OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

A Novel Method for Prediction of Attenuation of Millimeter Waves by Fog and Smoke

Hitesh Singh, Vivek Kumar, Boncho Bonev, Kumud Saxena

***Abstract**: Terrestrial radio wave link faces various challenges like attenuation caused by gases, water vapor and other weather phenomenon like rain, storms, snow, fog, cloud etc. These challenges are responsible for absorption and diffusion of energy. Another kind of obstacles observed by the radio waves on terrestrial path is vegetation, lamppost, grills and other urban constructions. Different phenomenon is studied under these conditions like reflection, diffraction, refraction, scattering, depolarization etc. In case of millimeter waves various propagation studies has been performed under different scenarios. More propagation studies are needed to be done especially for fog. In this paper radio wave propagation studies are performed for fog using proposed fog model and results are compared with the other model proposed in the Literature. Another propagation study is performed for smoke which is unique of its kind. This study indicates that even smoke can causes attenuation for millimeter wave frequencies.*

***Keywords:** Attenuation, Fog, millimeter waves, Radio wave propagation, Smoke, Cloud Attenuation*

I. INTRODUCTION

Radio wave propagation studies are the important factor for designing the links for future technologies. It is because future technologies are looking for higher frequency bands like millimeter waves, which are more sensitive towards environmental conditions. Radio wave links are divided into two main links terrestrial fixed links and satellite links.

Radio relay links which was also known as terrestrial links are based on the propagation of radio wave within the troposphere, i.e. the area between upper atmosphere and terrestrial surface. This is the most happening part of the atmosphere because most significant meteorological phenomenon occurs in this part like rain, clouds formation, fog, snow etc. The study of terrestrial fixed links deals with various effects like attenuation, refraction, reflection, transmission, scattering or depolarization. At millimeter frequency bands electromagnetic waves interact with natural atmosphere and with some metrological phenomenon like rain, hail, snow, dust storm etc. these interactions cause absorption and a diffusion of energy which causes attenuation of transmitted signals. Some studies indicate that attenuation caused by water vapor at 22 GHz is higher as compared with the attenuation caused by hail and ice crystals [1].

The satellite links are operated between satellite and the earth's surface or between earth's surface and satellite. The study of radio wave propagation in this link is simpler as compared with terrestrial links. This is because the influence of the ground can be neglected for satellite links, and thus allowing the elimination of ground diffraction and reflection phenomenon. Furthermore, since radio wave propagation through troposphere at the elevation angle is higher than some degrees so propagation path covered by the waves for this part of atmosphere is eliminated. Therefore the radio wave propagation studies at satellite links are précised to some phenomenon like free space path loss and other phenomenon linked to refractive index inside troposphere and absorption of energy due to the presence of gases, water vapor, oxygen and other weather events like rain, snow, hail, clouds.

II.LITERATURE REVIEW

Various researches have been conducted in order to find the effect of atmospheric gases on millimeter wave bands. One of the experimental studies was conducted in order to find out the effects of Oxygen and water vapor molecule on satellite communication links especially at ka bands [2].

The parameters used in this research study are relative humidity, pressure and temperature. The data are gathered from NASA's instrument called Atmospheric Infrared Sounder (ARIS). Observation of ka band signals is made from Nigeria Satellite NigComsat-I from 37 different locations. Radio wave attenuation of about 0.7 dB to 1.1 dB is observed for Ka bands. In atmosphere there are many gases present like NO2, O2, N2O and H2O however attenuation caused due gases are predominant for Oxygen and water vapor [3]. Due to the low density of other gases the attenuation caused by them is almost negligible.

Water vapor molecule is a polar in nature due to electric dipole which results in two absorption lines in micro-wave region at 22.23 GHz and 183.31 GHz. Although for water vapor another absorption line is present at far infrared region at 300 GHz.

Manuscript published on 30 September 2019
* Correspondence Author
Hitesh Singh*, Information Technology, NIET, Greater Noida, India
Vivek Kumar, Information Technology, NIET, Greater Noida, India
Boncho Bonev, Redio Communication and Video Technology, Technical university of Sofia, Bulgaria
Kummud Saxena, Information Technology, NIET, Greater Noida, India

In case of Oxygen molecule family of absorption lines for millimeter waves are present between 50 GHz and 70 GHz due to the presence of permanent magnetic moment in its molecular structure [4]. The highest absorption due to Oxygen molecule is observed at two frequencies i.e. 60 GHz and 118.75 GHz respectively.

It has also been observed that attenuation can be caused due to the presence of dust particles in atmosphere or dust storms [5, 6, 7]. The important parameter used while predicting the attenuation caused due to dust is visibility in km. the relationship between visibility and height are also been formulated in some studies. Some theoretical models have been developed in order to calculate the attenuation caused by dust. The parameter used in those models is particle size, visibility, frequency and propagation angle.

A cloud is consisting of mass of tiny droplets of water, crystals of ice, super cool water or contain suspended particles present in the atmosphere. The clouds are formed due to the saturation of atmospheric air, which is occur due to the cooling of air at due point [8]. Different types of clouds are available in the atmosphere, which are divided into three main type's namely low level, middle level and high-level clouds. Low level clouds are consisting of cumulus, cumulonimbus, stratus and stratocumulus. Middle level cloud consists of altocumulus, altostratus and nimbostratus. High level cloud consists of cirrus, cirrocumulus and cirrostratus clouds [8]. When the conditions like formation of clouds occur at ground level then it is called fog. The structure of fog and clouds are almost similar. Various studies are done in order to predict the attenuation caused by the clouds and fog.

Various models have been designed for the prediction of attenuation caused due to the presence of clouds. The cloud and fog models developed in the past are divided into three different categories. The first categories are consisting of prediction model which was based on Rayleigh Approximation and Mie Scattering theory. Those models are proposed by Gunn and Libe. The second category model is directly correlated to surface absolute humidity shown by Altshuler Model. In the third category model are majorly based on experimental studies. In this cloud water content are observed from meteorological data and computations. Attenuation was predicted by using slightly modified version of first category models. Modes lying in this category are Dintelmann and Slobin models [9].

These models mathematical form and prediction of attenuation due to clouds and fog varies over large ranges. One common parameter used in the above discussed model is Liquid Water Content. This fundamental parameter is most difficult to calculate and predict. While calculating radio wave attenuation caused by clouds Liquid Water Content is not only deciding parameter, other deciding parameter are drop size of water and temperature. Cloud drop size plays an important role as the size varies with height and other conditions like place of occurrence of clouds and weather conditions. Temperature of clouds also plays an important role.

Till now some common models of cloud attenuation are discussed which were also worked for fog? Those models are based on mathematical formulations and some statistical analysis of measured data. Some researches and propagation studies are performed in the past. Those are discussed in the next section. Climatologically data to identify the accuracy of water vapor content and liquid water content of clouds has been observed [10]. While calculating water vapor absorption certain uncertainties are observed. In order to minimize these uncertainties a channel model has been designed. It has also been observed that if the cloud temperature is known then attenuation effect of cloud is reduced. Separate observation is needed for the height and thickness of clouds in order to calculate the temperature of the clouds.

Lot of studies has been performed on cloud attenuation but very little on ice crystal. The experimental studies have been performed on cloud containing ice crystals [11]. Linear and cross polarization has been studied for two different scenarios. In first scenario radio link has been established between two different aircraft's flying into clouds. In the case of cross polarization discrimination has been observed. In second scenario satellite link was established. In this case polarization angle was about 10^0 and elevation angle of link was 3^0. The ice column was aligned by 50% in this scenario.

A new cloud attenuation model was designed which was based on the occurrence probability of clouds [12]. In these experimentation four different types of clouds was observed. The occurrence probability data was gathered from different meteorological stations located at different parts of the world. The results obtained from the proposed model were validated with the experimental data obtained from satellite beacon and radiometer.

Another research has been carried out over some parts of Indian sub-continent region [13, 14, 15, and 17]. The type of data observed from these studies is low cloud occurrence, of clouds for different months of year and time, and thickness of clouds. For frequency ranges from 10 GHz to 100 GHz regress experimentation was performed. The common observation was made from the above experimentation was that for the liquid water content of 1 g/m3 for 10 GHz the specific attenuation was observed about 0.88 dB/km and for 7.5 GHz is about 5.55 dB/km. In the region of Malaysia research is carried out in order to study the effect of clouds on satellite communication [16]. They have used the beacon of SUPERBIRD-C satellite. Annual cloud occurrence data has been observed and analyzed. Attenuation caused by clouds has been observed for five years and detailed analysis has been made from the observed data.

Another model has been proposed which was based on the non-precipitating clouds cover. Cloud density function has been proposed for liquid water content and content of ice on clouds. The results of this function are validated from Atmospheric Radiation Measurement Program of USA. The measurements using this function shows improved results of about 15%. Some research has been conducted for different climatic zones of African continent [19, 20, 21]. Long term measurements have been made for different parameters of clouds. Liquid water content observed for different zones shows degradation from the liquid water content of ITU-R model of about 32% to 90% occurring of 0.01% to 10% of time.

It has been observed that attenuation caused due to clouds at tropical region is higher because of greater occurrence of rain and other different cloud parameters.

III. METHODOLOGY

Various models are proposed in order to predict the attenuation caused by the clouds present in troposphere. The most common parameters used by the models are Liquid Water Content in g/m3, Frequency in GHz, in some case wavelength in cm, Temperature in K etc. Most of the cloud models are based on the experimental studies of region. As experiments are conducted for geographical regions and environmental factors are different for different geographical regions, so those types of models cannot be generalized. While designing those types of models more precise experimental data is needed. Some researchers have done experimentation for clear sky and partial and full cloud cover. They have observed that attenuation is significant for cloud cover. Some experiments are performed for a frequency range. Some research shows that attenuation caused by Liquid Water Content is higher than the attenuation caused by the ice crystals in troposphere. It has also been observed that attenuation at tropical rain forests is higher as compared to other regions. As cloud cover at different time intervals also plays an important role. Some researchers also show that low occurring clouds plays a significant role in attenuation caused by clouds.

A. Proposed Model

From these discussions it has been observed that a new model is needed for generalized purpose [9]. A Radio Wave Attenuation for Cloud and Fog (RWACF) model has been proposed which gives prediction of attenuation caused by the clouds. Proposed RWACF model is based on the Mie theory as most of the other models are based on Rayleigh Approximation Theory or experimental data. One of the advantages of proposed model over other model is use of Drop Size in meters as parameter. Other models are mostly based on LWC and Temperature. As researchers have confirmed that cloud has complicated structure so drop size also plays an important role while predicting the attenuation caused by clouds. It is also because for a certain heights LWC can remain constant, but size of water droplets may vary. If the drop size of a cloud is known and with other parameters like LWC, temperature etc. then by using our model attenuation by clouds can be predicted for any geographical region. Proposed model can work for frequencies ranges from 10 GHz to 100 GHz effectively. As our proposed model using lot of parameters like Drop Size, LWC, temperature etc., and so more precise results can be obtained. By using this model attenuation can be predicted for different layers of clouds.

After solving all equations and simplification as solved in [9] RWAMCF model is look like:

$$\Delta_{total} = \frac{rf}{u}(l + mr^2f^2 + nr^3f^3) \quad (1)$$

Where r is the radius of water droplets in meters, f is the frequency in GHz and u, l, m, n, are constants given in [9].

B. Motivation

The proposed cloud and fog attenuation model is based on Mie theory which was explained in details in [9], so our major parameter for our concern is drop size. For cloud attenuation some other parameters are important like liquid water content in g/m3 and temperature in degree C. Temperature is variable as it changes with height of a cloud. As it is known that cloud has complex structure, so it has different configurations. ITU model is majorly based on LWC and Temperature only. Our model is not only based on these parameters but on other parameters like drop size which is variable in size for different types of clouds and

for some cases different for same type of clouds. Our proposed model is implemented mathematically, and common parameters of Cumulonimbus clouds given as LWC =2.5 g/m3, T= 00C and r =8 microns are put in it to get the results and compared with other models

IV. EXPERIMENTAL SETUP AND RESULTS

The results clearly show that proposed model is almost matching the results of ITU cloud model. The difference of attenuation of ITU model and proposed model is about 10% only. Slobin model when implemented with same parameters show higher attenuation as compared with our model. While other models like Altshuler, Goldstein, Dintelmann and Allen shows less attenuation. The implementation of proposed model with different cloud structures are shown in Fig. 1.

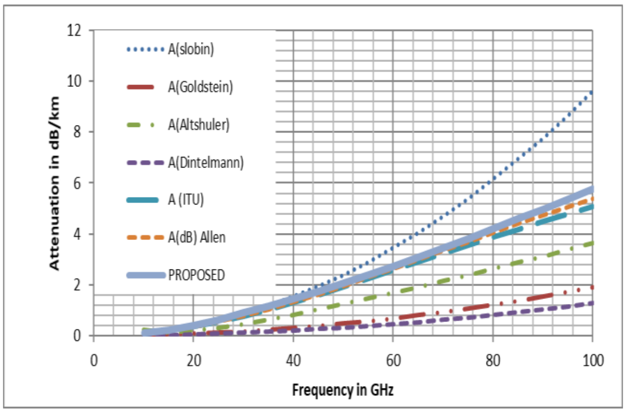

Fig. 1. Comparison of other models with Proposed Model for LWC =2.5 g/m3, T= 00C and r=8 microns.

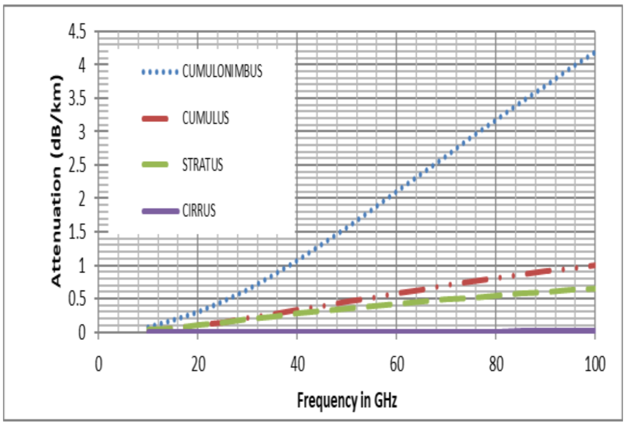

Fig. 2. Attenuation for Different clouds by Proposed Model for LWC =2.5 g/m3, T= 00C and r =8 microns.

The result shows that cumulonimbus shows very significant attenuation because of the low height and high liquid water content.

The drop size is also high as compared with other clouds. Very less attenuations caused by cirrus clouds. The possible reason for that its high altitude and very less water content.

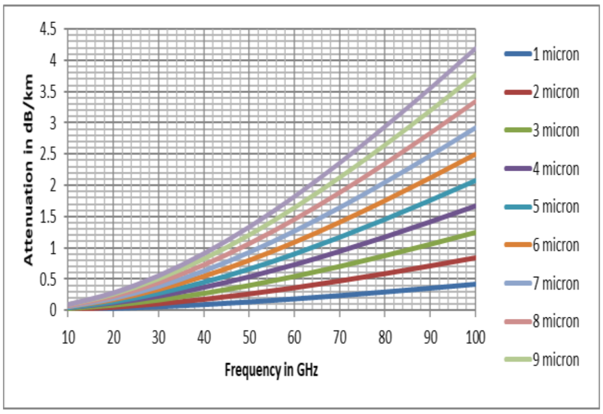

Fig. 3. Attenuation Vs. Different Drop size in microns for LWC =2.5 g/m3 and T= 00C.

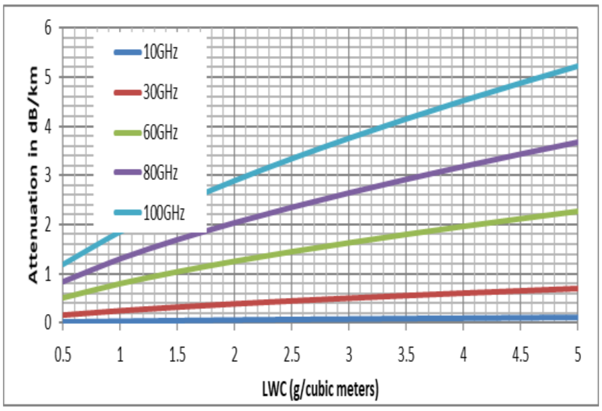

Fig. 4. Attenuation vs Liquid Water Content for T =00C and r =8 microns.

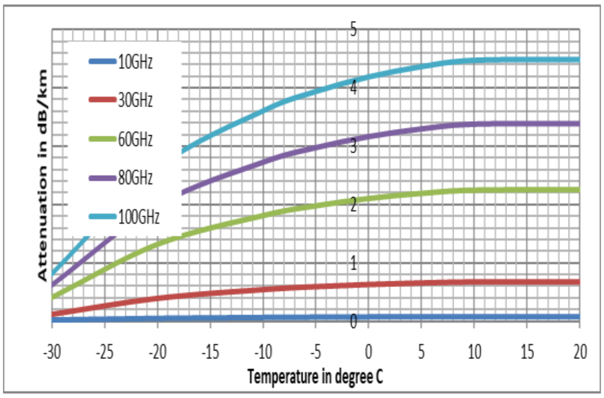

Fig. 5. Attenuation vs Temperature for for LWC= 2.5 g/m3 and r= 8 microns.

Fig. 3 shows the relationship between water droplets size in microns with specific attenuation in dB/km at different frequencies. It has been observed that for lower frequencies from 10 GHz to 30 GHz does not show much difference in attenuation with variations of size of drop. But for higher frequencies like 60 GHz and 100 GHz the difference in attenuation is higher for different drop size. The relationship between liquid water content and specific attenuation is depicted in Fig. 4. It has been observed that with the increase in parameter Liquid Water Content the attenuation is also increased. For lower frequencies like 10 GHz to 30 GHz not much attenuation is observed for different liquid water content values, but for higher frequencies like 60 GHz to 100 GHz significant difference is observed especially for higher values of liquid water content. Fig. 5 shows that Temperature of clouds also affects the attenuation caused by the clouds. It has been observed that a lower frequency does not show much attenuation for different temperatures. But for higher frequencies like 60 GHz and above significant difference was observed of about 1 (dB/km) to 1.5 (dB/km). One observation is also made that the higher temperature of about 0 to 10 degree C causes more attenuation as compare to lower temperatures like 0 to -200 C.

Table- I: Error Analysis of Proposed Cloud Model at Different Temperatures

Temperature	Average %age of Error
243.15	2.300983
248.15	2.419373
253.15	2.533578
258.15	2.64181
263.15	2.742289
268.15	2.833253
273.15	2.912958
278.15	2.979679
283.15	3.031712
288.15	3.067366
293.15	3.084963

Table- II: Error Analysis of Proposed Cloud Model at Different Frequencies

Frequency (MHz)	Average %age of Error
10	0.137582361
15	0.299368216
20	0.509526448
25	0.756574055
30	1.030225921
35	1.322160722
40	1.626073757
45	1.937381471
50	2.252834404
55	2.570163978
60	2.887803423
65	3.204682676
70	3.520083148
75	3.833536615
80	4.144755066
85	4.453581767
90	4.759956699
95	5.063891754
100	5.365452586

The proposed cloud model is further analyzed by doing error analysis by using $\text{error} = \frac{1}{n}\sum_{i=1}^{n}\frac{|x_{i\,apr}-x_{i\,ITU}|}{x_{i\,ITU}}.100\%$ (2)

Where i is current value number (for given frequency) and n is the number of calculation points. The results are given in Table 1 and Table 2.

In this error analysis the deviation of proposed model with ITU-R cloud model is discussed. The average deviation is approximately 3% at different temperature ranges from 243.15 K to 293.15 K. And for different frequencies the average deviation of error is around 2 to 5 %.

After calculation of attenuation caused by fog by the proposed model then studies are done for predicting the attenuation caused by smoke. In order to calculate the attenuation following equation is used.

$$A_{total} = 4{,}343 \cdot 10^3 \int_{r\,min}^{r\,max} \frac{\lambda^2}{2\pi} (kr)^3 (A1 + A2(kr)^2 + A3(kr)^3) \cdot \frac{5{,}5 \cdot 10^{-4}}{V \cdot r^2} dr$$

[dB/km] (3)

The parameters used in this equation are given in table 3. The smoke is mainly consists of carbon content. For the prediction of attenuation it required real and imaginary parts of dielectric constants of carbon. These parametric values are obtained from [22]. As for frequencies 10 GHz, 37 GHz and 74 GHz the values of real and imaginary parts of dielectric constants are known, so attenuation for these frequencies are calculated only. After substituting the values given in Table 3 in equation (3), get the specific attenuation in dB/km for smoke for visibility ranges from 0.1km to 0.5km respectively. The implementation results are shown in Fig. 6.

Table- III: Parameters used for calculation of attenuation due to smoke

f	e'	e"	a
10	2.02	10.8	0.000015
37	2.02	2.7	0.000015
74	2.02	1.35	0.000015

The results clearly show that attenuation caused by smoke is higher for lesser visibility i.e. for about 1.6 dB/km for visibility of 0.1 km at 74 GHz. It has also been observed that for higher frequencies higher attenuation is observed. For all frequencies much higher attenuation is observed at visibility 0.2 km and less.

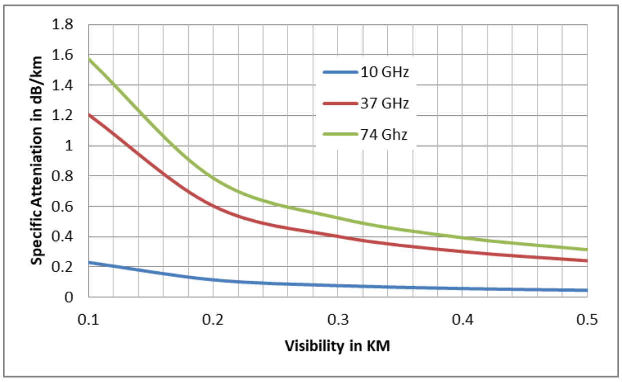

Fig. 6. Attenuation Vs. Visibility in km for smoke.

V. RESULT AND DISCUSSION

The results show that implementation model is closely aligned with the ITU model. This model has advantages over other models as it uses different parameters called droplet size in meters. As cloud and fog has complex structure and the size of droplet varies with height and different environmental factors. Size of drop plays a significant role in attenuation. Fig. 3 shows that with the increase in drop size the specific attenuation is also increases especially for higher frequencies. It has also been observed that with the variation of temperature also affects the attenuation due to fog and cloud. From Fig.5 it has been clearly shows that variation in temperature ranges from -30 degree C to 20 degree C as these temperature ranges are normally observed in the clouds. In case of the variation of attenuation is significant between higher frequencies about 1.5dB. Attenuation caused due to the presence of smoke is also presented in this article. It has observed that specific attenuation due to smoke is higher for lesser visibility of around 100 meters. The difference of attenuation was about 1dB/km.

VI. CONCLUSION

From the mathematical implementation of proposed cloud model, it is concluded that the variations of Liquid Water Content in a cloud have a significant impact on the attenuation caused by the Fog and clouds. As fog has complex structure. Sometimes dense fog is formed because of larger water content which may cause larger attenuation and sometimes it is thinner results in lesser attenuations. So, they vary with time. From the simulation work it has been observed that proposed model for predicting rain attenuation is closely matched with the original ITU cloud model. The experimentation for attenuation due to smoke is also studied which is of unique of its kind. This kind of study will be useful in the scenarios used by Military in warfare. The purpose of this experimentation was to show that more studies need to be performed for designing the terrestrial links for next generation mobile technologies.

REFERENCES

1. Seybold J S. “Introduction to RF propagation”, John Wiley & Sons, 2005 Oct 3.
2. Omotosho TV, Mandeep JS, Abdullah M. “Atmospheric gasimpact on fixed satellite communication link a study of its effects at Ku, Ka and V bands in Nigeria”, *In Proceeding of the 2011 IEEE International Conference on Space Science and Communication (Icon Space)*, pp. 69-72, 2011.
3. Frey TL. “The Effects of the Atmosphere and Weather on the Performance of a mm-Wave Communication Link”, *Applied Microwave and Wireless*, vol. 11, pp. 76-81, 1999.
4. Magono C, Nakamura T. “Aerodynamic studies of falling snowflakes” , *Journal of the Meteorological Society of Japan*, vol. 43(3), pp. 139-47, 1965.
5. Cheng L, English M. “A Relationship between hailstone concentration and size”, *Journal of the Atmospheric Sciences*, vol. 40(1), pp. 204-13, 1983.
6. Harb K, Omair B, Abdul-Jauwad S, Al-Yami A, Al-Yami A, “A proposed method for dust and sand storms effect on satellite communication networks”, *Innovations on communication theory INCT,(Istanbul, Turkey)*, pp. 33-7, 2012 Oct.
7. Harb K, Omair B, Abdul-Jauwad SH, Al-Yami A, “Systems adaptation for satellite signal under dust, sand and gaseous attenuations” *Journal of Wireless Networking and Communications, vol.*3(3), pp. 39-49, 2013.
8. World Meteorological Organization, ed (1975). Cirrus, *International Cloud Atlus.*
9. Singh H, Bonev B, Petkov P, Patil S, “Cloud attenuation model at millimeter frequency bands” “*International Conference on Infocom Technologies and Unmanned Systems (Trends and Future Directions) (ICTUS)*”, vol. 18, pp. 175-180, 2017.

10. Westwater ER., "The accuracy of water vapor and cloud liquid determination by dual-frequency ground-based microwave radiometry", *Radio Science*, vol. 13(4), pp. 677-85, 1978.
11. Papatsoris AD., "Effect of ice clouds on millimetre-wave aeronautical and satellite communications", *Electronics Letters*, vol. 33(21), pp. 1766-80, 1997.
12. Dissanayake A, Allnutt J, Haidara F., "Cloud attenuation modelling for SHF and EHF applications", *International journal of satellite communications*, vol. 19(3), pp. 335-45, 2001.
13. Sarkar SK, Ahmad I, Gupta MM., "Statistical morphology of cloud occurrences and cloud attenuation over Hyderabad, India", 92.60 Nv, 84.40. _x. 2005.
14. Kumar A, Sarkar SK., "Cloud attenuation and cloud noise temperature over some Indian eastern stations for satellite communication"
15. Sarkar SK, Kumar A., "Recent studies on cloud and precipitation phenomena for propagation characteristics over India", 92.60, Nv, 84.40.-x. 2007.
16. Mandeep JS, Hassan SI., "Cloud attenuation for satellite applications over equatorial climate", *IEEE Antennas and Wireless Propagation Letters*, vol. 7(15), pp. 2-4, 2008.
17. Maitra A, Chakraborty S. "Cloud liquid water content and cloud attenuation studies with radiosonde data at a tropical location", Journal *of Infrared, Millimeter, and Terahertz Waves*, vol. 30(4), pp. 367-73, 2009.
18. Mattioli V, Basili P, Bonafoni S, Ciotti P, Westwater ER., "Analysis and improvements of cloud models for propagation studies", *Radio Science*, vol. 44(02), pp. 1-3, 2009.
19. Omotosho TV, Mandeep JS, Abdullah M., "Cloud attenuation studies of the six major climatic zones of Africa for Ka and V satellite system design", *Annals of Geophysics*, vol. 56(5), pp. 1-8, 2013.
20. FET N. "Attenuation of Signal at a Tropical Location with Radiosonde Data Due to Cloud", *International Journal of Smart Home*, vol. 8(1), vol. 15-22, 2014.
21. Singh H, Kumar R, Bonev B, Petkov P., "Cloud Attenuation issues in Satellite Communications at millimeter Frequency Bands- State of Art", International Journal of Scientific and Engineering Research vol. 8(7), pp. 851-857, 2017.
22. K Kulemin GP., "Millimeter-wave radar targets and clutter", *Artech House*, 2003.

AUTHORS PROFILE

Dr. Hitesh Singh is PhD from Technical University of Sofia, Bulgaria. His Area of research is Wireless Communications, Propagation, and Cyber Security. He has done M. Tech and B. Tech in the field of Computer Science Engineering. He is the author of many books in the fields on computer science.

Prof. Vivek Kumar was born in UP, india. he received Ph.D in Computer Engineering and Technology from Suresh Gyan Vihar University, Jaipur in 2013. He did M.Sc. in Electronics from CCS university, Meerut (UP) in 1999. He is working as professor in the department of Information Technology at Noida Institute of Engineering and Technology. His area of interest in research are attenuations in waves, agent technology, fuzzy logic and case base reasoning.

Prof. bonchu was born in Stara Zagora, Bulgaria. He received both the M.Sc. and the Ph.D. degree in electrical engineering from the Technical University of Sofia, Bulgaria, in 1994 and 2008, respectively. From 1996 to 2013, he was an Assistant Professor in the Department of Radio Communications and Video Technologies, Faculty of Telecommunications, Technical University of Sofia. Now he is Associate Professor in the same department. He is teaching the courses of radio wave propagation, radio relay systems, electromagnetic compatibility and antennas. His current research interests focus on rain attenuation of radio waves, fractal antennas, microwave hyperthermia and FSO systems.

Prof. Kumud Saxena received the Ph.D. degree in Computer Science, from Dr. B.R. Ambedkar University, Agra, UP, India in 2016. Currently, she is associated with NIET, Greater Noida as HOD and associate Professor in Information Technology department. She has published and presented many papers in several reputed journals. Working on govt. aided projects. Her research interests include image enhancement, Communication system, soft computing, biometric based recognition, etc.