Journal of Atmospheric and Solar--Terrestrial Physics 152 (2017) 1–10

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar–Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Rain attenuation statistics over millimeter wave bands in South Korea

Sujan Shrestha, Dong-You Choi*

Department of Information and Communications Engineering, Chosun University, Republic of Korea

ARTICLE INFO

Keywords:
ITU-R P. 530-16
Millimeter wave communication
Rain attenuation
Rain rate

ABSTRACT

Rain induced degradations are significant for terrestrial microwave links operating at frequencies higher than 10 GHz. Paper presents analyses done on rain attenuation and rainfall data for three years between 2013 till 2015, in 3.2 km experimental link of 38 GHz and 0.1 km link at 75 GHz. The less link distance is maintained for 75 GHz operating frequency in order to have better recording of propagation effect as such attenuation induced by rain. OTT Parsivel is used for collection of rain rate database which show rain rate of about 50 mm/h and attenuation values of 20.89 and 28.55 dB are obtained at 0.01% of the time for vertical polarization under 38 and 75 GHz respectively. Prediction models, namely, ITU-R P. 530-16, Da Silva Mello, Moupfouma, Abdulrahman, Lin and differential equation approach are analyzed. This studies help to identify most suitable rain attenuation model for higher microwave bands. While applying ITU-R P. 530-16, the relative error margin of about 3%, 38% and 42% along with 80, 70, 61% were obtained in 0.1%, 0.01% and 0.001% of the time for vertical polarization under 38 and 75 GHz respectively. Interestingly, ITU-R P. 530-16 shows relatively closer estimation to measured rain attenuation at 75 GHz with relatively less error probabilities and additionally, Abdulrahman and ITU-R P. 530-16 results in better estimation to the measured rain attenuation at 38 GHz link. The performance of prominent rain attenuation models are judged with different error matrices as recommended by ITU-R P. 311-15. Furthermore, the efficacy of frequency scaling technique of rain attenuation between links distribution are also discussed. This study shall be useful for making good considerations in rain attenuation predictions for terrestrial link operating at higher frequencies.

1. Introduction

Rain induced attenuation can severely degrade the radio wave propagation at centimeter or millimeter wavelengths which restricts the path length of radio communication systems and limits the use of higher frequencies for line-of-sight microwave links. The rainfall results absorption and scattering of radio waves which result in the reduction of the received signal level. Above 10 GHz frequency liquid rain drops in the form of absorption and scattering become a serious contribute to transmission losses (Crane, 1996). When designing Line-of-Sight (LOS) microwave link or satellite link operating at frequency above 10 GHz, the occurrence of rain along the transmission path is considered as a main impairment factor for microwave system degradation (Freeman, 2007). The attenuation on any given path depends on the value of specific attenuation, frequency, polarization, temperature, path length and latitude (Kanellopoulos et al., 1990). It has created the need for balance between available bandwidth and rain attenuation at higher frequencies. Most attenuation prediction methods require the knowledge of 1 min rainfall rate statistics which in turn depends on the effective sampling time of the rain gauge (Mandeep et al., 2008). Rainfall rate is the main factor in determining rain induced attenuation in a given link. The most widely used statistics are rain rate exceeded for a given percentage of the year which have taken into consideration of averages of statistics over many years due to the extreme variability of rainfall statistics at a given location (Barclay, 2003). The local prediction model is analyzed in the South Korea, where the modified polynomial model shows the predictable accuracy for estimation of 1 min rainfall rate distribution (Sujan et al., 2016; Shrestha et al., 2016; Sujan and Choi, 2016). In recent years, some location in the South Korea have experienced periods of unusually heavy rainfall which might be resulted due to urban heat island phenomena. This creates the interest to study the recent rain attenuation data measured in the South Korea which can be compared with the prominent rain attenuation methods (Choi et al., 2012). Rain attenuation prediction models take into account of path reduction factor, which features both path length and rainfall rate. The product of path reduction factor and the physical path length of a microwave link is the effective path length. It is observed that the effective path length is smaller than the actual physical path length, which leads to the introduction of path reduction factor (Islam et al., 2012). The method

* Corresponding author.
E-mail addresses: sujan.shrestha1@gmail.com (S. Shrestha), dychoi@chosun.ac.kr (D.-Y. Choi).

http://dx.doi.org/10.1016/j.jastp.2016.11.004
Received 20 July 2016; Received in revised form 15 November 2016; Accepted 16 November 2016
Available online 23 November 2016
1364-6826/

for the prediction of rain attenuation on microwave paths has been grouped into two categories (Kestwal et al., 2014): the empirical method, which is based on measurement databases from stations in different zones within a given region and physical method, which make an attempt to reproduce the physical behavior involved in the attenuation process. However, when a physical approach is considered then all the input parameters needed for the analysis is not available. Empirical method is therefore the most used methodologies (Crane, 2003). Rain attenuation effects have been studied worldwide and various models for solving the problem have been reported which are detailed in (Yussuff Abayomi, 2016; Kesavan et al., 2011; Mandeep, 2009; Abdulrahman et al., 2012a, 2011, 2016) that primarily focuses on the application of ITU-R P. 530-16. The rain attenuation statistics for higher microwave band wireless link were evaluated in Japan where the results agree well with the ITU model (Hirata et al., 2009). Six prominent rain attenuation models are considered for their suitability to local environment, namely, ITU-R P. 530-16 (ITU-R P. 530-16, 2015), Da Silva Mello et al. model (da Silva Mello et al., 2007; Mello and Pontes, 2012), Moupfouma's model (Moupfouma, 2009), Abdulrahman model (Abdulrahman et al., 2011), Lin model (Lin, 1977) and differential equations approach (Abdulrahman et al., 2012b). The rest of the paper is organized as follows: In "Background" section, we present a brief overview of applicable rain attenuation prediction models for terrestrial microwave link. "Analyses of Experimental data" describes the experimental setup which was used to demonstrate the procedure feasibility, followed by "Result and discussion" which summarizes the applicability of several models. Lastly, "Conclusion" concludes the paper and includes the suggestion for further research.

2. Background

Rain attenuation over a terrestrial path can be defined as the product of specific attenuation (dB/km) and the effective propagation path length (km) (Robert, 1996). The rain attenuation, A (dB) exceeded at p percent of time is calculated as:

$$A=\gamma_R d_{\mathrm{eff}}=\gamma_R d * r \tag{1}$$

where, d_{eff} is the effective propagation path length which is the product of actual radio link, d in km and path reduction factor, r at the p time percentage.

The recommendation of the ITU-R P.838–3 (ITU-R, 2005) establishes the procedure of specific attenuation from the rain intensity. The specific attenuation, γ_R (dB/km) is obtained from the rain rate R (mm/h) exceeded at p percent of the time using the power law relationship as,

$$\gamma_R = kR^{\alpha} \tag{2}$$

where, k and α depends on the frequency and polarization of the electromagnetic wave. The constants appears in recommendation tables of ITU-R P. 838-3 (ITU-R, 2005) and also can be obtained by interpolation considering a logarithmic scale for k and linear for α. For the present location, values of two parameters at frequency 38 and 75 GHz under vertical polarization are obtained as k=0.384403456 and α=0.855219; k=1.099969083 and α=0.711048 respectively. Since the rainfall is not uniform along the propagation path, the effective propagation path length depends largely on the actual path length and reduction factor. The purpose of reduction factor is to reduce the actual path length filled with uniform point rainfall (COST, 255). Appendix A shows the applicable formulas for existing six rain attenuation models.

2.1. ITU-R P. 530-16

The ITU-R recommendation (ITU-R P. 530-16, 2015) suggests the path attenuation exceeded for 0.01% of the time as the product of specific attenuation, γ_R (dB/km) and effective path length, d_{eff} for the consideration of time-space variability of rain intensity along the terrestrial path. The obtained value is scaled by the empirical formula to other percentages of time between 1% and 0.001% whose detail approach can be found in (ITU-R P. 530-16, 2015). This method is advised to be used in all parts of the world which stated that the rain attenuation needs to be considered for any operating frequency beyond 5 GHz and for frequencies up to 100 GHz with path lengths up to 60 km. This model is tested for link distance of operating frequencies 38 and 75 GHz under 3.2 and 0.1 km links respectively.

2.2. Da Silva Mello model

The model uses the numerical coefficients that are derived for effective rain rate and equivalent rain cell diameter that were obtained by multiple non linear regressions, using the measured data available in the ITU-R databanks (ITU-R Databank). Details of the model are fully reported in (da Silva Mello et al., 2007; Mello and Pontes, 2012). This approach retains the general expression for d_{eff} and uses the full rainfall rate distribution at the links region for 38 and 75 GHz operating frequencies of 3.2 and 0.1 km link distance as input for the prediction of the cumulative distribution of rain attenuation.

2.3. Moupfouma's model

This model is based on the use of rain intensity $R_{0.01}$ (mm/h) exceeded for 0.01% of the time, and the determination of the percentage of time related to the exceedence of any given attenuation of interest. This model is applied for 38 and 75 GHz links operating frequencies under link distance of 3.2 and 0.1 km respectively. The detail approach can be found in (Moupfouma, 2009).

2.4. Abdulrahman et al

This method studied the relationship between path reduction factor and different link lengths by using the multiple non-linear regression techniques. The link distance of 3.2 and 0.1 km are maintained for 38 and 75 GHz frequencies respectively so as to test the applicability of this method. Detail description of model can be obtained in (Abdulrahman et al., 2011).

2.5. Lin model

The method accounts for partially correlated rain rate variations along the propagation path length. This method is applied in the link distance of 3.2 and 0.1 km which are maintained for 38 and 75 GHz operating frequencies respectively. Further detailed explanation can be obtained in (Lin, 1977).

2.6. Differential equations approach

The method involves differentiation of measured rain attenuation with respect to rain rate. The results are presented in the form of slope, which in turn is used for predicting the expected rain attenuation at%p of the time on a 3.2 and 0.1 km link distance of 38 and 75 GHz operating frequencies respectively. The detail methodology is given in (Abdulrahman et al., 2012b).

3. Analyses of experimental data

The experimental data of rain attenuation and rain rate were collected in line-of-sight terrestrial links located in Icheon, South Korea for 38 and 75 GHz under vertical polarization, for three years period from 2013 till 2015. These data are obtained from National Radio Research Agency (RRA) and successive year's database is still under maintenance. The 38 GHz link is set between Khumdang