Derivation of Path Reduction Factor from the Malaysian Meteorological Radar Data

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Abstract

Rain does not distribute evenly in a region experiencing precipitation. This is especially true in tropical regions as rain has been found to be more convective in nature rather than widespread. ITU-R has given the necessary information to calculate the attenuation due to rain in dB/km. However, to predict the total amount of attenuation due to rain that a microwave link might suffer, a path reduction factor is needed to account for the variability of rain rate occurring along the propagation path.

This paper presents a study of rain rate distribution in Malaysia using the Malaysian Meteorological radar data. The radar station is located in Kluang, Johor. Readings from the scanning angle of 0.5^{o} and from bins 32 to 51 were utilized in this study. Data were collected from 2nd January 1998 to 10th March 1998. Total scans where rain is detected were 7998 scans.

Analysis from this study confirmed that rain cell in Malaysia is highly convective and heavy rain occurs in patches or in an area of about 1.2 km in diameter. This preliminary analysis proposed a path reduction factor r derived from the radar data that can be used for predicting attenuation due to rain. Better radar specifications can produce a more accurate reduction factor. This will enable a reliable microwave link system planning and design to be obtained.

I Introduction

The major concern in microwave link design is the attenuation due to rain. Tropical countries, like Malaysia experience very high rain rate especially during the monsoon seasons. However, rain does not distribute evenly over space or over the ground that is experiencing precipitation. Rain usually occurs in cells where the rain rate is higher at the center of the rain cell and tapers rapidly toward the edge. This resulted from the nature of most rain cells, which are very convective [1]. Thus, when predicting the amount of attenuation due to rain that a microwave link might suffer, a path reduction factor is needed to account for the variability of rain rate occurring along the propagation path. This makes the path reduction factor r, an important parameter for the calculation of attenuation due to rain. As a result, this study is an important one and is a worthwhile effort.

II Methodology

The ability of a radar to scan a wide area around the radar site and not just a particular path made it a very attractive for many types of investigations. Radar can be used to measure the rainfall rate indirectly. This is achieved by knowing the radar reflectivity and then converting them into rainfall rate. The S-band frequency of the meteorological radar ensures that propagation effects such as rain attenuation are negligible [2]. The technology of radar for precipitation measurement is very stable and the results of observations are highly accurate [2,3]. Meteorological radar is also said to be a better tool to build a rain attenuation prediction model for terrestrial microwave radiocommunication [4].

Radar will emit a pulse towards a target. If the pulse hit the target, some energy will be scattered back to the radar. The backscattered or average power received by the radar depends on the radar parameters, on the shape, size, number and dielectric constant of raindrops. If these parameters are known, the radar reflectivity factor Z can be calculated. An empirical relationship can be established between Z and the rainfall rate R.

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In this study, several virtual links were set-up in the scanning area. The rain rate along each virtual links is known, thus enabling the calculation of attenuation due to rain. Range bins 32 to 51 were utilized. The elevation angle chosen in this study is 0.5^o, which is the lowest elevation angle of the radar system. Readings from this elevation angle is much nearer to the ground and thus giving the precipitation that occurs near the ground.

To derive the reduction factor r, virtual links of 1-km to 10-km are constructed in each radial line. Since, bin range of 32 to 51 are used, this means that there will be two 10-km links in a radial line. Using the rainfall rate data in each bin, attenuation due to rain is calculated using parameter values obtained from ITU-R.

The path lengths chosen are 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 km. For a 1-km path length, it is assumed that there will be 20 virtual path links within the range bins. For a 2-km path link, the first one will be from range bin 31 to 32. The next link will be from 32 to 33, and so on. Thus, there will be 19 virtual links within the range chosen. This is repeated for the rest of virtual links where there will be two 10-km path links for each radial line. This will produce a reduction factor for path lengths of 1 to 10 km and using curve-fitting technique, can be interpolated and extrapolated for other path lengths.

Attenuation for 0.01 % of the time for 1 to 10-km path lengths is calculated at 7 GHz. This frequency is chosen as it is in the middle of the spectrum that is usually used for terrestrial and satellite links. Reduction factor r is then deduced from these calculations.

III Rain rate for 0.01% of the time ($R_{0.01}$)

An important parameter in rain attenuation studies is the rain rate for 0.01% of the time or $R_{0.01}$. For a period of one year (364.25 days) which is equivalent to 524,5200 minutes, 0.01% of the time will be for 52.45 minutes. The determination of the rain rate for 0.01 percent of the time or $R_{0.01}$ comes from the fact that a good system must provide at least 99.99% reliability. Design and system engineers use this value to construct communications system such that the link is available for 99.99% of the time. I.e. the link can only be down for only for a total time of 52.45 minutes for the entire year. Systems built with this value ensure reliable microwave link and guarantee customer satisfaction. ITU-R has recommended the use of this parameter for attenuation studies.

The $R_{0.01}$.value obtained from the radar data is 120.9 mm/hr. This value is compared with $R_{0.01}$ values from the Meteorological Department in Johor [5] and ITU-R [6]. These values are given in Table 1.

Table 1. $R_{0.01}$ values from radar data, Johor Bahru and ITU-R

Source	$R_{0.01}$ value
Radar Data	120.9 mm/hr
Johor Bahru	120 mm/hr
ITU-R	120 mm/hr

The $R_{0.01}$ value from the radar data is comparable to the values obtained from the Meteorological Department, which is a long-term measurement, and the value from ITU-R.

IV Calculation of Attenuation due to Rain

Formulation of the reduction factor r from radar data followed the basis adopted by Goddard and Thurai [7]. The reduction factor r can be found using

$$r\,(t) = \frac{A_d\;(t)}{\gamma_s\;L} \qquad (1)$$

where r(t) is the reduction factor for a given time percentage, $A_d(t)$ is the radar derived total attenuation at corresponding time percentage (dB), γ_s is the specific rain attenuation at same time percentage (dB/km), and L is total path length (km).

The next step is to find $A_d(t)$. Using the values recommended by ITU-R [8] for the k and α coefficients at 7 GHz; value for the rain attenuation at this frequency is calculated. Thus, knowing the rain rate for each kilometer of each of the virtual links, the total attenuation due to rain for each virtual links can be obtained.

The distribution of the attenuation for 1-km path length for links operating at 7 GHz is given in Table 2.

Table 2 Distribution of attenuation for 1-km links operating at 7 GHz.

Attenuation (dB)	Number of readings for each attenuation value	Percent
0	4743844	85.241
0.082323	818496	14.707
0.631	1427	0.025641
1.1135	727	0.013063
1.9612	378	0.0067922
3.4549	203	0.0036477
6.0862	125	0.0022461
Total	5565200	100

The best-fit curve for the data in Table 2 with attenuation values as the y-axis and percentage as the x-axis is as shown in Figure 2. From Figure 2, the attenuation value for 0.01% of the time for the 1-km path links operating at 7 GHz is obtained. The attenuation distributions of all 1 to 10-km path links operating at 7 GHz are obtained in a similar manner. Table 3 gives the attenuation for 0.01% of the time for 1 to 10-km path links.

The specific rain attenuation, γ_s is calculated using [9,10]

$$\gamma_s = k\,R^{\alpha} \qquad (2)$$

Using Equation 1, Table 3, and Equation 2, the reduction factors for path lengths of 1 to 10-km at frequencies of 7 GHz are calculated. The reduction factor values are tabulated in Table 4 and plotted in Figure 3.

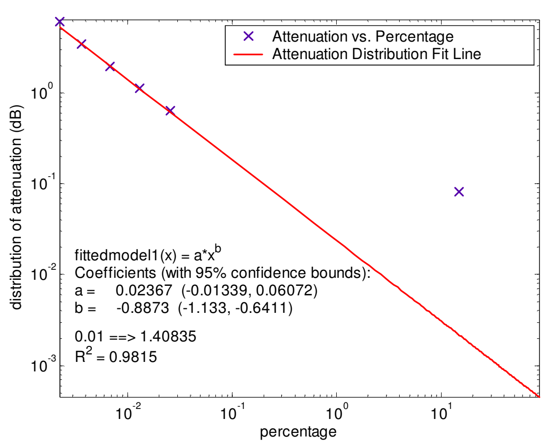

Figure 2 The best-fit curve for 1-km path links attenuation distribution.

Table 3 Attenuation (dB) for 0.01% of the time; at 7 GHz for path lengths of 1 to 10-km.

Path length	Attenuation (dB)
1-km	1.40835
2-km	2.62741
3-km	2.91245
4-km	3.17858
5-km	3.33466
6-km	3.49907
7-km	3.66776
8-km	3.84256
9-km	3.99616
10-km	4.14

Table 4 Reduction factor (r) values for 1 to 10-km path lengths at 7 GHz for 0.01% of the time.

Path length (km)	r
1	0.98465
2	0.91848
3	0.67875
4	0.55558
5	0.46629
6	0.40773
7	0.36633
8	0.33582
9	0.31044
10	0.28945

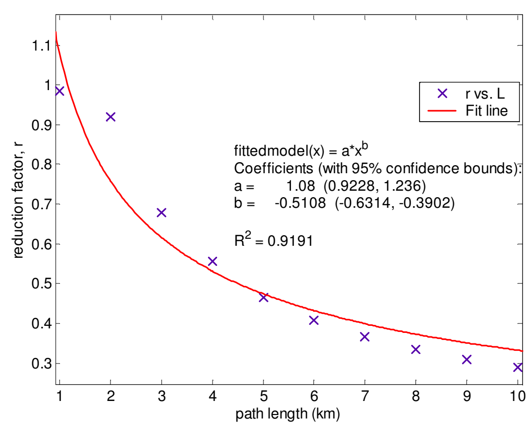

Figure 3 Reduction factor (r) plots for 1 to 10-km path lengths at 7 GHz for 0.01% of the time.

From the curve fit line in Figure 3, the proposed reduction factor model is given by

$$r = 1.08\,L^{-0.5108} \qquad (3)$$

where L is the path length in km.

The proposed model is compared with available models. These models are the Improved CETUC [11], Goddard [7], and ITU-R [12] models. This comparison is shown in Figure 4.

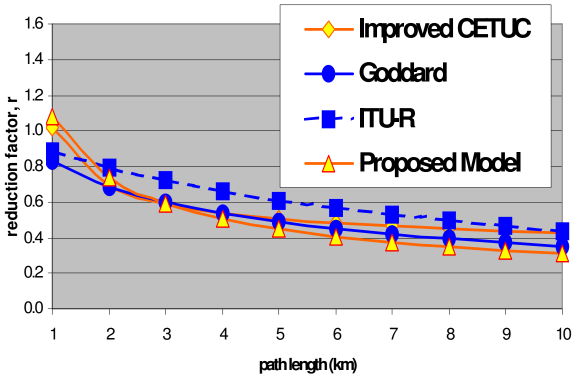

Figure 4 Comparison of reduction factor models.

5.0 Conclusion

This study proposed a reduction factor model that is derived using the Malaysian Meteorological radar data. It has a curve that is comparable to other models. The $R_{0.01}$ obtained in this study agrees very well with other sources.

References

[1] Nor Hisham Haji Khamis, Jafri Din, and Tharek Abdul Rahman, "Determination of Rain Cell Size Distribution For Microwave Link Design in Malaysia," *RFM 2004* October 5 - 6, 2004, Selangor, Malaysia.

[2] Goddard, J.W.F., "The Chibolton Rain Radar," *IEE Colloquium on National Radio Propagation Programme*, 8 January 1991, pp. 3/1 – 3/3.

[3] Japan Meteorological Agency, *Weather Radar Manual*, October 1979.

[4] Lahaie, P., Lecours, M., Bellon, R.A., "Use of Meteorological Radar Images to Build a Rain Attenuation Prediction Model for Terrestrial Microwave Radiocommunication ," *Canadian Conference on Electrical and Computer Engineering*, 14-17 Sept. 1993, vol.1, pp.68 - 71.

[5] S. K. A. Rahim, "Study of microwave signal attenuation over terrestrial link at 26 GHz in Malaysia," *Master Thesis*, Universiti Teknologi Malaysia, Skudai, Johor, May 2001.

[6] ITU-R P.837-4 Characteristics of precipitation for Propagation Modeling.

[7] Goddard, J.W.F., and Thurai, M., "Radar-Derived Path Reduction Factors for Terrestrial Systems," *IEE 10th International Conference on Antenna and Propagation*, 14-15 April 1997, Conference Publication No. 436, pp. 2.218-2.221.

[8] ITU-R P.838-1 Specific Attenuation model for rain for use in prediction methods.

[9] Rogers, R.R., "Statistical Rainstorm Models, Their Theoretical and Physical Foundations," *IEEE Trans. On Antennas and Propagation*, vol. AP-, no., July, 1976: pp. 547-566.

[10] Olsen, R.L., Rogers, D.V., Hodge, D.B., "The aRb Relation in the Calculation of Rain Attenuation," *IEEE Trans. On Antennas and Propagation*, vol. AP-26, no. 2, March 1978, pp. 318-328.

[11] Perez Garcia, N.A., et al, "Improved method for prediction of rain attenuation in terrestrial links," *Electronics Letters* vol. 40, no. 11, 27 May, 2004, pp. 683-684.

[12] ITU-R P.530-8 Propagation Data and Prediction Methods required for the design of Terrestrial Line-Of-Sight Systems.