A Communication Model for Inter-vehicle Communication Simulation Systems Based on Properties of Urban Areas

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Summary
In development of inter-vehicle communication (IVC) systems, simulation technologies are very essential to verify correctness and effectiveness of protocols and applications. In this paper, we focus on a model of radio wave propagation for IVC simulation systems and propose a communication model which behaviors of radio waves are applied to. In our model, a building density and an angle between a road and a line-of-sight of two vehicles are used instead of detailed information of buildings and maps. From experimental results, our model has 81% accuracy and three times computation speed-ups in comparison with the original land mobile communication model.
Key words:
communication model, inter-vehicles communication, simulation system, radio wave propagation

1. Introduction

Recently, many researches on inter-vehicle communication (IVC) have been reported [1-3]. In development of communication protocols and applications, especially in development of IVC systems, simulation technologies are very important. This is because practical experiments for IVC are very hard to be carried out. For example, in order to examine a possibility of communication among cars (mobile terminals), a lot of cars and communication equipment have to be provided and a huge area where the cars move freely has to be needed. Thus, it is very essential to provide simulation systems for developing inter-vehicle communication systems.

In simulation experiments, modeling methods of the real world and its implementation in simulation systems are keys to make results of simulation experiments effective. Furthermore, in simulation systems, a computational performance of the models is significant as well as accuracy of the models. Namely, it is very important to achieve correct result in reasonable computation time with adequate computing facilities.

Here, we focus on a communication model for IVC simulation. Until now, the communication model is paid little attention in simulation systems. In many traditional simulation systems, the communication model is very simple: a possibility of communication between two mobile terminals is determined on the basis of only the distance between two terminals [4, 5]. Also, this communication model can be used appropriately in free space, where no obstacles such as buildings exist. However, IVC systems are mainly used in urban areas where many buildings and other structures exist. In urban areas, the above simple model cannot be applied because radio waves are affected by buildings. Thus, for IVC simulation systems, an enhanced communication model which pays attention to behaviors of radio waves 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 directly 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 appropriately to IVC simulation systems, efficient algorithms for designing models have to be required.

In this paper, we propose a communication model for IVC simulation systems. As a land mobile communication model with low-height antenna, we note 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. Namely, this model has good accuracy but too bad computational performance. In order to achieve both good accuracy and good

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computational performance, we adopt a building existence ratio in the area and an angle between a road and a line-of-sight of two terminals in our proposed communication model. With our proposed model, we can achieve less computation cost and sufficient computation accuracy.

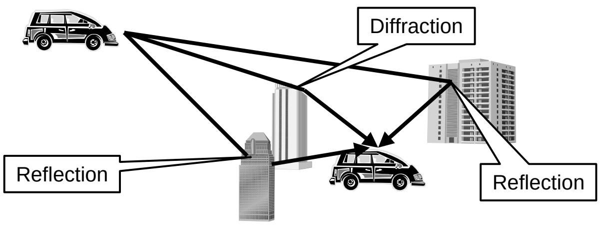


Figure 1: Multi-path fading

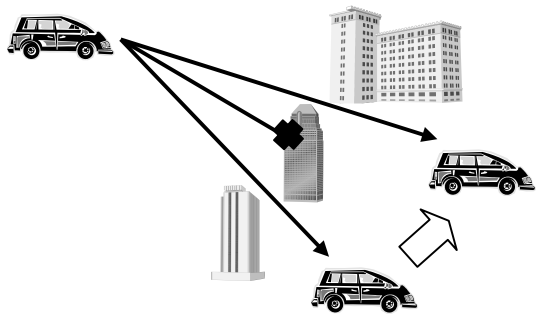


Figure 2: Shadowing

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 a communication 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 movement of mobile terminals and existence of obstacles in urban areas. The fluctuations are expressed with three independent factors: multi-path fading, shadowing and path-loss.

In urban areas, there are always many obstacles such as buildings between two mobile terminals. Thus, as shown in Figure 1, radio waves are reflected and diffracted, and transmitted through multi-path radio waves. 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, 8]. Thus, it is very important to take such fluctuations into account in inter-vehicle communication models.

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, 9].

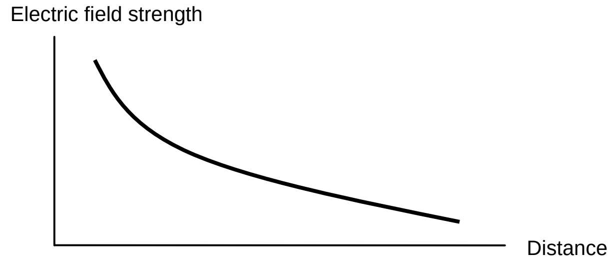


Figure 3: Path-loss

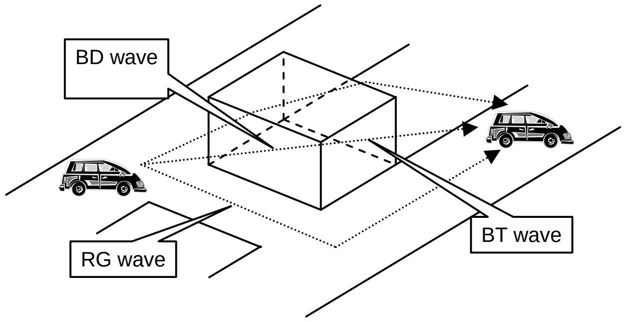


Figure 4: Three waves in Kaji model

Path-loss is caused by the distance between two terminals. Figure 3 shows a path-loss graph. This figure shows that a power of radio waves is decreased according to the distance between two terminals. For the path-loss, various models based on a height of antenna and obstacles have been proposed [6, 7, 10]. 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 radio waves: BT (building transmitted) wave, RG (road guided) wave and BD (building diffracted) wave. The BT wave represents radio waves transmitted by buildings. The RG wave represents radio waves propagated along streets. The 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

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}	25dB

propagation loss is selected as the propagation loss for path-loss. The propagation loss L is calculated as follows.

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

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

Figure 5 shows properties of electric field strength for each wave. When a distance between two terminals is short, the BT wave is dominant. However, as the distance is long, propagation losses of the BT wave increase. This is because the number of buildings between two terminals also increases. Propagation losses of the RG wave are small while radio waves propagate along roads. The propagation losses decrease suddenly whenever radio wave passes at intersections. The propagation losses of the BD wave hardly change. The BD wave is dominant when a distance between two terminals is long.

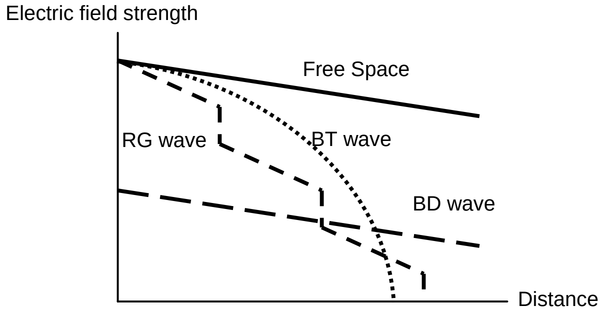


Figure 5: Properties of electric field strength

3. Communication Model for IVC

3.1 Approaches

In the previous section, Kaji model was introduced as one of the radio wave propagation models with a low-height antenna. By Kaji model, we can calculate propagation losses precisely. However, several detailed geographic information such as location, width, and height of buildings, its material, and so on must be provided. In general, such detailed information cannot be achieved. Furthermore, Kaji model takes huge time to calculate. This is because three independent radio wave propagation losses have to be calculated and relationships between mobile terminals and many numbers of buildings have to be calculated for each calculation. Therefore, Kaji model cannot be applied to IVC simulation systems.

For communication model in IVC simulation systems, we have to pay attention to following two points. First, we have to take radio wave propagation in urban areas into account. In IVC, communication occurs in several places. Especially, propagation losses by buildings occur mainly in the urban areas. In the urban areas, many roads are composed as a grid pattern, and roads are surrounded with buildings. Clearly, properties of radio wave propagation to the direction along a road differ from that to the direction cross a road because of the number of crossing building. Therefore, in order to calculate propagation losses, whether a line-of-sight is crossing a building block or not is very important. Second, we have to consider computation cost. In IVC simulation systems, many cars communicate with each other, and thus frequency of communication becomes huge. So, in order to develop communication model for IVC, both the accuracy of model and computation cost of model are considered.

Under the above circumstance, we adopt the following approach. First, we adopt a building existence

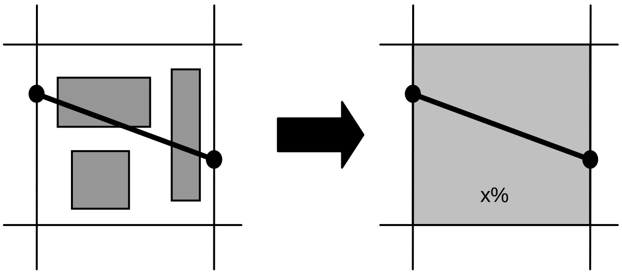


Figure 6: Building density

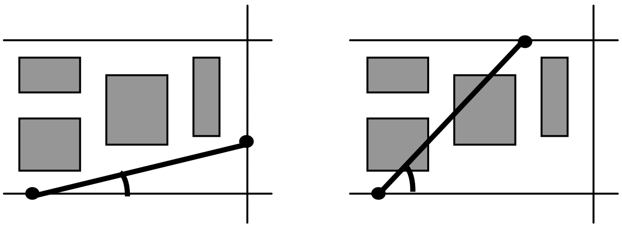


Figure 7: An angle between a line-of-sight and a road

ratio (building density) of an area instead of detailed information about buildings (Figure 6). 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 (Figure 7). 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 thus the influence of buildings cannot be ignored.

3.2 Proposed Communication Model

As shown in the previous section, we consider an angle between the line-of-sight and the road. As the angle increases, buildings have a great influence on propagation losses. Furthermore, the influence of buildings becomes constant from a certain angle. From this consideration, we suppose that the relationship between propagation losses and angles can be formed as trapezoid in Figure 8. In Figure 8, the angle stands for the angle between a road and a line-of-sight. As the angle increases, a propagation loss is also increased. This is shown as a transition section. The transition section also appears in opposite side (from $\phi-\alpha$ to ϕ). In the middle section (from α to $\phi-\alpha$),

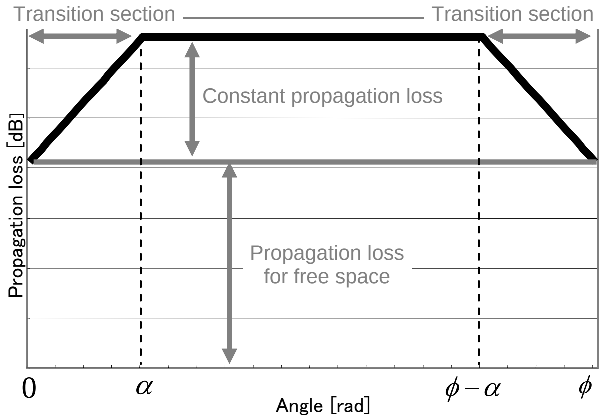


Figure 8: Relations between angles and propagation losses

a building block has influence on propagation losses. So, the propagation loss in this section becomes constant without relation of the angle.

First, we consider constant propagation loss. As described in Section 2, BT wave is dominant when the distance between two terminals is short. Therefore, the transmitted distance is required. By using the building density and a distance between two terminals, we can define the constant propagation loss as follows:

$$ConstantPropagationLoss = a_{11} \times BuildingDensity \times Distance.$$

As described in Table 1, it is known that a_{11} is 1dB. Therefore, constant propagation loss is defined as follows:

$$ConstantPropagationLoss = BuildingDensity \times Distance.$$

Next, we must decide threshold angle α for transition sections. For deciding the angle α, a distance from roads to the other terminal ($\sin\theta \times l$) is important. Here, we focus on the width of the road in urban areas. We assume that the width of the road including roadway, sidewalk and road shoulder is about 30m. In order to simplify the problem, we also assume that cars move at the center of the road. Then, the distance between the car and the building is about 15m. Therefore, the influence of buildings hardly exists in the distance (15m). When the distance is over 30m, more than a half of the distance between two terminals is buildings and the influence of buildings is dominant. Therefore, the angle α is calculated from the equation $\sin\theta \times l = 30$.

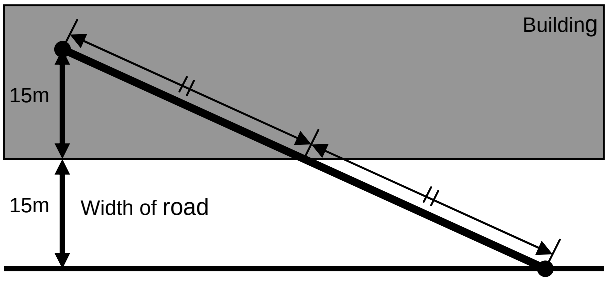


Figure 9: The width of the road

From above consideration, we construct the following communication model to calculate propagation loss L.

$$L(\theta) = \begin{cases} L_0 + \dfrac{d \cdot l \cdot \theta}{\alpha} & (0 \le \theta \le \alpha), \\ L_0 + d \cdot l & (\alpha \le \theta \le \phi - \alpha), \\ L_0 - \dfrac{d \cdot l \cdot (\theta - \phi)}{\alpha} & (\phi - \alpha \le \theta \le \phi), \end{cases}$$

$$where \quad \alpha = \sin^{-1}\frac{30}{l}$$

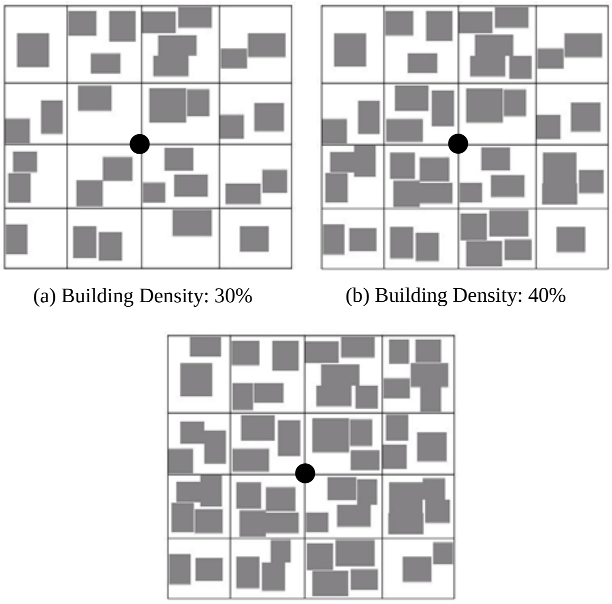
Here, θ is the angle between a line-of-sight and a road. L_0 represents the initial propagation loss. d is the building density. l is the distance of two terminals. α stands for the threshold angle. ϕ represents the parameter to switch intersection points and on-road points. ϕ is $\pi/2$ for intersection points, π for on-road points, respectively.

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. The conditions of experiments are as follows:

- field: 4 x 4 blocks,
- block: 75~100m on a side,
- building size: 10~50m on a side,



(a) Building Density: 30% (b) Building Density: 40%

(c) Building Density: 50%

Figure 10: Examples of fields

- building height: 10~25m,
- building density: 30%, 40%, 50%,
- distance between vehicles: 50m, 100m, 150m.

The size, position and height of buildings are arranged at random. 50 field patterns are prepared. Buildings for all patterns are also prepared. The center of the field is a basing points, and an angle is changed from 0 to $\pi/2$. Figure 10 shows examples of experimental fields. Furthermore, in order to evaluate the effectiveness of our model, the computation time for each model is also analyzed in another experiment. For evaluation of computation time, we measure the computation time to calculate propagation losses for 250,000 pairs because we assume the communication between 500 terminals at a certain moment. Conditions of experiments are as follows:

- field: 1000m x 1000m,
- road: grid pattern roads of 100m intervals,
- building size: 10~50m on a side,
- building height: 10~25m,

- building density: 50%.

The size, position and height of buildings are also arranged at random. The example of field is shown in Figure 11.

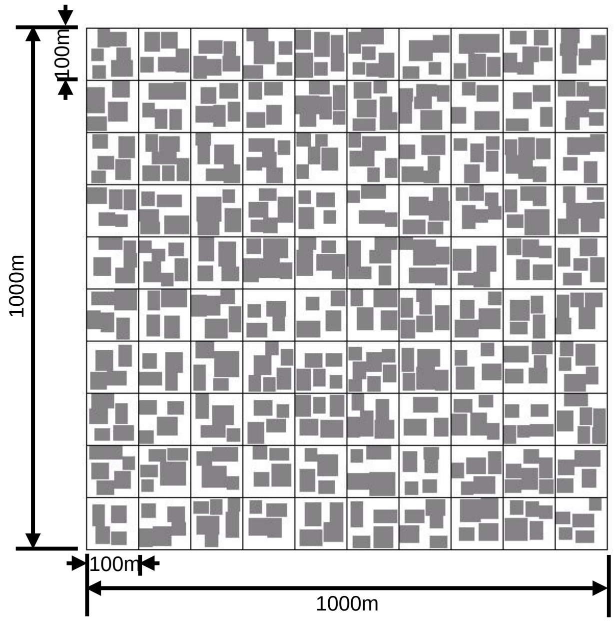


Figure 11: An example of field

4.2 Experimental Result

As described in Section 2, multi-path fading and shadowing occur in land mobile communication. A fluctuation range caused by multi-path 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 that our model calculates propagation loss incorrectly. Table 2 shows the accuracy of model. As a distance between vehicles increases, the accuracy decreases. This is because the BT wave is not dominant as the distance between two terminals is long. The total accuracy for all experiments is 81%.

Table 3 shows the computation time for two models. The computation speed of our model is about three times as fast as that of Kaji model.

4.3 Consideration

As described above, the total accuracy of our model is 81% in comparison with Kaji model. Also, in terms of computation cost, our model can compute propagation losses three times as fast as Kaji model. Of course, we cannot use our mode as a replacement of Kaji model for general conditions. However, In IVC, communication entities always move, and the number of entities is large. Thus, in IVC simulation systems, computation cost is more important than strictness of a communication model. In

Table 2: Accuracy

Density	Distance	The number of measuring points	The number of correct data	Accuracy
30%	50m	11,998	11,384	95%
30%	100m	16,902	12,860	76%
30%	150m	12,915	8,835	68%
40%	50m	9,776	9,346	96%
40%	100m	15,284	12,003	79%
40%	150m	10,829	8,152	75%
50%	50m	8,544	7,871	92%
50%	100m	12,682	9,616	76%
50%	150m	8,862	7,020	79%
Total		107,702	87,087	81%

Table 3: Time to calculate propagation losses

Our model	33,250msec
Kaji model	109,547msec

IVC communication model, the influence of existence of buildings on propagation losses has to be calculated effectively, not so strictly. Thus, from experimental results, we can conclude that our communication model can calculate propagation losses effectively without detailed information in urban areas nor processing time consumption in comparison with Kaji model.

5. Conclusion

In this paper, we propose a communication model for IVC simulation systems. A building existence ratio (building density) and an angle between a road and a line-of-sight of two vehicles are applied to our model. From experimental results, our model has 81% accuracy and three 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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