Theoretical Analysis of Obstruction's Influence on Data Dissemination in Vehicular Networks

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Abstract. In vehicular networks (VNs), the radio propagation characteristics between two vehicles is greatly affected by the intermediate vehicles as obstruction, which has also been verified in many measurements. This property will definitely influence the routing protocol design in VNs, where the estimation of the one-hop transmission distance is of utmost importance on the relay selection. However, to the authors' best knowledge, the obstruction's influence has not been taken into consideration theoretically. In this paper, we propose an analytical model on the obstructed light-of-sight (OLOS) transmission distance. Based on a probabilistic method, the probability density function (PDF) of the one-hop OLOS transmission distance is obtained. Monte Carlo simulations are conducted to verify our proposed analytical model.

Keywords: Light-of-sight · Obstruction · Transmission range · Vehicular networks

1 Introduction

In vehicular networks (VNs), the received signal strength is easily affected by obstructions, like the buildings, trees or the vehicles between the transceivers. With obstructions, the line-of-sight (LOS) transmission will degrade into obstructed line-of-sight (OLOS) transmission. Many experiments had shown that obstructions cause significant impact on the channel quality, where an additional 10 to 20 dB attenuation can be found on the received signal strength [1,2]. Therefore, it is of great importance to study the influence of possible obstructions on the system design and performance evaluation.

The radio range differs between LOS and OLOS scenarios because of different attenuation degrees, where the OLOS radio range is much shorter. The shorter the radio range is, the less the one hop transmission distance is, which is important for routing protocol design in data dissemination. For example, the end-to-end delay might increase in obstructed scenario because of more transmission hop count requirement. However, not much researches considered the influence of obstructions on the protocol design or performance evaluation, especially in the theoretical aspect, which will be the focus of this paper.

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Extensive experiment works had shown that the vehicles as obstructions between transceivers can cause obvious decrease of signal power [2–6]. Based on this observation, many researchers considered the obstructed light-of-sight (OLOS) transmission in the simulations for routing protocol verification [7]. However, to the authors' best knowledge, although some works had conducted analysis for the routing performance in VNs [8], the analytical model for the OLOS circumstance is still an open issue.

In this paper, we analyze and model the influence of vehicle as obstruction on the one hop link transmission range in a two-lanes highway scenario given the traffic density information. We use the widely accept condition than the OLOS radio range is shorter than the LOS radio range, which is taken into consideration. With a dedicated routing protocol, the one hop transmission range changes with the vehicular density, which is modeled using a probabilistic method. Our proposed theoretical framework can give the probability density function of the one hop link transmission range.

The remainder of this paper is organized as follows. The related work of the discussed issue is introduced in Sect. 2. Section 3 presents the model hypotheses and definitions. The analysis architecture is proposed in Sect. 4. In Sect. 5, simulations are carried out to verify the accuracy of the proposed anaytical model. Last but not the least, Sect. 6 concludes the paper and proposes some possible direction in future.

2 Related Work

Many researchers have conducted experiment on the influence of obstructions on the radio propagation characteristics for VNs. The influence of the buildings, especially in the intersection scenario, on the signal attenuation is target in [3,4], where an obvious decrease of signal power can be found. In the straight road scenario, signal obstructed by vehicles between the transceivers is the main target. Meireles *et al.* [5] found that a single obstacle can cause a drop of over 20 dB on received signal strength when two cars communicate at a distance of 10 m. Measurements were also conducted by placing a bus between two cars acting as an obstruction, and found that this obstruction can create an additional 15- to 20-dB attenuation [2,6]. In [9], the propagation path losses are presented based on the uniform theory of diffraction in the OLOS cases, with several intermediate vehicles, for the inter-vehicle communications in the 60-GHz band. Many other literatures also found such obvious signal strength attenuation from different measurement campaigns [10–14].

In recent years, some literatures also considered the influence on system performance evaluation and routing protocol design. Some researchers focused on developing simulation framework for a more realistic fading environment description [7]. However, although the results from these simulation frameworks can be more accurate, the time consumption problem cannot be neglected. On the other hand, it is an accurate and effective analytical model that can provide more clear understanding for the fundamental trade-off between obstruction features (e.g. vehicles' position) and performance expectation (e.g. transmission distance, hop count, throughput, and delay etc.). The influence of radio range on the system performance has been modeled analytically in some work [8]. However, the influence of some obstructions on the signal attenuation is not taken into consideration. In recent years, some researchers conducted analysis with obstructed radio range. Chen *et al.* [15] modeled the joint effects of radio environment and traffic flow on link connectivity to investigate the relation between the obstruction probability and inter-vehicle connectivity probability. However, they did not give way to calculate the obstruction probability and not derive the influence of obstruction on the transmission distance. As far as we know, no literatures derived the transmission distance distribution with obstructions in the theoretical aspects.

3 System Model

All the vehicles are assumed moving on a highway with two lanes. The vehicle's location can be obtained by the Global Position System (GPS) unit, which is assumed to be installed in each vehicle. A vehicle can know all its neighbour's position information from the continuous exchanged beacon information or triggering information. A transmitter or relay will choose the furthest vehicle as the next hop relay according to the aforementioned assumption. Vehicles are distributed along the road in accordance with a spatial one-dimensional Poisson point process (1-PPP), which has been deemed to be appropriate under free flow conditions. The width of road is ignored and the traffic flows are independent of each other. All drivers tend to maintain a constant spacing with their leader based on the car-following model, where all vehicles in the same lane have the same velocity.

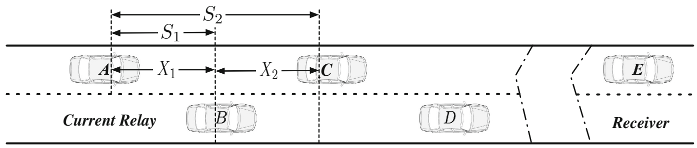

Fig. 1. An example for the adopted relay selection policy

Suppose that no static infrastructure exists or incomplete covered dedicated base stations are built, therefore, many transmission, especially when the transceiver distance is long, should be finished through multi-hop transmission. The baseline routing protocol chosen for this paper is the Greedy Perimeter Stateless Routing (GPSR) [16], based on which many work proposed some revised versions. The principle for this kind of protocols is that the furthest vehicle in current relay's radio range will be selected as the next hop relay. For example, in Fig. 1, suppose that vehicles, B, C and D are neighbours of the current relay vehicle A. Therefore, the vehicle D will be selected as the next hop relay, which is also named as the furthest vehicle in A's radio range. The distance between two relay vehicles is defined as *one-hop transmission distance*.

For the analysis tractability, the LOS radio range R_{LOS} and the obstructed radio range R_{OLOS} is assumed to be a constant.

4 Theoretical Analysis

Since the analysis is conducted on a two-lanes scenario, the derivation of one-hop transmission distance distribution is also divided into two cases: the intra-lane one-hop transmission distance and the inter-lane one-hop transmission distance. After obtaining both of the distribution of the single lane's one-hop transmission distance distribution, the two-lanes one-hop transmission distance distribution will be derived at the end of this section.

4.1 One-Hop LOS Transmission Distance

Let X_i denote the inter-vehicle distance between the $(i-1)$-th and the i-th nearest vehicle in the neighbouring vehicle set in the intra-lane scenario, which can be illustrated in Fig. 1. Since the inter-vehicle distance X_i are positive, independent, identically distributed, random variables, the n vehicles cumulative distance S_n is defined as:

$$S_n = \sum_{i=1}^{n} X_i,\ n \geq 1. \tag{1}$$

The cumulative density function (CDF) of the one-hop LOS transmission distance X_{L} will be derived as following. First, the probability of $F_{X_{\mathrm{L}}}(0)$ can be represented as:

$$F_{X_{\mathrm{L}}}(0) = \Pr\{X_{\mathrm{L}} = 0\} = \Pr\{X_1 > R_{\mathrm{L}}\}. \tag{2}$$

We have the density function of inter-vehicle distance X_1 as:

$$F_{X_1}(x) = 1 - e^{-\lambda x}. \tag{3}$$

and

$$f_{X_1}(x) = \lambda_1 e^{-\lambda x}. \tag{4}$$

Therefore, $F_{X_{\mathrm{L}}}(0)$ can be obtained as:

$$F_{X_{\mathrm{L}}}(0) = e^{-\lambda R_{\mathrm{L}}}. \tag{5}$$

Otherwise, when the one-hop LOS transmission distance is greater than zero, $F_{X_{\mathrm{L}}}(x)$ can be obtained as:

$$\begin{aligned}
F_{X_{\mathrm{L}}}(x) &= F_{X_{\mathrm{L}}}(0) + \Pr\{x > 0, X_{\mathrm{L}} \le x\} \\
&= e^{-\lambda R_{\mathrm{L}}} + \Pr\{X_1 \le R_{\mathrm{L}}\}\Pr\{S_N \le x, S_{N+1} > R_{\mathrm{L}}\} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{L}}})\sum_{n=0}^{\infty}\Pr\{N_{[0,x]} = n\}\cdot\Pr\{N_{[x,R_{\mathrm{L}}]} = 0\} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{L}}})\sum_{n=0}^{\infty}\frac{[\lambda x]^n}{n!}e^{-\lambda(x)}\cdot e^{-\lambda(R_{\mathrm{L}}-x)} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{L}}})e^{-\lambda(R_{\mathrm{L}}-x)}.
\end{aligned} \tag{6}$$

Consequently, we have the probability density function (PDF) of X_{L} as:

$$f_{X_{\mathrm{L}}}(x) = \lambda(1 - e^{-\lambda R_{\mathrm{L}}})e^{-\lambda(R_{\mathrm{L}}-x)}. \tag{7}$$

In summarization, the CDF of the one-hop LOS transmission distance can be obtained as:

$$F_{X_{\mathrm{L}}}(x) = \begin{cases} e^{-\lambda R_{\mathrm{L}}}, & x = 0 \\ e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{L}}})e^{-\lambda(R_{\mathrm{L}}-x)}, & \text{otherwise} \end{cases}. \tag{8}$$

4.2 One-Hop OLOS Transmission Distance

As for the CDF of the one-hop OLOS transmission distance $F_{X_{\mathrm{O}}}(x)$, the derivation should be split into three cases, that is $x = 0$ (case I), $0 < x \le R_{\mathrm{O}}$ (case II), and $R_{\mathrm{O}} < x \le R_{\mathrm{L}}$ (case III), respectively.

Case I: The CDF value $F_{X_{\mathrm{O}}}(0)$ can be obtained similarly as that for the LOS circumstance, we have

$$F_{X_{\mathrm{O}}}(0) = e^{-\lambda R_{\mathrm{L}}}. \tag{9}$$

Case II: When $0 < x \le R_{\mathrm{O}}$, it means that at least one vehicle existing in R_{O} distance. Therefore, we have

$$\begin{aligned}
F_{X_{\mathrm{O}}}(x) &= F_{X_{\mathrm{O}}}(0) + \Pr\{X_1 \le R_{\mathrm{O}}, X_{\mathrm{O}} \le x\} \\
&= e^{-\lambda R_{\mathrm{L}}} + \Pr\{X_1 \le R_{\mathrm{O}}\}\Pr\{S_{N-1} \le x - X_1, S_N > R_{\mathrm{O}} - X_1 | x \le R_{\mathrm{O}}\} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{O}}})\sum_{n=0}^{\infty}\Pr\{N_{[0,x]} = n\}\cdot\Pr\{N_{[x,R_{\mathrm{O}}]} = 0\} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{O}}})\sum_{n=0}^{\infty}\frac{(\lambda x)^n}{n!}e^{-\lambda x}\cdot e^{-\lambda(R_{\mathrm{O}}-x)} \\
&= e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{O}}})e^{-\lambda(R_{\mathrm{O}}-x)}.
\end{aligned} \tag{10}$$

Take the derivation at x, we can obtain the corresponding PDF as:

$$f_{X_{\mathrm{O}}}(x) = \lambda(1 - e^{-\lambda R_{\mathrm{O}}})e^{-\lambda(R_{\mathrm{O}}-x)}. \tag{11}$$

Case III: When $R_{\mathrm{O}} < x \leq R_{\mathrm{L}}$, it means that the first vehicle's position X_1 is greater than R_{O}. In this case, the first vehicle will be selected as the next hop relay, and we have

$$\begin{aligned} F_{X_{\mathrm{O}}}(x) &= F_{X_{\mathrm{O}}}(R_{\mathrm{O}}) + \Pr\{X_1 > R_{\mathrm{O}}, X_{\mathrm{O}} \leq x\} \\ &= F_{X_{\mathrm{O}}}(R_{\mathrm{O}}) + \Pr\{R_{\mathrm{O}} < X_1 \leq x\} \\ &= 1 + e^{-\lambda R_{\mathrm{L}}} - e^{-\lambda x}. \end{aligned} \tag{12}$$

Take the derivation at x, we can obtain the corresponding PDF as:

$$f_{X_{\mathrm{O}}}(x) = \lambda e^{-\lambda x}. \tag{13}$$

In summarization, the CDF of the one-hop OLOS transmission distance can be obtained as:

$$F_{X_{\mathrm{O}}}(x) = \begin{cases} e^{-\lambda R_{\mathrm{L}}}, & x = 0 \\ e^{-\lambda R_{\mathrm{L}}} + (1 - e^{-\lambda R_{\mathrm{O}}})e^{-\lambda(R_{\mathrm{O}}-x)}, & 0 < x \leq R_{\mathrm{O}} \\ 1 + e^{-\lambda R_{\mathrm{L}}} - e^{-\lambda x}, & \text{otherwise} \end{cases}. \tag{14}$$

Meanwhile, the PDF of the one-hop OLOS transmission distance can be obtained as:

$$f_{X_{\mathrm{O}}}(x) = \begin{cases} \lambda(1 - e^{-\lambda R_{\mathrm{O}}})e^{-\lambda(R_{\mathrm{O}}-x)}, & 0 \leq x \leq R_{\mathrm{O}} \\ \lambda e^{-\lambda x}, & \text{otherwise} \end{cases}. \tag{15}$$

5 Performance Evaluation

In this section, Monte Carlo simulations are conducted to verify our proposed analytical model.

5.1 Simulation Setup

In our simulations, vehicles move within a fixed region of a two-way highway road segment with the length of L. The vehicular density is assumed to be a constant value for a relative short time period, which is denoted as λ vehicles per second (vehs/s). To have a fixed number of vehicles in the target road segment, we assume that the exit vehicle will enter the highway immediately and start to move toward the opposite direction [17]. The default value of major parameters for this simulation is shown in Table 1.

Simulations were run using different parameters and system settings. The performance analysis is designed to compare the effects of different parameters, such as the LOS radio range, the OLOS radio range, and the vehicular density etc. For each simulation parameter set, the values of the one-hop transmission distance distribution are obtained by collecting a large number of samples such that the confidence interval is reasonably small. In most cases, the 95% confidence interval for the measured data is less than 10% of the sample mean.

Table 1. Default Value of the Simulation Parameters

Parameter	Description	Value
R_{L}	The LOS radio range	250 m
R_{O}	The OLOS radio range	150 m
λ	The vehicular density	0.01 vehs/s
N	The number of Monte Carlo simulations	10^5
N_{h}	The number of histogram	10

5.2 LOS Scenario

Figure 2 depicts the PMF of the one-hop LOS transmission distance, where the results are compared between the simulations and our analytical model. Since the statical results are from the extensive Monte Carlo simulations, only an estimation of probability mass function (PMF) can be obtained. For the tractability of the comparison, the PMF value is estimated from the proposed analytical model with a integral function. As can be seen from Fig. 2, results from our proposed analytical model matches with well with that from the simulations, which is verified using the chi-square goodness fit test. In general, the chi-square test statistic is of the form

$$\chi^2 = \sum_{i=1}^{N_{\mathrm{h}}} \frac{\rho_i^{\mathrm{ana}} - \rho_i^{\mathrm{simu}}}{\rho_i^{\mathrm{simu}}} \tag{16}$$

where N_{h} denotes the number of histogram, ρ_i^{simu} and ρ_i^{ana} represent the values from the Monte Carlo simulations and the proposed analytical model, respectively. Based on the chi-square test statistic theory, $\chi^2 = 2.0311$, which is less than 55.758, the threshold value corresponding to the 0.05 significance level.

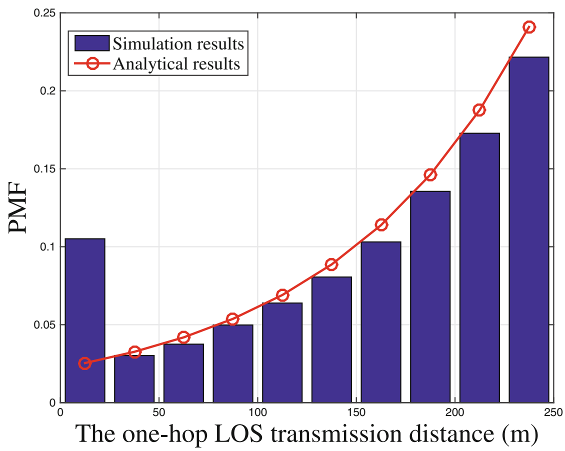

Fig. 2. The PMF of one-hop LOS transmission distance

That is, we can accept the hypothesis at the 0.05 significance level that the PDF from our proposed one-hop LOS transmission model fits with that from the statistical results with Monte Carlo simulations. Moreover, it's a significant tendency that the PMF value increases with the distance since the adopted routing protocol tries to select the furthest vehicle in its radio range as the next-hop relay vehicle.

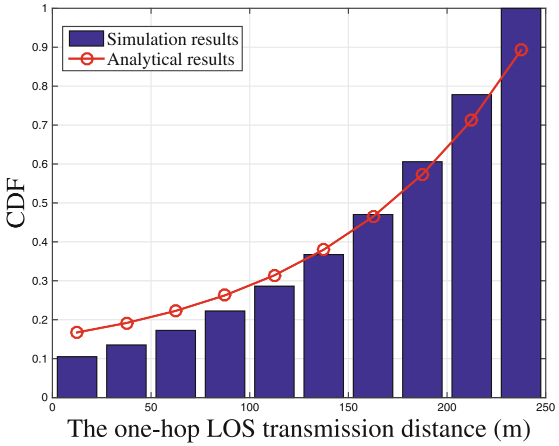

Fig. 3. The CDF of one-hop LOS transmission distance

Figure 3 conducts a comparison on the CDF of one-hop LOS transmission distance. Based on the chi-square test statistic theory, $\chi^2 = 1.4$, which is less than 55.758, the threshold value corresponding to the 0.05 significance level. We can accept the hypothesis at the 0.05 significance level that the CDF from our proposed one-hop LOS transmission model fits with that from the statistical results with Monte Carlo simulations.

5.3 OLOS Scenario

Figure 4 compares the PMF of the one-hop OLOS transmission distance between Monte Carlo simulations and our proposed analytical model. First, compared to the simulation results from that in Fig. 2, we can see that curve shape is quite different. By considering the intermediate vehicle's obstruction, the PMF of the one-hop OLOS transmission distance shows a significant fluctuation at the OLOS radio range. Although with one singular point, our analytical model can better describe the actual circumstance. Based on the chi-square test statistic theory, $\chi^2 = 1.5714$, which is less than 55.758, the threshold value corresponding to the 0.05 significance level. That is, we can accept the hypothesis at the 0.05 significance level that the PDF from our proposed one-hop OLOS transmission model fits with that from the statistical results with Monte Carlo simulations.

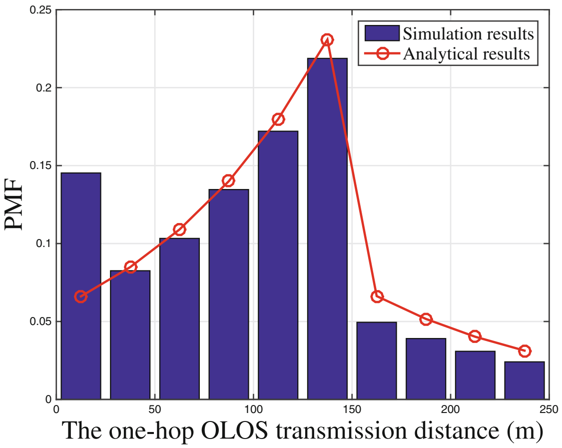

Fig. 4. The PMF of one-hop OLOS transmission distance

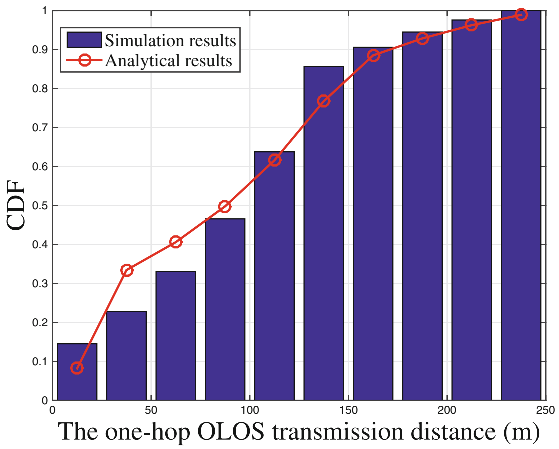

Fig. 5. The CDF of one-hop OLOS transmission distance

Figure 5 conducts a comparison on the CDF of one-hop OLOS transmission distance. Based on the chi-square test statistic theory, $\chi^2 = 1.8686$, which is less than 55.758, the threshold value corresponding to the 0.05 significance level. We can accept the hypothesis at the 0.05 significance level that the CDF from our proposed one-hop OLOS transmission model fits with that from the statistical results with Monte Carlo simulations.

5.4 Comparison Between LOS and OLOS Scenarios

Figure 6 presents the average one-hop transmission distance verse OLOS radio range R_{O}. Since the LOS circumstance is assumed no affected by the obstructions,

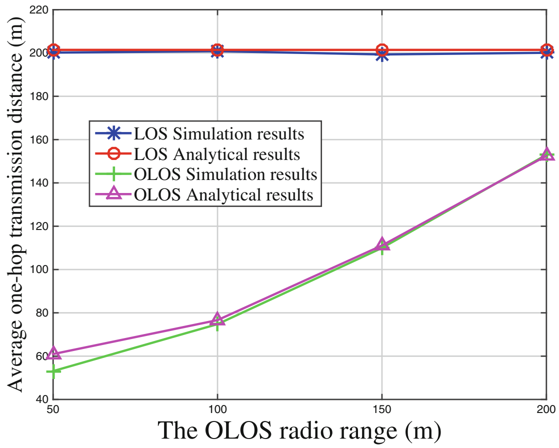

Fig. 6. The average one-hop transmission distance verse OLOS radio range

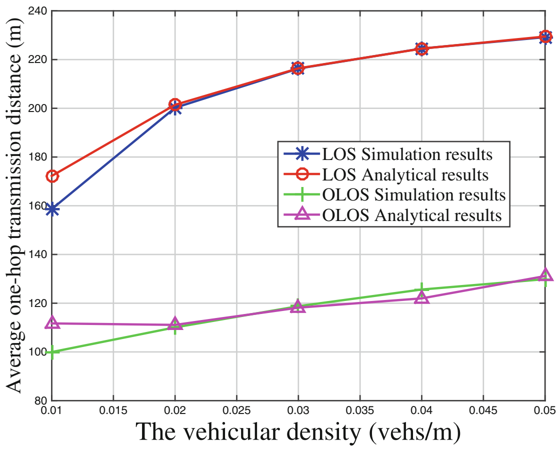

Fig. 7. The average one-hop transmission distance verse vehicular density

the average one-hop transmission distance keep stable with different OLOS radio range. In contrast, in the OLOS circumstance, the one-hop OLOS transmission distance increase with the OLOS radio range. Overall, in both LOS and OLOS circumstances, the simulation results of average one-hop transmission range match well with that from our proposed analytical model.

Figure 7 is plotted to show the influence of the vehicular density on the one-hop transmission distance. Both LOS and OLOS circumstances show a increasing tendency with the vehicular density. Again, in both LOS and OLOS circumstances, the simulation results of average one-hop transmission range match well with that from our proposed analytical model.

6 Discussion

This paper proposed an analytical model for the obstructed light-of-sight (OLOS) scenario in vehicular networks (VNs). The influence of the OLOS/LOS radio range and the vehicular density is carefully derived for the probability density function (PDF) of the one-hop transmission distance. With the PDF of the one-hop link distance, the traditional routing protocol can be modified to adapt to the real scenario, which will be one of our future works. Moreover, the performance evaluation is conducted with Monte Carlo simulations in this paper. An experiment-based model verification work will our another future work.

References

1. Meireles, R., Boban, M., Steenkiste, P., Tonguz, O., Barros, J.: Experimental study on the impact of vehicular obstructions in VANETs. In: Proceedings of IEEE Vehicular Networking Conference (VNC), pp. 338–345, December 2010
2. He, R., Molisch, A., Tufvesson, F., Zhong, Z., Ai, B., Zhang, T.: Vehicle-to-vehicle channel models with large vehicle obstructions. In: Proceedings of IEEE International Conference on Communications (ICC), pp. 5647–5652, June 2014
3. Mangel, T., Klemp, O., Hartenstein, H.: A validated 5.9 GHz non-line-of-sight path-loss and fading model for inter-vehicle communication. In: Proceedings of 11th International Conference on ITS Telecommunications (ITST), pp. 75–80, August 2011
4. Mangel, T., Schweizer, F., Kosch, T., Hartenstein, H.: Vehicular safety communication at intersections: Buildings, non-line-of-sight and representative scenarios. In: Proceedings of Eighth International Conference on Wireless On-Demand Network Systems and Services (WONS), pp. 35–41, January 2011
5. Boban, M., Vinhoza, T., Ferreira, M., Barros, J., Tonguz, O.: Impact of vehicles as obstacles in vehicular ad hoc networks. IEEE J. Sel. Areas Commun. **29**(1), 15–28 (2011)
6. He, R., Molisch, A., Tufvesson, F., Zhong, Z., Ai, B., Zhang, T.: Vehicle-to-vehicle propagation models with large vehicle obstructions. IEEE Trans. Intell. Trans. Syst. **15**(5), 2237–2248 (2014)
7. Sommer, C., Joerer, S., Dressler, F.: On the applicability of two-ray path loss models for vehicular network simulation. In: Proceedings of IEEE Vehicular Networking Conference (VNC), pp. 64–69, November 2012
8. Wang, B., Yin, K., Zhang, Y.: An exact Markov process for multihop connectivity via intervehicle communication on parallel roads. IEEE Trans. Wirel. Commun. **11**(3), 865–868 (2012)
9. Yamamoto, A., Ogawa, K., Horimatsu, T., Kato, A., Fujise, M.: Path-loss prediction models for intervehicle communication at 60 GHz. IEEE Trans. Veh. Technol. **57**(1), 65–78 (2008)
10. Paier, A., Bernado, L., Karedal, J., Klemp, O., Kwoczek, A.: Overview of vehicle-to-vehicle radio channel measurements for collision avoidance applications. In: Proceedings of IEEE 71st Vehicular Technology Conference (VTC 2010-Spring), pp. 1–5, May 2010
11. Boban, M., Meireles, R., Barros, J., Tonguz, O., Steenkiste, P.: Exploiting the height of vehicles in vehicular communication. In: Proceedings of IEEE Vehicular Networking Conference (VNC), pp. 163–170, November 2011

12. Abbas, T., Tufvesson, F., Karedal, J.: Measurement based shadow fading model for vehicle-to-vehicle network simulations. Int. J. Antennas Propag. (2012)
13. Wang, C.-X., Cheng, X., Laurenson, D.: Vehicle-to-vehicle channel modeling and measurements: recent advances and future challenges. IEEE Commun. Mag. **47**(11), 96–103 (2009)
14. Boban, M., Meireles, R., Barros, J., Steenkiste, P., Tonguz, O.: TVR: tall vehicle relaying in vehicular networks. IEEE Trans. Mob. Comput. **13**(5), 1118–1131 (2014)
15. Chen, R., Zhong, Z., Leung, V.C.M., Michelson, D.G.: Performance analysis of connectivity for vehicular ad hoc networks with moving obstructions. In: Proceedings of IEEE 80th Vehicular Technology Conference (VTC2014-Fall), pp. 1–5, September 2014
16. Karp, B., Kung, H.-T.: GPSR: Greedy perimeter stateless routing for wireless networks. In: Proceedings of the 6th Annual International Conference on Mobile Computing and Networking. ACM, pp. 243–254 (2000)
17. Zhang, Y., Cao, G.: V-PADA: vehicle-platoon-aware data access in VANETs. IEEE Trans. Veh. Technol. **60**(5), 2326–2339 (2011)