An Approximate Model of Radio Wave Propagation for Inter-vehicles Communication Simulation Systems

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Abstract *In development of inter-vehicles communication (IVC) systems, simulation technologies are very essential to verify the correctness of protocols. We focus on a model of radio wave propagation for IVC simulation systems and approximate the model. As a land mobile communication model, we adopt Kaji model. In our model, a distance between vehicles, a building density, and an angle between a road and a line-of-sight of two vehicles are used as the approximate parameters instead of detailed information of buildings. From experimental results, our model has 84% accuracy and 17 times computation speed-ups in comparison with the original Kaji model.*

Keywords: simulation model, radio wave propagation, inter-vehicles communication

1 Introduction

Recently, many researches on inter-vehicles communication (IVC) have been reported [1–3]. In development of communication protocols and applications, it is very important to verify the correctness of protocols in simulation. Especially, in development of IVC systems, simulation technologies are very essential. This is because practical experiments for IVC are very hard to be carried out since many cars and communication equipment have to be provided and a huge area has to be used freely in order to realize various traffic patterns.

In simulation experiments, modeling methods of the real world and its implementation in simulation systems are keys to make results of simulation experiments effective. By using correct models of the real world, correct results of simulation experiments can be achieved. Furthermore, by correct implementation of the models, simulation experiments can be performed with adequate computer facilities in reasonable time.

Here, we focus on a model of radio wave propagation for IVC simulation. Until now, a model of radio wave propagation is paid little attentions in simulation systems. In many traditional simulation systems, a model of radio wave propagation is very simple: the ability of communication between two mobile terminals is determined on the basis of only the distance between two terminals [4,5]. This model can be used in free space, in which obstacles such as buildings do not exist, but this model is too simple to analyze radio wave propagation correctly in many situations. Especially, in IVC simulation systems, we have to pay more attention to radio wave propagation in urban areas. Thus, for IVC simulation systems, more sophisticated model of radio wave propagation must be investigated.

In urban areas, radio waves are reflected, diffracted and transmitted by buildings. Thus, it is important to model such behaviors of radio wave propagation for IVC simulation systems. Until now, several models of radio wave propagation for land mobile communication have been proposed [6]. However, these models cannot be applied, as they were, to IVC simulation systems since these models are complicated and need detailed information for the area, such as the number of buildings, size of buildings and so on. Thus, in order to apply these models to IVC simulation systems, efficient algorithms for models have to be designed.

In this paper, we propose an approximate model of radio wave propagation for IVC simulation systems. As a land mobile communication model, we adopt Kaji model [7]. In Kaji model, detailed information of obstacles (buildings) must be provided for calculation of radio wave propagation. However, this condition is very tough, and it takes a lot of time to calculate radio wave propagation in urban area situations. In our model, we adopt a building existence ratio in the area and an angle between a road and a line-of-sight of two terminals. With our proposed model, we can achieve less computation cost and sufficient computation accuracy.

The rest of this paper is organized as follows. In Section 2, we introduce Kaji model as a model of land mobile communication. We propose an approximate model in Section 3 and evaluate our model in Section 4. Finally, we conclude this paper and give our future work in Section 5.

2 Radio Wave Propagation Model

2.1 Land Mobile Communication

In land mobile communication, various fluctuations of radio wave propagation occur because of the movement of mobile terminals and obstacles in urban areas. The conditions near roads always changes by the movement of mobile terminals. The fluctuation is expressed with three independent factors: multi-path fading, shadowing and path-loss.

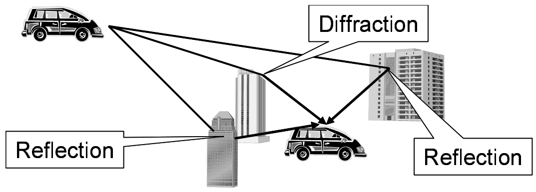


Figure 1: Multi-path fading

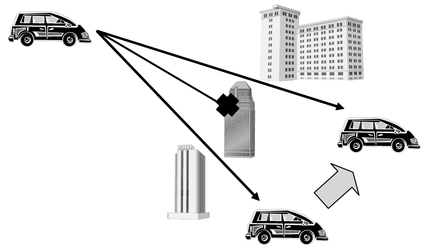


Figure 2: Shadowing

In urban areas, there are always many obstacles such as buildings between two mobile terminals. Thus, radio waves are reflected and diffracted, and transmitted through multi-path radio waves (Figure 1). A multi-path fading can occur when mobile terminals move in urban areas because of obstacles. It is known that diversity of radio wave signals is more than 20dB [6].

Although the distance between two terminals is fixed, a situation of radio wave propagation is changed gently because of obstacles. This fluctuation is called shadowing. The shadowing occurs because obstacles near the mobile station block radio waves (Figure 2) [6].

Path-loss is caused by the distance between two terminals (Figure 3). For the path-loss, various models based on height of antenna and obstacles have been proposed [6]. Path-loss models based on a low antenna height are suitable for IVC. For both multi-path fading and shadowing, theoretical analysis is achieved and mathematical model is proposed. Thus, we focus on path-loss below.

2.2 Kaji Model

Kaji model is one of models for path-loss in low-height antenna environments. This model is based on three independent propagating ra-

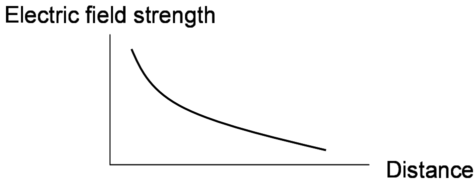


Figure 3: Path-loss

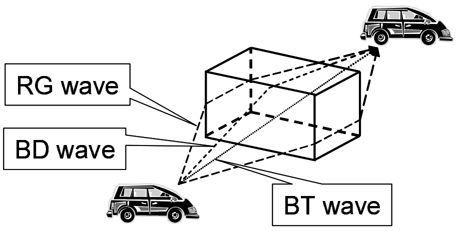


Figure 4: Kaji model

dio waves: BT (building transmitted) wave, RG (road guided) wave and BD (building diffracted) wave. BT wave represents radio waves transmitted by buildings. RG wave represents radio waves propagated by streets. BD wave represents radio waves diffracted at the top edge of buildings. Figure 4 shows these radio waves.

In Kaji model, propagation losses of three waves are calculated independently, and the minimum propagation loss is selected as the propagation loss for path-loss. The propagation loss L is calculated as follows.

$$
\begin{aligned}
L &= \min(L_{BT}, L_{RG}, L_{BD}).\\
L_{BT} &= L_{fs}(d) + a_{11} \cdot d\\
&\quad + b_{11} \cdot d_{11} + b_{12} \cdot d_{12} + b_{13} \cdot d_{13}.\\
L_{RG} &= L_{fs}(l) + a_{21} \cdot l + b_{21} \cdot n.\\
L_{BD} &= L_{fs}(d) + a_{31} \cdot d + L_{dt} + L_{dr}.
\end{aligned}
$$

Here, d and l represent the distance between two terminals. d is the linear distance and l is the road-path distance. L_{fs} stands for the propagation loss in free space. In the equations, a_{11}, a_{21} and a_{31} stand for the attenuation constants for each wave. In L_{BT}, b_{11}, b_{12} and b_{13} stand for the attenuation constants for concrete buildings, wooden buildings and street trees, respectively, and d_{11}, d_{12} and d_{13} stand for the transmitted distances for each obstacle. In L_{RG}, b_{21} is a propagation loss for street corners, and n is the number of corners in road

Table 1: Values of Kaji model parameters

Parameter	Value
a_{11}, a_{21}, a_{31}	0.04 dB
b_{11}, b_{12}, b_{13}	1 dB
b_{21}	25 dB

path between two terminals. Namely, L_{RG} is calculated on the basis of street corners. In L_{BD}, L_{dt} and L_{dr} stand for diffraction losses of the nearest building for each mobile terminal. Table 1 shows values of these parameters for 2.2GHz radio waves.

3 Approximate Model

3.1 Concept of Our Model

As described in the previous section, in order to calculate propagation losses in Kaji model, several detailed geographic information such as the locations of, the sizes of, the number of buildings, etc. have to be provided. However, such detailed information cannot be obtained generally. In addition, the calculation amount is vast because it is necessary to examine whether buildings obstruct the line-of-sight of two terminals. Therefore, in order to apply Kaji model to IVC simulation systems and achieve moderate computation time, we must provide an approximate model in which detailed information is not needed and computation time is reduced.

In order to construct our model, we have to pay attention to urban areas because propagation losses by buildings occur mainly at the urban areas. In the urban areas, many roads are composed as a grid pattern, and roads are surrounded with buildings. Clearly, radio wave propagation to the direction along a road differs from that to the direction cross a road. Therefore, in order to calculate propagation losses, whether a line-of-sight is along a road or not is very important.

Under the above circumstance, we adopt the following approach. First, we adopt a building existence ratio (building density) of an area instead of detailed information about buildings. The building density can be easily achieved in comparison with detailed information of buildings. Thus, with our model, propagation losses can be calculated widely. Furthermore, computation cost can be also reduced. Next, in order to solve the problem in which property of propagation losses is varied considerably by positional relationship between a road and a line-of-sight of two terminals, we adopt an angle between a road and the line-of-sight. There is little influence of buildings when the angle is sharp. This is because radio waves are propagated along roads as a free space. As the angle increases, radio waves tend to be transmitted by buildings, and the influence of roads can be ignored.

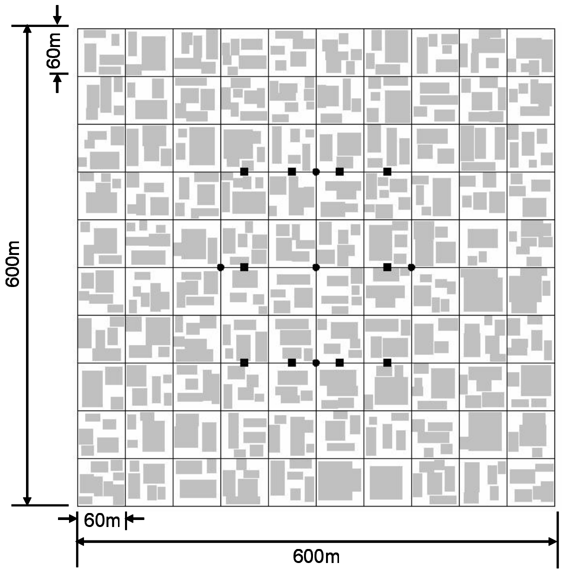


Figure 5: Experimental environment

3.2 Preparatory experiment

In order to examine the influence of a building density and an angle between a road and a line-of-sight on radio wave propagation, we perform preparatory experiments. We measure propagation losses which are calculated based on Kaji model. Conditions of experiments are as follows:

- field: 600m × 600m,
- road: grid pattern roads of 60m intervals,
- building:
  - size: 10 ∼ 50m on a side,
  - height: 25m,
  - building density: 50%,
- distance between vehicles: 50m, 100m, 150m.

The size and position of buildings are arranged at random. For experiments, five intersection points and ten on-road points are selected as the position of one vehicle (Figure 5). This is because the influence of roads on propagation losses differs in that the number of roads connected to the point is different. Therefore, a range of an angle is changed from 0 to $\pi/2$ for intersection points, and from 0 to π for on-road points, respectively.

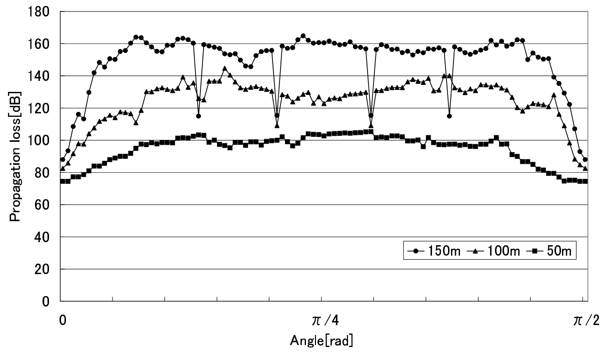
Figure 6 shows experimental results. As an angle between a road and a line-of-sight changes, a propagation loss at first increases, next stays constant, and finally decreases. As the line-of-sight leaves from the road, the line-of-sight tends to cross buildings. Therefore, the influence of a propagation loss by buildings becomes dominant. From the middle part of graphs, we can observe that propagation losses is proportional to the distance between two terminals.

3.3 Approximate Model

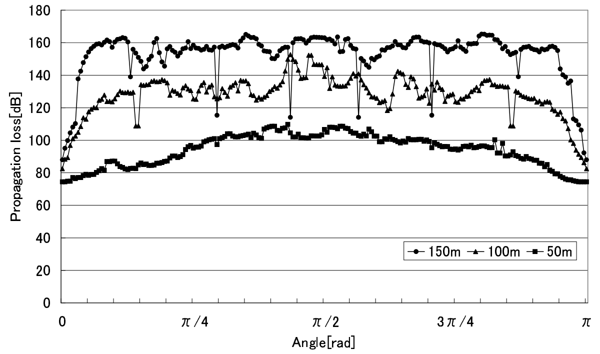
From observation of the above experiments, we propose an approximate model for Kaji model. Figure 7 shows our approximation of propagation losses. Namely, propagation losses in urban areas can be estimated in trapezoidal form. From the results in Table 2, the height (constant propagation loss) is calculated from both the building density and the distance between two terminals. The constant propagation loss is defined as follows:

$$ConstantPropagationLoss = \\ BuildingDensity \times Distance.$$

For transition sections, we have to estimate the threshold angle. We introduce a threshold angle α and propagation losses in transition section. For the initial propagation loss L_0, the



(a) Result for intersection points



(b) Result for on-road points

Figure 6: Propagation loss

building density d, the distance of two terminals l, our proposal approximate model is described as follows:

$$L_i(\theta) = \begin{cases} L_0 + \dfrac{d \cdot l \cdot \theta}{\alpha} & (0 \leq \theta \leq \alpha) \\ L_0 + d \cdot l & \left(\alpha \leq \theta \leq \dfrac{\pi}{2} - \alpha\right) \\ L_0 - \dfrac{d \cdot l}{\alpha}\left(\theta - \dfrac{\pi}{2}\right) & \left(\dfrac{\pi}{2} - \alpha \leq \theta \leq \dfrac{\pi}{2}\right) \end{cases}$$

$$L_r(\theta) = \begin{cases} L_0 + \dfrac{d \cdot l \cdot \theta}{\alpha} & (0 \leq \theta \leq \alpha) \\ L_0 + d \cdot l & (\alpha \leq \theta \leq \pi - \alpha) \\ L_0 - \dfrac{d \cdot l}{\alpha}(\theta - \pi) & (\pi - \alpha \leq \theta \leq \pi) \end{cases}$$

Here, $L_i(\theta)$ is a propagation loss for intersection points and $L_r(\theta)$ is for on-road points. From the experimental result shown in Table 3, we assume $\alpha = \pi/10$. In the tables $\theta_1, \theta_2, \theta_3$ and θ_4 express the threshold angles.

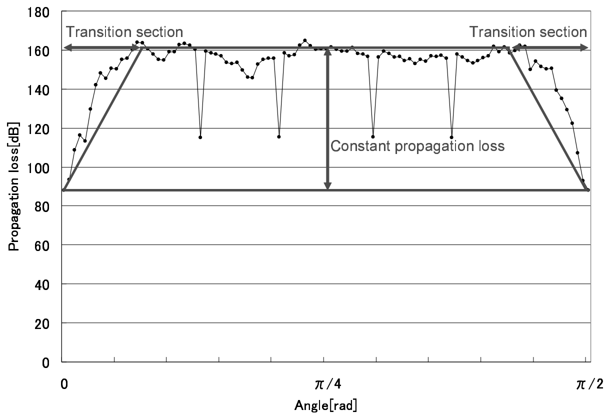


Figure 7: Relations between angles and propagation losses

Table 2: Propagation loss

(a) Intersection points

Distance	Propagation loss 0 ($\pi/2$)	$\pi/4$	Difference
50m	74 dB	103 dB	29 dB
100m	82 dB	123 dB	41 dB
150m	88 dB	161 dB	73 dB

(b) On-road points

Distance	Propagation loss 0 (π)	$\pi/2$	Difference
50m	74 dB	106 dB	32 dB
100m	82 dB	139 dB	57 dB
150m	88 dB	163 dB	75 dB

4 Evaluation

4.1 Experimental environment

In order to evaluate the accuracy of our model, the difference between a propagation loss calculated by Kaji model and that by our model is measured. Furthermore, in order to evaluate the effectiveness of our model, the computation time for each model is also analyzed. An experimental environment is the same as that in Section 3 except that the distribution of buildings is different. We select five intersection points and ten on-road points at random and calculate propagation losses for each angle.

Table 3: Angles regarded as constant propagation loss

(a) Intersection points

Distance	θ_1	θ_2
50m	$14\pi/200$ rad	$15\pi/200$ rad
100m	$16\pi/200$ rad	$15\pi/200$ rad
150m	$13\pi/200$ rad	$12\pi/200$ rad

(b) On-road points

Distance	θ_3	θ_4
50m	$48\pi/200$ rad	$34\pi/200$ rad
100m	$21\pi/200$ rad	$24\pi/200$ rad
150m	$13\pi/200$ rad	$33\pi/200$ rad

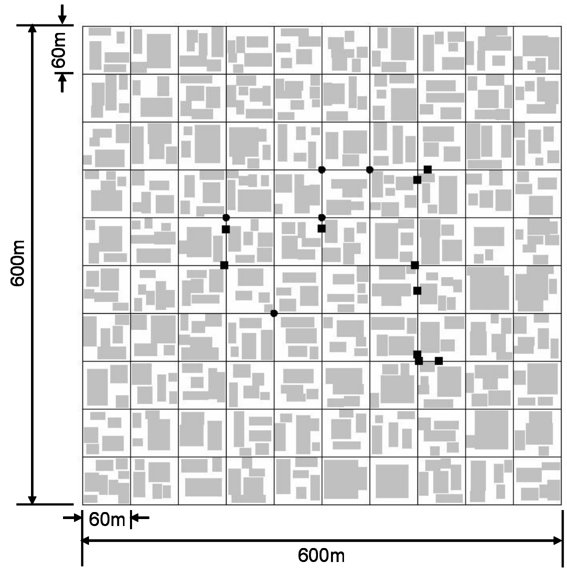


Figure 8: Experimental environment

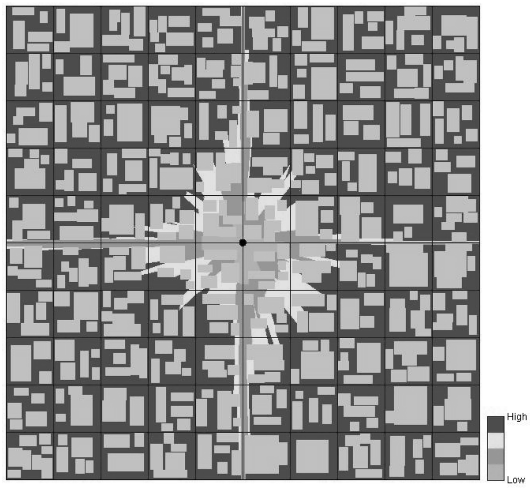


Figure 9: Propagation loss map

For computation time evaluation, we measure the computation time for generating the propagation loss map (shown in Figure 9). For generating this map, 360,000 times of calculation are required.

4.2 Result and consideration

As described in Section 2, multi-path fading and shadowing occur in land mobile communication. A fluctuation range caused by multipath fading may be 20dB [6]. So, in evaluation of our experimental results, we define the error difference as 20dB. Namely, if the difference of two calculation results is more than 20dB, we decide our model is incorrect. Table 4 shows the experimental result of the accuracy. As a distance between vehicles increases, the accuracy decreases. This is because the distribution of buildings between vehicles changes strongly when the distance is long. The BT wave is dominant when the distance is short. On the other hand, the other waves are dominant when the distance is long. One of the reasons that the accuracy decreases is that an approximate model is based on BT wave. The accuracy for all measures is 84%.

Table 5 shows the computation time for two models. The computation speed of our model is about 17 times as fast as that of Kaji model. From these experimental results, we can conclude that our model can calculate propagation losses correctly without detailed information in urban areas faster than the original model.

5 Conclusion

In this paper, we proposeds an approximate model of radio wave propagation. Kaji model which is one of models for land mobile communication was focused on. A distance between vehicles, a building existence ratio (building density) and an angle between a road and a line-of-sight of two vehicles were usable as the approximate parameters. We examined rela-

Table 4: Accuracy

	The number of measuring points	The number of correct data	Accuracy
50m(intersection)	834	821	98.4%
100m(intersection)	903	779	86.3%
150m(intersection)	1023	791	77.3%
50m(on-road)	1777	1612	90.7%
100m(on-road)	1875	1574	83.9%
150m(on-road)	1961	1483	75.6%
All measuring	8373	7060	84.3%

Table 5: Time to calculate propagation losses

Kaji model	49,855 msec
Approximate model	2,729 msec

tions between the angle and propagation losses by Kaji model. By the results, this relations could be expressed as trapezoids graph. From this observation, we formulated our model with three parts. From experimental results, our model has 84% accuracy and 17 times computation speed-ups.

In our future work, we must evaluate our model in real map. In addition, we must consider multi-path fading and shadowing, and implement IVC simulation systems with precise radio wave propagation model for the sake of founding research platform for IVC.

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