Hourly Attenuation Dependence, Fade Duration and Fade Slope Derived from Radiometer Measurements

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Abstract

The use of higher frequencies in satellite communications offers larger bandwidths but channel impairments also increases. Attenuation caused by gases, clouds and light rain must not be neglected. The radiometer is able to measure accurately the in excess to free space atmospheric attenuation better than a beacon receiver. The hour of the day dependence of attenuation can be an important issue in the user perceived quality of the services provided by satellite operators. Also the rate of change of attenuation and the fade duration are very important to design effective fade mitigation systems. We present some results obtained by radiometer measurements concerning both parameters and compare the results with available models where possible.

1. Introduction

A radiometer measures the atmospheric emission converting it to the so called sky noise temperature (Tsky). Under simple assumptions T_{sky} can be translated to attenuation through the use of the equivalent mean sky noise temperature (T_{mr}). The attenuation time series measured this way is not likely to be affected by scintillation such as beacon measurements but is not accurate above a few dBs. By a suitable choice of operating frequencies, one sensitive to water vapor emission (around 22.2GHz) mainly and other to liquid water (about 30GHz) an estimation of atmospheric integrated liquid water (L) and water vapor (V) contents can be made and so attenuation can be scaled to others frequencies. The results here presented were obtained in a long term experiment using a water vapor radiometer.

2. Radiometer Database Characterization and Data Processing

The experiment took place in Aveiro, Portugal during which four consecutive years of good data was collected with the radiometer pointing to former Olympus satellite with 42º elevation and 11º azimuth. The radiometer had three spectral lines: 21.3, 23.8 and 31.7GHz and T_{sky} was collected at a rate of 15S/minute. Radio sounding data from Lisbon was processed with a radiative transfer model to fine tune T_{mr} and mass absorption coefficients needed in V and L retrieval. All data analysis stages were performed with Matlab developed programs.

Preprocessing stage consisted of the screening of all measured time series, repair, classification and finally calculations of attenuation (Eq. 1 with T_c=2.7K) ceiled to a maximum of 11dB, I and V. All the time series, together with equal size corresponding quality flags, were stored in a comprehensive file directory structure.

$$At = 10\log\frac{T_{mr} - T_c}{T_{mr} - T_{sky}} \text{ [dB]} \tag{1}$$

The V and L retrieval can severely be contaminated due to precipitating water (rain). Two approaches excluded suspicious rain contaminated V and L data: one by removing full half days where rain was reported and

another by putting thresholds in measured sky noise. Data has been published elsewhere [1].

Processing consisted in a fully automated procedure that, in a monthly basis, loaded pre-processed data and performed several statistics including fade dynamics ones: fades and inter fades duration. In a recent work data was revisited to obtain fade slope[2] and day hour dependence of attenuation.

3. Hourly Attenuation Dependence

Attenuation results for two years are presented in the following Fig. 1 and Fig. 2 as cumulative distributions (CDs) given each four hours. It can be observed for less than 1dB there are no significant hourly variations. The rainy time is typically less than 2% of the total year so any hour variability here is due to water vapor and clouds.

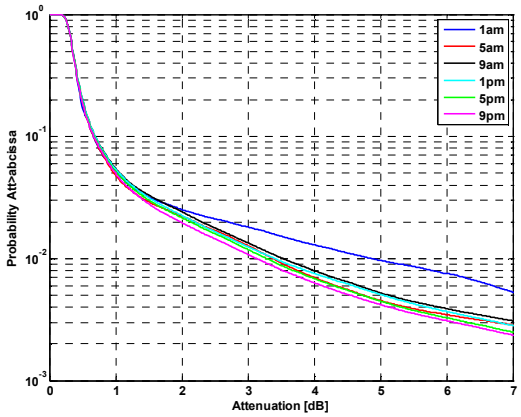
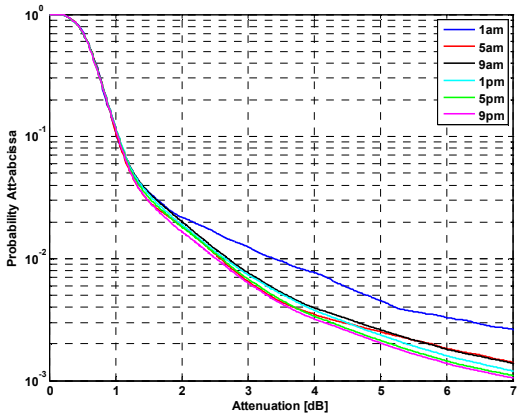


Figure 1 – Year 1994 CD´s - 31.7GHz



a) 23.8GHz

Figure 2 – Year 1994 CD´s - 23.8GHz

For attenuation above 1dB hour variability exists but it is not consistent from year to year. From a long time point of view however (Fig. 3 and Fig. 4), we can observe that hour variability is very small and even negligible bellow 2dB and the differences are less than 0.6dB for all time percentages up to 0.1% of the time. The 1am CD crosses the other hourly data around 10dB (not shown) so, pending the possible errors in attenuation for such thresholds, seems to indicate that moderate rain rates are more likely around early night time.

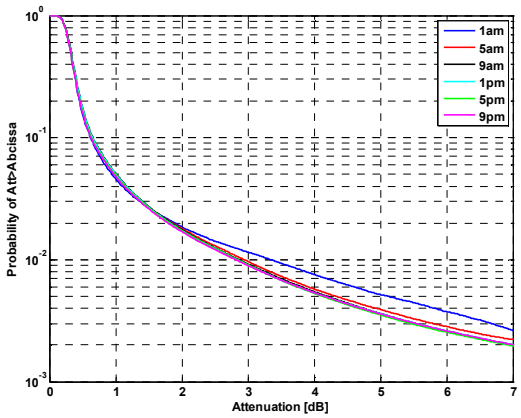


Figure 3 – Four Years CD´s: 31.7GHz

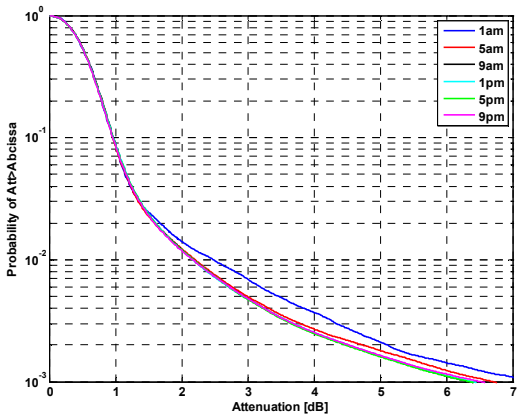


Figure 4 – Four Years hourly CD: 23.8GHz

4 Fade Dynamics

Dynamic aspects of the attenuation have deserved much attention on the propagation community. Fade slope can, to a certain extent, provide a prediction of what will be the fading in a near future and that is important information to design power control loops for fade mitigation techniques.

Fade duration statistics provide information of system outage and unavailability that is an immediate perceived quality of service but also as impact on system design down to coding and modulation of the information.

4.1 Fade Slope

Fade slope depends on the atmospheric mechanisms (rain cell development and movement, index of refraction irregularities, scattering on rain drops, etc), link parameters, propagation data conditioning (filtering) and the way it is calculated. The last two factors involves the low pass filter cutoff frequency (f_B) and the interval length (Δt) that, while conditioned to attenuation threshold, are up to now the parameters involved in the calculation of the probability density (pdf) of fade slope on the ITU-R P.1623 recommendation[3].

For fade slope analysis attenuation time series was filtered with 20, 40 and 60s integration time. For each filter several Δt values were used (8, 16, 32, 48, 64s) and the slope calculated at 1, 2, 3, 5 and 7dBs thresholds.

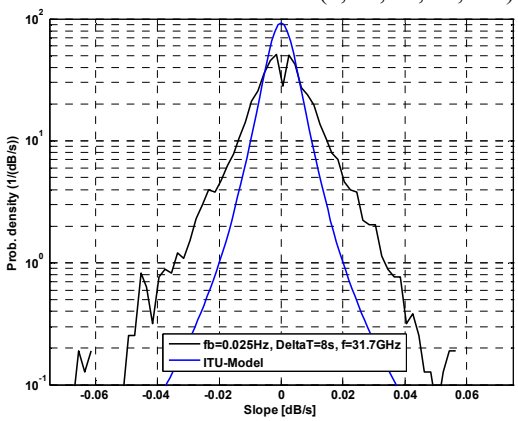


Figure 5 – Fade slope pdf and model (1dB)

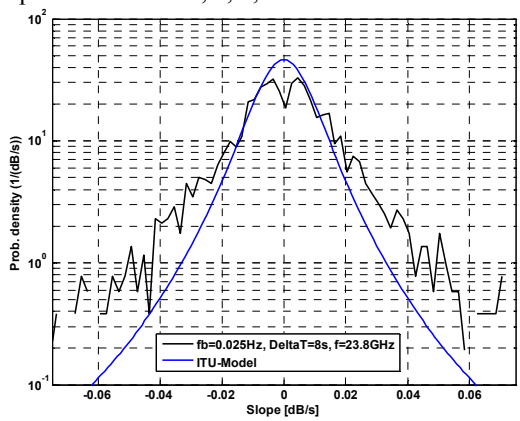


Figure 6 – Fade slope and model (2dB)

Fig. 5 and Fig. 6 depict two sample results from the all possible 75 combinations together with the above ITU Rec predicted pdf. These thresholds must have a contribution of mainly rain and clouds at 31.7GHz and rain and water vapor at 23.8GHz. The experimental pdf is a little bit asymmetric (median ~-0.005dB/s) and as a wider shape than that predicted by the model. Attenuation retrieval errors are not likely for these thresholds. Qualitative dependencies on Δt and f_B are however clearly verified by the database.

4.2 Fade Duration

The ITU model grossly divides the fade duration events in two ranges: from 1 up to about 30s (events determined by scintillation) and longer duration range. The model predicts the probability of having an event with duration longer than D –P(d>D/A)- as a power law for first range and by a lognormal distribution for the second one. The lognormal is described by median duration D_0 and σ the standard deviation of the log duration.

Results (Fig. 7 and 8) show that fade duration conforms very well to the lognormal distribution down to 4s duration. The estimated parameters are given in Table 1 (4 years data and between 500 minimum to 20k events). That is most of the expected contributions for the shorter duration events are clearly excluded with the intrinsic 0.125Hz cutoff frequency of the radiometer measurements. A pronounced deviation is however observed for 21.3GHz, 1dB threshold mainly (and also 31.7GHz) probably due to the water vapor and clouds attenuation.

Table 1 Lognormal fade duration parameters: 31.7 and 21.3GHz

Frequency	Parameter	1dB	3dB	5dB	7dB
31.7GHz	σ	1.75	1.55	1.41	1.39
	Do(s)	55	72	72	70
21.3GHz	σ	2.1	1.46	1.34	1.32
	Do(s)	20	63	69	67

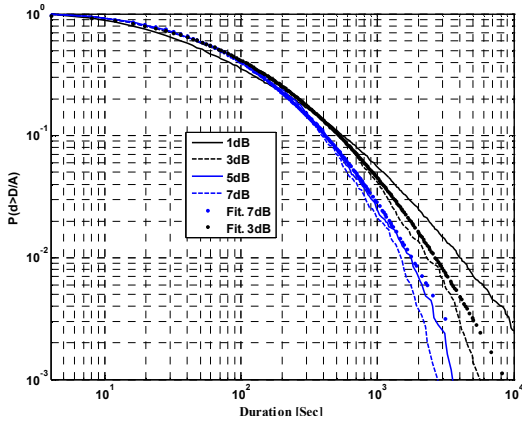


Figure 7 – Prob. of event longer than abscissa

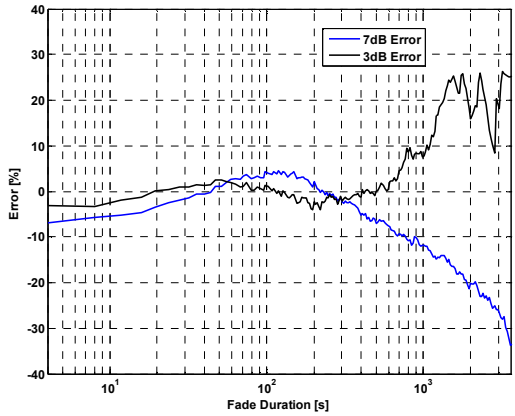


Figure 8 – Fitting errors (up to 3600s)

The fitting error, as calculated by Eq. (2), in the duration range of main interest (up to 3600s) is depicted in Fig. 8.

$$\varepsilon = 100.\ln \frac{P(d > D/A)_{Fitting}}{P(d > D/A)_{Exp}} \quad [\%] \tag{2}$$

5. Conclusion

There is not a marked hourly dependence of attenuation at least up to 7dB in spite of a much wider variation in a yearly basis. Such conclusion must be checked later by inspecting in the same period the available hourly rain rate.

Fade duration seems to be described essentially by a lognormal distribution from 4s and upwards. Median time is very similar for all thresholds except 1dB. Fade slope distribution density seems to give a wider spread than expected as well as a slightly no symmetrical behavior. Maybe the examination of other thresholds behavior and beacon data being collected at the site will give more insight on these preliminary results. Radiometer “senses” mainly the propagation volume closer to the antenna but as a larger beamwith than our beacon antenna so direct comparisons must nevertheless be careful.

A further step on the radiometer database study has been completed and we are planning to submit the data to ITU data bank.

6. Acknowledgments

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7. References

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3. Rec. ITU-R P.1623, "Prediction Method of fade dynamics on Earth space paths", ITU Recommendation