Beacon-measured Fade Slopes and Disdrometer Derivations with Variable Integration Time

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Abstract

Ultra-high throughput satellites (UHTS) operating at high frequencies provide large bandwidths but are severely impaired by atmospheric phenomena on the Earth–space path. Reliable short-term forecasts of channel characteristics can be used for fade mitigation techniques (FMT) such as adaptive coding and modulation (ACM) and site diversity. Numerical weather prediction (NWP) models are available on a global scale as a basis for such forecasts. Rain is the strongest effect, with the rain rate being highly variable in time. This study discusses which rain rate integration time and thus NWP forecast step is suitable for forecasting satellite channel characteristics. The rain attenuation is obtained from disdrometer measurements for various integration times and the resulting fade slope statistics are compared with beacon measurements and the model in the ITU-R P.1623 [1]. It is shown that NWP models with forecast steps of 5 minutes or less are interesting for such purpose.

1 Introduction

To meet the demand for larger bandwidths, satellite communications have started employing Ka-band frequencies and research efforts consider the Q, V and W bands. These higher frequencies are severely impaired by atmospheric phenomena (clouds and precipitation) and mitigation cannot consist on the mere provision of a power margin. More complex mitigation schemes require the dynamic reconfiguration of certain link parameters. Reliable short-term forecasts of channel characteristics can be used to aid these schemes. Previous attempts of short-term forecasts of satellite channel characteristics include [2].

Rain attenuation is the most significant atmospheric effect affecting propagation. The impact of rain on a propagating wave depends on the frequency and polarization of the signal, the elevation angle of the slant path and the characteristics of the rain event [3]. The high time variability of the rain rate becomes critical, since high time resolution is not commonly available in current NWP forecasts. A discussion of the effect of averaging the rain rate over 15-minute steps, available in some NWP models, can be found in [4]. The present study is dedicated to find which interval is suitable to reflect the dynamics of rain attenuation in satellite links.

2 Experimental Setup

2.1 2D-Video-Disdrometer

A disdrometer is an instrument used to measure the velocity and DSD of hydrometeors, among other parameters. The 2D-Video-Disdrometer (2DVD) uses high-speed line cameras to detect single particles and allows deriving their drop size distribution with adjustable integration time (i.e. the time interval during which the DSD and the corresponding rain rate are computed [5]). The measurements are validated by the use of calibration spheres.

One year of rainfall measurements (2018) in Graz (Austria) has been analyzed for this study. The procedure described in [5] was followed for the pre-processing of the data, comparing the relationship between the fall velocity of the particles and their diameter against the model given by Atlas *et al.* [6]. A length of the normal vector of 1.4 was chosen as threshold. The results are shown in Figure 1. 11 % of the particles were filtered, corresponding to drops outside of the marked area in the plot, which include snow, splashed drops after hitting instrument surfaces, particles falling through the edges of the measurement area and eventual system artefacts.

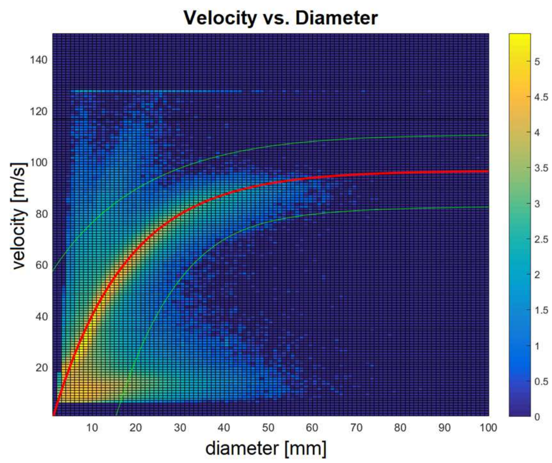

Figure 1. Cumulative count of particles (in logarithmic scale) in a velocity vs. diameter grid, recorded in Graz (Austria) during the year 2018. Red line: Model by Atlas et al. [6]. Green lines: thresholds for non-rain particle decision.

The DSDs measured by the disdrometer with 0.1 mm bin size and variable integration time are used together with the wavelength and forward scattering coefficients for the estimation of the attenuation time series. The scattering amplitudes of the raindrops were calculated using a point-matching algorithm [7] with up to 103 matching points on half of the raindrops circumference. The refractive index and temperature of water (5° C) were set. The model by Pruppacher and Beard [8] was used for the calculation of the raindrops oblateness. The link elevation is 35°.

2.2 Alphasat Ground Station

The Alphasat satellite hosts the Aldo Paraboni Payload, transmitting two beacon signals at 19.7 and 39.4 GHz. A propagation experiment is being carried out in Graz (Austria) to characterize the Earth-space channel at these frequencies. The Austrian Alphasat Communication Ground Station (GS3) is located at the Hilmwarte Tower (47.08 N, 15.46 E, 468 m a.m.s.l.). Detailed information about the experiment and previously obtained results can be found in [9].

The recorded beacon data is pre-processed in order to remove from the measured signals the effects induced by the space and ground equipment and identify the valid samples. The validated time series of rain attenuation have been used to obtain the fade slope statistics for the year 2018 with data availability of 91.83 % (i.e. number of valid samples collected by the receiver over the total number of samples ideally available during the same period). The sampling time of the measurements is 0.1 s. The time series of attenuation were low-pass filtered with a raised cosine filter of 0.025 Hz cut-off frequency. The time interval used for the calculation of the fade slope was 60 s.

3 Fade Slope

The design and use of FMT require knowledge on the dynamics of outage events. More concretely, the probability of occurrence of a fade slope corresponding to a given attenuation threshold. Fade slope is defined as the rate of change of attenuation with time. The relevant information is the slope of the slowly varying component of the signal, which involves filtering out scintillation and rapid variations of rain attenuation. Figure 2 shows an example of measured time series of attenuation, scintillation-filtered attenuation and fade slope.

The 2DVD-derived attenuation time series are used to assess the suitability of certain rain rate integration times for forecasting satellite attenuation. Comparisons with the ITU-R fade slope model were previously presented in [10]. Here, beacon-measured fade slope statistics are also used for the comparison. In view of a later application for the forecast of link characteristics using NWP models (Figure 3), the measured DSDs represent the rain data forecasted by the NWP models. Up to now, no such measurements and comparisons are known to the authors.

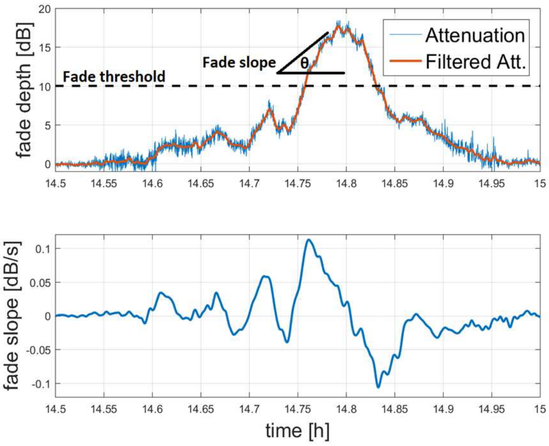

Figure 2. Time series of attenuation, scintillation-filtered attenuation and fade slope measured at 39.4 GHz with the Alphasat Ground Station in Graz (Austria).

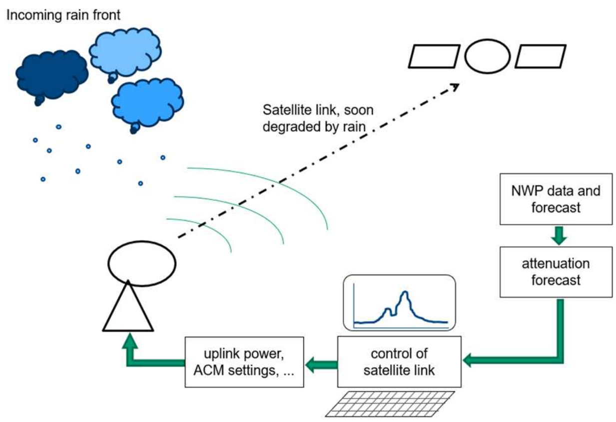

Figure 3. Fade countermeasures and service capacity management aided by forecast of satellite link characteristics based on NWP models.

4 Results

The set of integration times for the calculation of the DSDs and therefore the 2DVD-derived attenuation time series included 60, 300 and 900 seconds (i.e. 1, 5 and 15 minutes respectively). Figure 4 presents the obtained results as complementary cumulative distribution functions (CCDF) of the fade slope, i.e. the conditional probability that the absolute fade slope is exceeded for a given attenuation threshold. The results are compared with the beacon-measured fade slope statistics and the ITU-R model predictions.

As expected, longer integration times result in lower fade slopes. The fade slopes resulting from 15 minutes integrations cannot follow the dynamics of the attenuation events. Whereas the results from 1 and 5 minute integrations allow fast enough changes.

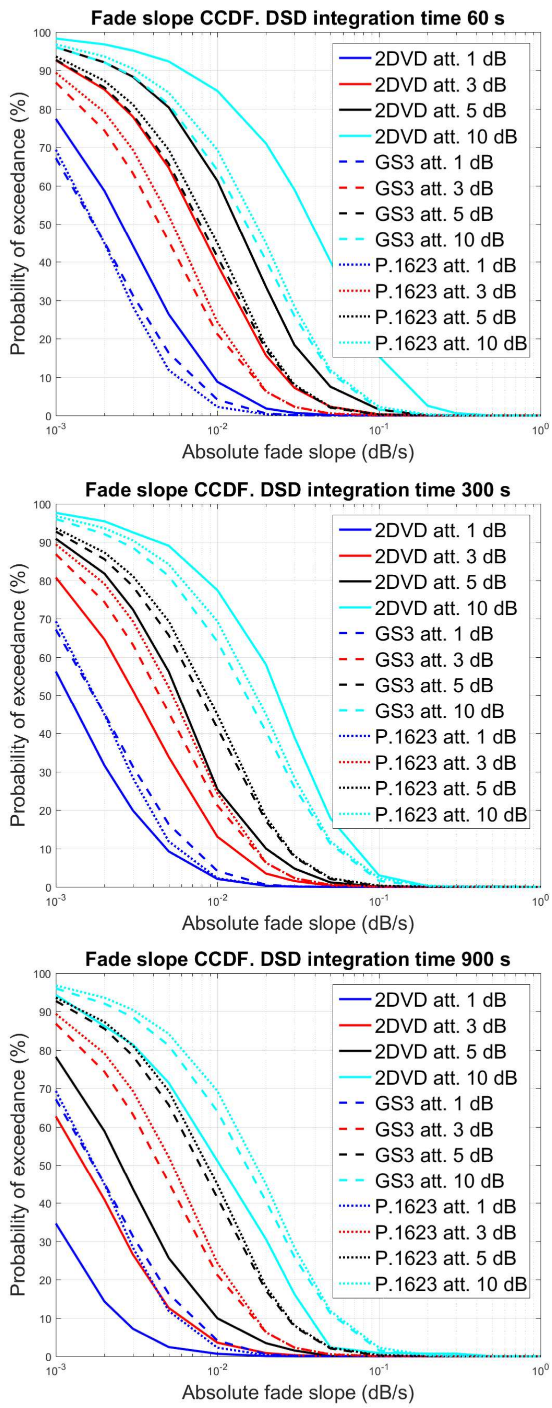

Figure 4. DVD-derived fade slope statistics with different integration times compared with beacon measurements and the model in ITU-R P.1623.

The dynamics of the 1-minute integration seem to be significantly faster than measured and predicted by the ITU-R model. The effect caused by applying point monitoring measurements for the integral parameters over the full slant path should be kept in mind, as the expected fade slope at a given attenuation level is likely to decrease with path length and therefore increase with elevation angle on satellite links [11].

5 Conclusion and Outlook

Fade countermeasures and service capacity management could be aided by short-term forecasts of satellite link characteristics based on Numerical Weather Prediction models. Rain rate integration times or NWP model steps of 5 minutes or less seem to be adequate for such forecasts, whereas integration times of 15 minutes or more can hardly follow the attenuation dynamics.

As the next step further, the data from 5-minute step NWP models (e.g. the rapid-INCA model [12]) will be used to compute the short-term forecasts of the satellite link. The obtained attenuations will be verified with satellite beacon measurements.

6 Acknowledgements

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7 References

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