Large Scale Assessment of Ka/Q Band Atmospheric Channel Across Europe with ALPHASAT TDP5: The Augmented Network

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***Abstract*—The upcoming migration of satellite services to higher bands, namely the Ka- and Q-bands offers many advantages in terms of bandwidth, data rates and system capacity. However, it poses challenges as propagation effects introduced by the various atmospheric phenomena are particularly pronounced in these bands and can become a serious constraint in terms of system reliability and performance. This paper outlines the goals, organization and some first results of an ongoing large propagation campaign consortium formed across Europe under the supervision of the European Space Agency; the campaign, shall ultimately assist in the validation and development of channel models targeting these-bands. Finally, the consideration of diverse climatic conditions and elevation angles along with the evaluation of the frequency and spatio-temporal effects, shall support the development of Fading and Mitigation Techniques and their assessment using real data.**

***Index Terms*— propagation, measurement, campaign, consortium, experiment, Alphasat, beacon, Ka-band, Q-band, attenuation, atmospheric effects, site diversity, frequency scaling.**

I. Introduction

The increasing demand for higher data rates for the numerous services using satellite links, the congestion of the lower frequency bands (C, Ku) and the fact that system capacity increases with the increasing amount of available spectrum is leading to the use of higher frequencies. In particular, for large broadband satellite networks, the limited spectrum available even in the Ka band is leading to the move the feeder link to the higher Q/V band where more spectrum is available [1].

As a general rule, moving to higher frequencies provides greater bandwidth and thus potential data rates but is i) more demanding in terms of technology (i.e., more complex systems) and ii) ultimately more prone to the effects of atmospheric gases, clouds, rain and tropospheric turbulence.

For earth-space systems operating up to Ku-Band the main task of system designers at the physical layer is the allocation of fade margin, and for that reason long-term statistics, mainly of the attenuation describing the system performance, is adequate. Systems operating at higher frequencies experience much more severe tropospheric losses, which, due to technical and economical limitations, cannot be compensated by the fade margin alone. Therefore, Fade Mitigation Techniques, FMT (also known as Propagation Impairment Mitigation Techniques, PIMT) have to be employed and alternative ways of using these systems have to be studied. This requires a thorough understanding of the temporal and spatial propagation characteristics of the radio channel. Furthermore, since the power resources are limited and bearing in mind a) the levels of atmospheric attenuation that have to be coped with and b) the higher performance requirements and complexity of these higher HTS systems, more accurate link budget calculations are required.

Propagation experiments and subsequent studies have been performed to measure, characterize and model the propagation effects globally. These efforts have 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, 4] 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 [5] 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.

Therefore, the two beacons at Ka- and Q- frequency bands of the Alphasat's payload TDP5 provide a unique opportunity to bridge the above mentioned gaps in Europe. A consortium consisting of five partners (RAL in UK; UoV in Spain; IT-Aveiro in Portugal; NTUA in Greece; and UCL in Belgium) and operating under European Space Agency (ESA) was established to conduct new coordinated propagation measurements in the Ka- and Q- bands in various locations across Europe using the beacon signals transmitted by the Alphasat satellite [6]. Furthermore, this network of measurements (known as ASALASCA) has been enhanced (to define the Augmented ASALASCA experiment) with coordinated measurements being conducted in Slovenia [7], Czech Republic [8] and more recently with the Q band measurements in Scotland by the Herriot Watt University.

This paper provides a description of the Augmented ASALASCA experiment, together with some preliminary results for understanding how to formulate the crucial - for the design and operation of new High Throughput Satellite (HTS) systems - problem of the spatial and temporal characteristics of the Q/V radio channel.

II. Experiment Objectives And Tdp#5

A. *Objectives*

The purpose of this activity is to provide representative propagation data of the coverage area across Europe for the design of the new (HTS) systems. In particular, taking into account the new needs and new scenarios that have arisen (e.g., Fade Mitigation Techniques, adaptivity concept, the increased tendency towards a generalised connectivity, etc.) it is necessary to overcome the limitations of the past measurements by conducting new experiments.

The new propagation data are required:

- to improve the accuracy of existing propagation models or to develop new models where the are required
- to conceive, design and optimize the new generation of satellite systems adopting Fade Mitigation Techniques (FMT)
- to study the variability and space-time correlation of propagation characteristics (e.g. joint statistics) that are fundamental for the planning, assessment and operation of the different FMTs
- to assist the standardization bodies (e.g. ITU) to improve their recommendations and experimental databases for use in the design, planning and operation of the new Ka and Q/V band exploitation.

In addition, the experiment provides the use of 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.

B. *TDP#5*

Alphasat (also referred to as Inmarsat-4A F4) is a commercial satellite located at 25.0ºE 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) with European coverage for propagation experiment purposes. The present campaign is utilizing both beacons to conduct propagation measurements at different sites across Europe

III. Experimental Sites

The exact locations of the experimental sites are listed in the Table I together with the elevation and azimuth angles and the starting date of measurements. After a successful verification regarding the experimental equipment, which guarantees the quality of the acquired data, the starting date of the coordinated experiment is the 1st of July 2016.

The distances between the experimental sites are listed in Table II. Site Diversity measurements (i.e., short scale spatial characteristics) are conducted in England at Ka- and Q – band. In Greece, site diversity measurements have been started in June 2016 at Ka-band whereas measurements at Q band are planned at the end of 2016.

A description of the technical characteristics of the receiving terminals and the measured propagation parameters are listed in the Table III. All the experimental sites support the beacon measurements with ancillary (data rain and meteorological data) – see Table IV.

IV. Execution Of The Campaign

The propagation campaign consists of three main sections: i) the data acquisition and pre-processing of the data section ii) the Numerical Atmospheric Simulator section and iii) the Data Analysis section.

In the first section the collected data of each experimental site are pre-processed to i) remove from the beacon signal the effects of the space segment and ground equipment ii) merge data from beacon receiver and ancillary instruments iii) identify valid data and archive raw and processed measurements.

The Numerical Atmospheric simulator provides statistical predictions of propagation parameters and time simulations of the radio channel conditions over the area of

TABLE I. CONSORTIUM EXPERIMENTAL SITES INFORMATION

Location	Latitude	Longitude	Above mean sea level	Elevation angle	Azimuth	Ka-band	Q-band
UK, Chilbolton	51.15ºN	1.43ºW	100 m	26.40º	147.45º	Since 11/03/2016	Since 11/03/2016
UK, Chilton	51.57ºN	1.29ºW	100 m	26.07º	147.77º	Since 11/03/2016	Since 11/03/2016
Portugal, Aveiro	40.612ºN	8.662ºW	12 m	31.80º	134.45º	KaSAT,1/1/2013	Since 1/4/2016
Spain, Vigo	42.170ºN	8.688ºW	447 m	30.60º	135.20º	Since 1/1/2015	Since 1/1/2015
Spain, Bilbao	43.257ºN	2.924ºW	10 m	32.74º	142.28º	Since 1/1/2015	No
Belgium, Louvain-la - Neuve	50.40ºN	4.37ºE	160 m	29.02º	153.96º	Planned for End 2016	Planned for End 2016
Greece, Athens-Zografou	37.975ºN	23.785ºE	210 m	45.97º	178.03º	Since 1/2/2015	Planned for End 2016
Greece, Lavrion	37.725ºN	24.052ºE	20 m	46.26º	178.44º	Since 1/6/2015	Planned for End 2016
Slovenia, Ljubljana	46.042ºN	14.488ºE	292m	36.0o	165.5o	Since 20/08/2015	Since 20/08/2015
Czech Republic, Prague	50.04ºN	14.488ºE	274m	31.80o	166.6o	Since 01/09/2015	Since 01/09/2015
UK, Edinburg	55.91ºN	3.32ºW	150m	21.47o	146.95	No	Since 1/5/2016

TABLE II. DISTANCE IN KM BETWEEN EXPERIMENTAL SITES (* Sites for Site Diversity i.e.., short scale spatial correlation)

	Chilton	Edinburg	Vigo	Bilbao	Aveiro	Athens	Lavrion	Louvain	Ljubljana	Prague
Chilbolton	47.85 *	544.9	1139.6	883.7	1296.1	2456.3	2492.5	416	1297.2	1127.5
Chilton		502	1184.9	931.4	1342.3	2468.5	2504.7	415.9	1304.	1118.2
Edinburg			1575.9	1407.2	1745.1	2831.1	2867.3	798.0	1652.1	1353.3
Vigo				486.1	173.3	2784.9	2816.3	1354.5	1892.6	1977.9
Bilbao					558.2	2318.7	2351.1	967.9	1408.7	1522.4
Aveiro						2791.7	2821.8	1484.4	1484.4	2078.4
Athens							36.31*	2063.5	1179.3	1531.4
Lavrion								2099.8	1215.6	1566.7
Louvain									891.4	719.9
Ljubljana										444.5

TABLE III. CHARACTERISTICS OF KA- AND Q- BAND TERMINALS

Exper. Site	Ka - Band							Q-Band						
	Meas Parm.	Antenna				Samp Rate (Hz)	Dyn. Range (dB)	Meas Parm.	Antenna				Samp Rate (Hz)	Dyn. Range (dB)
		Type	Size (mm)	Gain (dBi)	Track. system				Type	Size (m)	Gain (dBi)	Track. system		
UK, Chilbolton	CPA, scint.	Lens horn	500	39	yes	10	19	CPA, scint.	Cassegrain	500	44	yes	10	22
UK, Chilton	CPA, scint.	Lens horn	500	39	yes	10	19	CPA, scint.	Cassegrain	500	44	yes	10	22
Portugal Aveiro	CPA, scint	Diamond shaped	1500	47	Not needed	8	24.6	CPA, scint	Cassegrain	600	45.4	yes	8	27.5
Spain, Vigo	CPA, scint	Lens horn	350	36	yes	12	26.2	CPA, scint	Cassegrain	600	45.4	yes	12	30
Spain, Bilbao	CPA, scint	Lens horn	350	36	No	12	25							
Belgium, Louvain-la-Neuve	CPA, scint		1200	45	yes	10	30	CPA, scint	Cassegrain	1200	45	yes	10	30
Greece, Athens	CPA, scint	Parabolic	1200	46	yes	10	39.5	CPA, scint	Cassegrain	600	46	yes	10	>30
Greece, Lavrion	CPA, scint	Parabolic	1200	46	yes	10	36	CPA, scint	Cassegrain	600	46	yes	10	>30
Slovenia, Ljubljana	CPA, scint., XPD	Parabolic offset dish	1200	46	yes	6.1	32	CPA, scint., XPD	Parabolic offset dish	1200	51	yes	6.1	38
Czech Republic Prague	CPA, scint.	Parabolic offset dish	1972x 1822	48	In Elevati on	1Hz-20Hz	>30	CPA, scint	Parabolico ffset dish	1972 x 1822	55	In Elevati on	1Hz-20Hz	>30
UK, Edinburgh								CPA, scint	Cassegrain	600	45	yes	10	35

TABLE IV. ANCILLARY DATA*

Exper. Site	Rainfall Rate	Meteo Station	Radiometer	Weather Radar	RAOBS
UK, Chilbolton	Drop count RG, RD	T,P,RH, WS,WD	Radiometerics	Yes	Yes
UK, Chilton	Drop count RG,	T,P,RH, WS,WD			
Portugal, Aveiro	Drop count RG	T,P,RH, WS			
Spain, Vigo	Tips RG, RD	T,P,RH, WS		Yes	Yes, La Coruna
Spain Bilbao	Tips RG	T,P,RH, WS		Yes	Yes, Santander
Belgium, Louvain	Tips RGin Louvain	T in Louvain			
Greece, Athens	TipsRG	T,P,RH, WS,WD			
Greece, Lavrion	Tips RG	T,P,RH, WS,WD			
Slovenia, Ljubljana	Tips RG	T,P,RH, WS,WD			
Czech Republic, Prague	TipsRG	T,P,RH, WS,WD	yes		
UK, Edinburgh	Tips RG	T,P,RH, WS,WD			

* (T: temperature, P: pressure, RH: relative humidity, WS: Wind speed, WD: Wind direction, RG: rain, RD: Disdrometer

the ground terminals using radio-climatological data (e.g. ITU-R statistical maps) and NWP concurrent data.

These simulated data are used on one hand as a reference for the monitoring and calibration of instruments and on the other hand to generate ancillary or additional parameters not measured directly the equipment.

The Data Analysis section performs the statistical analysis of the measurements provided at the first section and the comparison of these data with the statistical output of the Numerical Atmospheric Simulator. The output of this system is then used for propagation modelling and improvement of the Numerical Atmospheric Simulator.

The first two sections refer to the execution of the measurements. Based on the experience of previous campaigns the following actions are also performed:

- Regular monitoring of the equipment and the recorded data. The objective of this activity is to identify eventual faults and promptly initiate recovery actions.
- The equipment is subject to a regular maintenance such as recalibration, replacement of defective or degraded parts.
- To enhance consistency of the obtained data we take into account current or past measurements (what we call the independent dataset DS1).

In the frame of 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. However, additional methods are complete and used by the consortium: RAL method [4] is used by RAL, NTUA and Heriot Watt University; IT-Aveiro method [9] is used by IT-Aveiro and UoV; JSI method [7] used by JSI; IAP method [8] used for the data collected in Prague.

Therefore, we are currently in the process of a harmonization between these approaches which involves: i) Harmonization of the theoretical underlying approaches of the methods; ii) Cross pre-processing of the same datasets.

In addition, for a common approach by all the experimenters the following data levels are used: Level 0: Measured Instrumental Data; Level 1: Raw Propagation Data. These datasets are used as inputs to Data acquisition and processing system; Level 2: Intermediate Propagation Data (for example, at this level the time series have been processed to remove outliers and the signal fluctuations from ground or space systems); Level 3: Validated Time Series. These datasets are the output of Data acquisition and processing system and Numerical Atmospheric Simulator; Level 4: Analyzed Experimental Statistics. Output of Data Analysis. Furthermore, for i) evaluating the quality of the measurements ii) identifying equipment malfunctions iii) identifying of any deviation from the experimental planning and campaign requirements the raw and pre-processed data time series together with the monthly statistics undergo a quality control by each experimenter. Then a further quality control is performed by RAL on a monthly basis.

V. FIRST RESULTS

Figure 1 shows the excess attenuation time series in UK (Chilton and Chilbolton) for both frequency bands during propagation effects on 12/07/2016 whereas Fig. 2 shows the Q–band excess attenuation statistics at Chilton (RAL) for July 2016.

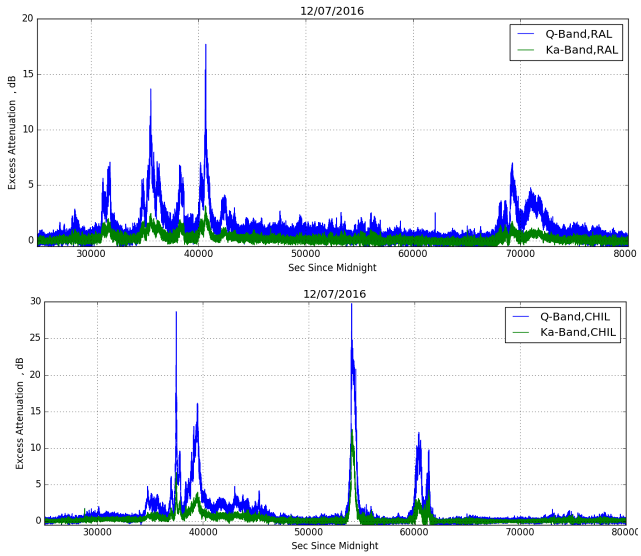

Fig. 1 Ka- and Q- frequency band Excess Attenuation time series during rain events occurred at RAL site and Chilbolton on 12th of July 2016 showing the concept of site diversity.

The experiment in Aveiro comprises of one beacon receiver for the Alphasat Q- band and another one for the Ka-band using the horizontally polarized 19.68 GHz beacon of the Ka-Sat 9A satellite. The arrangement provides a combined frequency and orbital diversity experiment. Fig. 3 depicts a substantial spread of the instantaneous attenuation scaling, for a very long event (3.5 hours with data filtered with an integration time of about 40 s). The cumulative distributions for the available 4 months are depicted in Fig. 4.

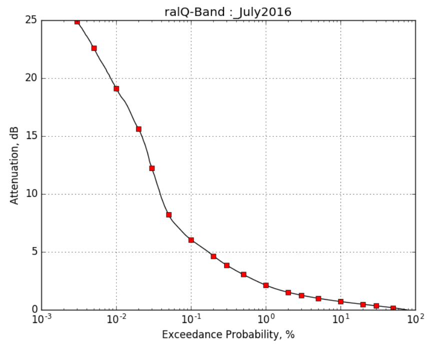

Fig. 2 Q-Band excess attenuation statistics for July 2016 measured at RAL establishment at Chilton.

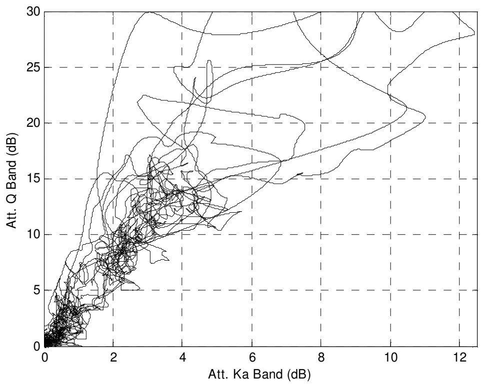

Fig. 3 Scatter plot of the attenution at Ka-band (Ka-sat) and Q-band measured at Aveiro: 13 September 2016 (3.5 hours duration event)

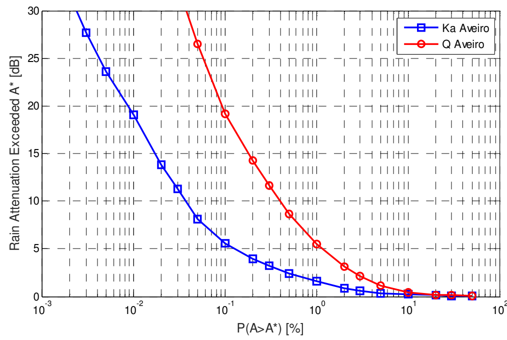

Fig. 4 Attenuation statistics measured at Aveiro: 1 April to 31 July 2016

VI. CONCLUSIONS

The Augmented ASALASCA experiment is in the early stages of the execution of measurements - the coordinated campaign started on the 1st of July 2016. The equipment verification review for the consortium members together with the planned operation of TDP5 until 2020 predict a representative sample of propagation measurements both in space (European coverage) and time. This representative sample is required for the characterizing the spatial and temporal behaviour of the radio channel necessary for the design and operation of HTS systems.

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