Propagation Characteristics of Wireless Communications in Crowded Train Cars

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Abstract

Electromagnetic field (EMF) distributions created by a 5.2 GHz wireless transmitter inside train cars are analyzed and propagation characteristics are determined from the analysis results. We use the FDTD technique and a large-scale parallel computing technique to precisely estimate the EMF distributions inside cars with passengers.

Keywords : wireless LAN, train cars, propagation characteristics, large-scale FDTD analysis

1. Introduction

The usage of wireless communication devices has extended to more environments such as cars, buses, and trains. Recently, some railway companies have begun in-car wireless LAN service. Some simulation results and experimental studies have been reported that address the estimation of propagation characteristics in train environments [1,2]. However, few studies have addressed the effect of EMF absorption by the passengers' bodies in train cars. The aim of this study is to develop an accurate and reliable method of estimating the EMF distributions in train cars so as to advance radio link design of wireless LANs operated inside the cars. Given the rapidly increasing variety of mobile communication devices, comprehensive measurements cost too much, and it is difficult to carry them out precisely. Therefore, we propose to apply large-scale numerical simulations to examine the EMF created by mobile radios [3,4]. The FDTD technique is an efficient way to solve Maxwell's equations for complex structures [5]. In addition, a large-scale parallel computing technique based upon several node partitions of a supercomputer is used because of its memory and speed capabilities [6]. This paper uses the parallel FDTD analysis technique to estimate the propagation characteristics of the typical train car model. To estimate the effect of the absorption by the passengers' bodies, we derive simplified histograms of the electric field distributions throughout the whole interior of the car.

2. Estimation method and train model

FDTD analysis is applied in order to derive spatial EMF distributions throughout the train car with passengers. Fig. 1 shows the two adjacent train cars model used in this study. This model is based on a typical commuter train now in active service in Japan [3]. A 5.2 GHz wireless LAN access point simulator, a vertical polarized half-wavelength dipole antenna located 2.1 m above the floor, is assumed to be placed at the front of the first car as shown in Fig. 1. The dimensions of the train used in the analysis model are as accurate as possible. Because our research interest of this paper is EMF distribution inside the cars, the outer parts of the cars such as rails, pantographs and so on, are not modelled in the analysis. The dimensions of the two adjacent cars are: length of 35.6 m, width of 2.78 m and height of 2.7 m. The train body is made of perfect electric conductor (P.E.C.). The window panels are made of 10 mm thick glass. The bench-type seats consist of P.E.C. and lossy material. The train-car gap is modelled by extending the metal floor. The ceiling luggage racks are made of P.E.C. Additionally, standing and sitting homogeneous human models [7] are used as passengers. These models have realistic shapes and their electric parameters are taken from a 2/3 muscle-equivalent phantom [8].

In order to estimate the absorption effects by the passengers' bodies, the occupancy rate is changed from 0 % to 100 % (0 % : without passengers, 20 % : 60 passengers, 40 % : 117 passengers, 60 % : 175 passengers, 80 % : 230 passengers and full capacity : 304 passengers). Tables 1 and 2 summarize the FDTD parameters and the parameters of the materials, respectively. The total problem space, including absorbing boundary condition, consists of 676×660×7246 cells. The memory required to execute the analysis is about 480 GB.

3. Field estimation results

Fig. 2 shows the 2-dimensional electric field distributions obtained by the FDTD analyses for various occupancy rate models. A vertically polarized wave at 30 dBm at 5.25 GHz is radiated from a half-wavelength dipole, located in car #1. Vertical (Ey) polarized electric field distributions on the horizontal plane at the height of 1.1 m from the car floor are shown in the figures. These figures show that attenuation effect due to passengers' bodies cannot be neglected when estimating the EMF in train cars. Even at the occupancy rate of 20 %, the electric field intensity in car #2 is about 10 dB lower than the case with no passengers.

Next, we apply histogram analysis to take into account the effects of RF absorption by passengers' bodies quantitatively. Based on the electric field distributions, we examined the histograms of each train car as shown in Fig. 3. Additionally, the modes of those histograms are plotted in Fig.4 with regard to occupancy rate. These are evaluated from 2-dimensional electric field distributions of the whole observation plane, 1.1 m above the floor. From the figures, we can confirm that the maximum attenuation of the electric field due the passengers is about 16 dB in car #1, which has the highest passenger density. In addition, the attenuation increases linearly with occupancy rate as shown in Fig.4. The rates of attenuation increase for car #1 and car #2 are -0.154 dB/% and -0.389 dB/%, respectively.

4. Conclusions

We estimated EMF distributions established in two adjacent train cars due to a 5.2 GHz wireless LAN terminal. Based on field distribution analyses, the energy absorption effects of the passengers' bodies were determined. Six models, with occupancy rates of 0, 20, 40, 60, 80 and 100 %, were developed and used in the numerical analyses of field distributions. We found that if both cars were full (with passengers), the field intensity in the car that held the transmitter might be about 16 dB lower in compared to no-passenger case. The intensity in the adjacent car might be 40 dB lower than the no-passenger case. We intend to conduct other estimations that consider different train models, more antenna sources, and different types of transmitting antenna.

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Table 1: FDTD parameters

Problem space	676×660×7246 (x , y , z)
Cell size (cubic)	d = 5 mm
Frequency	5.25 GHz
Absorbing B.C.	P.M.L. (16 layers)
Iteration	2,000
Antenna	1/2 dipole Input 1 W
Number of guard cells	60 (in all directions)
Number of nodes	8
Required memory	480 GB

Table 2: Parameters of train-car materials

Train-car body	P.E.C.
Seat (metal & pad)	metal: P.E.C. pad: ε_r =1.6, σ =10^{-3} [S/m]
Ceiling luggage rack	P.E.C.
Window	ε_r =5.0, σ =0.003 [S/m]
Car gap (floor: metal, side walls & ceiling: opened)	metal: P.E.C.

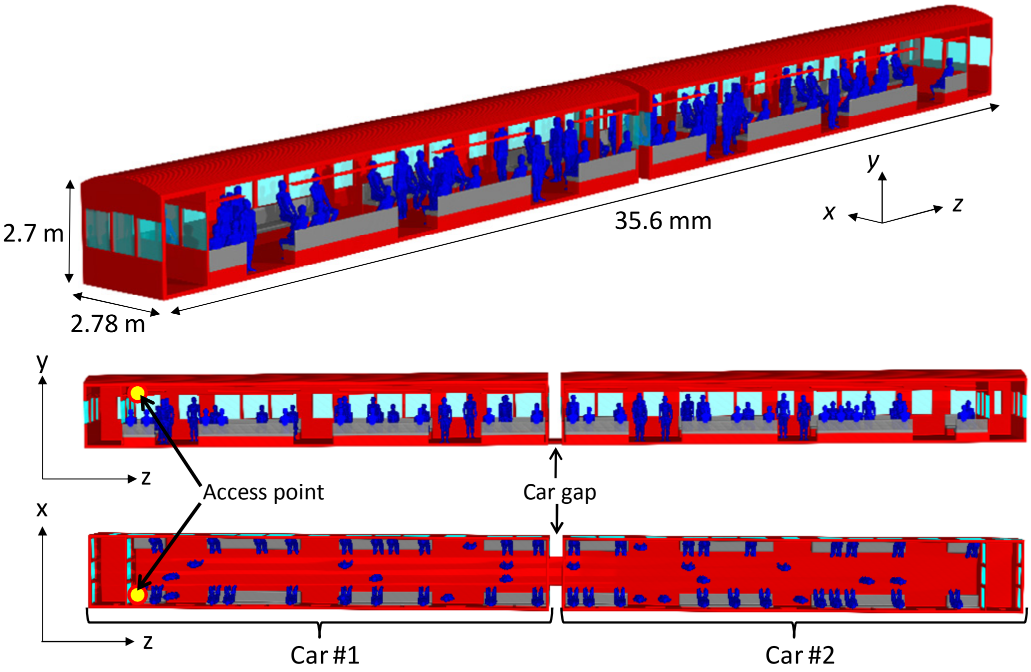

Figure 1: FDTD model for two adjacent train-cars (occupancy rate: 20 %).

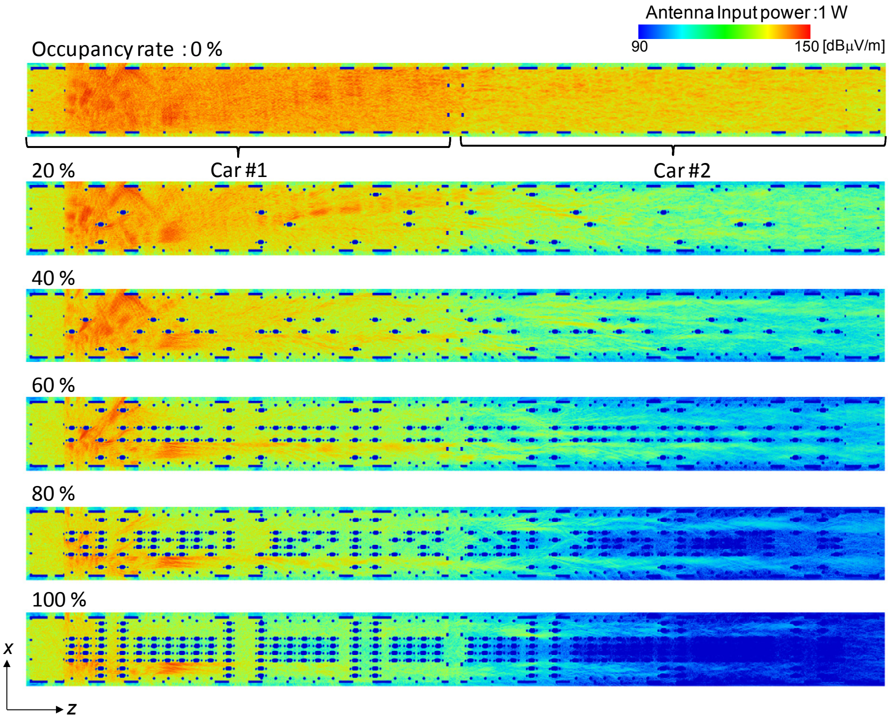

Figure 2: Electric field distributions inside the train cars on the horizontal plane at the height of 1.1 m from the floor.

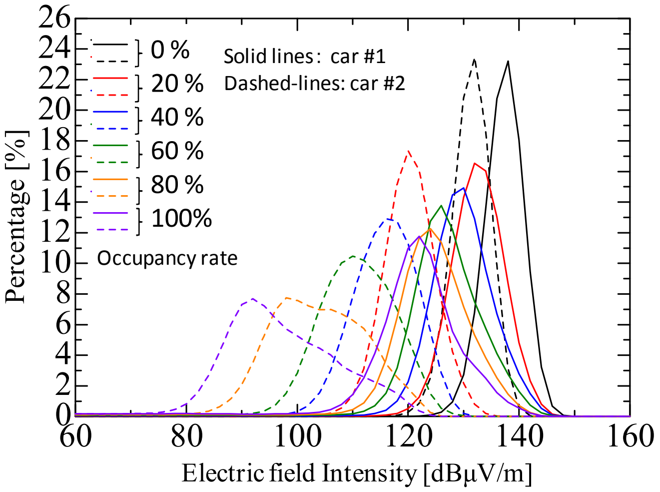

Figure 3: Electric field histograms derived from Fig.2.

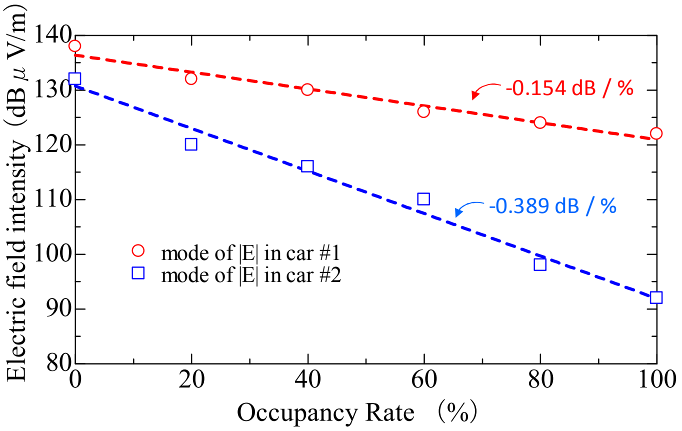

Figure 4: Attenuation characteristics versus occupancy rate of train cars.