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Real Time Prediction of Total Atmospheric Attenuation for mm-wave bands Satellite Links over Indian Region

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Abstract

The recent satellite communication systems tend to employ Millimeter wave frequencies to meet the ever increasing demands of capacity. Keeping view of the socio-economic and geographic diversities of India, estimation of attenuation due to different atmospheric components at mm-wave earth-space links in different parts of Indian region becomes very important. The development of channel model at mm-wave bands for predicting the total attenuation along earth-space paths caused by rain, clouds and atmospheric gases is the main objective of the current study. The use of the existing models from various propagation campaigns and ITU-R model are used along with the experimental data for effective means of prediction of total attenuation at mm-wave band of frequencies. The instantaneous frequency scaling is done in the present study to predict tropospheric attenuation caused by different atmospheric components at higher frequency bands from the lower band data.

1. Introduction

As the world communication frequency bands are getting filled up and thriving for high data rates, the demand on the spectral bandwidth and the speed of the transmission data rates increases day by day. So in order to speed up the transmission data rate and to provide more bandwidths, we are in need of moving to higher Millimeter wave frequencies. The use of the mm-wave frequencies can provide more capacity and data rate for roughly the same cost as present, but the link design needs to be evaluated as there are large amounts of losses associated with these higher frequencies.

The main factor for the signal degradation at mm-wave bands is the rain fall. Thus, there is need to develop new methods and techniques to overcome the rain attenuation effects and providing maximum signal availability in rainy conditions. The other factors that induce losses in the signal are the clouds, gases present in the lower atmosphere, the different layers in the atmosphere that causes scintillation and others like system losses and cable losses. The attenuation can be compensated by using various adaptive Fade Mitigation Techniques (FMT) [1]. To effectively implement various FMTs, accurate propagation modelling needs to be done at a prior. The existing propagation models are mainly validated for the temperate regions [2-6]. The proper propagation modelling at the mm-wave bands are very limited at tropical locations especially at India. One major limitation for generating propagation models in tropical regions is that propagation measurements are very limited at mm-wave frequencies in these regions. To carry propagation measurements at mm-waves high cost measuring instruments like radiometer, beacon receivers etc.are to be installed. To overcome this problem, in the present study, we have used the atmospheric data like temperature, pressure, relative humidity collected from easily available reanalysis databases from which gaseous and cloud attenuation are predicted at different mm-wave frequencies. Similarly, the rain rate data obtained from Global Precipitation Measurement (GPM) are used here to predict rain attenuation along earth-space path at different mm-wave bands.

2. Databases

The atmospheric data like temperature, pressure and relative humidity required to estimate gaseous attenuation and cloud attenuation are taken from ERA-5 database [7] for Kolkata ($22^0$34'N, $88^0$29'E), India for the period 2007 to 2010. Liquid water content and critical humidity value has been estimated applying Salonen model [8]. At the same location, the rain rate data is taken from Global Precipitation Measurement (GPM) [9] for the same period 2007 to 2010. The attenuation is predicted at different mm-wave frequencies like 30, 40, and 50 GHz. The path length is taken as 5 Km and elevation angle 36^0.

3. Total Attenuation Prediction

3.1: Rain attenuation prediction:

Rain attenuation prediction along earth space path has been done using the Synthetic storm technique (SST) [10]. SST predicts time series of rain attenuation from the rain rate measurement at a particular location and frequency. For this prediction, the following inputs are required to be given: length of signal path, rain rate, storm speed, frequency and elevation angle. According to [10], the precipitation medium is structured with raindrop layer(A) at 20° C and melting layer B at 0° C.

The specific attenuation can be calculated as follows:

$$\gamma(x_0) = k\, R^{\alpha}(x_0) \tag{1}$$

The parameters k and α are calculated from [11] for two layers A and B at 30 and 40 GHz. From specific attenuation signal attenuation along the satellite path can be obtained as follows:

$$A(x_o) = k_A \int_0^{L_A} R^{\alpha_A}(x_0 + \Delta x_0, \xi)\, d\xi + k_B \int_{L_A}^{L_B} R^{\alpha_B}(x_0, \xi)\, d\xi \tag{2}$$

L_A and L_B are the path lengths, Δx_0 is the shift occurred for the presence of layer B.

3.2: Gaseous attenuation prediction:

Using the method described in the recommendation ITU-R [12], the specific attenuation for atmospheric gases (oxygen and water vapour) is first predicted. Then the earth-space path attenuation is computed by integrating the specific attenuation along the full slant path length. The link elevation angle is considered as 36^0. This method is adopted for time series prediction of gaseous attenuation at 30 and 40 GHz for Kolkata region. The following input parameters are needed for the prediction: frequency, pressure, temperature, and water vapour density. The amount of water vapor can be obtained from relative humidity. This quantity is generally more easily obtained from weather data. So relative humidity must be converted to water vapour density. This can be done by using the method described in [13].

3.3: Cloud attenuation prediction:

Using the method described in the ITU-R model [14], the specific attenuation for clouds is first predicted. The cloud liquid water profile is obtained from Salonen model [8]. The model computes the specific attenuation of a signal as a function of liquid water density, signal frequency, and temperature. The specific attenuation can be computed as follows:

$$\gamma_c = K_l(f)M \tag{3}$$

where M is the liquid water density in gm/m^3. The quantity $K_l(f)$ is the coefficient of specific attenuation.

Then the cloud attenuation along the earth-space path is obtained by integrating the specific attenuation along the slant path length. The link elevation angle for Kolkata is considered as 36^0. This method is adopted for time series prediction of cloud attenuation at 30 and 40 GHz. The input parameters required for the prediction are: liquid water density, signal frequency, and temperature, path length.

3.4: Total attenuation prediction:

The total attenuation is calculated by adding the rain, cloud and gaseous attenuation as shown below:

$$A_{total}(f) = A_{gas}(f) + A_{cloud}(f) + A_{rain}(f) \tag{4}$$

Where f= 30 and 40 GHz. For the whole day of 12th August 2007, the time series prediction of rain, gases and cloud attenuations are made and then total attenuation series is calculated using Eqn (4). Fig.1 shows the time series prediction of the total attenuation for the day on 12th August 2007 at Kolkata, India at frequencies 30 and 40 GHz.

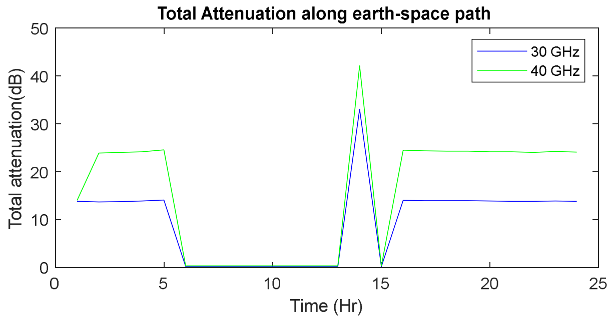

Figure.1 Predicted total attenuation series at the day on 12 August 2007 for earth space path of length 5 Km at the frequencies 30 and 40 GHz.

4. Application of frequency scaling method

4.1: Rain attenuation prediction:

In the present work, the frequency scaling has been made for each time series predicted rain attenuation value. As rain attenuation is varying with time and space, we cannot proceed with the statistical frequency scaling techniques. Firstly we calculated specific attenuation obtained from measured rain rate series as given in Eqn(1) for both f_h and f_{hl}.

Then the frequency scaling ratio computed as

$$FSR = \gamma(f_h)/\gamma(f_l) \tag{5}$$

and rain attenuation at higher frequency (f_h) is obtained from the rain attenuation at lower frequency (f_l) as

$$AR(f_h) = FSR \times AR(f_l) \tag{6}$$

For the rain event on 12 August 2007, A_{rain} (50 GHz) is predicted from A_{rain} (30 GHz) using Eqn. 5 and 6 and compared in Fig.2 with the A_{rain} (50 GHz) obtained from the Synthetic storm technique taking measured rain rate series as the input. Reasonably good matching has been observed between both the predicted results which ensures that instanteneous frequency scaling method can be applied to predict time series of rain attenuation at any mm-wave band frequency from the rain attenuation values at other low band frequencies, for example 30 GHz in the present case.

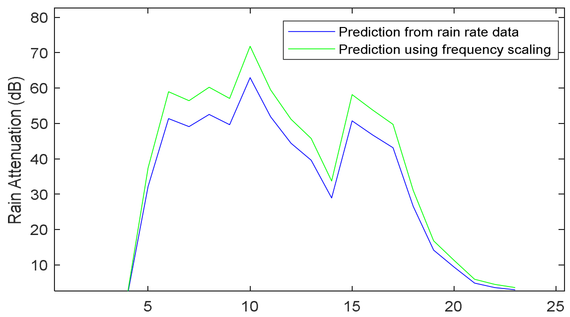

Figure.2 Comparison of rain attenuation series at the frequency 50 GHz at the day on 12 August 2007 between the prediction obtained from rain rate data and the prediction obtained using frequency scaling technique.

4.2: Cloud attenuation prediction:

The cloud length L along the path can be calculated from the cloud attenuation at lower frequency $Ac(f_l)$ as follows [8]

$$L = Ac(f_l)a_L(f_l) \quad (7)$$

Then cloud attenuation at higher frequency $A_C\ (f_h)$ can be calculated as

$$A_C\ (f_h) = \ a_L(f_h)L \quad (8)$$

The calculation of a_L can be obtained from ERA5 data as described in section 3.3.

For the day on 12 August 2007, A_{cloud} (50 GHz) is predicted from A_{cloud} (30 GHz) and compared in Fig.3 with the A_{cloud} (50 GHz) obtained directly from atmoshpheric parameters. Reasonably good matching has been observed between these predicted results which ensures that instanteneous frequency scaling method can be applied to predict cloud attenuation series at any mm-wave frequency from the cloud attenuation values at other low band frequencies for example 30 GHz in the present case.

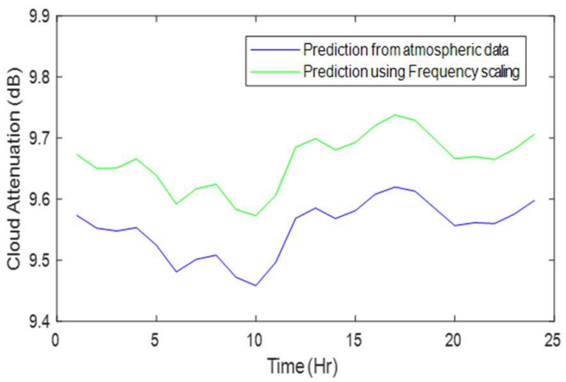

Figure.3 Comparison of cloud attenuation series at the frequency 50 GHz at the day on 12 August 2007 between the prediction obtained from rain rate data and the prediction obtained using frequency scaling technique.

For computing gaseous attenuation at higher frequency (50 GHz), we have to apply the method described in section 3.2 only. As per author knowledge no direct method is available to compute gaseous attenuation at higher frequency from the lower frequency measurements.

5. Conclusion

In the present study, time series prediction of attenuation due to different atmospheric components like rain, cloud, gases has been made for earth-space links at different mm-wave frequencies for Indian region. In the present study, instead of using costly measuring instruments, the estimation of cloud and gaseous attenuation are made from the freely available meteorological dataset like ERA-5. The rain rate data required to predict rain attenuation is taken from GPM measurements.From the measured data set at lower frequency 30 GHz, the rain and cloud attenuations are predicted at higher frequency 50 GHz using instantaneous frequency scaling technique and the validity of the prediction is successfully tested. If arrangements for continuous measurement of signal strength at mm-wave bands can be made, we can separate out the different attenuation components and the validity of the different attenuation prediction models can be tested for Indian region.

7. References

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