POLITECNICO DI TORINO

Master of Science in Communications Engineering

COMMUNICATION SYSTEMS

REPORT: ASSIGNMENT 4

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Luca Nepote (s315234)

1 Introduction

In the fourth assignment of the Master of Science course "Communication Systems" we have dealt with satellite link communications. Indeed, LEO Earth Observation Satellites generate data of the order of Tbits per day which have to be transmitted to the Earth.
The objectives of the project were:

- to design a robust payload link that could be used as a service for commercial ground stations. To do this, we must optimize capacity and latency for the communication link;
- to identify the most suitable locations for the ground stations;
- to understand how the environmental factors impact on our link;
- to assess if LEO relays are a viable solution for our communication.

The assignments' problem has been solved in the Matlab environment, using the Satellite Communication Toolbox with all the needed functions included.

2 First Part: Network Performance under "Clear Sky" and "Rainy Conditions"

In the first part of the assignment we have dealt with the performance of a network made up by a single EO satellite and four ground stations located in different points of the Earth.

2.1 Requirements

The requirements for the communication link were the following ones:

- the link margin had to be bigger than 3 dB;
- we must use a constant code and modulation, chosen between DVB-S2 and CCSDS;
- the network latency had to be smaller than 90 minutes;
- the Environmental Outage Probability related to the station had to be equal to 0.1%;
- according to the modulation used, the BER or FER had to be smaller respectively of 10^{-6} (for CCSDS) and 10^{-5} (for DVB-S2).

We moreover considered an "Additive White Gaussian Noise" (AWGN) channel with ITU-R P.618-13: it means that there are no-multi-path, overhead, interference, pointing losses, amplifier back off and a 20% of roll off.
For the methodology, we considered the worst-case static case.

2.2 Design choices and Algorithm

For our satellite communication system, we used the "Digital Video Broadcasting" DVB-S2 code, with QPSK modulation, code rate $R_c = \frac{9}{10}$ and ideal $E_s/N_o = 6.42$ dB, according to the table reported below, which has been taken from the documentation of the DVB code.
Notice that:

1- the values considered are in agreement with the minimum FER required by the assignment, indeed the table reported the cases for which the "Quasi Error Free PER" is equal to 10^{-7}, smaller of two orders with respect to the requirement;

2- because we considered a QPSK modulation, the number of bits is equal to $m = 2$ bits/symbol.

Table 13: E_s/No performance at Quasi Error Free PER = 10^{-7} (AWGN channel)

Mode	Spectral efficiency	Ideal E_s/No (dB) for FECFRAME length = 64 800
QPSK 1/4	0,490243	-2,35
QPSK 1/3	0,656448	-1,24
QPSK 2/5	0,789412	-0,30
QPSK 1/2	0,988858	1,00
QPSK 3/5	1,188304	2,23
QPSK 2/3	1,322253	3,10
QPSK 3/4	1,487473	4,03
QPSK 4/5	1,587196	4,68
QPSK 5/6	1,654663	5,18
QPSK 8/9	1,766451	6,20
QPSK 9/10	1,788612	6,42
8PSK 3/5	1,779991	5,50
8PSK 2/3	1,980636	6,62
8PSK 3/4	2,228124	7,91
8PSK 5/6	2,478562	9,35
8PSK 8/9	2,646012	10,69
8PSK 9/10	2,679207	10,98
16APSK 2/3	2,637201	8,97
16APSK 3/4	2,966728	10,21
16APSK 4/5	3,165623	11,03
16APSK 5/6	3,300184	11,61
16APSK 8/9	3,523143	12,89
16APSK 9/10	3,567342	13,13
32APSK 3/4	3,703295	12,73
32APSK 4/5	3,951571	13,64
32APSK 5/6	4,119540	14,28
32APSK 8/9	4,397854	15,69
32APSK 9/10	4,453027	16,05
NOTE:	Given the system spectral efficiency η_{tot} the ratio between the energy per information bit and single sided noise power spectral density $E_b/N_0 = E_s/N_0 - 10\log_{10}(\eta_{tot})$.	

Moreover, we want to use the whole bandwidth in order to transmit more data, so our $R_{b_{target}} = 375$ Mbps . We calculated then the real one:

$$R_{b_{gross}} = R_{b_{target}}/R_c$$

$$R_s = R_{b_{gross}}/m$$

$$B = (1+\rho)R_s = 250 \text{ MHz}$$

where ρ is the roll off equal to 20%.
Notice that the result is in agreement with the requirements because we must have a bandwidth smaller than 375 MHz. Moreover, the symbol rate R_s, doing the calculus, is equal to $R_s = 208.33$ Msps.
In the tables below we reported all the parameters involved in the simulation.

Communication System	EO Sat
Antenna Gain [dBi]	22
Frequency [MHz]	8219
TX Power [dBW]	3
System Loss [dB]	1
Modulation and Coding	DVB-S2
Symbol Rate / Bandwidth	208.33 / 250

Orbital Parameters	EO Sat
Altitude [km]	500
Inclination [deg]	97.4
Eccentricity	0
Right Ascension of Ascending Node [deg]	0
Argument of Periapsis [deg]	0
True Anomaly [deg]	0

Scenario	Parameters
Start Time	2023-01-01 @ 00:00:00
End Time	Start Time + Days (7)
Sample Time [s]	60

Earth Station	
Antenna Diameter [m]	3.7
Antenna Efficiency [%]	65
Frequency Band [MHz]	8219
Bandwidth [MHz]	<= 375
Clear Sky Temperature [K]	50.0
Receiver Temperature [K]	141.5
System Loss [dB]	< 1
Clear-Sky G/T [dB/K] @ 10-deg	>= 25
Satellite Tracking	Yes
MODCOD	DVB-S2
Minimum Elevation Angle	10

Locations	Coordinates [lat, lon, alt]
Inuvik	[68.35 -133.72 15]
Svalbard	[78.22 15.38 440]
Awarua	[-46.52 168.48 0]
Troll	[-72.01 2.53 1200]

Notice that all the parameters satisfy the constraints and the frequency has been chosen to be exactly in the middle of the available bandwidth.

The procedure followed for the simulation has been summarized in the following steps:

1- we built on the satellite the gimbal and the transmitter;

2- on the transmitter a gaussian antenna with "Aperture Efficiency" equal to 0.55 and "Dish Diameter" $= 0.197$ m has been added.
Notice that these parameters have been calculated using the formula of the parabolic reflector gain

$$G = 10log_{10}k\left(\frac{\pi D}{\lambda}\right)^2$$

where k is the aperture efficiency, D the dish diameter and G is the gain.

3- we built the ground stations, added a gimbal and a receiver to each one and point them to the EOSat.
Moreover, with the same formula used before, we calculated the gain in order to find the Gain temperature to build the receiver. Notice that the system temperature is given by the sum of the sky temperature and the receiver one. The "Gain to Noise Temperature Ratio" has been calculated with the formula

$$G/T = G_{rx} - 10log_{10}(T_{syst})$$

4- for each station we pointed the satellite to it, computed the link and access functions, the link intervals and the SNR. The last has been rescaled to the Eb/No real, taking into account the spectral efficiency and the roll off.

5- we calculated the atmospheric attenuation and recomputed the SNR taking into account this. The results have been plotted in the same figure, to notice the difference between the clear sky and rainy conditions.

6- repeat for all the stations involved;

7- to find the other requirements, we piggybacked on the functions present in the toolbox, building the timetables, grouping together the results for a single day when it is necessary and ordering them with respect to the time;

8- to find the mean daily capacity, for each station, we summed together the time that the EOSat was connected to the station, multiply it by the bitrate and divided the result over the seven days considered. For the whole network we considered the time for which the satellite was connected to at least one of the ground stations.

9- for the mean daily accesses, we summed together the number of different rows, that represented a different connection access, and divided it by over the seven days;

10- for the availability we considered the ratio between the total time for which the EOSat was connected and the total time of the seven days;

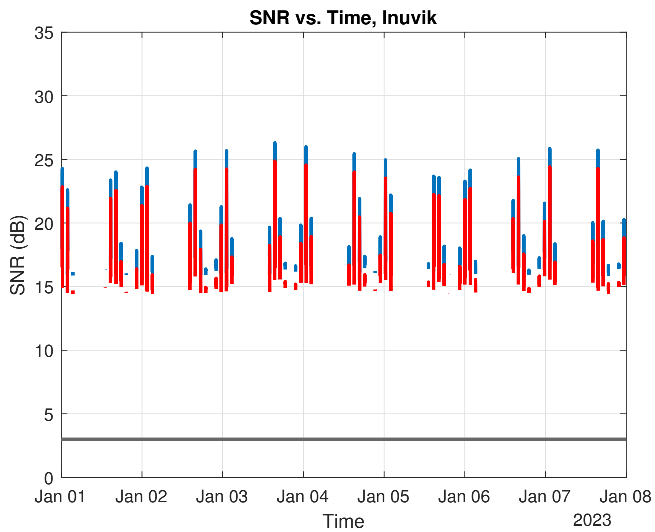
11- for the latencies, we studied the time passed between the end of a communication and the starting point of the next one. We looked for the maximum and the mean value of these;

12- we repeated from the 7-th point considering the losses due to the rainy conditions;

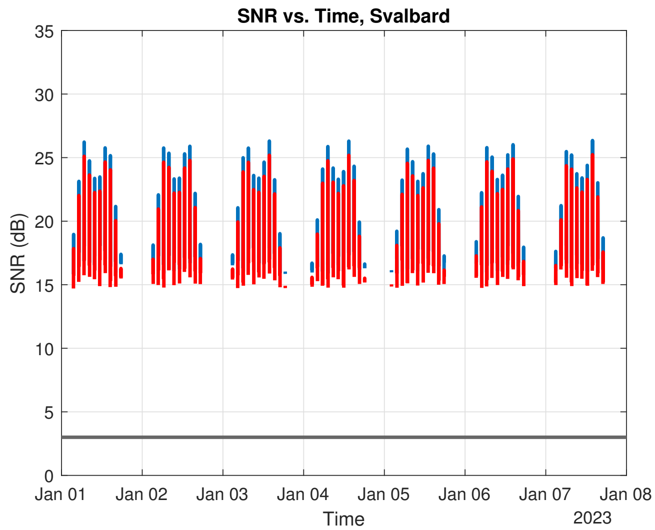
13- finally, we plotted the results.

2.3 Results and Comments

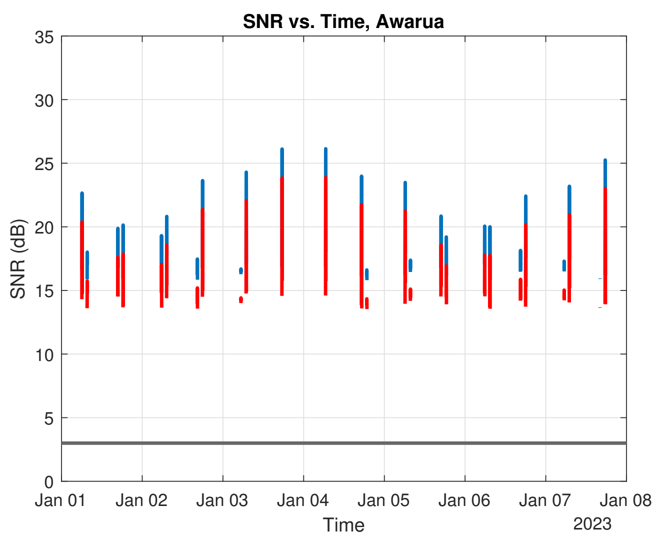
We report below the results obtained for the the required outputs. From now on we will consider the first station corresponding to the "Inuvik" one, the second as "Svalbard", the third as "Awarua" and the last corresponding to "Troll".
Considering at first the SNR for the different stations, we obtained the following results.



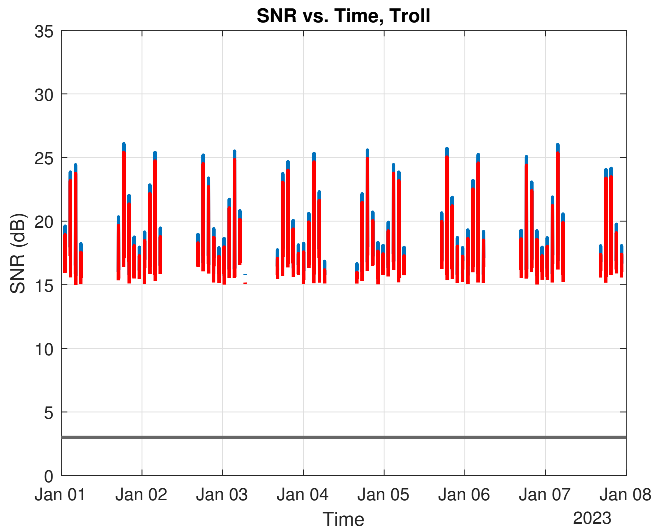
For the first station, the SNR is not constant over the entire time: there are some phases of the day in which the station is visible, it loses the connection and then it reconnects itself to the satellite.
Notice that the blue lines represent the case with clear sky conditions, whereas the red ones correspond to the SNR in presence of rain. As we expected, the rain interferes with the connection, making the SNR smaller with respect of the clear conditions. However, the loss is not too much and, where the connection is established, it remains above the threshold of 3 dB given by the specifications.



For the second station, the SNR is much more constant than the first case when the connection is established.
There are periodic losses of connection when the satellite becomes not visible from the ground station. However, the most part of the time is connected to the satellite.
Also in this case, the rain reduced the SNR but the results are still good.



The third station seems to be the one which works the worst: the SNR presents some peaks when the satellite is visible, but for the most it remains disconnected, transmitting no data to the ground station.

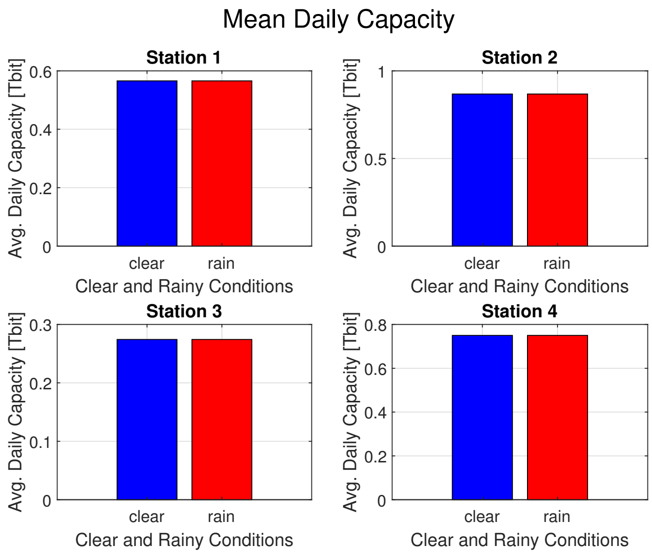


For the last station, the results are good. Often it is connected to the satellite, with some periodic connection losses.

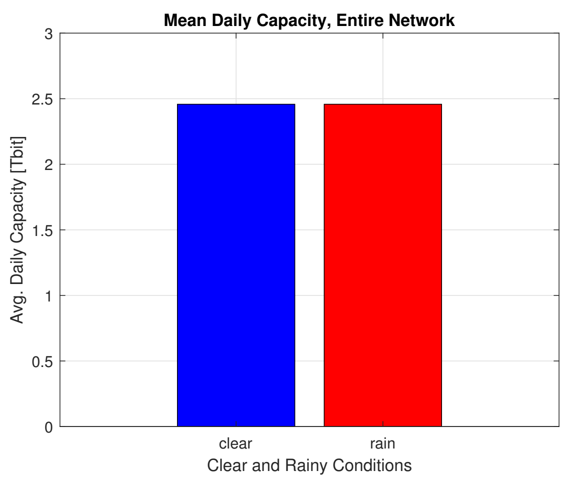
Notice that in all the cases considered, when the connection is up, the SNR remains above the threshold even in the rainy case. It means that, even if the bad conditions of the weather reduce the energy transmitted, they do not destroy our connection, so the satellite is still able to transmit data to the ground stations.

The second series of results we reported is the one related to the mean daily capacity, expressed in Tbits, for the single stations and the entire network. As we have done before, the analysis takes into account both clear sky and rainy conditions.

The mean has been computed over the seven days under study.



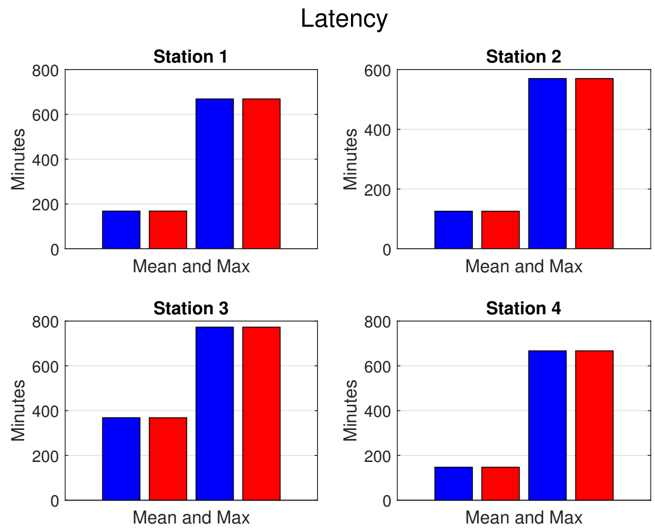
According to the pictures of the SNR, the capacity is bigger for the second station ("Svalbard") than for the other stations, whereas the worst case belongs to the third station ("Awarua").
Globally, the total mean daily capacity is up to 2.5 Tbits, satisfying with huge margin the requirement of 1 Tbits.



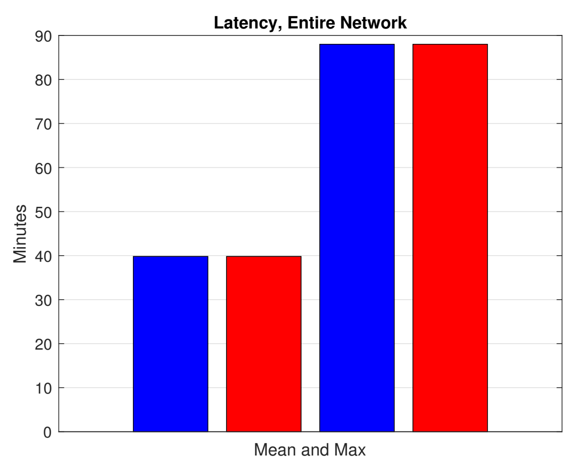
Moreover, we want to note that, even in the case with the rain, the results are still the same: this is due to the fact that, as we already said before, the bad weather conditions are not too much to cancel the connection, but they only reduce the SNR.

The next pictures represent the latencies both for the single station and for the entire network. The results are reported in minutes.
Notice that we considered the latency as the time needed to the station in order

to reconnect to the satellite when the communication is down.
In each picture the first two columns correspond to the latency mean, whereas the other two the maxima. Moreover, the blue bar represent, as before, the clear conditions, the red the rainy ones.

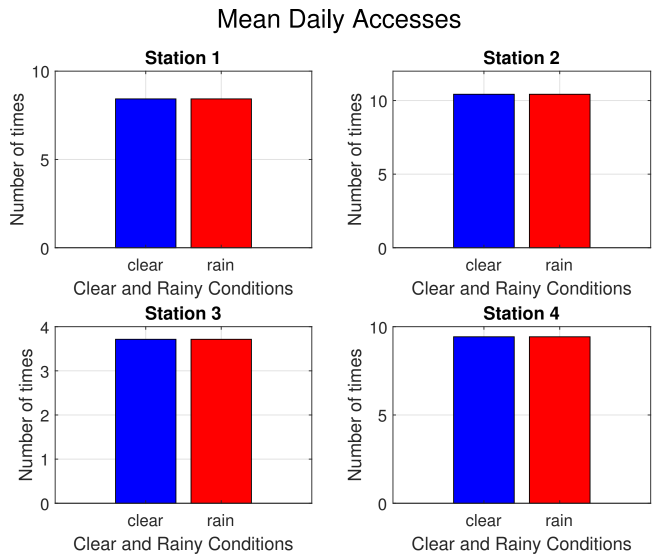


As we expected, the best performances are the ones related to the second station and the worst (for which the latency is bigger) the ones of “Awarua”.

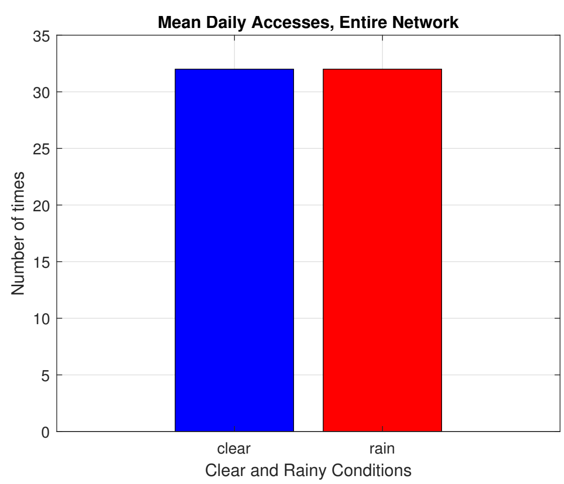


Considering the entire network, the latency reduces a lot because it is necessary that only one station is connected to the satellite in order to have communication: we have only 40 minutes of latency mean and up to 90 minutes of maximum latency.
Also in this case the rain does not modify the results.

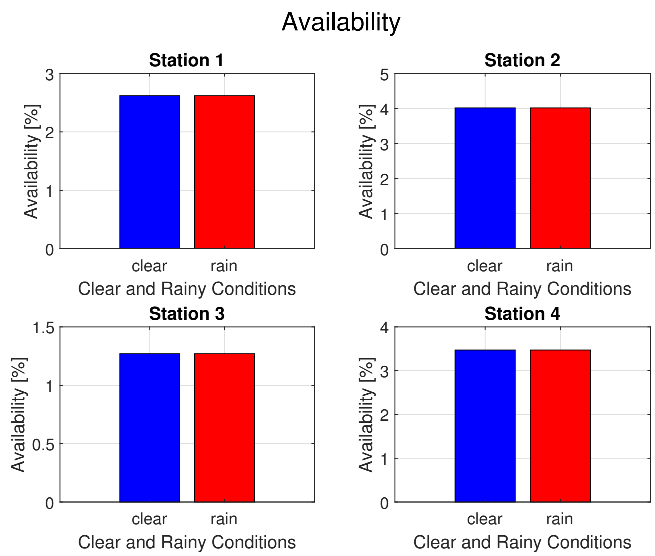
We then considered the mean daily accesses. The results are in agreement with the ones obtained before, so the highest number of times for which the station is connected to the EOSat is the one of the second station, and the least belongs to the third one.

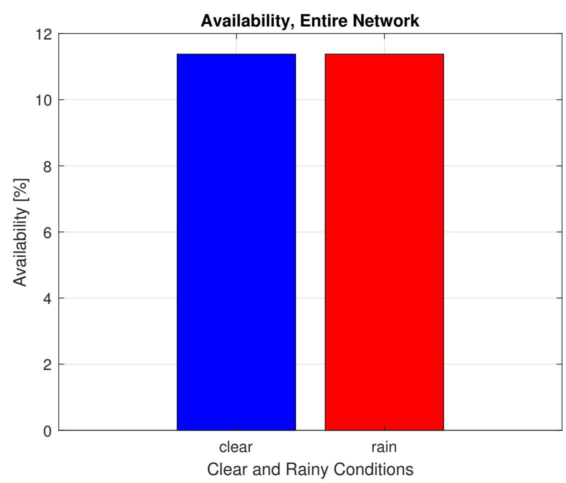


For the entire network the number of times for the connection is over 30 and the rainy conditions do not change the performance.



The last results we reported are the ones related to the percentage availability. All of the ones related to the single stations are under 5%, but if we consider the entire network it is up to 11%.
Notice that the availability is not really good because for the most part of the time the system is not connected to the satellite.





Concluding for the first part of the assignment, we want to note that in all the results reported, except for the SNR, the rain does not modify the performance of the network.
The best location to put a ground station is the one related to the station of "Svalbard".
Moreover, the total capacity required is completely satisfied with the code and modulation involved. However, the latency is still too much if we would like to have a continuous communication used for commercial services and the percentage availability is still too small.

3 Second Part: LEO Data Relay System Performance

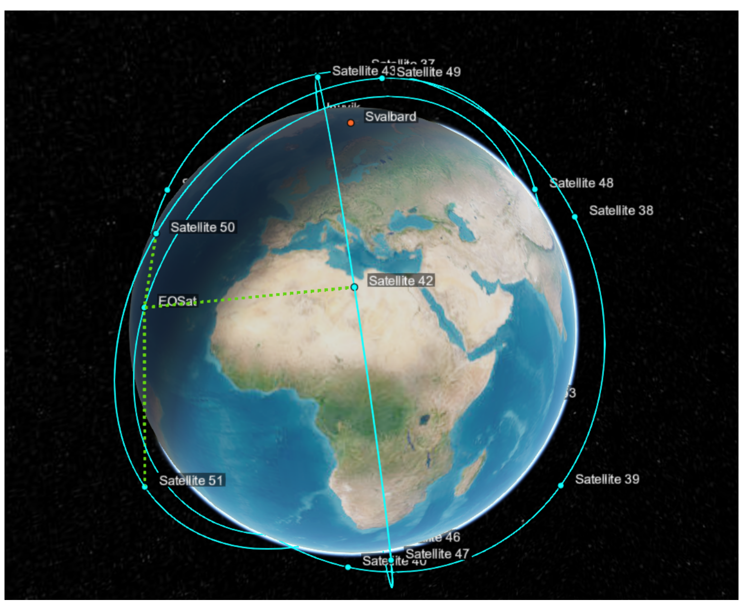
In this section we want to improve the communication capability for our service.

3.1 Specifications

In the second part we dealt with a LEO constellation, composed by:

- 3 planes;
- 6 satellites per plane, so 18 LEO satellites in total;
- 98.2 degrees of inclination;
- Laser Communication System of 4000 km maximum range;
- 100 degree field of view;
- EOSat used in the previous part.

All the other specifications were already inserted in the code given in the assignment.
The goal is to understand if LEO Data Relay System is a viable solution for the desired communication. To do that we analyzed the connectivity per time, the mean and the max latencies and the percentage system availability.
In the picture below we reported the system involved.

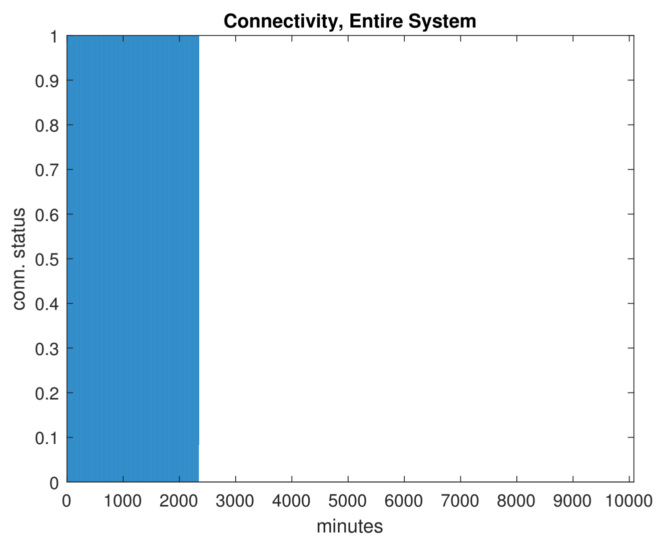


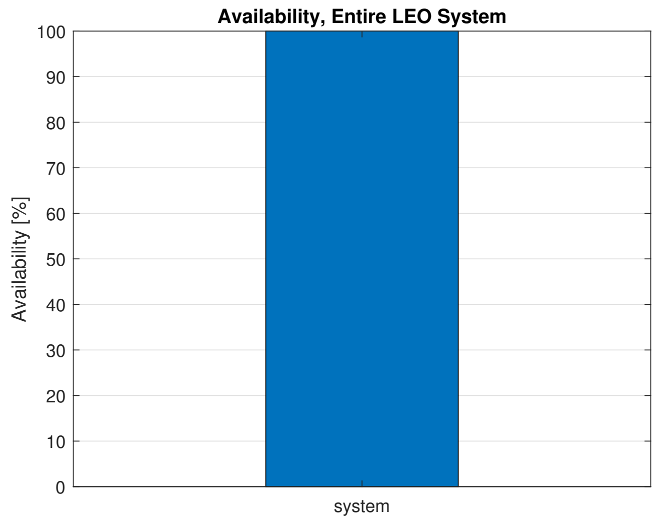
3.2 Design Choice and Algorithm

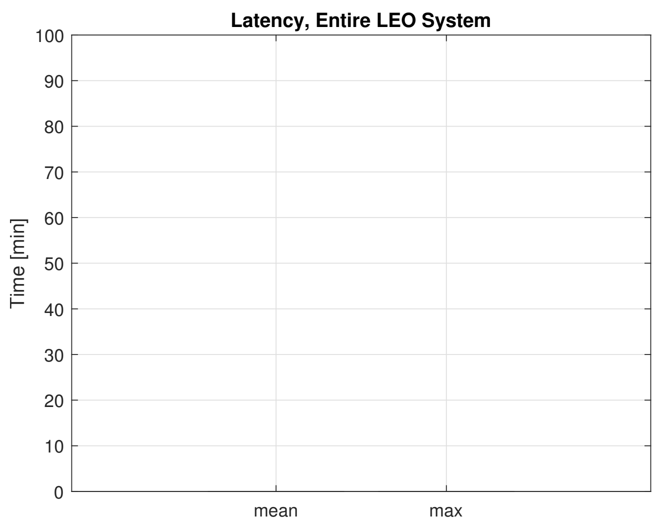
In order to calculate the requirements, we added a conical sensor to the gimbals of the EOSat, with maximum view angle equal to 100 as requested.
We then pointed the LEO constellation to the EOSat, calculate the range between it and the single LEO satellite and verify that it was under the maximum range given by the specifications. Working with the functions present in the Satellite Communication Toolbox present in Matlab we analyzed the connectivity, the latencies and the system access percentage.

3.3 Results and Comments

We reported the results obtained for the different requirements.
As we can see, the connectivity per time is up every minute, so the EOSat is always connected to the LEO constellation system. This could be seen also from the availability plot, which presents an availability of 100%, and the one of the latencies, which are both null.



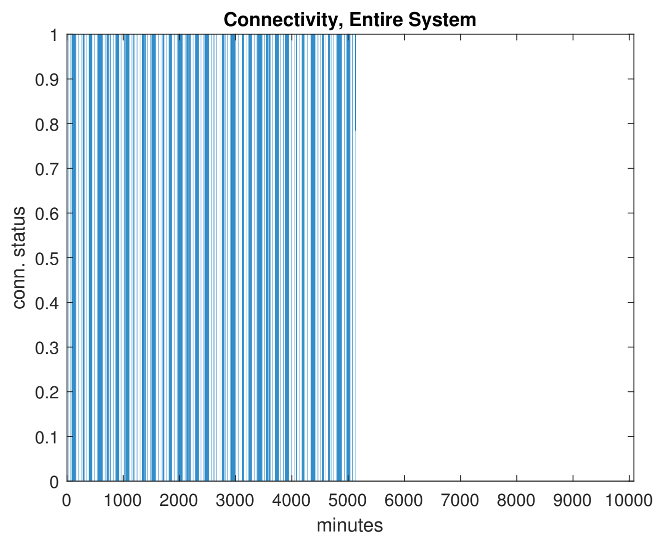


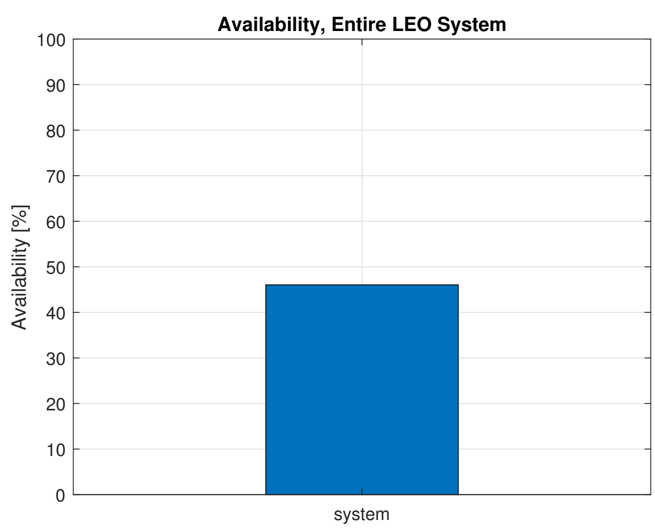


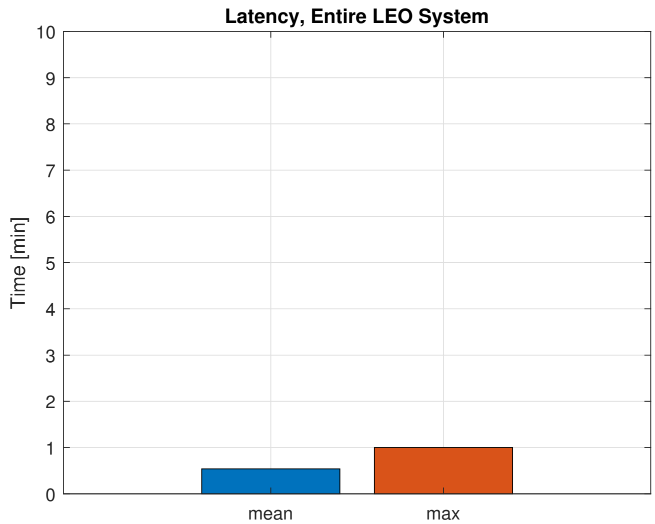
Concluding, using a LEO system perform really better with respect to using directly a communication link between the EOSat and the ground stations: indeed, the they are always connected between each other thanks to the high number of satellites involved and for their orbit. The 100% of availability is perfect for the commercial service desired.

3.4 Bonus Part

In this last section we analyzed the case in which the EOSat has to point to a given direction, that in our case is 90 degree.
We can note that the results are very different with respect to the previous case: indeed, the connectivity is no longer up for every instant of time, but the system connects and disconnects continuously. Moreover, the availability is under the 50% and the mean and maximum latencies, even if they are really small, are both different from zero.







In conclusion, when the satellite has to point to a specific direction, the results are no longer good and the system works worse.