Project – Analysis of the amount of data downloaded from an Earth Observation (EO) satellite using Adaptive Coding and Modulation (ACM).

Máster Universitario en Sistemas Espaciales

Course: Communications. Academic course: 2022/23

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# Project presentation

Scope – The scope of this project is to analyse the amount of data that can be downloaded from an EO satellite in a sun-synchronous orbit (SSO) by a predefined ground station using ACM (Adaptive Coding and Modulation).

This document explains the tasks than shall be carried out by students in order to complete the project.

Add your answers in the shadow tables that you will find along the document.

Organization: Students shall be organized themselves in groups of 4 students each with a team leader (TL). The TL will report who the team members are in the corresponding Moodle task.

Supervision and support: on-line tutorials in Teams will be carried out on demand by the students. It is recommended that each team shares the document with the lecturers using Microsoft Office 365. This would allow the supervision project progress.

Input data (communications):

* Minimum elevation angles: 10, 20, 30 degrees
* Frequency band: X band (8150 MHz)
* RF power of the satellite: 2 W
* On-board antenna: medium gain antenna (G=12 dBi)
* G/T of the ground station: antenna diameter is 4 m, antenna temperature is 40 K and receiver noise figure (LNA) is 2 dB
* Bandwidth: 70 MHz (symbol rate)
* Mission analysis period: 60 days
* Losses due to gaseous absorption and other impairments: 2,5 dB (X band).
* Link margin: 3 dB

# Task 0. Selection of system parameters

Each team shall investigate and select the next information:

* SSO – Select a typical SSO orbit for EO in the 550-700 km range. At least, inclination and altitude shall be provided.
* Select a ground station location

Please fill in the shadowed column of the table.

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| --- | --- | --- |
| Parameter | | *Input* |
| Reference EO mission selected and URL where information has been obtained | |  |
| Orbital inclination (degrees) | | *98* |
| Orbital altitude (km) | | *650* |
| Ground station | Longitude (deg E): | *40.55* |
| Latitude (deg N): | *-3.83545* |

# Task 1. Ground station to satellite slant range

Using a mission analysis simulator (GMAT, STK, Freeflyer), each team shall produce a matrix with information of the distance (range) to the satellite from the selected ground stations under different minimum elevation conditions.

During the pass, consider 10 seconds as sampling time to calculate the distances.

Export this range information to Matlab or similar software. In the next steps or tasks, this is the software that shall be used for the postprocessing and extraction of results.

Plot below the set of slant range data for the three minimum elevation angles specified in the project.

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# Task 2. Histogram with duration of visibility intervals

For the periods of visibility generated in Task 1, generate a histogram with the duration of the passes.

Three histograms (one per minimum elevation angle) will be graphed in the same figure for comparison purposes. Fill in the next table with information of the average pass duration:

|  |  |
| --- | --- |
| Minimum elevation (deg) | *Average pass duration (minutes)* |
| 10 |  |
| 20 |  |
| 30 |  |

Please include the figure in the next table.

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# Task 3. Calculation of C/N during the pass

The carrier to noise ratio (C/N) in the downlink can be calculated as:

Where:

* : EIRP of the satellite transmitter
* : G/T of the ground station
* : free space losses of the link
* : additional losses
* is the Boltzmann constant (-228,6 dBW/(K·Hz))
* is the noise bandwidth in Hz

First step in this task is the calculation of the ground station G/T. Antenna gain can be calculated using:

Consider a 60% antenna efficiency.

In this case study, noise temperature of the receiver is formed by the contribution of the antenna temperature and the receiver temperature in Kelvin:

Where is the receiver noise figure in dB, is the reference temperature (290 K).

Thus, the G/T of the ground station is obtained as:

For each of the passes, generate a script that:

* Calculate the free space losses (in dB) during the pass each 10 seconds
* Calculate the C/N of the link (*CNlink*) in dB each 10 seconds

Plot in the same graph with a *plotyy* or similar function the distance vs time and C/N variation during the pass.

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# Task 4. Selection of MODCOD and calculation of the amount of data downloaded during each pass and in total

MODCOD defines a joint modulation and channel coding scheme (e.g. QPSK ¾ means a signal modulated in QPSK that has been channel encoded with a coding rate of ¾ - 1 redundant bit per each set of 3 information bits). It is based on a subset of the schemes used in DVB-S2X standard.

In this project, consider ACM (Adaptive Coding and Modulation) as transmission scheme. It means that ground station and satellite can exchange information about the status of the link (e.g. C/N) and the satellite transmitter can modify the MODCOD in order to maximize the capacity of the link (i.e. select the MODCOD with higher spectral efficiency that satisfies the C/N of the link).

Consider the next table of MODCOD with information of the required C/N (*CNreq*) and spectral efficiency in bps/Hz (i.e. if the spectral efficiency is 3 bps/Hz, it means that in a bandwidth of B MHz, 3×B Mbps can be transmitted). The required C/N states which is the minimum C/N in the link to detect the received signal with a bit error rate low enough to consider a useful communication. Thus:

* If *CNlink* > *CNreq*, it means that the link is feasible and there exists a link margin (*LM* [dB] = *CNlink* - *CNreq*) to reduce transmit power, antenna gain, etc. The higher the link margin, the more over dimensioned the communication equipment is.
* If *CNlink* < *CNreq*, it implies a number of errors higher than specified, and the link is not feasible.

*Table. List of available MODCODs for the satellite link.*

|  |  |  |  |
| --- | --- | --- | --- |
| ID | MODCOD | *CNreq* [dB] | Efficiency [bps/Hz] |
| 1 | 256 APSK 31/45 | 18,59 | 5,41 |
| 2 | 128APSK 7/9 | 18,53 | 5,36 |
| 3 | 128APSK 3/4 | 17,5 | 5,17 |
| 4 | 64APSK 11/15 | 14,81 | 4,34 |
| 5 | 64APSK 32/45 | 13,98 | 4,21 |
| 6 | 32APSK 9/10 | 16,13 | 4,15 |
| 7 | 32APSK 8/9 | 15,83 | 4,10 |
| 8 | 32APSK 5/6 | 14,41 | 3,84 |
| 9 | 32APSK 4/5 | 13,83 | 3,68 |
| 10 | 32APSK 3/4 | 12,90 | 3,45 |
| 11 | 16APSK 8/9 | 13,08 | 3,28 |
| 12 | 16APSK 5/6 | 11,77 | 3,07 |
| 13 | 16APSK 4/5 | 11,19 | 2,94 |
| 14 | 16APSK 3/4 | 10,35 | 2,76 |
| 15 | 16APSK 2/3 | 9,08 | 2,45 |
| 16 | 8PSK 3/4 | 8,05 | 2,07 |
| 17 | 8PSK 2/3 | 6,68 | 1,84 |
| 18 | 8PSK 3/5 | 5,63 | 1,66 |
| 19 | QPSK 5/6 | 5,34 | 1,54 |
| 20 | QPSK 4/5 | 4,82 | 1,48 |
| 21 | QPSK 3/4 | 4,21 | 1,38 |
| 22 | QPSK 2/3 | 3,23 | 1,23 |
| 23 | QPSK 3/5 | 2,40 | 1,10 |
| 24 | QPSK 1/2 | 1,14 | 0,92 |
| 25 | QPSK 2/5 | -0,25 | 0,73 |
| 26 | QPSK 1/3 | -1,30 | 0,61 |
| 27 | QPSK 1/4 | -2,54 | 0,46 |

In this task, prepare a Matlab script that: 1) selects the most appropriate MODCOD to maximize the amount of data downlinked and 2) calculates the amount of data downlinked in each pass considering the spectral efficiency of the selected MODCOD and the time during which each MODCOD is used.

The selection of the MODCOD shall be carried out considering:

* The *CNreq*, of the selected MODCOD shall comply with *CNlink* > *CNreq ;*
* Each MODCOD shall be used during at least 10 seconds to avoid the continuous exchange of information between satellite and ground station;
* Selection of the MODCOD must be done each 10 seconds;
* Ensure the fulfilment of the link margin.

Plot the list of used MODCODs used in a representative pass (hint: use the *stairs* function in Matlab). Complete with a table showing the percentage of time that each MODCOD would be used.

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# Task 5. Comparison of results of downlinked payload data

Use the script developed in the previous task to obtain the amount of data that can be downlinked in each satellite pass.

If a MODCOD with spectral efficiency is used during seconds of the link, the amount of data downlinked in can be approximated as:

Where *B* is the signal bandwidth.

Students shall see the time each MODCOD is used and aggregate the amount of data downlinked during each interval.

Fill in the next table with information of the average data downlinked per pass and the total data downloaded in the 60 days for different minimum elevation angles:

|  |  |  |
| --- | --- | --- |
| Minimum elevation (deg) | *Average data downlinked per pass (MB)* | *Total downlinked in 60 days (MB)* |
| 10 |  |  |
| 20 |  |  |
| 30 |  |  |

# Task 6. Communication system architecture

Sketch in the next table a block diagram of the communication system architecture used to downlink payload data to the ground segment. Start from the instrument (camera) and finish in the transmit antenna to see the data flow in the satellite.

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Explain how the process of adapting the transmission scheme would be carried out. Provide pros and cons of the proposed solution.

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# Task 7. Addition of a new ground station

Ground segment engineers would like to evaluate the addition of a new ground station to download payload data from the satellite. Think of the impact on the mission and comment your ideas.

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# Task 8. Electrical power subsystem required for transmission

Make an approximate sizing of the electrical power subsystem to supply the communication subsystem for transmission during sunlight and eclipse. Batteries must be charged during sunlight to power supply the communication subsystem if an eclipse situation occurs during the communication with the ground station.

Consider that the power amplifier requires 80% of the power required by the radio subsystem. The power added efficiency (PAE) of the power amplifier is 50%

Calculate the required solar panel area for transmitting the payload data. Select a solar cell technology, a typical filling efficiency and losses of 10% between solar arrays and power bus.

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For transmission of payload data during eclipse hours, size the battery subsystem.

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Would it be possible to use a 3U CubeSat for this mission?

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# Task 9. Conclusions

Considering the previous results, fill in next table with your conclusions. Indicate how would you increase the amount of downloaded data and the impact on the system architecture. Comment if this communication architecture is feasible and discuss the complexity vs performance (capacity increase) trade-off.

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