Site Diversity Gain Estimated from Rain Rate Records

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Abstract. *The site diversity is used to mitigate the rain attenuation on satellite links. The attenuation is estimated through the rain rate-rain attenuation conversion based on the Assis-Einloft physical model in this study. Through the comparison of instantaneous attenuations at two receiving sites the site diversity gain is estimated. Examples of rain rate measurements in the Czech Republic followed by the site diversity gain estimation are added. This gain is greater on west-east situation of receiving sites achieving 10 dB on 0.01% exceedance level/100 km.*

Keywords

Site diversity, rain attenuation, satellite links, microwave communication.

1. Introduction

When planning microwave links (i.e. reasonable transmitter power, antenna diameters, receiver noise number etc.) it is, in addition, necessary to take into account the atmospheric attenuation, especially its major component that is caused by rain. According to the international conventions, the considerations are based on the cumulative distribution of the atmospheric attenuation corresponding to the „average year“ and „average worst month. The exemplary question, “what is the probability that the rain attenuation will exceed 10 dB” is to be answered very frequently.

The rain rate measurement and its statistical processing enable to estimate the rain attenuation statistics in a cheap way when compared with the direct attenuation measurement. Many models are used to convert the rain statistics into the attenuation ones as well as various mitigation methods are used to compensate the atmospheric (e.g. rain) attenuation.

2. Fade Mitigation

The site, frequency, time and polarization diversities belong to methods used to mitigate the degradation of radio signal caused by the atmosphere. This contribution is focused on the site diversity gain estimation based on the meteorological measurement.

The site diversity supports the enhancing of the reliability of satellite communications. The operating center compares signals being received at two or more sites and selects the less attenuated signal operatively. This switched signal is also less attenuated from the statistical point of view as the probability that the heavy rain occurs at two or more sites at the same moment decreases with the increasing distance between satellite signal receivers.

A direct way to evaluate the site diversity gain is the attenuation measurement at all receiving sites. This is rather expensive. Through the measurement using more rain gauges distributed over the territory of interest the site diversity gain can be roughly estimated.

There remains a problem: how to derive the rain attenuation from the rain rate. There are many models being suitable to estimate the rain attenuation distribution but not the instantaneous attenuation. Only through comparisons of instantaneous attenuations at different localities the site diversity gain can be evaluated. The physical Assis-Einloft model converting rain rates into attenuation was chosen in this contribution.

3. Description of Selected “Rain Rate-Rain Attenuation” Conversion Model

The Assis-Einloft model [1] converts the rain rate into the rain attenuation at given frequency and polarization. By other words the attenuation (in dB) is obtainable as a function of the independent variable rain rate on one hand and as a function of the link parameters (frequency, polarization, path length) on the other hand.

Even if the natural Assis-Einloft model was intended to compute the distribution of rain attenuation, its principle is suitable to estimate the instantaneous attenuation, which we use for the comparison of concurrent attenuations in order to estimate the site diversity gain.

This statement was also proved in the Hajný-Fišer model. This Hajný-Fišer model [2] is also using the Assis-Einloft’s modeling of the rain volume to compute the biscattering interferences due to rain. The results were successfully compared with the ITU-R method.

The Assis-Einloft model assesses the rain rate profile along the path of a radiocommunication link. The profile consists of two cylindrical parts. Constant rain rates occur in both of them. The diameter D of the inner cylindrical rain cell is

$$D=2.2(100/R)^{0.4} \quad \text{(km, mm/h)} \tag{1}$$

while the concentric external cylindrical rain cell ranges 33 km. The rain rate in the inner rain cell is R (R is measured by the rain gauge) while the rain rate R_0 in the external rain cell is

$$R_o=10\,[1-\exp(-0.0105R)] \quad \text{(mm/h, mm/h)} \tag{2}$$

Rain attenuation in one part is simply evaluatable through the product of the specific rain attenuation α and the rain area length where the rain rate is constant. The total attenuation in the rain volume is therefore given by the following formula:

$$A(R)=\alpha(R)\,D(R)+\alpha(R_o)[L_m-D(R)] \quad \text{(dB)} \tag{3}$$

where R is the rain rate (mm/h) measured by the rain gauge, L_m = min {33 km, L}, L is the length of the link (km), $\alpha(R)$ is the specific rain attenuation (dB/km, $\alpha \sim a\,R^b$; {a,b} are constants published like functions of the frequency and polarization in many tables of ITU-R, CCIR and in other contributions).

Remark: if $L<D(R)$

$$A(R) = \alpha(R)\,L \tag{4}$$

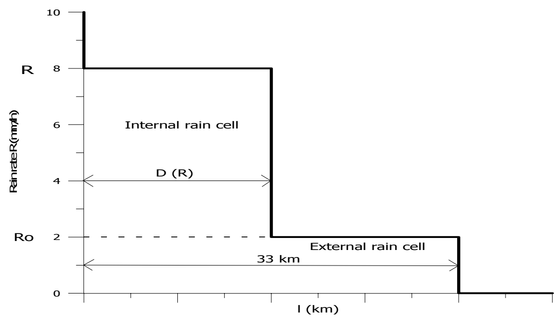

Fig. 1. The horizontal geometry of the Assis-Einloft model.

The model can be applied to terrestrial links in this described form directly. It works on satellite links similarly; we must be aware that the satellite link length in rain volume is derivable from the elevation angle Θ and the rain height. For the illustration purposes we chose a hypothetical satellite link where the rain height is 4 km and the elevation angle $\Theta=7.5^o$. The height of 4 km is often used in simple rain height models for middle climates. Then the 7.5^o elevation corresponds to the 33 km terrestrial path length approximately. The length of the link crossing the rain cell is obviously L =4 km/sinΘ.

Fig. 2 shows the ratio of attenuation (in dB) for different elevation angles related to the attenuation corresponding to the elevation angle $\Theta=7.5^o$. It can be used to estimate the attenuation for other elevation angles of satellite links. It is worth mentioning that the attenuation does not depend on the elevation monotonically and the deviation does not exceed +5% and –20% considering attenuation above 3 dB (at elevation $\Theta=7.5^o$).

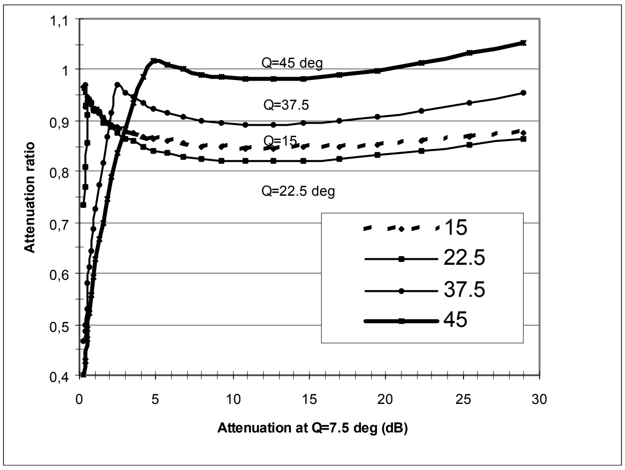

Fig. 2. The ratio of attenuation at given elevation to the attenuation at elevation $\Theta=7.5^o$, frequency is 12 GHz, the elevation angle Θ is a parameter.

4. Description of Czech Rain Rate Measurements Applied to Site Diversity Gain Estimation

The Institute of Atmospheric Physics Prague measures rain rates at 4 sites over the Czech territory. These sites are in Prague, Bořislav (70 km north to Prague) and in two sites in the town of Hradec Králové (100km east to Prague, first site "H1" is located at the astronomic observatory, second site "H2" lies close to the "U Náhona" Street). The mutual rain rate correlations and the distances between sites of measurements are shown in Tab. 1. One can notice that the correlation decreases with the distance as expected (Fig. 3); its value follows roughly the function

$$\text{Corr} \sim 31 \exp(-0.0157\, l) \quad (\%) \tag{5}$$

where l is the distance in km; coefficient of determination $Rdet^2$ achieves 96%.

Site	Code	PRG	BOR	H1	H2
Prague	PRG	*	**70 km**	**100 km**	**97 km**
Bořislav	BOR	10.9 %	*	**141 km**	**139 km**
Hradec Králové	H1	5.5 %	2.2 %	*	**8 km**
Hradec Králové	H2	5.8 %	4.3 %	30 %	*

Tab. 1. Mutual correlations between the rain rate responses at four measurement sites in CR. The distance in km (bold) is also added.

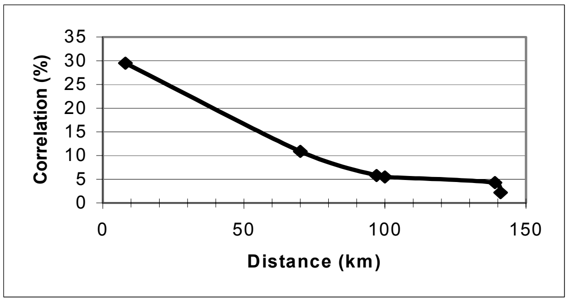

Fig. 3. Correlation between rain rates at various sites as a function of the distance.

The Tipping-bucket rain gauges (with the 0.2 mm rain amount resolution) were used in the described measurements. The distribution function of rain rates (integrated in one minute periods) is shown in Fig. 4. One can notice higher rain rates at both sites in Hradec Králové in comparison with sites in Prague and Bořislav. These results (from period June 1 to September 30, 2001) were applied to estimate the site diversity gain.

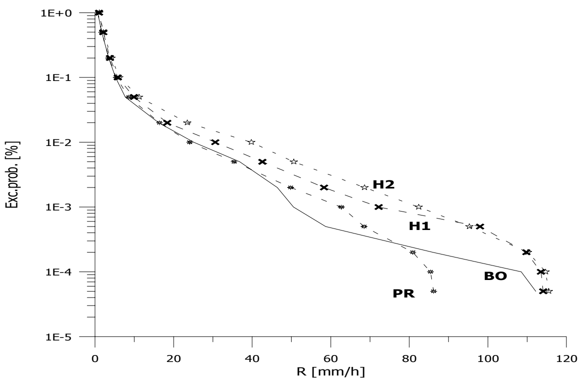

Fig. 4. The rain rate distribution at 4 localities in CR. (PR=Prague, BO=Bořislav, H1(2)=Hradec Králové 1(2). The June 1 to September 30, 2001 period is considered.

5. Estimation of Site Diversity Gain

The tipping-bucket rain records from four mentioned sites were converted into the time series of average one-minute rain rates. The technique described in [3] was applied. Using the method from paragraph 3 of this study the rain rate series were converted into the attenuation ones. Both series consist of the same one-minute intervals.

The couples of attenuations A(dB) from all possible pairs of measurement sites (X and Y) at every calendar minute were compared. Then the distributions of attenuation from its time series A(site X), A(site Y) and A(diversity XY) were computed, while

$$A(\text{diversity XY}) = \min \{ A(\text{site X}), A(\text{site Y})\} \qquad (6)$$

The diversity gain DG for site X at P(%) exceedance level is defined as

$$DG\ (P,X,XY) = A(P,X) - A(P,\text{diversity XY}) \qquad (7)$$

$$DG\ (P,Y,XY) = A(P,Y) - A(P,\text{diversity XY}) \text{ etc.} \qquad (8)$$

The results are summarized in Tab. 2. The diversity gain (left column corresponds to the value of the first site of the pair) is printed for given exceedance probability levels (0.1, 0.01 and 0.001 %). It is obvious that the site diversity gain is smaller when the distance between receiving points is small. It is the case of 2 sites in Hradec Králové 1 and 2 at a distance of 8 km. Anyway the possibility to save 9 dB at the 0.001% exceedance level (8 dB attenuation instead of 17 dB attenuation) is worthy (see also Fig. 7). The reader can also see that, generally speaking, the diversity gain does not depend on the distance only but also on the direction (orientation) of the connecting line between both sites of the investigated pair. The maximum of the diversity gain occurs in the pair Prague-Hradec Králové 1 (Fig. 5) and Prague-Hradec Králové 2 because the connecting line is West-East oriented. The West-East direction corresponds to the prevailing trajectory of cold fronts. We can see lower site diversity gain when comparing these pairs with Prague-Bořislav pair oriented North-South (Fig. 6) at the comparable distance.

Pairs	Diversity Gain (dB)					
	P = 0.1 %		P = 0.01 %		P = 0.001 %	
X – Y	DG(X)	DG(Y)	DG(X)	DG(Y)	DG(X)	DG(Y)
H1-H2	1.5	2.0	6.3	7.8	9.2	9.7
PRG-BOR	1.2	1.9	6.8	7.2	7.6	10.2
PRG-H2	2.7	1.7	10.4	7.5	15.8	12.7
PRG-H1	2.3	1.8	9.1	7.6	15.3	12.7
BOR-H2	1.3	2.9	6.9	10.3	6.3	12.1
BOR-H1	1.3	2.5	7.1	9.0	9.9	15.1

Tab. 2. Diversity gain of the studied measurement site pairs (left column corresponds to the first site of the pair on given exceedance probability). Frequency 12 GHz and elevation $\Theta=7.5^o$ were chosen. For site codes see Tab. 1.

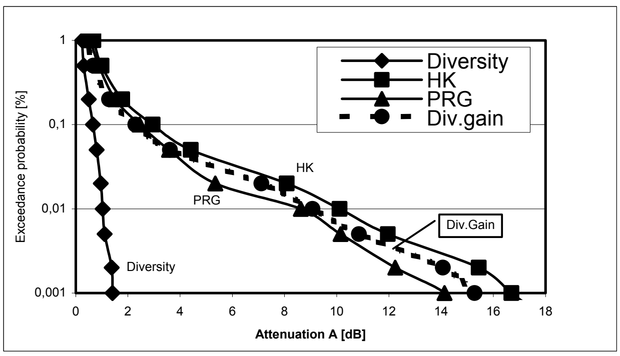

Fig. 5. Distribution of computed attenuation in Prague ("PRG") and Hradec Králové 1 ("HK"), distribution of the signal after the site diversity processing ("Diversity") and diversity gain ("Div. Gain")

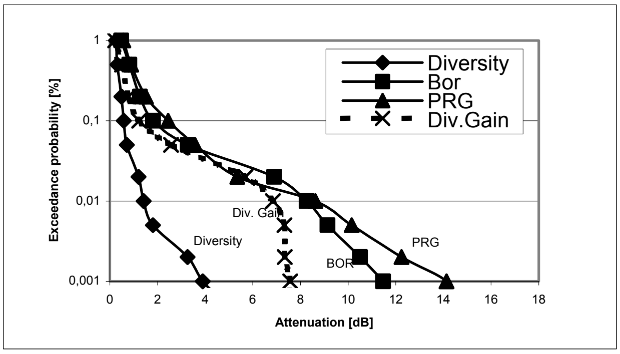

Fig. 6. Distribution of computed attenuation in Prague ("PRG") and Bořislav ("Bor"), distribution of the signal after the site diversity processing ("Diversity") and diversity gain ("Div. Gain")

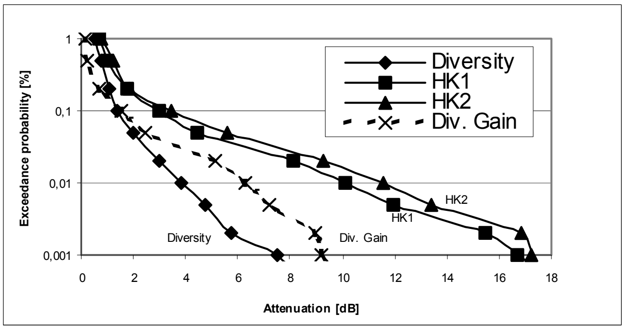

Fig. 7. Distribution of computed attenuation in Hradec Králové 1 and 2 ("HK1" and "HK2") and distribution of the signal after the site diversity processing ("Diversity") and diversity gain ("Div. Gain")

We can approximately extrapolate the results shown in Tab. 2 (frequency f_1 = 12 GHz) to other frequency f_2 using the frequency-scaling factor $F = (f_2/f_1)^2$ to multiply the 12 GHz diversity gain DG (f_1=12 GHz):

$$DG(f_2) \approx DG(f_1 = 12GHz)\,(\frac{f_2}{f_1})^2 \tag{9}$$

6. Conclusion

In this contribution an attempt to use the Assis-Einloft model to estimate the site diversity gain from recorded rain rates was shown. The actual rain rate measurements at 6 pairs of measurement sites in the Czech Republic were used to demonstrate the site diversity gain estimation at 12 GHz frequency.

The substantial results are shown in Tab. 2 and in Figures 5-7. One can see that the site diversity gain is worthy (6-10 dB on 0.01% exceedance level for distances above 8 km).

It is interesting to see that the diversity gain (increasing with the distance, as expected) does not depend on the distance only but also on the orientation of the connecting line between both sites of the investigated pair. By other words it means that the probability of the concurrent occurrence of heavy rains on west-east line is lower than the occurrence on the north - south line at comparable distance. This fact can be used by projecting the satellite signal receiving systems supported by the site diversity mitigation technique.

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References

[1] ASSIS, M. S., EINLOFT, C. M.: A simple method for estimating rain attenuation distribution. In *Proceedings of the Conference URSI*. La Baule, 1977, p. 301

[2] HAJNÝ, M., MAZÁNEK, M., FIŠER, O. Bi-static scattering function - radiation pattern calculation. In *COST Project 255, MC5 Meeting (CP51A09)*. Vigo, 1998, p. 1-17

[3] FIŠER, O. On the tipping-bucket rain measurement applied to microwave propagation (theory and actual results). In *Proceedings of URSI F Open Symposium*. Garmisch Partenkirchen, 2002 (CD).

About authors...

Ondřej FIŠER was born in Prague in 1952. He received his M.Sc. (Dipl.Ing.) degree in electrical engineering (1977) and Ph.D. degree in radioelectronics (1986), both from the Czech Technical University – FEL, specialization theory of electromagnetic field, radiowave propagation and microwaves. He works as a scientific researcher at the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic focusing on radiowave propagation through the atmosphere and radar meteorology. He is also an external lecturer of electromagnetism at the University of Pardubice.

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