Workshop – 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: 2020/21

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Scope – The scope of this workshop 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 workshop.

Organization: Students shall be organized themselves in groups of 5-6 students each with a workshop leader (WL). The WL will report the team members in the corresponding Moodle task.

Note.- This project shall be performed avoiding on-site meetings, so student groups are required to organize themselves using Teams.

It is recommended that each team shares the document with the lecturers using Microsoft Office 365. This would allow the supervision project progress.

Planning: each team WL will submit the document in Moodle before **April 30th, 2021**. Supervisors suggests to follow the next planning and incorporate the dates in which every task is finished in the following table.

	16/04/2021	17/04/2021	18/04/2021	19/04/2021	20/04/2021	21/04/2021	22/04/2021	23/04/2021	24/04/2021	25/04/2021	26/04/2021	27/04/2021	28/04/2021	29/04/2021	30/04/2021
	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE	WED	THU	FRI
	WEEK 1			WEEK 2							WEEK 3				
Task 0															
Task 1															
Task 2															
Task 3															
Task 4															
Task 5															
Task 6															
Task 7															
Task 8															

<u>Supervision and support</u>: on-line tutorials in Teams will be carried out on demand by the students.

<u>Input data (communications)</u>:

- Minimum elevation angles: 10, 20, 30 degrees
- EIRP of the satellite: 22 dBW
- G/T of the ground station: antenna diameter is 5 m, antenna temperature is 40 K and receiver noise figure is 2 dB
- Bandwidth: 300 MHz
- Mission analysis period: 60 days
- Losses due to gaseous absorption, rain attenuation and other impairments: 3 dB (X band), 6 dB (Ka).

Task 0. Selection of system parameters

Each team shall investigate and select the next information:

- SSO – Select a typical SSO orbit for EO. At least, inclination and altitude shall be provided.
- Select a ground station location

Please fill in the shadowed column of the table.

Parameter		*Input*
Reference EO mission selected and URL where information has been obtained		Sentinel-3 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/satellite-description/orbit
Orbital inclination (degrees)		98.65º
Orbital altitude (km)		814.5 km
Ground station	Longitude (deg E):	15º 24’
	Latitude (deg N):	78º 13’
Frequency (GHz)		X-Band (8-12 GHz)

Task 1. Ground station to satellite 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 20 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.

Deliverable from this task: set of range data for the three minimum elevation angles specified in the workshop. (See MATLAB code *Task1.m*)

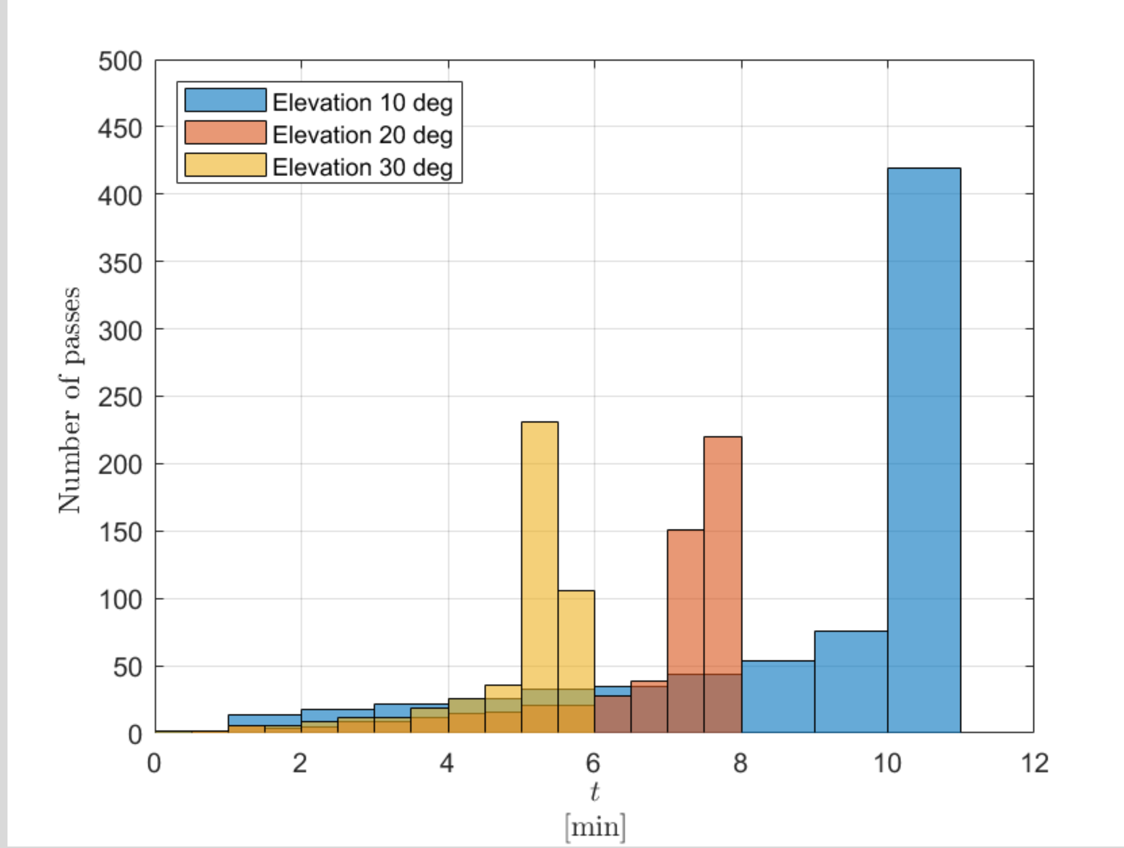
Task 2. Histogram with duration of visibility intervals.

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	*8.94*
20	*6.67*
30	*4.90*

Please include the figure in the next table.



Task 3. Calculation of C/N during the pass

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

$$\frac{C}{N}(dB) = EIRP_{sat}(dBW) + \frac{G}{T}(dB/K) - L_{fs}(dB) - L_a(dB) - k(dBW/K \cdot Hz) - 10log_{10}\left(B(Hz)\right)$$

Where:

- $EIRP_{sat}(dBW)$: EIRP of the satellite transmitter
- $\frac{G}{T}(dB/K)$: G/T of the ground station
- $L_{fs}(dB)$: free space losses of the link
- $L_a(dB)$: additional losses
- k is the Boltzmann constant (-228,6 dBW/(K·Hz))
- B 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:

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

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:

$$T(K) = T_{ant} + T_{rx} = T_{ant} + T_0\left(10^{\frac{NF(dB)}{10}} - 1\right)$$

Where $NF(dB)$ is the receiver noise figure in dB, T_0 is the reference temperature (290 K).

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

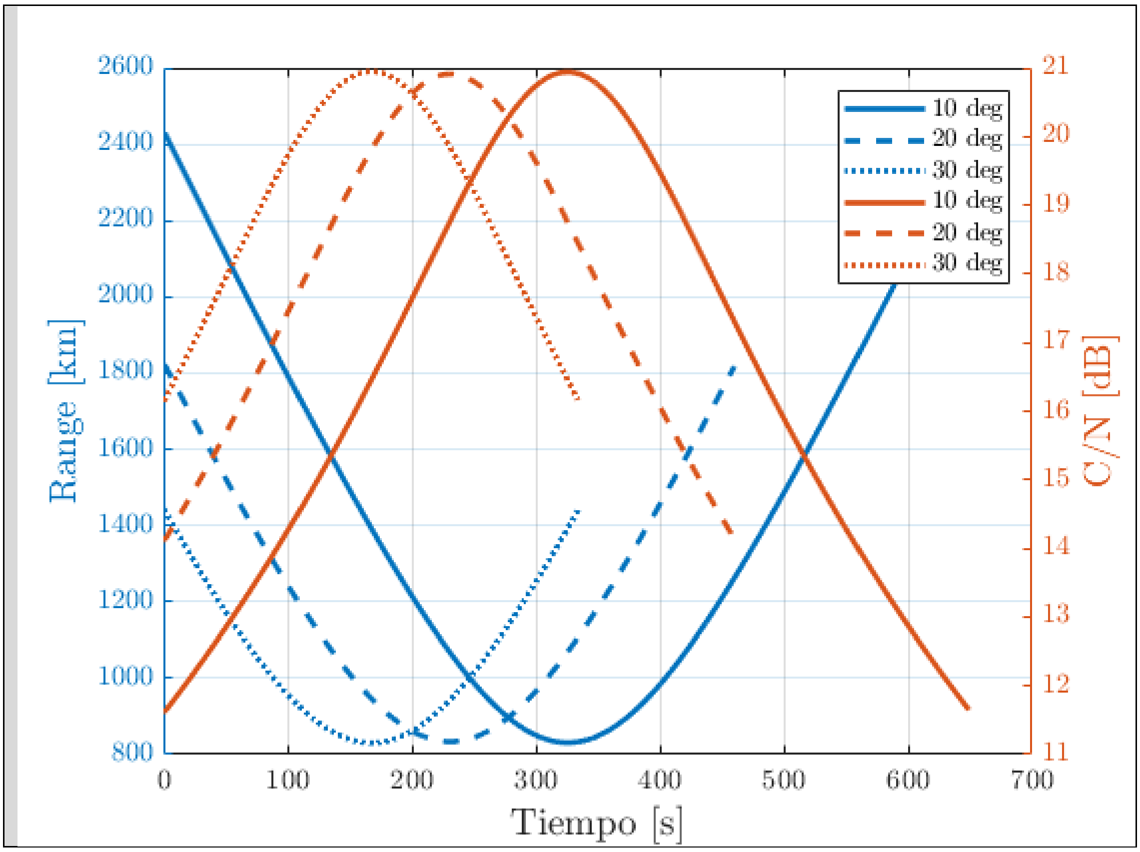
$$\frac{G}{T}(dB/K) = G(dBi) - 10log_{10}\left(T(K)\right)$$

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 (*CN_{link}*) 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.

Since there are a high number of passes for each elevation angle, the maximum duration pass has been chosen as a representative to plot the distance vs time.



Range [km]
C/N [dB]
Tiempo [s]
10 deg
20 deg
30 deg
10 deg
20 deg
30 deg
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
0
100
200
300
400
500
600
700
21
20
19
18
17
16
15
14
13
12
11

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 3 information bits).

In this wokshop we consider ACM (Adaptive Coding ad Modulation) 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 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 (CN_{req}) and spectral efficiency in bps/Hz (i.e. if the spectral efficiency is 3 bps/Hz, it means that in B MHz, 3B 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 $CN_{link} > CN_{req}$, it means that the link is feasible and there exists a link margin (LM [dB] = CN_{link} - CN_{req}) to reduce transmit power, antenna gain, etc. The higher the link margin, the more over dimensioned the communication equipment is.
- If $CN_{link} < CN_{req}$, it implies a number of errors higher than specified, and the link is not feasible.

Table. List of available MODCODs for the satellite link.

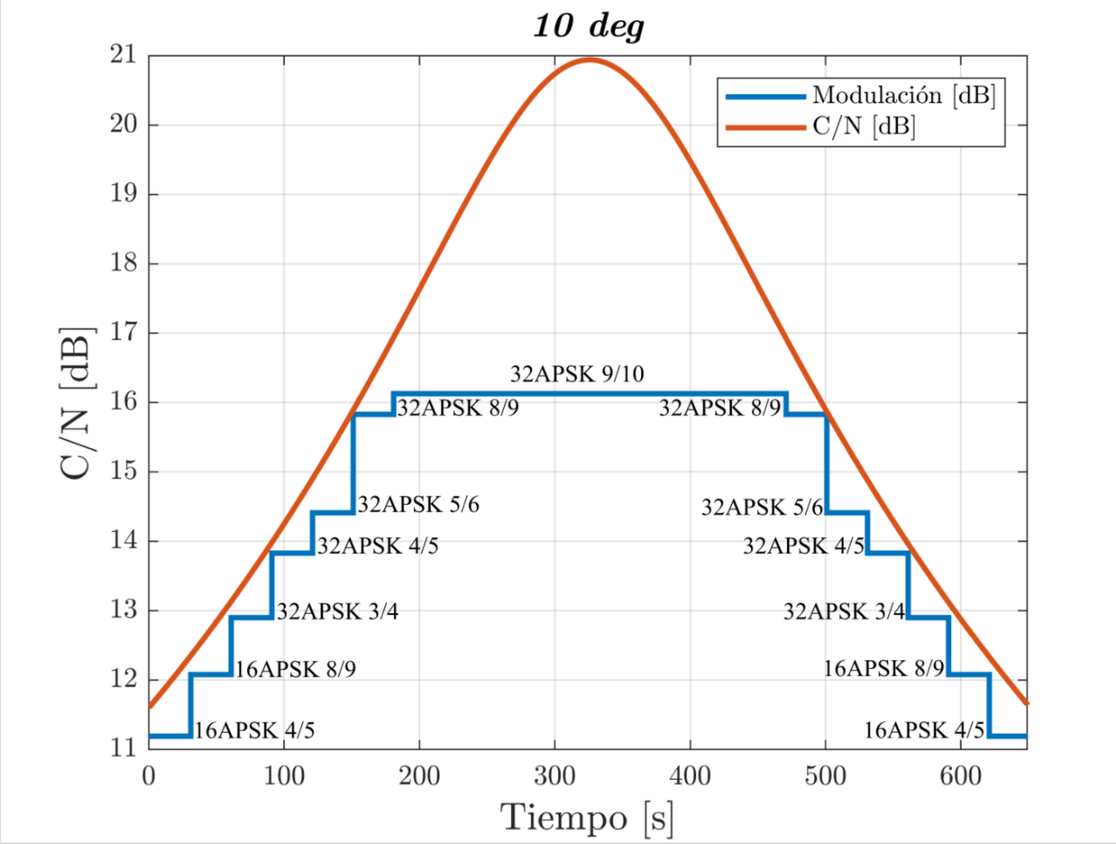
ID	MODCOD	CN_{req} [dB]	Efficiency [bps/Hz]
1	32APSK 9/10	16.13	4.15
2	32APSK 8/9	15.83	4.10
3	32APSK 5/6	14.41	3.84
4	32APSK 4/5	13.83	3.68
5	32APSK 3/4	12.90	3.45
6	16APSK 8/9	12.08	3.28
7	16APSK 5/6	11.77	3.07
8	16APSK 4/5	11.19	2.94
9	16APSK 3/4	10.35	2.76
10	16APSK 2/3	9.08	2.45
11	8PSK 3/4	8.05	2.07
12	8PSK 2/3	6.68	1.84
13	8PSK 3/5	5.63	1.66
14	QPSK 5/6	5.34	1.54
15	QPSK 4/5	4.82	1.48
16	QPSK 3/4	4.21	1.38
17	QPSK 2/3	3.23	1.23
18	QPSK 3/5	2.40	1.10
19	QPSK 1/2	1.14	0.92
20	QPSK 2/5	-0.25	0.73
21	QPSK 1/3	-1.30	0.61
22	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.

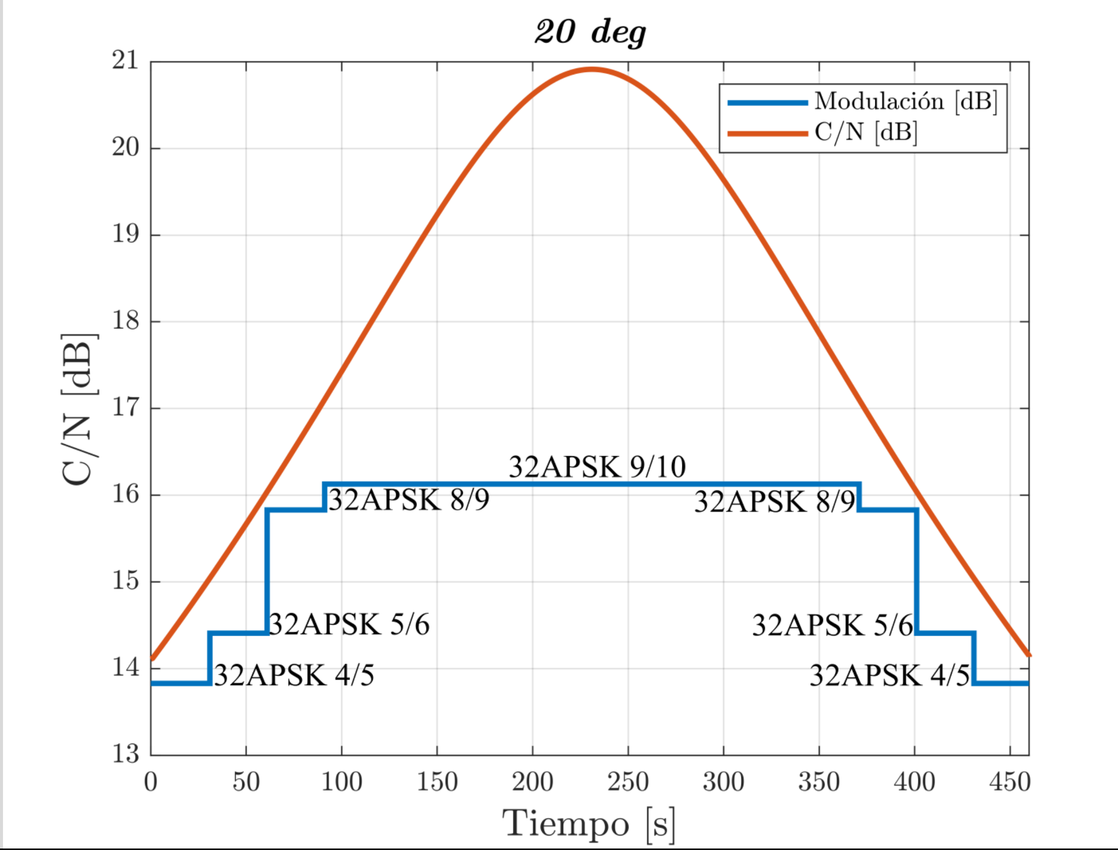
The selection of the MODCOD shall be carried out considering:

- The CN_{req}, of the selected MODCOD shall comply with $CN_{link} > CN_{req}$;
- Each MODCOD shall be used during at least 30 seconds to avoid the continuous exchange of information between satellite and ground station
- Selection of the MODCOD must be done each ten seconds.

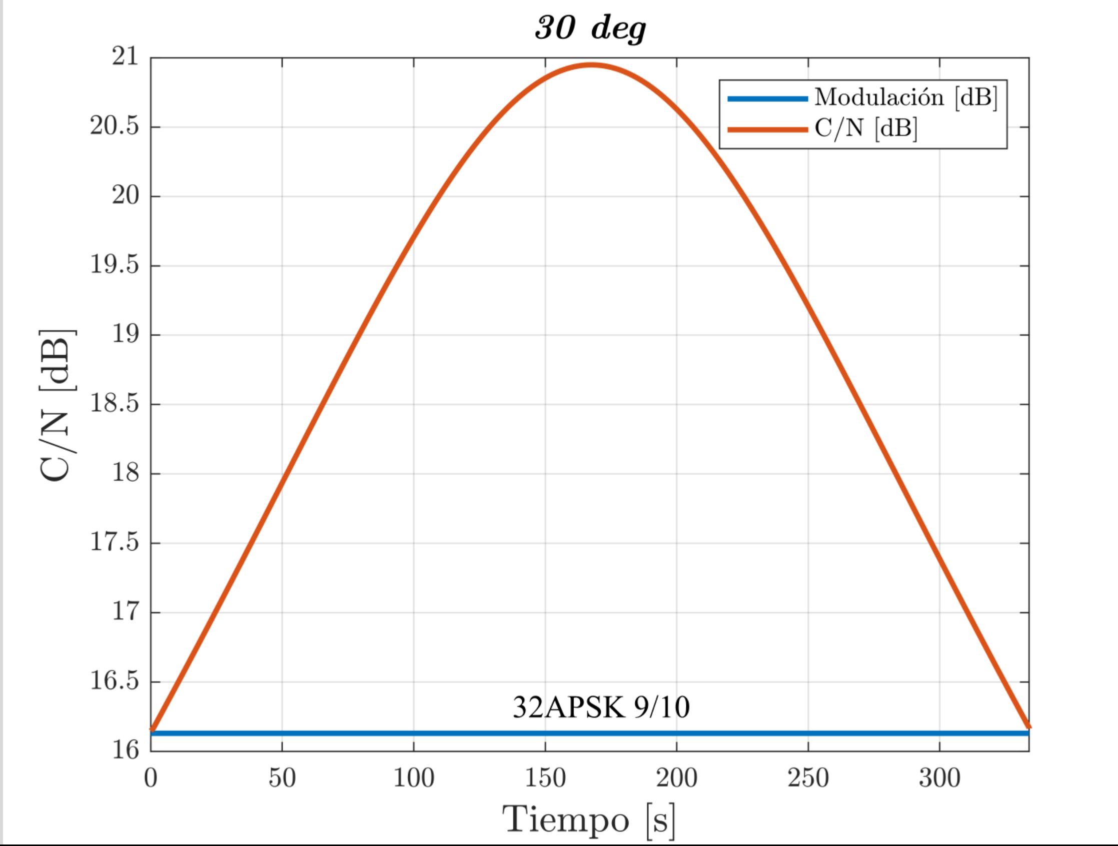
Plot the list of used MODCODs used in a representative pass (hint: use the *stairs* function in Matlab). Complete with a table showing the percentage of time that each MODCOD would be used.



MODCOD	Duration [s]	Percentage [%]
32APSK 9/10	290	44.55
32APSK 8/9	60	9.22
32APSK 5/6	60	9.22
32APSK 4/5	60	9.22
32APSK 3/4	60	9.22
16APSK 8/9	60	9.22
16APSK 4/5	61	9.37



MODCOD	Duration [s]	Percentage [%]
32APSK 9/10	280	60.61
32APSK 8/9	60	12.99
32APSK 5/6	60	12.99
32APSK 4/5	62	13.42



MODCOD	Duration [s]	Percentage [%]
32APSK 9/10	336	100

Task 5. Comparison of results of downlinked 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 $eff(bps/Hz)$ is used during T seconds of the link, the amount of data downlinked $D(MB)$ in T can be approximated as:

$$D(MB) = \frac{B(MHz) \cdot T(sec) \cdot eff(bps/Hz)}{8}$$

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	$7.40 \cdot 10^4$	$5.48 \cdot 10^7$
20	$6.04 \cdot 10^4$	$3.36 \cdot 10^7$
30	$4.60 \cdot 10^4$	$2.14 \cdot 10^7$

Task 6. Source encoding

Which source encoder would you select for the payload data (consider the payload instrument and proposed services by the mission)? Is it the source encoder lossy or lossless? Compare the number of raw images that could be downlinked to that using the proposed source encoder. Comment on the impact of the source encoder on the platform subsystems. Justify the answers.

The Sentinel 3 instrument OLCI produces 18.5 Gb of image data per half orbit with the full resolution (FR) capability.

The FR capability has a ground resolution of $res = 300\ m$,, the Earth radius is $R_T = 6371 \cdot 10^3\ m$, so the number of images that are obtained in a half orbit are $N_{imag} = \frac{\pi R_T}{res} = \ 66717.$ Nevertheless, the OLCI only takes ocean's images, and they cover the 70% of the Earth surface, so the total raw images are $N_{raw} = N_{imag} \cdot 0.7 = \ 46702.$

With the total amount of images and the data weight, the size of a single image is easy obtainable as $\frac{18.5 \cdot 10^3}{N_{raw}} = 0.396 \frac{Mb}{image}$.

The selected source encoder has been JPEG, which is lossy. Since the images are going to be practically monochrome and without many borders, it can be compressed in the order of 10% without losing appreciable quality.

The use of an on-board source encoder requires a greater processing capacity and therefore power, however it reduces the amount of data to transmit to the earth station and therefore also reduces the amount of power required to transmit all the science generated.

Minimum elevation (deg)	*Number of raw images downlinked per pass*	*Number of compressed images downlinked per pass*
10	$1.87 \cdot 10^5$	$2.07 \cdot 10^5$
20	$1.52 \cdot 10^5$	$1.69 \cdot 10^5$
30	$1.16 \cdot 10^5$	$1.29 \cdot 10^5$

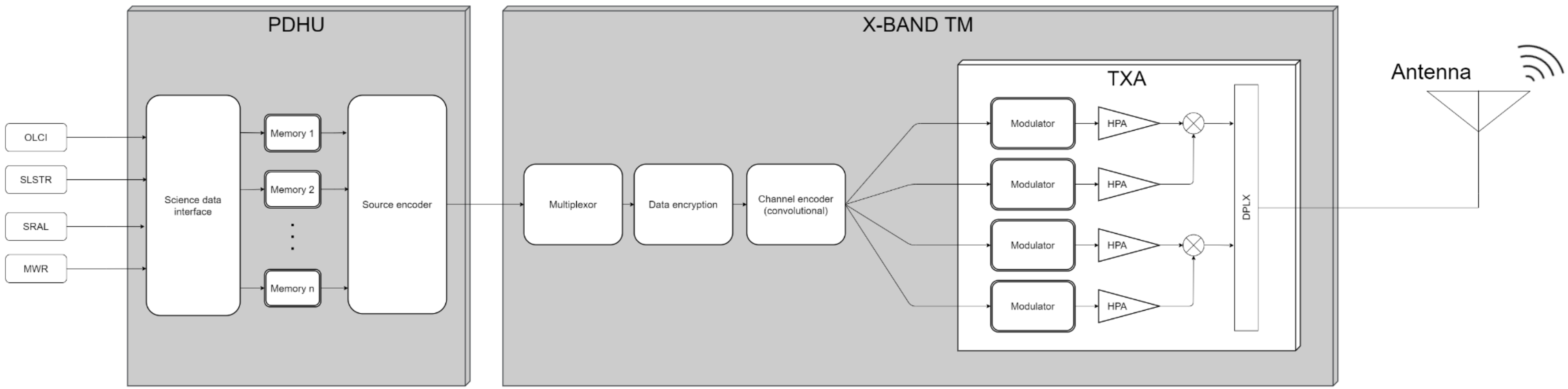
Task 7. Communication system architecture

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 (radar, camera, etc.) and finish in the transmit antenna to see the data flow in the satellite.

See page 13.

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

Adapting transmission scheme is commonly incorporated in most of satellite telecommunication systems because of its simplicity. Just modifying the waveform given in the modulator block a quite different modulation can be obtained. This scheme means a higher amount of data sent because of the better usage of bandwidth along pass. However, the systems get more complex, and a communication between modulator and computer has to be taken into account as well as the resource usage. Also, the adaptative modulation must be implemented and its software developed. Another important drawback is the power consumption.


PDHU
X-BAND TM
TXA
Antenna
OLCI
SLSTR
SRAL
MWR
Science data interface
Memory 1
Memory 2
Memory n
Source encoder
Multiplexor
Data encryption
Channel encoder (convolutional)
Modulator
Modulator
Modulator
Modulator
HPA
HPA
HPA
HPA
DPLX

Task 8. Conclusions

Considering the previous results, fill in next table your conclusions. Indicate how would you increase the amount of downloaded data and the impact on the system architecture.

In this workshop, Sentinel 3 payload communication has been analysed and an adaptive transmission scheme has been proposed. Firstly, accesses with Svalbard have been obtained using STK software for a later procurement of range and average pass duration depending on the minimum elevation angle. As expected, larger passes correspond with lower minimum elevation angles. Once timing and distance have been obtained, carrier to noise ratio was calculated according to environmental parameters given. As it can be seen in the figure (in the corresponding task) lower minimum elevation means wider passes but carrier to noise ratio depends mainly on range, being higher when the distance is lower close to middle of the pass. Then, for each pass, modulation had to be selected according to several constrains. Due to this constrains and possible modulation given, the resulting figure has a stair-like shape when a lower modulation is needed and maximizing bit rate when possible. Modulation efficiency with a time and bandwidth given, determines average and total downlinked data directly. Considering image size and compression rate, the amount of downlinked data in turn determined the number of images downlinked per pass. As it can be seen in the corresponding table, compression leads to a larger number of images and has more influence for lower minimum elevation angle due to the higher number of images. At the time of carrying out adaptative modulation schemes for space transmissions, the basic scheme barely differs from a non-adaptive modulation one. However, an additional connexion with the on-board computer must be taken into account as well as corresponding software and computer resources. In general terms, adaptative modulation means a wiser resource use and nowadays its implementation is quite simple so broadly satellites make use of it. A higher compression ratio could be implemented in order to obtain a greater number of downloaded data even though that would imply a worse image quality. This solution would have a very low impact on the system architecture. To avoid higher compression ratios, a Ku or Ka band could be selected since a higher download bit rate could be achieved with the same modulation. However, this solution means a higher impact on the system architecture.