Radio Propagation Loss Study by Hybrid Simulation for Smart Meter Communication in Apartment Building

Nodoka NAKAGAKI[†], Yasushi YAMAO[†], Reina NAGAYAMA[‡], Takuya KAWATA[‡]
[†] Advanced Wireless and Communication Research Center, The University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo, 182-8585 Japan
[‡] Tokyo Gas Co., Ltd.

***Abstract* – Recently, wireless smart meter systems for the life infrastructure such as electricity, gas and water attract much attention. Since radio propagation environments for the smart meter communication in apartment buildings are very complicated, it is difficult to analyze the propagation loss with ray tracing method. This paper proposed a hybrid simulation technique which combines ray tracing and FDTD methods. We first analyzed the radiation from a smart meter in the pipe shaft by FDTD method, and then calculated propagation loss between pipe shafts by ray tracing method. The results obtained by the hybrid technique are compared with those by the ray tracing only and the FDTD only. The hybrid method can extend analyzable area in the apartment building and is effective to obtain results close to FDTD method.**

***Index Terms* — smart meter, propagation loss, ray tracing, FDTD, pipe shaft.**

1. Introduction

A wireless smart meter system for the life infrastructure attracts much attention because it is expected to contribute more effective use of life resources such as electricity, gas and water [1]. A smart meter (SM) consists of a wireless transceiver and a microprocessor controlled resource flow meter. The resource flow is measured time by time and the data is sent via wireless packet communication to the data fusion center. The IEEE 802.15.4g Wi-SUN using 920 MHz is a typical protocol suitable for smart meter systems [2].

For smooth deployment of the system, knowledge of radio propagation characteristics for various environments is essential. Since SMs are required to be operated 10 years without battery change, its transmission power is low. In apartment buildings, SMs are installed in a small space called "pipe shaft (PS)". The PS is enclosed by thick concrete walls and a metal access door that form a lossy cavity space. Some part of transmitted radio wave power is radiated outside the PS after experiencing penetration loss through the concrete wall. It cannot be represented by a simple propagation model assumed in ray tracing, but handled only by electromagnetic analysis method such as FDTD (Finite-difference time-domain) [3]. Although the FDTD method gives accurate results for the PS analysis, it requires huge computing resources and cannot be employed for the whole building with several tens of apartment houses.

The hybrid propagation analysis method that combines ray tracing and FDTD is a candidate for solving the wide-area indoor propagation analysis [4, 5]. This paper proposed a hybrid simulation technique suitable for the propagation analysis between SMs. We analyzed the radiation from a SM in the PS by FDTD method and then calculated propagation loss between PSs by ray tracing method. The results obtained by the proposed hybrid technique are compared with those by the ray tracing only and the FDTD only.

2. Smart Meter System

The smart meter system for an apartment building is shown in Fig. 1. SMs are installed in each PS and measure the flow of electricity, gas and water for each apartment house. In order to combat multiple penetration loss of concrete walls in the building, multi-hop mesh network is formed so that measured data is relayed from a PS to the neighbor PS until it reaches the data sink node in the building. The neighboring PS is either in the same floor or in a different floor through the vertical pipe shaft hole.

Each SM in the PS has single antenna, which is a horizontally-polarized inverted-F type with 3D radiation pattern shown in the figure. The typical PS dimensions are also indicated in the figure.

3. Hybrid Propagation Simulation Method

As the common methods for UHF radio propagation analysis and estimation by computing, the ray tracing and FDTD methods are well known. The FDTD analysis gives an accurate result if all electromagnetic parameters and detailed dimensions of objects in the analyzed area are provided.

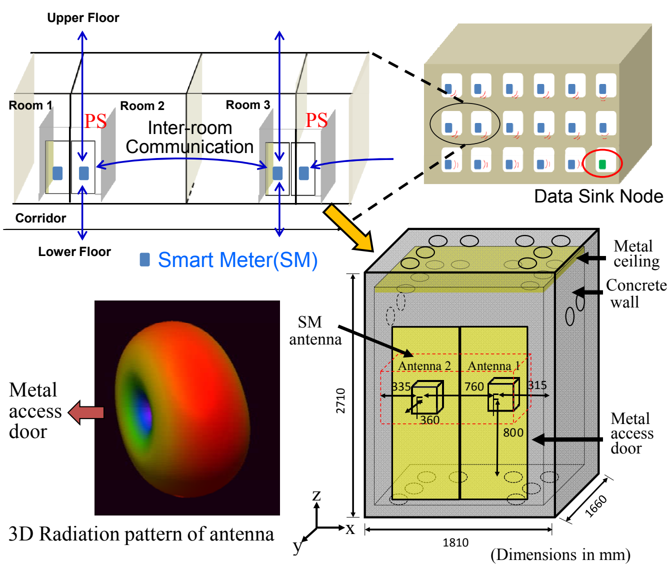


Fig. 1. Smart meter system for apartment building.

TABLE I Electromagnetic parameters

Material	Relative permittivity	Conductivity (S/m)	Magnetic Permeability
Concrete wall (200 mm)	7.2-j2.0	10.8	1
Metal access door	1	1.03×10^{7}	5000
Glass windows	6.27	1×10^{-12}	1

TABLE II Simulation settings

RF Frequency	920 MHz
Transmitting power	10 mW
Antenna height	0.8 m
FDTD simulator	XFdtd ver. 7
FDTD mesh size (average)	5 mm
Ray trace simulator	RapLab ver. 7.2
Max. number of reflections	3
Max. number of deflections	2
Max. number of penetrations	4
Ray search method	Imaging

However, it requires a large amount of computer memory determined by the number of meshes, therefore not suitable for wide area analysis. On the other hand, ray tracing method can save the memory and enables wide area analysis regardless of wave length, although the results include error due to roughness and ununiformity of reflection surface.

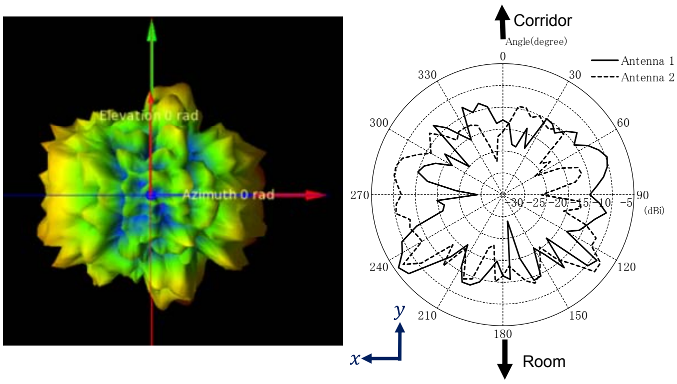
Hybrid technique based on combining ray tracing and the FDTD methods is suitable for the analysis of indoor propagation with realistic size of computer memory. In order to take full advantage of the method, we employ the FDTD method for analyzing the radiation from PS including pipes and SM antennas in it. Ray tracing method is employed for propagation path analysis between PSs. For combining two methods, we assume the PS as an imaginary antenna that radiates transmission signal from SMs. Therefore we first analyze the 3D radiation from the PS with the FDTD method, and then set the imaginary antennas instead of the original PSs and SMs in the ray tracing analysis model.

4. Simulated Results

The electromagnetic parameters and the simulation settings are shown in Table I and Table II, respectively.

Figure 2 shows the simulated radiation pattern from PS, (a) in 3D, and (b) on the horizontal plane. The 3D averaged radiation gain is -12.0 dBi, which corresponds to 920 MHz penetration loss due to concrete wall with thickness of 200 mm. Due to multiple reflections inside the PS, the radiation from PS presents a complicated pattern. Since the original SM antenna unit is set so that its null points are directed to the corridor access door and the backward, directional gains for the angles of 0° and 180° in Fig. 2 (b) are lower than the average gain. The peak gain is around -6 dBi with the direction of 235° for antenna 1 and 125° for antenna 2.

Fig. 3 shows total propagation loss from a transmitting SM to three SMs, Rx-a, Rx-b, Rx-c. They are obtained by three methods and compared. Rx-a is set in the same PS as the transmitting SM, whereas Rx-b and Rx-c are set in the neighboring PS that is 4.6 m apart. From the figure, the ray tracing method gives optimistic results compared with the FDTD and hybrid methods. As shown in Fig. 2, the radiation



(a) 3D pattern (Antenna1)   (b) Horizontal plane pattern

Fig. 2. Radiation pattern from PS

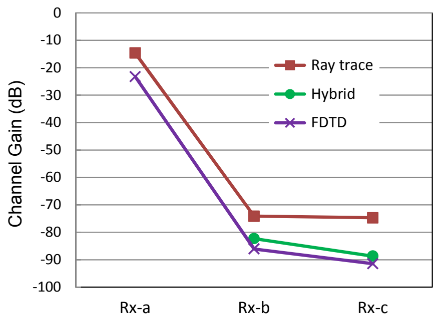


Fig. 3. Simulated propagation loss

pattern from PS is not uniform but disturbed. Therefore the regular rays in geometrical optics do not always become dominant waves. In the ray tracing simulation, radiation pattern from PS is based on the original antenna unit and only the penetration loss is added when the geometrical optics ray goes through the wall. It causes the difference in total propagation loss between SMs.

5. Conclusions

This paper proposed a hybrid simulation technique for estimating the propagation loss between smart meters in PSs. After obtaining the radiation pattern from PS by the FDTD method, propagation loss between pipe shafts is added by ray tracing method. The results by the hybrid technique are compared with those by the ray tracing only and the FDTD only. The hybrid method is shown to be effective to obtain results close to the FDTD method in the apartment building with pipe shafts while requiring less computer memory.

References

[1] S-W. Luan et al, "Development of a smart power meter for AMI based on ZigBee communication," Proc. IEEE PEDS 2009, Taipei, pp. 661-665, Nov. 2009.

[2] K. H. Chang, B. Mason, "The IEEE 802.15.4g standard for smart metering utility networks," Proc. IEEE SmartGridComm 2012, Tainan, no. 1, pp.476-480, Nov. 2012.

[3] D. M. Sullivan, "Electromagnetic simulation using the FDTD Method," Wiley IEEE Press, 2013.

[4] Y. Wang, S. Safavi-Naeini, S. K. Chaudhuri, "A Hybrid Technique Based on Combining Ray Tracing and FDTD Methods for Site-Specific Modeling of Indoor Radio Wave Propagation", IEEE Trans. Antennas and Propagat., vol.48, no.5, pp.743-754, May 2000.

[5] B. Reichel, T. P. Stefanski, "Hybrid Technique Combining the Backward Ray Tracing and the FDTD Method", Proc. European Conference on Antennas and Propagation (EUCAP), pp.1144-1147, 2014.