Comparison of the Performance of Rain Attenuation Prediction Methods for Terrestrial Links

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Abstract— **This paper presents the results of a comparative tests between rain attenuation prediction methods for terrestrial links. To perform the tests, experimental data from measurements available in the ITU-R data bank have been used. Results indicate that the method currently recommended by the ITU-R significantly underestimates the measured attenuation. Two other methods, proposed by Brazilian and Chinese administrations, provide more accurate results.**

Keywords: Rain attenuation, Terrestrial radio links, Propagation prediction methods.

I. INTRODUCTION

Rain attenuation is the major propagation impairment for systems operating at frequencies above 10 GHz. The presence of hydrometeors in the propagation path, particularly rain, causes scattering and absorption of the propagating wave.

The specific attenuation γ (dB/km) at a given frequency may be obtained from the knowledge of the complex index of refraction, terminal velocity and size distribution of the raindrops [1], [2]. For practical applications the relationship between specific attenuation and rain rate R (mm/h) can be approximated by a power-law $\gamma = k R^{\alpha}$ [3].

Attenuation due to rainfall along a path may be calculated by integrating the specific attenuation over the path length if the rainfall rate variation along the path is known. The difficulty arises from the fact that the field of rainfall rate is inhomogeneous in space and time [4].

The main difference in the various methods developed for predicting rain attenuation is in the models used to describe the time-space structure of rainfall rate. The "synthetic storm methods" generate attenuation statistics by converting rain rate/time profiles recorded at a point to rain rate/distance profiles, using the translation velocity of the rain pattern, estimated as the wind speed [5]-[7].

All other methods make use of cumulative distributions of rainfall rate measured at a point. Some of these methods derive the statistical profile of rain along the path assuming a single cell of suitable shape [8], or a statistical distribution of sizes for cells of a particular shape [9], [10]. Other methods characterize the statistical rain profile simply by a reduction coefficient [11]. An alternative procedure is to apply the reduction coefficient to the actual path length, which yields an effective path length over which the rain intensity may be assumed to be constant [12]-[14]. This concept is used in method recommended by the ITU-R.

II. METHODS TESTED

In this section, the ITU-R rain attenuation prediction method for terrestrial links is described. Next, the main assumptions of the other rain attenuation prediction methods included in the tests are briefly outlined.

A. The ITU-R method

The method for the prediction of rain attenuation in terrestrial links, given in Recommendation ITU-R P.530 [15], was originally developed based on the assumption that an equivalent cell of uniform rainfall rate and length d_0, randomly positioned in the great circle plane can represent the effect of the non-uniform rainfall along the propagation path.

Assuming that this equivalent rain cell may intercept the link at any position with equal probability, the effective path length is the average length of the intersection between the cell and path, given by:

$$A_{0.01} = \gamma_{0.01} \cdot d_{eff} = k\left(R_{0.01}\right)^{\alpha} \cdot \frac{d}{1 + d/d_0(R_{0.01})} \qquad (1)$$

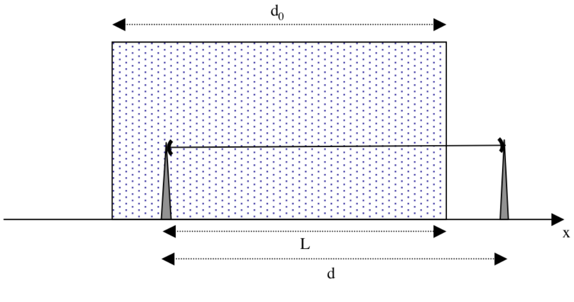

Figure 1. Equivalent rain cell

The diameter d_0 of the equivalent cell is empirically derived from experimental data. It depends on the long-term point rainfall rate measured in the region. In the current model, d_0 is an exponentially decaying function of the point rainfall rate

R(mm/h). The function parameters were adjusted using experimental data available some years ago.

Using this model, the rainfall rate exceeded at 0.01% of time ($R_{0.01}$) is used to predict the corresponding value of rain attenuation ($A_{0.01}$):

$$A_{0.01}(\mathrm{dB}) = \gamma_{0.01} \cdot d_{\mathrm{eff}} = k\left(R_{0.01}\right)^{\alpha} \cdot \frac{d}{1 + d / d_0(R_{0.01})} \tag{2}$$

where γ (dB/km) is the specific attenuation, calculated using the frequency and polarization dependent parameters k and α, given in Recommendation ITU-R P. 838 [16] and d is the actual path length.

To calculate the attenuation exceeded at other percentages of time between 1% and 0.001% an extrapolation formula is used [1]. This represents a shortcoming of the method, as in two regions with different distributions of point rainfall rate but similar values of R0.01, the same behaviour for the attenuation will be predicted. Also, empirical evidence [17] based on measured data now available indicates that this model may significantly underestimate the cumulative distribution of rain attenuation, particularly for region with severe rain regimes.

B. The Australian method

The Australian method was introduced in [18] as a proposed amendment to Recommendation ITU-R 530-12 [15]. It was motivated by the fact that paths in Australia appeared to experience significantly greater rain outage time than that predicted by the recommendation. The main suggestion of the model is to improve the calculation of the link effective path length d_{eff} by multiplying the actual path length d by the path adjustment factor r, but using a different expression than the existing ITU-R method. That is,

$$r = \left[\frac{1}{1 + (d / d_0)^{1.5}}\right]^{2/3} \tag{3}$$

where, for $R_{0.01} \leq 100$ mm/h,

$$d_0 = 26.2 e^{-0.0025 R_{0.01}} . \tag{4}$$

For $R_{0.01} > 100$ mm/h, in place of $R_{0.01}$, the value 100 mm/h is used. Amid the set of models tested, this the only one differentiating the extrapolation of rain attenuation from 0.01% to other percentages of time for absolute latitudes higher and lower than 30°.

C. The Brazilian method

The Brazil method is a semi-empirical model for the prediction of rain attenuation in terrestrial links, which has been developed using experimental data from DBSG3. Introduced in [19], the method retains the concept of an equivalent rain cell, which is the basis of the current ITU-R method, but considers the full rainfall rate distribution for the prediction, avoiding the use of extrapolation functions to obtain the rain attenuation exceeded in percentages of time other than 0.01%. In this course, to each percentage of time p% corresponds a different value for the effective path length of the link, $d_{\mathrm{eff}}(p)$. The latter is obtained by multiplying the actual path length d by the path adjustment factor r. This factor is given by

$$r_p = \frac{1}{1 + d / d_0(R_p)} , \tag{5}$$

where

$$d_0(p) = 119 \cdot R_p^{-0.244} \tag{6}$$

and R_p is the rainfall rate exceeded for p% of the time. Then, the concept of the effective rainfall rate, $R_{\mathrm{eff}}(p)$, is introduced, given by

$$R_{\mathrm{eff}}(R_p, d) = 1.763 \cdot R_p^{0.753 + 0.197/d} . \tag{7}$$

The attenuation exceeded at p% of the time is then given by

$$A_p(\mathrm{dB}) = \gamma_p \cdot d_{\mathrm{eff}} = k\left[\left(R_{\mathrm{eff}}(R_p, d)\right)\right]^{\alpha} \cdot \frac{d}{1 + d / d_0(R_p)} . \tag{8}$$

D. The Chinese method

The Chinese method , presented in [20], was proposed as a replacement of the rain attenuation prediction model in Recommendation ITU-R 530-12 [15]. The model is similar to the one recommended by the ITU-R, differing in the expression of the distance factor *r* and the formula for extrapolating the exceeded attenuation for 0.01% of an average year to other percentages of time. Specifically, the modified path adjustment factor *r* is given by

$$r = \frac{1}{0.477 d^{0.633} R_{0.01}^{0.073 \cdot \alpha} f^{0.123} - 10.579(1 - \exp(-0.024 d))} \tag{9}$$

while the extrapolation formula is expressed as

$$A_p = A_{0.01} \left(\frac{p}{0.01}\right)^{-[0.854 - 0.026 \ln((1+p)/p) - 0.022 \ln(1 + A_{0.01}) - 0.03 \ln f - 0.226(1+p)]} \tag{10}$$

In (9) and (10) above, *f* is the frequency of operation in GHz and *α* is the exponent of rain rate for the calculation of the specific rain attenuation γ (dB/km) according to Rec. ITU-R P.838 [7].

E. The UK method

Similarly to the Brazilian method, the UK model also employs the full rainfall rate distribution to calculate rain attenuation for different percentages of time. The UK model was introduced in [21] as a proposed modification of Rec. ITU-R P.530-12 [15]. After obtaining the rainfall rate R(p) and the specific attenuation, $\gamma(p)$ (dB/km) exceeded for p% for the

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range of time percentages required, the path adjustment factor r(p) is calculated as

$$r(p) = \frac{1}{0.874 + 0.0255\left[R(p)^{0.54} - 1.7\right] d^{0.7}} . \tag{11}$$

This adjustment factor is multiplied to the actual path length d to obtain the effective path length d_{eff} (km).

III. TESTING PROCEDURE

A. Test variable

For the purposes of the comparative testing, the test variable given in Rec. ITU-R P.311-12 [22] was used. For a given method and for each percentage of time, the value of the test variable for the i-th radio link is given by

$$Vi = \begin{cases} (Am,i / 10)^{0.2} \ln (Ap,i / Am,i) & \text{for } Am,i < 10 \text{ dB} \\ \ln (Ap,i / Am,i) & \text{for } Am,i \geq 10 \text{ dB.} \end{cases} \tag{12}$$

where Am,i (dB) is the measured attenuation and Ap,i (dB) the attenuation predicted for the i-th radio link.

B. Data bank

The data bank used in the tests includes the data currently available in Table C1-1 of DBSG3, that includes a total of 89 terrestrial links and is partially reproduced in Table 1.

TABLE I. ITU-R TERRESTRIAL RAIN ATTENUATION DATA BANK LINKS

Station	Latitude (degrees)	Path length (km)	Frequency (GHz)	Polarization (degrees)
Mendlesham	52.25	7.4	19.4	90
Mendlesham	52.25	7.7	37.402	90
Mendlesham	52.25	16.6	20.1	90
Mendlesham	52.25	2.9	22.1	90
Mendlesham	52.25	4	22.3	90
Mendlesham	52.25	7	22.1	90
Mendlesham	52.25	2.8	36.6	90
Mendlesham	52.25	7.4	36.1	90
Mendlesham	52.25	8.8	36.6	90
Mendlesham	52.25	3.7	37.4	90
Mendlesham	52.25	22.7	20.7	90
Kjeller	59.98	21.3	18	90
Stockholm	59.33	15	10.8	0
Stockholm	59.33	15	17.9	0
Stockholm	59.33	15	36	0
Darmstadt	49.87	20	12.4	0
Darmstadt	49.87	20	15	0
Darmstadt	49.87	20	29	0
Darmstadt	49.87	20	39	0
Leidschendam	52.08	12.4	35.5	0
Paris	48.86	58	11.7	0
Paris	48.86	12	13	0
Paris	48.86	15.4	13	0
Dijon	47.33	53	13	0
Dijon	47.33	23	19.3	0
Fucino	42.00	9.5	11	90
Fucino	42.00	9.5	17.8	90
Rome	41.90	25	11	90
Turin	45.07	22.5	11.4	90
Merrimack Valley	42.70	4.3	18	90
Palmetto	32.00	5.1	17.7	0
Holmdel	40.35	6.4	18.5	90
Tokyo	35.69	1.3	11.5	45
Tokyo	35.69	1.3	34.5	45
Tokyo	35.69	1.3	81.8	45
Brazzaville	-4.28	33.5	7	0
Rio de Janeiro	-22.90	8.6	10.9	0
Xixiang-Henan	35.35	2.5	12	0
Xixiang-Henan	35.35	2.5	25.3	0
Chilbolton	51.13	0.5	37	90
Chilbolton	51.13	0.5	57	90
Chilbolton	51.13	0.5	57	90
Chilbolton	51.13	0.5	57	90
Chilbolton	51.13	0.5	97	90
Chilbolton	51.13	0.5	97	90
Chilbolton	51.13	0.5	97	90
Chilbolton	51.13	0.5	137	90
Uvaly	50.07	15.3	14.92	0
Mostova	48.12	43.8	13.14	90
Pisek	49.79	39.4	13.03	90
Strahov	50.08	34	13.19	0
Strahov	50.08	34	13.10	90
Dubna 3	56.68	12.65	29.3	90
Dubna 3	56.68	12.65	19.3	90
Dubna 3	56.68	12.65	11.5	90
Bradesco II	-23.56	12.79	14.55	90
Bradesco II	-23.56	12.79	14.55	90
Cenesp 15	-23.56	12.78	14.55	0
Cenesp 15	-23.56	12.78	14.55	0
Cenesp 18	-23.56	12.78	18.61	90
Scania	-23.56	18.38	14.5	90
Scania	-23.56	18.38	14.5	90
Barueri	-23.56	21.69	14.53	90
Shell	-23.56	7.48	18.59	90
Paranapiacaba	-23.56	42.99	14.52	0
Paranapiacaba	-23.56	42.99	14.52	0
Barsília-STF	-23.56	4.48	23	90
Rio de Janeiro	-22.90	6.55	23	90
Fujtsu	2.92	1.4	32.6	0
Yotsuya	35.69	2.3	33.4	90
Yotsuya	35.69	2.3	33.4	90
Yotsuya	35.69	2.3	33.4	90
Akasaka	35.67	2.1	32.6	90
Akasaka	35.67	2.1	32.6	90
Akasaka	35.67	2.1	32.6	90
Koenji	35.69	1.2	23.2	90
Koenji	35.69	1.2	23.2	90
Karagasaki	35.62	9.1	15.25	90
Karagasaki	35.62	9.1	15.25	90
Karagasaki	35.62	9.1	15.25	90
Shiyakusyo	35.28	6.37	18.58	90

IV. TEST RESULTS

The test variables were evaluated at the 11 percentages of time used in DBSG3, namely 0.001%, 0.002%, 0.003%, 0.01%, 0.02%, 0.03%, 0.06% and 0.1% of annual time. To have a more complete assessment of the terrestrial prediction methods performance, three different tests were run.

A. Results for Test 1

Test 1 includes all data, comprising a total of 81 datasets. The average value, standard deviation and r.m.s. value of the testing variable at each percentage of time for are shown in Figures 2 to 4.

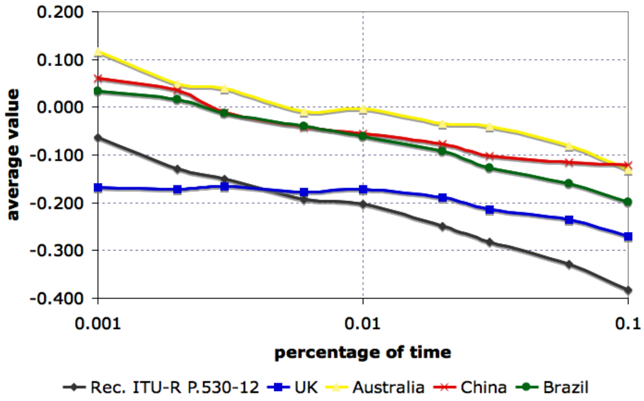

Figure 2. Average error – test 1.

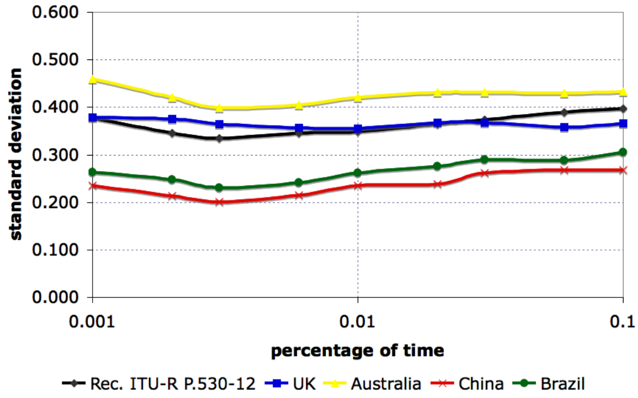

Figure 3. Standard deviation – test 1.

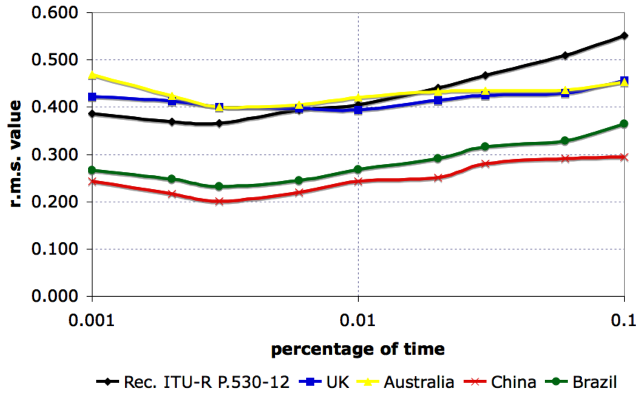

Figure 4. R.m.s. error – test 1.

B. Results for Test 2

Test 2 includes only single year data, corresponding to 44 datasets. The average value, standard deviation and r.m.s. value of the testing variable at each percentage of time for are shown in Figures 5 to 7.

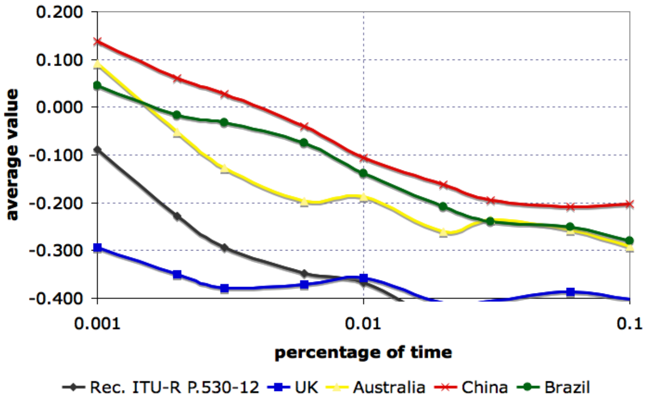

Figure 5. Average error – test 2.

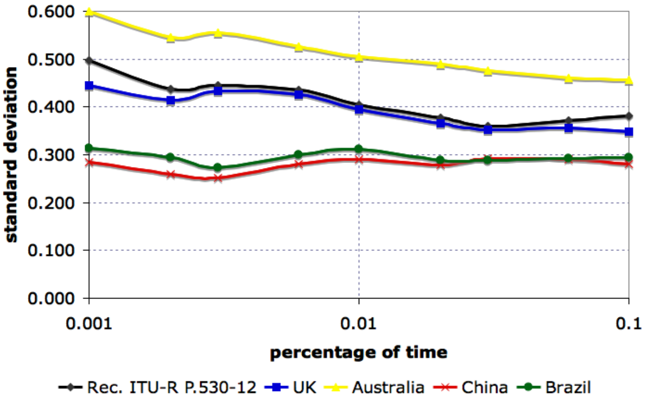

Figure 6. Standard deviation – test 2.

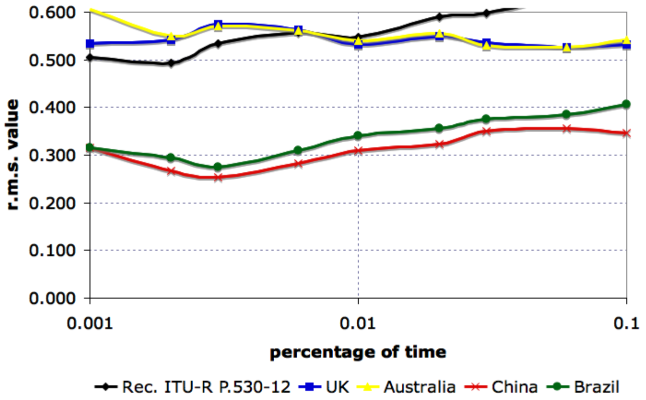

Figure 7. R.m.s. error – test 2.

C. Results for Test 3

Test 3 includes multiple year data where single-year statistics are not present, including a total of 37 datasets. The average value, standard deviation and r.m.s. value of the testing variable are shown in Figures 8 to 10.

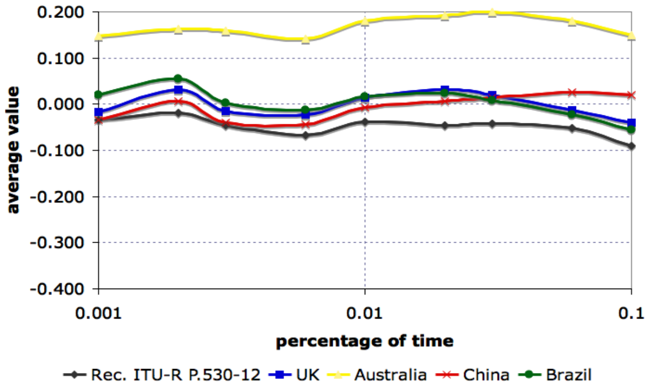

Figure 8. Average error – test 3.

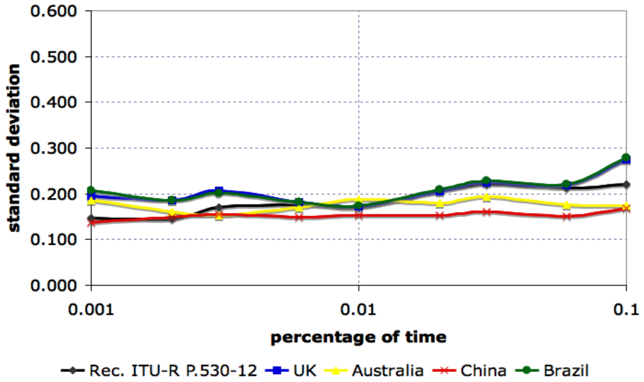

Figure 9. Standard deviation – test 3.

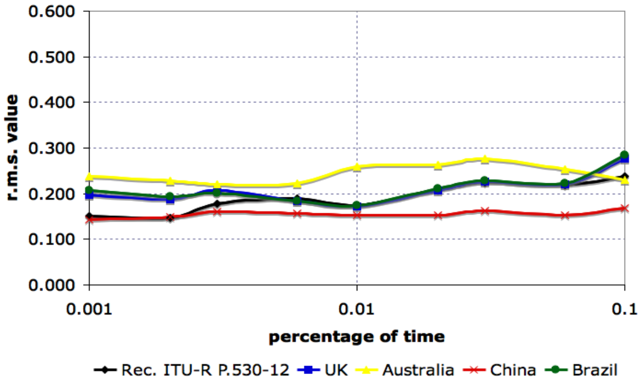

Figure 10. Equivalent rain cell

V. CONCLUSIONS

Four models proposed for predicting the average annual rain attenuation distribution in terrestrial links were tested and compared to the existing ITU-R model.

Test results indicate that the Brazilian and Chinese methods provide a large improvement over the method currently recommended by the ITU-R. The Brazilian method has the advantage of using the full rainfall rate distribution as input for predicting the attenuation distribution. Also, the attenuation dependence on frequency is completely described by the parameters k and α, as should be expected from the physical point of view.

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