Analysis of measured tropospheric effects and link budget calculation for a Q-band LEO satellite

Introduction

Space communications, both ground-to-satellite and satellite-to-ground, are expected to grow dramatically over the next decade. This growth follows the recent deployment of new satellite constellations and the ever-increasing data requirements for communications and Earth observation from space.

To meet the demand for higher data rates, new space terminals must be designed, working at higher frequencies than current systems, for example in the Q and W bands. However, while the total amount of data increases at higher frequencies, the degradation due to tropospheric gases, clouds, and rain becomes more important. These effects need to be properly assessed for the design of future generations of satellites, especially as the current ITU atmospheric channel propagation models remain to be further validated at higher frequencies. Hence, new measurement campaigns are required.

Since 2017, UCLouvain has been part of a campaign led by the European Space Agency to collect received power measurements from the Alphasat satellite beacons at 19.7 and 39.4 GHz. From these measurements, attenuation time series can be extracted, from which atmospheric propagation models can be developed and validated.

In this project, you will have the opportunity to work with real data coming from the UCLouvain Alphasat receiver in order to assess the validity of current ITU models. You will then use the ITU models to calculate the link budget for a LEO satellite to determine the required on-board power for the satellite.

Part I – Analysis of Alphasat measurements at Louvain-la-Neuve

The goals of the first part of the project is to extract tropospheric effects from Alphasat measurements. Four months of data are available, one per season: September 2019, December 2020, March 2021, and June 2021. They do not come from the same year as the Alphasat receiver sometimes suffer from failure events, preventing the use of its data. Hence, the months have been chosen in order to give you data of good quality, i.e., without too many missing days.

For each month, you have to compute the excess attenuation time series at 19.7 and 39.4 GHz, and get its statistics (i.e., its complementary cumulative density function, CCDF). Then, a comparison between both frequencies and the ITU models, provided by the RAPIDS software, is expected.

More specifically, the following items should be detailed in your report:

- Explanations of the processing applied to obtain the excess attenuation from the raw measurements, with appropriate personal illustrations

- Analysis of the computed excess attenuation CCDFs (monthly and yearly[1]): comparison between the frequencies, comparison with ITU models, discussion and comments (e.g., origins of the differences between the months, the frequencies, and the models)

Part II – Link budget computation for a LEO satellite

The second part of the present project is to calculate the link budget to evaluate the power on-board the satellite (EIRP), in the Q band (37.5 GHz). In order to observe some effects related to the location of the receiving Earth station (difference of climate), the link budget is computed for two locations: Louvain-la-Neuve and a second station, based on you group number (see Table 1).

Location	*Latitude*	*Longitude*	*Altitude above mean sea*	*Group*
Belgium *Louvain-la-Neuve*	*50.668°N*	*4.615°E*	*160 m*	*All*
Cyprus Kofinou	34.86°N	33.38°E	120 m	1
Sweden Kiruna	67.85°N	20.26°E	300 m	2
VA, USA Wallops Islands	37.95°N	75.05°W	10 m	3
Antartica McMurdo	77.80°S	166.4°E	200 m	4
Greece Athens	37.98°N	23.79°E	210 m	5
Singapore Bukit Timah	1.35°S	103.79°E	164 m	6
Italy Florence	43.81°N	11.22°E	50 m	7
TX, USA Houston	29.56°N	95.10°W	5 m	8
CA, Goldstone Goldstone	35.28°N	116.78°W	900 m	9
Spain Madrid	40.42°N	3.70°W	660 m	10
Slovania Ljubljana	46.04°N	14.51°E	298 m	11
Spain Tenerife	28.30°N	16.50°W	2300 m	12
Sweden Esrange	67.88°N	21.12°E	300 m	13
Iceland Reykjavik	64.12°N	21.69°W	100 m	14
ACT, Australia Canberra	35.31°S	149.12°E	650 m	15
Japan Usuda	36.07°N	138.21°E	1456 m	16

[1] To obtain yearly statistics, we will assume that each of the chosen months is representative of a season, such that a full year (12 months) is approximated by the four months (one per season).

Location	*Latitude*	*Longitude*	*Altitude above mean sea*	*Group*
UK Goonhilly	50.05°N	5.18°W	110 m	17
South Africa Hartebeesthoek	25.89°S	27.68°E	1276 m	18
Ghana Kuntunse	5.75°N	0.28°W	50 m	19
Greece Lavrion	37.72°N	24.05°E	20 m	20
Spain Vigo	42.17°N	8.69°W	400 m	21
Chile Santiago	33.42°S	70.67°W	520 m	22
Kenya Malindi	3.22°S	40.12°E	15 m	23
UK Madley	52.03°N	2.84°W	118 m	24

Table 1: Geographical coordinates of Earth receiving sites

The parameters to use for the link budget are given in Table 2.

Important note

You need to derive a proper method to account for the LEO orbit and the varying elevation angle (the RAPIDS tool will not do it for you). Indeed, RAPIDS II provides the troposphere impairments for GEO satellites. The final attenuation should be corrected for non-GEO satellites using a conditional probability:

$$P(A > A_{th}) = \sum P\,(A > A_{th}|\theta_i)P(\theta_i)$$

where θ_i is the elevation angle in any bin *i* and $P(\theta_i)$ is the probability occurrence of the non-GEO satellite in elevation angle θ_i. Further information can be found in ITU-R recommendations[2], as well as on additional documents available on Moodle. Every group is free to choose a given LEO orbit (e.g. MetOp A/B/C, or COMS, etc.).

Q band	
Frequency	37.5 GHz
Q Band Polarization	Dual polarization (RHCP* and LHCP*)
Boresight	Nadir
EIRP	?? dBW
Receive antenna gain	45 dBi
LNA noise temperature	450K
Receiver bandwidth	50 Hz
Min C/N for detection	10 dB

Table 2: Main characteristics of W- and Q-band beacons

(* RHCP=Right Hand Circular Polarization – LHCP= Left Hand Circular Polarization)

[2] https://www.itu.int/rec/R-REC-P.618/en, https://www.itu.int/rec/R-REC-S.1257/en

For this part of the project, make sure to:

- Present the total attenuation as well as the attenuation for various components (rain, gases, clouds, scintillation), with a thorough analysis (discussion, comments, explanations, etc.) of the difference between both locations
- Explain how LEO statistics have been obtained from GEO statistics, based on your choice of satellite
- Obtain the link budget for both locations and the proposed EIRP, assuming an availability of the station of 99.0, 99.5, 99.9 and 99.99% of the time
- Discuss the feasibility and the relevance of both station with respect to the chosen LEO satellite

Deliverable

A brief report, **to be uploaded on Moodle before the day of the exam in January**, will contain your answers to the items listed above, for both parts of the project. The report must be written with a scientific style (e.g., explanations of the performed computations, relevant figures, discussions, good spelling, etc.) and include an introduction as well as separate sections for each part of the project, with their associated conclusions.

A **formative** discussion about the preliminary results (10 minutes for presentation + 5 minutes for feedback) will take place during WEEK 14.