

Large Scale Assessment of Ka/Q Band Atmospheric Channel Across Europe with ALPHASAT TDP5 : A New Propagation Campaign

S. Ventouras¹, F. P. Fontan², A. Rocha³, F. Jorge³, A. Z. Papafragkakis⁴, A. D. Panagopoulos⁴, Ch. I. Kourogiorgas, D. D. Vanhoenacker⁵, A. Graziani⁵, A. Martellucci⁶

¹ STFC Rutherford Appleton Laboratory, RAL Space, Oxford, UK, spiros.ventouras@stfc.ac.uk

² Escola de Enxeñaría de Telecomunicación, University of Vigo, Vigo, Spain, fpfontan@tsc.uvigo.es

³ Institute of Telecommunications – University of Aveiro, Aveiro, Portugal, arochoa@av.it.pt

⁴ School of Electrical and Computer Engineering, National Technical University of Athens, Athens, Greece, thpanag@ece.ntua.gr

⁵ Institute of Information & Communication Technologies, Université catholique de Louvain, Louvain, Belgium, danielle.vanhoenacker@uclouvain.be

⁶ European Space Agency, ESTEC, TEC-EEP, Noordwijk, The Netherlands, Antonio.Martellucci@esa.int

Abstract—The ever growing demand for higher data rates in satellite based services along with the congestion of the lower part of the frequency spectrum has led to the migration of new services to higher bands, such as the Ka-, Q/V bands. However, propagation in these bands is more prone to the atmospheric impairments; thus, the effects of the various atmospheric phenomena need to be accurately modeled and quantified in order to allow for efficient and reliable system design. To this end, a new propagation campaign consortium has been established across Europe (UK, Spain, Portugal, Belgium and Greece) to conduct measurements in the Ka- and Q- bands using Alphasat's beacons. This shall allow the validation and enhancement of existing propagation models and support the development of Fading Mitigation Techniques. The objective of this paper is to present the new propagation campaign giving details for the various experimental sites.

Index Terms—propagation, measurement, campaign, Alphasat, beacon, Ka-band, Q-band, propagation experiment, atmospheric attenuation.

I. INTRODUCTION

The constantly increasing demand for higher data rates to support the numerous satellite services and greater system capacity to accommodate larger number of users, along with the congestion of the lower frequency bands has led to a migration of services in higher bands, namely at the Ka-, Q-, and V-band [1]. As a general rule, moving to higher frequencies provides greater bandwidth and therefore potential data rates; however, it involves the use of more complex hardware and is significantly impaired by the various atmospheric phenomena (e.g. gases, clouds, rain, and tropospheric turbulence) which can strongly affect reliability and system performance. The severe tropospheric losses experienced in this frequency range cannot be compensated by a simple fade margin obtained by the complementary cumulative distribution of the attenuation. Instead, Propagation Impairments Mitigation Techniques (PIMTs) or Fade

Mitigation Techniques (FMTs) are necessary for improving the Quality of Service (QoS) and the average throughput of the links.

It is therefore essential that in the aforementioned frequency bands, tropospheric degradation shall be adequately modeled as a function of both space (over the region covered) and time, to allow for potential optimization of the satellite resources. Propagation experiments and subsequent studies have been performed to measure, characterize and model the propagation effects globally; these efforts have mostly been directed towards the requirements of professional communications (e.g., broadcasting), giving parameters like link availability over a year or the worst month.

The two major past propagation experiments in Europe - using the ESA OLYMPUS satellite [2] and the Italian ITALSAT F1 satellite [3] at Ku/Ka and Q/V band respectively - allowed the collection of relevant propagation data in these frequency bands. These activities together with subsequent studies have been fundamental in providing the basic knowledge on the physical aspects governing the radio-wave propagation in slant path. However, aspects relevant to the design of advanced radio communication systems (such as the characterization of spatial and temporal properties of the radio channel) that emerged only during the end of these campaigns could not be properly addressed in the original OLYPMUS and ITALSAT propagation measurements.

A consortium consisting of five partners and operated under a European Space Agency (ESA) contract was established to conduct new propagation measurements in the Ka- and Q- bands in various locations across Europe using the beacon signals transmitted by the Alphasat satellite. The consortium has been created after the response to ESA ITT AO/1-7963/14/NL/LvH. There will be extensive concurrent measurements for the 5 Groups and all the locations of quantities such co-polar signal attenuation, sky noise temperature, tropospheric delay, wind speed and direction,

rainfall rate. The retrieved tropospheric parameters that will be available for statistical processing and modeling will be: in-excess attenuation, total attenuation, scintillation, and depolarization.

II. NEW PROPAGATION CAMPAIGN OBJECTIVES

Taking into account the new needs and new scenarios that have arisen (e.g., FMTs) it is necessary to overcome the limitations of the past measurements by conducting new experiments.

The new propagation data are required to:

- improve the quality of the tropospheric models above Ka-band (statistics and time series).
- develop accurate first and second order statistical

III. ALPHASAT'S ALDO PARABONI PAYLOAD

Most propagation campaigns take advantage of the beacon signals available as part of a satellite's payload; beacons are often used to monitor satellite's position, as pilots for telemetry or even for antenna pointing purposes and are most often unmodulated, constant power Continuous Wave (CW) signals. Alphasat (also referred to as Inmarsat-4A F4) is a commercial satellite located at 25.0°E and operated by Inmarsat, however, in cooperation with European Space Agency (ESA) it carries (among others) the so-called Aldo Paraboni Technology Demonstration Payload 5 (TDP #5) providing two fully redundant beacons in the Ka- and Q- bands (19.701GHz and 39.402 GHz respectively) for propagation experiment purposes. The present campaign will utilize both beacons to

Location	Latitude	Longitude	Above mean sea level	Elevation angle	Azimuth	Ka-band	Q-band
UK, Chilbolton	51.15°N	1.43°W	100 m	26.40°	147.45°	yes	yes
UK, Chilton	51.57°N	1.29°W	100 m	26.07°	147.77°	yes	yes
Portugal, Aveiro	40.612°N	8.662°W	12 m	31.80°	134.45°	KaSAT	yes
Spain, Vigo	42.170°N	8.688°W	447 m	30.60°	135.20°	yes	yes
Spain, Bilbao	43.257°N	2.924°W	10 m	32.74°	142.28°	yes	No
Belgium, Louvain-la - Neuve	50.40°N	4.37°E	160 m	29.02°	153.96°	TBD	TBD
Greece, Athens-Zografou	37.975°N	23.785°E	210 m	45.97°	178.03°	yes	No
Greece, Lavrion	37.723°N	24.048°E	20 m	46.26°	178.44°	yes	No

Table 1: Consortium experimental sites information

models (fade slope, fade duration, number of outages per day and their duration, etc.), for the full year or conditional to the hour of the day, the season, etc.

- improve space-time channel characterization and modeling.
- develop new approaches for site diversity: temporal and spatial distribution of statistics as well as concurrent time series.
- use Numerical Weather Forecast simulators for the estimation of propagation effects in order to have a more accurate modeling over the full satellite service coverage and a possible extension to regions where less propagation measurements are available.
- assist the standardization bodies (e.g. ITU-R) to improve their recommendations and experimental databases.
- to revise the ITU-R Recommendations related to long term and short –term statistics of atmospheric channel (e.g. [4], [5], [6])

conduct propagation measurements at different sites across Europe.

IV. PROPAGATION CAMPAIGN DETAILS

The campaigns consists of a consortium of five partners, namely RAL in UK; NTUA in Greece; IT-Aveiro in Portugal; UoV in Spain and UCL in Belgium. The partners will combine their resources to form a network of ground stations; at their facilities, data acquisition systems will receive the Alphasat's beacon(s) signal(s) as well as record ancillary information. The exact locations of the experimental sites are listed in Table 1.

Generally any experiment to collect data consists of the following main topics that are considered as critical for its success:

- a) Representative data: collection of a representative sample for the scientific requirements.
- b) Data quality: the quality of the data should be such to allow for reliable extraction of the required information.

- c) Metadata: for the sufficient description of the data – necessary for the accurate use of data.

In the design of the experiment the following were also considered:

- similar activities are being conducted in other locations across Europe;
- a communication experiment payload is ongoing, with beams directed towards Tito Scalo, Southern Italy, Spino d’Adda, Northern Italy and Graz, Austria;

co-polar only); the receivers at Vigo are located indoors and are equipped with an antenna pointing (two-axes tracking system) based on OEM files with 0.01° resolution. The Bilbao receiver is placed on a building terrace inside an open hut sheltering it from the rain without tracking system. All receivers use single down-conversion (to L-band from Ka-, to 142 MHz from Q-band). The signal is fed to Universal Software Radio Peripherals (USRPs) for further processing using a FFT open loop detection algorithm operating on MS Windows. The dynamic range for the Ka-band receivers is

Experimental Site	Measured Parameters	Antenna				Sampl. Rate (Hz)	Dynamic Range (dB)
		Type	Size (mm)	Gain (dBi)	Track. system		
UK,Chilbolton	Copolar Att., Scintillations	Lens horn	500	39	yes	10	19
UK,Chilton	Copolar Att., Scintillations	Lens horn	500	39	yes	10	19
Portugal, Aveiro	Copolar Att., Scintillations	Diamond shaped	1500	47	Not needed	8	24.6
Spain,Vigo	Copolar Att., Scintillations	Lens horn	350	36	yes	12	26.2
Spain,Bilbao	Copolar Att., Scintillations	Lens horn	350	36	No	12	25
Belgium, Louvain-la-Neuve	Copolar Att., Scintillations		1200	45	yes	10	30
Greece, Athens	Copolar Att., Scintillations	Parabolic	1200	46	yes	10	22
Greece, Lavrion	Copolar Att., Scintillations	Parabolic	1200	46	yes	10	22

Table 2: Characteristics of Ka-band terminals

- there is a lack of propagation data in the South East of Europe;
- NWP data are now very important for the optimization of new HTS systems.

The propagation campaign consists of three main sections:

- the data acquisition and pre-processing of the data section
- the Numerical Atmospheric Simulator section and
- the Data Analysis section.

V. BEACON RECEIVERS

Below follows a brief description of the receivers used at each partner’s location. It has to be mentioned here that because of the inclination of the Alphasat orbital plane (the inclination is anticipated to increase up to ± 3 degrees in a couple of years) the receiving terminals have to be equipped with a tracking system. Summary of each receiver’s characteristics can be found in Table 2 and 3 for the Ka- and Q-band respectively. Measurements shall be made by a network of time synchronized (GPS) stations across the coverage area to ensure the obtained data qualify for temporal correlation studies..

A. UVigo

Two sites are available one in Vigo (Ka- and Q-band measurements, co-polar only) and another in Bilbao(Ka-band,

33.5 dB and for the Q-band receiver 37.2 dB at 12Hz sampling rate.

B. IT-Aveiro

Two receivers are deployed in Aveiro, targeting the Ka-band (KaSat beacon at 19.68GHz) and Q-band (Alphasat Q-band beacon at 39.402GHz). The Ka-band receiver is equipped with an outdoor 1.5m antenna, uses triple down-conversion to 10.7 kHz IF and interfaces to a computer by a National Instruments data acquisition card; it conducts both co-polar and cross-polar measurements at 8 Hz sampling rate, resulting into 24.6 dB dynamic range. On the computer runs custom acquisition software developed in C++ which performs FFT estimation.. The Q-band receiver consists of an 60 cm antenna and utilizes double down-conversion to a 142 MHz IF; the signal is fed to a USRP connected to a computer running a custom real-time estimation software (either FFT or PLL) developed in Matlab. The antenna will be mounted on a two axis tracking system with resolution and accuracy better than 0.05°.

C. NTUA

NTUA will conduct propagation measurements utilizing the Alphasat’s Ka-band beacon at two sites separated about 36.5 km of each other: at the NTUA Campus and at Lavrion; the receiving stations are based on the Software Defined Radio (SDR) paradigm and are built using exclusively high-grade off-the-shelf parts. Each of them will consist of a 1.2m Ka RX offset dish antenna paired with a Low Noise Block (LNB) utilizing single down-conversion in the L-band; the signal is

ultimately fed to a USRP connected to a single board computer for further processing. The measurements are derived using a spectral estimation real-time processing algorithm (FFT-based, based on the GNU Radio framework). In order to ensure accurate measurements an open-loop elevation tracking mechanism is deployed based on OEM files. Significant effort will be put to ensure that the tracking system's error will be kept in the range of $\pm 0.1^\circ$. Finally, a GPS Disciplined Oscillator (GPSDO) is used as a clock reference for both the LNB and the single-board computer,

through radomes of woven PTFE windows. The dynamic range for the receivers is 19 dB for the Ka- and 22 for the Q-band one, both at 10 Hz sampling rate. It should be noted that a site diversity experiment will be conducted at both frequency bands (Ka and Q).

VI. ANCILLARY DATA AND INSTRUMENTATION

All the experimental sites support the beacon measurements with ancillary data.

Experimental Site	Measured Parameters	Antenna				Sampl. Rate (Hz)	Dynamic Range (dB)
		Type	Size (mm)	Gain (dBi)	Track. system		
UK, Chilbolton	Copolar Att., Scintillations	Casegrain	500	44	yes	10	22
UK, Chilton	Copolar Att., Scintillations	Casegrain	500	44	yes	10	22
Portugal, Aveiro	Copolar Att., Scintillations	Casegrain	600	45.4	yes		27.5
Spain, Vigo	Copolar Att., Scintillations	Cassegrain	600	45.4	yes	12	30
Spain, Bilbao	x	x	x	x	x	x	x
Belgium, Louvain-la-Neuve	Copolar Att., Scintillations		1200	45	yes	10	30
Greece, Athens	x	x	x	x	x	x	x
Greece, Lavrion	x	x	x	x	x	x	x

Table 3: Characteristics of Q-band terminals

offering accuracy in the order of μ s. Only co-polar measurements will be conducted, with a minimum expected dynamic range of 35 dB at 10 Hz sampling rate. The measurements from the two sites shall allow for site-diversity studies.

D. UCL

The equipment is not yet selected. Three candidates have been analyzed, in the limit of the budget.

E. RAL

RAL Space will conduct measurements in both Ka- and Q-bands (co-polar component only) at two sites, Chilbolton and Chilton (47.8 km apart). The receivers have been used in prior campaigns, and are complete with A/D back ends allowing digital signal output for further analysis. All receivers use single down-conversion to a 70 MHz IF, while the beacon signal powered is measured using a Novella Satcoms B150 70MHz phase locked tracking receiver with a noise bandwidth of 300Hz and a tracking range of ± 100 kHz. The local oscillators are DROs phase locked to an internal crystal reference and the LO frequency is multiplied by 3 to drive the mixer. In addition a tracking antenna mechanism will be procured in order to obtain the highest link budget available. The receivers (and the antennas) will be located inside a specially adapted Portakabin (similarly to that used in the ITALSAT campaign). The antennas will view the satellite

A. UVigo

The auxiliary instrumentation available at the Vigo consists of a weather station in terrace next to the beacon receive, capable of measuring rain rate (0.1mm/sec, tipping bucket), relative humidity, ambient temperature, indoor temperature, pressure and wind speed/direction.. Collocated, there is an optical disdrometer. At both sites, local weather C-Band radar data is available with update rates of 10 min. Both sites have access to PPI and CAPPIS. NWP data over a box volume defined by the UVigo link up to the tropopause is available from the regional weather service (MeteoGal) with an update rate of 1 hour and a spatial resolution of 1 km. From Vigo's beacon receiver, the nearest RAOBS centre is at La Coruña 130 km away. In the case of Bilbao it is the RAOBS center at Santander 75 km away. METAR aeronautical reports are available from the neighboring airports of Vigo 8 km from the beacon receiver and Bilbao 5 km from the beacon receiver.

B. IT-Aveiro

The main meteorological parameters to be measured, and the associated equipment all from are ambient temperature and humidity, wind speed and rain rate by means of a drop counter gauge and a tipping bucket type.

C. NTUA

An advanced wireless amateur weather station will be installed at each site. It is capable of recording ambient

temperature, relative humidity, air pressure, wind speed, wind direction and UV radiation. For extra accuracy separate professional tipping bucket solution has been installed capable of measuring rain at a rate of 0.2mm/sec.

D. UCL

There is no meteorological equipment deployed at the moment. The meteorological stations available in Louvain-la-Neuve will be used, (a tipping bucket rain gauge and temperature sensor), located 1 km west from the receiver.

E. RAL

The main meteorological instruments available are rain gauges (high resolution drop-counting and tipping bucket, the drop-counting gauges have a 10-sec integration time, with a quantisation of 0.0033mm of rain accumulation per drop), impact disdrometers). Also measured are air temperature, humidity, air pressure, wind speed and wind direction. Available are also an operational radiosonde, approximately 28 km from Chilbolton, a radiometer (channels in the 20-30GHz interval for water vapour), a GPS receiver. And Ceilometer Zenith-pointing cloud radars (35GHz and 94GHz) providing continuous cloud profiles over Chilbolton. Finally, a 3GHz rain radar is available for event-based studies (i.e. not continuous operation) as well as access to data from Met Office C-band radar network.

VII. PREPROCESSING AND SOFTWARE FOR MODEL TESTING

Pre-processing of the recorded beacon and meteorological data is one of the most crucial tasks for a successful experiment because it contributes to the high quality of the data. There are various methods for the preprocessing in the literature such as in [3] and [7]. The RAL method in [3] is based on the Fourier series and has been successfully used during the OLYMPUS, ITALSAT and GBS propagation campaigns. The method is in line with the NASA approach for Earth Observation and Science Data Information System Processing (EOSDIS) [<http://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products>]. Furthermore in the frame of an ESA contract [ESA4000109353] a Propagation Data Processing System (PDPS) is being implemented to receive the data from the measurement sites and to help the experimenters for the data pre-processing and processing of the measured data. This software will be used for the pre-processing of the raw data.

Before the model testing there will be developed procedures and the corresponding software in MATLAB and PYTHON in order to prepare the collected measurements and the independent datasets for the statistical analysis and the validation procedures of model testing.

Apart, from the single links first order statistics, joint statics will be derived on spatial, temporal and frequency domain. In the former case of spatial diversity, the

measurement data sets of every region will be used in order to derive the joint exceedance probability of attenuation for as many sites as possible, e.g. In case that three sites are available both bivariate and tri-variate joint statistics will be evaluated. Generally multivariate statistics will be available from the statistical analysis software. Moreover, the joint statistics of site diversity attenuation for sites with large separation distance will be of use in order to consider the effects on the joint statistics not only the effect of the separation distance but also the effect different elevation angles (unbalanced diversity systems) and the differences in climatic conditions. These attenuation values may be either total attenuation values or in-excess attenuation.

VIII. CONCLUSIONS AND FURTHER WORK

There are many issues that should be discussed and designed among the consortium member along with the installation of the receivers. It is expected that all the receivers that will participate in the campaign will be fully operational in June 2016. During the conduction of the measurements using the ALPHASAT Aldo Paraboni payload beacons other measurements from current and past propagation campaigns will also be considered. Moreover, ALPHASAT experiments' objective is to demonstrate the effectiveness of FMTs in improving the achievable data throughput in a real Q/V band satellite link.

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