Tests of Rain Attenuation Prediction Models for Satellite links through Long Term Data

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Abstract—In this contribution, we solve two problems. Both relate to models predicting rain attenuation on satellite links. The first problem is the sensitivity test of models to changes in rainfall heights. We show how much the rain attenuation changes in dependence on the percentage change of the height of the rain volume (area) in cases of various rain attenuation models. The second problem we are dealing with is the testing of chosen models using 3 years attenuation and rain rate measurements. The comparison of models is performed through relative difference between measured and estimated (by model) attenuation.

Keywords—rain attenuation, prediction models, model testing, model sensitivity

I. Introduction

The rain attenuation models estimate CCDF (Complement Cumulative Distribution Function) of rain attenuation A from link parameters (elevation, rain height, frequency, polarization) but first of all from given rain rate CCDF. Indeed, in many practical cases we can consider rain attenuation only as rain is the most devastating atmospheric phenomenon in comparison with snow, hail, fog, water vapor and cloud attenuation The latter play more important role in low availability systems.

The rain attenuation CCDF serves as important and basic parameter for satellite as well as for terrestrial microwave link planning.

II. Brief Description of Tested Models

All rain attenuation models are based on rain rate CCDF at given locality We chose the latest ITU-R model [1] from 2017 for testing. In [2] there are instructions how to compute the necessary specific rain attenuation from rain rate. This model is considered as a broadly recommended standard and is also preferred in this study. This model is based on the idea that the CCDF - distribution function of normalized intensity by rain has a walled course in all areas. The standardized precipitation intensity is rain rate R divided by the rain intensity R_{001} at the probability level (exceeding probability) 0.01% (most often it is of the average year or "worst month" period).

For considered ITU-R model it is not necessary to know the rain rate CCDF but only the rain rate exceed for 0,01% of considered period (labeled R_{001}), By other words this 0.01% exceedance probability represents 53 minutes per year. In the Czech Republic this value is 26 mm/h after ITU-R grid databank. Our measurements indicate a slightly different value, namely 31 mm/h. The ITU-R model then calculates one A_{001} rain attenuation value, which is exceeded at probability level of 0.01%. The attenuations for other percentages of exceedances are then calculated by a general equation, for instance (4). We compare this ITU-R [1] model with the much simpler "old" ITU-R model [3], which is based on the same principle.

To remind the simple "old" ITU-R model look at next equations:

$$A_{0.01} = k\, R_{0.01}{}^{\alpha}\; L_S r_{0.01} \tag{1}$$

$$L_O = 35 \exp(-0.015 R_{0.01}) \tag{2}$$

$$r_{0.01} = \frac{1}{1 + L_G / L_O} \tag{3}$$

where k and α are constants dependent on frequency, elevation angle Θ and polarization (for its values see [2]), R_{001} is rain rate [mm/h] exceeded for 0.01% of time, A_{001} is attenuation in [dB] exceeded also for 0.01% of time, r_{001} is reduction factor, L_s is slant path length through rain area, L_G=L_s cos (Θ), Ls = h_R/sin (Θ) where h_R is rain height. Attenuation A_p corresponding to other exceedance probabilities p [%] within range 0.001-1 % are obtainable from following formula:

$$\frac{A_p}{A_{0.01}} = 0.12 p^{-(0.546 + 0.043 \log p)} \tag{4}$$

For comparison, we selected other models, namely the Brazilian Assis-Einloft [4] model and its improved version by Mr. Costa [5]. These models are as simple as the ITU-R models, but they calculate CCDF of rain attenuation not from one point of CCDF precipitation intensity, but from all probabilities of CCDF range.

III. Data Used for Tests

To test our models we used results of the Aldo Paraboni Q/V Communications and Propagation experiment within the Technology Demonstration Payloads. It is carried by the satellite Alphasat. Used frequencies are 19.7 GHz, vertical polarization and 39.4 GHz (linear polarization, canting angle 45°). Elevation angle in Prague is 31°. Height of zero isotherm is roughly 3 km in Prague. Rain height is after to the ITU-R model [6] 3.36 km. The problems and solutions with data processing and analysis were described in [7] and [8].

From attenuation time record we derived attenuation annual CCDF for 2016, 2017 and 2018 years and also for total 3-year period (2016-2018). The corresponding rain rate time series and CCDF are at our disposal, too. Rain rates were measured by the Tipping-bucket rain gauge.

IV. PRELIMINARY TESTS OF MODEL SENSITIVITY

The sensitivity of a model, equation, algorithm etc. is defined as first derivative of resulting quantity by one input parameter of interest. In our case we investigated satellite link attenuation changes in dependence on rain height. In this case, the sensitivity is $\mathrm{d}A/\mathrm{d}h_R$ while its unit being [dB/km]. It is the same unit like in the specific rain attenuation case. We wondered how important it is to know the height of the rain volume accurately. Or whether it is enough to know the rain height approximately and how accurately.

If we look at the pictures (Fig.1 and Fig.2) that compare two ITU-R models [1,3], we see that the new ITU-R [1] model is obviously more sensitive to changes in the values of rain heights h_R (practically of the heights of the zero isotherm). For example, for the elevation of our satellite station in Prague, which is about 30°, the attenuation at exceedance probability level of 0.01% changes by about 2.8 dB with a kilometer change of rain height (i.e. $\mathrm{d}A/\mathrm{d}h_R$=2.8 dB/km). So it can be deduced that a 100m deviation (or if you want 100m error) in the height of the rain height h_R determination would cause rain attenuation errors of about 0.3 dB while in the old ITU-R model case this error would be about 0.2 dB only. At extremely low elevation angles, these errors would, of course, be higher, see Fig.1 and Fig.2.

The percentage variation on the horizontal axis in Figs. 1,2 means by how many percent we have changed the height from its correct value for these tests. We see that with increasing height the sensitivity of the attenuation determination is always lower.

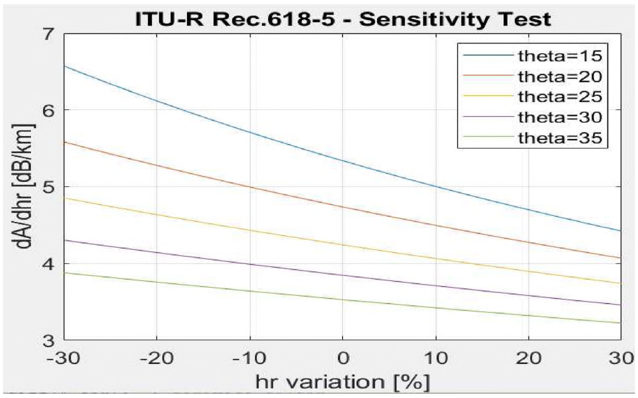

Fig. 1. Attenuation sensitivity on rain height (dependence on rain height percentage change) in the case of "old" ITU-R model

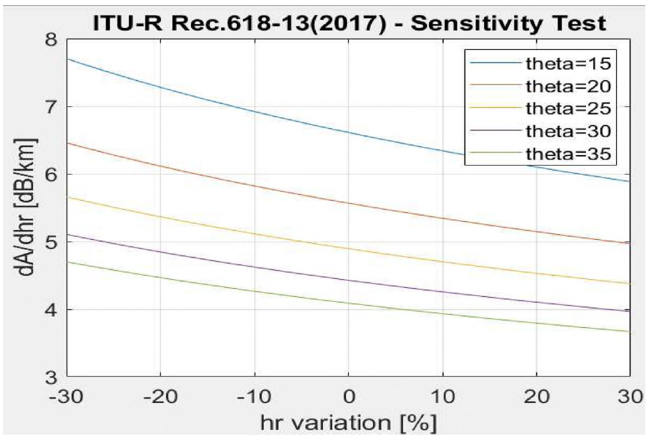

Fig. 2. Specific attenuation changes in dependence on rain height percentage change in the case of "new" ITU-R model

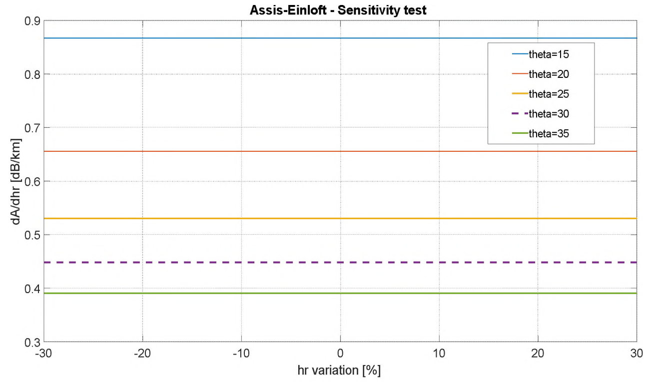

Fig.3. Attenuation changes in dependence on rain height percentage change in the case of Assis-Einloft model

In the case of model Assis-Einloft [4] (Fig.3) we can see that the sensitivity of attenuation on rain height is much lower than in the case of both ITU-R models. The sensitivity for the elevation used on the link in Prague is 0.45 dB/km, so an inaccurate determination of rain height by 100 m will cause errors in the determination of attenuation of about 0.05 dB, which is negligible. Also in the Assis-Einloft model case we see that the lower elevation of the link, the greater sensitivity to changes in the determination of rain height. Further conclusions can be performed seing Figures 1-3 according to the needs of the reader.

V. COMPARISON OF MODEL RESULTS WITH LONG TERM MEASUREMENTS

In the following, we follow up on the measurement, processing and analysis of Alphasat satellite attenuation by the receiver in Prague, which we performed in [9-12].

Comparison of 3 year CCDF after four chosen rain attenuation models with attenuation measurement is shown in Fig.4, while frequency being 19.7 GHz. The measurement is presented by dotted line. One can see good fit of all models with attenuation measurement, first of all of the "new" ITU-R model as well as of the Assis-Einloft model - original version. These models match well.

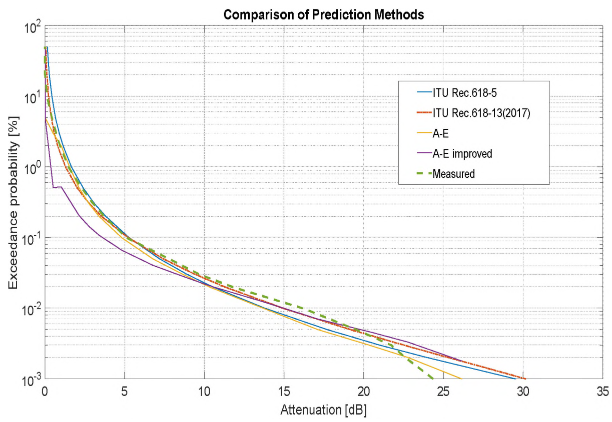

Fig.4. Comparison of three years measurement of 19.7 GHz rain attenuation CCDF with its predistion using four models labeled in figure. Data are from Prague

As far as the situation at 39.4 GHz: we see it in Fig.5. There the measured value is in green and we can clearly see that the receiver is able to measure up to about 22 dB (from 0.02% of exceedance probability upwards). The old ITU [3] and Assis-Einloft improved [5] models visually match the measured values as best models.

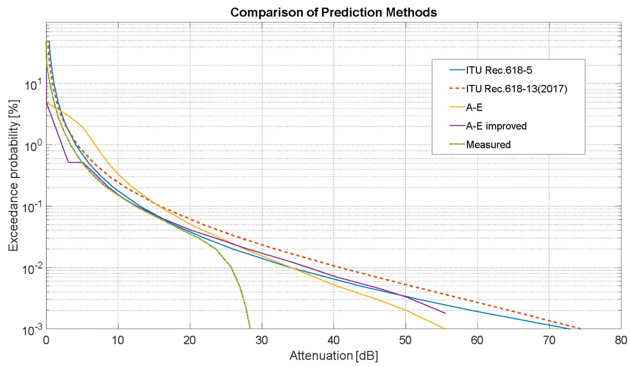

Fig.5. Comparison of three years measurement of 39.4 GHz rain attenuation CCDF with its prediction using four models being labeled in figure legend. Data are from Prague.

VI. Test of Model Fit with Long Term Measurement

We prepared a table with CCDF of predicted and measured attenuation for a wide spectrum of exceedance probabilities (0.001-10%). All conclusions published below correspond to this table. We have added to the table the relative deviation of the attenuation between the model and the measured attenuation. It is in percentage.

In Tab.1, which contains only selected and most important values from the table mentioned above, we see a comparison of the rain attenuation calculation for the 3-year period 2016-2018 according to the models presented here with the attenuation from our attenuation measurement by a satellite receiver in Prague.

We wondered if the new ITU model [1] was better than the old one [3]. Yes, it is and quite significantly, on both monitored frequencies. It can be seen that its formulation was based on long-term experience.

When it comes to model accuracy at both frequencies, in all cases the accuracy of the models is better at a lower frequency, i.e. at 19.7 GHz. In addition to the physical reasons, we must mention here the possible influence of the smaller dynamic range of the receiver at 39.4 GHz.

An interesting finding was that the older version of the Assis-Einloft model [4] proved to be good for 19.7 GHz, better than its newer version [5]. At 39.4 GHz, the Assis-Einloft model improved [5] proved to be the best, where the new ITU-R model did not work accurately.

VII. Conclusion

In this study, we mainly wanted to test the new ITU-R model for rain attenuation prediction [1]. We have shown that, as expected, the new model is more accurate than its older version [3], but it requires more complex programming. To determine the effective height of rain in order to use it within new ITU-R model, it is necessary to have a database of average heights of zero isotherms from all over the world on your computer, which is fortunately available. It is in the so-called grid form. According to ITU-R, the height of the rain is then the average height of the zero isotherm increased by 360 m. The old ITU-R model [3] determines the height of rain from an approximate relationship, where the input parameter is latitude. We also found that the new ITU-R model [1] is more sensitive to possible inaccuracies of the rain height knowledge. Regarding the confrontation of the investigated models and measured values, the agreement or disagreement of individual models with the measurement is discussed in Chapters V and VI.

TABLE I Relative difference between measured and predicted rain attenuation for certain exceedance probabilities and its average. Three years measurement of satellite link attenuation and rain rates from Prague was used

	ITU-R Rec.618-5			
Exc.Prob. [	0,02	0,1	1	Average
19.7 GHz	10,5	3,6	13,2	28,0
39.4 GHz	10,3	4,9	21,5	102,2
	ITU-R Rec.618-13(2017)			
Exc.Prob. [	0,02	0,1	1	Average
19.7 GHz	4,2	2,3	12,5	13,7
39.4 GHz	35,1	27,5	28,4	82,8
	Assis-Einloft			
Exc.Prob. [	0,02	0,1	1	Average
19.7 GHz	12,3	5,5	4,9	20,5
39.4 GHz	17,2	26,1	101,6	67,0
	Assis-Einloft improved			
Exc.Prob. [	0,02	0,1	1	Average
19.7 GHz	9,4	28,2	38,3	32,3
39.4 GHz	19,9	2,8	33,2	37,6

Generally speaking all tested models are more accurate at lower frequencies. And it is, more or less, also true that newer versions of both models are more accurate.

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