Proceedings of ISAP'04, Sendai, JAPAN

TOMOGRAPHIC RAIN MEASUREMENT SYSTEM USING TRANSMISSIONS FROM GEOSTATIONARY SATELLITES

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1. Introduction

Satellite transmissions at the frequencies higher than 10 GHz suffer from attenuation due to rain. For design of satellite link operating at the frequencies, it is indispensable to evaluate the influence of rain. There were several efforts to measure rain statistics by using rain gauges and radars, and rain attenuation characteristics on actual satellite links. However, the rain attenuation measurements were usually intended to establish attenuation statistics, i.e. time percentage where attenuation exceeds a certain specified value. This is, so to speak, static feature of satellite signal attenuation. As well known, however, rain rate varies with time and rain structure changes even within one rain cell. These variations cause a dynamic behavior of attenuation by reflecting variation of spatial structure of rain, rain cloud evolution and rain cell motion. For the development of advanced communications system, it might be necessary to understand the nature of this dynamic link behavior. Rain structure can be measured with radar, and with its data, we can estimate the dynamic behavior of satellite link. However, radars do not necessarily exist with satellite communication links. It is therefore preferable to measure the dynamic rain condition using the satellite links themselves the quality of which are under evaluation.

This paper introduces its principle [1] and implementation of a novel system for two-dimensional rain field mapping, and discusses on the preliminary result [2].

2. Theory

Computerized tomography (CT) technique has been widely applied for imaging human body and other object. It was also used in the ionospheric physics for imaging electron density distribution by using satellite signals [3] and rain field mapping by using a network of ground-based transmitters [4]. There are many geostationary satellites for broadcasting service at Ku band frequency. As in the ionospheric tomography, we will be able to reconstruct two-dimensional rain field by measuring rain attenuation in some Ku band geostationary satellite links. However, geostationary satellite links are fixed in space, so it is impossible to scan rain fields with satellite motion. Around Japan area especially near Tokyo, clouds tend to move from west-southwest to east-northeast direction. Because rain cell moves without changing its internal structure over several tens of minutes [5], rain cell motion relative to the fixed links is equivalent to scan the rain cell with the satellite links. Around the Tokyo area, elevation angle of geostationary satellite is about 45 degrees. Although the elevation angles differ slightly from one another depending on the satellite latitudes, we assume that they are the same as one another and define a plane spanned by the propagation paths as a propagation plane. This situation is shown in Figure 1.

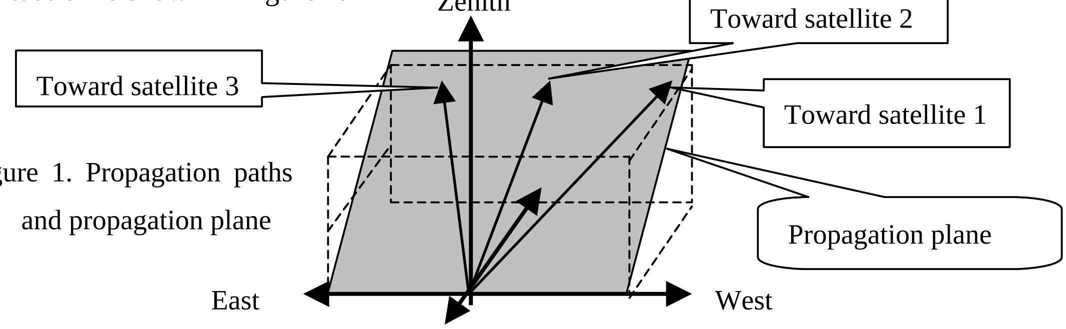

Figure 1. Propagation paths and propagation plane

ISBN: 4-88552-207-2 C3055©IEICE

By dividing the propagation plane into rectangular cells and assuming that rain rates are uniform in each of the cells, we can obtain the following equation relating attenuation data $\boldsymbol{A}$ with two-dimensional distribution of attenuation coefficient $\boldsymbol{K}$.

$$\boldsymbol{A} = \boldsymbol{K} \cdot \boldsymbol{P} \qquad (1)$$

where $\boldsymbol{P}$ is a path length matrix that gives lengths of the fraction of propagation paths in the cells. Once the propagation paths are specified, we can define the propagation plane and the cells. Thus, $\boldsymbol{P}$ is a known matrix. Because $\boldsymbol{A}$ is a vector of measurement data, we can obtain the two-dimensional distribution of attenuation coefficient $\boldsymbol{K}$ by inverting (1).

3. Receiving system of satellite transmissions

By referring to the theory discussed in the previous section, a satellite receiving system has been constructed on a building in our campus. It consists of three Ku-band antennas of 1.5-m diameter for receiving the BSAT-2a (geostationed latitude : 110°E), JCSAT-3 (128°E), and Superbird-B2 (162°E) (see Figure 2 from left to right).

Figure 2. Ku-band receiving antennas for tomographic rain measurement system.

Received signals are down-converted to 1-GHz IF signals at the antenna site, and the IF signals are fed to our laboratory with cables. Field strengths of the IF signals are measured with spectrum analyzers. The data are being recorded in a personal computer (PC) for further analysis. Rain gauge has also been installed near the antenna site and the rain signal is also being recorded in the same PC. The PC time is controlled to synchronize with the broadcasted Japan Standard Time.

4. Data analysis

Because of the ill-posed nature, (1) cannot be solved by using a usual method. Instead of it, we solve (1) by using a quasi-matrix inversion technique and a non-linear least-mean-square error technique. In the former, quasi-inversion of $\boldsymbol{P}$ is directly calculated by the Mathematica software to obtain the solution of $\boldsymbol{K}$, while in the latter, the least-mean-square solution of $\boldsymbol{K}$ is obtained by using Marquardt method starting from a certain initial vector. In the preliminary analysis using a quasi-matrix inversion technique, however, there was a problem of appearing negative attenuation coefficients in some of the propagation plane cells. To overcome the problem, all elements of the $\boldsymbol{K}$

vector are constrained to a non-negative value in the algorithm of solving (1) using Marquardt method. Because the attenuation coefficient is expressed by a power-law of rain rate as $k = \alpha R^{\beta}$ (k : attenuation coefficient, R : rain rate, $\alpha = 1.86 \times 10^{-2}, \beta = 1.162$) at 12 GHz [6], we can estimate the rain rate in each cell by a simple algebraic calculation.

Figure 3 is an example of the rain attenuation data taken on 17 July 2003.

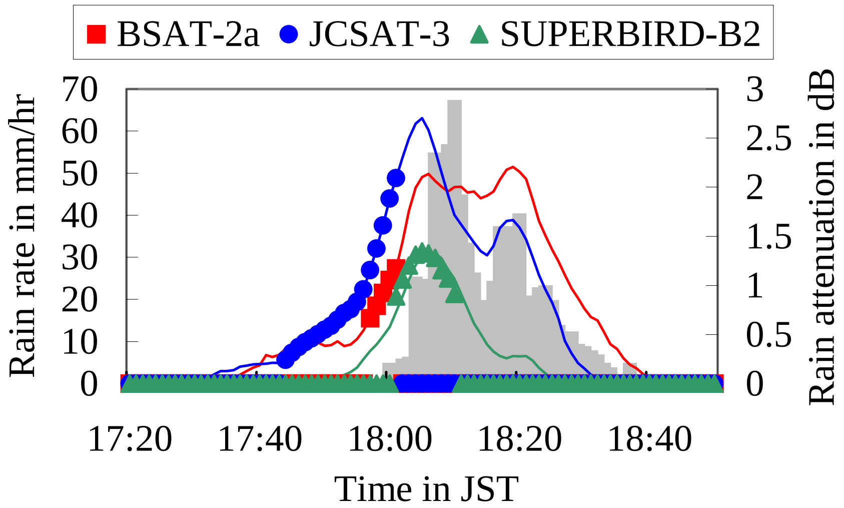

Figure 3. Rain attenuation data of satellite transmissions along the three propagation paths (see right scale) taken on 17 July 2003.. Bar graph indicates rain rate measured with the rain gauge near the antenna site (see left scale).

Assuming that the rain area that causes the attenuation shown in Figure 3 moves from west to east with a constant speed without changing its structure, we can specify some propagation paths that are passing through the rain area at different locations by assuming the rain area speed. Thus we can extract the attenuation data vector $\boldsymbol{A}$ from the measurement data. Because the path length matrix $\boldsymbol{P}$ is known by specifying the satellites and cell size, two-dimensional distribution of attenuation coefficient $\boldsymbol{K}$, and hence rain rate distribution is obtained by using the techniques mentioned above. In the following analysis, we assume that the cell size is 1-km square and there are six cells in the x direction and five cells in the y direction. Total number of cells is thus 30. Number of propagation data, i.e. the number of propagation paths that scan the rain area is determined as 41 from a geometrical consideration. Here the speed of rain area motion is assumed to be 4 m/s. Figure 4 shows the estimated result of rain rate distribution using the quasi-matrix inversion technique. Figure 5 is also the estimated rain rate distribution, but is processed using the non-linear least-mean-square error technique. Here, the initial vector is assumed to be uniform over the entire area.

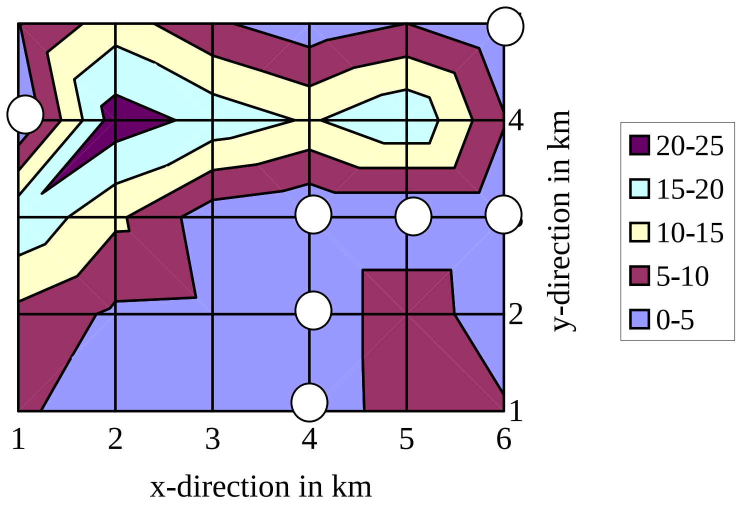

Figure 4. Estimated rain rate distribution using the quasi-matrix inversion technique. At the white circle points, the estimated attenuation coefficients are negative, so they are forced to be zero.

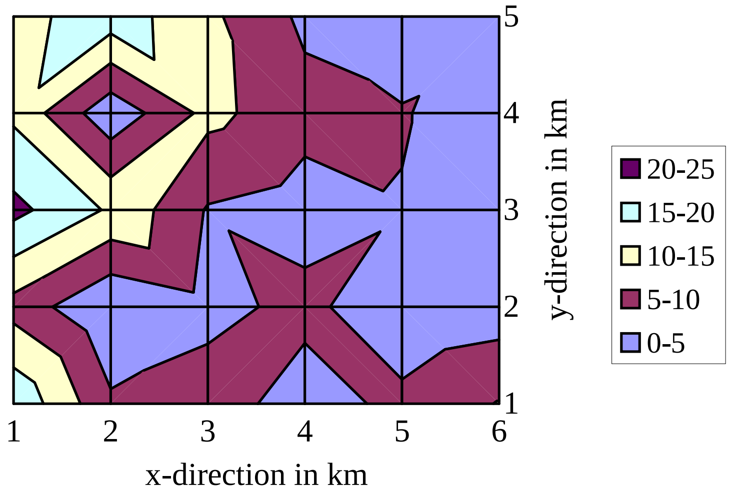

Figure 5.
Estimated rain rate distribution using the non-linear least square technique.

In Figure 4, there is a peak at (x, y) = (5, 4) km. This appears for compensating the influence of negative attenuation coefficients at x = 4 km line and y = 3 km line, so it is a spurious peak. In Figure 5, on the other hand, there is no problem of negative attenuation coefficient, and hence the spurious peak disappears. Existence of high rain rate area in the left hand side is common in both figures partially indicating the validity of the present estimation.

5. Concluding remarks

This paper presents the basic principle and hardware implementation of tomographic rain measurement system, and discusses on the early result of data analysis using the quasi-matrix inversion technique and the non-linear least-mean-square error technique. The latter technique allows us to constrain attenuation coefficients under estimation non-negative, so it can estimate the rain rate distribution more reasonably than the former one. The result shows the applicability of the present system for rain measurement. The estimated rain rate distribution, however, depends on the initial distribution given to the estimation algorithm, so its appropriate choice is the key of success of the present approach. The result needs validation by comparing with rain rate distribution measured with another means.

Acknowledgment

The present work is supported by the Special Research Fund of the Tokyo Metropolitan Government.

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