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| **Radiocommunication Study Groups** |  |
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| Received: 15 March 2017  Subject: Rain attenuation modelling | **Document 3M/178-E** |
| **16 March 2017** |
| **English only** |
| China (People’s Republic of) | |
| PROPOSED revision TO RECOMMENDATION ITU-R P.530-16 | |
| Analysis of wet antenna effect and rain attenuation prediction modelling | |

# 1 Abstract

According to the DBSG3 Databank (file name C1\_1\_v4.csv), the “adjustment factor” (“rainfall rate adjustment factor” or “path adjustment factor”) used to predict rain attenuation for terrestrial links sometimes exceeds 1, especially for short links (shorter than 1 km), this is unreasonable, furthermore it cannot be suitable for links with higher frequency and shorter distance (shorter than 1 km), which are expected to be massively utilized in 5th-generation wireless systems.

A lot of experimental researches have demonstrated the contribution of wet antenna effect to path attenuation during rain, and the magnitude and nature of the wet antenna attenuation has been the subject of numerous investigations‎[2]-‎[9]. Wet antenna effect is introduced to explain this phenomena and a new model is proposed in this document. Compared with three rain attenuation prediction models for terrestrial links, namely Recommendation ITU-R P.530-16 model and China model (proposed in Doc 3J/16-3M/31，2012. improved in Doc 3J/39-3M/76, 2016.) and Korea model (proposed in Doc. 3J/121-3M/214, 2015), the proposed model get the smallest RMS error. Furthermore, the rainfall rate adjustment factors of new model are calculated and analysed by using the DBSG3 Databank, which reveal more reasonable values and relationships with rainfall rate and path length and therefore has a more extensive application range.

# 2 Analysis

Due to the inhomogeneity of the rain along the link, the Recommendation ITU-R P.530-16 model and Korea model use path adjustment factors to predict rain attenuation, while the China model uses a rainfall rate adjustment factor. As shown in Figure 1, the adjustment factors increase when path length decreases for all the three models, and they increase to a maximum value of 2.5 for Recommendation ITU-R P.530-16 model and China model, while it increases to even larger values for Korea model. Furthermore, when the rainfall rate reduced for example to 0.1 mm/h shown in Figure 2, the adjustment factor of Korea model can reach even larger values when path length decreases, and for Recommendation ITU-R P.530-16 model and China model, the factor changes non-monotonically with path length.

However, for the short path within 1 km, the adjustment factor should be equal to one approximately in physical meaning, because when path is short, the rainfall rate should remain constant along the whole link, and similar discussion has been done by Italy in   
Doc 3J/13-3M/39(2016). Therefore the applicability of these models for very short radio link is problematical.

Figure 1

Adjustment factor as a function of path length (frequency: 60 GHz, rainfall rate: 40 mm/h)



Figure 2

Adjustment factor as a function of path length (frequency: 60 GHz, rainfall rate: 0.1 mm/h)



*Note from the Secretariat: Equations to be clarified*

Furthermore, rain attenuation models mentioned above can be described as  and  , with rainfall rate adjustment factor and path adjustment factor , where  andare provided by Recommendation ITU-R P.838-3 and is the measurement link attenuation. Using the parameters included in the DBSG3 Databank, and  are obtained and shown in Figure 3 and Figure 4, named measurement rainfall rate adjustment factor and measurement path adjustment factor. It shows that both and  increase with the decrease of path length, and the maximum value are about 5 and 3.2, respectively.

Figure 3

Rainfall rate adjustment factor calculated by DBSG3



Figure 4

Path adjustment factor calculated by DBSG3



It is well known that when path length  is small, and should be approximately equal to 1 due to the constant rainfall rate along the link, so , where  is the specific rain attenuation (dB/km) provided by Recommendation ITU-R P.838. The measurement link data of specific rain attenuation  are obtained by taking  (measurement link attenuation in DBSG3) divided by the path length , and the ratio  should be equal to 1 in theory.

Eight links with path length equal to 0.5km are selected seen in Table 1, the corresponding ratio  is shown in Figure 5, which indicates a ratio larger than 1, that is to say, the measurement link specific rain attenuation is larger than that provided by Recommendation ITU-R P.838-3. Figure 6 shows the ratio  of all the data in table C1\_1\_v4 of DBSG3, and it shows a trend that  increases with path length decreases and more  happened on shorter links.

Table 1

Experiment data in table C1\_1\_v4 of DBSG3 with path length equal to 0.5

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NO | STATION\_NO | T\_CTRY | EXP\_NO | PATH\_LTH | START\_DATE | END\_DATE | DURATION | FREQUENCY |
| 1 | 1119 | GB | 1 | 0.5 | 1984/10/1 | 1985/9/30 | 334.021 | 37 |
| 2 | 1119 | GB | 2 | 0.5 | 1982/10/1 | 1983/9/30 | 207.182 | 57 |
| 3 | 1119 | GB | 3 | 0.5 | 1983/10/1 | 1984/9/30 | 349.977 | 57 |
| 4 | 1119 | GB | 4 | 0.5 | 1984/10/1 | 1985/9/30 | 276.029 | 57 |
| 5 | 1119 | GB | 5 | 0.5 | 1982/10/1 | 1983/9/30 | 316.245 | 97 |
| 6 | 1119 | GB | 6 | 0.5 | 1983/10/1 | 1984/9/30 | 348.078 | 97 |
| 7 | 1119 | GB | 7 | 0.5 | 1984/10/1 | 1985/9/30 | 334.146 | 97 |
| 8 | 1119 | GB | 8 | 0.5 | 1984/10/1 | 1985/9/30 | 295.982 | 137 |

Figure 5

Ratio of experiment data in table 1



Figure 6

Ratio of all experiment data in table C1\_1\_v4 of DBSG3



Analysis indicates that both rainfall rate adjustment factor and path adjustment factor are larger than 1 when path is short which follow the truth offered by experiment data in table C1\_1\_v4 of DBSG3. Wet antenna effects may be the cause mentioned in Doc 3J/13-3M/39(Italy，2016). Water layers attaching to the surfaces of reflectors, radomes and horn caps in the presence of rain are known to cause significant attenuation, which play an even greater role in short link. Recorded the measurement link attenuation as, link true rain attenuation as , and then wet antenna attenuation can be obtained as , while researches suggest they follow the relationship‎[7]‎[9]:

 (1)

For the data with 0.5 km path length shown in table 1,  is the measurement link attenuation and the corresponding true rain attenuation  equal to specific rain attenuation (Recommendation   
ITU-R P.838) multiply by 0.5 km. Figure 7 shows the relationship between wet antenna attenuation and rain attenuation with  and .

Figure 7

Relationship between wet antenna attenuation and rain attenuation



# 3 New rain attenuation prediction model

Doc 3J/121-3M/145(China, 2010) introduces the concept of rainfall rate adjustment factor based on the EXCELL rain cell model, and propose a rain attenuation model as:

 (2)

Doc 3J/16-3M/31(China, 2012) gives the rainfall rate adjustment factor  as：

 (3)

In formula (3), when  approaching 0,  increases to unrealistic values, to avoid this, a new rain attenuation model is proposed considering the wet antenna attenuation, and in formula (1) is instead of a relationship, and formula (3) is also modified. The new model with parameters derived by regression with experimental data in DBSG3 is as follows:

 (4)

 (5)

 (6)

# 4 Comparison of various models

## 4.1 Comparison of prediction accuracy

The accuracy of proposed model, namely “China newmodel”, is tested based on the Doc 3M/FAS/2(2009) fascicle “Guidelines for testing terrestrial prediction methods” and 3M/FAS/1(2016) fascicle “On testing variables for the selection of prediction models” against  
ITU-R SG 3 Databank [Table C1\_1\_v4, file name C1\_1\_v4.csv.] , and the results are compared to “China model” and “Korea model” and “ITU-R P.530-16 model”.

The comparison of average prediction errors are summarised in Table 2 and the errors for the time percentage from 0.001% to 0.1% are shown in Table 3. It can be seen that the proposed new model gets the best performance.

Table 2

Comparison of the average prediction errors

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Prediction method | Mean | r.m.s | STD | Weight years |
| ***China new model*** | ***–0.004*** | ***0.215*** | ***0.215*** | 121.55 |
| China model(2016) | 0.007 | 0.228 | 0.227 |
| Korea model(2015) | -0.003 | 0.242 | 0.242 |
| ITU-R P.530-16 model | -0.052 | 0.217 | 0.211 | 122.66 |

Table 3

Comparison of the prediction errors for each time percentage

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| China new model | | | | | | | | | | |
|  | 0.001 | 0.002 | 0.003 | 0.006 | 0.01 | 0.02 | 0.03 | 0.05 | 0.10 | Ave. |
| Years | 48.44 | 74.85 | 108.29 | 131.76 | 155.47 | 154.04 | 156.54 | 141.78 | 122.78 | 121.55 |
| Mean | -0.056 | 0.006 | -0.007 | -0.006 | 0.018 | 0.024 | 0.005 | -0.017 | -0.040 | –0.004 |
| RMS | 0.212 | 0.202 | 0.191 | 0.193 | 0.209 | 0.218 | 0.242 | 0.210 | 0.239 | 0.215 |
| STD | 0.204 | 0.202 | 0.191 | 0.193 | 0.208 | 0.217 | 0.242 | 0.209 | 0.236 | 0.215 |
| China model | | | | | | | | | | |
| Years | 48.44 | 74.85 | 108.29 | 131.76 | 155.47 | 154.04 | 156.54 | 141.78 | 122.78 | 121.55 |
| Mean | -0.058 | 0.008 | 0.006 | 0.010 | 0.037 | 0.036 | 0.014 | -0.008 | -0.038 | –0.007 |
| RMS | 0.223 | 0.201 | 0.190 | 0.199 | 0.218 | 0.233 | 0.259 | 0.229 | 0.262 | 0.228 |
| STD | 0.216 | 0.200 | 0.190 | 0.199 | 0.215 | 0.231 | 0.259 | 0.229 | 0.259 | 0.227 |
| Korea model | | | | | | | | | | |
| Years | 48.44 | 74.85 | 108.29 | 131.76 | 155.47 | 154.04 | 156.54 | 141.78 | 122.78 | 121.55 |
| Mean | 0.076 | 0.087 | 0.049 | 0.006 | 0.007 | -0.011 | -0.041 | -0.039 | -0.055 | 0.003 |
| RMS | 0.235 | 0.228 | 0.218 | 0.205 | 0.223 | 0.240 | 0.266 | 0.246 | 0.290 | 0.242 |
| STD | 0.222 | 0.210 | 0.212 | 0.205 | 0.223 | 0.239 | 0.263 | 0.243 | 0.285 | 0.242 |
| ITU-R P.530-16 model | | | | | | | | | | |
| Years | 48.44 | 74.85 | 108.29 | 131.76 | 155.47 | 155.04 | 157.54 | 145.78 | 126.78 | 122.66 |
| Mean | -0.014 | 0.006 | -0.029 | -0.042 | -0.035 | -0.042 | -0.060 | -0.072 | -0.132 | -0.052 |
| RMS | 0.195 | 0.176 | 0.174 | 0.187 | 0.200 | 0.207 | 0.233 | 0.249 | 0.276 | 0.217 |
| STD | 0.195 | 0.176 | 0.172 | 0.182 | 0.197 | 0.202 | 0.225 | 0.239 | 0.242 | 0.211 |

## 4.2 Analysis of rainfall rate adjustment factor of China new model

Figure 8 gives the rainfall rate adjustment factor of the proposed model, seen in formula (5), use the input parameters in table “C1\_1\_v4.csv” of DBSG3, Figure 9 and 10 show the comparison of adjustment factor of four models as a function of path length with different rainfall rate. It indicates the trend that the rainfall rate adjustment factor increases with rain rate and path length decreases, and the maximum value is around 1. The adjustment factor of the proposed model is more reasonable compared with other models mentioned above.

Figure 8

Rainfall rate adjustment factor of China new model calculated by DBSG3



Figure 9

Comparison of adjustment factor as a function of path length (frequency: 60 GHz, rainfall rate: 40 mm/h)



Figure 10

Comparison of adjustment factor as a function of path length (frequency: 60 GHz, rainfall rate: 0.1 mm/h)



# 5 Conclusions

The adjustment factors of rain attenuation prediction models are either set to a constant value  
(ITU-R P.530-16 model and China model) or increase to even more unrealistic values when path length decreases, which violates physical principle and limits the applicability of the models for short radio links within 1 km. A new rain attenuation considering the wet antenna attenuation is proposed to solve the problem in this document. Test results show that the prediction RMS error of the proposed model is smaller than other models, and the new model gives a more reasonable rainfall rate adjustment factor, according to the table “C1\_1\_v4.csv” of DBSG3, which makes it suitable both for long and short links. Therefore, the modifications to the Recommendation  
ITU-R P.530-16 are given in Annex 1.

# References

1. ITU-R database on terrestrial light-of-sight links, <http://saruman.estec.esa.nl/dbsg3/categories.jsp?category=rainAttenuationStat>.
2. Jacobsons, M. D., D. C. Hogg, and J. B. S. Snider. Wet reflectors in millimetre-wave radiometry-experiment and theory. IEEE transactions on geoscience and remote sensing,  
   Vol. 24, No. 5, 784-791, 1986.
3. W. Klaassen. Attenuation and reflection of radio waves by a melting layer of precipitation. Proc. Inst. Elect. Eng. H, Microw. Antennas Propag., vol. 137, no. 1, pp. 39–44, 1990.
4. Cheah, J. Y. C.. Wet antenna effect on VSAT rain margin. IEEE Trans. Commun.,  
   Vol. 41, 1238-1244, 1993.
5. Kharadly, M. M. Z. and R. Ross and B. Dow. Analysis of the ACTS-Vancouver path propagation data. Proc. NAPEX XX and ACTS Prop. Studies Mini Workshop, 67-83, Fairbanks, AK, June 1996.
6. Atle Borsholm. Modelling and Experimental Validation of the Surface Attenuation Effects of Rain on Composite Antenna Structure at Ka-Band. May 1999, NMSU-ECE-99-004.
7. M. M. Z. Kharadly and R. Ross. Effect of wet antenna attenuation on propagation data statistics. IEEE Trans. Antennas Propag., vol. 49, no. 8, pp. 1183-1191, Aug. 2002.
8. J. S. Mandeep, Jabatan Kejuruteraan Elektrik, Elektronik, and Sistem Fakuliti Kejuruteraan dan Alam Bina. Analysis effect of water on a ka-band antenna. Progress In Electromagnetics Research Letters, Vol. 9, 49-57, 2009.
9. J.M.Garcia-Rubia, J. M. Riera, A. Benarroch and P. Garcia-del-Pino.Estimation of rain attenuation from experimental drop size distributions. IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 839–842, 2011.
10. ITU-R Doc. 3M/39，Discussion document on considerations on the models for rain Attenuation prediction on terrestrial links and on the experimental data included in the sg 3 database (table c1-1)，Italy，2016.
11. ITU-R Doc. 3M/31，Modification to rainfall rate adjustment factor for Modelling and Prediction Methods of Rain Attenuation Statistics，china，2012.
12. ITU-R Doc. 3M/76, China\_2012 model improvement and additional analysis with other rain attenuation prediction models proposed to ITU-R P.618 AND ITU-R P.530，China，2016.
13. ITU-R Doc. 3M/214, Proposed modification to recommendation ITU-R P.530-15,  
    A new approach for the effective path-length model for rain attenuation based on rain-cell characteristics, Korea, 2015.
14. Recommendation ITU-R P.530-16(07/2015)，Propagation data and prediction methods required for the design of terrestrial line-of-sight systems.

Annex 1

**Draft revision to Recommendation ITU-R P.530-16**

**1 Replace the text in Section 2.4.1 as following**

The following procedure provides estimates of the long-term statistics of the terrestrial line-of-sight path rain attenuation:

*Step* 1: Obtain the rainfall rate, *Rp*,exceeded for *p* % of an average year (with an integration time of 1 minute). If this long-term statistic cannot be obtained from local data sources, an estimate can be obtained from maps of rainfall rate given in Recommendation [ITU-R P.837](http://www.itu.int/rec/R-REC-P.837/en). If *Rp* is equal to zero, the predicted rain attenuation is zero for *p* % of an average year and the following steps are not required.

*Step* 2: Calculate the rainfall rate adjustment factor,, for *p*% of the time and the actual path-length *d*:



 (32)

*Step* 3: Calculate the wet antenna attenuation:

 (33)

*Step* 4: Obtain the frequency-dependent coefficients, *k* and *α*, given in Recommendation  
ITU-R [P.838](http://www.itu.int/rec/R-REC-P.838/en), and the predicted attenuation exceeded for *p*% of an average year is obtained from:

 dB (34)

*Step* 5: If worst-month statistics are desired, calculate the annual time percentages *p* corresponding to the worst-month time percentages *pw* using climate information specified in Recommendation ITU-R [P.841](http://www.itu.int/rec/R-REC-P.841/en). The values of *A* exceeded for percentages of the time *p* on an annual basis will be exceeded for the corresponding percentages of time on a worst-month basis.

The prediction procedure outlined above is considered valid in all parts of the world at least for frequencies up to 100 GHz and path-lengths up to 60 km.

**2** As the sequence number of equations in the revision are different from that in Recommendation ITU‑R P.530-16, there should be the corresponding changes after Section 2.4.1.

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