Dual Frequency Use Technique for 40-GHz Satellite Communication During Rainfall Attenuation

Wataru Chujo
Meijo University
Tempaku-ku, Nagoya 468-8502, Japan

Takeshi Manabe
Osaka Prefecture University
Sakai, Osaka 599-8531, Japan

Shin-ichi Yamamoto and Kenji Suzuki
Space Communication Systems Lab, NICT
Koganei, Tokyo 184-8795, Japan

***Abstract*—Dual frequency use technique that uses both 12- or 20-GHz and 40-GHz satellite downlinks is proposed to share resources mutually for achievement of higher communication capacity with restricted use of the satellite transmission power during rainfall attenuation. Communication capacity of the satellite downlink is estimated from the satellite availability by applying frequency diversity and dual frequency use techniques. Dual frequency use technique achieves superior communication capacity for 40-GHz attenuation range from 5 to 10 dB during rainfall when the satellite power is shared between 12- or 20-GHz and 40-GHz downlinks.**

Keywords— *rainfall attenuation; millimeter wave; satellite communication; frequency diversity; dual frequency use*

I. Introduction

Satellite communication capacity depends extensively on available bandwidth and transmission power. 12- or 20-GHz satellite downlink generally does not provide enough bandwidth for increase in data traffic in modern society. Communication satellites with wide bandwidth that can be achieved, for example, in the millimeter-wave bands are necessary to provide sufficient data transfer between a satellite and earth stations. However, the use of millimeter-wave frequencies suffers from rainfall attenuation. In this paper, dual frequency use technique that uses 12- or 20-GHz and 40-GHz satellite downlinks is proposed to increase the bandwidth of a satellite and to overcome the rainfall attenuation. We focus attention on comparison of frequency diversity and dual frequency use techniques and have estimated communication capacity of the frequency diversity and dual frequency use [1]. However, satellite transmission power was not restricted in the analysis. In particular, in the dual frequency use technique, we need to share transmission power of the satellite between 12- or 20-GHz and 40-GHz frequencies to make maximum utilization of the allocated frequencies and to achieve maximum communication capacity. Communication capacity using dual frequency use technique is analyzed and compared with that using frequency diversity under the condition that total transmission power of the satellite is constant.

II. Measurement System for 12.65- and 18.9-GHz Ranfall Attenuations

Time-series of 12.65-GHz downlink signal of JCSAT2A located at 154°E and 18.9-GHz downlink signal of WINDS located at 143°E are received at Kashima Space Technology Center, NICT. Polarizations of the measured signals of JCSAT2A and WINDS are linear and circular, respectively. Fig. 1 illustrates a diagram of measurement system of 12.65- and 18.9-GHz received signals. Downlink signal of 12.65 GHz from JCSAT2A is received by an antenna with a dish diameter of 1.0 meter, is converted to 1.45 GHz, and is sampled at intervals of 1 second with a signal level meter (Leader LF986). Downlink signal of 18.9 GHz from WINDS is simultaneously received by another antenna with a dish diameter of 4.8 meter, is converted to an intermediate frequency of 70-MHz band, and is sampled at intervals of 1 second using a spectrum analyzer (Advantest U3741).

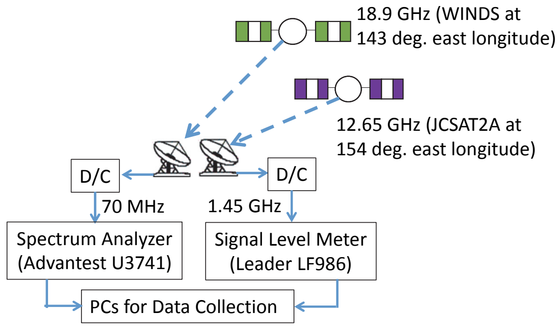
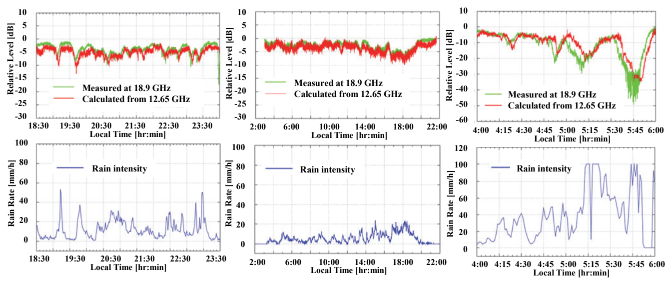


Fig. 1. Measurement system for 12.65- and 18.9-GHz downlink signals.



(a) October 24 (b) October 30 (c) November 1

Fig. 2. Comparison between the measured rainfall attenuations at 18.9 GHz and those calculated from the measured rainfall attenuations at 12.65 GHz during October 24 – November 1, 2010.

By assuming that the rain is uniform over the propagation path, 18.9-GHz attenuation, $A_{18.9}$, is calculated from the measured 12.65-GHz attenuation, $A_{12.65}$, utilizing ITU-R rain attenuation model [2] as

$$A_{18.9} = K_{18.9}\left(\frac{A_{12.65}}{K_{12.65}L}\right)^{\frac{\alpha_{18.9}}{\alpha_{12.65}}} L. \qquad (1)$$

where $A_{12.65}$ and $A_{18.9}$ are attenuations, and $K_{12.65}$, $\alpha_{12.65}$ and $K_{18.9}$, $\alpha_{18.9}$ are frequency-dependent coefficients for 12.65- and 18.9-GHz signals, respectively. L is the propagation length where environmental lapse rate is assumed to be -6.5 K/km. In Fig. 2, the measured rain attenuation at 18.9 GHz is compared with that calculated from the measured rain attenuation at 12.65 GHz. The attenuation at 18.9 GHz calculated from 12.65 GHz agrees well with that measured at 18.9 GHz. From this result, the downlinks of JCSAT2A and WINDS can be considered to follow the same path as far as their rain attenuations are concerned even though their orbital longitudinal positions are about 10 degrees away from each other. We analyzed availability and communication capacity of the satellite downlinks with 12.65 or 18.9 GHz and 40 GHz even though these two satellites have azimuth angle difference of 17 degrees at Kashima Space Technology Center, NICT. 40-GHz attenuation calculated from 12.65- and 18.9- GHz attenuations by using Eq. (1) are shown in Fig. 3. It is confirmed that the 40-GHz attenuation calculated from the 12.65-GHz attenuation changes with the same period at the same time as that calculated from the 18.9-GHz attenuation.

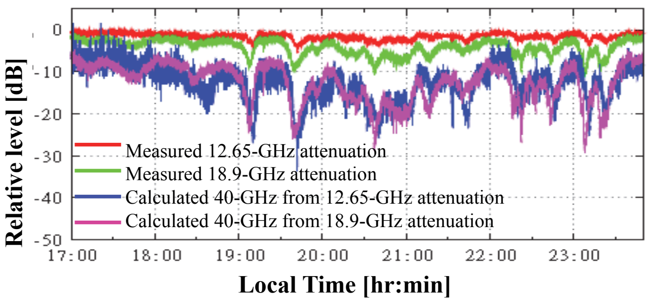


Fig. 3. Attenuation examples at 40 GHz calculated from the attenuation at 12.65 and 18.9 GHz measured on October 24, 2010.

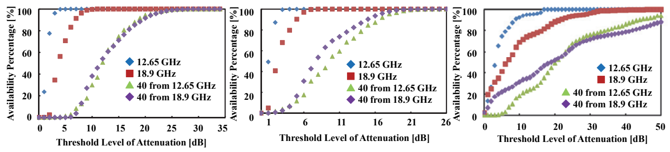
III. Satellite Availability during Rainfall Attenuation

In order to estimate communication capacity of the satellite downlink, satellite availability was calculated from 12.65-, 18.9- and 40-GHz rainfall attenuation. We analyzed the attenuated signal for 8 days when rainfall intensity exceeded 10 mm/h. The satellite availability, SA, is defined as

$$SA = \frac{S_{AT}}{S_{AT} + S_{UT}}, \qquad (2)$$

where S_{AT} and S_{UT} are the available and unavailable time, respectively during which the attenuation of the satellite link exceeds a prescribed threshold level of attenuation.

Fig. 4 illustrates availability percentage of measured 12.65-, 18.9-GHz, and calculated 40-GHz links during October 24 – November 1, 2010. As the threshold level of attenuation for 40-GHz link is increased, availability percentage is increased. The availabilities of 40-GHz downlink calculated from 12.65- and 18.9-GHz rainfall attenuation nearly overlap with each other.



(a) October 24 (b) October 30 (c) November 1

Fig. 4. Sattelite availability of measured 12.65- and 18.9-GHz and calculated 40-GHz downlinks during October 24 – November 1, 2010.

Fig. 5 shows cumulative availability percentage of 12.65-, 18.9-, and 40-GHz satellite downlinks during rainfall attenuation for 8 days. The results show the availability of 12.65- or 18.9-GHz link is much higher than that of 40-GHz link during rainfall attenuation. Therefore, frequency diversity or dual frequency use technique that uses 12.65- or 18.9-GHz and 40-GHz satellite downlinks are useful to increase the satellite availability during rainfall attenuation.

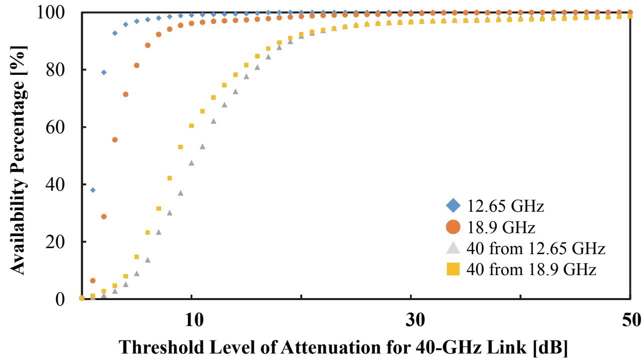


Fig. 5. Cumulative satellite availability of measured 12.65- and 18.9-GHz and calculated 40-GHz signals during rainfall attenuation for 8 days.

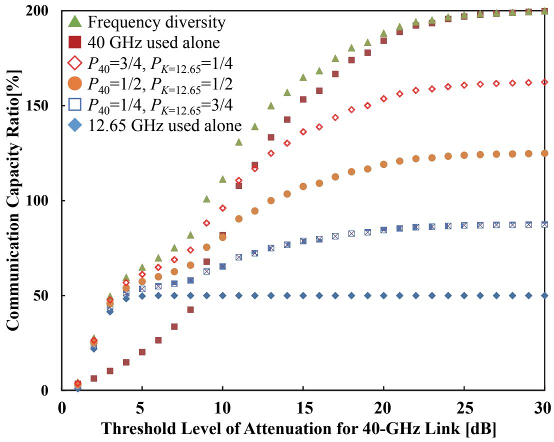
IV. Communication Capacity during Rainfall Attenuation

Frequency diversity and dual frequency use techniques are compared from the viewpoint of communication capacity of the satellite downlink. Frequency diversity technique utilizes only 40-GHz link on a clear day and changes the frequency to 12.65- or 18.9-GHz link on a rainy day when 40-GHz signal attenuation exceeds the threshold level of attenuation. On the other hand, dual frequency use technique utilizes both 12.65- or 18.9-GHz and 40-GHz frequencies even on a clear day and optimally controls the satellite power ratio of the 40-GHz to the 12.65- or 18.9-GHz link due to alternation of the most suitable threshold level of 40-GHz link during rainfall attenuation. As the threshold level of 40-GHz satellite link is increased, power ratio of the 40-GHz to the 12.65- or 18.9-GHz link is decreased. Communication capacity (bits per second) during rainfall attenuation using frequency diversity technique, C_{div}, and the capacity using dual frequency use technique that uses 12.65- or 18.9-GHz and 40-GHz satellite links, C_{dual}, are defined by the following equations:

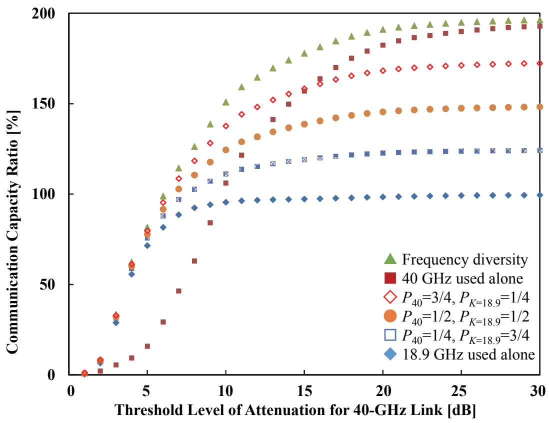
$$C_{div} = SA_{40}C_{40} + SU_{40}SA_{div}C_K, \qquad (3)$$

$$C_{dual} = SA_{40}\left(P_{40}C_{40} + P_K C_K\right) + SU_{40}SA_{div}C_K, \qquad (4)$$

where C_K, C_{40}, C_{div}, and C_{dual} are communication capacities of 12.65- or 18.9-GHz link alone, 40-GHz link alone, frequency diversity, and dual frequency use, respectively. C_k and C_{40} represents communication capacity when all the transmission power is only used for 12.65- or 18.9-GHz link and 40-GHz link, respectively. SA_{40} and SU_{40} are the satellite availability and unavailability of 40-GHz link, and SA_{div} is the availability for 12.65- or 18.9-GHz link when 40-GHz link is unavailable. P_K and P_{40} are power ratio shared between 12.65- or 18.9-GHz and 40-GHz links, respectively under the condition that total transmission power of the satellite is constant when dual frequency use technique is applied. Communication capacity of 12.65-GHz link alone, $C_{K=12.65}$, is assumed to be half of the capacity of 18.9-GHz link alone, $C_{K=18.9}$, and communication capacity of 40-GHz link alone, C_{40}, is assumed to be twice of the 18.9-GHz capacity, $C_{K=18.9}$.



(a) 12.65 GHz and 40 GHz



(b) 18.9 GHz and 40 GHz

Fig. 6. Communication capacities of the satellite downlink during rainfall attenuation using frequency diversity and dual frequency use techniques between 12.65 or 18.9 GHz and 40 GHz.

Fig. 6 illustrates the communication capacities of the satellite downlink during rainfall attenuation when frequency diversity and dual frequency use techniques are applied to 12.65- or 18.9-GHz and 40-GHz links. The communication capacity ratio of 12.65-, 18.9-, and 40-GHz link used alone is assumed to be 50, 100, and 200 %, respectively in Fig. 6. The abscissa axis shows threshold level of attenuation for 40-GHz link due to rainfall attenuation. Although frequency diversity always has better communication capacity than that using dual frequency use technique, it wastes the allocated frequency for the satellite downlink on a clear day. Only 40-GHz link is used and 12.65- or 18.9- GHz link is never used when 40-GHz signal attenuation is less than the threshold level of attenuation in the frequency diversity. On the other hand, communication capacity using dual frequency use technique is almost the same as that using frequency diversity particularly at around lower threshold level from 5 to 10 dB when one quarter of the power is assigned to 12.65- or 18.9-GHz link and other three quarters of the power is assigned to 40-GHz link. Dual frequency use technique leads to nearly the same communication capacity when the satellite transmission power is properly shared between 12.65- or 18.9-GHz and 40-GHz links.

V. Conclusion

Dual frequency use technique that uses 12- or 20-GHz and 40-GHz satellite downlinks during rainfall attenuation was investigated and compared with frequency diversity technique in order to improve the communication capacity of 40-GHz satellite downlink under the condition that total transmission power of the satellite is constant. Satellite availability was calculated from rainfall attenuation of 12.65-, 18.9-, and 40-GHz links. Communication capacity was estimated from the availability of each frequency link by means of frequency diversity and dual frequency use techniques when the transmission power of the satellite is shared between 12.65- or 18.9-GHz and 40-GHz links. Dual frequency use technique achieved nearly the same communication capacity as that of frequency diversity during rainfall attenuation when threshold level of attenuation for 40-GHz link is within the range from 5 to 10 dB under the condition that total transmission power of the satellite is constant. Although communication capacity of 40-GHz link used alone was assumed to be two or four times higher than the 18.9- or 12.65-GHz capacity, respectively in the analyses, the results suggest that the dual frequency use technique is more useful than the frequency diversity if 40-GHz link plays a subsidiary role for 12.65- or 18.9-GHz link. Further research on 40-GHz dual frequency use technique combined with multi-beam antenna configuration is needed.

References

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[2] ITU-R, "Specific attenuation model for rain for use in predictions methods," Recommendation ITU-R P.838-2, 1992-1999-2003.