

Trends in Rain Attenuation Model in Satellite System

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Abstract — Satellite communications system operating in frequency band over 10GHz, is restricted in steady operation due to severe signal attenuation by dispersion and absorption of the air including rainfall. Since signal attenuation by rainfall in the satellite system is more serious than that of the terrestrial system, it should be exactly expected from the system design phase. There are many rain attenuation prediction models for satellite links such as Lin model, Crane model, SAM Model, Flavin model, Paraboni-Riva model, Excell model, DAH model and ITU model. If the overseas model is applied to the design and operation of the domestic satellite system, it can occur big error compared with real attenuation quantity in domestic environment. To estimate it more exactly, it should be developed appropriate model at domestic environment.

This paper looks around the existing rain attenuation models and compares those models. And then it proposes the direction for Korean domestic model.

Keywords — Rain attenuation prediction, Model, Satellite

I. Introduction

Satellite communications system operating in frequency band over 10GHz, is restricted in steady operation due to severe signal attenuation by dispersion and absorption of the air including rainfall.

To provide the most serious loss source is scatter and absorption by rain particle, therefore the most important considering factor in satellite system design and operation is attenuation loss phenomena by just rainfall. Especially, since signal attenuation by rainfall in the satellite system is more serious than that of the terrestrial system, it should be exactly expected from the system design phase.

In case of the statistical rain attenuation prediction model for satellite links, various international prediction models were proposed from Lin model, Crane model, and SAM (Simple Attenuation Model) developed in North America 1980 to Flavin model, Paraboni-Riva model, Excell model, DAH model. After ITU-R evaluates the accuracy between the existing model and new proposed model and amends better model as an international model.

If the overseas rain attenuation prediction model such as American DAH model (COMSAT Lab. and INTELSAT cowork) selected in international standard model at ITU-R is

applied to the design and operation of the domestic satellite system, it can occur big error compared with real attenuation quantity in domestic environment. To estimate it more exactly, it should be developed appropriate model at domestic environment.

II. Trends of the Rain Attenuation Models

Worldwide Activities

Since the statistical rain attenuation prediction model is proposed by Olsen et al of CRC (Communication Research Center) in 1978, prediction equation has been developed that is can estimate simply attenuation quantity by any rainfall rate R [mm/hr] to $A(R)$ [dB] = $\gamma(R) \cdot L_{eff}$. Rain attenuation factor $\gamma(R)$ means the amount of rain attenuation [dB/km] per unit length [km] in any rainfall rate; it is changed upon frequency, polarization, refractive index of the rain particle, shape and size distribution characteristics of the raindrop. L_{eff} stands for effective link length [km] which rainfall exists on satellite link. Like a previous description, as the characteristics of the rain attenuation factor is changed upon rainfall rate, so the time rate characteristics of the entire rainfall attenuation quantity, namely statistical characteristics of the rain attenuation is also different.

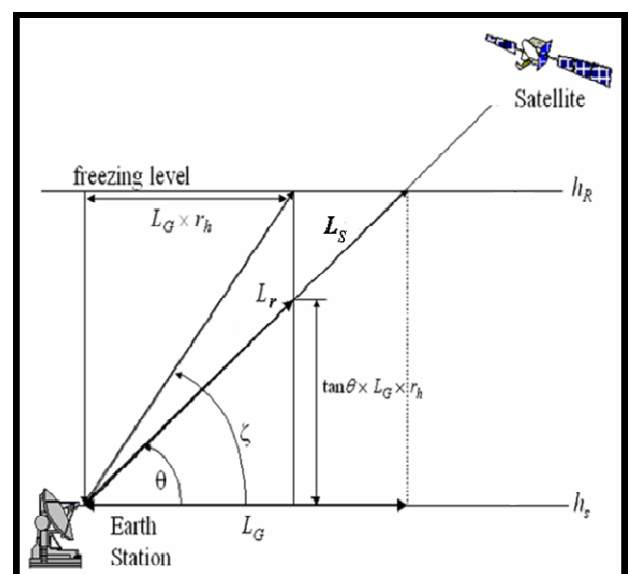


Figure 1. Path diagram of the rain attenuation in satellite link

Even if rain is same strength, as the size distribution of the raindrops differ from regions, so rain attenuation factor $\gamma(R)$ is also different from area characteristics. And the previous effective link length L_{eff} is related to rain height (melting layer) and rainfall cell [Figure 1], characteristics of those rain height and rainfall cell vary from also rain region. And a time rate characteristic of the yearly rain rate for predicting statistical rain attenuation characteristics is different from weather band of the rain region.

The development procedure of the rain attenuation prediction model(A) is considered rain attenuation factor(γ) which is from rainfall particle scattering factor and raindrop size distribution, and effective path length(L_{eff}) which is from rain height from rain rate via its distribution, as shown in figure 2.

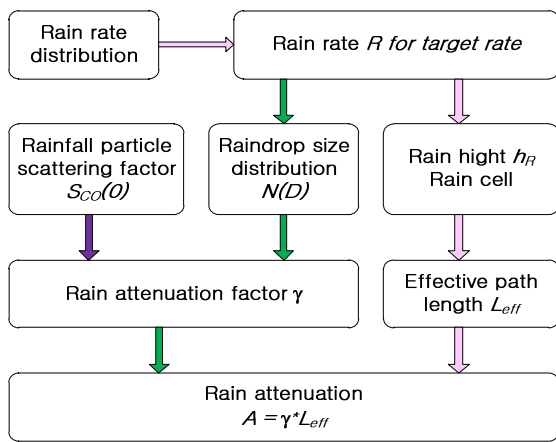


Figure 2. A procedure of the rain attenuation prediction model

An another flow for the rain attenuation prediction method is from rain attenuation factor by theoretical form, effective path length by empirical form, rain rate attenuation by statistical form as shown in figure 3.

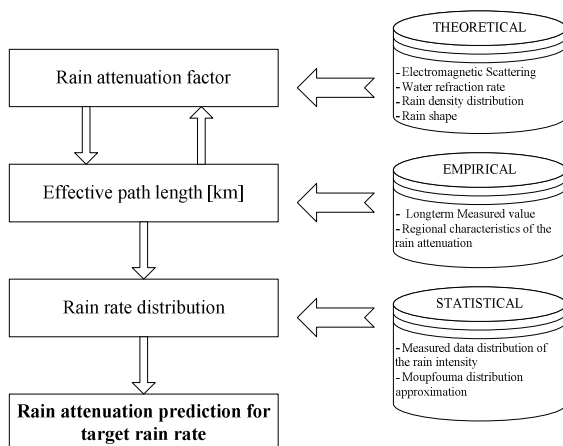


Figure 3. A flow of the key technology for rain attenuation prediction

○ Study for Rain attenuation factor

Theoretical study for scattering and absorption of the wave signal by rainfall had been performed from Mie's radio wave theorem(1903) by a spherical particle to rain attenuation factor prediction methods by Ryder(1943), Medhurst(1968), Olsen(1978), ITU-R(1982), etc.

Rain attenuation factor γ means rain attenuation [dB/km] per unit length for any rain rate, given by under theoretical model equation;

$$\gamma = 20 \log(e) \times 10^3 \int_0^{D_m} \frac{2\pi}{k^2} \text{Re} \{S(0)\} N(D) dD [km]$$

$$= a R^b$$

Where, $S(0)$: forward scatter factor in rainfall particle, $N(D)$: number of raindrop that is diameter D per unit volume.

There are Laws-Parsons distribution, Marshall-Palmer distribution, Joss distribution, Japan region distribution proposed by Ihara, the equatorial region distribution proposed by Ajayi, Gamma distribution, Weibull distribution, etc as a rainfall size distribution models.

Based on the above theoretical model of those factors, Olsen and Maggiori had proposed rain attenuation factor prediction model, ITU-R recommends international standard model as a global model for the rain attenuation factor, which can be applied to 40GH [ITU-R P.838-1].

But since density distribution by raindrop size for a given rain rate becomes different upon weather band and region, it is inevitable to develop the rain attenuation factor prediction model which characteristics of the density distribution measured by domestic raindrop size is reflected.

○ Study for effective link length

The rain attenuation characteristic is affected by special distribution of the rain rate, so the characteristic of the rain rate is not uniformed for the satellite whole path, it is defined path length considering space distribution of the radio path for the given rain rate on receiving point, that is effective path length.

There are D-D model, Lin model, Crane model, DAH model, SAM (Simple Attenuation Model), etc in effective path length, and DAH model proposed by COMSAT Lab. and INTELSAT in U.S.A. is adopted to ITU-R standard model [18].

ITU-R model makes a goal one global model, as it is based on DAH model which uses the data measured in America using Ka band ACTS satellite, it is very difficult to apply to domestic rain environment, it has also disadvantage that is not used physical variables of the rain height, rain cell, etc

○ Study for Rain rate distribution

The timely ratio distribution prediction model of rain rate is the fact that shows statistically the annual rainfall ratio data which is measured, prediction model of the probability distribution function such as Gamma, log-normal, etc was proposed. Currently the experience distribution function which Moupfouma (CNET, France) presented in 1982 is widely applied mostly.

ITU-R(P.837) recommends the followings as condition of the long period data which is necessary for the timely ratio distribution prediction of rainfall ratio.

- Long period measured data for over 10 continuous years
- Measured data with cumulating time of under 1 minute

The characteristics of the timely ratio distribution of rainfall ratio is important element in availability evaluation of system and the global model for that is recommended in ITU-R (P.837)[17]. But as the timely ratio distribution characteristics of rainfall ratio is also different by weather band and region, it is reasonable to utilize the developed prediction model using measured data in domestic region..

○ Trends of the rain attenuation measurement using satellite signal

The rain attenuation measurement studies using satellite signal have been carried out using their own satellite beacon signal at advanced countries such as U.S.A., EU, Italy, Japan, etc.

In United States, NASA is performing the study of the radio characteristics of the satellite link in Ku and Ka band receiving satellite signal such as CTS, ACTS, etc.

In EU, there is performed the study of the satellite rain attenuation prediction and it's compensation schemes of the satellite link using OTS, OLYMPUS, etc with COS 255 and 280 cooperative projects

In Italy, they are performing a measurement and a study of the rain scattering characteristics for the 40/50GHz frequency loading a measurement instrument at ITALSAT-F1 satellite.

In Japan, they are actively driving forward a study of the radio propagation characteristics in satellite on loading transmission equipment for O band (Infrared light wavelength) in ETS-VI.

From the above analysis, table 1 shows the parameters necessary for the rain attenuation prediction models.

ITU-R accomplishes an international standardization of the more accuracy prediction model on evaluating the accuracy of between the rainfall attenuation prediction models which is proposed newly and the existing standard model, and recently they are actively advanced the improvement discussion about the rainfall attenuation factor, effective path length model etc.

Table 1. parameters necessary for the rain attenuation prediction models

Models	Frequency, f	Rain rate, R	Angle, θ	Remark
DD	Increase	Increase	NA	
Lin	Increase	Increase	Decrease	
Global	Increase	Increase	Decrease	
SAM	Increase	Increase	Increase	Min. in $\theta=75$
L-W	Increase	Increase	Decrease	
ITU-R	Increase	Increase	Decrease	
DAH	Increase	Increase	Increase	

It is known that the characteristics of the attenuation and scattering by wet snow or ice particles is different from that of the rainfall and additive loss is occurred in melting layer, therefore a research activities for the effect to affected in satellite link by the weather condition besides rainfall too are actively advanced in foreign countries.

Domestic Activities

○ Study for Rain attenuation factor

A theoretical analytic study of the rainfall scatter for rain shape was performed by joint project between Chungnam University and ETRI from 1997 to 1998 in my country.

Recently Chungnam University has developed rain attenuation prediction model to apply to millimeter wave on measuring a raindrop size distribution actually in national environment using distrometer which can measure various characteristics of the rainfall, and proved its appropriateness through measurement in terrestrial link of the 44GHz band.

○ Study for Rain rate distribution

They have ever developed the domestic model of the rainfall rate distribution on analysis of the measured data by weather station during 10 years from 1984 to 1993 in same joint project, that model is the result which a rain rate is converted from 20 minute data to 1 minute data. But since nowadays weather stations are measuring the rain rate by 1minute unit, it is not necessary to convert the rain data.

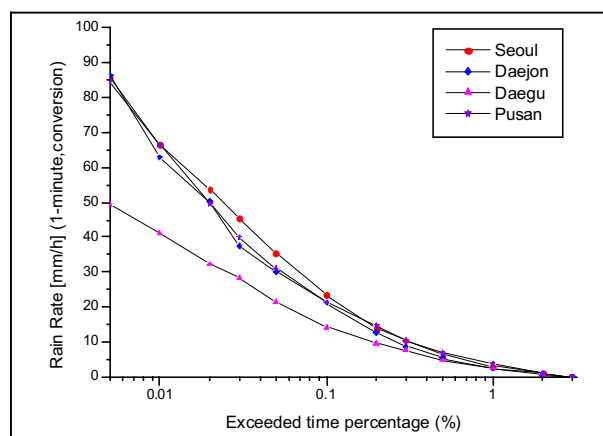


Figure 4. Result of the conversion model in cumulative 1 minute data

○ Study for effective path length

Chungnam University have ever made a research activity for the effective path length using Koreasat Ku band satellite beacon data which measured by ETRI and the rain attenuation factor model which developed by ADD-Chungnam University joint project, but the more systematic modeling and actual verification study using Ka band beacon signal data is needed.

A study is never performed for characteristics of the rain height and rate cell for development rain attenuation prediction model reflecting physical characteristics of the Ka band satellite link. Also it is never performed for that of the wet snow, ice particle and melting layer in nation.

III. Future works

All nation abroad are developing their own rain attenuation models based on their regional characteristics, in the above facts, and ITU-R recommends a global model which have adopted by ITU-R to none developed countries.

Like this problem, because satellite signal attenuation by rainfall implies regional own characteristics and internationally proposed prediction model has been developed through the measurement and analysis for rain environment of the outside country not the domestic environment. As it is difficult to apply to domestic environment directly, it is needed that we develop our own model appropriated in our domestic environment.

It is important that the modeling for the characteristics of the annual timely ratio distribution in domestic environment in evaluation of the system availability and in measurement of the distribution characteristics by raindrop size greatly affected to rain attenuation factor.

It is necessary that we develop our own model using real data measured from beacon signal of the real satellite, and is verified it.

We are planning to complement the existing model using actual data measuring raindrop size distribution by Ka band satellite for rain attenuation factor, and to develop new model from rain height on calculating data by upper-air observation and weather radar and from estimation of the compensation factor based on characteristics of the rain distribution for a effective path length, and to develop new model of the domestic regional rain ratio distribution by analysis of the measuring data in a large number of regions using Ka band satellite and long-term minute data from AWS of the weather

station. Otherwise we will use the conversion model developed by Chungnam University-ETRI project for the region none of the long-term minute rain data.

We also plan to compare estimation value to measurement value and to verify them through measurement of the satellite beacon signal for the above three items.

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