FDTD Simulation of Radio Wave Propagation at Intersection Surrounded by Concrete Block Walls in Residential Area for Inter-Vehicle Communications Using 720 MHz Band

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Abstract

Inter-vehicle communication system using 720 MHz band to prevent car crashes at an intersection has been proposed in Japan recently. In this paper, the propagation characteristics at an intersection surrounded by concrete block walls in residential area were analyzed by using the FDTD method for the first time. We investigated the influence of wall thickness and source locations on the propagation characteristics. As a result, the common wall thickness and source locations do not strongly affect the propagation loss. Furthermore, we analyzed the power delay profile by taking into consideration the structure of the concrete block walls.

Keywords : Inter-vehicle communication Radio wave propagation Intersection Concrete block wall FDTD method

1. Introduction

Inter-vehicle communication system using 720 MHz band at an intersection has been proposed in Japan recently [1]-[4]. The IVC system has a high possibility to prevent car crashes with invisible cars on the blind spot at a poor visibility intersection. In Japan, there are many intersections surrounded by concrete block walls in residential area. These intersections usually have poor visibility. However, the propagation characteristics for 720 MHz band at these intersections are not well known.

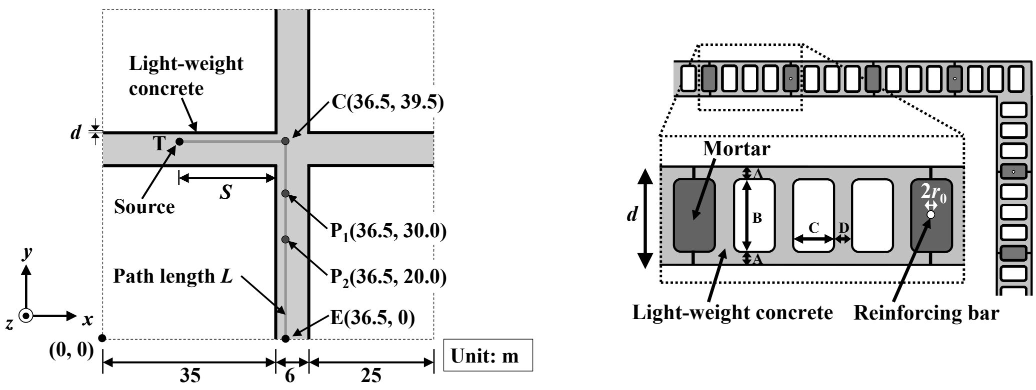
The radio wave propagation characteristics at an intersection surrounded by buildings have been traditionally analyzed by using the ray tracing method [2]-[4], which is generally simple and fast. However, the method can not analyze objects smaller than several wavelengths. Moreover, the calculation time increases sharply when the analysis of complex structures in which penetrating waves exist is carried out. On the other hand, the finite difference time domain (FDTD) method is one of powerful and versatile methods. Although it is usually inefficient compared with the ray-tracing method, the FDTD method is suitable for heterogeneous and complex structures.

This paper presents an analysis of the radio wave propagation characteristics at an intersection surrounded by concrete block walls for the 720 MHz band. The characteristics are analyzed for the first time by using the FDTD method. More specifically, the impact of the thickness of the compound walls, wave source location, and wall structure on radio wave propagation was investigated. The following tasks are performed: 1) the propagation loss is analyzed; 2) the quasi-impulse responses are analyzed to obtain the power delay profile. These characteristics are very important when estimating communication quality.

2. Propagation Characteristics of Radio Waves at Intersection Surrounded by Concrete Block Walls in Residential Area

2.1 Intersection Surrounded by Concrete Block Walls

Figure 1 shows an intersection surrounded by concrete walls in a residential area. Here, roads with one lane in each direction and the concrete block walls which enclose houses are located.



(a) Intersection (b) Concrete block walls

Figure 1: Intersection surrounded by concrete block walls in residential area.

Point T corresponds to a source location. The parameter S corresponds to a distance from the intersection to point T. Points P_1 and P_2 correspond to the observation locations at non-line-of-sight (NLOS) region for the quasi-impulse response analyses. Table 1 shows the sizes of concrete blocks. These sizes are based on the Japanese Industrial Standards. Here, d=0.12 m and 0.10 m are the most common thickness of concrete block walls in Japan. Table 2 shows the parameters used in this simulation. Here, S=20 m corresponds to the stopping distance for vehicle of speed 40 km/h. The wall thickness $d=\infty$ corresponds to the case that all area inside walls is filled with a uniform light-weight concrete. The light-weight concrete was assumed to have the electrical constants recommended for 1 GHz by ITU-R [5]. In this study, two-dimensional FDTD analyses (E_z, H_x, H_y) were carried out as a first step.

Table 1: Sizes of concrete blocks.

Thickness d [cm]	Sizes of concrete blocks [cm] A	B	C	D
12.0	2.4	7.2	8.0	2.4
10.0	2.4	5.2	8.0	2.4

Table 2: Parameters used in this simulation.

Wave source	Frequency f [MHz]	720	
	Distance S [m]	20, 15, 10, 5	
Uniform concrete wall	Thickness d [m]	∞, 0.12, 0.10	
	Light-weight concrete	ε_r	2.0
		σ [S/m]	0.0278
Concrete block wall	Thickness d [m]	0.12, 0.10	
	Light-weight concrete	ε_r	2.0
		σ [S/m]	0.0278
	Mortar	ε_r	5.6
		σ [S/m]	0.0117
	Reinforcing bar	r_0 [mm]	4.0
Spatial increment	Δ [mm]	8.0	

2.2 Propagation Loss Analysis

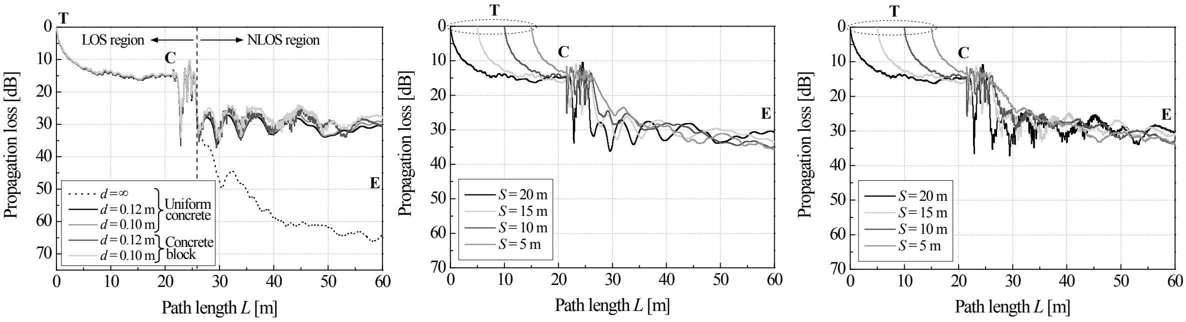
In this section, the propagation loss analyses are discussed. Figure 2 illustrates the propagation loss on the path TCE for 720 MHz. The path length L is measured from point T for the case of S=20 m. The propagation loss is obtained by taking the average of E_z over the vehicular width w_v=1.8 m in transverse direction to the path. Moreover, the propagation loss on the path is normalized by the value on the point T. Hereafter, we investigate the influence of wall thickness, source locations and wall structures.

2.2.1 Characteristics for Uniform Concrete Walls

First, the influence of wall thickness d is described. In the case of $d=\infty$, the propagation loss become very large because most propagation waves cannot arrive at the NLOS region. In contrast, in the case of d=0.12 m, the propagation loss becomes small because the relatively strong waves penetrating through the walls are observed at the NLOS region. Furthermore, wall thickness d=0.12 m and 0.10, which are most commonly used, have almost the same propagation loss characteristics. Next, the influence of source location S is described. In the case of $d=\infty$, the propagation loss depends strongly on the source location S. In contrast, in the case of d=0.12 m, the propagation loss does not depend strongly on the source location S.

2.2.2 **Characteristics for Concrete Block Walls**

First, the influence of wall thickness *d* is described. The propagation loss does not depend on the most commonly used wall thickness. Next, the influence of source location *S* is described. The dependence on the source location *S* is small similarly to the uniform concrete wall case. Finally, the influence of wall structures is described. The propagation loss for concrete block walls is slightly different from that for uniform concrete walls on the whole.



(b-1) Uniform concrete walls. (b-2) Concrete block walls.

(a) Effect of wall thickness *d*, where *S*=20 m.

(b) Effect of source location *S*, where *d*=0.12 m.

Figure 2: Propagation loss on the path TCE.

2.3 **Quasi-impulse Response Analysis**

Although a strict impulse response analysis should be carried out, the FDTD method cannot treat pure impulse waves. For that reason, quasi-impulse waves are used. The modulated Gaussian pulse wave was input in the quasi-impulse response analyses. The center frequency and the half-power band width of the modulated Gaussian pulse wave were f_c=720 MHz and f_0=60 MHz, respectively. The power delay profile and the azimuthal power delay profile were observed at the points P_1 and P_2. The azimuthal power delay profiles were obtained by the method in which the direction of arrival is estimated using the multiple signal classification (MUSIC) algorithms [6]. It becomes possible to estimate the propagation path of radio waves based on the observation results for the arrival time and the arrival direction of the azimuthal power delay profile. The elements of array antenna were lined up in the *x* direction at the observation points. The number of elements was five. Each distance between array antennas was set to 64.0 mm.

2.3.1 **Power Delay Profile**

Figure 3 shows the power delay profile and the azimuthal power delay profile on the point P_2. The values are normalized by the maximum value on the point T. The arrival angle θ is measured from *x*-axis. First, the characteristics for uniform concrete wall are described. In the case of $d=\infty$, the received power for source location *S*=20 m at NLOS region is very small because there is not the penetrating waves through the wall. In contrast, in the case of *d*=0.12 m, both the penetrating waves and the reflected waves can be observed at NLOS region. Next, the characteristics for concrete block wall are described. The penetrating waves through the wall are stronger than the reflected waves from the opposite side wall. This seems to be due to the fact that the reflection coefficient of the walls is reduced by cavities in the concrete blocks. Furthermore, the shapes of power delay profiles spread compared with those for uniform concrete walls

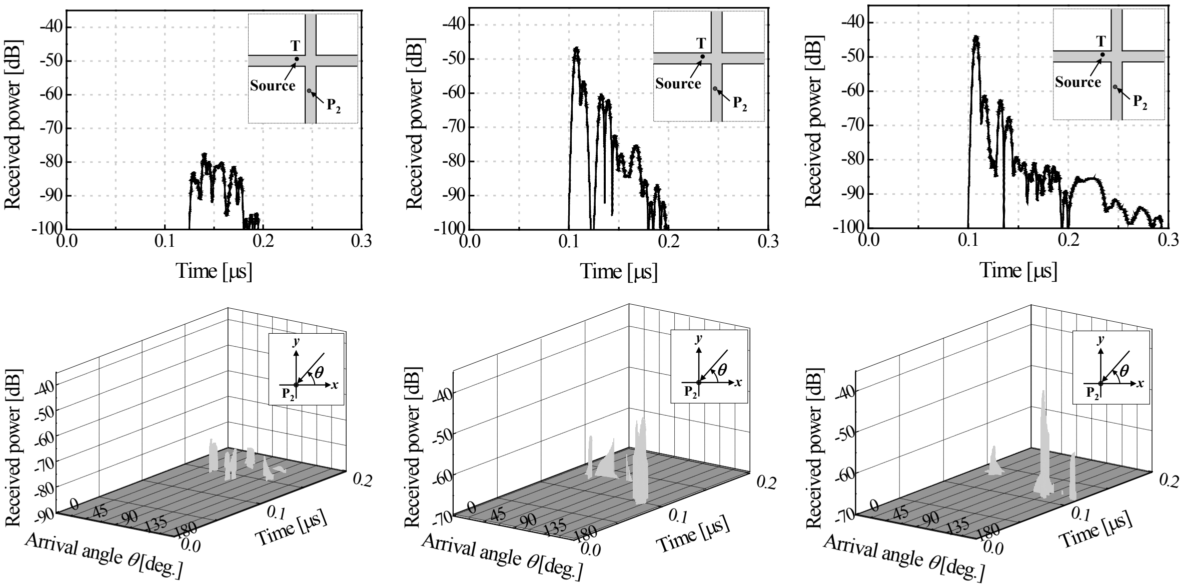
3. Conclusion

In this paper, the propagation characteristics at an intersection surrounded by concrete block walls in residential area were analyzed by using the FDTD method for the first time. We investigated these characteristics taking account of wall thickness, source locations, and wall structures. As a result, following new knowledge is obtained;

1) Penetrating waves through concrete block walls can not be ignored.

2) Concrete block walls have propagation loss characteristics that are similar to those for uniform concrete walls when the thickness is the same.
3) Propagation loss is almost independent of common wall thickness and source location.
4) The amount of delay time is increased in comparison with the results obtained for uniformly light-weight concrete walls.

In the near future, we plan to investigate the propagation characteristics taking into consideration the ground, antennas, vehicles, and the Doppler effect in three-dimensional space.



(a-1) d=∞ (a-2) d=0.12 m

(a) Uniform concrete walls. (b) Concrete block walls, where d=0.12 m.

Figure 3: Power delay profile and azimuthal power delay profile on the point P_2, where S=20 m.

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