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A Study on Site Diversity Techniques related to Rain Front Motion using Ku-Band Satellite Signals

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1. Introduction

The effects of rain attenuation on the link performance are significant in satellite communications using frequencies of higher than 10 GHz. To mitigate the attenuation effects, site diversity techniques are often introduced between two stations a few tens of kilometers away from each other [1]. So far, the distance between two stations required to establish sufficient site diversity effects has been discussed in terms of the improvement on joint cumulative time percentages of rain attenuation or rainfall rate [2]. However, there has not been much discussion on relationship between horizontal scale or motion of rain fronts and effects of site diversity techniques.

In this study, Ku-band satellite signals have been measured for the past four years since September 2002 at three observation points: Osaka Electro-Communication University (OECU) in Neyagawa, Osaka, Research Institute of Sustainable Humanosphere (RISH) in Uji, Kyoto, and Shigaraki MU Observatory of Kyoto University in Koga, Shiga, which are 20-50 km away from each other [3]. Directions and velocities of the motion of rain areas are then estimated from the time difference in each rainfall event between these stations. Finally, their relationship with the operation of site diversity techniques is discussed

2. Observation Methods

At the three stations, the Ku-band broadcasting satellite (BS) signals (11.8GHz, RHCP, EL=41 °) have been continuously observed. At RISH in Uji, however, the Ku-band down-link signal (12.7GHz, HP, EL=49 °) of Superbird C that connects RISH to the Equatorial Atmosphere Radar (EAR) had been observed instead of the BS signal up to July 2005 [4]. These signal levels are recorded by personal computers equipped with 16 bit AD converters. For the estimation of attenuation and its statistics, the observed data are further averaged over 1 min. RISH in Uji, Kyoto is located 23.3 km northwest (16.0 km, 16.9 km) from OECU in Neyagawa, Osaka, while MU in Koga, Shiga is located 45.9 km east northeast (44.2 km, 12.4 km) from OECU.

Figure 1 shows an example of rain attenuation observed at the three locations on October 8, 2005. In Fig.1(a), we can see that the attenuation of greater than 3-5 dB occurred during 15:20-17:00 LT at each location in order of RISH (thin line), OECU (dashed line), and MU (thick line). In Fig.1(b), cross-correlation functions of the rain attenuation are then calculated between OECU and the other locations. The thick line indicates the result obtained from the combination of OECU and MU, while the thin line is that of OECU and RISH, in the range of lag times from -60 to 60 min. The correlation values as large as 0.8-0.9 are found in the peaks of both cross-correlation functions. The lag times obtained from these peaks indicates that the attenuation occurred 19 min earlier (-19 min) at RISH and 52 min later (+52 min) at MU, respectively, than at OECU. Also, the high correlation values of 0.8-0.9 suggest that the three locations should similarly observe the attenuation caused by rain bands or rain cells of the same rain front passing over them.

Fig.1(c) thus shows velocity and direction (arrow) of the rain area estimated from the time differences in attenuation occurrence among the three locations, as well as their geographical relationship with OECU [3]. Thin and thick dashed lines indicate the positions of the rain front inferred at RISH and MU, respectively, which passed over them in this order. The rain area

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associated with the front is shown to move southeastward at a velocity of 4.6 m/s. The direction of the motion is 146.3 ° clockwise from the north. On October 8, 2005, on the other hand, the weather charts published by Japan Meteorological Agency indicates that a cold front similarly passed southwestward over the Kansai area including Osaka, Kyoto, and Shiga. The velocity and direction of the rain area described in terms of those perpendicular to the cold front of the weather charts are 4.5 m/s and 143 °, respectively, being in good agreement with the present observation obtained from the three locations.

3. Velocity and Direction of Each Rain Front Type

The total number of rainfall events simultaneously observed at the three locations from September 2002 to December 2006 exceeds 200 samples. Almost all rainfall events successfully deduce the time differences in rain attenuation occurrence of RISH and MU from that of OECU, using the lag times of the peaks of their cross-correlation function with correlation coefficients of more than 0.6. A number of rainfall events also show that the motion of rain areas inferred from the lag times agrees well with that of rain fronts or cyclones obtained directly from the weather charts. Specifically, examples of correspondence between them amount to 69 for warm fronts, 85 for cold fonts, and 31 for stationary fronts, respectively. Figure 2 shows scatter plots of passing velocities (a) and directions (b) for warm fronts (circles), cold fronts (triangles), and stationary fronts (pluses) between those obtained from the lag times of attenuation and the weather charts. The velocity and direction of warm and cold fronts are similarly those perpendicular to the front lines as illustrated in Fig.1(c), while the motion of rain areas for “stationary” fronts is rather inferred from that of cyclones that move along the front lines [5]. Table 1 summarizes the number of each rainfall type used for the estimation, together with average and standard deviation of their passing directions.

It is seen from Fig,2 that velocity and direction of the rain areas deduced from the time difference of attenuation agree well with those of rain fronts or cyclones directly detected on the weather charts, with correlation coefficients of nearly 0.9 between them. Thus, the present observations of rain attenuation at the three locations prove to represent the motion of rain areas associated with that of rain fronts or cyclones. In addition, Table 1 demonstrates that each rain type has its characteristic passing directions of rain areas: warm fronts from south to north, cold fronts from northwest to southeast, and stationary fronts from west to east.

4. Site Diversity Effects

In this section, site diversity effects are numerically examined using the 1-min rain attenuation data of the Ku-band satellite signals simultaneously recorded for the past four years from 2002 to 2006 at the three locations of OECU (Neyagawa, Osaka), RISH (Uji, Kyoto), and MU (Koga, Shiga), which are 20-50 km away from each other. Prior to the comparison of the attenuation observed at each location, the Ku-band down-link signal levels of Superbird C that had been measured at RISH up to July 2005 are converted to those expected for the frequency, polarization, and elevation angle of the BS signal, assuming the Marshall-Palmer type raindrop size distribution. In addition, the BS signal levels measured at MU which is located in a highland basin 385 m above the mean sea level (MSL) are adjusted to those as expected in a lowland near the MSL as at OECU and RISH [1].

Figure 3 depicts the results of site diversity effects calculated for any two of the three locations. The calculation is made for the attenuation data obtained from all the rainfall events using the above-mentioned methods. In Fig.3, the cumulative time percentages of the rain attenuation obtained at OECU, RISH, and MU indicate the almost same values up to 8 dB, so the site diversity effects seem to be equally evaluated for any two locations down to the time percentages of about 0.05%. As for the site diversity effects, the signal levels switched between OECU and RISH (cross, O-R) that have the shortest distance (23.3 km) indicate the highest joint cumulative time percentages, yielding the least improvement. On the other hand, the signal levels switched between OECU and MU (plus, O-M) that have the longest distance (45.9 km) are found to

indicate slightly higher joint cumulative time percentages than those obtained between OECU and RISH (diamond, O-R), giving rise to rather insufficient improvement.

Thus, the present observational results suggest that the site diversity effects should not necessarily increase as the distance between the two stations increases. The reason for this peculiar phenomenon may lie in the difference of passing directions of the rain areas according to their rain types, such as warm, cold, and stationary fronts, because the lag times and the correlations of the attenuation are not simply determined by the distance between two locations as was illustrated in Fig.1.

The diversity effects are then examined for three kinds of rainfall events divided by the rain fronts, and their joint cumulative time percentages are separately calculated for the total time percentages of 0.5, 0.1, and 0.05% for the single station, which are roughly equivalent to the attenuation of 1.8, 3.9. and 5.0 dB, respectively. Figure 4 indicates the distances of any two of the three locations (O-R, R-M, O-M) and the time percentages of the site diversity effects for the rain types of warm, cold, and stationary fronts. As concerns the distances of the two locations depicted in the left-side plots, their average lengths projected to the direction of the motion of rain areas are indicated (circle), together with the original geographical distances (cubic). As shown in Fig.4, the lengths between the two locations projected to the rain area motion are quite different according to each rain type.

In the case of the stationary fronts along which the rain areas, as a whole, move from west to east, the length between the stations projected the rain area motion are nearly proportional to the geographical distances, giving rise to similar site diversity effects as the joint probabilities decrease. In the other cases, such as the warm and cold fronts, however, the site diversity effects based on the low joint probabilities are not necessarily related to the geographical distances but rather to the length between the stations projected to the rain area motion.

5. Conclusions

Directions and velocities of the motion of rain areas are estimated for each type of rain fronts, using time differences detected in the rain attenuation of the Ku-band satellite radio wave signals that have been measured at Osaka Electro-Communication University (OECU) in Neyagawa, Osaka, Research Institute of Sustainable Humanosphere (RISH) in Uji, Kyoto, and Shigaraki MU Observatory of Kyoto University in Koga, Shiga, for the past four years since September 2002. These directions and velocities are shown to agree well with those manually obtained from the motion of rain fronts in the weather charts published by the Meteorological Agency. A numerical estimate of the effects of satellite diversity techniques indicates that between any two of the three locations (OECU, RISH, MU) separated by 20-50km, the joint cumulative time percentages of rain attenuation become lower as the two locations are aligned along the direction of the rain area motion. Therefore, the site diversity effects are shown to largely depend on the lengths between the stations projected to the rain area motion.

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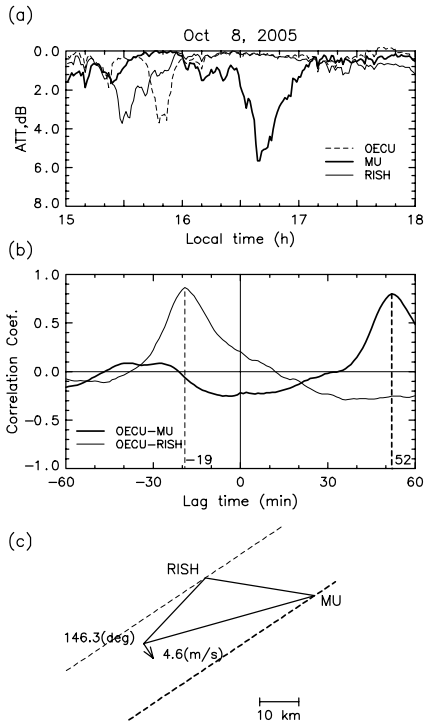

Figure 1: (a) Examples of rain attenuation, (b) cross - correlation functions, (c) velocity and direction of the rain front at the three locations.

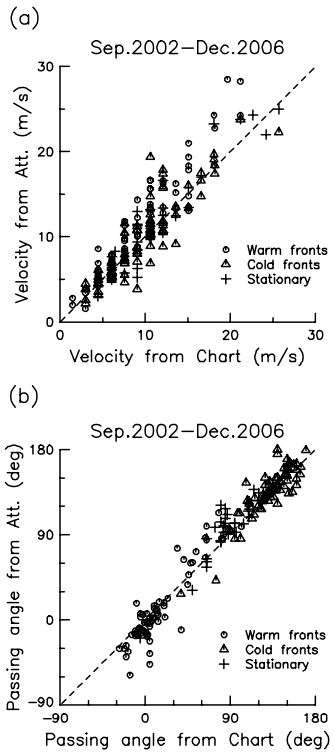

Figure 2: Scatter plots of (a) velocity and (b) direction of the rain area motion obtained from the lag times of attenuation and weather charts.

Table 1: Direction of the rain area motion

	Events	Av. (S.D.) deg
warm	69	13.72 (40.80)
cold	85	135.08 (28.12)
stationary	31	96.75 (31.87)
total	186	80.30 (65.69)

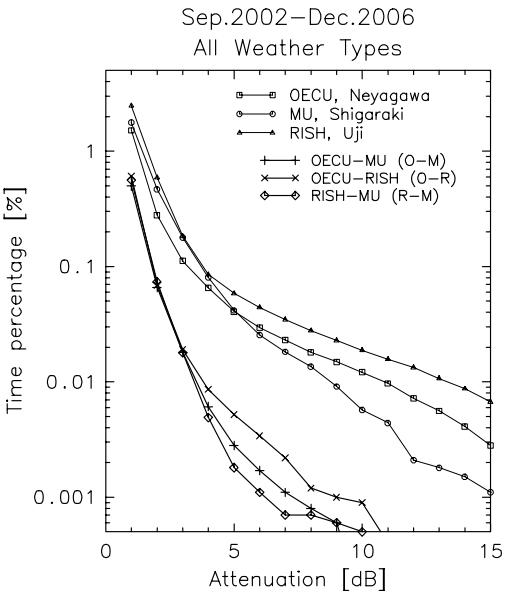

Figure 3: Cumulative time percentages at OECU, RISH, and MU, and joint probabilities between any two of the three stations.

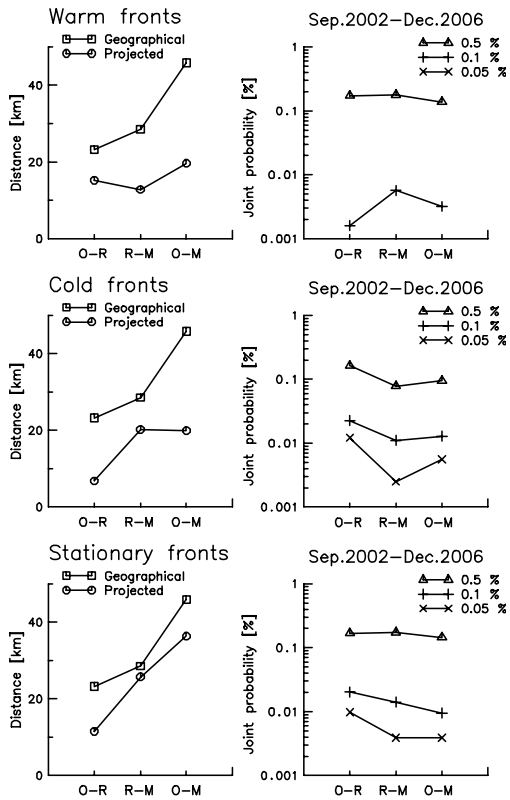

Figure 4: Diversity effects (Joint probabilities) of each rain type for the cumulative time percentages of 0.5%, 0.1%, and 0.05%.