Link budget

1. Introduction

A link budget assesses the various gains and losses that impact signal transmission from the satellite to the ground station, ensuring the communication link meets performance requirements.

By analyzing key factors such as transmission power, antenna gains, path losses, and atmospheric attenuation, we predict the signal-to-noise ratio (SNR) and system reliability. This revised document details the methodology, assumptions, and calculated outcomes, providing a comprehensive understanding of the system's performance and limitations. These results are essential for validating the design and ensuring reliable data transmission for the IEEE Open PocketQube Kit mission. Please check the data budget for additional information regarding COMMS budgets.

2. Methodology

The methodology for calculating the link budget involves several key steps. First, we generated separate tables for each type of link: uplink and downlink. For each link, three different scenarios were considered: nominal, adverse, and favorable.

- Nominal scenario: Normal operation and conditions.
- Adverse scenario: Worst expected performance.
- Favorable scenario: Best possible performance.

It is important to note that all scenarios are calculated at a fixed orbit altitude of 500 km. The adverse and favorable scenarios have been updated to assess the variability of other parameters, such as antenna gain and losses. Additionally, we have revised the valid link margin for the nominal scenario to 3 dB for an orbit altitude of 500 km. Finally, calculations for the -3σ and RSS worst case have been performed using the adverse and favorable scenarios.

Parameter	**Value**	**Description**
Central Frequency [MHz]	868	
Bandwidth [kHz]	125	

Spreading Factor	11	
Orbit Height [km]	500	Fixed altitude as per the Mission Analysis calculations.
Maximum Transmitted Power [dBm]	22	Maximum transmitted power as specified in the transceiver datasheet (SX1262).
Gain of the Monopole Antenna [dBi]	4	A quarter-wavelength monopole antenna has a gain of 5.15 dB. To account for a safety margin, we assume a gain of 4 dBi for the antenna.
Gain of the Patch Antenna [dBi]	12	Gain of the GS Yagi antenna as specified in the datasheet.
Polarization Losses [dB]	3	3 dB as we are using circular polarization.
Losses Due to Atmosphere [dB]	2	According to ITU-R recommendation 618, atmospheric losses are very small, primarily due to ionospheric scintillation. Also, ITU-R P.840-8 shows negligible attenuation due to clouds and rain at 868 MHz. Atmospheric losses are considered to be 2 dB.
Losses Safety Margin [dB]	3	As recommended in one of the RIDs, a link margin of 3 dB is applied.
Sensitivity for SF=11 [dBm]	-134.5	Given our bandwidth and spreading factor, our sensitivity is -134.5 dBm.
Sensitivity for SF=11 [dB]	-17.5	SNR sensitivity is -17.5 dB.

Please note that the gain of the quarter-wavelength monopole antenna shown in the table is 4 dBi. The theoretical gain of a quarter-wavelength monopole antenna is based on the gain of a half-wave dipole antenna, which is approximately:

$$G_{\text{dipole}} \approx 2.15\,\text{dBi}$$

Since a quarter-wavelength monopole antenna radiates only over half of the space due to the presence of a ground plane, its gain increases by 3 dB. Therefore, the gain of the monopole antenna is given by:

$$G_{\text{monopole}} = G_{\text{dipole}} + 3\,\text{dB} \approx 2.15\,\text{dBi} + 3\,\text{dB} \approx 5.15\,\text{dBi}$$

To incorporate a safety margin in our calculations, we assume a gain of 4 dBi for the quarter-wavelength monopole antenna.

3. Study cases

This section introduces each one of the scenarios that will be used for this link budget.

Favorable Scenario	Nominal Scenario	Adverse Scenario
500 km orbit height	500 km orbit height	500 km orbit height
0dB pointing losses	0.5dB pointing losses	1dB pointing losses
5.15dBi antenna gain	4dBi antenna gain	0dBi antenna gain (no deployment)
3dB link margin	3dB link margin	3dB link margin

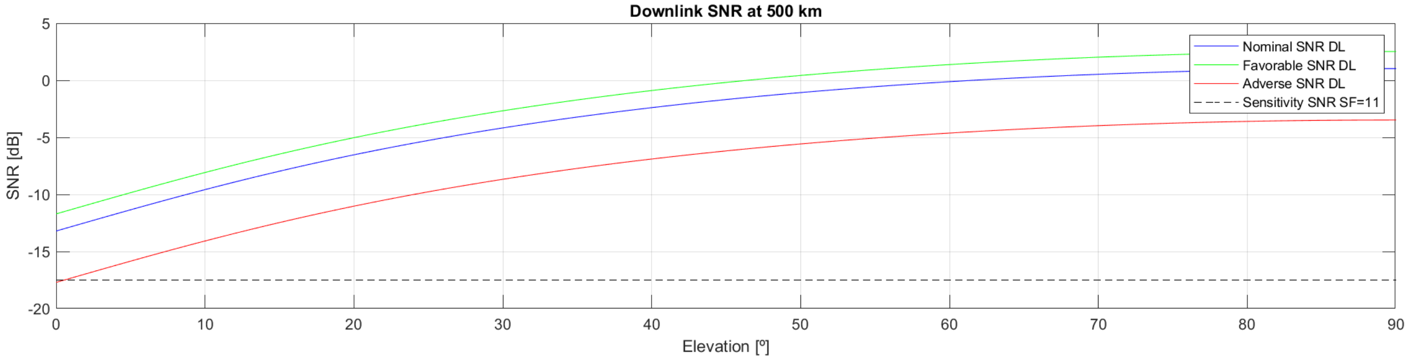
4. Analysis of the results

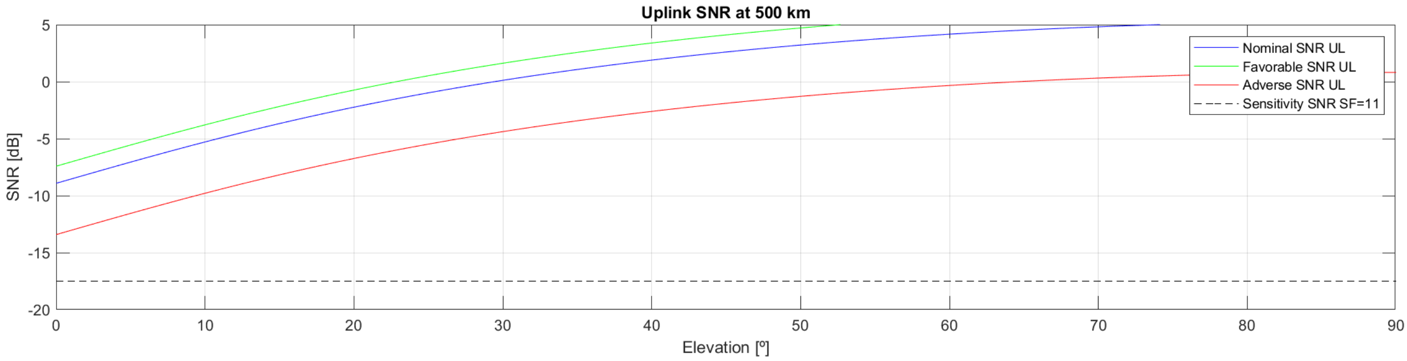
This section presents the results from the Link budget analysis, detailing the findings for each study case across all three scenarios.

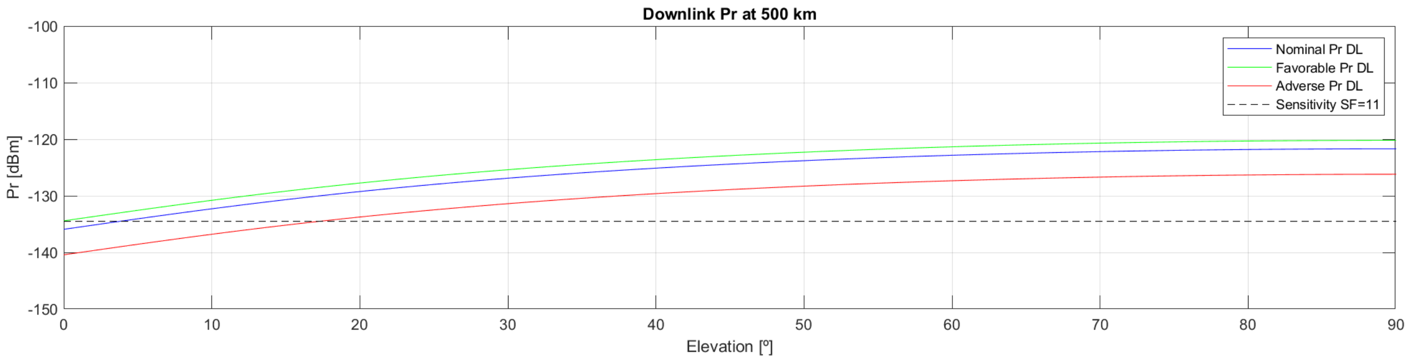
4.1. Power and SNR requirements

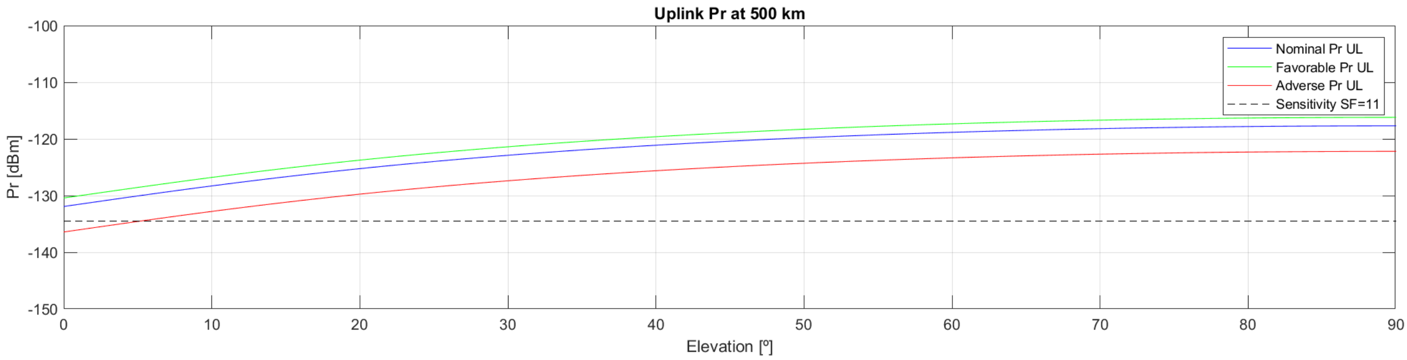
After running the code we created to compute the link budget, we have generated Figures shown below. These figures display the received powers for both Downlink and Uplink at each edge, as well as the corresponding SNR values. Note that the sensitivities outlined in the previous section are also represented as lines in the plots. The analysis of these results will determine the **minimum elevation angle required for contact**, identified by the intersections between the thresholds and the received power or SNR. A summary of the results is presented in this table:

Scenario	Favorable		Nominal		Adverse	
	Prx	SNR	Prx	SNR	Prx	SNR
Downlink [min elevation angle]	0	0	4	0	17	1
Uplink [min elevation angle]	0	0	0	0	5	0









5. Conclusions

Once the link was computed, we looked for the references on the LoRa to demonstrate the disability of the link despite having a negative SNR [1]. Also, the approach to use LoRa on our mission was due to a recommendation from our professor, as the theoretical feasibility was demonstrated in [2]. To conclude, in addition to some experiments, [2] helped us to choose SF =11 and BW = 125 kHz.

1. **Favorable Scenario:**
   - Both uplink and downlink communications are highly reliable.
   - Minimum elevation of 0°, ensuring robust communication links.
2. **Nominal Scenario:**
   - Taking into account an antenna gain of 4dBi and a link margin of 3dB as recommended by ESA's expert.
   - Communications remain reliable, though with slightly higher minimum elevation angles (4° for downlink and 0° for uplink).
   - Communications are feasible but require more optimal conditions compared to the favorable scenario, especially for the downlink.
3. **Adverse Scenario:**
   - Taking into account no antenna deployment as well as worst system performance.
   - Uplink communication is possible but requires minimum elevation of 5°.
   - Downlink communication is possible but requires minimum elevation of 17°.

In our analysis, we calculated the -3σ margin, which provides a conservative estimate of the link performance under adverse conditions. The calculated -3σ margin was found to be 4.9505, indicating the minimum acceptable performance level for reliable communication.

Additionally, the worst-case RSS analysis yielded a total RSS of 3.4689. This worst-case scenario confirms the robustness of our system, with a link margin superior to 0 dB, as it demonstrates the ability to maintain communication links even under challenging conditions.

Both parameters were calculated as detailed in ECSS-E-ST-50-05C, section 8.

The link budget analysis demonstrates the feasibility of our communication system for the PoCat Lektron mission PocketQubes, developed under ESA's FYS4! program. The analysis considers different scenarios for uplink and downlink communications, including favorable, nominal, and adverse conditions.

Moreover, when taking adverse conditions, we find that communication is possible even in challenging scenarios. This confirms the link's feasibility.

6. References

[1] RF Wireless World. LoRa Sensitivity Calculator. https://www.rfwireless-world.com/calculators/LoRa-Sensitivity-Calculator.html, 2024.

[2] L. Fernandez, J. A. Ruiz-De-Azua, A. Calveras, and A. Camps. Assessing lora for satellite-to-earth communications considering the impact of ionospheric scintillation. IEEE Access, 8:165570–165582, 2020.

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