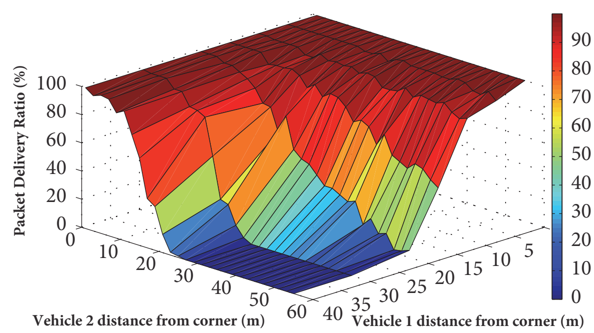
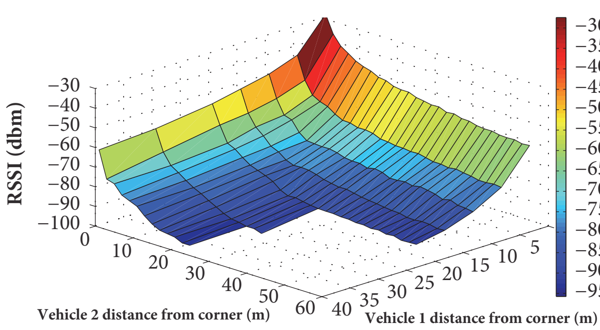


FIGURE 13: RMSE between simulation result and real experiment result.



(a) PDR

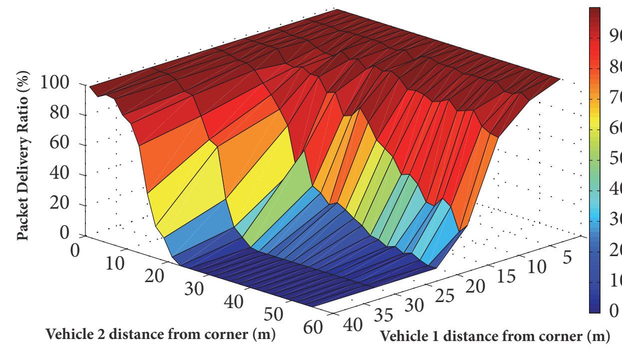


(b) RSSI

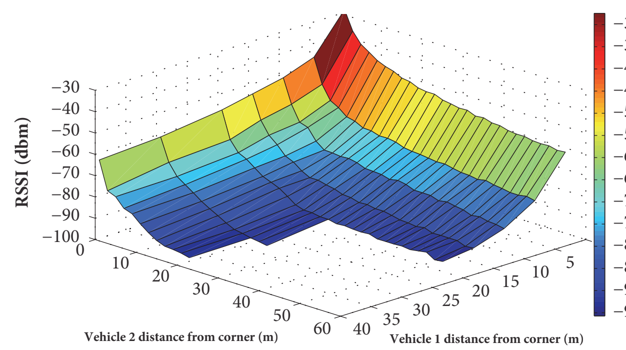
FIGURE 14: Results from the simulation with $\alpha = 1.1$ for blind corner with large obstruction. (a) PDR. (b) RSSI.

According to Figure 13, we suggest the weight factor α for each type of blind corners as follows.

For the first and the second blind corners of the building with large obstruction, we use α between 1.1 and 1.3. The simulation results using the recommended values 1.1 and 1.3 are shown in Figures 14 and 15, respectively. As can be seen, Figure 14 provides similar results to Figures 9(a) and 9(b). Figure 15 provides similar results to Figures 9(c) and 9(d).



(a) PDR



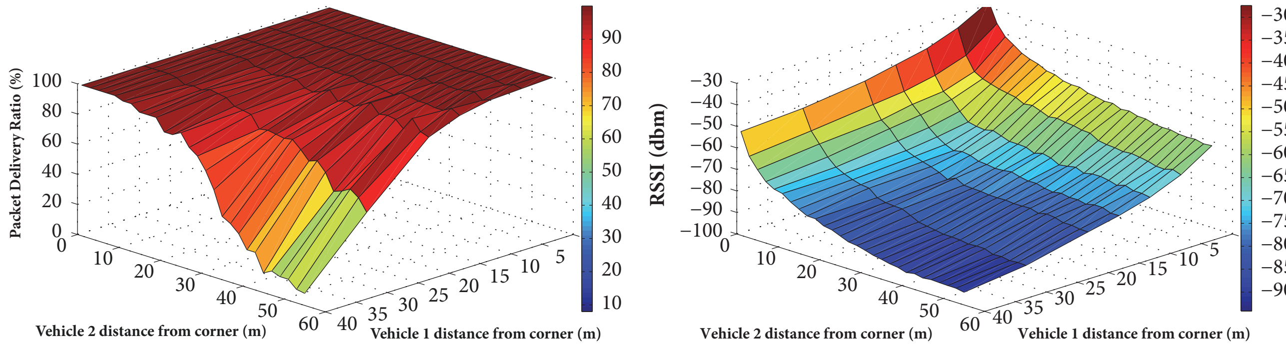
(b) RSSI

FIGURE 15: Results from the simulation with $\alpha = 1.3$ for blind corner with large obstruction. (a) PDR. (b) RSSI.

For the third and the fourth blind corners of the building with small obstruction, we use α between 0.4 and 0.5. The simulation results using the recommended values 0.4 and 0.5 are shown in Figures 16 and 17, respectively. As can be seen, Figure 16 provides similar results to Figures 9(e) and 9(f). Figure 17 provides similar results to Figures 9(g) and 9(h).

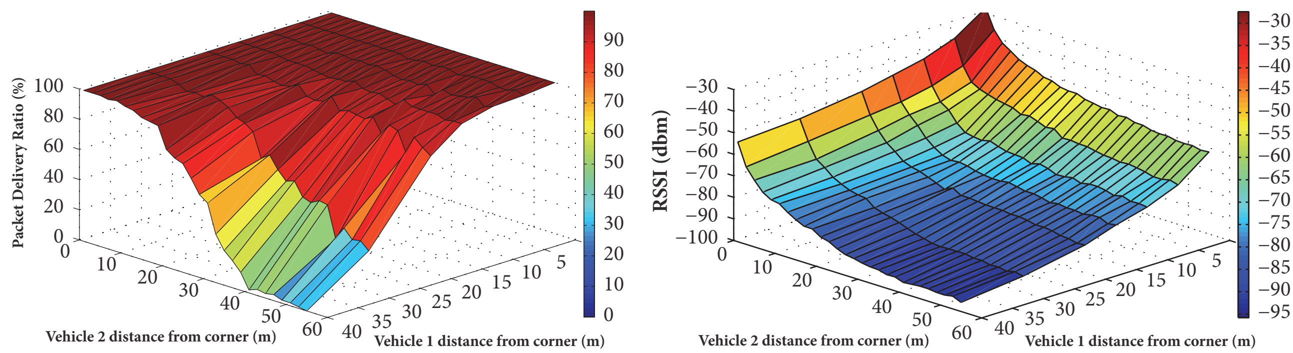
The results from the simulation are close to the results from real experiments. However, the results from the simulation have a higher PDR and average RSSI, and the graph trends are smoother than the graph for real experiments. This is because in real experiments there might be some other factors that we cannot detect or some factors that are difficult to produce in simulations such as environmental interferences.

We also compare our work with the obstacle model [8, 9] which is implemented in NS-3. The obstacle model is also embedded in Veins framework based on Omnet simulator, which is another popular network simulator. Therefore, we use the obstacle model as our baseline. The simulation scenario is set the same as the real experiment scenario, which is shown in Table 2. The results using the obstacle model are shown in Figure 18. As can be seen, the graph characteristics of PDR reduce rapidly at a specific range. The result does not reflect communication in real world, where PDR gradually reduces. Compared to our results shown in Figures 14–17, it can be seen that our model can provide much more similar results to the real world and better represents the real characteristics of IEEE 802.11p at blind corners.



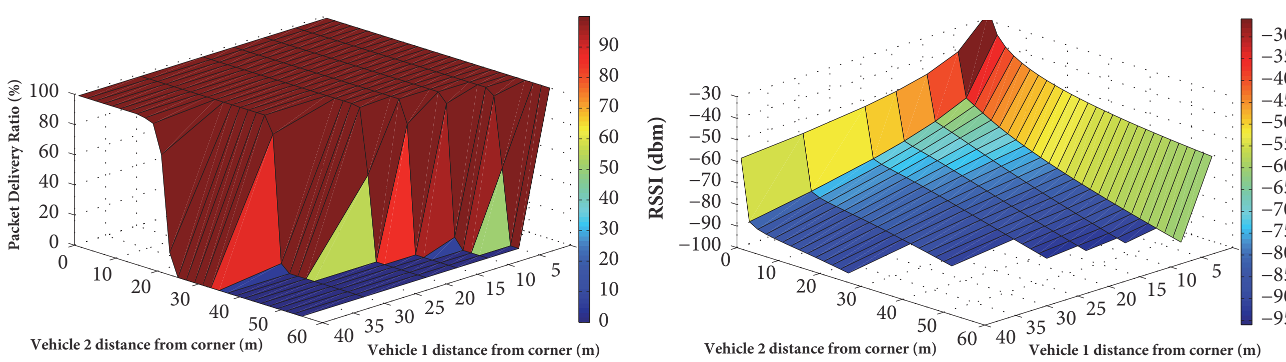
(a) PDR (b) RSSI

Figure 16: Results from the simulation with $\alpha = 0.4$ for blind corner with small obstruction. (a) PDR. (b) RSSI.



(a) PDR (b) RSSI

Figure 17: Results from the simulation with $\alpha = 0.5$ for blind corner with small obstruction. (a) PDR. (b) RSSI.



(a) PDR (b) RSSI

Figure 18: Results from the simulation when simulating with obstacle model. (a) PDR. (b) RSSI.

6. Conclusion

In this paper, we propose the blind corner model that represents the characteristics of IEEE 802.11p communication at blind corners. We modify the distance calculation when the signals travel through blind corner. Our model utilizes the minimum distance between the vehicles to the corner, which is the most important variable for propagation model calculation. Moreover, our model has a parameter to adjust the degree of the obstruction. We also conduct extensive real experiments with IEEE 802.11p communication devices and do comparison to the simulation result. According to the experimental results and the simulation results, we suggest that the parameter should be set between 1.1 and 1.3 for the buildings with large obstruction and between 0.4 and 0.5 for the buildings with small obstruction. The comparison result shows that our proposed model can represent the characteristics of IEEE 802.11p communication at blind corners better than the obstacle model. Therefore, our research is useful in research field. The protocols and applications can be tested realistically in blind corner scenarios by using our model.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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