Analysis of Communication Link Between Satellites and the Ground in the Northern Region of Brazil for Image Processing

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***Abstract*--Link analysis is important to assess the viability and performance of communications between satellites and ground stations, especially for image processing applications. The Northern Region presents unique challenges due to its vast territorial extension and the presence of the Amazon Rainforest, which can interfere with satellite communication due to the density of vegetation. Therefore, it is crucial to understand and assess the communication link in this region in order to ensure efficient and reliable data transmission between satellites and ground stations. Communication parameters such as bandwidth, frequencies used, signal attenuation, interference and other factors that can affect the quality of communication between satellites and the ground will be analyzed. In addition, image processing may require robust communication to transmit data collected by satellites back to ground stations, where it will be processed and used for various applications.**

***Index Terms*--Satellite, antenna, link, image processing, uplink, downlink.**

I. Introduction

DUE to continuous technological advances and the growing use of the Internet, remote sensing and satellite communication applications have become increasingly relevant. Remote sensing, for example, plays a crucial role in a variety of areas, from Earth observation to the collection of environmental and climate data. The success of these operations depends heavily on the quality and efficiency of communication links between satellites and ground stations.

In Brazil, climatic and geographic diversity has a significant influence on the effectiveness of these links. The North Region, with its equatorial climate and dense forest cover, presents unique challenges for the installation and maintenance of communication infrastructure. Climatic conditions, such as high rainfall and varied topography, can impact the stability of links and the quality of data transmission.

To optimize communication between satellites and ground stations, it is essential to analyze the communication parameters. Antenna gain, signal attenuation, bandwidth and polarization are essential aspects to ensure effective transmission. Furthermore, the concept of link budget is crucial to determine the minimum transmission power required and to assess the viability and performance of communication.

Digital processing of satellite images is a crucial step in transforming the raw data received from satellites into useful information. Satellite images, often captured in several bands of the electromagnetic spectrum, have a wide range of applications, including environmental monitoring, agriculture, meteorology, cartography and urban analysis. In the context of this research, the focus is on obtaining clear images of terrain in the Northern Region of Brazil, where cloud cover often makes visualization difficult.

Based on the simulations of the link between the CBERS-2B satellite and the Data Reception and Recording Station (ERG INPE/CUIABÁ), the data received are "raw" images that require processing to be interpreted by humans and for computer vision applications. The construction of algorithms for processing these images is essential, and the choice of processing methods varies according to the objective. In this case, the objective is the detection of river banks. For this purpose, an image from the INPE image catalog was selected and processed using MATLAB software. The NIR (Near-InfraRed) band was used to highlight the presence of water and the Canny filter was used to detect edges after image normalization.

ANSYS STK (Systems Tool Kit) has emerged as a powerful tool for simulation and analysis of space systems, allowing detailed simulations to be performed to evaluate communication between the satellite and the ground station. The analysis of the link budget generated by STK provides critical parameters, such as Effective Isotropic Radiated Power (EIRP), flux density and bit error rate, offering a comprehensive

view of the link quality and communication efficiency.
This study is essential for the development of future space missions and for the continuous improvement of satellite communication systems, considering the challenges imposed by Brazil's climatic and geographic conditions, as well as for the application of image processing algorithms to obtain accurate and useful information from the collected data.

II. The Link

The link between the satellite and the ground station is essential for satellite communication and is divided into two parts: uplink and downlink. The uplink involves the transmission of data from the ground station to the satellite, while the downlink deals with the transfer of information from the satellite back to the ground station.

With the evolution of communication technologies and the growing demand for connectivity, especially in relation to the Internet, the efficiency of these links has become increasingly critical. In the context of remote sensing, this communication infrastructure is essential to support a wide range of applications, from Earth observation to environmental monitoring[1].

The continuous development of these technologies is imperative to ensure that the transmitted data remains intact, confidential and authentic, ensuring the reliability of satellite communication operations. This focus on the security and efficiency of the satellite-to-ground link is crucial to enabling advanced applications, such as image processing, which directly depends on the robustness of these communications[3].

III. Climatic Aspects

The climate in Brazil is strongly influenced by its position in the equatorial belt, with the North region playing a central role, especially due to the presence of the Amazon. The climate of this region is predominantly rainy, which contrasts with the semi-arid Northeast, despite its latitudinal proximity. In the Amazon, high rainfall is essential for the maintenance of the tropical forest and results from ascending air currents that promote the formation of clouds, influencing the local and regional hydrological cycle.

This atmospheric phenomenon directly affects the climate of the Northeast, where the subsidence of the air limits the formation of clouds and, consequently, precipitation, even with the presence of humid trade winds. The North region is also influenced by disturbances in the Tropical Atlantic Ocean, such as the Intertropical Convergence Zone (ITCZ) and easterly waves, which modulate local climate conditions. The Low-Level Jet, a flow of intense winds in the lower layers of the atmosphere, connects the hydrological cycle of the Amazon to that of the Paraná and Prata river basins[4].

The climatic and geographic conditions of the Northern region, characterized by high rainfall, low-lying terrain, dense forests and frequently flooded plains, pose significant challenges for the installation of communication infrastructure. Minimal temperature variations and heavy rainfall can impact the stability of data links, making it crucial to consider these factors when planning communication and research projects in the region.

IV. Link Budget And Ansys STK

The concept of link budget is essential in telecommunications engineering, especially in wireless communication systems. It allows the assessment of the viability and performance of communication between two points, such as satellites, ground stations, and mobile devices. When calculating the link budget, engineers determine the minimum transmission power required to ensure reliable communication and adequate signal quality, taking into account the environment and operating conditions. This analysis is crucial for the development of efficient communication systems, especially in critical applications such as satellite communications and mobile networks[5].

Ansys STK (Systems Tool Kit) is a specialized tool for space systems simulation, covering mission analysis, orbital dynamics, and satellite communications. Its advanced graphical interface allows for the accurate modeling and analysis of complex space systems, and is widely used by space organizations, government agencies, and satellite companies. STK is recognized in the aerospace community for its ability to perform detailed and advanced analyses[6].

Among its functionalities, STK offers satellite orbit simulation, sensor and communications coverage analysis, and space and military mission planning. In the context of link budget, STK can be used for satellite network planning, signal coverage analysis, and interference assessment, being a valuable tool for the telecommunications and remote sensing areas.

A. Parameters

The parameters are essential for the simulation and among those used we have those that are essential, which in this case are those of Radiocommunication (ITU-R), referring to the part of the International Telecommunication Union (ITU) responsible for regulating and coordinating the use of the radio spectrum and radio communications at a global level. The ITU is a United Nations agency dedicated to issues related to information and communications technologies. ITU-R establishes standards and guidelines for the use of the radio spectrum, which is a finite and vital resource for various forms of communication, such as radio, television, mobile telephony and satellite communications[7]. The following recommendations were used in the link simulation:

- ITU-R P.531-13 [8] for Ionospheric Fading Loss Model.
- ITU-R P.618 [9] Section 2.5 for Total Propagation Calculation. Local Rain Data enabled.
- ITU-R P.618-12 [10] for Tropospheric Scintillation Loss Model.
- ITU-R P.618-13 [11] for Rain Loss Model.
- ITU-R P840-7 [12] for Clouds and Fog Model.

B. Ansys STK

In ANSYS STK, data from the CBERS-2B satellite can be retrieved directly from the software database through the "From STK Data Federate" option. This functionality allows users to access a vast collection of pre-existing information about multiple satellites, including orbital data, mission parameters, and physical characteristics. The choice of CBERS-2B for simulation in STK is due to some factors:

- Data Availability: Since the satellite is inactive, its historical and technical data are in the public domain, facilitating access for academic and research use, within the scope of what is released to the general community. And with this data already included in the models, this facilitates simulation.
- Representativeness: CBERS-2B is an example of a remote sensing satellite, being useful for testing and validating various simulation scenarios, such as Earth observation, orbit analysis and satellite communications.
- Compatibility with STK: STK's integration with databases such as Data Federate ensures that simulations are based on real and accurate data, increasing the validity and reliability of the results obtained.

The CBERS-2B simulation evaluates aspects such as orbital trajectory, sensor orientation, and communication with ground stations. This allows for detailed analysis of satellite performance and exploration of hypothetical scenarios for research. These simulations are crucial for studying ground coverage, data quality, communications efficiency, and satellite lifecycle management, helping to improve satellite systems and plan future space missions.

As a ground station, the “Facilities” option includes “Cuiaba_Station”, a model of the Data Reception and Recording Station (ERG INPE/CUIABÁ), located in Morro da Conceição, approximately 9 km from the center of the city of Cuiabá. This station is responsible for receiving data from the CBERS satellites in Brazil.

The station is equipped with two reception subsystems and two recording subsystems. The reception subsystems include a 10-meter diameter antenna that operates in the S and X bands, an 11.3-meter diameter antenna operating in the X band, and another 11.3-meter antenna with dual polarization capability, in addition to the respective Radio Frequency equipment. The recording subsystems are formed by the DAS-1 and DAS-2 subsystems, each with a recording capacity of up to 160 Mbit/s, and by the MATRA/CBERS recording subsystem, specifically designed for receiving images from the CBERS satellites.

When starting the simulation of the CBERS-2B satellite using ANSYS STK, one of the crucial steps is to perform the link budget. This process involves the analysis and detailed calculation of the various parameters that affect the communication between the satellite and the Data Reception and Recording Station (ERG INPE/CUIABÁ).

Below we have the link budget delivered by the software with an analysis of the link and with important data so that we can analyze what was collected.

As you can see on “Fig. 1,” we had access for about 15 minutes. As in “Fig. 1,” you can see the details from the link budget, in “Fig. 2,” you can see the remaining details of the link budget.

Satellite-Cbers2B_32062-Transmitter-Transmitter1-To-Facility-Cuiaba_Station-Receiver-Receiver1: Link Budget - Short Form

Time (UTCG)	EIRP (dBW)	Rcvd. Frequency (GHz)	Rcvd. Iso. Power (dBW)	Flux Density (dBW/m^2)	g/T
22 May 2024 17:42:55.550	30.000	14.500318	-155.937	-111.254362	20
22 May 2024 17:43:55.000	30.000	14.500316	-154.829	-110.146147	20
22 May 2024 17:44:55.000	30.000	14.500312	-153.560	-108.877171	20
22 May 2024 17:45:55.000	30.000	14.500302	-152.109	-107.425900	20
22 May 2024 17:46:55.000	30.000	14.500284	-150.448	-105.765068	20
22 May 2024 17:47:55.000	30.000	14.500249	-148.591	-103.907901	20
22 May 2024 17:48:55.000	30.000	14.500181	-146.718	-102.034812	20
22 May 2024 17:49:55.000	30.000	14.500059	-145.443	-100.759706	20
22 May 2024 17:50:55.000	30.000	14.499910	-145.625	-100.941857	20
22 May 2024 17:51:55.000	30.000	14.499800	-147.117	-102.433621	20
22 May 2024 17:52:55.000	30.000	14.499740	-149.024	-104.341277	20
22 May 2024 17:53:55.000	30.000	14.499709	-150.850	-106.166645	20
22 May 2024 17:54:55.000	30.000	14.499693	-152.468	-107.785078	20
22 May 2024 17:55:55.000	30.000	14.499685	-153.882	-109.198462	20
22 May 2024 17:56:55.000	30.000	14.499680	-155.120	-110.436496	20
22 May 2024 17:57:27.631	30.000	14.499679	-155.730	-111.047229	20

Fig. 1. Link Budget part 1.

22 May 2024 08:10:56

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g/T (dB/K)	C/No (dB*Hz)	Bandwidth (kHz)	C/N (dB)	Eb/No (dB)	BER
20.000000	92.661732	32000.000	17.6102	20.6205	1.000000e-30
20.000000	93.769947	32000.000	18.7184	21.7287	1.000000e-30
20.000000	95.038923	32000.000	19.9874	22.9977	1.000000e-30
20.000000	96.490194	32000.000	21.4387	24.4490	1.000000e-30
20.000000	98.151026	32000.000	23.0995	26.1098	1.000000e-30
20.000000	100.008193	32000.000	24.9567	27.9670	1.000000e-30
20.000000	101.881283	32000.000	26.8298	29.8401	1.000000e-30
20.000000	103.156388	32000.000	28.1049	31.1152	1.000000e-30
20.000000	102.974237	32000.000	27.9227	30.9330	1.000000e-30
20.000000	101.482473	32000.000	26.4310	29.4413	1.000000e-30
20.000000	99.574817	32000.000	24.5233	27.5336	1.000000e-30
20.000000	97.749449	32000.000	22.6979	25.7082	1.000000e-30
20.000000	96.131016	32000.000	21.0795	24.0898	1.000000e-30
20.000000	94.717632	32000.000	19.6661	22.6764	1.000000e-30
20.000000	93.479598	32000.000	18.4281	21.4384	1.000000e-30
20.000000	92.868865	32000.000	17.8174	20.8277	1.000000e-30

Fig. 2. Link Budget part 2.

C. Results

- Effective Isotropic Radiated Power (EIRP): 30.0 dBW.
- Received Frequency: 14.5 GHz.
- Received Isotropic Power (RIP): -155.937 dBW.
- Flux Density: -111.25 dBW/m².
- Gain-to-Temperature Ratio (g/T): 20.0 dB/K.
- Carrier-to-Noise Ratio: 92.66 dB*Hz.
- Bandwidth: 32000 kHz.

D. Performance parameters

- Carrier-to-Noise Ratio (C/N): 17.61 dB.
  The ratio of the carrier power to the noise power at the receiver.
- Energy per Bit Signal-to-Noise Ratio (Eb/No): 20.62 dB.
  The ratio of the energy per bit of the received signal to the power spectral density of the noise.
- Bit Error Rate (BER): $1*10^{-30}$.
  The probability of a bit error during transmission.

Based on the given parameters, we can conclude that the link has a high Effective Isotropic Radiated Power (EIRP), indicating robust effective power transmission. The flux density is also quite high, which suggests good received signal quality.

The C/No and Eb/No ratios are significantly greater than zero, indicating that the signal-to-noise ratio is high, which is desirable for good reception quality. Furthermore, the extremely low bit error rate suggests high reliability in data transmission.

However, it is important to note that the C/N ratio is relatively low compared to other parameters, which may indicate some signal degradation during transmission or reception.

Based on the given data, the link budget indicates robust RF transmission with high signal quality and an extremely low bit error rate, which suggests reliable and effective communication.

V. Image Processing

Image processing is a technique in the field of computer science and electrical engineering that involves the manipulation and analysis of digital images through computational algorithms. Its main objective is to improve the quality of images or extract useful information from them.

As a technique, it involves certain steps and processes, so it is very important to understand and know how to apply each step so that the final result is as useful as possible. That said, we must briefly study these steps. In “Fig. 3,” the flowchart details the image processing steps.

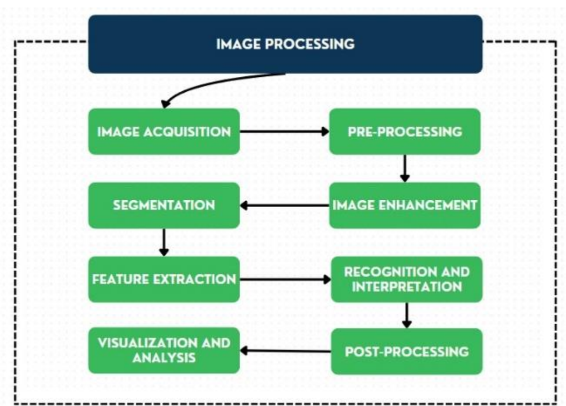

Fig. 3. Image Processing Steps.

Digital processing of satellite images involves the application of a series of algorithms to handle the unique datasets obtained from satellites. These images have a wide range of applications. The primary focus of this research is to obtain clear imaging of the ground within the Northern Region, which is often cloudy.

The data collected by satellites are "raw" images and need to be processed to be observed and studied by humans and machines in computer vision applications. The application of processing algorithms for satellite imaging is defined by the objective, which in this case is to detect rivers. With this purpose in mind, images can be acquired from catalogs, such as the INPE (National Institute for Space Research) image catalog.

MATLAB software was chosen for the development of this study due to its numerous built-in filter functions and the ability to easily adjust filter parameters. MATLAB allows for the extraction of bands captured by satellites, such as the Near-Infrared (NIR) band, which is an excellent option for studies involving water resources. For detection, normalization techniques, region of interest enhancement, and edge detection filters such as the Canny and Sobel filters, which are already included in the software's libraries, were used. For this purpose, a simple code[13] was implemented so that it could be demonstrated how these filter work

The first step is to extract the Near Infra-Red Band from the *.tif* archive, archives of that type can be downloaded in public web libraries, like INPE (INSTITUTO NACIONAL DE PESQUISA ESPACIAL).

In order to see something distinguishable the selection of a Region of Interest (ROI) must be used to highlight a part of the image in a frame. The “Fig. 4,” is an example of Near-Infrared (NIR) band file.

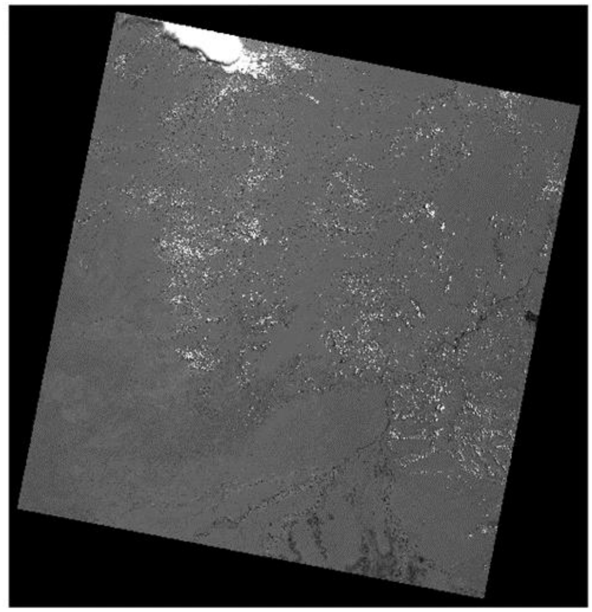

Fig. 4.NIR BAND.

Then, with an appropriated Region of Interest coordinates selected, the application of this ROI came just has a future comparation method. The “Fig. 5,” shows a Region of Interest that was used.

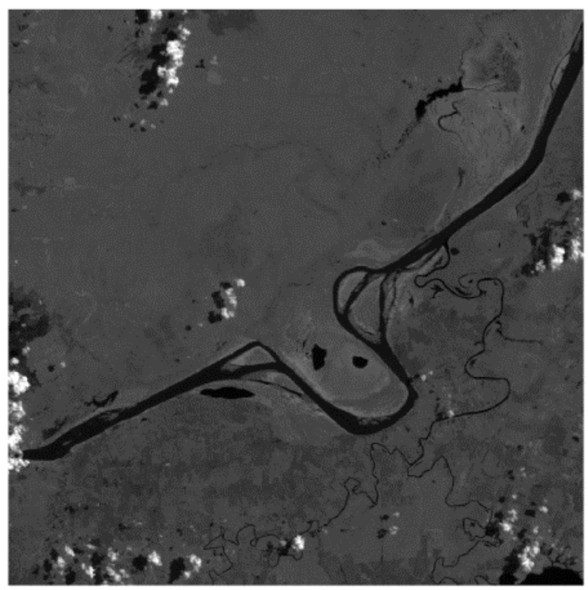

Fig.5.Region of Interest.

After that, the Sobel Filter can be applied in the whole image. The result after applying the sober filter can be seen in “Fig. 6,”.

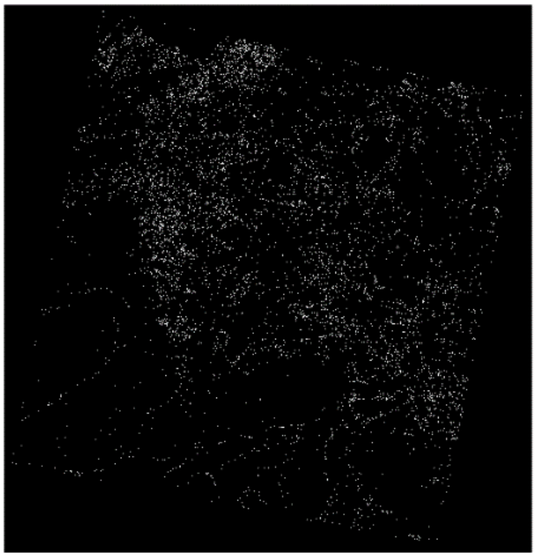

Fig.6. Sobel Filter

For sampling purposes, is possible to apply the same coordinates of the last Region of Interest in the image post processed with the filter, having results to available to compare. Now with the Sobel Filter applied, the same Region of Interest can be used as shown in “Fig. 7,”.

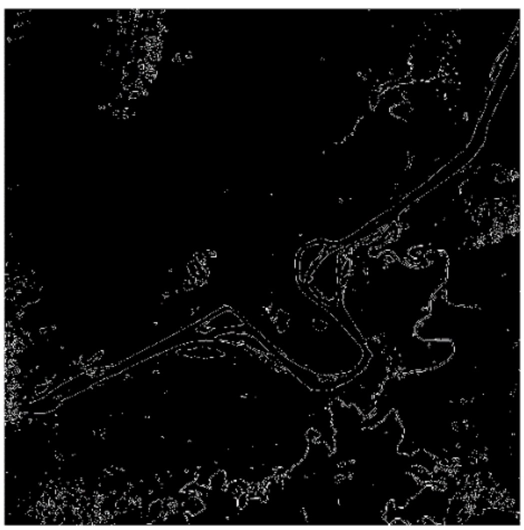

Fig.7. Region of Interest applied in the Sobel Filter

VI. Results

The Sobel Filter, together with the Near Infra-Red band, generates good results in this task. Identifying rivers with clarity, removing excessive edges, like from the clouds, terrain and other interferences that might appears.

VII. Conclusion

The link process between a satellite and a ground station is of paramount importance for the Amazon and plays a fundamental role in enabling faster and more frequent monitoring of the region. Image processing is a key product of the satellite-to-ground communication link.

The communication link between ground stations and satellites traveling over the Northern Region faces some interference and difficulties, not only due to weather conditions but also because of geographical features. High rainfall levels, large cloud volumes, difficult-to-access terrain, and other environmental issues make establishing direct contact between satellites and ground stations essential for advancing monitoring efforts and analyzing the collected data that will directly impact society.

Image processing, along with the link process, is crucial because most of the information we receive from satellites comes in the form of images. These images and their characteristics vary according to the sensor, purpose, bands, and resolutions.

The existence of these processes in regions such as the north is vital for monitoring a wide range of changes caused by human activity, such as terrain alterations, sudden changes in river courses, flooded areas, and even for monitoring fires and deforestation.

The result can be considered a success in learning image processing techniques, as it is possible to clearly observe the edges of rivers and bodies of water, paving the way for new research and studies in the field.

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