Indoor Propagation Estimation Combining Statistical Models with Ray-Tracing

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***Abstract*—In order to improve estimation accuracy of the statistical model, we present a novel method. In this method, we classify NLoS region using number of reflections and diffractions calculated by ray-tracing, and then applies different statistical models to each regions. First, we make statistical models. We classify measurements of NLoS region using the conditions up to 3 times reflections, 1 time diffraction, and others, and develop statistical models of each region. Then we compare fitting errors of the developed statistical models. The fitting error decreased from 4.18 dB to approximately 3 dB after some classification, but the fitting error did not decrease any more. Next, we evaluate the calculation errors using the developed statistical models. The calculation error became minimal of 3.77 dB when we classify NLoS into up to 2 times reflection and others, and then tended to increase when we classify further. From the above results, it is optimal that the NLoS region is classified into 3 regions.**

Keywords—propagation estimation; statistical model; ray-tracing

I. INTRODUCTION

To introduce indoor wireless network smoothly, it is required to calculate radio placement design in a few minutes. In the radio placement design, received power distribution is calculated iteratively, and the time required for one calculation needs to be adequately short with small calculation error. 3D ray-tracing is unsuitable, because it takes comparatively lots of time, and calculation error become large arising from unspecified structure material. Therefore, the statistical model [1] is useful for this purpose. Previously, a method applying two different statistical models to each LoS and NLoS region [2] has been employed. However, since the dominant propagation mechanism is different from each receiving point in NLoS, it seems that the calculation error is large if we use a single statistical model. Therefore, in order to improve the estimation accuracy, we present a novel method. In this method, we apply the independent statistical models to the NLoS region according to the differences in propagation mechanisms such as reflection or diffraction.

Section II introduces the method to create and calculate with statistical models. Section III shows the result of measurement in an office floor to create statistical models. Section IV presents a classification method focused on the number of reflections and diffractions. We compare the fitting error of the statistical models to the measurements shown in section III, and present that the consideration up to 3 times reflections and 1 times diffraction is sufficient. In Section V, we evaluate the calculation error using the developed statistical models shown in section IV, and present that the calculation error is 3.77 dB.

II. METHOD OF CREATING STATISTICAL MODELS AND ESTIMATION

Before the estimation, we create statistical models in each indoor environment such as office, factory or residence. In the each indoor environment, the number of reflections and diffractions of the ray arriving at the receiving point are calculated using 3D ray-tracing. Then, measured received points are classified by conditions using these counts. The statistical model is fitted to the each measurement using least-squares method, and the fitting parameters are determined independently to the each measurement. The statistical model is taken to be

$$P_r = P_t + G_t + G_r + 20\log(c/4\pi f) + a + b\log(r) \qquad (1)$$

where P_r [dBm] is received power, G_t [dBi] is absolute gain of the transmitting antenna, G_r [dBi] is absolute gain of the receiving antenna, P_t [dBm] is transmitted power, f [Hz] is frequency, r [m] is straight-line distance between the transmitting and receiving antennas, a [dB] and b are parameters for the statistical model in each condition. a corresponds to mean attenuation of wave due to reflections and diffractions. b corresponds to mean distance attenuation of the wave. c [m/s] is the speed of light.

In the estimation, receiving region is classified according to the classification condition. We use 2D ray-tracing and 2D structure model of estimation area to determine the each region. Since we use 2D ray-tracing calculation time is enough short. Then received powers are estimated using the statistical models matching each region.

III. MEASUREMENT

We measured propagation characteristics in an office floor to develop statistical models. Figure 1 shows the blueprint of the office floor, Tx1–Tx3, and Rx1-Rx3. The elevator hall is surrounded by metal walls. Desks equipped with partitions (1.5 m) are arranged on the floor. And some meeting rooms are arranged at the right and left side. Transmitting antenna was set

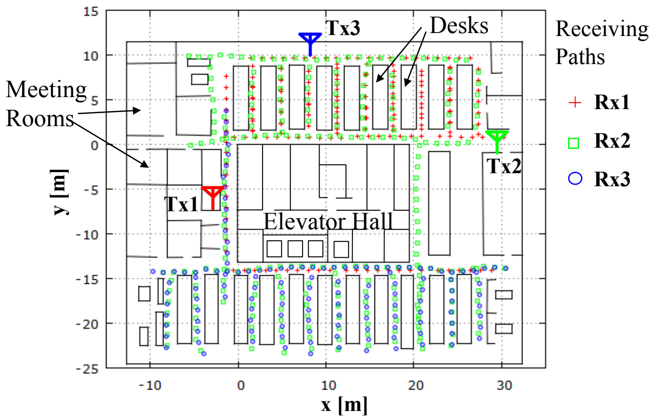

Fig. 1. Transmitting antennas (Tx1-Tx3) and receiving paths (Rx1-Rx3) in the model creation environment.

on either of Tx1~Tx3, and received power is measured along the path for each transmitting antenna. The spacing between receiving points is 0.3~2cm. Both the transmitting and receiving antennas are vertically polarized without directivity in the horizontal plane. Frequency is 2.462 GHz, transmitted power is 25.2 dBm, transmitting antenna height is 2.1 m, and receiving antenna height is 1.5 m. In order to eliminate fast fading (0.5–5λ), a value resampled at 1λ after block averaging over 5λ was used as the measurement value. The number of samples was 5901.

IV. Comparison of Fitting Errors Depending on Classification Method

Figure 2 shows the classification conditions for propagation characteristics based on the reflection and diffraction count. The vertical item indicates rays reflected n times, and the horizontal item indicates rays diffracted m times. Hereafter, the symbols of LoS, and A~H denote classification conditions.

Rays contribute to received power are those with high field strength. Thus, we assume the order of ray strength, and classify the region which contains ray of larger strength first. Generally, the more number of reflections and diffractions increases, the more field strength decreases. And, statistically, amount of attenuation in a single diffraction is greater than that in a single reflection. Therefore, the order of field strength was assumed to be LoS > A > B > C > D > E > F > G > others. In order to verify the appropriate number of classifications of the NLoS region, some level of classification was done. Namely, we classify NLoS region as follows. First, we classify all measurements into LoS which has largest field strength and others (=NLoS). Second, NLoS is classified into A which has 2nd largest field strength and others (=NLoS\A). Furthermore, NLoS\A is classified into B and others (NLoS\A\B). Where, X\Y denotes the measurements which remove Y from X (set-theoretic difference of X and Y). We classify NLoS into 8 regions at most by performing above classification successively.

We compare the fitting errors of each developed statistical model. Fitting error Δ is taken to be

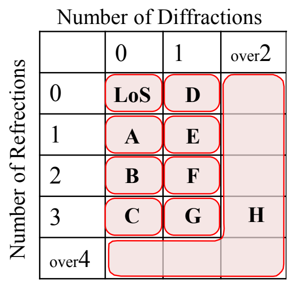

Fig. 2. Classification conditions using number of refrections and diffractions.

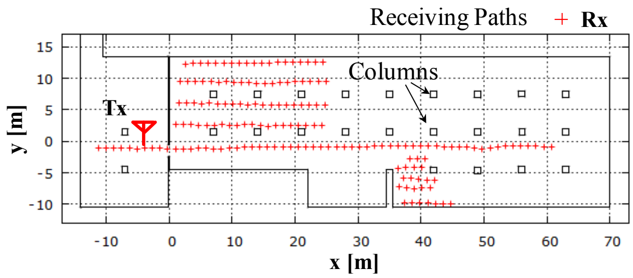

Fig. 3. Transmitter and receiving paths in the evaluation environment.

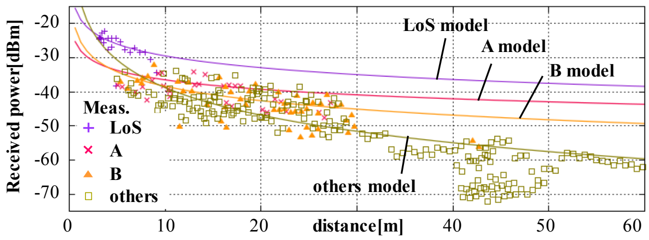

Fig. 4. Example of received powers in the evaluation environment and statistical models developed in the creation environment (Method II).

$$\Delta = \frac{1}{N}\sum_{i=1}^{N}\left|P(i) - P_{mdl}(i)\right| \tag{2}$$

where N is the number of measurement points, $P(i)$ [dBm] is received power at measurement point i, and $P_{mdl}(i)$ [dBm] is the calculated value of the statistical model at the measurement point i. Table 1 shows the fitting error of the statistical model for each classification method, where I~VII denote the number of classification method., and NLoS total denote the fitting error averaged in NLoS. The fitting error (NLoS total) for the conventional method is 4.18 dB, and decreases to approximately 3 dB after some classification. However, the fitting error did not decrease furthermore. When we classify using the method VI, the statistical model became irrational, because the received power of the model increases as the distance increases (b > 0). Therefore, calculation error is indicated as N/A in Table 1, and we do not perform further classification.

V. Verification

With each method of classification, a comparison was carried out in an environment different from that of the statistical model creation (evaluation environment). Figure 3 shows a blueprint of the evaluation environment, position of the transmitting antennas, and receiving paths. Columns continue from the floor to the ceiling. Transmitting antenna height was 1.8 m, and receiving antenna height is 1.5 m. Although items such as desks and lockers are arranged in the evaluation environment, none of these intersect with rays lower than the transmitting/receiving antenna height, and thus they are eliminated from the model. The other measurement conditions (polarization, frequency, transmitting power) and the method of block averaging measurement values are the same as in the environment for creating the statistical model.

Table 2 shows the calculation error and calculation time in each region of the evaluation environment. Calculation error was evaluated by Eq. (2). The calculation error of conventional method for NLoS was 4.64 dB, and calculation time was 4 ms. The calculation error became minimal of 3.77 dB when we classify NLoS into up to 2 times reflection and others (Method II), and the calculation time in this method was 48 ms which is small enough. Figure 4 shows the estimation results of the method II. The calculation error tended to increase when we classify further from the method II. We estimate that increase of the error is due to the measurements distributed in the range 40~45 m in the evaluation environment which has relatively low strength against the statistical model. This is because columns are contained in the first Fresnel zone (~2m) of the rays in the evaluation environment, but there are few columns in the environment for creating the statistical model. Thus, we estimate that almost no samples that match the propagation mechanism of the evaluation environment are included in the creating environment.

VI. CONCLUSION

This paper presents a novel method in which we classify NLoS region using number of reflections or diffractions, and then applies independent statistical models to each region. We evaluated the fitting errors of classification conditions, and it was shown that classifying NLoS into 3 regions was sufficient. We evaluated calculation error of proposed method in the office floor (80m × 20m), and we get 3.77 dB in the calculation time of 48 ms. Therefore, the classification of NLoS into 3 region is optimal. We will investigate classification method in another environment.

REFERENCES

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TABLE I. FITTING ERRORS OF EACH CLASSIFICATION METHOD

	Classification Method	LoS	A	B	C	D	E	F	G	others	NLoS total
Conv.	LoS, others	2.74	-	-	-	-	-	-	-	4.18	4.18
I	LoS, A, others		3.23	-	-	-	-	-	-	3.93	3.58
II	LoS, A, B, others			3.56	-	-	-	-	-	3.27	3.35
III	LoS, A, B, C, others				3.27	-	-	-	-	2.92	3.25
IV	LoS, A, B, C, D, others					2.01	-	-	-	3.07	3.028
V	LoS, A, B, C, D, E, others						2.77	-	-	3.20	3.007
VI	LoS, A, B, C, D, E, F, others							1.70	-	N/A	N/A
VII	LoS, A, B, C, D, E, F, G, others	↓	↓	↓	↓	↓	↓	↓	N/A	↓	↓

TABLE II. CALCULATION ERROR OF EACH CLASSIFICATION METHOD

	Classification Method	Calculation Error [dB]										Calculation
		LoS	A	B	C	D	E	F	G	others	NLoS total	Time [ms]
Conv.	LoS, others	1.51	-	-	-	-	-	-	-	4.64	4.64	4
I	LoS, A, others		3.17	-	-	-	-	-	-	4.63	3.90	24
II	LoS, A, B, others			3.70	-	-	-	-	-	4.44	3.77	48
III	LoS, A, B, C, others				4.51	-	-	-	-	4.67	4.01	60
IV	LoS, A, B, C, D, others					2.99	-	-	-	8.29	4.53	84
V	LoS, A, B, C, D, E, others						8.21	-	-	N/A	4.52	234
VI	LoS, A, B, C, D, E, F, others							N/A	-		N/A	N/A
VII	LoS, A, B, C, D, E, F, G, H, others	↓	↓	↓	↓	↓	↓	↓	N/A	↓	↓	↓