

Cloud Attenuation issues in Satellite Communications at millimeter Frequency Bands- State of Art

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Abstract— Over the past decades satellites has been evolved to provide a variety of services like, navigation, data, voice, videos, etc. Frequencies above 10 GHz provide new opportunities to meet the high bandwidth demands of current telecom sector. The telecom industry is looking for higher for higher frequencies because they provide higher bandwidth greater than 1 GHz which is useful for higher data rates transmissions. This article provides the brief overview of cloud attenuation and its effects on satellite communications. Different models are discussed followed by different work done on these issues. A comparative study has also been provided for different proposed models for SatCom. .

Index Terms— Satellite Communication, Millimeter Wave, Cloud Attenuation, Liquid Water Content, and Temperature.

1 INTRODUCTION

THE earth is surrounded by a layers of gases called Atmosphere. This layered atmosphere consists of gases like Nitrogen 78.09%, Oxygen 20.95%, Argon 0.93%, Carbohydrate 0.04% and small amount of other gases, including with suspended particles like aerosols, dust particles, water vapor, water droplets, ice crystals, clouds etc.

A cloud is consist of mass of very small water droplets, ice crystals, super cool water or some suspended particles present in atmosphere. The formation of clouds is due to saturation of atmospheric air, which is the results of cooling of air at dew point. It is also formed when it gets sufficient moisture from its surroundings in order to raise due point to ambient temperature.

There are different types of clouds available in atmosphere. These are divided into three main type namely low level, middle level and high level clouds [1]. Low level clouds consist of cumulus, cumulonimbus, stratus and stratocumulus. Middle level clouds consist of Altocumulus, Altostratus and nimbostratus. The high level clouds consist of cirrus, cirrocumulus and cirrostratus [1].

Cumulus clouds are generally found at the height of 2000 to 3000 feet. It can be found at whole part of globe except poles due to extremely cold climate. They rarely cause rain except fewer light showers. Cumulonimbus is found at the height of 2000 to 45000 feet. They are very common at temperate and tropical regions. They are cause of heavy rains ad hails. They are consisting of liquid water and ice crystals at top. Stratus clouds are found at the height of 0 to 6500 feet. They are very common at coastal areas and mountains. It causes only light drizzle. Stratocumulus clouds are generally found at the height of 2000 – 6500 feet. They are very common clouds which causes rain and snow.

Altocumulus is found at 6500 to 18000 feet. They are also found worldwide with light rain. Altostratus clouds are found at the height of 6500 to 16500 feet. They are causing light ran and snow. They contain both snow and liquid. Nimbostratus is found at 200 to 18000 feet. They causes moderate to heavy showers and snow fall. They contains raindrops, snow crystals etc.

Cirrus clouds are highest of all clouds and are found at the height of 16500 to 45000 feet. They are compose of ice crystals. Cirrocumulus is found at the height of 16500 to 45000 feet. They are usually consists of ice crystals. These clouds are usually a transition phase between cirrus and cirrostratus cloud. Cirrostratus clouds are difficult to spot, which appears as pale and milky. They are found at the height of 2000 to 42000 feet.

Till now brief discussion of atmosphere and clouds are explained. The next part of paper is consists of various models proposed till now for cloud attenuations on satellite communications, then followed by some work done in this area. Then comparative study results are presented. As we have seen that cloud structure is very complex so it has some significant impact on satellite communications.

2. CLOUD ATTENUATION MODEL

Various researchers in past has done lot of research on cloud attenuation. Some has proposed models on cloud attenuation. Some very famous models are discussed in this section.

Gunn [2] has presented theoretical results in the form of equations, graphs and tables. His theoretical equation is compared with published work. The input parameters used in this model are liquid water content in gm/m^3 , density of wter in g/cm , wavelength in cm and imaginary part of absorption coefficient K of material.

The results presented by Staelin [3] give integrated information about liquid water content of cloud and water vapor distribution at different heights. It has been observed that accuracy of results for liquid water content is less than the accuracy for water vapor distribution.

Slobin in his work [4] has presented general review of cloud types, liquid water density, and noise temperature and attenuation calculations. They have calculated attenuation and noise temperature for 15 different sites of America. The test years are all calendar data and more precise data are needed to be taken. Measurements for elevation angle are missing in his work.

Altshuler et al [5]. In his model has done an extensive study for cloud attenuation. The experimentation was done for the frequency from 15 to 35GHz at Boston, USA. Extensive sets of data are collected for total cloud cover and partial one. For each data set they have used 29 elevation angle profiles starting from 1 degree to 20 degree. Their results have shown that the attenuation was proportional to slant path distance. They have also described a method for finding radius and height. They have also examined the relationship of humidity with attenuation. They have compared the attenuation caused by full and partial cloud cover with clear sky attenuation and observed that cloud attenuation is significant. Finally they have derived an algorithm for estimating total attenuation due to clouds while taking input parameters as elevation angle, frequency, and surface humidity.

Experimentation was done by Liebe [6] for calculating attenuation caused by clouds, rain, fog, haze, water vapor and dry air for frequencies up to 1000 GHz. They have derived an empirical model based on their readings. The input parameters they have used are pressure, temperature, relative humidity suspended water droplets and rainfall rate.

Salonon and Uppala [7] has presented a new model for estimating attenuation caused by clouds in earth satellite links. Their model is modified from Liebe [6] model. They use temperature and humidity profile as an input parameters. They have verified their model from results of radiometer measurements at three different locations in Europe. Their model can be applied to mid altitude with elevation angle of 15 to 40 degree.

Dissaayake et al [8] has developed a new model for cloud, rain attenuation and low angle fading. Their model works at low elevation angles below 10° . They had done empirical study for combined attenuation. The slant path data has been collected from various experimental performed in beacon and radiometer. For the frequencies used in their model has observed very less attenuation of about 1.5 dB for cloud.

Dintelmann et al [9] has developed a semi empirical model for cloud attenuation. They have collected the statistics for ground based humidity and surface temperature. They modified Sobin's model [4] for cloud attenuation. Some of the models parameters are derived from experiments conducted at frequencies 20 GHz and 30 GHz respectively.

Konefal et al [10]. has described a method which can provide monthly predictions for aircraft – earth, satellite – earth and aircraft – aircraft link attenuation statistics. The method has given very satisfactory results on present statics and will be good for predicting cloud attenuation.

A cloud and gas attenuation model has been proposed by Wrenck et al [11]. at frequencies 30 GHz and above. Their experimentation was done using a beacon of Italian Space Agency satellite ITALSAT F1. The measurement shows that the proposed model behaves very well for frequency up to 40 GHz.

According to the recommendations of ITUR P840 - [12] they provide methodology for predicting cloud attenuation. The model's curves, maps given are used to predict attenuations caused by fog and clouds by researchers and engineers.

3. WORK DONE BY OTHER RESEARCHERS

In the above discussions some researchers has proposed various models for cloud attenuations. Some models are based on mathematical formulations and some are statistical analyses of measured data. Based on these models some researchers has done various studies.

Westwater [15] has observed a climatological data to identify the accuracy of water vapor content and liquid water content of clouds. According to author there are certain uncertainties which are available while calculating water vapor absorption. They have designed a channel model for minimize these uncertainties. It has been observed that the attenuation effects of cloud are reduced if the effecting radiating temperature of clouds is known. In order to know this temperature a separate reading is needed to be taken for base height and thickness of cloud.

Papatsoris [16] has discussed about attenuation due to ice clouds. Till now lot of research has focused on liquid water content but very little has discussed about ice crystals effect on propagation. They have done experimentation based on linear and cross polarization for two different scenarios. In first scenario aircraft to aircraft link was established and cross polarization discrimination was observed. In this scenario the polarization angle was 20° and ice column was 30% aligned. Second scenario was inter satellite links. In this scenario the polarization angle was 10° with 3° elevation angle. And ice columns are aligned by 50%.

Dissanayake et al [17]. has presented a cloud attenuation model which was based on the occurrence probability of four different cloud types. The occurrence probability are derived from various meteorological stations present throughout the world. Predictions of this models was compared with cloud attenuation data gathered from a satellite beacon and radiometer.

Sarkar et al. [18] has carried out a research for occurrence of clouds at different parts of Indian sub-continent. Out of these observations they have deduced the observation of Hyderabad region for low level cloud coverage. For different months and data at day time and night time are also observed they have done experimentation for frequencies ranges from 10 GHz to 100GHz . they have observed that for liquid water content of about 1 g/m^3 the attenuation at 30 GHz was 0.88dB/km and for 75GHz is about 5.55 dB/km.

Anil et al. [19]. has presented a cloud attenuation study mainly focused on eastern part of India. They have also measured the cloud occurrence data for different months and time, and also the thickness of clouds ae also observed. The frequency on which they have worked are 10 GHz, 18 GHz, 32 GHz, 44 GHz and 70GHz respectively.

Sarkar et al. [20] has done a study on radiowave attenuation of rain and cloud both for different parts of India, from 2000 to 2007. The cumulative results of their detailed study were presented graphically.

Mandeep et al. [21] has carried out propagation experimentation of clouds for Penang region by using SUPERBIRD-C satellite beacon. The occurrence of cloud is observed throughout the year. They have studied the cloud attenuation from satellite for 5 years and then make analysis of measured data n different proposed model.

Animesh et al. [22] has carried out a measurements at Kolkata region of India by using Salonen model [7] and compared it with ITU-R model. They have also observed cloud occurrence throughout the year and collected Liquid Water Content from radiosonde data. They have done measurements for frequencies from 10 GHz to 100 Ghz. Their observations shows that cloud attenuation at below 50 GHz lesser then the value of ITU-R model and greater for frequencies above 70 GHz.

The Mattioli et al. [23] the Decker and Salonen was analysed for non precipitation cloud attenuation and based on their results a new cloud model was formed. A nw cloud density function was introduced for cloud liquid water content and ice content. The performance of this function was examined at Atmospheric Radiation Measurement Program of USA. This new function has shows an improved results in calculating cloud detection about 15%. The overall results of the simulated model are compared with measured data and significant measurements are observed.

In [24] Temidago et al. has done long term measurements from 1953 to 2011 for various parameters of clouds at different six climate zones of Africa. The present results shows good correlation between monthly distribution of cloud temperature, cloud cover, cloud top height and precipitation frequency at six zones. The liquid water content observed for six zones shows degradation from the liquid water content of ITU-R model by

32% to 90% occurring of 0.01% to 10% of time. It has observed that cloud attenuation at tropical rain forest is high because of greater occurrence of rain and many cloud parametric factors.

In [26] Bijoy has studied attenuation dueto cloud ice content and attenuation due to cloud liquid water content at different frequencies at tropical region. Their results shows that attenuation caused by liquid water content is higher then attenuation cause by ice content in troposphere.

In [27] Ahmed Ali et al. has done experimental for cloud attenuation at some sites for Sudan. They have observed that low cloud occurrence plays a significant role for attenuation. According to them cloud attenuation and cloud noise temperature plays a significant role at radio wave attenuation due to clouds. They have done experimentation at 10 GHz, 16 GHz, 32 GHz, 44 GHz and 70 GHz.

4. RESULTS

Various models for cloud attenuation has been discussed in section II of this paper. From them some of the models who has common parameters lie Liquid Water Content and temperature are taken. For fixed Liquid water content as 1g/mm^3 at temperature 277K various models has been implemented. The results have been depicted in Figure 1.1. From these results we can clearly see that the slobin model shows significant attenuation whereas other models including ITU give satisfactory results. From figures 1.2 to 1.5 we had implemented various models for different clouds like cirrus, stratus, cumulus and cumulonimbus for their different properties lie temperature and liquid water content. From the results it has been observed that cumulonimbus cloud causes a significant attenuation as compared to other clouds. And cirrus causes very little attenuation for different frequencies.

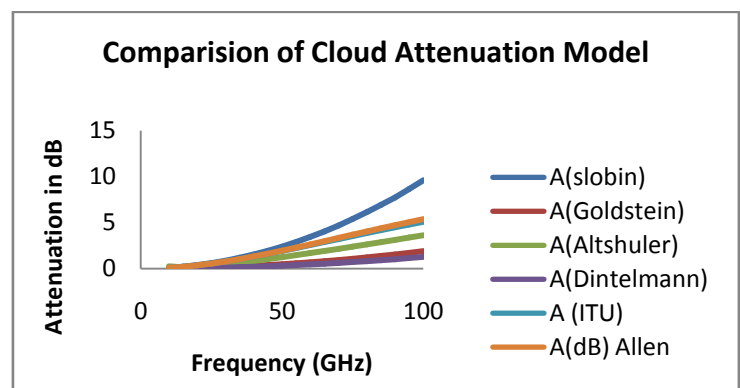


Fig. 1 Comparative Study of Various Models

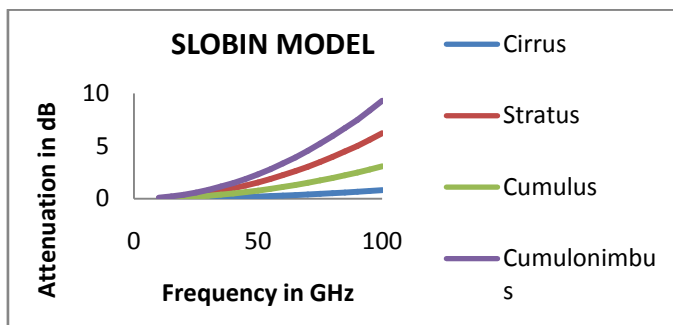


Fig.2. Comparative Study for different clouds by Slobin Model

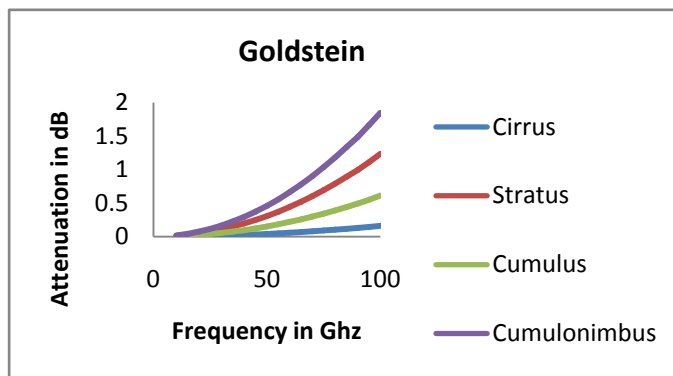


Fig.3. Comparative Study for different clouds by Goldstein Model

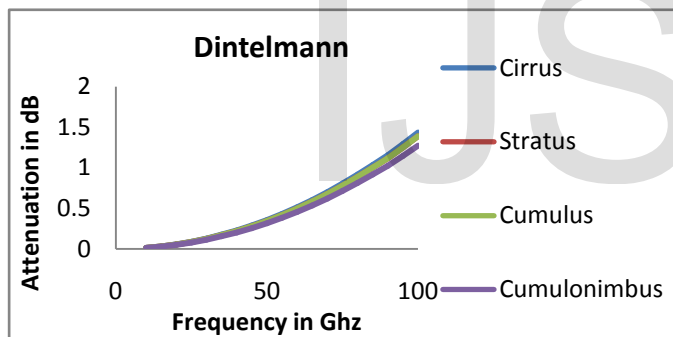


Fig.4. Comparative Study for different clouds by Dintelmann Model

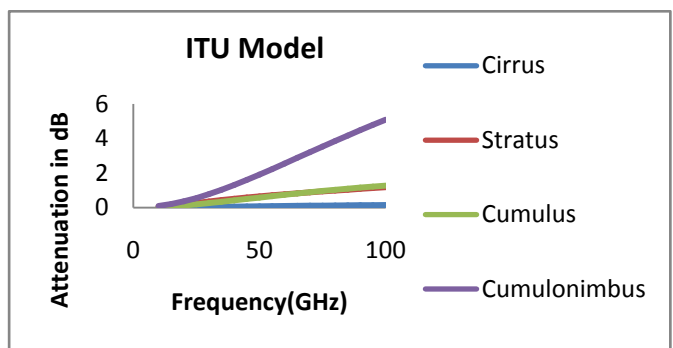


Fig.5. Comparative Study for different clouds by ITU Model

5. CONCLUSION

Cloud attenuation at mm wave is significant. The results from different studies indicate that, for the upper portion of the mm wave band, cloud attenuation dominates at

small percentage of the year. Ice clouds can deteriorate the performance of communication system specially if dual polarization technique is used. Ice clouds due to low dielectric constant of ice and small size ice crystals are less prone to have radio attenuation. Super cooled water can cause significant attenuation. In order to develop cloud attenuation model, the cloud cover data need to be combined with other important cloud parameters like, Liquid Water Content, Temperature, vertical extent, horizontal extent, and electromagnetic absorption properties of cloud are need to be considered. If the temperature is less than -20 degree Celsius then it contains only ice. If the temperature is greater than 0 degree Celsius then it contains all liquid. If between -20 to 0 degree then it contain mixture of ice and liquid. There can be significant variations of water density within a cloud. At lower elevation angles the cloud attenuation is higher. The inhomogeneity of cloud in horizontal directions plays an important role. Liquid Water Content is used as an important parameter for various models. The cloud has liquid water content for 0.1 to 1.0 g/m³. The thickness of light cloud is around 0.2 KM, medium is around 0.5 KM and heavy is around 1.5 to 2 KM. The extra noise in terms of noise temperature, which is generated by cloud, degrades the signal to noise ratio of the satellite receivers.

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