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Soft Clustering for Enhancing ITU Rain Model based on Machine Learning Techniques

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Abstract
With the many folds increase in demand for capacity in mobile broadband communication technology every year, wireless carriers must be prepared for the tremendous increase in mobile traffic in coming years. It forces scientists and researchers to come up with new wireless spectrum bands which has capabilities to support higher data rates. The higher spectrum bands like millimeter waves are the candidate band for this type of problems. This band comes with the challenges of radio wave attenuations oof signals due to the presence of gases, water vapor and other weather phenomenon like rain, storms, snow, hail etc. Different models are presented in order to predict attenuation due to rain out of which ITU-R model is the widely acceptable model. The ITU-R model contains complex methodology for calculating regression coefficients which are depends on frequency and polarization. In this paper, K-Means algorithm is used to propose an improved ITU-R model. Proposed model can make up the shortcoming of ITU-R model to determine the break-up points in frequency range and obtained soft clusters have been trained by machine learning algorithms then proposes a mathematical model for prediction of radio wave attenuation due to rain. The implementation results of proposed model were also compared with the ITU-R model.

Keywords Rain attenuation · ITU model · Satellite communication · Millimeter waves · Clustering · Regression analysis

1 Introduction

Radio wave attenuation is primarily caused by the absorption of a radio signals by some atmospheric phenomenon like rain, snow, ice, clouds, dust etc. These attenuations are more prevalent in the frequency range above 10 GHz. Attenuation caused by rain is not only limited to satellite up-link and down-links, but it can also affect the point-to-point terrestrial

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microwave links above 10 GHz [1–5]. The attenuations caused due to presence of rain is called rain fade. Some of the studies comprised of mathematical models [3, 8, 10]. Results of these models are compared with the ITU-R model. Some experimentation has been performed at different geographical locations. Based on the results obtained, empirical model was developed in order to predict attenuation due to rain. These models tries to predict the attenuation but it was not accurate in case of real situation. The recommendations ITU-R [4] rain attenuation model is the widely used method for the predictions of rain effects on satellite communications system. In order to predict the attenuations for particular frequencies the values of k and α coefficients for both horizontal and vertical polarization are required. In order to calculate the values of these coefficients complex methodologies are given in ITU-R recommendations [4]. Some simpler methodology is needed to be developed in order to find these values.

The proposed paper has contributed following points:

- A simpler and improved model is developed in order to calculate values of K and α coefficients in order to calculate specific attenuation.
- An algorithm is developed in order to calculate specific attenuation in dB/km caused due to rain.
- A statistical analysis has been done in order to measure the performance of proposed model.

The present paper is organized in following manner. Second section discuss about the literature review. Section third is described about the proposed model. Fourth section discuss about the results and discussions followed by the last conclusion section.

2 Literature Review

In order to predict the attenuation caused due to rain, lot of studies has been performed. Details of these studies are shown in Table 1.

The recommendations ITU-R rain attenuation model is the widely used method for the predictions of rain effects on satellite communications system [4].

The attenuation is calculated for 99.99% fade depth by:

$$A_{0.01} = \mathrm{kR}^{\alpha} drdB \tag{1}$$

where R is given by 99.99% of rain rate for rain region in mm/h, kR^{α} is the specific attenuation in dB/km and d is the link distance in km. the formula for r is given as:

$$r = 1/(1 + d/d0) \tag{2}$$

where

$$d0 = 35e^{-0.015R}\mathrm{km} \tag{3}$$

where $d0$ is the effective path length and r is called the distance factor. K and α are the regression coefficient for frequencies and polarization [4].

In Fig. 1, a comparative study of different model like ITU-R, Gracia, RAL and Brazil were shown. In this implementation it is observed that brazil model shows more attenuation as compared with the ITU-R model. This is because of the different geographical conditions as brazil model was based on different experimental studies conducted in brazil.

Table 1 Comparative analysis of literature review

References	Method/Instrument	Frequency (GHz.)	Site	Findings
[6]	Mathematical Model	10 GHz. to 100 GHz		A mathematical model was developed for the prediction of attenuation due to rain and results are compared with ITU-R model
[7]	Rain Measurements	21.8 GHz, 73.5 GHz	Malaysia	The measured results are compared with the ITU-R Model. The maximum measured rain attenuation is for 0.03% of time is 40.1 dB and 20 dB for 1.8 km and 0.3 km link
[8]	Rain Attenuation	Ka–Band	Kuala Lampur	Observation has been made that ITU-R model provides lower RMS value of about 14.37 with respect to rain rate
[9]	Rainfall intensity and attenuation due to rain experimental study	73.5 GHz	Malaysia	The measured value at this region matches with the ITI-R rain model. For rain rate of 108 mm/h attenuation observed was 40.1 dB
[10]	Modification of ITU-R model	26 GHz, 38 GHz, 25 GHz, 75 GHz	Malaysia, Japan, Korea	Modification of distance factor r present in ITU-R model are performed in this work and statically analysis is performed
[11]	Mathematical model was proposed	10 GHz to 100 GHz		A mathematical model was proposed for predicting of attenuation due to rain. Results are compared with ITU-R Model
[12]	Computational Intelligence model was introduced	10 GHz above		A modified model for the prediction of attenuation due to rain, which was based on ML techniques
[13]	Mathematical model for path reduction	26 GHz	Malaysia	A mathematical model was introduced the modification of path reduction factor for predicting attenuation due to rain
[14]	Empirical formulation measurements for Indian Meteorological Department for 2018	Ka Band, 20.2 GHz, 30.5 GHz	Tirupati, India	Measurements are taken from the IMD and are compared with the ITU-R models and different statically analyses are done based on different parameters

Table 1 (continued)

References	Method/Instrument	Frequency (GHz.)	Site	Findings
[15]	Measurements of rain rate by using mm wave links observations	Mm waves	Spain	Millimetre wave links of 71 to 76 GHz and 81 – 86 GHz are used for measurements of rain intensity. The measured results are compared with the actual results of rain gauge. Deviation of 0.8 to 0.9 in rain rate are observed from the data of mm wave and rain gauge
[16]	Nigerian communication satellite, NIGECOMSAT and Nigeria Meteorological centre (NIMET)	1 GHz to 100 GHz	Nigeria	The observed rain rate in August and September was 1.95 mm/h and 5.57 mm/h with attenuation of 11.01 dB and 19.67 dB
[17]	Different experimental campaign of Q – Band satellite	Q Band	Malaysia	New propagation experimentation was performed based on W-Band low Earth Orbit satellite communication
[18]	Empirical Model was Proposed	10 GHz to 100 GHz		An empirical model was proposed which was based on Rayleigh approximation. The results were compared with the ITU-R model
[19]	Experimentation was performed	Mm wave	Malaysia	Propose a new model for the prediction of rain attenuation for terrestrial links by using measured rain attenuation data
[20]	Mathematical model was compared	Mm wave		In order to predict attenuation due to rain three different fitting model was compared namely, polynomial, power and exponential. Results shows that polynomial model is good as compared to others
[21]	Experimental study	10 GHz above	Nigeria	Experiments are carried out in order to identify the effect of various environmental conditions in radio wave propagation. It was observed that rainfall rate and relative humidity are directly proportional degradation of signal quality

Table 1 (continued)

References	Method/Instrument	Frequency (GHz.)	Site	Findings
[22]	ML algorithm was used to predict attenuation due to rain. C band German weather service Deutscher radar	C- Band		Convolution Neural Network was used to predict the attenuation due to rain when data of rainfall rate and signal attenuation was observed by radar
[23]	MEASAT Ka band beacon	Ka Band	Malaysia	Different models like Folasade, Renuka and Xiang Yeo and ITU-R were used to predict rain attenuation. Data was collected from MEASET satellite and statistical analysis are done
[24]	Tropical rain measuring mission precipitation radar (TRMM-PR)	Mm wave	West Africa	Rain rate of 6 countries of west Africa was analyzed. Cumulative rain rate distribution was presented
[25]	Mathematical Model was proposed	20 GHz and 30 GHz	–	A model was proposed to predict the cross-polarization distribution at 20 GHz and 30 GHz from the rain attenuation
[26]	New Algorithm was proposed for the scaling of frequency		–	The accuracy of proposed model was about 2.5 dB for 95% confidence
[27]	Experimental study, Troposphere data acquisition networks (TRODAN)	26.5 GHz To 40 GHz	Sub-Sahara region	More attenuation was observed at equatorial region as compared to tropical zones
[28]	Survey Paper	THz Bands		Challenges face by THz communication links was discussed
[29]	Alphasat satellite measurements study	19.7 GHz to 39.4 GHz	Ljubljana, Slovenia	Statistical analyzed of 1 year data was performed

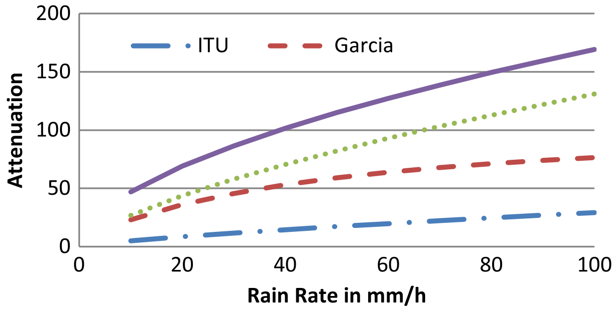

Fig. 1 Comparison of various rain models

The Figs. 2, 3, 4 and 5 shows the value of k and α over frequency in GHz for horizontal and vertical polarization described in ITU-R rain model [4]. From the following figures it is clearly observed that the values of k and α are very uneven for frequencies 1 to 10 GHz.

In order to predict the attenuations for particular frequencies the values of coefficients are identified with the help of these graphs. Due to the unevenness of the curves, researchers find it very difficult to identify the values. Some methodology is needed to be developed in order to find these values.

Different mathematical, empirical and experimental studies have been performed in last decade. It has been concluding from the studies that rain affects significantly the deterioration of radio signals. Due to the complex nature of rain more thorough study of attenuation due to rain is required. The work done till now is based on mathematical analyses. This paper discusses about the machine learning approach. Before implementation of Machine learning it is very important to understand about Machine Learning.

Machine learning is a tool that transforms data into knowledge. Data has exploded over the past 50 years. This large amount of data is useless without analyzing and finding hidden patterns. Machine learning techniques are used to automatically detect important basic

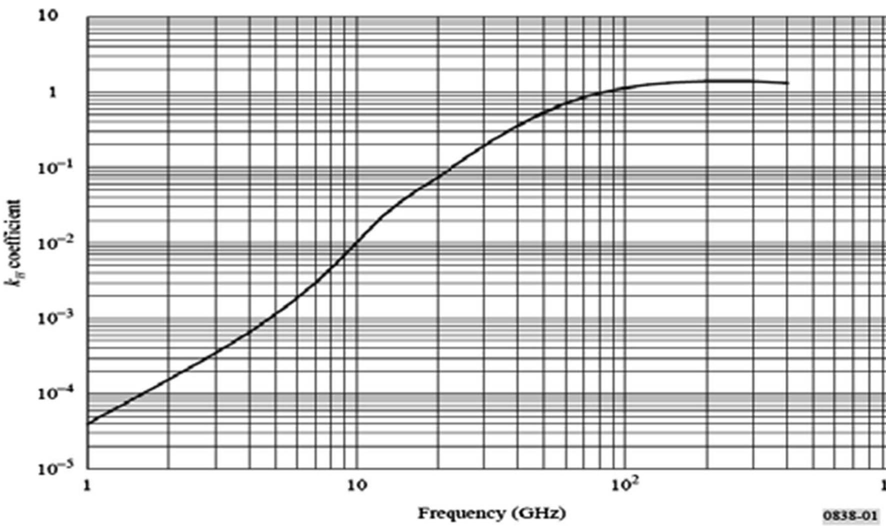

Fig. 2 Value of K coefficient for horizontal polarization

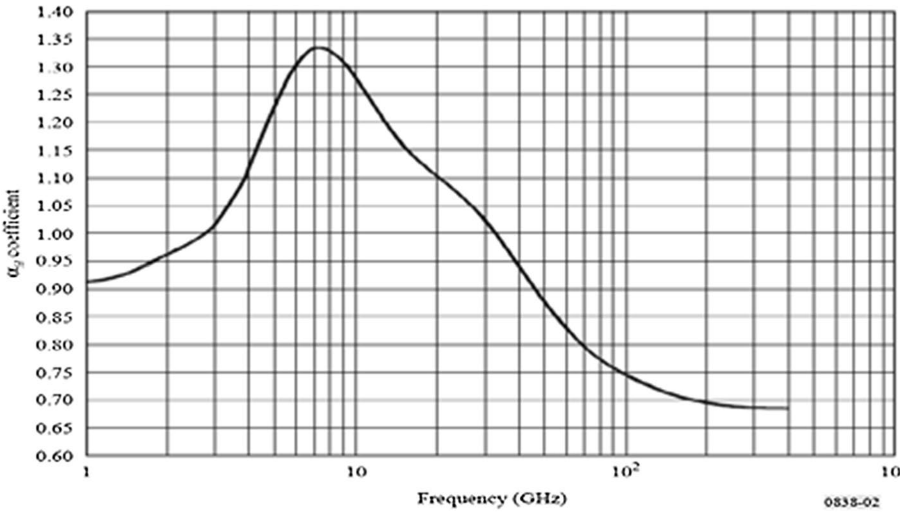

Fig. 3 Value of α coefficient for horizontal polarization

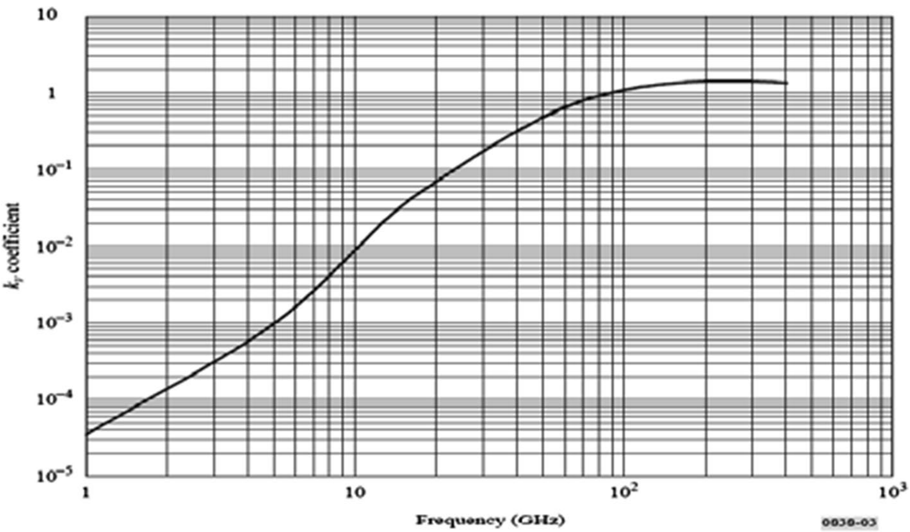

Fig. 4 Value of k coefficient for vertical polarization

patterns in complex data. Late patterns and problematic information can be used to predict future events and make all kinds of difficult decisions.

In supervised learning, the goal is to learn the mapping (rules) between input and output sets. For example, an entrance could be a weather forecast and a production could be a beach visitor. The purpose of supervised learning is to study a map that explains the relationship between temperature and number of beach visitors.

For example, in the course of training, the model behaves by identifying data about previous input and output pairs, and "supervise" learning accordingly. In the beach example,

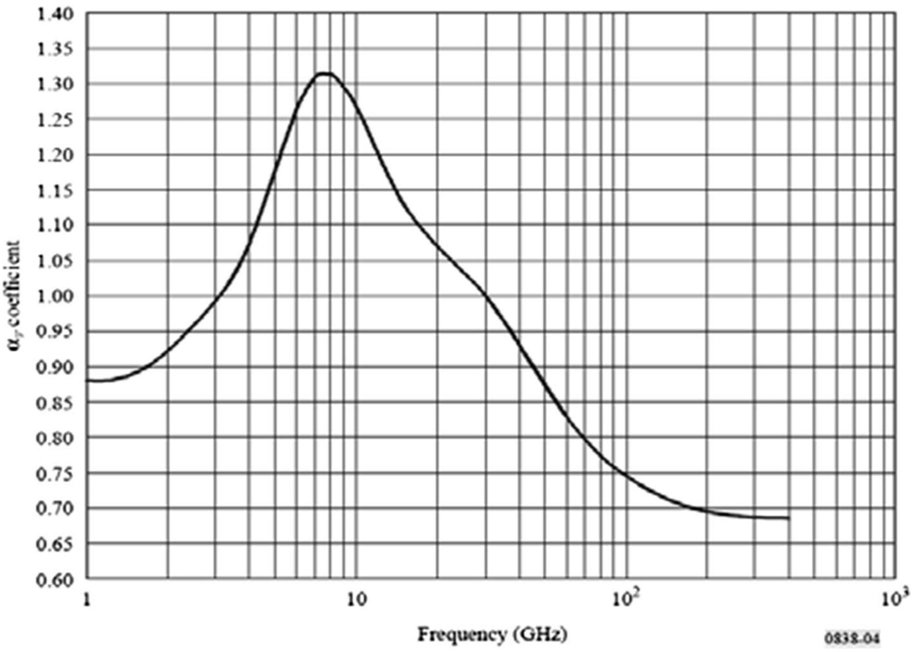

Fig. 5 Value of α coefficient for vertical polarization

new temperature calculation related data have been collected for long time and a machine learning algorithm used by collected data predicts temperature for future visitors.

Regression is another form of supervised learning. The difference between classification and regression is that regression outputs numbers rather than classes. Therefore, regression is useful for predicting numerical problems such as stock market prices, temperature on a specific date, or probability of events. For unsupervised learning, the examples provide input only. There are no obvious examples of results to find.

3 Proposed Model

The problem in ITU-R recommendations model is that availability of complex methodology for calculation of k and α coefficients. One of the solutions for this problem is finding out approximations. In order to get better results of approximation, machine learning algorithms come into play. When curve is drawn between the frequency and k-coefficient, it is not so smooth for getting approximation equation. One of the solutions of this problem is to break the curve into different parts and do approximation in order to get polynomial equations. The challenges are that to break down the curve in different sections. It is a very complicated task to make decision for finding the breaking point of the curve. In order to solve this problem, machine leaning algorithm have been incorporated for classification. Soft-Clustering algorithm is used to identify the breaking point. After classification different curves are drawn between K-coefficient versus frequency for each classification.

Table 2 Clusters of frequency range from 1 to 100 GHz

Cluster no	Frequency range
1	1 GHz–3.5 GHz
2	4 GHz–7 GHz
3	8 GHz–11 GHz
4	12 GHz–23 GHz
5	24 GHz–49 GHz
6	50 GHz–75 GHz
7	76 GHz–100 GHz

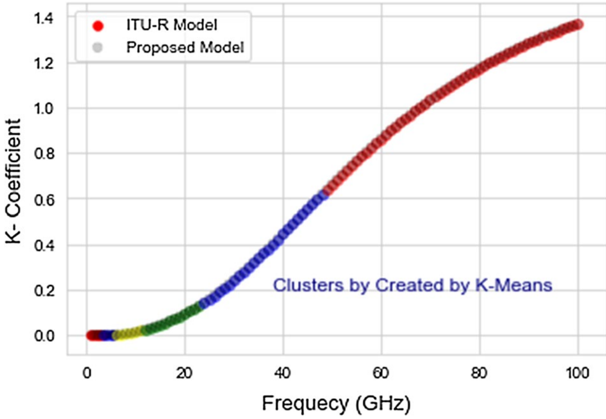

Fig. 6 Cluster of *K*—Coefficients versus frequency

Then in order to fit the curve, regression analysis techniques of machine learning have been incorporated in proposed model (Table 2).

The first task is to draw the curve between *K*-coefficient versus frequency (GHz) then in order to get the breaking point, classification algorithms of Soft-Clusteringis performed. Soft-Clustering techniques breaks the curves in different parts based on the chanaging properties of the curve. The implementation is shown in Fig. 6. In this graph, curves breaks into seven clusters. Then in order to get approximation curve, regression analysis of machine learning algorithm is used. In that algorithm, training values are *k*-coefficient and frequency in GHz. Regression algorithm is applied multiple number of times in order to get fitted curve with minimum errors. From fitted curve different equation are obtained for *K*-values at different frequency range from Eqs. (4)–(8). Detailed description of obtained expression are as follows:

From 1 to 100 GHz value of *k* for Vertical Polarization is given by:

$$K = ax^3 + bx^2 + cx + d \tag{4}$$

Values of coefficient *a*, *b*, *c* and *d* are taken from Table 3.

From 1 to 100 GHz value of α for Vertical Polarization is given by:

$$\alpha = ax^3 + bx^2 + cx + d \tag{5}$$

Values of coefficient *a*, *b*, *c* and *d* are taken from Table 4.

In the same way, model for horizontal polarization developed and related equations.

Table 3 Coefficient values for Eq. (4)

Frequency (GHz.)	*a*	*b*	*c*	*d*
76 to 100	8.155×10^{-7}	-3.406×10^{-4}	1.5148	−1.189
50 to 75	-6.11×10^{-7}	-4.236×10^{-5}	.0367*X*	−.7043
24 to 49	-8.089×10^{-6}	1.078×10^{-3}	-2.573×10^{-2}	.249
12 to 23	9.389×10^{-6}	-3.624×10^{-4}	1.322×10^{-2}	−.0984
8 to 11	1.05×10^{-5}	3.955×10^{-4}	-5.761×10^{-3}	.01855
4 to 7	7.182×10^{-5}	-9.509×10^{-4}	4.174×10^{-3}	−.005832
1 to 3.5	-9.259×10^{-6}	6.897×10^{-5}	-7.371×10^{-5}	.00004464

Table 4 Coefficient values for Eq. (5)

Frequency (GHz.)	*a*	*b*	*c*	*d*
49 to 100	-4.57×10^{-7}	1.359×10^{-4}	-1.46×10^{-2}	1.234
32 to 48	1.191×10^{-6}	5.934×10^{-4}	-7.385×10^{-3}	1.156
15 to 31	-2.888×10^{-5}	2.169×10^{-3}	-6.07×10^{-2}	1.562
10 to 14	-6.5×10^{-4}	2.807×10^{-3}	−.4281	3.339
5 to 9	1.353×10^{-2}	−.3024	2.129	−3.237
1 to 5	1.027×10^{-2}	5.377×10^{-2}	−.1859	.7122

Table 5 Coefficient values for Eq. (6) and (7)

Frequency (GHz.)	*a*	*b*	*c*	*d*	*e*
49 to 100	3.505×10^{-7}	-2.256×10^{-4}	4.185	0.9132	–
24 to 48	$= -6.858 \times 10^{-6}$	8.923×10^{-4}	1.682	.127	–
12 to 23	6.548×10^{-6}	6.722×10^{-6}	3.543	−.02894	–
6 to 11	-1.103×10^{-5}	3.714×10^{-4}	-4.052×10^{-3}	1.891×10^{-2}	−.03282
3.5 to 5	$= -2.953 \times 10^{-6}$	1.502×10^{-5}	-3.767×10^{-5}	2.745×10^{-4}	-1.832×10^{-4}
1 to 3	-2.167×10^{-5}	1.3117×10^{-4}	-2.506×10^{-4}	2.139×10^{-4}	-4.74×10^{-5}

are as follows.

From 1 to 11 GHz value of k for horizontal polarization is given by:

$$k = ax^4 + bx^3 + cx^2 + dx + e \tag{6}$$

From 12 to 100 GHz value of *k* for horizontal polarization is given by:

$$k = ax^3 + bx^2 + cx + d \tag{7}$$

Values of coefficient *a*, *b*, *c*, *d* and *e* are taken from Table 5.

From 1 to 100 GHz value of α for horizontal polarization is given by:

$$\alpha = ax^3 + bx^2 + cx + d \tag{8}$$

Values of coefficient *a*, *b*, *c* and *d* are taken from Table 6.

4 Algorithm for Proposed Model for Calculating specific attenuation due to rain in dB/km

In order to calculate following steps are need to be performed.

STEP 1: Identify the rain rate R in mm/h.
STEP 2: For vertical polarization follow step 3 and step 4.
STEP 3: Calculate values of k from equation 4.
STEP 4: Calculate value of α from equation 5.
STEP 5: For Horizontal polarization follow step 6 to step 7.
STEP 6: Calculate value of k from 1 GHz to 11 GHz from equation 6 and from 12 GHz to 100 GHz from equation 7.
STEP 7: Calculate value of α from equation 8.
STEP 8: Substitute the values of k, α, and R in expression kR^{α} to calculate specific attenuation in dB/km.

5 Results and Discussions

The values of *K*-Coefficients and *α*-Coefficients for both horizontal and vertical polarization are described from Eqs. (4)–(8). Implementation of this model and comparative studies are described in Figs. 7 and 8 for both vertical and horizontal polarization. The implementation described the graph between frequencies in GHz and specific attenuation in dB/km. Different parameters used in the model are frequencies from 1 to 100 GHz, *K* and *α* Coefficients for both vertical and horizontal polarization calculated from Eqs. (4)–(8), rain rate in mm/h (Tables 7, 8, 9 and 10).

For frequency of 60 GHz, the error observed was 0.0595 which one is very low. For rain rate of 50 mm/h, error became 0.5131. Details are shown in Table 11. From Table 11, it has been observed that proposed model performs better then ITU-R model

Table 6 Coefficient values for Eq. (8)

Frequency (GHz.)	*a*	*b*	*c*	*D*
49 to 100	$= -4.1 \times 10^{-7}$	1.286×10^{-4}	0.01465	−1.27
31 to 48	$= -5.75 \times 10^{-7}$	1653×10^{-4}	0.0173	−1.332
16 to 30	-1.175×10^{-6}	2.265	0.01992	−.374
8 to 15	-5.225×10^{-5}	02292	−.3516	−3.004
5 to 7	.001	1.65×10^{-2}	−.2981	1.67
1 to 4	-1.987×10^{-2}	.2132	.7368	1.106

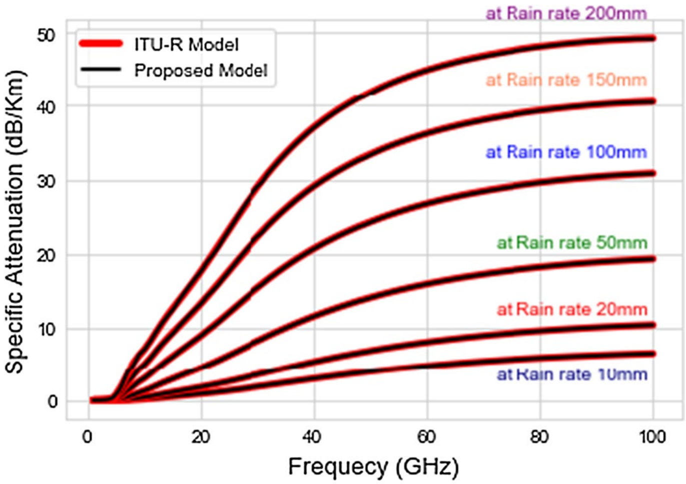

Fig. 7 Comparative results of ITU-R and Proposed model for vertical polarization

Table 7 Statistical analysis by rain rate for vertical polarization of proposed model

Rain Rate(mm)	MAPE	MAD	MSE	RMSE
10	0.0347653	0.002239	7E-06	0.002645
20	0.0472638	0.004878	3.56E-05	0.005967
30	0.0545734	0.007418	8.55E-05	0.009244
50	0.0637808	0.012264	0.000243	0.015583
100	0.0766477	0.023587	0.000927	0.030448
150	0.0847631	0.034341	0.001967	0.044355
200	0.0905204	0.044574	0.003318	0.057601

Table 8 Statistical analysis by frequency for vertical polarization of proposed model

Frequency (GHz)	MAPE	MAD	MSE	RMSE
10	0.235637	0.007341	0.000116	0.010768
20	0.206861	0.01559	0.000427	0.020668
30	0.084417	0.01432	0.000424	0.020587
40	0.202419	0.035548	0.002086	0.04567
50	0.246357	0.053304	0.004755	0.068958
60	0.059585	0.013556	0.000288	0.01697
70	0.148185	0.0381	0.002383	0.048818
80	0.101982	0.028545	0.001387	0.037238
90	0.101982	0.028545	0.001387	0.037238
100	0.159928	0.046368	0.003594	0.059952

Table 9 Statistical analysis by rain rate for horizontal polarization of proposed model

Rain rate	*MAPE*	*MAD*	*MSE*	*RMSE*
10	0.205156	0.0028881	1.91616E-05	0.004377
20	0.25049	0.006004473	8.22352E-05	0.009068
30	0.277764	0.009157345	0.000189759	0.013775
50	0.312493	0.015459727	0.000536958	0.023172
100	0.370386	0.031301791	0.002167443	0.046556
150	0.388728	0.047340782	0.004883605	0.069883
200	0.409145	0.063531722	0.008694314	0.093243

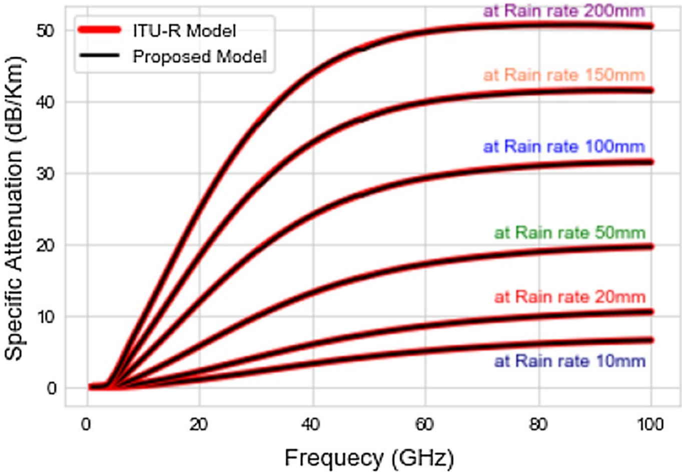

Fig. 8 Comparative results of ITU-R and Proposed model for Horizontal polarization

Table 10 Error analysis for vertical polarization

Rain Rate	Average % Error	Frequency	Average % Error
10	0.347493	10	0.235637
20	0.41843	20	0.206861
30	0.460002	30	0.084417
50	0.513103	40	0.202419
100	0.587101	50	0.246357
100	0.587101	50	0.246357
150	0.63046	60	0.059585
200	0.661234	70	0.148185
	80	0.101982	
	90	0.041088	
	100	0.159928	
	80	0.101982	

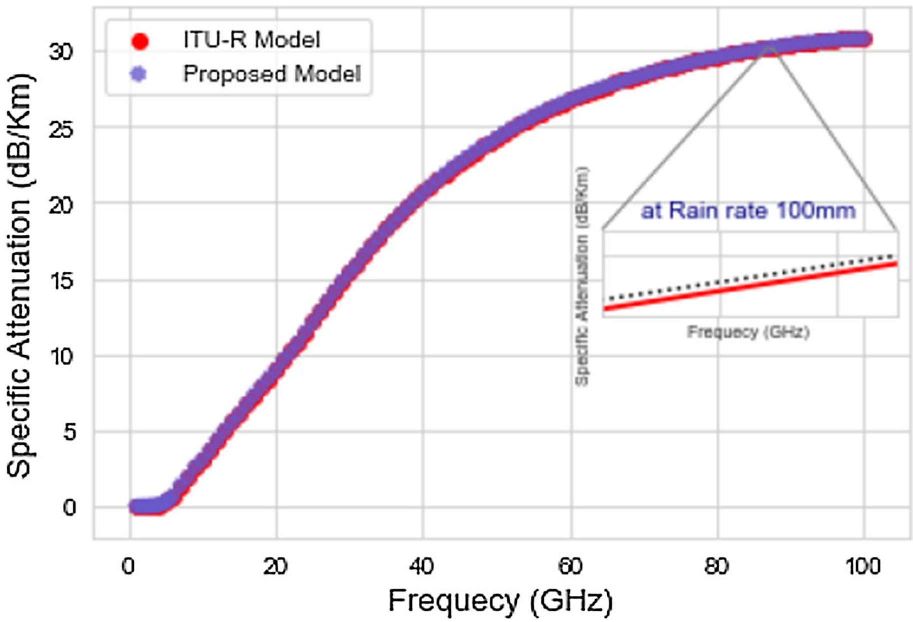

Fig. 9 Comparative result of ITU-R and Proposed model at 100 mm

Table 11 Error analysis of horizontal polarization

Rain rate	Average % error	Frequency	Average % error
10	0.205156	10	0.23972
20	0.250902	20	0.027062
30	0.277764	30	0.011496
50	0.312493	40	0.11971
100	0.370386	50	0.389374
150	0.388728	60	0.018992
200	0.409145	70	0.232976
	80	0.147941	
	90	0.012691	
	100	0.411524	

and are simpler to use and less complex in nature. It has also been observed that with the rise in frequency the attenuation is also increased for above 10 GHz frequency ranges.

The highly accurate approximation model was obtained due to the use of machine learning techniques. Two machine learning algorithms was used, one is Soft-Clustering algorithm and another is regression analysis. The clustering algorithm helps to classify the curves where exactly they change their property. In this case property was the change of flow of curves that is increase or decrease of curves. Once the continuous flow was identified then it will be easy to implement regression analysis in order to obtain polynomial equations (Fig. 9).

Statically analysis of obtained model was performed and results are shown in Tables 7, 8, 9 and 10. The parameters used in order to analyses performance of proposed model are MAPE, MAD, MSE, and RMSE for rain rate of 10 mm/h, 20 mm/h, 30 mm/h, 50 mm/h, 100 mm/h, 150 mm/h and 200 mm/h. Same are done with frequency ranges from 10 to 100 GHz (Table 11).

The values of K-Coefficients and α-Coefficients for both horizontal and vertical polarization are described from Eq. (4)–(28). Implementation of this model and comparative studies are described in Figs. 7 and 8 for both vertical and horizontal polarization. The implementation descried the graph between frequencies in GHz and specific attenuation in dB/Km. Different parameters used in the model are frequencies from 1 to 100 GHz, K and α Coefficients for both vertical and horizontal polarization calculated from Eq. (4)–(8), rain rate in mm/h. average % error has been calculated for the implementation results obtained for proposed model and ITU-R model.

In case of higher frequencies from 80 to 100 GHz. at rain rate of 10 mm/h, 50 mm/h, 100 mm/h and 150 mm/h, proposed results are comparable with ITU-R model shown in Fig. 10.

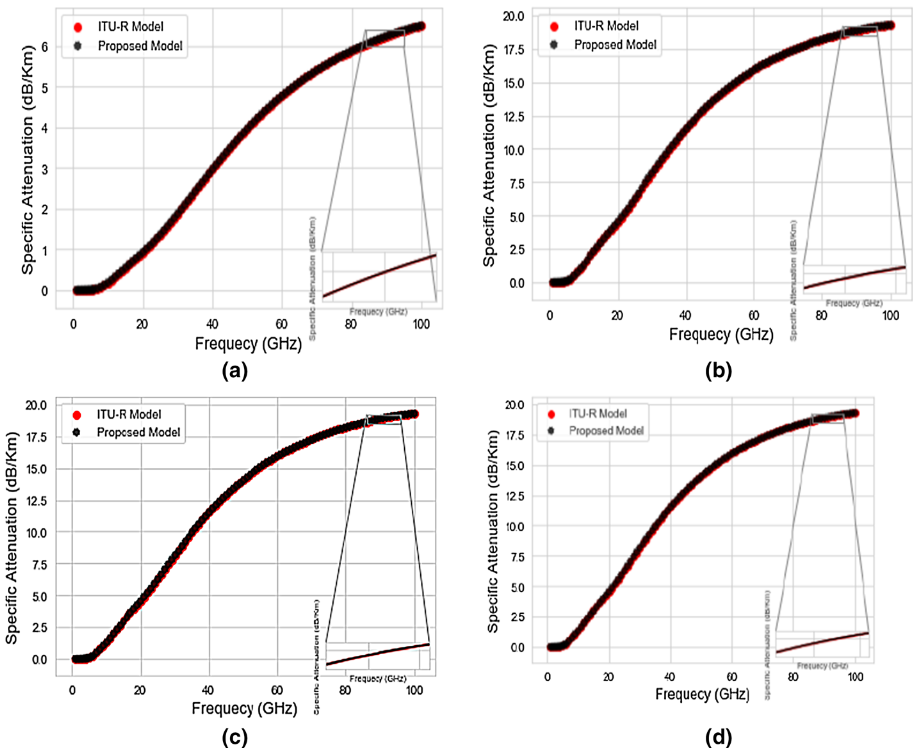

Fig. 10 Comparative result of ITU-R and proposed model (rain rate at **a** 10 mm/h, **b** 50 mm/h, **c** 100 mm/h and **d** 150 mm/h)

6 Conclusions

Various researchers have proposed different models for rain attenuations but ITU-Rain model is widely acceptable model. In the ITU model different values of regression coefficients k and α are given for different frequencies. In this work approximations are calculated for those values in the form of approximation curves. From the simulation work it has been observed that approximation model closely matches with the original ITU-Rain model. Different equations are provided for different values. It helps researchers and engineers to identify coefficients for a given frequencies.

Author contributions A simpler and improved model is developed in order to calculate values of K and α coefficients in order to calculate specific attenuation. An algorithm is developed in order to calculate specific attenuation in dB/km caused due to rain. A statistical analysis has been done in order to measure the performance of proposed model.

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Data Availability All data used in this research are available. We can provide whenever ask to do so.

Code availability all codes used in this research are available. We can provide whenever ask to do so.

Compliance with Ethical Standards

Conflicts of interest There is no any conflicts of interest.

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