Large Scale Site Diversity Experimental Campaign Between Greece and UK Using ALPHASAT: First Results

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Abstract. There is an imminent migration of satellite communications to higher frequency bands in order to support the next generation services; this however, poses new challenges in terms of system design. With increasing frequency signal propagation becomes more prone to atmospheric phenomena and therefore accurate channel modeling is required. In this paper an ongoing propagation campaign in Ka and Q band taking place in Greece and UK using ALPHASAT's beacons is outlined. Some first results from the acquired measurements are presented, indicating the advantages of using site diversity techniques in feeder links; finally, a preliminary evaluation of large scale site diversity gains in terms of outage capacity is accomplished by means of simulated data.

Keywords: Ka-band · Q-band · Propagation · Campaign · Measurements
ALPHASAT · Beacon · Site diversity · Outage capacity

1 Introduction

The increasing demand for very high data rate services has imposed new requirements in satellite communication systems; although current satellite networks can offer capacities in the order of hundreds of Gbps, it is estimated that next generation satellite systems shall be able to support Tbps of throughput to accommodate the upcoming multimedia services [1]. The imminent migration of services to the Ka and Q/V bands is therefore well justified, particularly when taking into consideration the already congested frequency spectrum. These bands offer massive bandwidth (allegedly up to 5 GHz for the V-band feeder-link case [1]), nevertheless up the ante on system design as signal propagation at these bands can be severely impaired by the various atmospheric phenomena (gases, clouds, rain and tropospheric turbulence) [2].

To facilitate the design of high availability systems, accurate propagation modeling is of utmost importance; such models provide the means to quantify and potentially mitigate the impact of atmospheric effects on signal propagation, ensuring that the

P. Pillai et al. (Eds.): WiSATS 2017, LNICST 231, pp. 174–183, 2018.
https://doi.org/10.1007/978-3-319-76571-6_17

required Quality of Service (QoS) requirements are met in an efficient manner. Producing propagation models is nevertheless a non-trivial task; it is key that they are validated against real long-term data from diverse climatic regions obtained from experimental campaigns. In the past two major experimental campaigns were conducted in Europe, one using the ESA OLYMPUS satellite (targeting Ku and Ka bands) and another one using the Italian ITALSAT F1 satellite (targeting the Q/V bands) [3]; although high-quality measurement data were acquired during these campaigns, the spatio-temporal correlation characteristics of signal propagation were not thoroughly investigated. Since 2013 the European Space Agency (ESA) coordinates the transmission of a payload dedicated to propagation measurements in Ka and Q bands using the ALPHASAT satellite. Many measurement campaigns making use of this payload are ongoing across Europe, aiming to populate the scientific databases with new, valuable data. The National Technical University of Athens (NTUA) in Greece and the STFC Rutherford Appleton Laboratory – RAL Space in the UK are currently conducting measurements in both Ka and Q bands using ALPHASAT's payload, with the objective -among others- to study frequency and site diversity schemes as will be explained in the following. Both NTUA and RAL Space are also members of the relevant ESA contract "ASALASCA" [4].

2 Gateway Site Diversity Concepts

It is well known that with increasing frequency signal propagation becomes more prone to atmospheric phenomena; even under non-rainy conditions a high fade margin is oftentimes required to account for gases, cloud attenuation and scintillation particularly for the Q/V bands. Adding rain attenuation on top of these effects lowers the system availability even further, rendering it troublesome at the very least, unless a Fading Mitigation Technique (FMT) [5] or some form of redundancy is employed.

Considering feeder links (gateway – satellite links) system availability is of overriding significance as an outage can result into service disruption for a vast number of users; the typical availability requirement is in excess of 99.9% and the typical FMT used is uplink power control. The feeder link is designed with a high link margin (in the order of a few dB) so as to be able to compensate for possible fade attenuation effects; however, depending on the climatic region and the elevation angle, fade attenuation events can be in the order of 15–20 dB [2] for a non-negligible percentage of time. It is therefore evident that setting up a link margin alone is insufficient to maintain the high availability requirement.

A technique that can be used to mitigate the impact of severe propagation effects on feeder links is site diversity [6]. This involves either the installation of complementary, spatially separated back-up (redundant) gateways to support each already existing gateway, or in its "smart" version [7], the exploitation of already existing gateways to reroute the traffic dynamically in order to achieve the required fading link availability (Smart Gateway Diversity). In this paper, the conventional site diversity will be examined for the case of Ka- and Q-band.

In a conventional site diversity scheme, a primary (master) gateway is interconnected using a high-capacity, high-availability network (e.g. optical fiber) to a pool of auxiliary, back-up gateways each of which is spatially separated from one another. The separation distance between each pair of gateways should be greater than the maximum expected rain cell radius so as to ensure the atmospheric phenomena are uncorrelated at each site. When the master gateway experiences a deep fade e.g. as a result of intense rainfall, a controller shall register the event, enable a back-up gateway (the one experiencing the lowest atmospheric attenuation) and reroute all traffic through this gateway until the master station's signal level recovers (e.g. attenuation falls below a predefined threshold). This technique is transparent to the satellite and can dramatically increase the availability of the system (the outage probability theoretically equals the product of the single probabilities for each station, if statistical independence occurs). The overall system availability shall then be bottlenecked by the user links that traditionally merely use Adaptive Coding and Modulation (ACM) techniques.

3 Campaign Details

The novel feature of this campaign [8] is that concurrent measurements are acquired across two locations with vastly different topography and climatic characteristics, Greece and the UK. Greece is characterized by its Mediterranean climate with long-lasting, hot summers and relatively mild winters; during the winter season, very intense rainfalls (convective precipitation) usually take place at irregular intervals, however, they last no more than a few consecutive days. Also, diurnal temperature variations are very common during the whole year but particularly pronounced during the spring and summer seasons (i.e. very high temperatures during the day that drop drastically at night). On the other hand, the temperate oceanic climate experienced in the UK is characterized by cool and cloudy weather and frequent showers during almost the entire year (stratiform precipitation); temperature fluctuations across different seasons are considered small and extreme weather phenomena are infrequent.

The currently ongoing propagation measurements take place at four sites, two in Greece (Athens and Lavrion, about 36.5 km apart) and two in the UK (Chilbolton, Chilton, 47.8 km apart); at each site both Ka and Q band measurements are conducted. This configuration allows for the study of frequency diversity as well as site diversity schemes in small and large scale distances. As per common practice, the measurements are carried out using beacon signals, i.e. Continuous Wave (CW) signals of constant power and frequency; the beacon signals received at 19.701 and 39.402 GHz for the Ka and Q bands respectively are transmitted by the ALPHASAT satellite at 25.0º E. ALPHASAT -although a commercial satellite (commercial name Inmarsat-4A F4) carries payloads for experimental purposes under the coordination of the European Space Agency. Among them is the so-called Aldo Paraboni Technology Demonstration Payload 5 (TDP #5), carrying two fully redundant, coherent beacons at the aforementioned frequencies.

Despite being a geosynchronous satellite, ALPHASAT is placed on a slightly inclined orbital plane to prolong its life (maximum expected inclination less than 3.0º).

As a result, its apparent position as observed from the ground varies over time necessitating the use of antenna tracking systems. The tracking systems can take advantage of the precalculated positions of the satellite provided by means of Orbit Ephemeris Messages (OEM) files, to account for the azimuth and elevation angle changes over time at the various locations (Fig. 1).

Fig. 1. Locations of the beacon receivers used in the campaign

To allow for truly concurrent measurements, all receivers are synchronized using GPS time as reference and the received signal samples are timestamped, converted to a unified form and stored in a common database for further consolidation and processing; this allows for quick data retrieval and direct comparison between data across the different sites.

3.1 NTUA Receivers

NTUA has designed, tested and deployed two identical Ka-band beacon receivers at the NTUA Campus and at the Lavrion Technological and Cultural Park; they are currently fully operational. Another two receivers targeting Q-band have also been designed and tested and are in the process of deployment at the time of writing this. All receivers are based on the Software Defined Radio (SDR) principle, making use of high-grade off-the-shelf parts whenever possible to lower the procurement and service costs and to allow for quick provisioning.

The Ka-band receivers consist of 1.2 m offset dish antennas while the Q-band ones consist of 60 cm shrouded parabolic antennas. After undergoing filtering, amplification and down-conversion at the Low Noise Block (LNB) units, the signals are fed to a Universal Software Radio Peripheral (USRP) which further samples them, digitizes them and passes them to a computer for further processing; the computer runs a custom software based on the popular GNU Radio framework. The signal power estimation is done using a real-time FFT algorithm, providing 10 Hz of sampling rate. Apart from the beacon signal measurements, the noise power in the same bandwidth is measured and recorded [9].

All oscillators used in the receiver chains are locked to an external GPS Disciplined Oscillator (GPSDO) to ensure that extremely high frequency stability is achieved. Also, all antennas are equipped with an accurate tracking system designed in-house. The measured dynamic range for the Ka-band receivers is in excess of 39 dB; for the Q-band case it is estimated at 35 dB.

3.2 RAL Space Receivers

RAL Space has already deployed four receivers targeting both the Ka- and Q-band ALPHASAT's beacons. They are located at Chilbolton and Chilton and comprise of equipment already used successfully in past propagation measurement campaigns; all equipment is located indoors, in a specially adapted Portakabin with woven PTFE windows.

The antennas used are 50 cm in diameter, lens horn type and cassegrain type for the Ka- and Q-band respectively. Each antenna has its own (commercially procured) tracking system, ensuring that the movement of the satellite does not influence the measurements. The beacon reception is based on conventional techniques, i.e. Phase Locked Loop (PLL) envelope detection using a PLL tracking receiver configured with a noise bandwidth of 300 Hz and a tracking range of 100 kHz. The output of the PLL receiver is fed to a computer-attached Analog to Digital Converter (ADC) for further processing (sampling, digitization etc.).

The available dynamic range for the Ka-band receivers is 19 dB while for the Q-band ones is 22 dB; all receivers operate at a 10 Hz sampling rate and measure only the co-polar component, the latter being the case for NTUA receivers as well.

3.3 Ancillary Instrumentation

At all receiver locations ancillary instrumentation has been in operation since the beginning of the campaign; this allows for in-situ meteorological measurements, allowing for further study of the correlation between the fading statistics and the observed meteorological events. All ancillary measurements are synchronized to the receivers and saved with the appropriate meta-tags for later processing. Besides the recorded measurements, data from other local stations or the national weather service agencies can be accessed should they be required.

4 First Site Diversity Results Using Measurements

The following constitutes a first attempt to evaluate a small/large scale diversity scheme using concurrent measurements from the four receiver sites. The configuration is as follows: in Greece the NTUA Lavrion (LTCP) is considered the primary gateway whereas the NTUA Athens (Campus) the secondary one. Until now only Ka-band measurements are available in Greece and therefore the diversity scenario involves only Ka stations (at 19.701 GHz); in the UK the primary gateway is considered to be in Chilton while the secondary one in Chilbolton. In the UK Q-band measurements (at 39.402 GHz) are also available and therefore are the ones presented. Two days have been selected for these scenarios, namely 12/09/2016 and 28/11/2016.

4.1 Performance for September 12, 2016 (No Fades)

Regarding this particular day no fades are experienced by any station. Both primary and secondary gateways can support other gateways that are located elsewhere in the world and experience fading (Fig. 2).

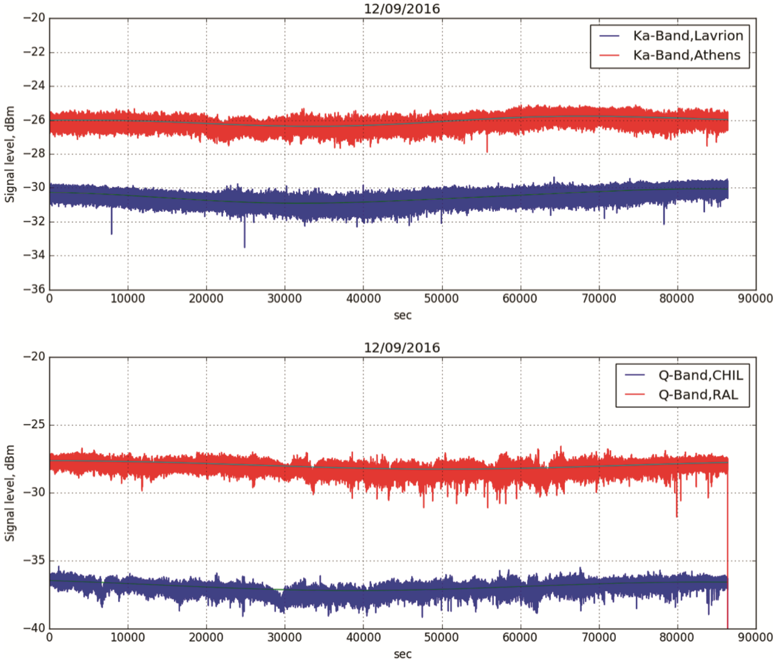

Fig. 2. Beacon received power time series for the diversity scenario on 12/09/2016.

4.2 Performance for November 28, 2016 (Rain in Greece)

On this day the stations located in Greece experienced high attenuation as a result of intense rainfall; on the other hand, the weather in the UK remained dry and therefore the stations did not exhibit any significant fading (Fig. 3).

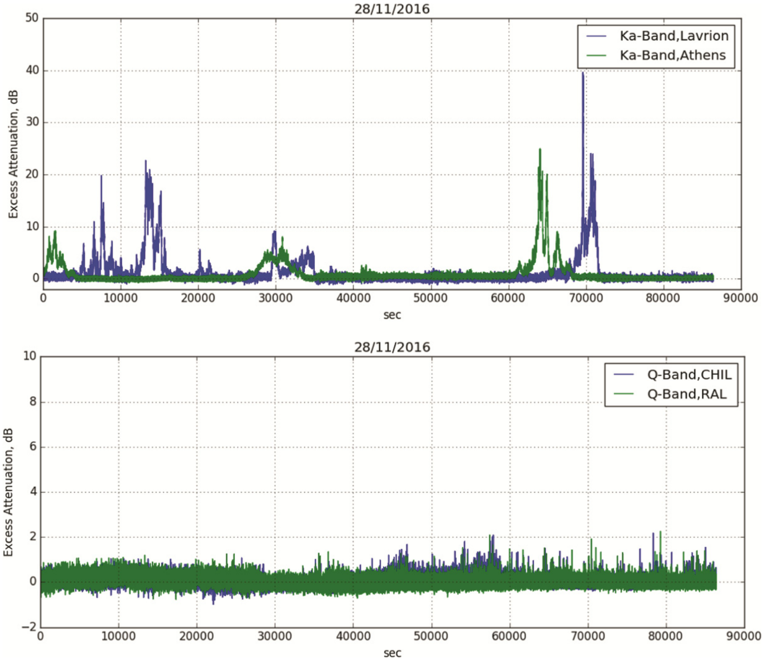

Fig. 3. Excess attenuation time series for the diversity scenario on 28/11/2016.

With a fade margin of 10 dB for the primary station in Greece (NTUA Lavrion) and 5 dB for the secondary station (NTUA Athens) the Greek gateway achieves 100% availability on 28/11/2016 (perfect switching is assumed). During the same day the English station could support other gateways experiencing fading.

5 Capacity Evaluation Using Simulation

As the campaign is still ongoing and measurements are acquired, it is useful to have a reference baseline against which results can be compared. Using the well-established multidimensional stochastic dynamic modeling in [10], 1 year of rain attenuation data have been generated for two of the four locations, namely Athens, GR (primary gateway) and Chilton, UK (secondary gateway) at both Ka- and Q-band. This provides a clear picture of what one should expect in terms of large scale diversity gains; finally, using the methodology in [11], the expected improvement in outage capacity is presented (Figs. 4, 5, 6 and 7).

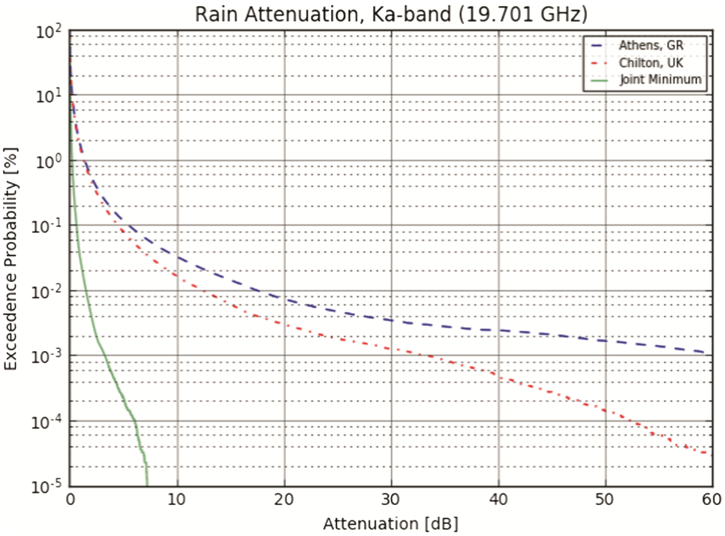

Fig. 4. Rain attenuation exceedance probabilities for Ka-band (19.701 GHz), single and joint minimum scenarios.

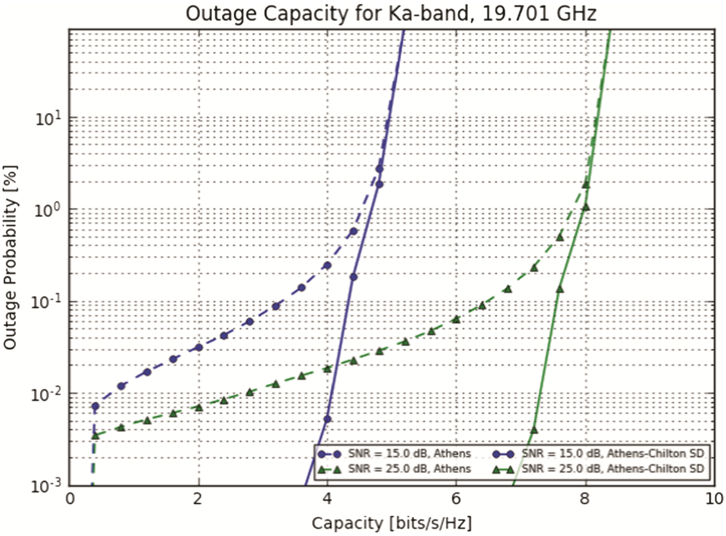

Fig. 5. Comparison between the resulting Ka-band outage capacities: a. using only the primary gateway in Athens, GR and b. using Site Diversity with the secondary station in Chilton, UK.

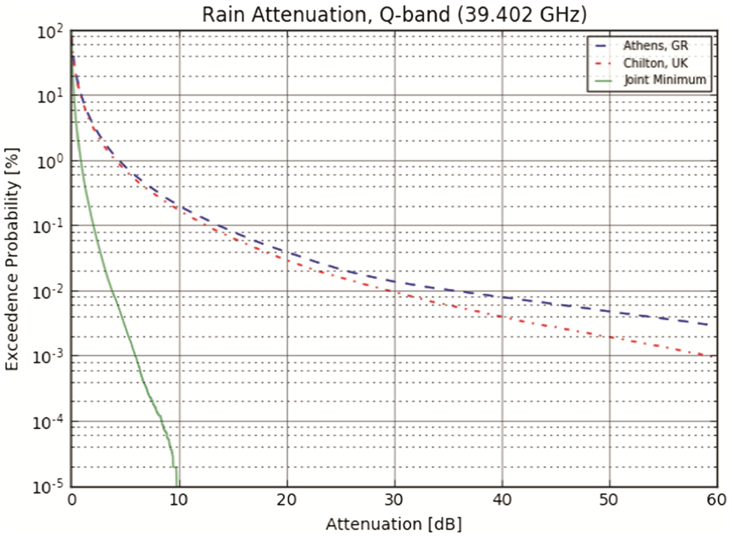

Fig. 6. Rain attenuation exceedance probabilities for Q-band (39.402 GHz), single and joint minimum scenarios.

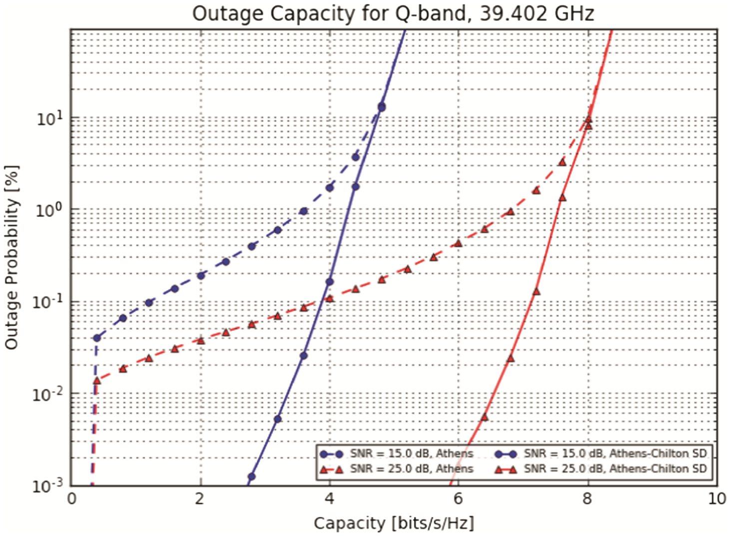

Fig. 7. Comparison between the resulting Q-band outage capacities: a. using only the primary gateway in Athens, GR and b. using Site Diversity with the secondary station in Chilton, UK

6 Conclusions and Future Work

The ongoing measurement campaigns in Greece and UK have been presented; as more data are collected, joint statistics on the frequency, temporal and spatial domains will be derived; the data shall be ultimately used to populate scientific databases (e.g. ITU-R) and to develop and validate new propagation models, FMTs and small/large site diversity techniques.

Acknowledgments. This work is funded by the ESA contract "Large Scale Assessment of Ka/Q Band Atmospheric Channel using the ALPHASAT TDP5 Propagation Beacon".

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