

Measurement Based V2V Path Loss Analysis in Urban NLOS Scenarios

Jihoon Joo, Odongo Steven Eyobu, Dong Seog Han*
School of Electronics Engineering
Kyungpook National University
Daegu, Republic of Korea
dshan@knu.ac.kr

Hong-Jong Jeong
CTO
Wayties Inc.
Seoul, Republic of Korea
hj@wayties.com

Abstract— The importance of an accurate path loss model of vehicular environments is critical for the vehicular communication system design. However, estimating the path loss in vehicular environments is difficult due to high dynamics and low antenna heights. In this paper, we propose a line-of-sight (LOS) path loss model in vehicle-to-vehicle (V2V) scenarios and provide deep analysis of shadow fading in urban non-LOS (NLOS) scenarios by the deductive method with the proposed LOS model. The results can be utilized as reference material for further analysis of V2V path loss measurements.

Keywords— V2V path loss model, measurements, urban NLOS scenarios, shadow fading.

I. INTRODUCTION

Understanding the nature of path loss in vehicular communication is an extremely important issue for the purpose of system design and deployment [1]. Especially for vehicular communication system, the path loss model is widely utilized because the performance evaluation mainly depends on computer simulations due to both financial and time cost limitation. Also, the vehicle-to-vehicle (V2V) propagation model can be reflected in the protocol design for improvement of system level performance [2].

Path loss in vehicular environments is difficult to estimate due to high dynamic factors and low antenna heights. Dynamics represented by mobilities of vehicles make varying surrounding environments therefore making vehicular communication channel environments difficult to be standardized. Also, antenna placements for vehicles are restricted to the roof of the vehicle which is highest placement. Thus vehicular communication channel environments can easily be exposed to obstacles which induce non-line-of-sight (NLOS).

There have been some efforts to model the path loss in vehicular environments. Extensive survey of the V2V measurement campaign and path loss models can be found in [3]. Cheng *et al.* [4] proposed a dual-slope path loss model for V2V scenarios in suburban. Path loss models in various environments for V2V scenarios, including urban, suburban, rural, and highway are proposed in [5]. The path loss modeling for specific NLOS scenarios such as sloped terrain is studied in [6]. However, these models are not standardized so they cannot be guaranteed to be same in all other environments.

In this paper, we analyze received power measurement data in NLOS scenarios with a deductive method. In other words, the path loss model for line-of-sight (LOS) scenarios is proposed with extensive experiments with our V2V path loss measurement campaign. Then we compare the LOS model and received power data in NLOS scenarios and analyze the shadow fading effects.

The remainder of this paper is organized as follows. In Section II, we provide the V2V path loss measurement campaign utilized in our experiments. Section III presents our measurement data in both LOS and NLOS scenarios and proposes LOS model and analysis of NLOS measurement data. The conclusion of this paper is made in Section IV.

II. V2V PATH LOSS MEASUREMENT CAMPAIGN

For the V2V path loss measurement, two cars equipped with commercial vehicle-to-X (V2X) platforms which are totally compliant with IEEE 802.11p and wireless access in vehicular environments (WAVE), international standards for vehicular communications, were utilized. Communication parameters of V2X platforms were set to general beaconing scenarios: a center frequency of 5.89 GHz (control channel), a channel bandwidth of 10 MHz, a transmission power of 20 dBm and a packet length of 400 bytes. For the efficiency, we set the transmission interval of 50 ms, two times frequent for general beaconing, to collect more measurement data per unit time. Note that shorter transmission interval has no effect on the reception performance if there are only two communicating nodes. Omnidirectional antennas were utilized and the heights of antenna placement were 1.5 m.

We classified the measurement environments as LOS and NLOS scenarios. The received signal strength measurement data in the LOS path loss scenario were acquired with regard to the separation distance between transmitter and receiver from 0 m to over 1000 m. Note that the coverage of the V2X communications is defined as 1000 m in the WAVE standard. For NLOS path loss scenario, we considered a block of several buildings as an obstacle which blocks LOS between transmitter and receiver. Experiments were conducted with two cars driving around the building while they tried to keep the constant distance.

This research was supported by the MSIP (Ministry of Science, ICT and Future Planning), Korea, under the ITRC (Information Technology Research Center) (IITP-2016-H8601-16-1002) supervised by the IITP (Institute for Information & communications Technology Promotion)

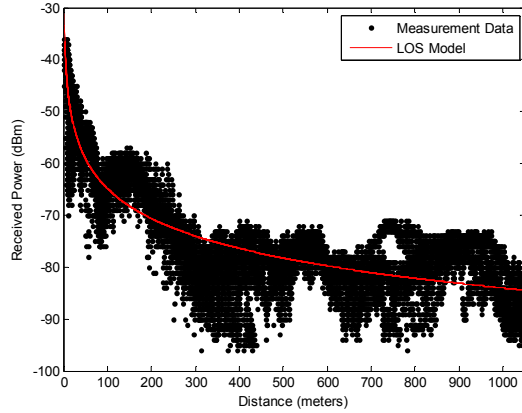


Fig. 1. Measurement received power data in LOS scenarios and their modeling results.

III. V2V PATH LOSS MEASUREMENT DATA ANALYSIS

This section introduces LOS measurement data and their modeling results, plus NLOS measurement data and their comparison results with a LOS model to observe a shadow fading effect for NLOS scenarios.

A. Modeling a Line-Of-Sight Measurement Data

Fig. 1 shows that the received power with respect to the separation distance according to our LOS measurement environments described in Section II. The LOS measurement data have 19,630 acquisitions spread over the distance [7].

To model the LOS measurement data, we consider two large-scale fading models: two-ray ground reflection model and log-distance path loss model. The two-ray ground reflection model used in this paper is expressed as follows:

$$P_r(d) = \begin{cases} P_t + 10 \log \left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \right) & \text{where } d \leq d_c \\ P_t + 10 \log \left(\frac{G_t G_r h_t^2 h_r^2}{d^4 L} \right) & \text{where } d > d_c \end{cases} \quad (1)$$

where $P_r(d)$ denotes the received power in dBm according to distance, P_t is transmitted power in dBm, G_t and G_r are antenna gains for transmitter and receiver, λ is a carrier wavelength, h_t and h_r are heights of transmitter and receiver anten-

TABLE I. GOODNESS OF FIT COMPARISON FOR LARGE-SCALE FADING MODELS

Model	RMSE	SSE	R-squared	Adjusted R-squared
Two-ray ($d \leq d_c$)	13.5500	4.1220e+06	-0.2362	-0.2362
Two-ray ($d > d_c$)	9.1040	1.1610e+06	-2.0050	-2.0050
Log-distance	5.3240	5.5640e+05	0.8220	0.8219

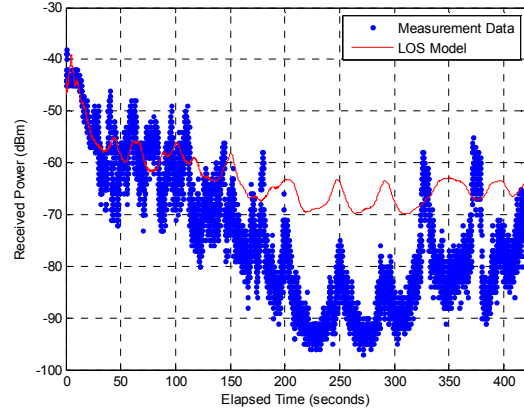


Fig. 2. Measurement received power data in our NLOS environments and their corresponding results from LOS model.

nas, d is distance between transmitter and receiver, L is a system loss. And the crossover distance d_c of equation (1) is expressed as $d_c = (4\pi h_t h_r) / \lambda$.

The log-distance path loss model used in this paper is expressed as follows:

$$P_r(d) = P_t - PL0 - 10 \cdot \gamma \cdot \log \left(\frac{d}{d_0} \right) \quad (2)$$

where $PL0$ is the amount of path loss at the reference distance d_0 . γ is the path loss exponent.

We compare the LOS measurement data with above two large-scale fading models and analyze the goodness of fit for each model. The metrics for goodness of fit are root-mean-square error (RMSE), sum of squared errors (SSE), coefficient of determination (R-squared) and adjusted R-squared. For RMSE and SSE, the result closer to zero is considered as better fit. For the R-squared and adjusted R-squared, the result closer to one is considered as better fit. Equations for calculating goodness of fit metrics are omitted in this paper.

Table I shows the results of calculating goodness of fit metrics for each large-scale fading models. Among the models, log-distance path loss model shows the best fit for received signal power measurement data in LOS scenarios. If we set the reference distance as 10 m, best fitted parameters of the model are $PL0$ of 65.66 and γ of 1.917. Note that the distribution of small-scale fading effect follows a normal distribution with $N(0, 5.3240^2)$. Fig. 1 also illustrates the fitted LOS model in red line.

B. Analysis on Non-Line-Of-Sight Measurement Data

Our approach to analyzing NLOS measurement data is comparing NLOS measurement data with LOS model deduced from the previous section. Experiments for NLOS induced by building as an obstacle scenario were conducted according to the measurement campaign described in Section II.

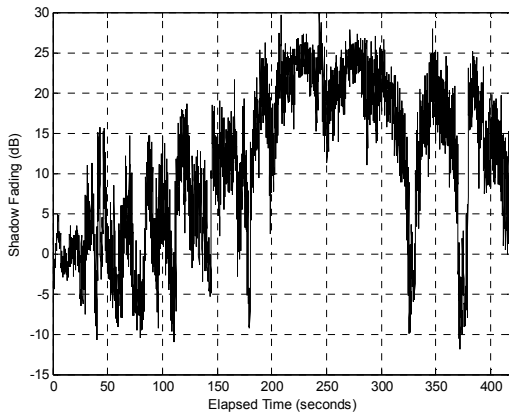


Fig. 3. Shadow fading effect in our NLOS measurement environments.

Fig. 2 shows received power measurement data versus elapsed time in NLOS scenarios and corresponding LOS model with respect to the separation distance. As well illustrated in Fig. 2, the received power data in some interval fit well to the LOS model and data in another interval have a big difference to the LOS model. This is because LOS and NLOS environments can occur by turns when two cars are driving around the block of buildings. Therefore, we can conclude that intervals where LOS model resides below or inside of received power data points are actually taken in the LOS environments. Otherwise, intervals where LOS model resides above of measurement data are acquired in actual NLOS scenarios. The results of LOS model are fluctuating because the separation distance is calculated with each GPS location. Note that the driving route and speed of each car is almost same.

A shadow fading effect which is signal attenuation from NLOS environments due to a building as an obstacle can be calculated by the difference between LOS model results and actual received power data in NLOS scenarios. Fig. 3 illustrates shadow fading effect extracted from our NLOS measurement data same as used in Fig. 2. As it can be seen in Fig. 3, the shadowing is distributed from 10 dB to almost 25 dB in received power data in NLOS scenarios. The severeness of shadowing also depends on how much the LOS path is blocked. In our NLOS measurement scenarios, driving around the block of buildings, the shadowing is relatively weaker when the preceding car just curves to a corner which is around 15 dB. The

strongest shadowing, around 25 dB, occurs when the cars are located on the opposite side of the block.

IV. CONCLUSION

In this paper, we studied V2V path loss in both LOS and NLOS environments with measurements. Several contributions are made in this paper. First, the proper measurement campaign was configured to evaluate the performance of actual vehicular communications by utilizing commercial V2X platforms which are totally compliant with WAVE standards. Second, we proposed V2V path loss model in LOS environments which utilizes both log-distance path loss model and extensive received power measurement data. Not only path loss factors, but also small-scale fading factors for LOS environments were modeled. Third, deep analysis of receiving power measurement data in NLOS environments was provided.

For the future work, modeling of V2V path loss in NLOS environments will be explored in depth. Classification of NLOS scenarios in detail will be studied due to the ambiguity of NLOS. Specific NLOS environments specialized for driving situation should be addressed to model the nature of V2V path loss.

REFERENCES

- [1] T. S. Rappaport, *Wireless communications: principles and practice*. New Jersey, NY, USA: Prentice Hall PTR, 1996.
- [2] C.-X. Wang, X. Cheng, and D. Laurenson, "Vehicle-to-vehicle channel modeling and measurements: Recent advances and future challenges," *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 96–103, Nov. 2009.
- [3] H. Lin, H. Tsai, M. Boban, "Scooter-to-X communications: Antenna placement, human body shadowing, and channel modeling," *Ad Hoc Networks*, vol. 37, no. 1, Feb. 2016.
- [4] L. Cheng, B. E. Henty, D. D. Stancil, F. Bai, and P. Mudalige, "Mobile vehicle-to-vehicle narrow-band channel measurement and characterization of the 5.9 GHz frequency band," *IEEE J. Sel. Areas Commun.*, vol. 25, no. 8, pp. 1501–1516, Oct. 2007.
- [5] J. Karedal, N. Czink, A. Paier, F. Tufvesson, and A. F. Molisch, "Path loss modeling for vehicle-to-vehicle communications," *IEEE Trans. Veh. Technol.*, vol. 60, no. 1, pp. 323–328, Jan. 2011.
- [6] P. Liu, D. W. Matolak, B. Ai, R. Sun, "Path Loss Modeling for Vehicle-to-Vehicle Communication on a Slope," *IEEE Trans. Veh. Technol.*, vol. 63, no. 6, Jul. 2014.
- [7] J. Joo, D. S. Han, H. Jeong, "First Fresnel Zone Analysis in Vehicle-to-vehicle communications," *2015 Int. Conf. on Connected Vehicles and Expo (ICCVE)*, IEEE, 2015.