A STUDY ON THE EFFECTS OF SATELLITE DIVERSITY ON Ka-BAND RAIN ATTENUATION IN THREE EARTH-SPACE PATHS

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ABSTRACT

The effects of satellite diversity on Ka-band rain attenuation were investigated in three propagation paths with azimuth angle separation of about 30 deg in Japan. The Ku-band (14/12 GHz) attenuation was converted to the Ka-band down-link (19.45 GHz) attenuation by the frequency scaling methods considering the difference of raindrop size distributions. As for the attenuation of 20 dB, time percentage of the cumulative distribution is decreased down to about 60% and 40% of the original 0.01%, in two- and three-path diversity systems, respectively, The effects of satellite diversity, however, largely depend on the type of rainfall events,

INTRODUCTION

High frequency bands such as Ka-band or millimeter-wave band now start to be used in commercial satellite communications. In Ka-band (30/20 GHz), however, the effect of rain attenuation is more significant than in lower frequency bands, such as Ku-band (14/12 GHz) and C-band (6/4 GHz) [1]. Some countermeasures for rain attenuation using site and/or satellite diversities are therefore required in order to operate reliable Ka-band satellite communication links. But up to now, measurements or observational data that support the effects of such diversity techniques are still very sparse. Fortunately, three kinds of satellite signal levels were simultaneously observed almost continuously during the four years of 1995-1998 at Osaka Electro- Communication University in Neyagawa, Osaka, Japan (36N, 136E). These signals came from Ku-band JCSAT and BS (Broadcasting Satellite) and Ka-band N-Star. Their orbital positions are 150, 110, and 132E, respectively, giving slightly different path conditions with separation of 30 deg in azimuth angle. In this study, the effects of satellite diversity techniques are assessed among these three satellite-to-ground (down-link) paths in terms of the improvement of unavailable time percentages due to rain attenuation.

OBSERVATIONAL TECHNIQUES

The Ka-band rain attenuation was observed by the beacon receiver of the earth station which receives the beacon signal of N-Star (19.46 GHz) with a 6-m diameter Cassegrain antenna. On the other hand, the Ku-band attenuation was observed by AGC voltages of the BS tuner for Japan's broadcasting satellite and the VSAT system for JCSAT, which have offset parabola dishes of 1.2-m and 1.8-m diameter, respectively The azimuth angle is nearly southward for N-Star and its elevation angle is about 50 deg. The azimuth angle is, however, rotated eastward and westward by about 30 deg from the south for JCSAT and BS, respectively. Accordingly, their elevation angles are about 47 and 41 deg, respectively The BS tuner detects the down-link (12 GHz) attenuation of the broadcasting signal, while the VSAT system detects up- and down-link (14/12 GHz) attenuation, because the signal of the indoor unit (IDU) transmitted from VSAT was again received by the same IDU. Each signal was sampled at 1 sec interval, and averaged over 1 min to be compared with 1 min rainfall rate measured simultaneously.

To investigate Ka-band rain attenuation statistics among the three paths, the Ku-band signal attenuation levels obtained from JCSAT and BS were first converted to Ka-band attenuation levels using frequency scaling methods based on the frequency characteristics of the specific attenuation (dB/km) at both frequency bands [2]. Since the frequency characteristics strongly depend on the kind of raindrop size distribution (DSD), a relevant DSD was chosen from three representative types of Joss-drizzle (Jd), Marshall-Palmer (MP), and Joss-thunderstorm (Jt) in each rainfall event by the ground measurements using an optical sensor. In the process of selecting DSD, we also referred to cross-polar phase of the Ka-band N-Star circular-polarization signal, which is similarly sensitive to the kind of DSD [3].

COMPARISON OF RAIN ATTENUATION

As a result of the frequency scaling methods, we obtained the almost -same levels of Ka-band rain attenuation for the three propagation paths in each rainfall event. Fig. 1 shows an example on July 17, 1996. As was mentioned above, the Ku-band attenuation measured by BS and JSCAT was converted to the Ka-band attenuation in each path. It can be seen from the figure that the attenuation occurred in the order of the paths for BS, N-Star, and JCSAT. This means the occurrence of severe attenuation in this order of the paths, as the associated precipitating clouds moved from west to east.

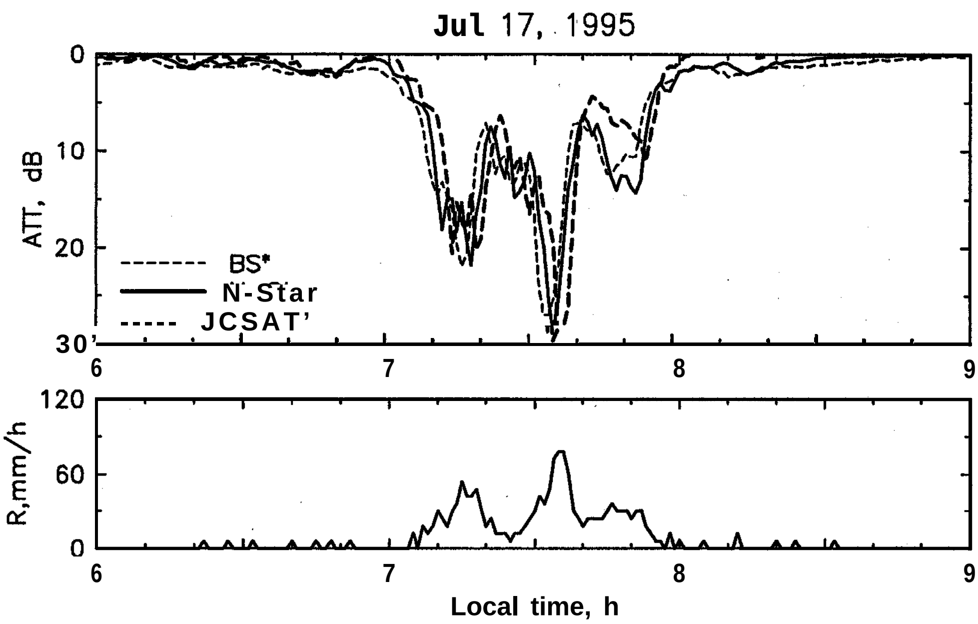

Fig. 1. Ka-band rain attenuation observed in three earth-space paths. BS and JCSAT signals are converted from Ku- to Ku-band using frequency scaling methods. Also shown are 1-min rainfall rates.

This. phenomenon was, in general, found on other observational days when the rain front passed from west to east over the site. In rare cases in which cyclones passed south to the site, or typhoons approached from the south, to contrast, the appearance of attenuation moved from east to west, according to the anti-clockwise rotation of cloud systems in the northern hemisphere. The time difference between these peaks of attenuation is only one to a few minutes. However, there is still some possibility to avoid large attenuation of 10 to 20 dB, which may cause an outage of communication links, to some extent by switching channels among the three propagation paths separated each other by about 30 deg in azimuth angle. So, the effects of satellite diversity for Ka-band satellite communication links are then estimated at an interval of 1 min, using numerical calculations that choose a signal of the lowest attenuation level among two or three of these paths each minute.

ATTENUATION STATISTICS AND DIVERSITY EFFECTS

Fig.2 shows time percentage of cumulative distribution of rain attenuation on each path during the observational period of 1996-1998. The results of satellite diversity effects on two or three paths are also shown. It is found from Fig.2 that in long-term statistics during the four years, however, Ka-band attenuation values calculated from JCSAT and BS signals show slightly larger time percentages than those actually observed by N-Star for each attenuation level, These larger time percentages are possibly caused by their lower elevation angles; i.e., a little longer propagation paths in the rain region. For the time percentage of 0.01%, Fig.2 indicates that the Ka-band attenuation reaches around 20 dB in each propagation path of JCSAT, BS, and N-Star. When the satellite diversity is conducted in the two and three paths, however, the attenuation is shown to be reduced to about 17 dB and 16 dB, respectively, for the same time percentage.

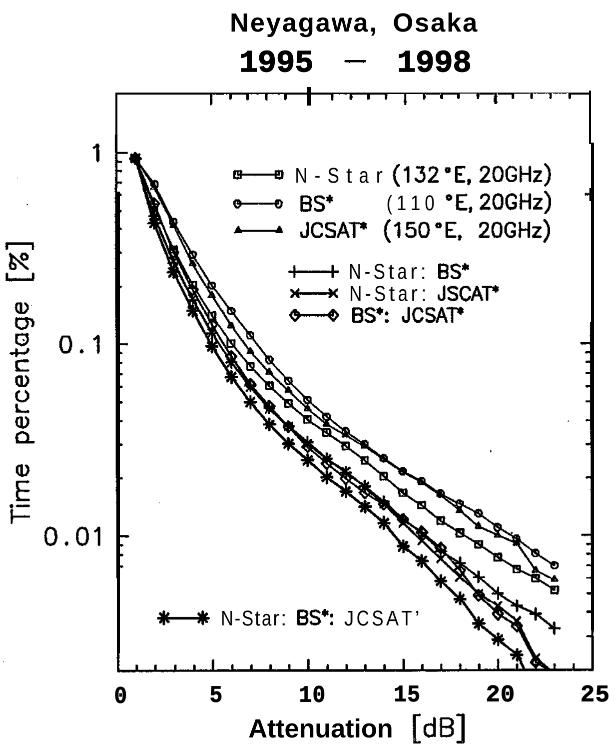

Fig. 2. Time percentage of cumulative distribution of Ka-band attenuation. Also shown are the results of two- or three-path satellite-diversity estimates.

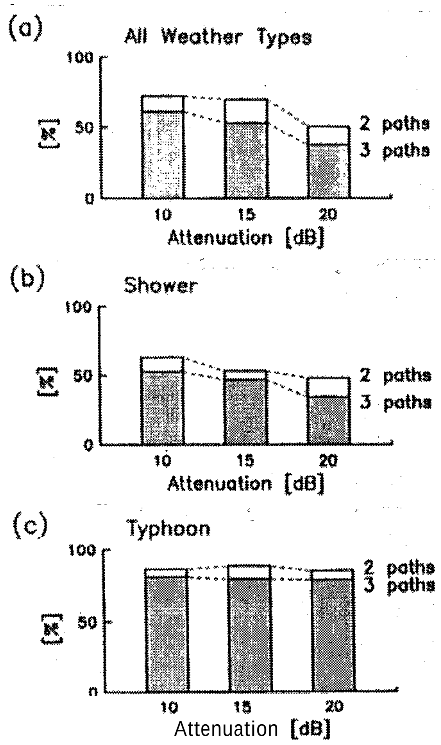

Fig. 3. Decrease of time percentages for specified attenuation due to the two-or three-path satellite diversity techniques in each weather type.

As for the attenuation of 20 dB, on the other hand, time percentage of the cumulative distribution was shown to decrease down to about 60% and 40% of the original 0.01%, in two- and three-path satellite diversity systems, respectively, The effects of satellite diversity techniques, however, largely depend on the type of rainfall events. Fig.3 shows the decrease of time percentage of the cumulative distribution for (a) all weather types, (b) shower, and (c) typhoon during the four years. The results are shown for the attenuation of 10, 16, and 20 dB in the two- or three-path diversity systems. In the case of shower, the satellite diversity technique is found to be more effective, since the convective clouds have a comparatively small horizontal scale of, say, less than 5 or 10 km, which is near the path difference of the present system. In the case of typhoon, on the contrary, the time percentage is not decreased very much and the effects of the diversity are not so significant, because more widely spread cloud systems or clusters may exist in typhoon.

CONCLUSIONS

The effects of satellite diversity techniques on Ka-band rain attenuation were assessed in three propagation paths with each azimuth angle separation of about 30 deg. The data of the rain attenuation had been observed over the four years of 1996-1998 in Osaka, Japan. The up- and/or down-link Ku-band (14/12 GHz) attenuation was converted to the Ka-band down-link (19.46 GHz) attenuation by the frequency scaling methods, taking into account the kind of raindrop size distribution in each event. As for the attenuation of 20 dB, time percentage of the cumulative distribution is decreased down to about 60% and 40% of the original 0.01%, in two- and three-path diversity systems, respectively, The effects of satellite diversity, however, largely depend on the type of rainfall events.

For example, convective precipitating clouds associated with summertime shower or cold fronts of extratropical cyclones have a comparatively small horizontal scale of, say, less than 5 or 10 km. This small scale size seems to be rather suitable for an operation of satellite diversity, even if the path difference is no more than a few km. Tropical typhoon or subtropical stationary fronts that may come to or stay over Japan frequently in rainy seasons around the summer, on the contrary, consist of more widely spread cloud systems or clusters, where the path difference of each satellite may not be sufficient for a successful operation of satellite diversity Therefore, an improvement of the satellite link capacity such as time percentages for a given attenuation level should be investigated in more detail for various kinds of rain events, using a numerical estimation of these satellite diversity techniques.

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