Propagation Models for Simulation Scenario of ITS V2V Communications

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Abstract- **Unified computer simulation scenario of ITS vehicle to vehicle (V2V) communication has been proposed. In the scenario, several aspects of V2V communications, such as physical layer systems, communication protocols, road traffic models, environment models and so on are defined. In this paper we present propagation models adopted in the scenario. We first introduce a propagation loss estimation model that has been adopted as the basic model and also present two specific models. We show the calculated results by using the ray tracing method for the two models.**

I. INTRODUCTION

In recent years, research activities aiming at improving safety performance of automobiles by applying the wireless communication have been vigorously carried out all over the world [1]. For instance, in order to prevent collisions of vehicles at intersections with poor visibility, a method where position information is exchanged between vehicles by using vehicle-to-vehicle communication (V2V) is attracting attention. As a new way of the development of such ITS applications, computer simulations are often used to assess the effect of the developed systems and to evaluate the system design of a variety of applications [2, 3]. So far, software simulations for the development of the ITS applications have been done "layer by layer". For example, communication systems for ITS and traffic flow have been considered in simulations separately. In order to appropriately simulate and evaluate the ITS applications where behaviors of several component layers are mutually and closely related, unified operation of all layers must be done in the simulations. These movements of the integration of the simulators for ITS applications have already begun in Japan and worldwide. In Japan, ITS Simulator Promotion Committee was formed in Japan Automobile Research Institute (JARI) and the unified ITS simulator was discussed by experts in various aspects of ITS research. One of the purposes of the committee is to develop a common simulation and evaluation methodology for ITS applications. As the results of the energetic work of the committee, "Standard Simulation and Evaluation Scenario for ITS Applications (VER1.0)" was established in 2010. Also in the following year (2011), the scenario was revised in order to present more detailed information assuming a concrete ITS application. In the revised scenario three actual applications, safe driving assistance application, energy saving application and telematic application, are presented, and the additional exploration and review of the scenario are performed. It includes the detailed description of the traffic flow simulation model, the radio wave propagation model and the road model. The results of such activities are compiled as VER. 1.1 [4].

In this paper, we introduce the radio wave propagation models defined in the scenario.

II. STANDARD SIMULATION AND EVALUATION SCENARIO FOR ITS APPLICATIONS

"Standard Simulation and Evaluation Scenario for ITS Applications" includes three applications as mentioned above. For each application, road model, traffic flow simulation model and communication protocol model are defined. For the wireless communication system the IEEE802.11p system is commonly assumed for the all applications.

The details of the simulation procedures for the three applications are presented and the evaluation methodologies are also described in order to make the comparison of the simulated results easy and fair. Since it is important for such scenario to be used commonly and widely, the document describing the scenario is freely available at the website of JARI [4].

III. REQUIRED PROPERTIES FOR RADIO PROPAGATION MODEL

As a radio propagation model for simulations of general wireless communications, the following propagation characteristics should be modeled and simulated.

A. *Propagation loss*
B. *Fading*
C. *Reflections*
D. *Diffractions*
E. *Shadowing*

In the standardized scenario, the above characteristics are considered as follows.

A. *Propagation loss*

The most important environment for simulations of ITS applications is thought as a populous city area since it is traffic accident-prone. In such environment, the propagation becomes so-called a "street canyon" propagation, where radio waves propagate along the road. The street canyon propagation model in ITU-R Recommendation P.1411-5 (hereinafter, P.1411 model) is adopted as the basic model of the scenario, since it is a typical model of such environments and is used worldwide. However, for the safe driving assistance application, the environment is difficult to be simulated by P.1411 model and it is necessary to simulate the individual environments more precisely. Therefore individual propagation models are constructed for the applications.

B. Fading

In order to make the implementation of simulation easier, signal level fluctuation due to the fading is not considered in the standard scenario. However, for simulations with small time granularity, the fading should be considered. In such a case, Rayleigh fading model is recommended in the scenario.

C. Reflections, D. Diffractions, E. Shadowing

Since P.1411 model is supposed to predict the propagation loss in actual street canyon environments, such effects as reflection, diffraction and shadowing by the surrounding buildings and vehicles are included in the propagation loss calculation formula. However, if obstacles are very close to the transmitter (Tx) or the receiver (Rx), the influence cannot be considered by the formula. Since the current scenario only focuses on the basic part of ITS simulations, the effect is not taken into consideration. It requires further study.

In the models of the safe driving assistance applications, these effects are individually taken into account by the ray tracing calculation.

IV. Radio Propagation Model in Standard Scenario

A. P.1411 Model

ITU-R recommendation P.1411-5 [5] is a recommendation giving various propagation models of point-to-point transmission in short-range propagation environments. In the recommendation, the propagation model for a street canyon environment is included. In the standard scenario, the model is used as the basic model. Some modifications are made in order to adjust the model to be used appropriately in ITS simulations. Note that the model is originally created for the prediction of the propagation loss in a micro-cell communication environment, not for a V2V environment.

The propagation loss of a LOS environment is calculated by the street canyon LOS model in P.1411 where the equivalent antenna height is set to zero. The equivalent antenna height is omitted in order to simplify the simulation. The propagation loss in the LOS environment L_{LOS} in (dB) is given by the following equation where d (m) is the distance between Tx and Rx.

$$L_{\mathrm{LOS}} = L_{\mathrm{bp}} + 6 + \begin{cases} 20\log_{10}\left(d / R_{\mathrm{bp}} \right) & \text{for } d \le R_{\mathrm{bp}} \\ 40\log_{10}\left(d / R_{\mathrm{bp}} \right) & \text{for } d > R_{\mathrm{bp}} \end{cases} . \quad (1)$$

R_{bp} and L_{bp} are the distance from Tx to the breakpoint in (m) and the loss at the breakpoint in (dB), respectively. They are given by the following equations where h_{b} and h_{m} are the Tx and the Rx antenna heights in (m) and λ is the wavelength in (m) at the carrier frequency.

$$R_{\mathrm{bp}} \approx \frac{4 h_{\mathrm{b}} h_{\mathrm{m}}}{\lambda}, \quad L_{\mathrm{bp}} = \left| 20\log_{10}\left(\frac{\lambda^2}{8\pi h_{\mathrm{b}} h_{\mathrm{m}}} \right) \right| . \quad (2)$$

The loss in the NLOS environment, L_{NLOS} (dB), is given by the following formula.

$$L_{\mathrm{NLOS}} = -10\log_{10}\left(10^{-L_{\mathrm{r}}/10} + 10^{-L_{\mathrm{d}}/10} \right), \quad (3)$$

where L_{r} and L_{d} are propagation losses in dB of the reflected waves and the diffracted waves, respectively. They are given by the following formulae.

$$L_{\mathrm{r}} = 20\log_{10}(x_1 + x_2) + x_1 x_2 \frac{f(\alpha)}{w_1 w_2} + 20\log_{10}\left(\frac{4\pi}{\lambda} \right), \quad (4)$$

$$L_{\mathrm{d}} = 10\log_{10}\left[x_1 x_2 (x_1 + x_2) \right] + 2D_a - 0.1\left(90 - \alpha \frac{180}{\pi} \right) + 20\log_{10}\left(\frac{4\pi}{\lambda} \right). \quad (5)$$

The distances x_1 and x_2 and the road widths w_1 and w_2 are shown in Fig. 1 and the units are in (m). α is the angle of the two crossing roads in (rad). $f(\alpha)$ and D_a are given by the following expressions.

$$f(\alpha) = \frac{3.86}{\alpha^{3.5}}, \quad D_a = \left(\frac{40}{2\pi} \right)\left[\arctan\left(\frac{x_2}{w_2} \right) + \arctan\left(\frac{x_1}{w_1} \right) - \frac{\pi}{2} \right]. \quad (6)$$

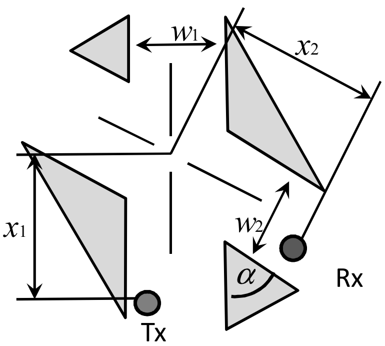


Fig. 1 Distances and road widths of NLOS environment.

P.1411 generally gives realistic values of propagation loss observed in the actual environment. However, in a viewpoint of the implementation to ITS simulations it has some defects. One is the relation of the magnitudes of the predicted propagation losses by LOS and NLOS formulae at areas close to intersections. In such areas, there are some cases where the propagation loss predicted by the NLOS formula is less than that by the LOS formula. It is not realistic, hence we make a modification to the original P.1411 model.

In the modified method, the propagation loss in the vicinity of intersections is given by the larger value of the propagation losses obtained by the following two methods : (See Fig. 2)

- Propagation loss calculated by the LOS formula, where d is the distance of the straight path between Tx and Rx.
- Propagation loss calculated by the NLOS formula with the distances x_1 and x_2 in Fig. 2.

Further, in P.1411 model, a propagation loss calculation method for turning at intersections twice or more times is not defined. It is calculated below in the modification. Using the distances x_1', x_2', and x_3' shown in Fig. 3, the larger propagation loss among the following two losses is selected.

- Propagation loss calculated by the NLOS formula where x_1=x_1' and x_2=x_2'+x_3'.
- Propagation loss calculated by the NLOS formula where x_1=x_1'+x_2' and x_2=x_3'.

The above method is considered based on the measured result [6].

P.1411 model is used as the propagation loss model for the energy saving application, the telematics application, and a part of the safe driving assistance application.

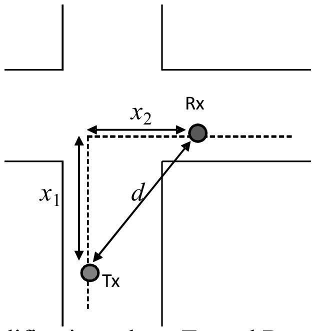


Fig. 2 Modification where Tx and Rx are close to intersection.

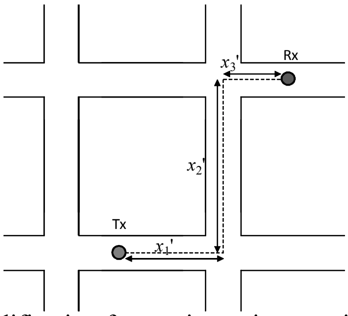


Fig. 3 Modification for turning at intersections twice.

B. Propagation models for safe driving assistance applications

P.1411 model gives the propagation loss in a typical propagation environment, but it does not consider the particular circumstances, such as individual road shape, presence or absence of blocking vehicles, curving road, etc. Such environmental influences are required to be taken into consideration for ITS simulations especially for the safe driving assistance application. Therefore, in the standard scenario specific propagation models are defined for the application. The following three specific applications are presented in the safe driving application.

- Collision avoidance application at T-shape junctions.
- Right-turn collision avoidance application at cross-shape intersections (right-turn application).
- Rear-end collision avoidance application at a curve (curve application).

T-junction environment is assumed for the first application. Since this environment is close to the cross-shape intersection like the assumed environment in P.1411 model, P.1411 model is used as the propagation model for the application.

We use P.1411 model as the basic model assuming street canyon propagation environment. However, in the environments of right-turn and curve applications, the propagation loss cannot be well predicted by P.1411 model since the blocking by vehicles and walls generates the essential factor of the propagation. However, a well-established propagation loss estimation formula like P.1411 model does not exist for such environments. Therefore, we calculate the propagation loss in the applications by the ray tracing method. In the scenario document, the propagation loss in these applications is presented by tables of the propagation loss values at discrete locations of Tx and Rx. Users of the scenario are supposed to interpolate the discrete values to obtain the loss at arbitrary positions of Tx and Rx.

It is necessary to identify the carrier frequency for the ray tracing calculation. We select two frequencies 760MHz and 5.8GHz considering the frequencies used for ITS in Japan and the world.

Figure 4 shows the assumed environment of the right-turn application, where a collision of two vehicles moving in the opposite lanes is anticipated. The right-turn waiting vehicle at the intersection is between the two moving vehicles. Since the direct path (both in vision and in radio) is blocked by the right-turn waiting vehicle, if one of the vehicles (Tx) turns right at the intersection, the possibility of the collision is high. It is a typical situation of traffic accident, and such situation is often assumed for the evaluation of the collision avoidance application by ITS.

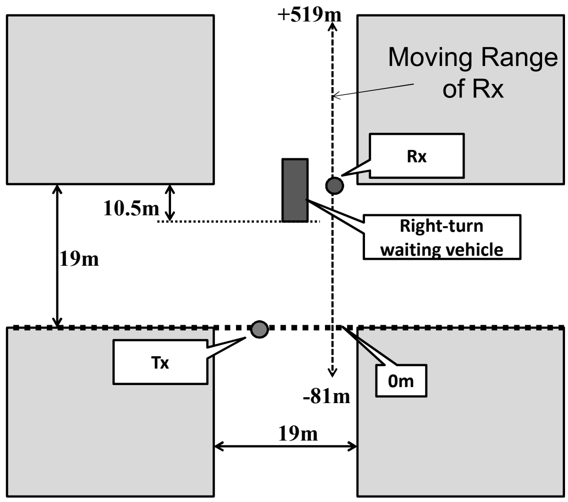
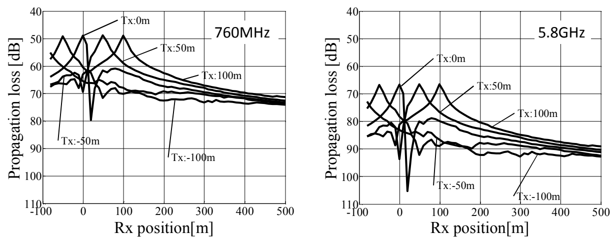


Fig. 4 Assumed road model for right-turn application.



(a) 760MHz (b) 5.8GHz

Fig. 5 Example of propagation loss of right-turn application.

Figure 5 shows some results of the ray-tracing calculation for the model of Fig. 4. In the figure, a large propagation loss is predicted for Tx at 0m and Rx at 20m. This shows the case where the direct path is blocked by the closely-located blocking vehicle.

Figure 6 shows the environment model for the curve application. In the application, an accident, where a vehicle entering into the curve rear-ends the stopping vehicle beyond the curve, is assumed. The situation often occurs in traffic jam. Assuming a metal wall inside the curve, the situation is NLOS, where the direct path between Tx and Rx is blocked by the wall. The case is assumed for the worst case, since in usual actual roads, such as highways, another metal wall is also installed outside of the curve. It generates reflected paths and the propagation loss becomes smaller.

Similarly to the right-turn application, since well-established path loss estimation model for the situation does not exist, we calculate the path loss of this model by the ray tracing and give two-dimensional tables of the propagation loss with 10m interval of Tx and Rx positions.

In the calculation of the propagation loss of this application, we divide the propagation model into two cases, LOS and NLOS, according to the positions of Tx and Rx.

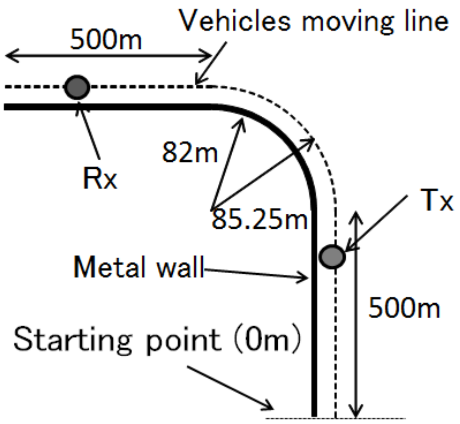


Fig. 6 Assumed road model for curve application.

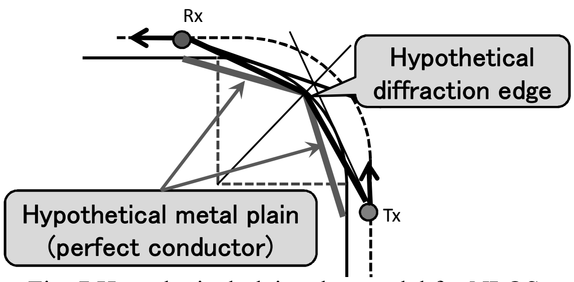
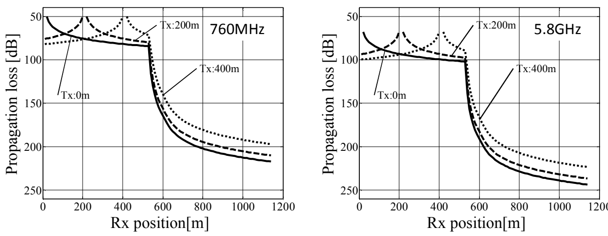


Fig. 7 Hypothetical plain edge model for NLOS.



(a) 760MHz (b) 5.8GHz

Fig. 8 Example of propagation loss of curve application.

For the LOS situation, we use the free space path loss. For the NLOS situation over the curve as shown in Fig. 7 the propagation loss is calculated by Uniform Theory of Diffraction (UTD). We assume hypothetical metal plains to model the long curve and calculate the diffraction loss by the hypothetical edge by UTD.

In a viewpoint of the precise estimation of the propagation loss, there remains a room for discussion of the usage of this model. We adopt the model for simple calculation of propagation loss, since the environment model is hypothetical and therefore it is not a purpose of the model to calculate an exact value of the loss.

Figure 8 shows examples of the propagation loss of the curve application. The Tx and Rx positions are expressed by the length of the ways from the starting point shown in Fig. 6. In the LOS situation, where the Rx position is less than around 500m the loss is considerably small, while the loss increases very rapidly when Rx is beyond the curve.

V. SUMMARY

In this paper, we introduce the propagation model defined in "Standard Simulation and Evaluation Scenario for ITS Applications." We adopt P.1411 model to calculate the propagation loss as the basic formula. Since it has some defects to be used in the ITS simulations, we make two modifications to the model. For the safe driving assistance application, two specific environment models are presented and the propagation loss in the environments is calculated by the ray-tracing method.

ACKNOWLEDGMENT

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