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Towards retrieving weather information from signal quality measurements of thousands of small Ka-band satellite terminals in Europe

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Abstract

It is estimated that the number of very small aperture terminals (VSATs) used for internet connectivity is in the range of millions worldwide. These terminals typically work at Ka-band with 20 GHz downlink and 30 GHz uplink. Since these frequencies are significantly affected by rain, the VSATs can be used to derive rain rates opportunistically. This paper summarizes an initiative to study the signals of thousands of VSAT terminals within the Hylas satellite network and reports on the effects that need to be considered for opportunistic remote sensing of rain.

Index Terms – VSAT, Ka-band, opportunistic remote sensing.

1 Introduction

For the measurement of rain, several dedicated instruments exist. Rain gauges provide a direct measurement of precipitation, while weather radars represent a remote sensing technique. Due to the respective measurement principles, both techniques have advantages and limitations. Given the temporal and spatial variability of precipitation, especially during extreme weather events, the density of rain gauge networks and the coverage of weather radars are often a limiting factor for meteorological and hydrological purposes.

Besides using dedicated sensors for the measurement of rain, it was shown that the signal attenuation in microwave links can also be used to retrieve the average rain rate along the link if frequencies are used that are attenuated by the troposphere. Initially, terrestrial microwave links were studied e.g. [1], [2], [3] and later also Ku-band satellite-to-earth microwave links were used [4], [5]. The opportunistic use of the link information in both terrestrial and satellite links is a useful complement for existing sensors.

This summary paper presents signal quality measurements of thousands of Ka-band terminals used for internet connectivity. Ka-band frequencies are significantly affected by the troposphere, thus, these links are very sensitive for the retrieval of weather information. Advantageous is also the fact that number of Ka-band terminals used in the USA and in Europe for internet connectivity is in the range of several millions [6].

This paper is organized as follows. Section 2 presents the satellite network and the ground terminals that are investigated for this study. Section 3 provides sample link data. Section 4 explains the theoretical concept of rain rate retrieval from attenuation measurements, while Section 5 summarizes signal effects that have been considered in order to determine the tropospheric attenuation. Finally, Section 6 provides a short summary and an outlook to future work.

2 Satellite network and ground terminals

For the present study, signal data from thousands of ground terminals within Avanti's Hylas network are investigated. Avanti runs currently four Hylas satellites. The Hylas satellites offer both broadcast and broadband services. For this study, data from Hylas 1 and Hylas 2 have been analyzed. The broadband payload characteristics of Hylas 1 and Hylas 2 are presented in Table 1 and Table 2, respectively.

Table 1. Hylas 1 broadband payload characteristics.

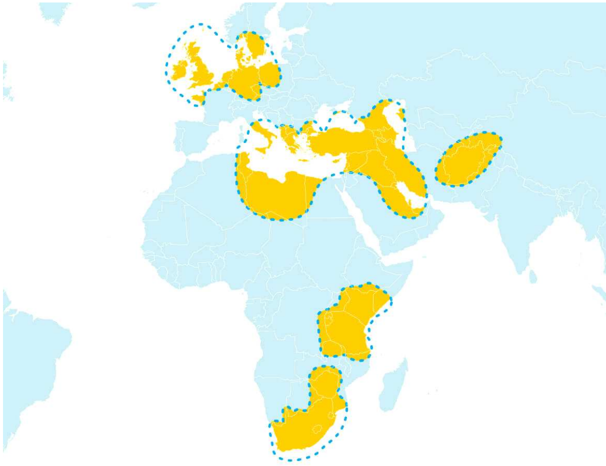
Uplink Frequency Range	
Forward	27.5 - 29.5 GHz
Return	29.5 - 30.0 GHz
Active Forward Transponders	8
Forward Channel Bandwidth	250 MHz per beam
Downlink Frequency Range	
Forward	19.7 - 20.2 GHz
Return	18.1 - 19.7 GHz
Active Return Transponders	2
Return Channel Bandwidth	120 MHz per beam
Polarization	Circular

Table 2. Hylas 2 broadband payload characteristics.

Uplink Frequency Range	
Forward	27.5 - 29.5 GHz
Return	29.5 - 30.0 GHz
Active Forward Transponders	24
Forward Channel Bandwidth	230 MHz per beam
Downlink Frequency Range	
Forward	19.7 - 20.2 GHz
Return	17.7 - 19.7 GHz
Active Return Transponders	6
Return Channel Bandwidth	220 MHz per beam
Polarization	Circular

Hylas 1 and 2 cover service areas in Europe, Africa, and the Middle East. Figure 1 illustrates the coverage of both satellites.

(a)



(b)

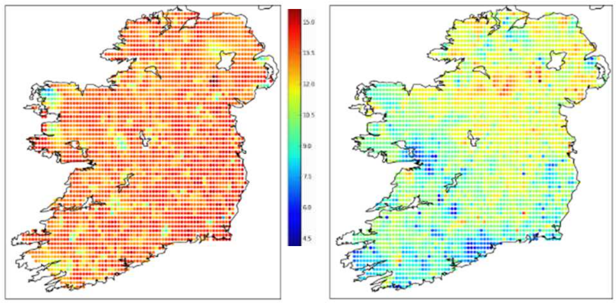
Figure 1. Coverage of Avanti satellites Hylas 1 (a) and Hylas 2 (b). (Source: https://www.avantiplc.com/our-fleet/)

In general, the users of the broadband service install the VSAT (Very Small Aperture Terminal) themselves and for the correct pointing a mobile application is provided. The VSAT consists of the reflector dish and an outdoor unit that integrates feed horn multiplexer, power amplifier, upconverter, low noise receiver and downconverter. This outdoor unit is connected to an indoor modem via a coaxial cable that also provides power supply to the outdoor unit.

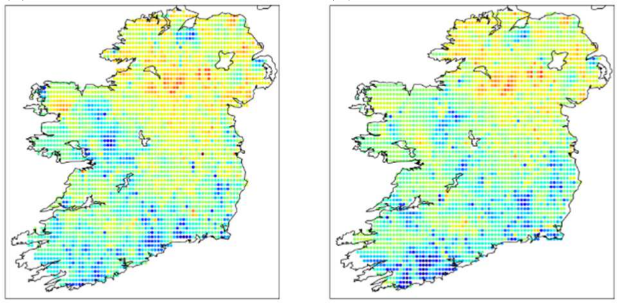
The end users deploy different dish sizes and modems. Dish sizes from 74 to 120 cm are usual. The almost exclusively used modems come from the manufacturers Hughes and Gilat.

3 Sample data

The VSATs report the received signal strength every 5 or 10 minutes, depending on the modem. The actual value measured is the energy per symbol over noise power spectral density (E_s/N_0), which is proportional to the carrier to noise ratio (C/N). For very favorable conditions, like clear sky situations, with good pointed dish antennas, E_s/N_0 values of 16 can be reached while the values can drop significantly below 10 during rain events. Figure 2 shows signal maps for the island of Ireland retrieved by the E_s/N_0 signals of the VSATs during a clear-sky situation and during a bypassing rain front. The reason for not perfect signal values of some terminals during clear-sky is due to the pointing quality of the antennas.



(a) (b)



(c) (d)

Figure 2. Instant values of measured signal values (E_s/N_0) of ground terminals on the island of Ireland. Panel (a) shows the situation during clear sky conditions; Panels (b) to (d) show signal measurements during a bypassing rain front [7].

4 Rain rate retrieval

As for terrestrial links [3], also for satellite links the path-averaged specific attenuation *k* (in dB/km) can be approximated by

$$k \sim c \cdot R^d \qquad (1)$$

where
R is the path averaged rain rate (in mm/h)
and *c* and *d* are frequency dependent coefficients

the inversion of Equation (1) leads to the retrieval of the rain rate as

$$R \sim a \cdot k^b \qquad (2)$$

where $a = (1/c)^{1/d}$ and $b = 1/d$.

For a meaningful rain rate retrieval, knowledge of the rain cells as e.g. cloud top height is crucial since the received rain rate is averaged over the whole path. The more precisely the attenuated path can be determined, the better the retrieval is.

Vital for the rain rate retrieval is also the determination of the attenuation. A variety of non-tropospheric signal effects have to be understood in order the attenuation can be determined. Section 5 summarizes these effects and describes how the effects are considered within this study.

5 Non tropospheric signal effects

5.1 Antenna pointing

The pointing of the individual ground terminals is directly related to the signal strength that can be received. In order to estimate the degree of mispointing of individual terminals, the pattern of dish antennas was determined by using reference terminals. The reference terminals are equipped with precise motors that allow pointing within a certain segment, both in azimuth and in elevation. The pattern of a 74 cm dish antenna is presented in Figure 3. The pattern was determined by deliberately mispointing the antenna during clear sky conditions and recording the respective signal levels.

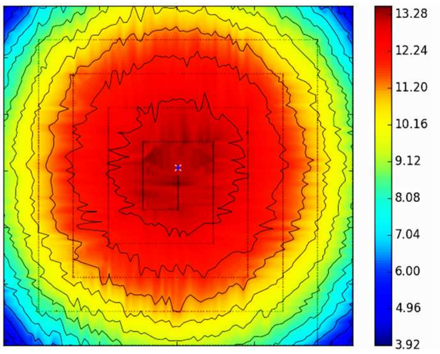


Figure 3. Antenna pattern measurement that reports the expected signal level as a function of the mispointing angle for a typical 74 cm dish antenna used within the Hylas network.

5.2 Orbital effects

As most geostationary satellites, Hylas 1 and Hylas 2 are not fully stationary. If a fixed pointed directional antenna is receiving signals from a satellite that varies slightly its position in the course of a day, signal variations are induced. It was investigated theoretically what periodicities in signal time series are induced by the orbital movement of inclined geostationary satellites: depending on the actual pointing, spectral components with a periodicity ~12 and ~24 hours occur. If these frequencies are filtered from VSAT signal time series the orbital effects can be suppressed while the wanted tropospheric effects remain unaffected.

5.3 Modem effects

As mentioned above, modems and outdoor units from several manufacturers are used within the Hylas satellite network. It has been found that Hughes modems underestimate while Gilat modems overestimate the E_s/N_0 values. By performing a long term experiment that compared the reported signals of both modems with a reference instrument, correction curves could be found [8].

Based on this experiment, the following formulae should thus be used for the correction [8]:

For the VSATs with Hughes modems

$$E_s/N_{0\ Ref} = 0.02832 \cdot (E_s/N_{0\ H})^2 + 0.7092 \cdot E_s/N_{0\ H} + 0.4467 \quad (3)$$

For the VSATs with Gilat modems

$$E_s/N_{0\ Ref} = 0.8666 \cdot E_s/N_{0\ G} + 0.7232 \quad (4)$$

where

$E_s/N_{0\ Ref}$ Corrected reference value of the energy per symbol over noise power spectral density

$E_s/N_{0\ H}$ Energy per symbol over noise power spectral density as estimated by a Hughes modem

$E_s/N_{0\ G}$ Energy per symbol over noise power spectral density as estimated by a Gilat modem

5.4 Footprint effects

The expected signal level of an individual VSAT is also dependent on its position within the satellite beam that is covering the respective area. Therefore, the information of the nominal footprint of every beam is taken into account when determining the expected maximal signal level at the position of a certain ground terminal. For verification, the footprint of certain beams was also empirically determined by studying the signals of the terminals within the respective beam. Figure 4 illustrates the retrieval of the footprint information of the beam 5 of Hylas 2 by using one month of signal data from the ground stations within this beam.

6 Summary and outlook

This study presents the data and the main procedures used to derive attenuation maps from a Ka-band VSAT network. The verified attenuation maps are the basis for the retrieval of meteorological information as the rain rate.
For the future, the integration of link date of more satellites is envisaged since other elevation and azimuth angles can provide a tomographic view of the troposphere, which in turn will increase the retrieval of meteorological parameters. Ongoing research also focuses on the retrieval of the movement of the footprint, e.g. due to satellite maneuvers.

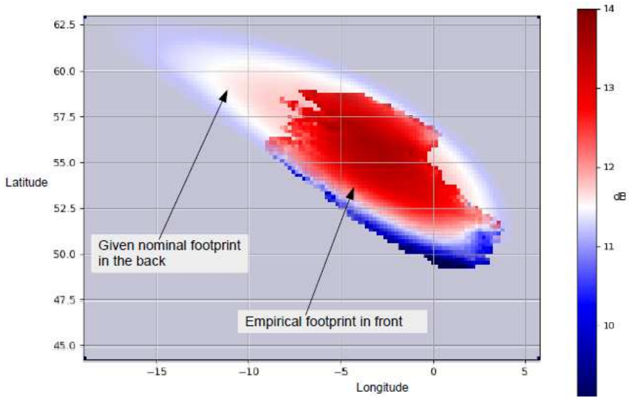


Figure 4. Verification of the footprint of one beam (Hylas 2, beam 5, UK) based on one month of measured signal values (E_s/N_0) of the ground stations within the beam. In the back the nominal footprint is indicated as the expected received E_s/N_0 values at the given location.

7 Acknowledgements

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8 References

1. H. Messer, A. Zinevich, P. Alpert, “Environmental monitoring by wireless communication networks”, Science 312, p.713, 2006.

2. H. Leijnse, R. Uijlenhoet, J. N. M. Stricker, “Rainfall measurement using radio links from cellular communication networks”, Water Resources Research, 43, W03201, doi:10.1029/2006WR005631d, 2007.

3. R. Uijlenhoet, A. Overeem, H. Leijnse, “Opportunistic remote sensing of rainfall using microwave links from cellular communication networks”, WIREs Water, Wiley Periodicals, 2018, https://doi.org/10.1002/wat2.1289.

4. L. Barthès and C. Mallet: “Rainfall measurement from the opportunistic use of an Earth–space link in the Ku band”, Atmos. Meas. Tech., 6, 2181–2193, https://doi.org/10.5194/amt-6-2181-2013, 2013.

5. M. Colli et al., "A Field Assessment of a Rain Estimation System Based on Satellite-to-Earth Microwave Links," in IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 5, pp. 2864-2875, May 2019, doi: 10.1109/TGRS.2018.2878338.

6. B. Schneiderman, “VSAT Market Trends”, Satellite Executive Briefing, vol.10, no. 3, April 2017, http://www.satellitemarkets.com/pdf/pdf2016/apr17.pdf

7. F. Teschl, V. Eder, L. Costa, S. Amberger, O. Koudelka, “Link quality parameters in VSAT networks for effective operation and for weather monitoring”, Proceedings of International Astronautical Congress (IAC), Guadalajara, Mexico, 26-30 September 2016.

8. F. Teschl, R. Teschl, V. Eder, “Calibrating Ka Band Satellite Down-Link Modem Measurements for Rainfall Monitoring” accepted at European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, March 15-20, 2020.