Orbit and data estimation

In order to choose the good modulation and data rate, we need to estimate the data that we want to store in the satellite and then transmit it to the ground station to have a feedback on our mission. It depends on various parameters such as the period of the orbit, the number of orbit per day and the overall visibility of the satellite.

Calculate period of the CubeSat

An artificial satellite of the Earth rotates slower and slower as it is away from Earth to respect the 3rd law of Kepler which says that a^3 / T^2 is a constant for objects rotating around the same body, where a is The semi-major axis of the orbit and T the period of revolution.

This constant is for the Earth: $GM / 4\pi^2$ where G is the gravitational constant and M the mass of the Earth is:

$G = 6.67259 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$

$M = 5.9736 \times 1024$ kg and thus $GM / 4\pi^2 = 1.00965 \times 10^{13}$

We suppose that our orbit is a perfect circle and that ECE3SAT's orbit will be between 400 and 1000km.

Hypothesis 400km

$a = 400km + 6378km$ (radius of Earth) $= 6{,}778 * 10^6$ m so $a^3 = 3.114 * 10^{20}\ m^3$

So we have the formula $a^3/T^2 = GM / 4\pi^2 = 1.00965 \times 10^{13}$

So $T^2 = a^3 / 1.00965 \times 10^{13} = 3.114 * 10^{20} / 1.00965 \times 10^{13} = 3.084 * 10^7\ s^2$

T = 5553,6 s or 92,56 min

Hypothesis 1000 km

a = 7378 km

$a^3 = 4.016 * 10^{20}\ km^3$

$T^2 = 3.9778197 * 10^7\ s^2$

T = 6307,0 or 105 min

So the orbit period of the ECE3SAT is between 90 and 105 min. It's about 15 revolutions around Earth per day. Now we have to determine which revolution provide visibility to the satellite and size of the window to transmit data.

For this step, the software Gpredict was used. It can track various satellite in orbit and give a lot of information such as the orbit speed, the footprint (area of visibility of the satellite), the elevation and the time and duration of each pass over the ground station. We used 5 different projects that have similarities with our desired orbit: DUCHIFAT-1, SWISSCUBE, AAUSAT IV and II and finally FUNCUBE-1.

From the data that we acquired with this software, we can say that about 6 orbits over 15 per day are in range of the ground station. Plus, 3 of those remaining orbits have such a low elevation (angle between the satellite and the horizon) that we can't receive much data because of the obstacles between the ground station and the satellite such as building, mountain, plains.

So we have only 3 orbits per day that we can truly exploit each day. From the data that Gpredict give to us, we can say that the average visibility of a low orbit CubeSat in those orbit is between 7 and 13 minutes so an average of 10 min.

So basically we have 30 minutes of visibility per day.

Determine the size of the data.

Data name	Data size per occurrence (bits)	Type of data	Number of occurrences	Sampling period (s)	Data size without encapsulation (bits)	Data size with re-emission and encapsulation (bits)	Type telemetry
GPS longitude	32	float	1	50	3456	11616	ADCS Telemetry
GPS latitude	32	float	1	50	3456	11616	
GPS altitude	32	float	1	50	3456	11616	
ADCS magnetometer data	32	float	3	25	20736	68760	
ADCS gyroscope data	32	float	3	25	20736	68760	
ADCS photo sensor data	32	float	5	25	34560	114288	
ADCS sensor consumption	16	integer	22	150	12672	42072	
ADCS sensor state	1	Boolean	22	50	2376	8064	
ADCS sensor temperature	16	integer	11	25	38016	125904	
Magnetorquer's tilt	16	integer	3	50	5184	17424	

Battery's power level	8	integer	1	150	288	1176	EPS and
Photo Voltage power level	8	integer	3	150	864	2904	temperature
Module consumption	16	integer	16	150	9216	30456	telemetry
Battery temperature	8	integer	1	25	1728	5808	
EDT motor velocity	32	float	1	50	3456	11616	
EDT wire velocity	32	float	1	50	3456	11616	
EDT positioning head status	8	integer	1	50	864	2904	
EDT motor status	8	integer	1	50	864	2904	EDT telemetry
EDT measurement system status	8	integer	1	50	864	2904	
EDT current in the guides	16	integer	1	50	1728	5808	
Tether state	8	integer	1	50	864	2904	
IsSafeMode	1	Boolean	1	50	108	636	
IsEclipseMode	1	Boolean	1	50	108	636	
IsADCSOn	1	Boolean	1	50	108	636	
IsTCSOn	1	Boolean	1	50	108	636	
IsEDTOn	1	Boolean	1	50	108	636	
IsAntennaDeployed A-UHF	1	Boolean	1	100	54	474	
IsAntennaDeployed B-UHF	1	Boolean	1	100	54	474	OBC telemetry
IsAntennaDeployed A-VHF	1	Boolean	1	100	54	474	
IsAntennaDeployed B-VHF	1	Boolean	1	100	54	474	
3.3V bus current	8	integer	1	50	864	2904	
3.3V bus voltage	8	integer	1	50	864	2904	

5.0V bus current	8	integer	1	50	864	2904	
5.0V bus voltage	8	integer	1	50	864	2904	

The period of sampling is arbitrarily fixed. We will come back to this point later.

The data without encapsulation is calculated in this way: data size * number of occurrence * (orbit time / sampling period). Basically this is the raw data that the satellite generates for one orbit. We must add to this raw data the size of the encapsulation of the AX25 protocol. In a concern of reliability of the transmission, we decided that the maximum data we can send with one AX25 frame is 1024 bits out of the 2048 bits possible.

So the data with encapsulation is calculated in this way: (data without encapsulation + rounding of upper unit of (data without encapsulation/1024) * size of AX25 frame) * number of re-emission. We want to reemit the same AX25 frame because in this protocol, when you fail to transmit one bit, the whole frame is erased and you have to start from the beginning.

For information, we fixed the number of re-emission to 3 and the maximum size of an AX25 frame is 104 bits without the data.

By summing all the data with encapsulation of the different fields, we can have the total weight of the information we have to transmit each orbit by the satellite. We add a marge of 20% to this sum.

For the moment the total amount we have to transmit per orbit is 207663 bits or about 208 kbit.

Capacity of transmission

Now that we have a precise model of the estimation of data we need to add two constrains: the capacity/speed of transmission of the data and the memory of the satellite.

The memory problem is quite easy to put in equation:

- we must assure that all the data that we store in one day can be transmitted within an interval of 30 min of visibility we found earlier.
- We must assure that we can stock the equivalent of 8 orbits of data in the memory of the satellite: we are not able to transmit data each orbit of our satellite and sometimes, you can have 8 successive orbits without visibility as we can see in Gpredict for similar projects.

The capacity/speed of transmission depends of several parameters: the baud rate in symbol per second (here we took the hypothesis of a symbol = 1 bit), the visibility duration of one exploitable orbit, the ratio between exploitable orbit and total orbit per day.