Base Station Antenna Effective Gain Based on Incoming Wave Distribution in Vertical Plane

Koshiro KITAO †, Tetsuro IMAI †, and Yoshio ITOH††
†NTT DOCOMO, INC. ††Tottori University
†3-5, Hikari-no-oka, Yokosuka-shi, Japan, ††4-101, Koyamacho-minami, Tottori-shi, Japan
†{kitaok,imait}@nttdocomo.co.jp ††itoh@ele.tottori-u.ac.jp

1. Introduction

In cellular systems, it is common to use base station (BS) antennas that have a sharp beam pattern in the vertical plane to reduce the amount of interference to neighboring cells. It is well known that the distribution of incoming waves affects the effective gain of antennas that have a directional pattern [1, 2]. In this report, we statistically evaluate the BS antenna effective gain based on the power angle profile (PAP) measured at a BS that is established on the roof of a building in an urban area. This report is structured as follows. First, we describe the statistical characteristics of the PAP in the vertical plane at a BS based on measurement results using a super-resolution method employing a linear array antenna. We also show the distribution of the angle spread (AS) and mean angle (MA) based on measurement results. We then statistically evaluate the BS antenna effective gain based on measured PAPs. Finally, we examine the application of a simple incoming wave model to the evaluation of the antenna effective gain, and verify the validity of the model by comparing the statistical characteristics of the antenna effective gain calculated using the model to the antenna effective gain calculated using the measured PAP.

2. Measurement

The PAP measurements were performed in Tokyo, Japan. We transmitted pseudonoise code from the MS and complex delay profiles were measured for each element of a 16-element linear array antenna established on a BS. The PAP in the vertical plane at the BS was obtained by applying Unitary ESPRIT to the measured complex delay profiles. The measurement frequency was 2.2 GHz and the BS height was 58 m. Each element of the BS antenna was arrayed vertically and the horizontal half - power beamwidth (HPBW) of each element was 34 degrees. A sleeve antenna was used as the MS antenna and the antenna was established on the roof of the measurement vehicle. The MS points were set at 82 locations and the distance between the BS and MS were distributed from 200 to 1600 m. The polarization of the BS and MS antennas was vertical.

3. Measurement Results

Fig. 1 shows all the measured PAPs. The direction angle of the MS is indicated as 0 degrees in the figure, and the circles represent the incoming waves. The total power of the PAP at each MS point is normalized to one. The black line represents the average PAP with a one-degree averaging interval. The average PAP has well-known characteristics approximated as a Laplacian distribution [3]. When performing a regression analysis of the average PAP, the following equation is obtained.

$$P_r = 10 \log e^{-|\theta|/1.1} \quad \text{(dB)} \qquad (1)$$

The correlation coefficient between the average PAP and the regression results is computed to be 0.84. Moreover, Fig. 2 shows the distribution of all the measured ASs. The median value of the ASs is approximately 0.9 degrees and it is greater than the average value of 0.2 to 0.4 degrees when the distance between the BS and MS is 1 to 4 km, which is reported in [4]. We consider that this is caused by an increase in the difference between the direction angle of the scatterer and the direction angle of the MS as the distance becomes shorter. Fig. 3 shows the distribution of the MA. Since the MA is the center direction of the PAP and the median value of the MA is nearly 0 degrees, the average direction of the incoming waves is in the direction of the MS. The standard deviation of the MA is 2.6 degrees. Moreover, we calculate the correlation coefficient between the distance and the absolute value of the ASs and MAs, and find that the correlation coefficient of the AS is -0.2 degrees and the correlation coefficient of the MA is -0.2 degrees; therefore, the correlations are low.

4. Evaluation of Antenna Effective Gain Based on Measure PAP

A. **Definition of Antenna Effective Gain**

There are many reports regarding the antenna effective gain [1, 2]. One of the methods in these reports compares the received level of the evaluated antenna to the received level of a reference antenna. In this report, we adopt a similar method. More specifically, we define antenna effective gain G_e as the difference between the received level of the evaluated antenna, P_e, and the received level of the isotropic antenna, P_i. G_e is expressed in the following equation.

$$G_e = P_e - P_i \quad \text{(dB)} \tag{2}$$

B. **Evaluation of Antenna Effective Gain Based On Measured PAP**

We calculate P_e and P_i in (2) using the measured PAP and evaluate the antenna effective gain, G_e. We evaluate G_e using the evaluation model shown in Fig. 4. In the model, the evaluated BS antenna is a vertical linear array antenna with element spacings of $\lambda/2$ where λ denotes the wavelength. The BS antenna height is 50 m and the cell radius is 1000 m. The main beam of the BS antenna is directed toward the cell edge and the MS direction from the BS is the direction of the main beam from the BS antenna (MS exists at the cell edge).

As described in Section 3, the correlation between the measured AS, MA, and the distance is low. Therefore, we assume that the AS and MA are independent of the distance and the PAP does not change depending on the distance in the evaluation model. Since the measured PAP is normalized to the direction of the MS, 0 degrees of the PAP is set to the direction of the MS in the evaluation model and the PAP is multiplied by the BS antenna pattern to obtain P_e and P_i in (2).

Fig. 5 shows the relationship between the number of elements in the BS antenna and the average antenna effective gain when the MS exists at the cell edge. The antenna effective gain is averaged in decibels. In the same figure, the dotted line indicates the theoretical value of the BS antenna peak gain. The figure shows that as the number of elements increases, the average antenna effective gain decreases compared to the theoretical values. As the vertical HPBW decreases by increasing the number of elements, the case in which the incoming waves arrive outside the antenna beam increases due to the influence from the AS and the difference in the MS and MA directions. Therefore, the received level decreases and the average effective gain decreases compared to the theoretical values. When the number of elements is 32, the average antenna effective gain decreases by 1.5 dB compared to the theoretical values. Fig. 6 shows the relationship between the number of elements and the standard deviation of the antenna effective gain. The standard deviation is also calculated in decibels. The figure shows that as the number of elements increases, the standard deviation increases. Since the HPBW decreases as the number of elements increases, the variation in the effective gain, which is caused by AS and changes in the MA increases, and the standard deviation increases.

.

5. Incoming Wave Model

We examine the application of the incoming wave model proposed for the horizontal plane in [5] to the evaluation of the effective gain for an arbitrary antenna. The model is as follows.

(1) Average power of incoming waves

The incoming waves are set in the range of θ' from -45 to 45, and the interval of each wave is set to one. The DOA of the *i*th incoming wave at the BS is $\theta' = i$, and the power of the *i*th incoming wave is R_i. The average power of R_i is set to agree with the Laplacian function. The Laplacian function is expressed using the following equation.

$$L_i = 10 \log(\exp(- | \theta_i | / \sigma_A) \quad \text{(dB)} \tag{3}$$

where σ_A is the AS. The direction angle of $\theta'=0$ is the direction angle of the MS.

(2) Probability density function (PDF) of the power for each incoming wave

The power of each wave, R_i, is set to change in a lognormal distribution where the PDF is expressed in (4), and the average power of R_i is set to the Laplacian function expressed in (3).

$$P(R_i) = \frac{1}{\sqrt{2\pi}\sigma_s} \exp\left\{ \frac{-(R_i - L_i)^2}{2\sigma_s^2} \right\} \tag{4}$$

where σ_s (in decibels) is the standard deviation of the power of each wave. The incoming waves are uncorrelated to each other and change randomly.

We calculated the antenna effective gain by using the model in a computer simulation and adjusted model parameters σ_A and σ_s so that the calculated antenna effective gain approaches the effective gain calculated using the measured PAP. The BS antenna effective gain of the main beam direction is important for radio link design; therefore, we adjusted these parameters so that the effective gain of the model approaches that from the measured PAP when the MS exists in the direction of the main beam. The results are σ_A = 14 degrees and σ_s = 17 dB.

Fig. 5 and Fig. 6 show the averaged value and the standard deviation of the antenna effective gain calculated using the model when the MS exists in the direction of the main beam. The simulation results are close to these values calculated using the measured PAP. Based on the above mentioned results the model is applicable in the evaluation of the antenna effective gain.

Furthermore, we compare the distribution of the AS and MA calculated using the model with the values calculated using the measured PAP to evaluate whether or not the model expresses the propagation characteristics appropriately. Fig. 3 shows the distribution of the AS of the model. The figure shows that the distributions of the model and those calculated using the model are close. The average for the model is 1.1 degrees and standard deviation is 0.7 degrees. Both values are very similar to the values calculated using the measured PAP. Fig. 4 shows the distribution of the MA calculated using the model. Comparing the distribution of the model to the distribution calculated using the measured PAP, both distributions are close within - 1 degree to 1 degree; however, the absolute value of the MA calculated using the measured PAP is greater than that for the model at the same cumulative probability outside of this range. Because of this, the standard deviation of the model is 1.1 degree smaller than that calculated using the measured PAP. Based on these results, we clarified that the probability that the incoming waves arrive from the direction that is considerably different from the MS direction in a real environment is greater than the same probability in the model. We consider that this difference does not significantly impact the evaluation of the antenna effective gain; however, it is an area for future investigation from the viewpoint of the modeling of the incoming wave.

6. Conclusions

The effective gain of the BS antenna for cellular systems was evaluated based on the measured vertical PAP. We examined the incoming wave model for the antenna effective gain evaluation. We clarified the following characteristics.

1) The average vertical PAP in an urban area is approximated as a Laplacian function.
2) The average angle spread in an urban area is approximately 0.9 degrees.
3) The antenna effective gain, which is calculated using the incoming wave where the average value of each incoming wave is set to the PAP of the Laplacian function and each wave changes to a lognormal distribution, is close to the antenna effective gain calculated using the measured PAP.

Clarifying the physical mechanism of the incoming wave is left as a future topic for investigation.

References

[1] J. Bach Andersen and F. Hansen, “Antennas for VHF/UHF personal radio: A theoretical and experimental study of characteristics and performance,” *IEEE Trans. Veh. Technol.*, vol. VT-26, no. 4, pp. 349-357, 1977.

[2] T. Taga, “Analysis for mean effective gain of mobile antennas in land mobile radio,” *IEEE Trans. Veh. Technol.*, vol. VT-39, no. 2, pp. 117-131, May 1990.

[3] K.I. Pedersen, P.E. Mogensen, and B.H. Fleury, “A stochastic model of the temporal and azimuthal dispersion seen at the base station in outdoor propagation environment,” *IEEE Trans. Veh. Technol.*, vol. 49, no. 2, pp. 437-447, Mar. 2000.

[4] Y. Ebine, T. Takahashi, and Y. Yamada, “A study of vertical space diversity for land mobile radio,” *IEICE Trans. Commun.*, vol. J73-B-II, pp. 286-292, June 1990.

[5] K. Kitao and S. Ichitsubo, “Model of incoming wave at base station to evaluate the performance of intersector soft handover, ” *IEEE Trans. Veh. Technol.*, vol. VT-56, no. 6, pp. 3642-3648, Nov. 2007.

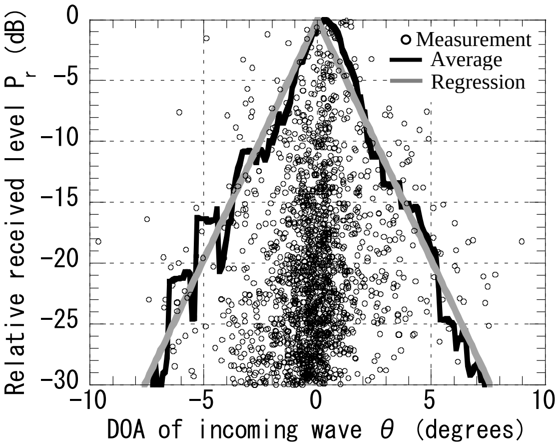

Fig. 1 PAP

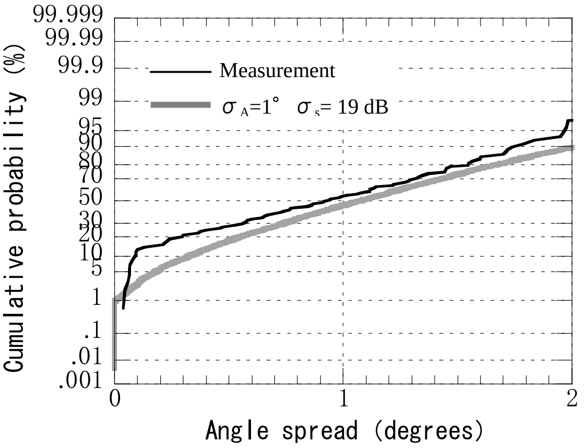

Fig. 2 Distribution of AS

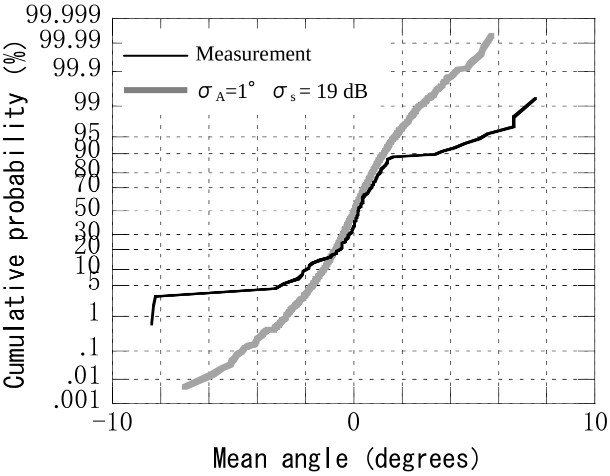

Fig. 3 Distribution of MA

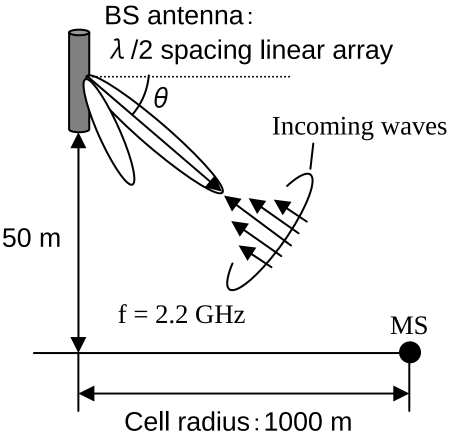

Fig. 4 Evaluation model for antenna effective gain

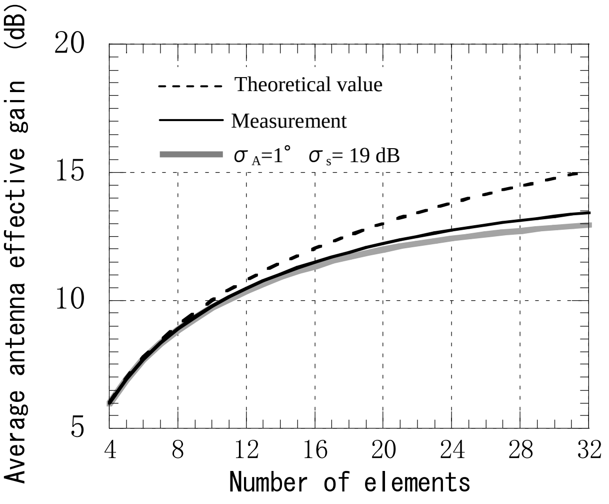

Fig. 5 Average antenna effective gain for main beam direction vs. number of elements

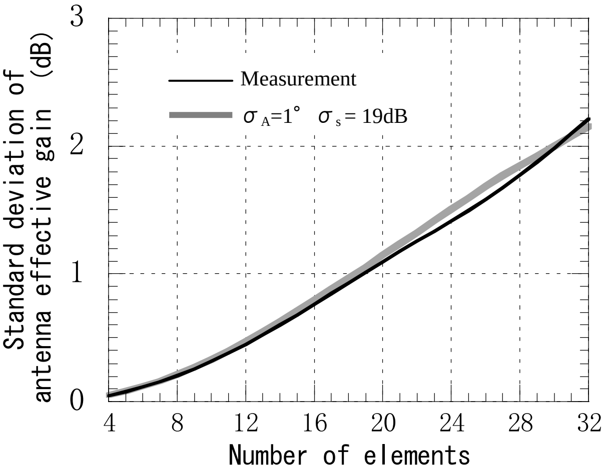

Fig. 6 Standard deviation of antenna effective gain vs. number of elements