**4D1-3**

# Quantitative Assessment of Site Diversity from Rainfall Spatial Correlation Characteristics

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## 1. Introduction

Satellite communication using high frequency is expected to transmit much information. But this technology has a communication impediment due to rainfall. The higher frequency we use, the bigger impediment occurs. There are some countermeasures to this phenomenon. One of those is site diversity. The quantitative evaluation of site diversity that how much distance apart between two receiving stations, how much effectiveness can be obtained has not been discussed by data measured in a short period of time. So, we researched effect when we carry out site diversity between two sites using by Japanese rainfall data measured every 1minute.

## 2. Rainfall data

We analysed Japanese rainfall data measured by Japanese Meteorological Agency and distributed by Incorporated Foundation Meteorological Business Support Center. This rainfall data is measured every one minute. In this research, we used these data measured at 13 spots in the Kanto region of Japan (Tokyo, Yokohama, Chiba, Katsuura, Choshi, Tateyama, Kumagaya, Chichibu, Utsunomiya, Maebashi, Tsukuba, Mito, and Nikko). These data are accumulated over 8 years.

## 3. Rainfall intensity spatial correlation property

Rainfall intensity spatial correlation coefficient evaluates rainfall similarity between one point and another point. This correlation coefficient is represented by formula (1) on Fig.1. Character cov is covariance and var is variance. $R_1$ is one point's rainfall intensity and $R_2$ is another point's one. We calculate this coefficient from the combination of two spots selected from among the 13 spots. Also correlation coefficient is represented by distance $D$ as a parameter like formula (2) on Fig.1. Coefficients $a$ and $b$ are calculated by least-squares method and plotted in Fig.2.

## 4. Effect of site diversity

### 4.1 Calculation of diversity gain

Effect of site diversity is represented by taking difference between carrying out site diversity and not carrying out. This time, the difference is calculated by rainfall intensity difference. Fig.3 shows rainfall cumulative distribution difference between average cumulative distributions of Tokyo and Yokohama and that of site diversity case on these two spots. Please note red arrow on Fig.3, this is difference of rainfall intensity when cumulative time is 0.01%. In another words, this is difference of rainfall intensity when communication availability is 99.99%. We calculated this difference from the combination of two spots selected from among the 13 spots. Using this rainfall intensity difference, we calculated diversity gain (DG) by using formula of rain attenuation described below.

$$A = \alpha R^{\beta} L$$

In this calculation, we assumed that satellite communication band using circular polarization is 22GHz, availability assumes three cases (99%, 99.9%, 99.99%) and length of rainfall area is 5km[1]. Then diversity gain can be represented by correlation coefficient as a parameter. Fig.4 shows the

results. The lower correlation coefficient becomes, the higher value of diversity gain is. Because of this, we make model formula to formulate relationship between spatial correlation coefficient and diversity gain.

**4.2 Model formula of diversity gain**

In equation (3) in Fig.5, *DG* is diversity gain and coefficient k and n are calculated by least-squares method. Furthermore, correlation coefficient is represented by equation (2) on Fig.1. So equation (2) on Fig.1 can be substituted into the model formula. We plotted distance dependence of diversity gain. Fig.6 shows this result. For example, if you want to gain 25dB of diversity gain when availability is 99.99%, you find that you have to locate earth station 30km apart. This number is the distance between Shibuya and Hachioji.

# 5. Comparison with the empirical formula in ITU Recommendation

Due to data source, data used in our analysis can not derive diversity gain data in less than 20km distance. So we compared two curves calculated by empirical formula in ITU and our model formula. Empirical formula in ITU is shown in Fig.7[2]. Empirical formula in ITU can be used only in the range of 20km or less. *G* is diversity gain. *D* is distance between two places. *A* is limit amount of rain attenuation does not occur the quality deterioration of communication in case of assuming availability. Character *f* is frequency, *θ* is elevation angle and *ψ* is the angle of the line connecting two earth station and incident of radio wave direction. I assumed that satellite position was 135degrees east longitude and calculate by the average of cumulative distribution of 13 places. Fig.8 shows difference of dependence of diversity gain curve. Thick curves are calculated by empirical formula in ITU and thin curves are calculated by model formula. This shows that model formula is different from empirical formula in ITU when availability is 99.99%. But, when availabilities are 99% and 99.9%, these curves are quite similar.

# 6. Conclusion

We calculate rainfall spatial correlation coefficient and effect of site diversity on two places using rainfall data in Kanto area. From this, we succeeded to formulate relationship between spatial correlation coefficient and diversity gain. Moreover, diversity gain was able to be represented by distance. And from dependence of distance, it becomes possible to know that how much distance apart between two earth stations, how large effect can be obtained in the Kanto area. But, we find out there are differences between model formula and empirical formula in ITU in case of availability is 99.99%. So this should be considered the validity of model formula about high availability by using data in the range of 20km or less.

Remained issue on this research is integral time dependence. Fig.9 shows time series of rainfall intensity in Tokyo in one day. This shows that peak of curve was measured at one minutes intervals is different from that of curve was made by being averaged to 10minutes data of one minutes intervals. From this, characteristic changes may appear due to differences in measurement interval. See Fig.10, it is found that correlation coefficient is calculated by averaged 10minutes data is bigger than measured at one minutes interval. So we are going to survey this integral time dependence property and apply this property to interpolation of data in the range of 20km or less. Eventually, improvement of model formula can be applied to other compensation technology time diversity and adaptive satellite power control.

## References
[1] ITU Recommendation, ITU-R P.838-3
[2] ITU Recommendation, ITU-R P.618-10

$$\rho = \frac{\text{cov}(R_1, R_2)}{\sqrt{\text{var}(R_1)\text{var}(R_2)}} \quad (1)$$

$$\rho(D) = e^{-aD^b} \quad (2)$$

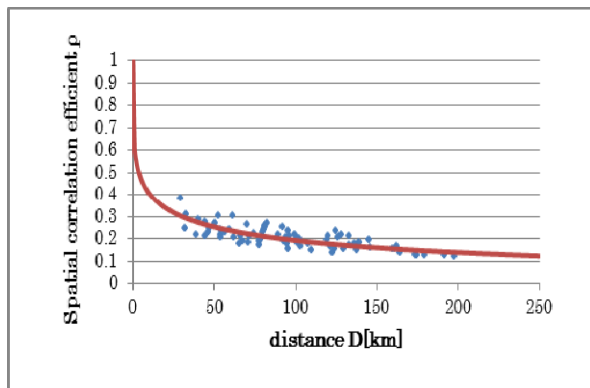Fig.1 Formula regarding to correlation coefficient

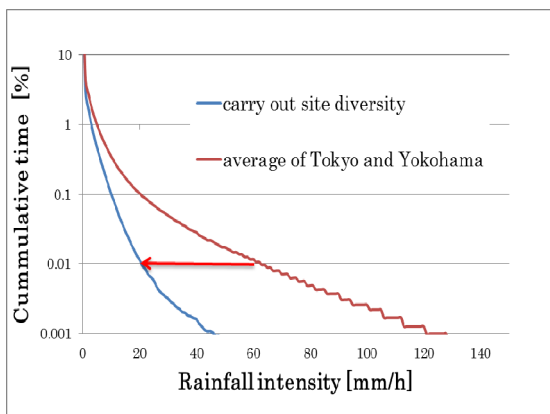Fig.2 Spatial correlation coefficient as a function of distance
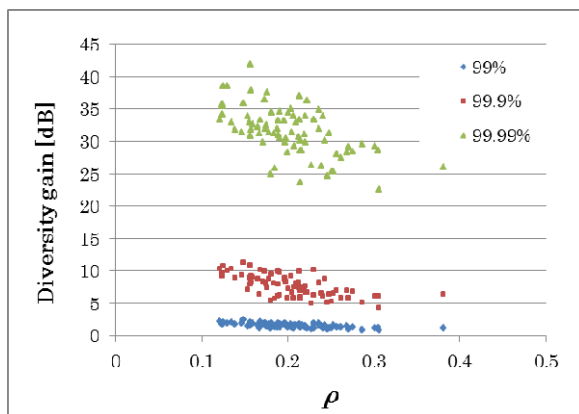
Fig.3 Effect of site diversity

Fig.4 Relation between diversity gain and correlation coefficient

$$DG = k(1 - \rho)^n \quad (3)$$

$$DG = k\{1 - \exp(-aD^b)\}^n \quad (4)$$
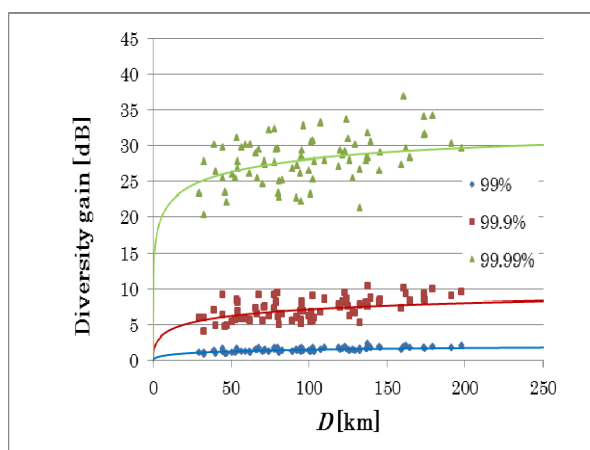
Fig.5 Model formula of diversity gain

Fig.6 Distance dependence of diversity gain

$$G_d = a'(1 - e^{-b'D}) \qquad (5)$$

$$a' = 0.78A - 1.94(1 - e^{-0.11A}) \qquad (6)$$

$$b' = 0.59(1 - e^{-0.1A}) \qquad (7)$$

$$G_f = e^{-0.025f} \qquad (8)$$

$$G_\theta = 1 + 0.006\theta \qquad (9)$$

$$G_\psi = 1 + 0.002\psi \qquad (10)$$

$$G = G_d G_f G_\theta G_\psi \qquad (11)$$

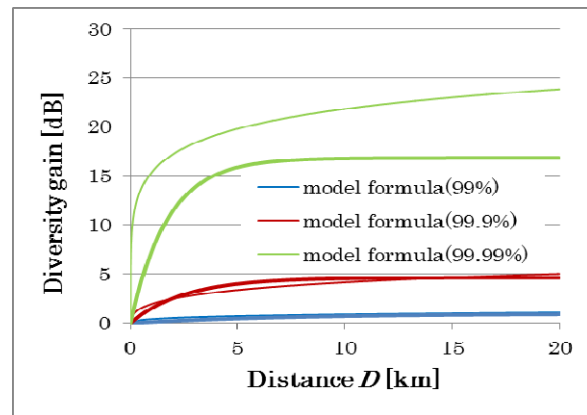Fig.7 Empirical formula of
ITU Recommendation



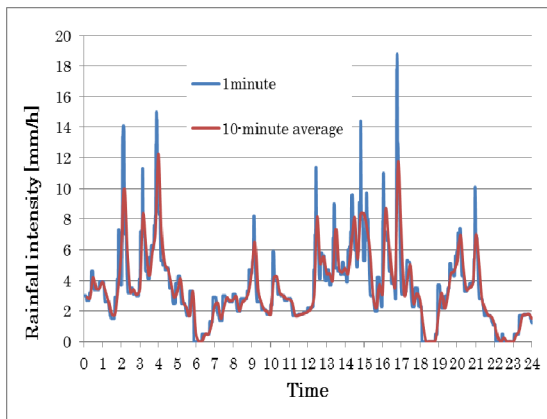Fig.8 Comparison of model formula
and Empirical formula in ITU



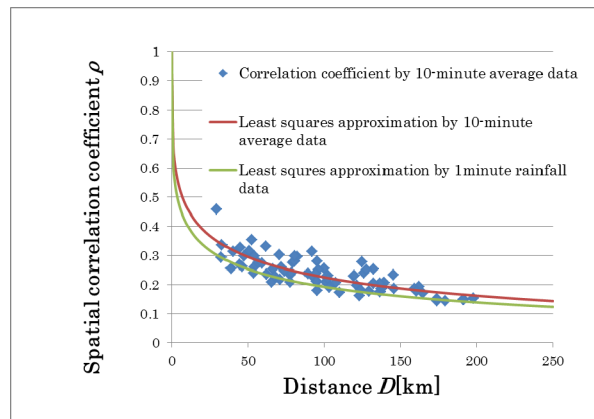Fig.9 Comparison of rainfall time
series measured 1minutes and
10-minute average



Fig.10 Effect of integral time dependence