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A REVIEW OF SIGNAL ATTENUATION MODELS

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Abstract

Due to increase in demand of satellite communication, the frequency band below 10 GHz has become overcrowded, thus there is a requirement of high frequency bands. However the frequency bands above 10 GHz has higher signal power degradation compared to lower frequency signal. This degradation of signal power is known as attenuation. This causes service interruption, signal loss therefore reducing the QOS (Quality of Service) at the receiver end. Thus efficient analyses of attenuation are essential. This paper presents a review about signal attenuation, its causes and effects on transmission system. This paper also present different methodology, models which are used in the prediction of signal attenuation by different researchers. The predicated attenuation can be used for designing transmission system and also used for installment of efficient power system. At last a comparison is presented among different models as per their prediction of attenuation.

1. Introduction

Since the last few decades, the applications of satellite communications have become essential in our society. Their application area includes navigation, weather forecasting, telecommunication and dis-aster management. Radio waves of frequency range (1-40 GHz) are used for the transmission of data from satellite to earth. However due to overcrowded frequency bands below 10GHz and advancement in the application of satellite

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communication such as DBS (Direct Broadcast Satellite) systems and NGSO (Non Geostationary Orbit) increases the requirement of high frequency bands such as Ku, Ka bands. The frequency range of Ku bands and Ka bands are (11-16) GHz and (20-30) GHz respectively However Power level of the electromagnetic wave received by the terminal is responsible for the data transmission rate of the wave. Thus Power insufficiency may led to slow data transmission rate or in some cases data loss. Dilution of the wave in space during its propagation is the main cause of power loss between earth space paths. This power loss led to slow data transmission rate at the receiving end. The main causes of signal attenuation is rain, which have a non-spherical shape and thereby cause the attenuation of horizontal wave greater than the vertically polarized wave. “The consequences of rain attenuation are loss of signal power level at receiving end” [23]. “This led to the waste of transmission power in a bid to insure QOS (Quality of Service) at the receiving end” [14]. Thus to avoid the path loss, efficient analysis of signal attenuation must be performed. This paper is aimed to present over-view about signal attenuation and different models used for its prediction. The section 2 of this paper gives information about influence of atmosphere on the signal attenuation while section 3 briefly explain different methods to analyse attenuation and various empirical models and at last section 4 of this paper present a comparison about prediction by different models and outline the error associated with each different empirical models.

2. Influence of Atmosphere

In satellite communication system, the carrier which helps in signal transmission passes through the atmosphere. Atmosphere is a thick gaseous layer which surrounds the earth and attached through it by the force of gravitation. Atmosphere has a significant influence on signal transmission because of various phenomena such as absorption, reflection, rain attenuation, cloud, fog scattering, polarization and fading. Since atmosphere contain free electrons, ions and molecules thus its interaction is mainly depend on frequency of radio waves. Thus attenuation is directly proportional to frequency of radio waves. Mainly two regions of atmosphere the Troposphere and the Ionosphere have significant influence on the wave propagation. Troposphere extends from earth surface to altitude of 15 km whereas Ionosphere extends from 80km to 600km of altitude. “Ionosphere is the uppermost layer of the atmosphere where maximum ionization exists. Since solar radiation is main cause of ionization in ionosphere, it is dependent on sunspots, time, location and season” [1]. Thus Ionosphere has the maximum influence on the signal transmission [2]. The Ionosphere consists of two layers E layer and F layer. E layer is lower part of the Ionosphere which extends from 80km to 113km. E layer is responsible for the reflection of lower frequency signal. “Whereas F layer is the uppermost layer of the Ionosphere which is mainly responsible for higher frequency reflection. F layer is further divided into F1 layer (lower portion) which extends from 150 to 200 km above earth surface and F2 layer (upper portion) which extends from 200 to 500 km” [2]. F2 layer is mainly responsible for high frequency wave reflection during day and night. In region other than Ionosphere i.e. troposphere energy losses is mainly due to cloud, fog, rain attenuation, absorption, attenuation due to snowfall and fog. From above all rain attenuation is the major cause of signal loss beyond frequency 10 GHz. Dry snow have very less effect whereas Wet snowfalls have greater attenuation. The consequences of this is signal loss, power loss and in some cases full data loss at the receiving end. There are various sub problems in the propagation of signal in satellite communication.

A. Attenuation due to atmospheric gases

At microwave and mill metric frequency attenuation is mainly caused by oxygen and water vapour absorption. “Below frequency of 3GHz path attenuation due to atmospheric gases, cloud and rain is very small, thus often neglected” [15]. Attenuation due to atmospheric absorption is highly dependent on frequency. The general effects are attenuation is higher for higher frequency and are maximum near the absorption spectra for each molecule. Since water absorption line is near 22.3 GHz thus at this frequency maximum loss of signal happens [1-2].

In atmosphere A total gaseous attenuation over a path length of r (km) is given by:

$$A = \int_0^{\beta_0} [\beta_0(r) + \beta_w(r)]\, dr,\ dB \tag{1}$$

Where β_0 attenuation coefficient of oxygen and ßw attenuation coefficient of water (in decibel per kilometre) [5].

B. Attenuation due to Rain and clouds

In the Troposphere, rain is the main cause for the reduction of signal strength. If wavelength of signal of transmission is double the diameter of rain drop size, then signal attenuation happens. Thus for higher frequency signal has lower wavelength and thus more attenuation. The loss due to rain in wave propagation is given by.

$$L = 10 \log \frac{p_r(0)}{P_r(r)} \tag{2}$$

Where, $P_r(0) =$ Signal power before rain region, $P_r(0) =$ Signal power after rain region, r = Path length through the rain region [6]. "The propagation loss due to rain attenuation is expressed by γ specific attenuation in decibels per kilometer and is given by" [5]:

$$L = \gamma l_r \tag{3}$$

Where, $\gamma =$ Specific attenuation (dB/km), $l_r =$ Rain path length (km) [7].

Specific attenuation can be found based on ITU-R specific attenuation model [8] as:

$$\gamma = aR^b \left\{\frac{dB}{Km}\right\} \tag{4}$$

Where a and b are frequency dependent coefficients.

Clouds also causes attenuation for higher frequency signal propagation but they produces attenuation of different intensity which is caused due to diverse nature of clouds. Clouds having ice crystals cause very less attenuation whereas clouds having water content may cause significant attenuation. In warm places, clouds are thicker thus they cause more attenuation than other region.

Table 1. Relation between Frequency (Ghz) and Free Space Path Loss (dB).

S. No.	Frequency	Free Space Path

1.	3GHz	193dB
2.	4GHz	195.7dB
3.	5GHz	197.2dB
4.	6GHz	199.0dB
5.	7GHz	200.2dB
6.	8GHz	201.5dB
7.	9GHz	202.9dB
8.	10GHz	203.7dB
9.	11GHz	204.4dB
10.	12GHz	205.1dB
11.	13GHz	206dB
12.	15GHz	207dB

Above table 1 gives a “relation between free space path losses corresponds to frequency in clear sky presented in” [9]. This table shows that as the frequency increases propagation loss in clear sky also increases.

3. Rain Attenuation Prediction Methods

The attenuation due to the rain is the main hitch in design of satellite communications link working above the frequency of 10 GHz. Thus for the efficient installation of satellite communications, proper calculations of attenuation is required. There are several methods for predicting attenuation, which may be divided into two categories: Empirical Method, Physical Method [10].

A. Physical Method

“Analytical models that are used to simulate the physical behaviour involved in the attenuation process are referred to as physical techniques” [1]. By the help of this method an insight of physical process involved in radio wave propagation and its path loss can be experienced. This method does not require all the input parameter for analysis. “Physical approaches necessitate the use of labs and a comprehensive set-up in order to compute attenuation" [10]. Thus these methods require lots of time for precise result and cost for proper installation of labs. The main advantage of this method is that their result is precise and is based on real problems.

B. Empirical Method

In this method we take measured data of any climatic zones and by mathematical expression develop model and evaluate attenuation. The main advantage of these methods is their mathematical simplicity, which leads to many applications such as Excel model, Cranes two-component model [11], Seville, ITU-R model and Specific attenuation model (SAM). Empirical methods do not consider physical process involved in propagation but only based on knowledge of absorption and scattering behaviour of molecules. This model is new and uses measured data for its predication. "The model's key flaws are its reliance on particular measurable data and its failure to link the physical processes involved" [10].

4. Rain Attenuation Models

During the past few decades many attenuation models have been given, in which many are revised version and still many have to come. Some of the previous given models are ITU-R rain model, Flavin model, Crane model, SAM model, Moupfouma model, Yameda model etc [12].

A. ITU-R Model

The ITU-R, one of the three divisions of the International Telecommunication Union, is responsible for radio communications (ITU). The International Telecommunication Union (ITU-R) is in charge of radio frequency spectrum management and satellite orbit resources. This also improves the standard of radio communications system. ITU-R model is designed for world wide application for efficient calculation of attenuation in radio wave region. ITU-R provides stepwise approach for rain attenuation prediction in terrestrial region; however, this model has limitation that it doesn't work well in Tropical region [13]. It happens because the mean radius of raindrops in tropical regions is larger than in non-tropical regions, whereas the model is based on temperate regions [14]. Using ITU-R coefficients and a reference to this section, rain attenuation may be determined for any location

[15, 16]. Rain rate and specific attenuation (A) is used to estimate the impact of rain on radio wave propagation:

$$A\left(\frac{dB}{Km}\right) = aR^b \tag{5}$$

Where R = rain rate (in mm/hr. exceeded for 0.01% of an average year) obtained from any meteorological department a and b parameters are function of polarization and frequency which can be find experimentally.

In atmospheric attenuation prediction, the rate of rainfall is crucial. Since meteorological department gives rainfall in millimeter (mm.) whereas rain attenuation is calculated by rain rate which is in mm/hr. Thus it is essential to convert rainfall into rain rate as follows:

To calculate rain rate divide the given data by observation time (10min, 20min . . . etc.)

$$R_D = L \times \frac{60}{T} \tag{6}$$

Where, RD = rain rate (mm/hr.), L = maximum rainfall in mm for time interval T min [17].

Table 2. Models Studied by different researchers.

S. No.	Models	Descriptions
1	Unified method	In this method signal attenuation is analysed by using rain rate distributions which are obtained from meteorological department. Multiple non-linear regression are used to obtain numerical coefficient which are used in calculation [18].
2	DAH Model (Dissanayake Allnutt, and Haidara Model)	DAH model uses rain rate and rain heights. This model uses log-normal distribution of rain rate to analyse rain attenuation. In DAH Model rain height is fixed to 5km [20].

3	SAM Model (Simple Attenuation Model)	Simple attenuation model was used for satellite communication in frequency range from 10GHz to 35GHz [21]. This model develops algebraic equation for the calculation of specific attenuation coefficient, path profile and isothermal height.
4	CG Model (Crane Global Model)	Crane Global (CG) model works on 0^0C and depend on temperature, isothermal height (H_0) and excessive precipitation events [22].
5	RK Model (Ramachandran and Kumar Model)	This model analyse signal attenuation by using statistics which are derived at less than 60^0 elevation angle [23].
6	GL Model (Gracia Lopez (Model	The GL (Gracia Lopez Model) is a satellite radio connection that has been tested across numerous nations. This model has been tested on 77 various European, American, Japanese, and Australian satellites.

5. Result

Different methods are used to anticipate signal attenuation due to rain at Ku band across an earth space route, as stated above. In this experiment the data analyzed have rain rates at 0.01% of the time. Thus the rain rates are 50.35 and 59mm/hr. for two different locations [25]. Here percentage error $\varepsilon(P)$, is used to compare the result of different models. Percentage error can be defined as, "percentage errors, $\varepsilon(P)$, between measured Earth satellite attenuation data $(A_{\%p,\,\text{measured}})$ in dB and the model's predictions $(A_{\%p,\,\text{predicted}})$ in dB are calculated as follows" [25].

$$\varepsilon(P)_T = \frac{A_{\%p,\,\text{predicted}} - A_{\%p,\,\text{measured}}}{A_{\%p,\,\text{measured}}} \times 100[\%] \tag{7}$$

The comparison between different models percentage error as per different time percentage of rain rate given by different researchers is shown in Table 3. The evaluated error percentage was obtained at the frequency band of 12.5GHz. A different model which was analyzed at this frequency band shows their variation with the measured data. SAM (Simple Attenuation Model), Crane Global (CG) model and Gracia Lopez model shows highest variation than measured specific attenuation model. Thus this model are least precise at this frequency. Whereas, the most precise model at this frequency is Ramachandran and Kumar (RK) model and at lower attenuation ITU-R model also shows good precision to the measured attenuation value.

Table 3. Calculated percentage error [0.01% to 1%] for 12.5GHz [25].

(GL)Model	-0.99	-0.95	-0.87	-0.74	-0.55	-0.44	-0.35	-0.21
(RK) Model	-0.79	-0.71	-0.55	-0.37	-0.12	0.13	0.42	0.48
(CG) Model	-0.99	-0.95	-0.80	-0.70	-0.48	-0.32	-0.20	0.03
(SAM) Model	-0.99	-0.95	-0.86	-0.70	-0.45	-0.27`	-0.12	0.17
(DAH) Model	-0.89	-0.85	-0.76	-0.66	-0.55	-0.46	-0.38	-0.23
Unified Model	-0.94	-0.88	-0.79	-0.67	-0.51	-0.42	-0.34	-0.21
ITU-R Model	-0.84	-0.78	-0.66	-0.53	-0.38	-0.26	-0.15	0.04
Time Percentage%	1	0.5	0.2	0.1	0.05	0.03	0.02	0.01

Abbreviations Used:

GL – Gracia Lopez RK - Ramachandran and Kumar CG-Crane Global

SAM-Simple Attenuation Model DAH-Dissanayake, Allnutt, and Haidara

Thus from this table we can estimate that Ramachandran and Kumar model works well for rain rate of range 0.03% to 0.05%. ITU-R model shows less error as per the reduction in rain rate this shows that ITU-R model works well with temperate region or where rain rate is lower [13].

6. Conclusion

The rain attenuation and rain rate are compared with respect to various models. The above data is given at the frequency bands of 12.5 GHz satellite communication links. Rain rate of above data is taken for the range of 0.01% to 1%. The preceding findings demonstrate that when the time percentage is $0.01\% \leq P \leq 1\%$, ITU-R, RK model (Ramachandran and Kumar), proposed technique displays superior rain attenuation valuation. On the contrary, when time percentage is $0.01\% \leq P \leq 1\%$, ITU-R P. 618-13, DAH, shows good estimation against the measured results. The predicative analysis of the model is judged through percentage error of the measured data and predicated data. Thus this paper present comparison of measured data and predicated data from different empirical method. The ITU-R model gives good accuracy at Time percentage at 0.01%. For further accuracy a new proposed model also can be proposed which have better efficiency than other established empirical model. Thus for better accuracy than existing model proposed model can be developed by measured data, which have better accuracy. This paper compares theoretically the different models, their accuracy and their uses. The result obtained can be used by system designers to analyze the attenuation between earth space paths. Thus analyzed attenuation can be used for the efficient setup of transmission system and predicating the most precise power level of the transmitting signal. This power level decides the data transmission from sending to receiving terminal. However, more tests and experimental data is required for better understanding of signal attenuation at the frequency above 10 GHz.

References

[1] J. Chebil and T. A. Rahman, Development of 1 min rain rate contour maps for microwave applications in Malaysian Peninsula, Electronics Letters 35(20) (1999), 1772-1773.

[2] Propagation data and prediction methods required for the design of earth-space telecommunication systems, ITU-R, P.618-8, ITU, Geneva, Switzerland, 2003.

[3] U. Kesavan, A. R. Tharek, A. Y Abdul Rahman and S. K. Abdul Rahman, Comparative studies of the rain attenuation predictions for tropical regions, Progress in Electromagnetic Research 18 (2011), 17-30.

[4] Recommendation ITU-R P.618-10 (10/2009), Propagation data and prediction methods required for the design of earth-space telecommunication System, P Series.

[5] CCIR, Report 719, Attenuation by atmospheric gases, Recommendations and reports to the CCIR 5 (1978), 97-102.

[6] Hany E. Green, Propagation Impairment on Ka-band SATCOM links in Tropical and Equatorial Regions, IEEE Antennas and Propagation Magazine, April 46(2) (2004).

[7] C. Shkelzen and M. Kresimir, Rain Attenuation at Low Earth Orbiting Satellite Ground Station, Presented in 48th International symposium ELMAR-2006, 07-09 Zadar, Croatia, June 2006.

[8] ITU-R Recommendation P. 838-1, Specific Attenuation model for Rain for use in Prediction Methods, Geneva, 1992.

[9] Gerard Maral and Michel Bousquet, Satellite Communications Systems, systems, Techniques, and Technologies, Wiley, book, 5th edition, John Wiley and Sons Ltd, 2009.

[10] Mukesh Chandra Kestwal, Sumit Joshi and Lalit Singh Garia, Prediction of Rain Attenuation and Impact of Rain in Wave Propagation at Microwave Frequency for Tropical Region (Uttarakhand, India), International Journal of Microwave Science and Technology Volume 2014, Article ID 958498, 6 pages.

[11] R. K. Crane, Evaluation of global and CCIR models for estimation of rain rate statistics, Radio Science 20(4) (1985), 865-887.

[12] COST 255, Final Document: Radio Propagation modeling for new SatCom services in Ku-band and above, 2002.

[13] Y. A. Abdulrahman, R. Islam and T. A. Rahman, An improved ITU-R rain attenuation prediction model over terrestrial microwave links in tropical region, EURASIP Journal on Wireless Communications and Networking, 2012, Article 189 2012.

[14] L. A. R. Da Silva Mello, M. S. Pontes, R. M. de Souza and N. A. P´erez-Garc´ıa, Prediction of rain attenuation in terrestrial links using full rainfall rate distribution, Electronics Letters 43(25) (2007), 1442-1443.

[15] F. Moupfouma and L. Martin, Modeling of the rainfall rate cumulative distribution for the design of satellite and terrestrial communication systems, Int. J. Sat. Communication 13 (1995), 105-115.

[16] J. S. Ojo, M. O. Ajewole and S. K. Sarkar, Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria, Progress in Electromagnetic Research B 5 (2000), 207-223.

[17] A. Ali, M. A. Alhaider and M. A. Shatila, Rain map for radio wave propagation design in Saudi Arabia, International Journal of Infrared and Millimeter Waves 7(11) (1986), 1777-1793.

[18] M. R. Islam, M. A. Rahman, S. K. Eklas Hossain and M. S. Azad, Rain fade analysis on earth-space microwave link in a subtropical region, 5th International Conference on Electrical and Computer Engineering (ICECE 2008), Dhaka, Bangladesh (2008), pp-793-798.

[19] L. Mello and M. S. Pontes, Unified method for the prediction of rain attenuation in satellite and terrestrial links, Journal of Microwaves, Optoelectronics and Electromagnetic Applications 11(1) (2012), 1-14.

[20] A. Dissanayake, J. Allnutt and F. Haidara, A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths, IEEE Transactions on Antennas and Propagation 45(10) (1997), 1546-1558.

[21] W. L. Stutzman and K. M. Yon, Simple rain attenuation model for earth-space radio links operating at 10-35 GHz, Radio Science 21(1) (1986), 65-72.

[22] R. K. Crane, Prediction of Attenuation by Rain, IEEE Transactions on Communications 28(9) (1980), 1717-1733.

[23] V. Ramachandran and V. Kumar, Modified rain attenuation model for tropical regions for Ku-Band signals, International Journal of Satellite Communications and Networking 25(1) (2007), 53-67.

[24] J. A. Garcia-Lopez, J. M. Hernando and J. M. Selga, Simple rain attenuation prediction method for satellite radio links, IEEE Transactions on Antennas and Propagation 36(3) (1988), 444-448.

[25] Sujan Shrestha and Dong-You Choi, Rain Attenuation Study at Ku-Band over Earth-Space Path in South Korea, Department of Information and Communications Engineering, Chosun University, Republic of Korea.