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A Method to Transform Rainfall Rate to Rain Attenuation and its Application to 21GHz Band Satellite Broadcasting

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1. Introduction

The 21-GHz satellite broadcasting is expected to transmit large-capacity signals such as ultrahigh-definition TV or Super Hi-Vision [1, 2]. The 21.4 to 22.0-GHz band, however, suffers from large rain attenuation. In this regard, we have been studying a rain fade mitigation techniques, in which the radiation power is increased locally in the area of heavy rainfall ("boosted" beam)while keeping the "nationwide" beam with the same frequency by using an onboard phased array antenna (See Fig.1) [3, 4]. In order to design such satellite broadcasting system, it is necessary to evaluate the service availability when using the locally increased beam technique.

In this paper, first a method to transform rainfall rate to rain attenuation in the 21GHz band is described, second its application to the analysis of the service availability is presented when using the locally increased beam technique in the 21GHz band broadcasting satellite.

2. A Method to Transform Rainfall Rate to Rain Attenuation

There are no time series datasets of rain attenuation covering Japan in the 21GHz band. Therefore, the rain attenuation data should be derived from the rainfall rate data, that is, radar analysis and Automated Meteorological Data Acquisition System (Radar-AMeDAS). The ITU-R recommends a method to predict rain attenuation exceeded for a probability p% of the average year (A_p) [5] and also recommends a method to predict rainfall rates exceeded for a probability p% of the average year (R_p) [6]. We made conversion table between A_p and R_p by making correspondence for a same probability p% of the average year. The parameters used for calculating A_p and R_p are given in Table 1. Fig. 2 shows an example of the calculated conversion graph from rainfall rate to attenuation at Tokyo.

Table 1 Parameters for calculating A_p and R_p in Fig. 2 at Tokyo

f	Location	φ	Longitude
21.7 GHz	Tokyo	35.68 deg. N	139.77 deg. E
h_s	Satellite orbit	θ	$R_{0.01}$
-0.007 km	110 deg. E	37.99 deg.	47.25 mm/h
h_R	L_s	α	k
4.16 km	7.89 km	1.07	0.086
γ_R	$r_{0.01}$	$v_{0.01}$	L_E
5.35 dB/km	0.66	1.11	4.96 km
$A_{0.01}$			
26.58 dB			

$R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)
h_s : height above mean sea level of the earth station (km)
θ: elevation angle (degrees)
φ: latitude of the earth station (degrees)

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f : frequency (GHz)
h_R : the rain height as given in Recommendation ITU-R P.839.
L_s : the slant-path length
γ_R : the specific attenuation = $k\ (R_{0.01})^{\alpha}$
$r_{0.01}$: the horizontal reduction factor for 0.01% of the time
$v_{0.01}$: the vertical adjustment factor for 0.01% of the time
L_E : the effective path length
$A_{0.01}$: the predicted attenuation exceeded for 0.01% of an average year

The Radar-AMeDAS data (rainfall rate) is given with the accuracy of 1 mm/h. In order to convert the Radar-AMeDAS data to the rain attenuation, A_p is expressed as a function of R_p by the following polynomial approximation.

$$\begin{aligned} A_p =& 1.45318\times10^{-13}\times R_p^9 - 3.94782\times10^{-11}\times R_p^8 + 4.37272\times10^{-9}\times R_p^7 - 2.504\times10^{-7}\times R_p^6 + 7.60468\times10^{-6}\times R_p^5 \\ & -1.02469\times10^{-4}\times R_p^4 - 1.01461\times10^{-4}\times R_p^3 + 1.0271\times10^{-2}\times R_p^2 + 6.6654\times10^{-1}\times R_p + 9.3582\times10^{-2} \end{aligned} \quad (1)$$

In Fig.2 the measured data, which is scaled up from 11.84GHz to 21.7GHz using the method in [5], is also shown. We have measured the rainfall rate and the rain attenuation at 11.84 GHz at Tokyo from April 2000 to December 2003 [7]. The measured time series data was divided in every 1 hour. The rainfall were measured as cumulative in 1 minute rainfall and its summation was 1 hour rainfall rate. The rain attenuation values were measured at every 1 second and the maximum value in the 1 minute, which corresponds to the accumulation time for the rainfall, is taken as a representative value. The rain attenuation data of every 1 hour (60 values) were classified by the rainfall rate with 1 mm/h step. The number of the data observed for 5 mm/h, 10 mm/h and 15mm/h is 89, 13 and 4, respectively. The rain attenuation data observed in 10 mm/h rainfall event is shown in Fig.3 as an example. The rain attenuation value (ordinate) in Fig. 3 was observed exceeding the time period of the abscissa. The rain attenuation values corresponding to one minute were the maximum value during each one hour observation. The rain attenuation values corresponding to 60 minutes were the minimum value always exceeded during each one hour observation. The line for the median value is derived by taking the median value from the 13 rain attenuation values at each one time period of the abscissa. The median values for 1 minute and 30 minute period are 3.41 dB and 1.81 dB, respectively. The rain attenuation values at 21.7GHz scaled from the 12GHz band measured using the method in [5] are 5.60 dB and 10.34 dB, respectively. The scaled values in 21.7 GHz for the rainfall rates of 5 mm/h, 10mm/h and 15 mm/h are summarized in Table 2. The median values of 30 minutes, which corresponds to 50% probability, in 21.7 GHz for the rainfall rates of 5 mm/h and the 10 mm/h coincides well with the values derived by Eq. 1. The median value of 30 minutes for the rainfall rate of 15 mm/h does not agree well with the value derived by Eq. 1. The reason for this disagreement seems due to the insufficient number of data, i.e. 4.

Table 2 The rain attenuation values at 21.7GHz scaled from the 12GHz band measured

Rainfall rate	5 mm/h	10 mm/h	15 mm/h
Median value of 30 min. (50%)	2.83 dB	5.60 dB	7.02 dB
Median value of 1 min. (1.67%)	6.02 dB	10.34 dB	15.18 dB

3. Application of the Method to the Analysis of the Service Availability

The method to transform rainfall rate to rain attenuation in the 21GHz band described in Section 2 is applied to the analysis of the service availability for 21GHz band broadcasting satellite using the locally increased beam technique.

We assumed the service area consisted of major islands of Japan but some remote islands. The service area is divided with 2.5×2.5 km square, which corresponds to the mesh size of the Radar-AMeDAS data. We applied the relationship between the rainfall rate and the rain attenuation value in the 21GHz band as shown in Fig.2, which was derived at Tokyo, to the whole service area.

By analysing the link budget for the 21GHz band satellite broadcasting, the rain attenuation values which are compensated by the nationwide beam and the boosted beam are 5.59 dB and 11.74dB, respectively (See Table 3).

Table 3 Rain attenuation values to be compensated

	Nationwide beam	Boosted beam
Rain attenuation compensated	5.59 dB	11.74 dB

The period of the Radar-AMeDAS data is 1 year (2005) and the time interval is 30 min, that is, the rain is assumed to be constant during a 30 minute interval. The shape of a boosted beam is circular and the diameter of a boosted beam is 200 km. The boosted beam adaptively directs a point in the service area such that the boosted beam includes the maximum number of mesh point (2.5×2.5 km) at which the rain attenuation exceeds 5 dB. This value of 5 dB corresponds to the rain attenuation compensated by the nationwide beam when a boosted beam is generated, whereas the value of 5.59 dB in Table 3 corresponds to the rain attenuation compensated by the nationwide beam when the service area is covered by a uniform nationwide beam.

The service availability evaluated at Tokyo is shown in Table 4. It can be said from Table 4 the following remarks.

(a) The time percentage in a year derived using the method described in this paper and the Radar-AMeDAS data in the year 2005 for the rain attenuation of 5.59 dB and 11.74 dB well agreed with the time percentage derived using the Rec. ITU-R P.618-8, (1) and (2), (4) and (5) in Table 4, respectively.

(b) The service availability at Tokyo degrades by 0.068%, which is 99.914% of (4) minus 99.846% of (3), by directing the boosted beam adaptively to compensate the rain attenuation in the whole service area.

Table 4 Service availability at Tokyo in the 21GHz band broadcasting satellite

(1)	Time percentage in the year of 2005 not exceeding the rain attenuation of 5.59 dB when the nationwide beam covers the service area	99.640%
(2)	Time percentage in a year not exceeding the rain attenuation of 5.59 dB by Rec. ITU-R P.618-8	99.711%
(3)	Time percentage in the year of 2005 not exceeding the rain attenuation of 11.74 dB when the boosted beam adaptively directs a point in the service area	99.846%
(4)	Time percentage in the year of 2005 not exceeding the rain attenuation of 11.74 dB when the boosted beam is always fixed at Tokyo	99.914%
(5)	Time percentage in a year not exceeding the rain attenuation of 11.47 dB by Rec. ITU-R P.618-8	99.930%

4. Conclusion

We showed a method to transform rainfall rate to rain attenuation in the 21GHz band using the Recommendations in ITU-R and derived an approximation equation to transform the rainfall rate to the rain attenuation at Tokyo. The method was applied to the analysis of the service availability for 21GHz band broadcasting satellite using the locally increased beam technique. This method is useful to analyse and design the service availability of the 21GHz band broadcasting satellite system.

It is needed to derive such conversion expression to transform the rainfall rate to the rain attenuation at each point other than Tokyo for further study.

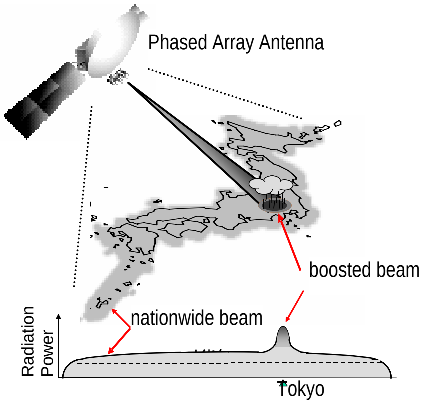

Figure 1 Concept of compensation for rain attenuation by phased array antenna

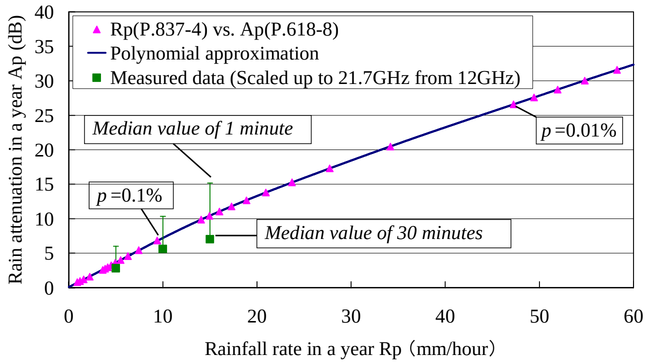

Figure 2 Conversion from rainfall rate to rain attenuation

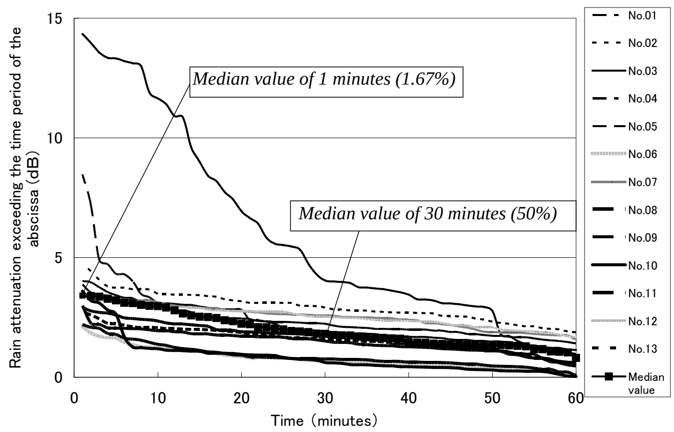

Figure 3 The rain attenuation data observed in 10 mm/h rainfall event

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