POS2-35

Effects of Azimuthal Difference on Orbital Diversity Using Multiple Satellites

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1. Introduction

Satellite communication is now one of the popular ways of communication, broadcasting, navigation systems, earth observation systems, and so on. For transmitting vast amount of data quickly, the higher frequencies, for example, the Ku (12/14 GHz) and Ka (20/30 GHz) bands are more suitable than the lower frequencies. However, because there is a problem of using the higher frequencies over 10 GHz on the earth-satellite communication, we need to take measures against the problem [1]. At the higher frequencies over 10 GHz, satellite signal strength is easily weakened by heavy rainfall. Hydrometeor scattering and absorption, occurring when radio waves propagate through the lower atmosphere , result in power loss. There are some diversity methods but this paper presents orbital diversity technique using four satellites through the position of the effect of azimuthal difference.

2. Orbital Diversity

Orbital diversity method engages multiple satellites to insure that rain attenuation occuring at the same time on each Earth-space path is significantly less than the rain attenuation occuring on either individual path [2] (Fig. 1). This method increases the fade margin by continuously selecting the least-attenuated radio path from multiple satellites spaced angularly on the geostationary orbit. The selection of least-attenuated path is based on one of the following criteria: signal combining, signal selection, or signal switching. Because heavy rain has a tendency to localize, orbital diversity using multiple satellites which have azimuthal difference provides a diversity gain. The effects of orbital diversity, however, largely depend on the type of rainfall events. The link performance is also expected to be gradually improved as the azimuthal angle separation increases. Ku-band rain attenuation is given by the following equation:

$$A_{diversity}(t) = minimum\{A_{S1}(t), A_{S2}(t), \ldots, A_{Si}(t), \ldots, A_{Sn}(t)\} \quad (1)$$

where $A_{diversity}(t)$ represents reception level attenuation at time t after applyed the orbital diversity method and $A_{Si}(t)$ represents the attenuation of the received level for the i-th satellite and $A_{diversity(t)}$ is the attenuation of the received level after applying the orbital diversity method.

3. Measurement System

The effects of orbital diversity on Ku-band rain attenuation are investigated on multiple Earth-space links with azimuthal angle separations ranging from about 5° to 72° by continuously receiving downlink signals from four geostationary satellites, i.e., AsiaSat-3S, BSAT-2A, JCSAT-3A, and JCSAT-2A, at Kashima Space Technology Center of National Institute of Information and Communications Technology, Ibaraki, Japan [3]. Measurement period was about 27 months from March 2009 to May 2011. Details of the satellites used in our measurement are shown in Table 1. We installed four satellite dishes

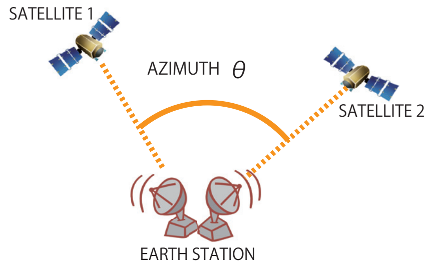

Figure 1: The configuration of an orbital diversity system.

on the top of a building at Kashima Space Technology Center for the four geostationary satellites. The downlink signals from the four satellites are received by antennas 1.0 m in diameter. The received signal levels are sampled at intervals of one second with three signal-level meters and a spectrum analyzer.

Table 1: Summary of satellites

Satellite	Long. [°E]	Az. [°]	El. [°]	Frequency [GHz]	Pol.
AsiaSat-3S	+105.5	230.2	34	12.33	V
BSAT-2A	+110	225.4	37	11.77	R
JCSAT-3A	+128	201.0	46	12.35	V
JCSAT-2A	+154	158.1	46	12.3	V

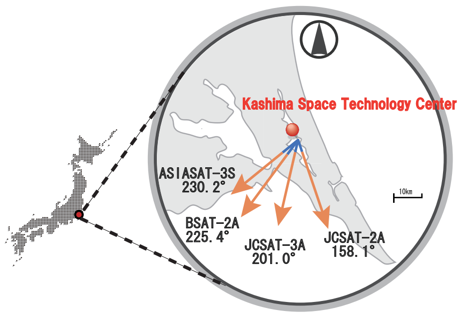

Figure 2: The location of the Earth station and the azimuthal directions of the four satellites.

4. Application of Orbital Diversity Method for a Heavy Rain Event

In this paper, we measured the rain attenuation as the difference of the received level at time t when it rains from a reference received level for clear condition as given by

$$A(t) = P(t) - P_s \quad (2)$$

where $P(t)$ represents the reception level at time t, and P_s represents the reference received level.

Figure 3 shows the time series of attenuations measured for four satellite links from 17:00 to 18:00 on September 8, 2010, when a typhoon passed near the Earth station. During this event, one-minute rainfall intensity reached as high as about 100 mm/h at the Earth staion.

Figure 3 represents that orbital diversity works efficiently when heavy rain happened. The received signal levels of western two satellites AsiaSat-3S and BSAT-2A are lower than those of eastern two satellites JCSAT-2A and JCSAT-3A from 17：30 to 17：40. It indicates that orbital diversity works because of rain area migration.

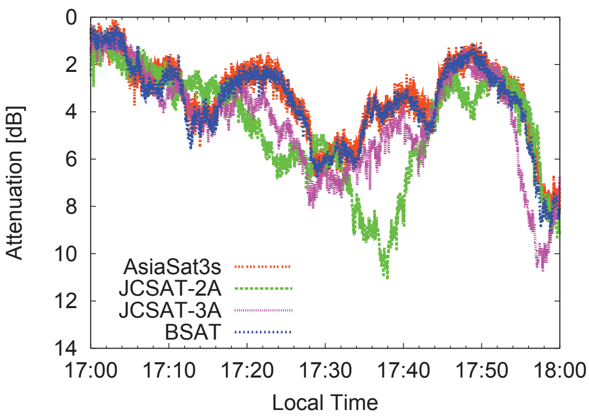

Figure 3: Time series of attenuations measured for four satellite links on September 8, 2010, when a typhoon passed near the Earth station.

5. Cumulative Probability Distribution

Figure 4 compares the cumulative probability distributions of attenuations measured for four satellites links from March 2009 to May 2011 with the cumulative distribution of the attenuation obtained by applying orbital diversity for four satellite links for the same period. It is found that the attenuation level was reduced by 1-3 dB by applying orbital diversity.

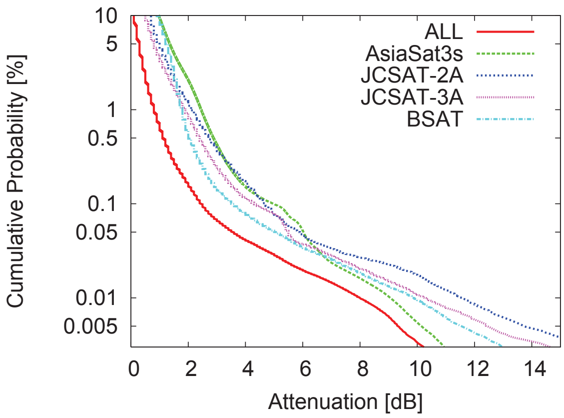

Figure 4: Cumulative probability distributions of attenuations for four satellite links without diversity and that obtained by applying of orbital diversity for four satellite links.

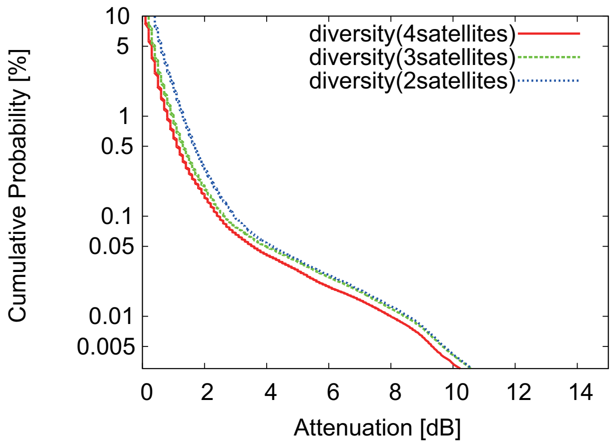

Figure 5: Comparison of cumulative probability distributions of attenuations obtained by applying orbital diversity for different number of sattellites.

Figure 5 compares the cumulative probability distributions of attenuations obtained by applying orbital diversity for two, three, and four satellites. This figure shows that the improvement in the cumulative probability distribution of attenuation is only marginal even when the number of satellites involved in the orbital diversity is increased from two to four. This results indicates that the orbital diversity characteristics is determined by the angular separation of the outer-most pair of the satellites.

6. Diversity Gain

In what follows, we define the diversity gain $G_{S1-S2}(P)$ for two satellites, S_1 and S_2, as the decrease of attenuation A_{S1-S2} when the diversity is applied relative to the average attenuation for two satellite links for the same cumulative probabilityas given by

$$G_{S1-S2}(P) = AVERAGE[A_{S1}(P), A_{S2}(P)] - A_{S1-S2}(P). \quad (3)$$

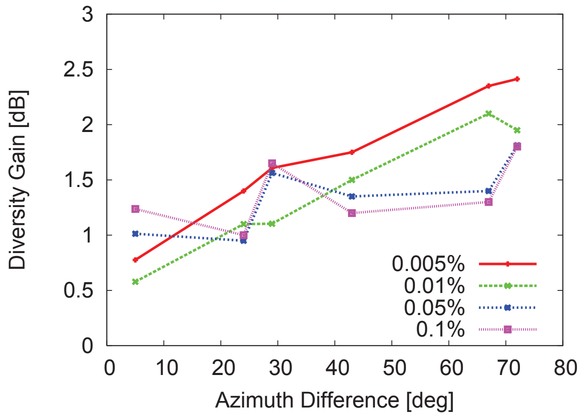

Figure 6: Dependence of the diversity gain on the angular separation of two diversity satellite.

Figure 6 shows the diversity gains achieved by orbital diversity with two satellites as a function of angular separation of two satellites for different cumulative probabilities. The diversity gain increases linearly with the angular separation of two satellites for cumulative probabilities less than 0.01 % while the increase in the diversity gain as a function of the angular separation is not appreciable for cumulative probabilities higher than 0.05 %. This result is considered to reflect the tendency that heavy rains, which occur with small percentage of time, are likely to localize within small areas, while weak rains, which occur with larger percentage of time, are likely to be wide spread.

7. Conlusion

In this paper, we have shown two-year-long measurement results of rain attenuation for four geostationary satellite links differing in their azimuthal angles to show the effects of orbital diversity. The orbital diversity gain is found to increase linearly as a function of the angular separation of two satellites for cumulative probabilities less than 0.01 % while the increase of the diversity gain is not appreciable for cumulative probabilities higher than 0.05 %. This indicates that we can achieve the orbital diversity gain higher than 2 dB for heavy rains for which the cumulative probability is lower than 0.01 % when we take the azimuthal separation of two satellites wider than about 50°.

References

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