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Nine Years of Excess Attenuation Statistics of Earth-Space Propagation Experiments at Ka-Band in Toulouse, France

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Abstract—Since 2009, ONERA has been running a Ka-band propagation experiment in Toulouse (south of France). A rain gauge, a microwave profiling radiometer and a beacon receiver able to record the 19.7 GHz signal from Hot Bird 6 satellite and the 20.2 GHz signal from Astra-3B satellite have been deployed. This paper gathers nine years of results from the still ongoing experiment. The annual, monthly and seasonal complementary cumulative distribution functions of rain attenuation are presented. A comparison is made with the annual rain attenuation prediction method of Recommendation ITU-R P.618-13 and its dispersion given by Recommendation ITU-R P.678-3. Fade slope and fade duration statistics are studied for different attenuation thresholds.

Index Terms—propagation, Ka-band, measurements, satellite communications.

I. INTRODUCTION

More and more satellite communication systems are being deployed at high frequency bands (between 18 and 50 GHz), to benefit from wider bandwidth with respect to lower frequency bands in order to offer high data rate multimedia services. The use of these high frequency bands (Ka and Q/V bands) is however limited by the influence of the propagation channel through the troposphere whose impact can be reduced on feeder links by the implementation of gateways in site diversity configuration. The influence of the propagation channel for the Fixed Satellite Service has been extensively studied in the past 30 years and propagation prediction methods have been developed and tested with respect to experimental campaigns [1]. Some of these propagation experiments took place in Europe [2][3], Japan[4] and in the USA [5]. ONERA developed propagation Earth stations to participate to the propagation experiment that had been planned with the satellite STENTOR. These stations have been designed to receive the 20.7 GHz and 41.4 GHz beacons of STENTOR [6]. After the unfortunate loss of the satellite, tests have been carried out to try to collect the 20.7 GHz beacon of the GBS satellite but without success because of the inclination of the orbit that prevented to receive this satellite with the antenna of the ONERA Earth station (1.2 m diameter) and without tracking system. At this time, it was decided to modify one of the

Earth station RF chain in order to be able to receive the 19.7 GHz beacon of the EUTELSAT HotBird 6 satellite. ONERA ran a propagation experiment in Toulouse with the 19.7 GHz beacon of EUTELSAT HB6 from January 2008 to March 2011 [7], then from March 2011 up to now the propagation Earth station has been tracking the 20.2 GHz beacon of ASTRA-3B [7][8].

The results shown in this paper provide long term (nine years) results for a fixed measurement site in a temperate region in Western Europe. Long term experiments are necessary to compute both stable annual attenuation CCDF and seasonal CCDF. With respect to other measurement campaigns, such as [2][3][4][5], the novelty relies both in the duration and the location of the experiment. Therefore, this work brings new insights for the dimensioning of Earth-Space satellite systems.

Section II of this paper describes the main characteristics of this propagation experiment. The space and ground segments are described succinctly. Section III provides statistical analyses of rain attenuation at Ka-band. Annual, monthly and seasonal complementary cumulative distribution functions (CCDF) of rain attenuation are presented. A brief comparison is made with the annual rain attenuation prediction method recommended in ITU-R P.618. Finally, fade slope and fade duration are studied for different attenuation thresholds.

II. DESCRIPTION OF THE PROPAGATION EXPERIMENT

A. Space Segment

Hotbird 6 was launched on 2002 on the geostationary orbit at a longitude of 13°E. The Ka-band payload of the satellite boarded a downlink beacon operating at 19.7 GHz and whose EIRP was around 18 dBW in Toulouse.

Astra-3B was launched on May 2010 on the geostationary orbit at a longitude of 23.5°E. The Ka-band payload of the satellite transmits a downlink beacon operating at 20.2 GHz in vertical polarization and whose EIRP is around 29 dBW in Toulouse.

B. Ground segment

The experiment is located on the roof of the DEMR building of ONERA at 43.5710°N and 1.4716°E. Astra-3B is received at an elevation of 35.11° and an azimuth of 147.57°. The climate normals in Toulouse, computed over the period 1981-2010 are the following [9]: the mean number of rainy days is 95.7 days/year, and the mean rainfall amount is 638.3 mm/year. In July 2009, a Ka-band beacon receiver, a radiometer and a rain gauge were deployed on this site to study propagation effects and to generate the relevant statistical distributions. The rain gauge is a dual-chamber tipping bucket rain gauge with 1 second of resolution and 1 min integration time. Its collecting area is 500 cm² and bucket capacity is 0.1 mm. The rain gauge data are converted into rain rate measurements (in mm/h) according to the methodology described in [10]. The data from the rain gauge allows checking the consistency of the beacon receiver data, given that most of the time the attenuation observed in the beacon receiver data corresponds to rain rate derived from the rain gauge data for the same period of time. This is not true, however, when the rain cells are located between the beacon receiver and the satellite beacon antenna and not on the experimental site. The radiometer is a Radiometrics TP-WVP 3000, operated almost continuously since 1999. It is able to retrieve vertical profiles of water vapor, liquid water and temperature from sky brightness temperature measurements for 5 channels between 22 and 29 GHz and 7 channels between 52 and 59 GHz. The radiometer is used to estimate accurately the 0 dB reference attenuation level in the beacon measurements. The beacon receiver is composed of a 1.2 m parabolic antenna with a RF chain immediately placed at the output of the antenna in order to avoid feed losses. A first down-conversion is done from Ka-band to 110 MHz and a second one from 110 MHz to 10 MHz. Then, the signal is digitized and processed by a signal processing card. The data processing tool, presented in [7], is highly inspired from the methodology defined during the OLYMPUS Propagation experiment (OPEX) [2][11][12]

III. STATISTICAL ANALYSES

Nine full years (July 2009 to July 2018) of data have been processed. Daily rainfall rate and rain attenuation time series have been produced and statistical analyses of excess attenuation have been performed.

Fig. 1 shows the CCDF of rain attenuation generated from July 2009 to July 2018, both from Hotbird 6 and Astra3B experimental data.

A brief comparison with the rain attenuation statistics prediction method of recommendation ITU-R P.618-13 has been performed. It shows a slight over-estimation of the predictions performed with Recommendation ITU-R P.618-13 in Toulouse. As mentioned in Recommendation ITU-R P.618-13, when comparing measured statistics with the prediction, allowance should be given for the rather large year-to-year variability in rainfall rate statistics. Therefore,

the dispersion computed using Rec. ITU-R P.678-3 is presented on Fig. 1 and shows some underestimation of the inter-annual variability observed over the 9 years for time percentages lower than 0.1 %. One could note that the 2010-2011 and 2012-2013 CCDFs are out of the dispersion for attenuation probabilities lower than 1%.

Fig. 2 gives the monthly CCDF of rain attenuation from the ASTRA-3B 20.2 GHz beacon measurements. A large month-to-month variation can be observed showing that the variability of rain attenuation needs to be modelled on a monthly basis too.

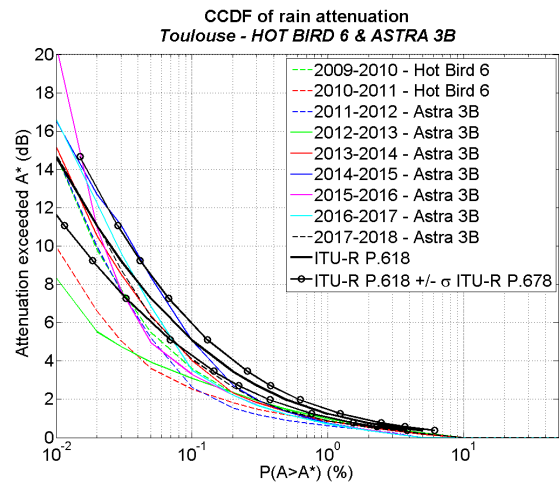


Fig. 1. Annual CCDF of excess attenuation in Toulouse from July 2009 to July 2018 (9 years) and comparison w.r.t. ITU-R P.618 and ITU-R P.678.

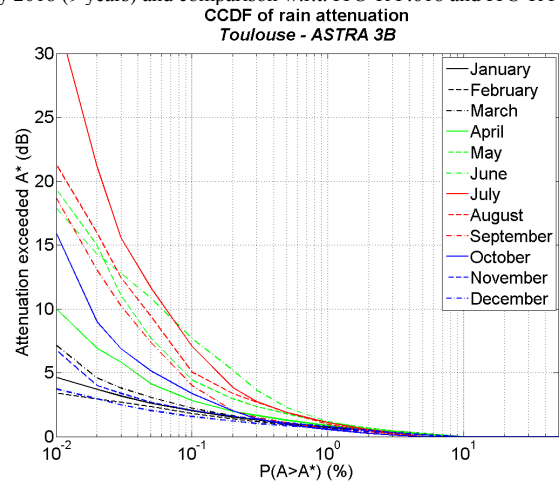


Fig. 2. Monthly CCDF of rain attenuation at 20.2 GHz (7 years of data).

Fig. 3 to Fig. 6 represent the dispersion of seasonal variations of excess attenuation on Astra-3B 20.2 GHz beacon measurements (that is over 7 years). In those plots, winter is considered from January to March, spring from April to June, summer from July to September and autumn from October to December.

As expected, the highest attenuation values occur in summer while the lowest values occur in winter. Whatever the month, the rain attenuation values range from 2 dB to 8 dB for a probability of exceedance of 99.9% and from 4 dB to more than 30 dB for a probability of exceedance of 99.99%. On the other hand, the weaker variability appears in winter, when precipitations are more of stratiform shape.

Fig. 7 shows the CCDF of exceeded fade slope. The considered attenuation thresholds are: 3 dB, 5 dB, 10 dB and 15 dB. A time interval of 60 s has been selected to compute fade slope values [7], in order to avoid a filtering distortion effect. It can be noticed that the higher the attenuation thresholds, the higher the probability to find strong local attenuation slope values. For a 3 dB threshold, 0.1 dB/s is exceeded over 60 s for more than 0.1%. For a 15 dB threshold, 0.3 dB/s is exceeded over 60 s for more than 0.1%.

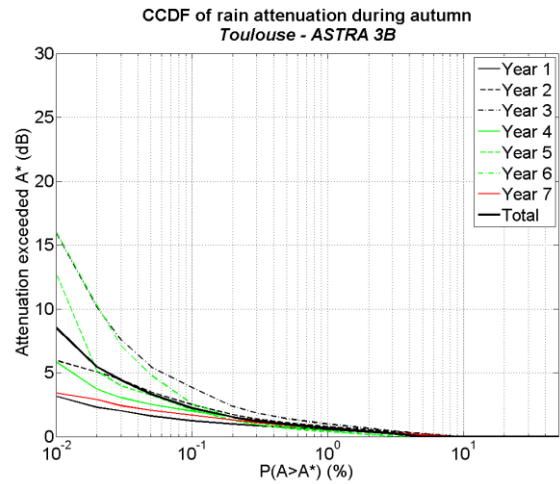


Fig. 5. CCDF of autumn excess attenuation in Toulouse from 2012 to 2018.

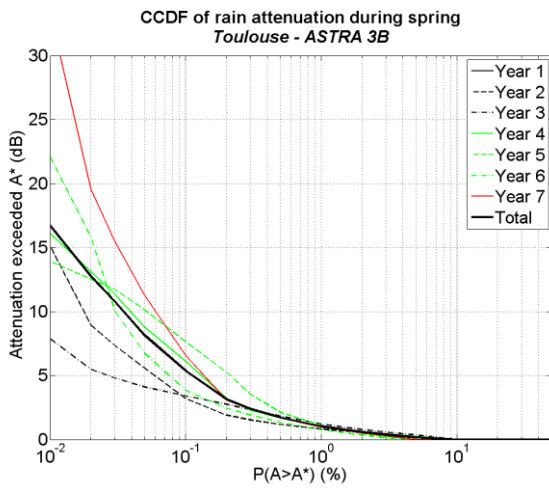


Fig. 3. CCDF of spring excess attenuation in Toulouse from 2012 to 2018.

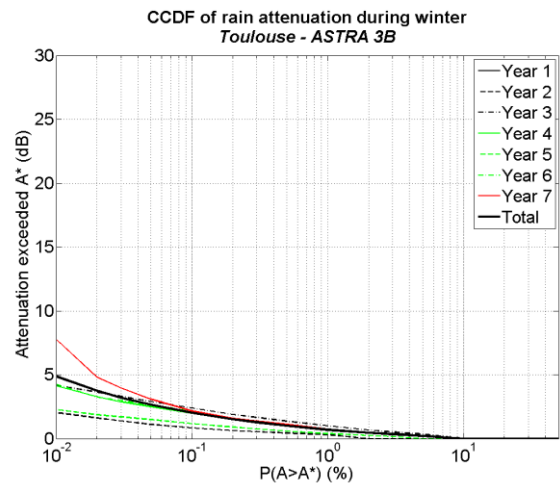


Fig. 6. CCDF of winter excess attenuation in Toulouse from 2012 to 2018.

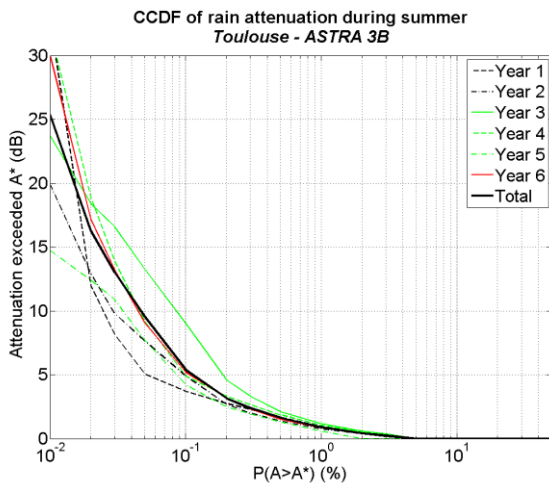


Fig. 4. CCDF of summer excess attenuation in Toulouse from 2012 to 2018.

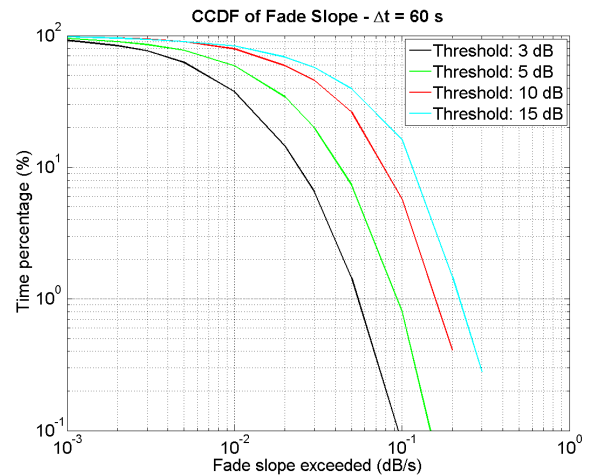


Fig. 7. CCDF of attenuation slope for Astra-3B.

Finally, Fig. 8 and Fig. 9 show respectively the relative number of fades and their duration for different thresholds. In Fig. 8 for durations longer than 200 s no monotonic behaviour with respect to threshold is observed. In Fig. 9, a monotonic behavior with respect to threshold is observed for more than 40% of the relative fade time. Lower values of the relative fade time correspond to more heterogeneous phenomena, thus leading to non-monotonic behavior. Therefore, the results need to be further investigated by using the full 10 years datasets (the last year has not been processed yet) and by studying the dispersion of fade dynamics statistics.

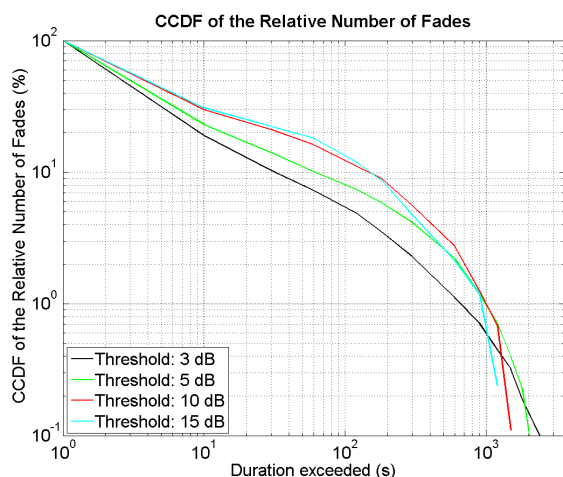


Fig. 8. CCDF of the relative number of fades for different thresholds for Astra-3B.

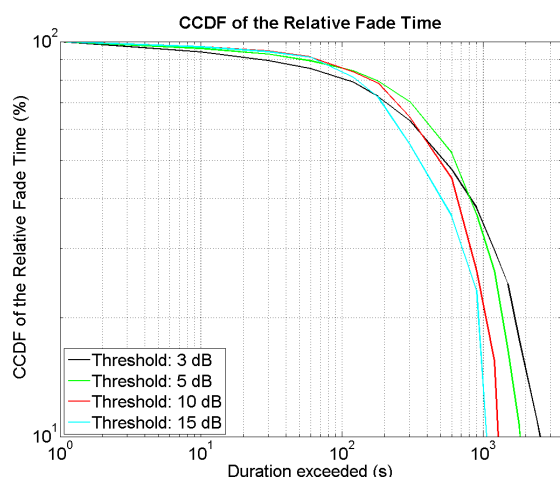


Fig. 9. CCDF of the relative fade duration for different thresholds for Astra-3B.

IV. CONCLUSION

ONERA is currently running a Ka-band propagation experiments in Toulouse with a rain gauge, a radiometer and a beacon receiver able to record the 19.7 GHz and 20.2 GHz signals from Hot Bird 6 and Astra 3-B. In this paper, nine years of data collected at Ka-band have been presented. First order statistics show a large dispersion of yearly statistics of

rain attenuation and a very high seasonal and month-to-month variation. Thus, monthly prediction methods are still needed for predicting rain attenuation. On the dynamic point of view, a quasi-stable fade slope statistics with 9 years of measurements was observed with clear stable increasing fade slopes with respect to the attenuation threshold. On the other hand, fade duration statistics seem less stable and seem to be more or less independent from the attenuation threshold.

Future work will focus on data processing from July 2018 to nowadays, to obtain a unique 10 years time series at Ka-band. Also, a study should investigate further the dispersion of fade dynamics statistics to better understand the impact of the threshold.

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