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Performance Analysis of a Rain Fading Predicted Model in Tropical Areas for 5G Communication

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Abstract—The basic climatic characteristic of the tropical areas is abundant precipitation throughout the year. For such precipitation the radio signal (RF) power of these areas gets diminished in communicating any signaling information from a sender to a receiver i.e., rain fading occurs in these areas. Rain fading is one of the major causes which decline the characteristics of radio system in tropical areas. To reduce excessive rain fading various fade reduction techniques such as diversification techniques, adaptive power control technique, and adaptive waveform technique have been used. Frequency diversification technique is an effective technique for diminishing rain fading. In this work in order to diminish rain fading, a suggested model has been implemented. Frequency diversification improvement factor is accepted to heighten the performance of this suggested model. Besides, by adopting an experimental data sheet, a comparison of this suggested model with a number of various existing rain attenuation predicted models has been depicted for validation of the suggested model. The experiment was performed by accepting two mm-Wave connectors acting on two frequencies of 26 GHz and 38 GHz, respectively, for observing which model renders better result in the tropical region with respect of various distances, frequencies, and elevation angles.

1. INTRODUCTION

There is no denying the fact that in recent years the need for a remarkable development of bandwidth by telecom developers has been felt inevitable for a shift to greater bands of frequency suitable for the application of the Fifth Generation (5G) technology [1]. In tropical areas, prevalence of raindrops is a very common feature. Besides, the impact of radio link gets elevated at frequencies beyond 7 GHz on account of excessive rainfall [2, 3] in tropical areas. Therefore, it is significant to foretell accurately the reduction of radio signal brought about by rainfall for the device of 5G wireless system of high efficiency [4]. The rainfall statistics of 1-minute and rainfall beyond the limit by a certain percent in the middle of a year are the most commonly used parameters to decide rainfall reduction [5, 6]. Various models have been constructed by applying the aforesaid parameters to anticipate the diminishment of rainfall. Yet, most of these designs have been directed and focalized on areas with moderate rainfall [7]. This phenomenon causes problems when these designs are used in tropical countries on account of heavy rainfall. Therefore, a drive to estimate rainfall data was conducted at Universiti Teknologi Malaysia (UTM) [8]. A number of extensively applied speculative models are historically based, using traditional data of a given area [9], while others are corporeally based, devised to restore the corporeally based reduction technique which consecutively needs additional variables and extensive duration to be considered [10]. Numerous studies have examined significant rainfall reduction and various problem-solving models to reduce the problems [9–12]. Earth orbit transmission link is a system that combines a sub-channel with a space unit. Modern technology requires a very sophisticated technology that requires a lot of frequency bands. The world is facing a shortage of frequency spectrum that requires

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high waves. In the case of Satellite transmission, the erection of a spot connection is not so comfortable particularly at the time of working accompanying the highest quality waves including rainfall reduction being notably affected by high waves. That kind of phenomenon brings about signal fading that influences the space station communication. For an estimate of accurate space station communication, variables required deserve an analysis for developing designs which assist the detection of the probable reduction. To quantify the decrease in signal power on account of rainfall, different designs have been improved with various variables including environmental situations, arrangement setting, as well as the unreliability of spatial potency by the developers. Hence, no complete forecast about extinction in earth orbit transmission link is available. To access the entire communication estimate, a reduction design seems inevitable for the climatic response which affects transmission with respect to wireless message at channel level. The use with respect to rainfall scale is in the design of an accurate satellite link budget. Radio distribution atmospheric signal includes the effects of gases involving wind as well as hygrometer like rainfall, mist, etc. Wireless messages meet signal natures like consumption and dispersion. Hence, excessive decrease is noteworthy in signal power when rainfall is above a certain margin for the line-of-sight links [13]. In extremely high frequencies, wireless signals (electromagnetic waves) get easily affected by atmospheric fading, and rainfall possesses a major outcome of signals [14]. This phenomenon reduces power of signal, disrupts atomization, and raises thermal process. The reduction of signal power bears more importance for Ku-band, i.e., over 12 GHz. Decrease in signal power because of snow fall is exceedingly low when being less than 60 GHz, and therefore, it is ignored [15]. Conception about rainfall reduction obeys a relation of rate of occurrence and length of wave. In other words, the rate of occurrence and length of wave bear a mutual relation. Now, a reduction grows as the length comes closer to the size of a normal raindrop of 1.5 millimeters, and a slight reduction occurs in S band and C band. Because of increase in frequency, the length of wave comes close to the dimensions of raindrops and enhances attenuation. Fading appears greater on the Ku band, and it also deserves importance with respect to K band. The rainfall design includes specific deficiencies explained by ITU Radiocommunication Sector [16] on the basis of rate of repetition and atomization applied to designs that the developers have suggested. Paying attention to the leading parameters in computing decrease in space station transmission should be emphasized. Measurements using selected models are performed in major cities of India.

A number of previous research works have been studied for ascertainment of the application of rain attenuation predicted model for 5G technology in the tropical zones. However, it is revealed that no such type of work executed in this paper is available at any previous research work.

The introduction part of this paper is illustrated in Section 1. Different existing predicted models are described in Section 2. Section 3 narrates the proposed model. Section 4 depicts experimental arrangement. Section 5 illustrates result analysis. Section 6 provides conclusion. References have been included after the completion of all sections.

2. DIFFERENT EXISTING PREDICTED MODELS

Various methods as well as programs to reduce weight loss, particularly for the top waves have been improved by developers. A number of designs to mitigate rainfall have been expanded by many researchers and ITU Radiocommunication Sector design [17] for rainwater harvesting which has been extensively adopted. Various emerging models are compared to ITU-R design to be reliable especially wherein the measured details of information are not accessible [18]. Different designs are available to predict measurement of precipitation. The models are selected on the basis of their reliability, accuracy, and comprehensive testing previously performed.

2.1. ITU Radiocommunication Sector Design

ITU Radiocommunication Sector rainfall reduction design [17] appears as an extensively adopted design for measuring rainfall reduction in a space station transmission arrangement. Next, this process renders a measurement for extended data of rainfall reduction in a slanted area where frequencies range till 55 GHz. The required variables are: $R_{0.01}$: rate of rainfall in the area of 0.01% of a moderate duration of one year (mm/h), h_{se}: height over sea level (km), h_{re}: rain height, L_{SF}: sloping route range, α:

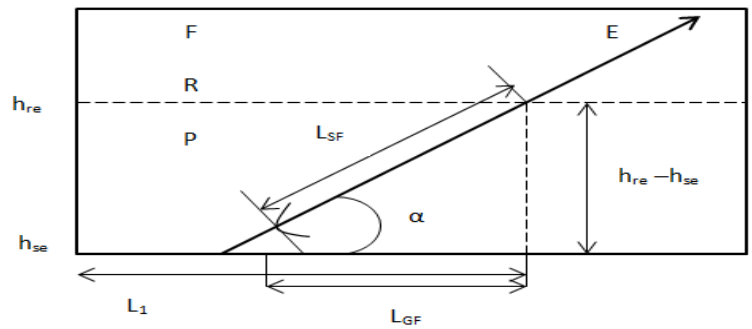

Figure 1. Simplified diagram of an Earth-Space Link.

elevating angle in degrees, Φ: angular distance with respect to a land location on its meridian north or south of the equator, f: frequentness in GHz, R_a: active earth diameter (8500 km). Figure 1 [17] displays the Earth zone system which provides the variables to be included in the process of predicting a reduction when F shows snowfall; R shows altitude of rain; P shows liquid form of rainfall; and E defines the Earth-spot length. Specified rain diminishment (dB/km) of 0.01% is shown below in Equation (1)

$$\gamma_{SR} = k(R_{0.01})^{\alpha} \text{ dB/km} \tag{1}$$

Variables k as well as α is available at ITU-R P.838-3 [17]. The decrease of an anticipated inclination method which has exceeded 0.01% of the annual estimate is available as per equation stated below in Eq. (2)

$$A_{0.01} = \gamma_{SR} L_{EF} \text{ dB} \tag{2}$$

where L_{EF} denotes the extent of the effective route. L_{EF} can be computed and is expressed in terms of Equation (3) quoted below

$$L_{EF} = \frac{1}{L_1 + L_{SF}\cos\alpha} \int_{-L_1}^{L_{SF}\cos\alpha} L_{SF}(x)\, dx = \frac{1}{1 + \frac{L_{SF\cos\alpha}}{L_1}} \cdot L_{SF} \tag{3}$$

Limit reductions exceeded by other mid-year percentage (P) points, in range 0.001% to 5%, determined from a reduction to exceed 0.01% on average year are as follows

$$\begin{aligned}
&\text{If } P \geq 1\% \text{ or } |\Phi| \geq 36^\circ: \quad y = 0, \quad y \text{ signifies a parameter relying on link characteristics}\\
&\text{If } P < 1\% \text{ or } |\Phi| < 36^\circ, \quad \alpha \geq 25^\circ: \quad y = -0.005(|\Phi| - 36)\\
&\text{else } y = -0.005(|\Phi| - 36) + 1.8 - 4.25\sin\alpha\\
&A_P = A_{0.01}\left(\frac{P}{0.01}\right)^{-(0.655+0.033\ln(P)-0.045\ln(A_{0.01})-y(1-P)\sin\alpha)}
\end{aligned} \tag{4}$$

This process renders a measure of long-term enumeration of fading due to rainfall. When this process is compared to the estimated figures and forecasts, an acceptable approval should be given annual fluctuations in rainfall statistics. The ITU Radiocommunication Sector design is not suitable for raindrops features. ITU Radiocommunication Sector design only anticipates signal diminishment caused by rainfall. It is reported that the ITU-R measurement design requires better rainfall information rate exceeding 0.01% duration and therefore, that component produces the outcome like an overdose of ITU Radiocommunication Sector rainfall reduction model. ITU Radiocommunication Sector model has laid down a number of guidelines and statistics for mitigating rainfall with hydrometer accompanied by earth-zone wireless connections. Variables such as slope extent and rainfall extremity suggested by ITU-R are also internationally recognized as a reference to improve hydrometeor-based mitigation development design. Nevertheless, the execution of the ITU Radiocommunication Sector design is acceptable, but superior to the simple attenuation model [19].

2.2. Simple Attenuation Model (SAM)

The design improved by Stutzman and Yon [19] was named as SAM design to reduce rainfall measurement performance on earth-zone link networks acting upon 10–35 GHz frequency band. It is a much skewed model which is widely accepted. It includes individual features of combining form and convective types of rain. In variable rainfall (at $R > 10\,\text{mm/h}$), the inclined path is determined in the following form in Equation (5)

$$A_S = \gamma_{SR} \frac{1 - \exp\left[-\gamma_{SR} a \ln\left(\frac{R_{\%P}}{10}\right)\right] L_{SF} \cos\alpha}{\gamma_{SR} a \ln\left(\frac{R_{\%P}}{10}\right) \cos\alpha} \tag{5}$$

where L_{SF} (km) is the inclined path of rainfall; α (degree) is the angle of elevation between horizontal and skewed approaches; Specific attenuation $\gamma_{SR} = k(R_{0.01})^{\alpha}$ dB/km. Actual invariable $a = 1/22$. On the basis of estimated information, the mathematical expression of active rainfall is illustrated below

$$\begin{aligned} H_{ER} = H_1; &\quad R \leq 10 \text{ millimeter/hour} \\ H_1 + \text{Log}\left(\frac{R}{10}\right); &\quad R > 10 \text{ millimeter/hour} \end{aligned} \tag{6}$$

Plain computation of rainfall provides a decrease as an operation in respect of moderate rainfall. This rainfall data is applied to measure annual rainfall data. The developers of this design applied fundamental variables like a certain reduction in the angle of inclination with raindrops of less than 10 millimeters/hour. For a rainfall level of more than 10 millimeters/hour, the developers made a particular expression regarded as the experimental invariable. The SAM model does not work well in comparison with other models increasingly accurate. But since it needs only a little statistical information of rainfall forecast, computation is easily performed. The ITU-R design is accomplished successfully in poor latency while the performance of SAM models satisfies up to 30 mm/h of rainfall.

2.3. García-López's Design

García-López et al. [20] have established a plain technique of predicting precipitation that is considered as an acceptable characteristic and provides sufficient results. In the tropics, the assessments of the constants accepted as the overtime computation of reduction are given individually. The proposed rainwater harvesting method of García-López et al. can be found as,

$$A_S = kR^{\alpha} L_{SF} / \left[m + \left\{\frac{L_{SF}(nR + pL_{SF} + q}{r}\right\}\right] \tag{7}$$

wherein R implies the rainfall point (millimeter/hour); k and α indicate the variables relying upon frequentness, atomization, and inclination of altitude (provided by ITU-R [17]); m, n, p, q, r constants are provided by García-López et al. An inclined route reaches the altitude of rain. In Equation (7) $m = 0.7$, $n = 18.35$, $p = -16.51$, and $q = 500$ (based on location). In hot weather, $m = 0.72$, $n = 7.6$, $p = -4.75$,, and $q = 2408$. 'r' is a scaling factor and chosen as 10^4. According to García-López et al., the altitude of rain is given by,

$$\begin{aligned} H_{RE} = 4; &\quad 0 < |\varphi| < 36^\circ \\ 4 - 0.075(|\varphi| - 36^\circ); &\quad |\varphi| \geq 36^\circ \end{aligned} \tag{8}$$

where $|\varphi|$ signifies angular distance with respect to land location on its meridian north or south of the equator. Correctness with respect to Garcia's system for reducing rainfall is more perfect than rainfall reduction designs such as ITU Radiocommunication Sector as well as SAM. In accordance with Bhattacharya et al. [21], García-López method provides a sufficient measure of rainfall reduction in the northern region of India. Garcia et al. have developed the correctness of the suggested design, and its constants can be simply changed in any area if rainfall reduction data and simultaneous rainfall data are obtained.

2.4. Moupfouma Design

In accordance with Moupfouma [22], the global microwave communication gets displayed for real extent of the transmission path "L_A" corresponding to the space between the two lower channels. Determining the equal length of the "L_q" distribution method, correction item "τ" that makes a rain uniform in the whole distribution method should be defined as,

$$L_q(R_{0.01}, L_A) = L_A \exp\left(\frac{-R_{0.01}}{1 + \xi\left(L_A\right) R_{0.01}}\right)$$

where $\xi(L_A) = -100$ for any $L_A \leq 7\,\text{km}$ and $\xi(L_A) = [\frac{44.2}{L_A}]^{0.78}$ on account of $L_A \leq 7\,\text{km}$.

Hence, an interpretation with respect to rainfall reduction has been changed to

$$A_{0.01} = k(R_{0.01})^{\alpha} \cdot L_q(R_{0.01}, L_A) \tag{9}$$

where $R_{0.01}$ and $A_{0.01}$ denote rate of rainfall and attenuation of path at 0.01% of time. The ultimate important disadvantage of this design is that it overrates the decline of the calculated method, particularly at high rainfall levels.

2.5. Da Silva Mello Design

The extrapolation process described by Da Silva Mello et al. [23] and accepted by dint of recent ITU-R [24] transpires a large limit of the forecast method. This is because a similar decrease in rainfall would be anticipated for a pair of areas including various raindrops patterns only with the same merits of $A_{0.01}$. In order to rectify this incorrectness, this process of thorough raindrops dispersal was established being a part of the forecast rain fading accumulating dispensation (CD), which provides Equation (10) below

$$A_{S\%P} = \gamma_{SR\%P} d_{ef} = k(R_{ef}\left(R_{\%P}, D\right))^{\alpha} \frac{D}{1 + \dfrac{D}{D_0(R_{\%P})}} \tag{10}$$

wherein R_{ef} is the active rainfall value, the operation with respect to D as well as $R_{\%P}$. The interpretation of R_{ef} as well as variable D_0 is provided in terms of Equations (11) and (12)

$$R_{ef} = 1.763 R_{\%P}^{0.753+0.197/D} \tag{11}$$

$$\text{and } D_0 = 119 R_{\%P}^{-0.244} \tag{12}$$

D is the real route extent, and D_0 is the component of rainfall.

The statistical constants reflected in Eq. (11) as well as Eq. (12) are detected through arbitrary retrogression, applying data obtained from ITU Radio Communication Sector data processing storage. It is observed that the law of force applied to D_0 in Equation (12) renders satisfactory outcomes compared to exponent rule applied to the recent ITU-R design.

2.6. Crane Global Attenuation Design

The Crane Global Attenuation design was devised to be used on Earth. This model relies completely on geographical observance of rainfall and vertical variations in climatic thermal reading [25, 26]. Rainfall reflects uneven horizontally, and a numerical design for contributing a measure in respect of impact of uniformity upon a scale about degradation arises needfully [25, 27]. Crane executed the design with slight presentation in respect of route side view with descriptive operations. Sufficient outcomes of design ranged between 0 km and 22.5 km. While this range was divided into two portions. The 1st portion ranged between 0 and $\delta(R)$ km, and the 2nd portion ranged between $\delta(R)$ km and 22.5 km when two exponent operations were used [25, 27]. An example of reduced rainfall provided by Crane, 1996 is expressed in Equations (13) and (14) below:

$$A_H\left(R, D\right) = \gamma_{SR}\left(R\right)\left(\frac{e^{m\delta(R)} - 1}{m} + \frac{e^{nD} - e^{m\delta(R)}}{n} e^{\alpha P}\right) \quad \delta\left(R\right) < R < 22.5 \tag{13}$$

$$A_H\left(R, D\right) = \gamma_{SR}\left(R\right)\left(\frac{e^{m\delta(R)} - 1}{m}\right) \quad 0 < D < \delta\left(R\right) \tag{14}$$

wherein $A_H(R, D)$ signifies the horizontal attenuation of path. R denotes the rain rate in mm/hr. $\gamma_{SR}(R)$ indicates the specific rain fading.

Resting constants reflect real coefficients for piece-wise exponent design:

$$P = 0.83 - 0.17\ln(R), \quad b = 0.026 - 0.03\ln(R),$$
$$\delta(R) = 3.8 - 0.6\ln(R), \quad v = P/\delta(R) + b, \quad m = \alpha v, \quad n = \alpha b.$$

3. PROPOSED MODEL

According to [28], a rain attenuation predicted model has been developed for the tropical regions for 5G communication. The model proposed in this work is effective in reducing rainfall, high frequency and high blurring limits. It is also suitable for all natural conditions and areas with high rainfall. At high rainfall the potential for active gamma distribution [29] can be expressed by a decrease of 0.01% as follows

$$\Gamma(10^{-4}) = \int_0^{\infty} g^{10^{-4}-1} e^{-s} dg, \quad 10^{-4} > 0 \tag{15}$$

where $\Gamma(10^{-4})$ is the gamma function, and g is a function.

The gamma distribution is used to represent high rainfall levels because the percentage of rainfall is usually from 2% to 10%. The proposed model is designed for a frequency range of 3.6 to 71 GHz. The fade margins have been chosen from 12 dB to 16 dB to increase the reliability of the communication link. This model also provides better result than that of ITU-R model in respect of development factor of diversification [28]. Reliability of the proposed communication link model is also supported for the frequency range 5–40 GHz [30] and 50–90 GHz [31]. The proposed model is expressed by the equation in the following manner [28]

$$I = a\exp(bf_d) \tag{16}$$

where 'I' implies the development factor of diversification. 'a' and 'b' indicate coefficients in respect of signal dispersion. 'a' and 'b' depend on fade margins. 'f_d' denotes the divergence of frequency. The values of coefficients 'a' and 'b' rely on the fade margin shown in Table 1 below.

Table 1. Constant values for predicted model.

Fade limit (decibel/Kilometer)	Constant a	Constant b
12	1.456	−0.006848
13	2.106	−0.01438
14	3.258	−0.02782
15	4.376	−0.0349
16	6.899	−0.05235

Again, development component of diversification I can be expressed in the following manner

$$I = \frac{p_{01}}{p_{02}} = \frac{1}{1+y^2}\left(1 + \frac{100y^2}{p_{01}}\right) \approx 1 + \frac{100y^2}{p_{01}} \tag{17}$$

where p_{01} and p_{02} signify the consecutive percent of only one location and variation period, and y^2 is a parameter relying on the link features. Considering $100y^2 = V$, Equation (17) again can be expressed in the form of Equation (18) noted below

$$I = 1 + V/p_{01} \tag{18}$$

If $V = a$, from Equations (16) and (18) an equation is derived which is displayed in Equation (19) quoted below

$$\begin{aligned} 1 + a/p_{01} &= a\exp(bf_d) \\ \text{Or, } a/p_{01} &= a\exp(bf_d) - 1 \\ \text{Or, } 1/p_{01} &= a\exp(bf_d) - 1/a \end{aligned} \tag{19}$$

So the predicted sloping route attenuation and sloping route range of the model predicted in this paper are depicted below

$$\text{Slopingroute attenuation } A_s = \gamma_{SR}[a\exp(bf_d) - 1/a]L_{EF}\,\text{dB} \tag{20}$$

where γ_{SR} denotes the specified rain attenuation (dB/km), and L_{EF} signifies the extent of the effective route.

$$\text{Sloping route range } L_{SF} = h_{re} - h_{se}/\sin\alpha \tag{21}$$

4. EXPERIMENTAL ARRANGEMENT

Taking two mm-Wave connectors an experiment was conducted acting on two frequencies of 26 GHz and 38 GHz respectively at UTM Johor campus [5]. Placing the connectors in the middle portion of micro-wave laboratory roof, the experiment was tested. Besides, a transmitter-receiver was placed at a long-distance communication tower between two 301 meter aerials. Both aerials were enveloped in a radar dome to protect the effect on wet aerials. The output level of automatic gain controller (AGC) for radio frequency (RF) unit was associated with a PC utilizing a procurement process of information. In order to capture data the data logging is regulated by software which has been developed applying C language. Thereafter, the sample gap was put for one second. Then the information was entered to a data bank and was stocked in it. Data was collected for 24 months, and a satisfactory 99.95% data acquisition was obtained. The rain vessel gage of a cap width of 0.2 millimeter was placed on an identical ceiling. Rain gage added timestamp because of every cap for a 0.1 second fixed determination. The same way to calculate the average rainfall of 60-seconds [32] was utilized for carrying information during amalgamation period of 60 seconds. On account of 0.01% of span 60-seconds rainfall was visible with 116 millimeters/hour in measuring areas. The experimental setup is displayed in Figure 2 below.

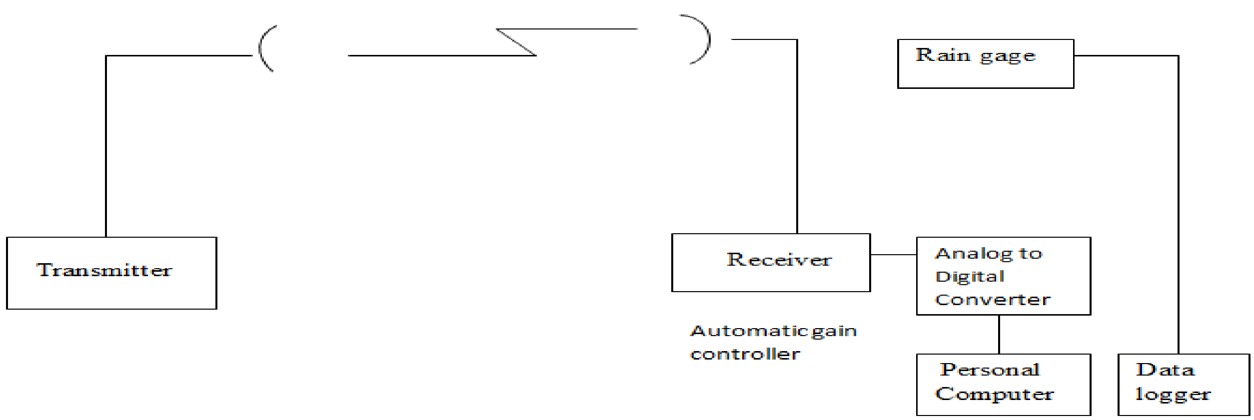

Figure 2. Experimental set up for data collection of rainfall.

5. RESULT ANALYSIS

It is displayed from Figures 3, 4, 5, 6, 7, and 8 below that the model suggested in this paper reflects better result than that rendered by the other existing models. From the experimental data 26 GHz and 38 GHz frequencies have been adopted to ascertain the result in respect of this suggested design. As any distance may be considered to verify outcome in regard to this suggested model, 1.5 km and 2 km path lengths have been chosen here. For these distances the desired outcomes have also been achieved, and it is displayed in Figures 5 and 6 below. The elevating angles of the proposed model have been considered 30° and 45° respectively and compared with various existing predicted rain attenuation models for the said angles to observe performance of the model suggested in this work.

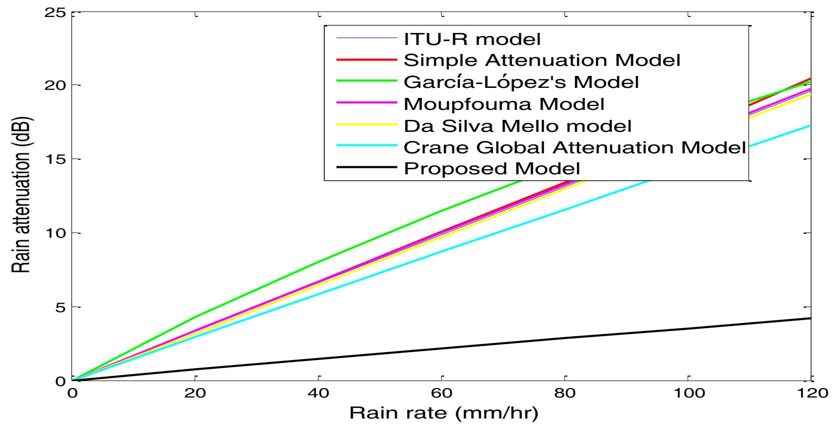

Figure 3. Comparison between suggested model and other existing models for 26 GHz.

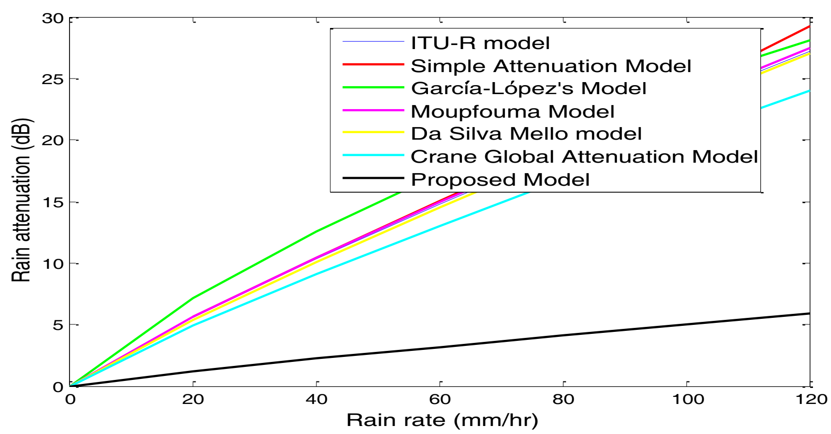

Figure 4. Comparison between suggested model and other existing models for 38 GHz.

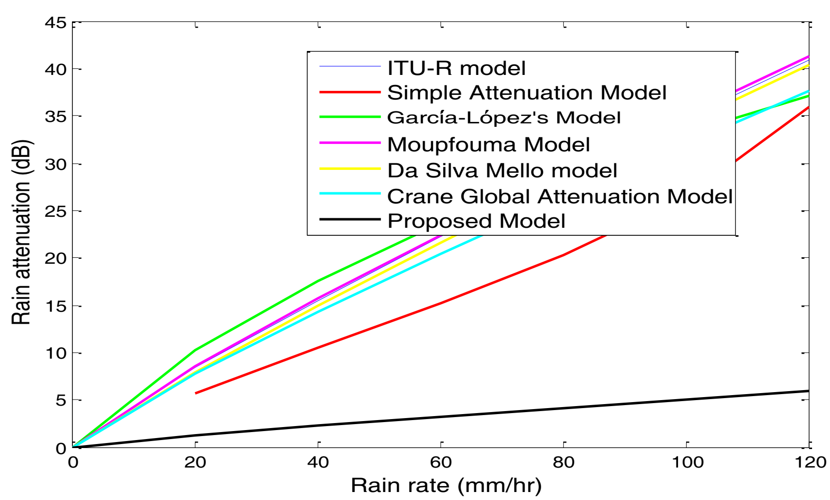

Figure 5. Comparison between suggested model and other existing models for distance 1.5 km.

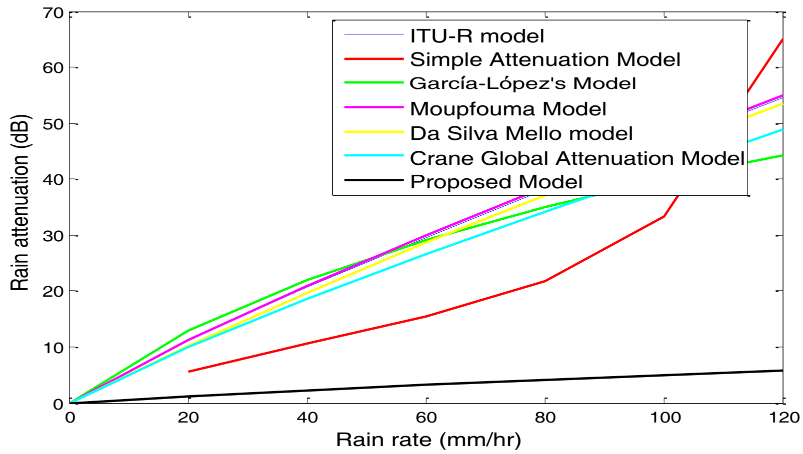

Figure 6. Comparison between suggested model and other existing models for distance 2 km.

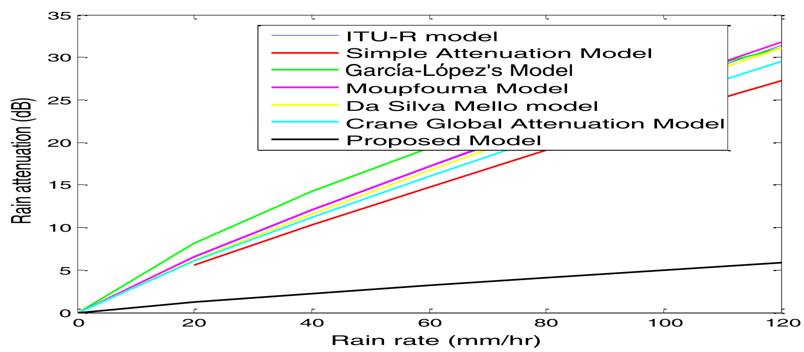

Figure 7. Comparison between suggested model and other existing models for 30° elevation angle.

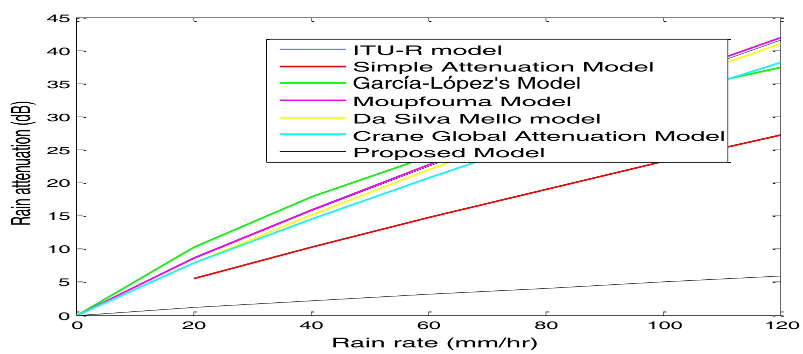

Figure 8. Comparison between suggested model and other existing models for 45° elevation angle.

6. CONCLUSIONS

In summary, in this paper it is shown that the suggested model of this work ranges between 3.6 and 71 GHz for 12 to 16 dB fade margins. Frequency variation improvement factor has been adopted to develop the sloping route attenuation and oblique route length of the suggested model. It is obvious from the graphs plotted in Figures 3 and 4 that the suggested model renders better result than that of other models for 26 GHz and 38 GHz which are accepted from the experimental data sheet. The graphical representations as displayed in Figures 5 and 6 clearly demonstrate that the proposed model produces satisfactory result in comparison with other models for 1.5 km and 2 km distances. Again from the graphs plotted in Figures 7 and 8 it is clear that the suggested model shows better result than that of other models for 30° and 45° elevating angles. Further, for the validation of the proposed model it is also added that the element of improving the frequency variance with respect to the base frequency is lower in the predictive model than in the ITU-R model, and this proposed model is supported for other frequency ranges, i.e., for 5–40 GHz and 50–90 GHz which has been discussed in the proposed model under Section 3. Hence, it is concluded that this suggested model in this paper can be considered as an effective model to heighten the 5G communications in tropical areas as this model diminishes rain attenuation in respect of frequencies, distances, and elevating angles.

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