Empirical CDF-Based Power Control Method for Obstructed V2V Communications

Keita KATAGIRI[†a)], ***Student Member***, **Koya SATO**[††b)], ***Member***, ***and*** **Takeo FUJII**[†c)], ***Fellow***

SUMMARY Radio environment estimation is an important technology to realize reliable vehicle-to-vehicle (V2V) communications. However, in V2V communications, it is difficult to estimate radio environment characteristics accurately owing to the dynamic change of surrounding environments. Mainly, a received signal power significantly fluctuates by obstacle vehicles between a transmitter and a receiver. In this paper, we propose a simple power control method for V2V communications existing an obstacle vehicle. The proposed method first estimates the empirical cumulative distribution function (CDF) of the instantaneous received signal power based on the actual measurements. Then, the power control is performed using the estimated CDF. The simulation results clarify that the proposed method can enhance the efficiency of the transmission power while precisely guaranteeing a permissible communication quality.
key words: *Vehicle-to-vehicle communications, radio propagation, empirical CDF, power control*

1. Introduction

To realize reliable autonomous driving systems, vehicles need to share the safety information of surrounding vehicles, such as the location of vehicles, by communicating with each other. Vehicle-to-vehicle (V2V) communication is considered one of the methods to realize this requirement. However, it is difficult to guarantee the reliability of V2V communications because the communication environment dynamically changes owing to the movement of a transmitter and a receiver. Thus, a transmitter should properly determine its communication parameters based on the prediction results of the surrounding radio environment. Radio environment estimation has been considered an important field in V2V communications.

An empirical propagation model such as the Okumura-Hata model is utilized to predict the radio environment. However, since these models are generated via measurements in a typical environment (e.g., an urban), the estimation precision is around 8 [dB] at best owing to the shadowing and multipath fading [1].

Several researchers have studied a measurement-based spectrum database (MSD) [2–4] to enhance the radio environment prediction. The MSD is constructed by collecting massive radio environment contents, such as the instantaneous received signal power, in the real observations. The MSD constructs a radio map that expresses the average received signal power in each location. The radio map enables us to accurately predict the radio environment compared to empirical models [5].

However, the conventional radio map only estimates the average received signal power of each location [5]; hence, the multipath fading component is canceled out. Meanwhile, in V2V communications, the instantaneous received signal power intensely fluctuates in an obstructed line-of-sight (OLOS) environment in which the link between a transmitter and a receiver is obstructed by vehicles like trucks and buses, etc. As an example, D. Vlastaras *et al.* [6] have observed the received signal power in the OLOS environment by experiment. Besides, many works have observed the received signal power under various OLOS environment [7–12]. However, most conventional researches only have observed the received signal power fluctuation in 1 obstacle vehicle; thus, the design method of the communication parameters has not been proposed. Even if the radio environment characteristics can be elaborately understood via a measurement campaign, the transmitter may not know how to design its communication parameters based on the estimated radio environment.

Therefore, we firstly model the propagation models for OLOS based on related works. Then, this paper proposes a simple power control method exploiting the empirical cumulative distribution function (CDF) of the instantaneous received signal power. The cloud server collects instantaneous received signal power samples in the real V2V communications. After the empirical CDF is estimated, the power control is performed based on the lower percent point that guarantees the permissible outage probability. The simulation results clarify that the proposed method can enhance the efficiency of the transmission power while precisely guaranteeing a permissible communication quality.

The remainder of this paper is summarized as follows. Section 2 shows the overview of the system model. Section 3 describes the probability distribution models in the OLOS environment. After we explain the proposed method in Section. 4, we describe the simulation setups in Section. 5. Section 6 shows the simulation results and Section 7 concludes this paper.

2. System Model

Fig. 1 shows the system model in this paper. As a simple situation, we consider the V2V communication on the high-

[†]Advanced Wireless and Communication Research Center (AWCC), The University of Electro-Communications
1–5–1 Chofugaoka, Chofu, Tokyo 182–8585, Japan
[††]Artificial Intelligence eXploration Research Center (AIX), The University of Electro-Communications, Tokyo 182-8585, Japan
a) E-mail: katagiri@awcc.uec.ac.jp
b) E-mail: k_sato@ieee.org
c) E-mail: fujii@awcc.uec.ac.jp

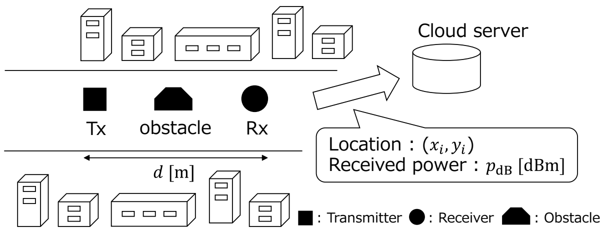

Fig. 1: The system model.

way. The communication distance d [m] is assumed to be fixed because the distance may be constant on the highway for a certain time. Additionally, it is assumed that 1 obstacle exists between a transmitter and a receiver. Although there are 2 or more obstacles in the realistic environment, it is difficult to describe the radio propagation models in multiple obstacles owing to space limitations. We deal with this task in future work.

The transmitter sends a beacon signal including the transmission position and transmitter ID every 100 [ms] based on IEEE 802.11p to the receiver. After demodulating the beacon signal, the receiver stores the position information, the instantaneous received signal power, and the center frequency in its storage and reports those data to the cloud server. We assume that N instantaneous received signal power samples are accumulated in the cloud server by the measurement. Then, the cloud server calculates the transmission power using the proposed method that will be described in Section 4. The cloud server provides the calculated transmission power to the transmitter. By using this information, the transmitter may reduce own transmission power.

If d is very large, we may need to consider the radio propagation extrapolation for precisely designing the transmission power. Due to space limitations, we consider this task as future work.

3. Probability Distribution Models

This section presents the shadowing and the multipath fading models for the OLOS environment based on conventional works. From the reference [6], the shadowing per obstacle follows the log-normal distribution. The probability distribution function (PDF) of the log-normal distribution is expressed as:

$$f_{\mathrm{shadow}}(W) = \frac{1}{\sqrt{2\pi}\sigma_{\mathrm{s}}} \exp\left\{-\frac{(W-\mu_{\mathrm{s}})^2}{2\sigma_{\mathrm{s}}^2}\right\}, \tag{1}$$

where W [dB] is the shadowing, $f_{\mathrm{shadow}}(W)$ is the PDF of W, μ_{s} [dB] and σ_{s} [dB] denote the mean and standard deviation of W, respectively.

Next, we model the multipath fading distribution. The multipath fading per obstacle follows the Nakagami-m distribution from the reference [12]. The PDF of the Nakagami-m distribution is represented as:

$$f_{\mathrm{fade}}(R) = \frac{2m^m}{\Omega^m \Gamma(m)} R^{2m-1} \exp\left(-\frac{m}{\Omega}R^2\right), \tag{2}$$

where $R = 10^{\frac{F}{20}}$ is the amplitude obeying the Nakagami-m distribution, F [dB] is the multipath fading, $f_{\mathrm{fade}}(R)$ is the PDF of R, $\Omega = \mathbb{E}[R^2]$ is the mean power, and $\Gamma(\cdot)$ denotes the Gamma function.

Moreover, the actual estimated distribution is a compound distribution of the shadowing and the multipath fading. There are several compound distributions, such as the Suzuki distribution [13]. However, it is difficult to consider all compound distributions in real environments. Thus, we estimate the empirical CDF of the instantaneous received signal power to perform the power control.

Additionally, in the realistic environment, the instantaneous received signal power may significantly fluctuate if there are static obstacles, such as buildings and walls. Especially, this phenomenon occurs in the urban area where the geographic conditions are complicated. Besides, the assumed radio propagation model may not be utilized if the communication environment dynamically changes owing to the movement of the transmitter and receiver. Even so, the proposed method may accurately predict radio propagation because we estimate the empirical CDF of the instantaneous received signal power. Such site-specific dispersion may be considered in our method.

The shadowing may not be observed if the height of the obstacle is lower than the heights of the transmitter and receiver. Although it is no longer an OLOS environment, the proposed power control enables us to enhance the efficiency of the transmission power further.

4. Proposed Method

We explain the simple power control method exploiting the empirical CDF. This paper defines that the instantaneous received signal power p_{dB} [dBm] becomes less than a desired one p_{d} [dBm] as an *outage event*. The proposed method controls the transmission power so that the permissible outage probability x_{out} is guaranteed. The empirical CDF is first approximately estimated by creating the histogram of p_{dB} by a class width c [dB] as follows:

$$F_{\mathrm{emp}}(p_{\mathrm{dB}}) \approx \sum_{P_{\mathrm{dB}} \le p_{\mathrm{dB}}} c \cdot P_{\mathrm{emp}}(P_{\mathrm{dB}}), \tag{3}$$

where F_{emp} is the empirical CDF, P_{dB} is a random variable that represents the p_{dB}, and P_{emp} denotes the empirical PDF of p_{dB}. Then, the lower percentage point $p_{\mathrm{th,dB}}$ [dBm] is calculated so that satisfies the following equation:

$$F_{\mathrm{emp}}(p_{\mathrm{th,dB}}) = x_{\mathrm{out}}. \tag{4}$$

However, it is difficult to accurately derive $p_{\mathrm{th,dB}}$ since the empirical CDF is discretely calculated based on the empirical PDF using Eq. (3). The estimation accuracy of $p_{\mathrm{th,dB}}$ depends on the number of received signal power samples and the class width c. Therefore, we approximately estimate $\hat{p}_{\mathrm{th\_max}}$ [dBm] using the following equation:

Table 1: Simulation parameters.

Maximum transmission power $P_{\mathrm{Tx\_max}}$	19.2 [dBm]
Center frequency	760 [MHz]
Path loss index γ	3.0
Mean of μ_{s} [6]	12.7 [dB]
Standard deviation of σ_{s} [6]	6.7 [dB]
Scale parameter of gamma distribution β	1.0
Fading parameter m [12]	1.42
Communication distance d	100 [m]
Reference distance d_0	10 [m]
Permissible outage probability x_{out}	0.1
Class width c	0.1 [dB]
Desired power p_{d}	-90.0 [dBm]

$$\hat{p}_{\mathrm{th\_max}} = \max_{p_{\mathrm{th,dB}}}\{F_{\mathrm{emp}}(p_{\mathrm{th,dB}}) \le x_{\mathrm{out}}\}. \tag{5}$$

Finally, the transmission power after the power control is represented as:

$$\hat{P}_{\mathrm{Tx\_con}} = P_{\mathrm{Tx\_max}} - (\hat{p}_{\mathrm{th\_max}} - p_{\mathrm{d}}) \quad [\mathrm{dBm}], \tag{6}$$

where $\hat{P}_{\mathrm{Tx\_con}}$ is the transmission power after the power control and $P_{\mathrm{Tx\_max}}$ [dBm] is the maximum transmission power, respectively.

5. Simulation Setups

To evaluate the effectiveness of the proposed method, we use the computer simulation. In this simulation, $p_{\mathrm{dB}}(d)$ is defined as follows:

$$p_{\mathrm{dB}}(d) = P_{\mathrm{Tx\_max}} - L_{0,\mathrm{dB}}(d_0) - 10\gamma\log_{10}\left(\frac{d}{d_0}\right) - W + F, \tag{7}$$

where d_0 [m] is the reference distance and γ is the path loss index. Moreover, $L_{0,\mathrm{dB}}$ [dB] is the free space path loss. The definition is represented as:

$$L_{0,\mathrm{dB}}(d_0) = 10\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)^2, \tag{8}$$

where λ [m] is the wavelength.

Here, W is obtained by random value that follows the log-normal distribution with mean μ_{s} and standard deviation σ_{s}.

The true power of F follows the gamma distribution and its PDF is given by

$$f_{\mathrm{gamma}}(z) = \frac{1}{\Gamma(\nu)}\beta^{\nu} z^{\nu-1}\exp(-\beta z), \tag{9}$$

where $z = R^2$, β is the scale parameter, and ν is the shape parameter that corresponds to the fading parameter m in Nakagami-m distribution. F is calculated by converting the random value that follows Eq. (9) to the logarithm value.

The simulation procedures are summarized as follows:

(a) p_{dB} represented Eq. (7) is obtained for N samples.

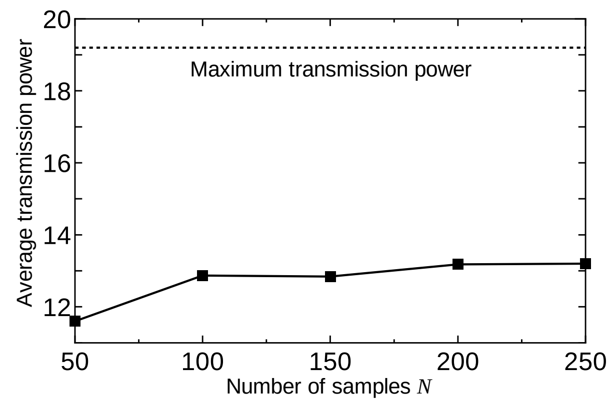

Fig. 2: Average transmission power versus N.

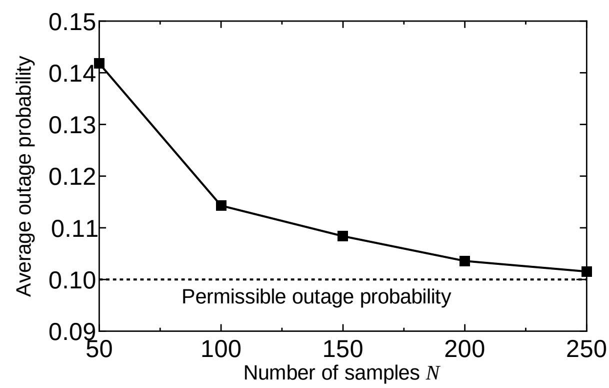

Fig. 3: Average outage probability versus N.

(b) F_{emp} is estimated using the N samples.

(c) $\hat{p}_{\mathrm{th\_max}}$ and $\hat{P}_{\mathrm{Tx\_con}}$ are derived based on Eqs. (5) and (6), respectively.

(d) p_{dB} is obtained again by setting $P_{\mathrm{Tx\_max}}$ to $\hat{P}_{\mathrm{Tx\_con}}$ in Eq. (7) for 10,000 samples.

(e) The number of samples that fall below p_{d} is counted and outage probability is calculated.

We perform the above procedures 10 times and calculate the average outage probability and the average transmission power. Table 1 shows the simulation parameters. The transmission power and center frequency are based on the standard of the V2V communications in Japan.

6. Results

Figs. 2 and 3 show the average transmission power and the average outage probability. These results reveal that the proposed method can significantly reduce the transmission power. Additionally, the permissible outage probability can precisely be guaranteed in an increase of N.

7. Conclusion

We have proposed the simple power control method that exploited the empirical CDF for obstructed V2V communications. The proposed method first estimates the empirical CDF of the instantaneous received signal power by the actual measurements. Then, the power control is performed based on the calculation of the lower percent point that guarantees the permissible outage probability. The evaluation results have revealed that the proposed method can reduce the transmission power significantly while precisely guaranteeing the permissible outage probability. As one of future works, we need to verify the effectiveness of the proposed method via a measurement campaign.

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