Analysis on V2V Connectivity under Dual-slope Path Loss Model in Urban Scenarios

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Abstract

Studying the connectivity characteristics is essential to investigate the communication performance metrics in wireless vehicular networks. In this paper, connection probability in V2V urban scenarios is analyzed based on a dual-slope path loss model. Conducted on both line-of-sights (LOS) and obstructed LOS (OLOS) radio propagation environments, the simulation results validate the correctness of the analysis. It is found that both the radio environment and transmission distance have the significant impact on connection probability.

1. Introduction

As a special type of mobile ad hoc networks (MANETs), vehicular ad hoc networks (VANETs) comprise self-organizing vehicles and roadside infrastructures, which can disseminate safety-related warnings and traffic messages through wireless multi-hop links via two communication modes: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I).

The safety messages and traffic information are supposed to be received by every individual vehicle in time, in order to efficiently avoid accidents and remarkably reduce traffic congestions [1]. On account of dynamics of network topology and complex radio environments, the wireless transmission is difficult to establish and maintain. In addition, the connected links may be interrupted unpredictably [2]. Hence, it is fundamental and essential to investigate the properties of link connectivity in V2V scenarios.

There are a range of published literatures about connectivity performance analysis for vehicular networks. Some of the existing papers reflect the effects of radio environment on connectivity performance based on log-normal shadow fading model for VANETs scenarios [3-5]. Considering the complexity of radio environment in urban scenarios, the analysis under log-normal shadowing model might be limited in capturing the realistic characteristics and the existence of surrounding obstacles, such as the buildings and other vehicles.

In this paper, the effects of the radio environment in V2V urban scenarios on connectivity characteristics are analyzed based on a more realistic model: dual-slope path loss model. The connection probability of inter-vehicle link can be calculated based on dual-slope path loss model, regarding both line-of-sights (LOS) and obstructed LOS (OLOS) radio propagation environments.

The remainder of the paper is organized as follows. Section 2 briefly introduces the dual-slope path loss model. In Section 3, the connection probability of inter-vehicle link can be analyzed and the simulation results are presented. Finally, Section 4 concludes the paper.

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2. Path Loss Model

To more realistically capture the radio propagation characteristics and accurately describe the path loss over distance, dual-slope path loss model in [6] fits the mean values of measurement data sets of both LOS and OLOS in V2V urban scenarios.

The dual-slope path loss model can be expressed as

$$PL(d) = \begin{cases} PL_0 + 10n_1 \log_{10}\left(\dfrac{d}{d_0}\right) + X_\sigma & \text{if } d \le d_b \\ PL_0 + 10n_1 \log_{10}\left(\dfrac{d_b}{d_0}\right) + 10n_2 \log_{10}\left(\dfrac{d}{d_b}\right) + X_\sigma & \text{if } d > d_b \end{cases}, \tag{1}$$

where d is the transmission distance, $PL(d)$ is the path loss at distance d (in dB), PL_0 is the reference path loss at the reference distance d_0, d_b is considered as the breakpoint distance at which the first Fresnel zone touches the ground, n_1 and n_2 being the path loss exponents which indicate the rate with which the received signal power decays within d_b and from d_b respectively. The breakpoint distance d_b is about 165 m in urban environment for vehicular communications.

3. Connection Probability

Connection probability, denoted by P_c, can be defined as the probability that two individual vehicles are connected and can directly communicate with each other. For two vehicles separated by a certain distance d, they can directly communicate, conditioned on that the path loss over the transmission distance d is less than a given threshold value PL_{th}, that is $PL(d) < PL_{th}$.

When the transmission distance is less than the breakpoint distance, that is $d < d_b$, the connection probability of two communication vehicles in this situation can be calculated as

$$\begin{aligned} P_c(d) &= \Pr\{PL(d) < PL_{th}; d < d_b\} \\ &= \Pr\{PL_0 + 10n_1 \log_{10}(d) + X_\sigma < PL_{th}\}, \\ &= \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{10n_1 \log_{10}(d / r_0)}{\sqrt{2}\sigma}\right)\right] \end{aligned} \tag{2}$$

where the function $\operatorname{erf}(t) = \frac{2}{\sqrt{\pi}}\int_0^t e^{-x^2}dx$, and $r_0 = 10^{\frac{PL_{th} - PL_0}{10n_1}}$ is a critical transmission range in the absence of shadowing fading (i.e. σ =0) within d_b.

In the same way, the connection probability in the case that the transmission distance is farther than the breakpoint distance ($d > d_b$) can be given by

$$\begin{aligned} P_c(d) &= \Pr\{PL(d) < PL_{th}; d > d_b\} \\ &= \Pr\{PL_0 + 10n_1 \log_{10}\left(d_b / d_0\right) + 10n_2 \log_{10}\left(d / d_b\right) + X_\sigma < PL_{th}\}, \\ &= \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{10n_2 \log_{10}(d / (d_b r_1))}{\sqrt{2}\sigma}\right)\right] \end{aligned} \tag{3}$$

where $r_1 = 10^{\frac{PL_{th} - PL_0 - 10n_1 \log_{10}(d_b)}{10n_2}}$ is also a critical transmission range farther than d_b.

Therefore, the connection probability P_c can be numerically calculated by combining formulas (2) and (3). Obviously, the connection probability mainly depends on the transmission distance and radio environments. We establish a simulation platform to evaluate the effects of different radio propagation parameters on the connection probability in V2V urban scenarios. Both the analytical and simulation results are obtained under the dual-slope path loss model, in both LOS and OLOS radio environments.

Table 1 illustrates the radio propagation parameters for dual-slope path loss model in V2V urban scenarios based on the measurement data sets of both LOS and OLOS in [6]. To reflect more realistic characteristics, the effects of radio environments on connectivity probability are studied and simulated based on these parameters.

Table 1. Radio Propagation Parameters

	n_1	n_2	σ
LOS	1.84	2.85	4.15
OLOS	1.93	2.74	6.67

Both the analytical and simulation results of connection probability P_c under dual-slope path loss are presented in Fig. 1, based on the simulation parameters of LOS and OLOS in urban scenarios as revealed in Table 1. Connection probability P_c can be represented as a function of transmission distance.

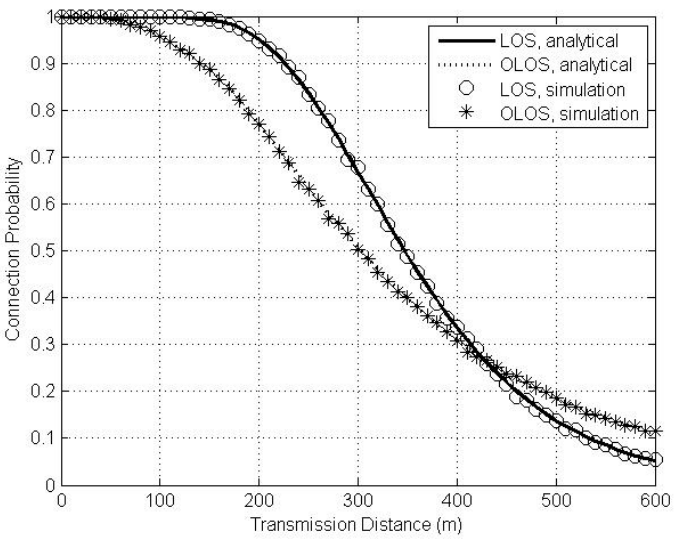

Fig. 1. Connection probability *Pc* under dual-slope path loss model.

As depicted in Fig. 1, the simulation results fit well in the analysis, validating the correctness of analytical deviation. Evidently, the connectivity performance is better in LOS radio propagation environment than that in OLOS in the case of short transmission distance in urban scenarios. As demonstrated in the figure, the connection probability is higher in LOS environment when the communication distance is less than about 420 m. It is noteworthy that the connectivity can achieve higher in OLOS environment when the transmission distance is farther than 420 m.

4. Conclusion

In this paper, the effects of radio environment on the connectivity characteristics of wireless link are studied based on the dual-slope path loss model in V2V urban scenarios. Both the analytical and simulation results of connection probability are presented in the situations of both LOS and OLOS radio propagations. It can be found that the connection probability is better in LOS propagation in the case of shorter communication distance, while connectivity can get improved under OLOS environment in longer transmission distance.

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