Attenuation Statistics for Satellite Propagation Channel using Optimized Rain Event Selection

Bernard Adjei-Frimpong[1]
László Csurgai-Horváth[2]

[1] Budapest University of Technology and Economics, Department of Broadband Infocommunications and Electromagnetic Theory; H-1111 Budapest, Egry J. u. 18, Hungary; bernard.frimpong@hvt.bme.hu
[2] Budapest University of Technology and Economics, Department of Broadband Infocommunications and Electromagnetic Theory; H-1111 Budapest, Egry J. u. 18, Hungary; csurgai@hvt.bme.hu

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Abstract The European Space Agency (ESA) in cooperation with Inmarsat launched the Alphasat communication satellite in 2013 with an experimental payload developed under the frame of ARTES 8 telecommunications program. The Aldo Paraboni payload is hosting two coherent beacons to carry out scientific measurements in the Ka and Q band. Wave propagation characterization and rain attenuation measurements are done in order to qualify the radio channel and improve the existing propagation models. In this paper we detail our measurements and compare them with ITU-R recommendations for rain attenuation statistics. To compare the measured rain attenuation with ITU models it is essential the appropriate selecting the rain events in the time series. In this paper, we present the results of measurements and also manually selected rain events where the goodness of selection is qualified by ITU-R P.837 rain probability for a specific geographical location.

Keywords Rain attenuation, fading statistics, event selection

1. INTRODUCTION

The propagation effect of radio waves on the performance of wireless communication systems operating at frequencies above 10GHz is very significant. Therefore, it is important to carry out propagation measurement taking local climatic data into consideration using ITU-R rain attenuation prediction recommendation for as accurate as possible the prediction of performance of radio communication applications operating at these frequencies. These ITU R recommendations were developed to mainly assist in designing effective satellite-earth communication links.

In order to produce accurate predictions from the relevant ITU recommendations such as ITU R P.618 [1] and ITUR P.837 [2] and local climatic conditions play a major role in this process. Nevertheless, radio propagation attenuation assessments due to rain, basically rely on ITU-R P.837 recommendation, based on the local rainfall measurement data obtained.

The ITU-R P.837 recommendations contain maps of the R0.01% parameter have been generated using ECMWF database. These recommendations were developed using rain attenuation statistics for rainfall environments native to each country; thus, owing to their peculiarities, therefore, are used to study the effects of rain attenuation in the rainfall environment of any country and regional location.

In the paper, we have manually selected the rain events from rain attenuation data measurements, gathered from Alphasat experimental payload at Budapest University of Technology and Economics (BME) receiver station [1] and subsequently processed to obtain the attenuation statistics of the rain event predictions.

2. DESCRIPTION OF THE ALPHASAT PROPAGATION EXPERIMENT

Alphasat is an European satellite which was launched in 2013, with two beacons to spear head wave propagation characterization in the Ka (19.701GHz) and Q (39.403GHz) band respectively. The Alphasat beacon receiver station is located on top of the department's building at BME, N47.48° latitudes and E19.06° longitudes at a height of 120m [1]. The building blocks of the receiver station are modified terrestrial microwave radio equipment with several hardware and firmware modifications. Both the Ka and the Q-band receivers are based on identical outdoor unit (ODU) construction; the difference is only the frequency of the locally synthesized signals to provide an identical 140MHz IF frequency (Figure 1). As the orbit of Alphasat is low-inclination geosynchronous a tracking system is also operated in order to eliminate the daily variation of the received signal power.

Figure 1. High performance antennas with tracking system

The ODU is a double conversion heterodyne receiver with synthesized local signal sources. Its original noise figure has been reduced from 5dB to 3dB and in order to generate a stable and jitter-free down-converted intermediate frequency (IF) signal, the oscillator block in the ODU is also changed. The reference oscillator of the synthesizers is now designed to achieve a high stability, low phase noise OCXO with less than ± 1.0 ppb/day stability. The down-converted, filtered (bandwidth=100kHz) and amplified IF signals are connected with a low attenuation coaxial cable to the indoor unit (IDU) and the calibrated gain of the ODU is 100dB.

The indoor unit is based on a modified I-Q demodulator that processes the incoming IF signal. The 140 MHz IF signal is under sampled with 80MHz analog/digital converter unit. The role of the quadrature digital downconverter (QDDC) module is to convert down the sampled signal into baseband quadrature component signals. The baseband signals (I, Q) are decimated (512) and filtered by CIC and FIR filters.

The ODU also contains an internal temperature sensor with 1°C accuracy. This sensor is used for the temperature-compensation of the ODU's amplifier circuits. During the calibration of the ODU in a thermal-chamber the temperature-dependency of the complete receiver chain was determined. The firmware has a built-in compensation table; therefore, the result is a temperature-independent, high accuracy level measurement. The temperature-compensated values are averaged and fed to a fine gain control unit that ensures the nominal 100dB ODU gain. The filtered and decimated signal is processed by an 8192 point FFT where the beacon signal can be detected as the highest amplitude spectral component. The carrier amplitude measurement is performed within 1 second and the final data is forwarded after a logarithmic conversion to the data collecting system. The resolution of the received power is 0.2dBm. By taking into account the speed of A/D conversion, the decimation and the FFT buffer size, the system bandwidth is 80MHz/512/8192=19.07Hz.

3. IMPLEMENTATION OF ITU-R RAIN ATENNUATION MODELS

ITU-R P.618 recommendation can be applied to calculate rain attenuation statistics for satellite-Earth radio links that can be compared with measured data in order to qualify the receiver station and also to draw conclusions about the variations caused by the local climatic environment.

The ITU-R P.618 rain attenuation model uses the rain rate at 0.01% probability level for attenuation estimation. This model has been derived on the basis of the log-normal distribution, and the point rain intensity and attenuation distribution generally conform to the log-normal distribution. Inhomogeneity in rain on the horizontal and vertical directions is accounted for based on the prediction. This model is applicable across the 4–55 GHz frequency range and the 0.001–5% percentage probability range. The estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 55 GHz are obtained according to the procedure given below. The following parameters are used in this calculation:

$R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)
h_s: height above mean sea level of the earth station (km)
θ: elevation angle (degrees)
φ: latitude of the earth station (degrees)
f: frequency (GHz)
R_e: effective radius of the Earth (8.500 km).

When local data for the station height above mean sea level is not available, an estimate can be obtained from the maps of topographic altitude given in Recommendation ITU-R P.1511 [4]. These procedures are provided here, with the line-by-line model presented first, followed by the approximation to the models.

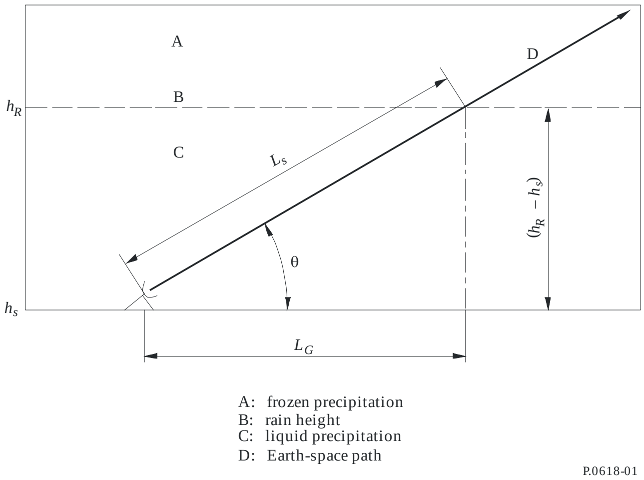

Figure 2. Rain height calculation based on ITU-R [2]

This method provides an estimate of the long term statistics of attenuation due to rain. When comparing measured statistics with the prediction, allowance should be given for the rather large year-to-year variability in rainfall rate statistics (see Recommendation ITU R P.678 [5]).

The beacon receiver stations (at our station at BME as well) usually record the received signal's power. In order to get attenuation statistics, the received signal (power) should be converted to attenuation. This can be done by applying different methods, but they are influencing the precision of the attenuation statistics estimation as well. The key issue is how we determine the clear sky level, as the reference level. Due to lack of a radiometer (as it is also at BME) the simplest method to apply is the long-term median or mean value of the received power time series as reference level. To take into account the long-term signal variations a more effective method is used to select manually the individual rain events. As ITU-R P.837 [3] gives the probability of rain at a specific geographical location the value predicted from attenuation measurements should correspond with it and in this way, it may prove the quality of rain event selection as well.

The basic principle of ITU-R837 involves the use of a database of parameters (P_{r6}, M_t, and β), This database is available from the website of ITU's 3M group. The method to derive the rain rate exceeded for a given probability of the average year, and a given location is as follows.

Step 1. Extract the variables (P_{r6}, M_T, and β) for the four points closest in latitude (Lat) and longitude (Lon) to the geographical coordinates of the desired location. The latitude grid extends from +90°N to −90°S in steps of 1.125 steps; the longitude grid extends from 0° to 360° in steps of 1.125.

Step 2. From the values of P_{r6}, M_T, and β at the four grid points, obtain the values Pr6 (Lat, Lon), Mt (Lat, Lon), and β (Lat, Lon) at the desired location by performing a bi-linear interpolation, as described in Recommendation ITU-R P.1144.

Step 3. Convert M_T and β to M_C and M_S as follows:

$$M_C = \beta M_T,\ M_S = (1 - \beta)\, M_T \tag{1}$$

Step 4. Derive the percentage probability of rain in an average year, P_0 by using

$$P_0(Lat, Lon) = P_{r6}(Lat, Lon)\left(1 - e^{-0.0079(M_S(Lat,Lon)/P_{r6}(Lat,Lon))}\right) \tag{2}$$

If P_{r6} is equal to zero, the percentage probability of rain in an average year and the rainfall rate exceeded for any percentage of an average year are equal to zero. In this case, the following steps are unnecessary.

Step 5. Derive the rainfall rate, R_P, exceeded for p% of the average year, where $p \leq p_0$, from

$$R_P(Lat, Lon) = \frac{-B + \sqrt{B^2 - 4AC}}{2A}[mm/h] \tag{3}$$

where

$$A = ab$$
$$B = a + c\ln\left(\frac{P}{P_0(Lat, Lon)}\right)$$
$$C = \ln\left(\frac{P}{P_0(Lat, Lon)}\right) \tag{4}$$
$$a = 1.09, b = \frac{M_C(Lat, Lon) + M_S(Lat, Lon)}{21797 P_0}$$
$$c = 26.02b$$

4. RESULTS

It should be taken into consideration that an important model parameter for rain attenuation prediction is R_{001}, the rain rate exceeded for 0.01% of an average year, which characterizes the local climate at the measurement point. According to the precipitation map provided by ITU [3], R_{001} is equal to 35.1mm/h for Budapest. Nevertheless, this constant may be influenced by the actual annual weather conditions causing deviations from the long-term statistics.

In this experiment we processed the time series of measured received power which provides the relevant information and it can be converted to attenuation. As we already mentioned, there are different solutions to do this conversion.

Method 1: The measured values are subtracted from the median (clear sky) received power and has been calculated over an entire year. The attenuation events are mainly caused by rainy periods.
The Complementary Cumulative Distribution Function (CCDF) of rain attenuation provides the probability of exceeding different attenuation levels. Its monthly distributions reveals how the rain events significantly influence the actual weather conditions.
In Figure 2 is displayed the complementary cumulative distribution function (CCDF) of the measured attenuation for Ka and Q-band together with the distribution curves predicted by the ITU-R P.618 recommendation for an entire year of 2016.

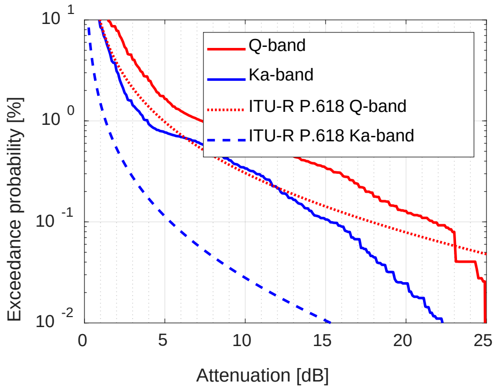

Figure 3. CCDF for Ka and Q band, compared with the ITU-R, clear sky level calculated with median

In order to estimate the error between measurements and the ITU-R model, the root mean square error (RMSE) has been applied. Therefore, we calculate the RMSE between the measured and the predicted attenuation values using the following as the square root of the expected value of the power of differences between the measured and modelled values. Figure 4 and Figure 5 displays the RMSE for the Q and Ka band respectively.

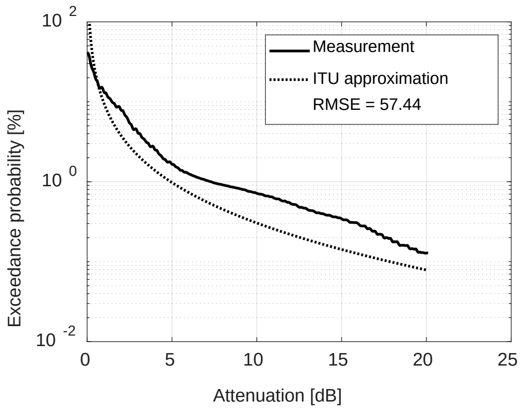

Figure 4. RMSE for Q-band, clear sky level calculated with median

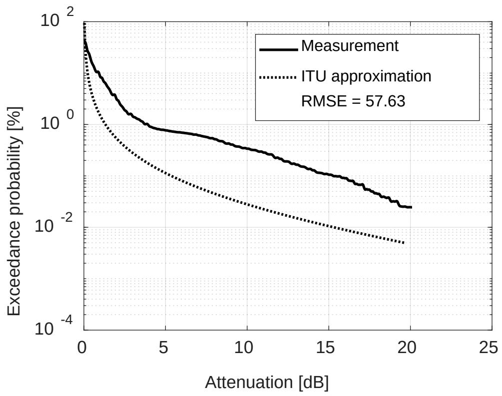

Figure 5. RMSE for Ka-band, clear sky level calculated with median

Method 2: The measured values are subtracted from the mean (clear sky) received power and has been calculated over an entire year. There are no significant changes comparing to the previous one example.

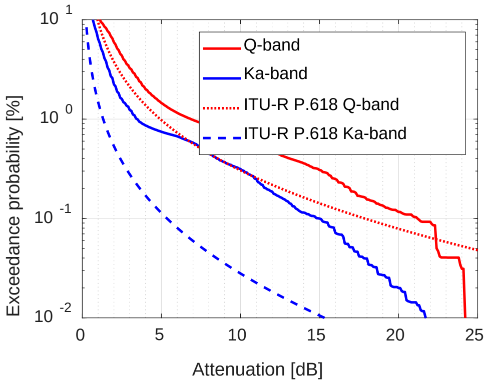

Figure 6. CCDF for Ka and Q band, compared with the ITU-R, clear sky level calculated with mean

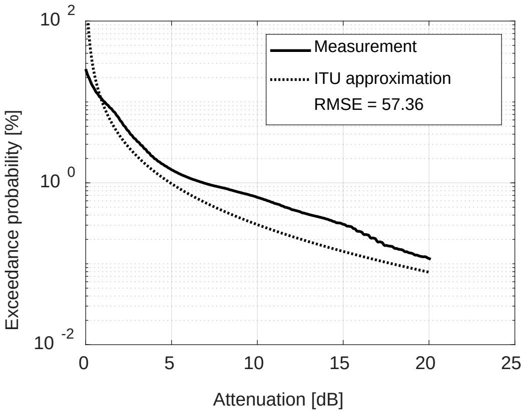

Figure 7. RMSE for Q-band, clear sky level calculated with mean

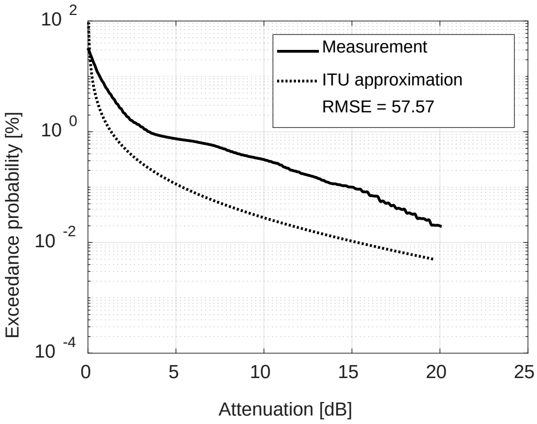

Figure 8. RMSE for Ka-band, clear sky level calculated with mean

Method 3: The rain events are selected manually. The following figure depicts an example if we select the rainy periods manually, allowing the best approximation of the clear sky level around the individual rain events. This method ensure to take into account the variable clear sky level that may cause by clouds, air humidity or other effects except of the rain. The figure is relating to May, 2016 for the Ka-band radio channel.

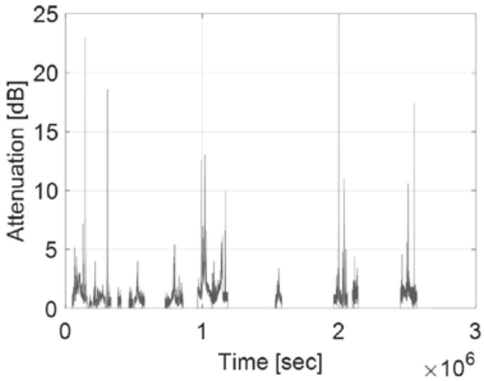

Figure 9. Ka band, manually selected rain events time series, May, 2016

When we apply the manually selected events for first order statistical calculations (attenuation CCDF) a better approximation of the ITU-R curve can be observed (comparing with Figure 8). The result is depicted in Figure 10. for the Ka-band.

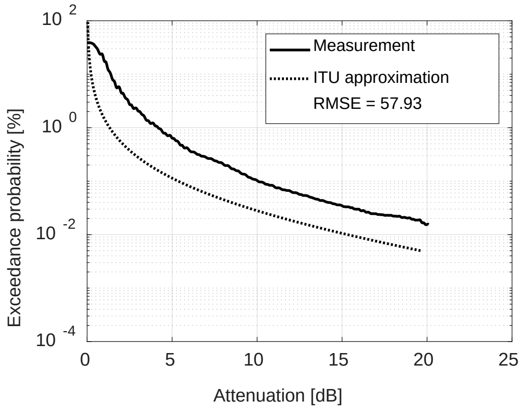

Figure 10. RMSE for Ka-band, manually selected rain events, May, 2016

5. CONCLUSIONS

In this paper we investigated the satellite-Earth propagation channel in the Ka and Q band and we presented measurement results from the Alphasat beacon receiver station in Budapest, Hungary. The main goal of this paper was to demonstrate how to converted the received power time series to attenuation time series, and it was demonstrated that by selecting manually the rain events ensure better approximation of the statistics provided by ITU-R. We calculated RMSE errors for the comparison and proved the results.

In our future work, we want to finish the manual event selection for the whole year that may provide the most accurate rain attenuation statistics for the geographical location of the receiver station.

Sources

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