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AN OVERVIEW OF THE ALFA CRUX CUBESAT MISSION FOR NARROWBAND COMMUNICATION

Leandro Ribeiro Reis,* Renato Alves Borges,* João Paulo Leite,* Chantal Cappelletti† and Simone Battistini‡

The development and operation of a reliable voice and data communication systems in remote or difficult-to-reach areas is still a challenge in the modern world. In this framework, the mission Alfa Crux, based on a nanosatellite system under development at the Laboratory of Simulation and Control of Aerospace Systems (LODESTAR), University of Brasilia (UnB), Brazil, proposes the use of narrow bandwidth to create data and voice connections from low orbit. The Alfa Crux system aims at contributing to improve agricultural monitoring, water level controlling in rivers and reservoirs, as well as improving the communications technology between devices (M2M) and the Internet of Things (IoT), especially in remote regions where communication infrastructures on land are unreliable or cost prohibitive. The main problem addressed in this work concerns the development of a nanosatellite communication system based on UHF amateur radio frequency band. The choice of the frequency band is based on the fact that the use of narrowband in nanosatellite communication systems has relevant characteristics such as energy efficiency, spectrum, reliability, performance, safety, communication range, among others. This paper presents an overview of the communication architecture of the space mission of the nanosatellite Alfa Crux.

INTRODUCTION

Narrowband communication is becoming increasingly relevant in applications where electromagnetic waves have a harder time propagating due to the topological conditions of terrain and obstacles such as treetops, rain, metal structures, among others. The relevance of narrowband is due to its favorable wave propagation and penetration properties using frequencies around 300 MHz to 4 GHz (UHF, L and S), being extremely useful for military and civilian applications [1], [2].

Narrowband characteristics such as low data rate, low power consumption and low latency are favorable conditions for different applications of Internet of Things (IoT) technology that focuses on establishing a device network that allows equipment to communicate with each other through their smart devices such as sensors and actuators. Increasingly, the number of these connected devices is growing in many applications in different

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fields such as public health, smart cities, logistics, transportation, agriculture, energy management, communication, natural disasters, location, among others [1], [2], [3].

An efficient way of aligning narrowband characteristics with IoT related applications is with the use of satellites, as they increase connectivity with expanding coverage area [4]. Due to the versatility of launch opportunities and the low costs of realization [5], nanosatellites end up being a very suitable tool for this application compared to conventional satellites. The most relevant example is that of CubeSats, a class of nanosatellites that is being used as a means of access to space by various countries in various sectors [6], [7], [8].

For communications missions, the most favorable orbits are the low altitude ones (Low Earth Orbits - LEO) due to the shorter distance from the Earth, signal loss and reduced delay compared to Geostationary Earth Orbit (GEO) for instance, [6]. However, the area that can be covered with LEO missions is not large. As a solution, constellations of CubeSats have been proposed and launched in recent years to provide continuous coverage of the planet, which ultimately results in a more performing and reliable system [1], [2], [9], [10], [11].

Due to this increased connectivity created from a low orbiting constellation of CubeSats, new opportunities are emerging such as Internet of Things (IoT) and Machine to Machine (M2M) technologies, especially for low data rate applications, which can provide interesting solutions to remote and hard-to-reach areas such as forests and oceans where satellite coverage is often the only one available.

The advantages of using narrowband in nanosatellite communications for IoT and M2M technology applications can been found in a number of studies where it is possible to mention a smaller difficulty in relation to the topographies, better cost over other communication technologies, energy efficiency, safety and data integrity, no need for large numbers of transmission stations, greater coverage area, since terrestrial systems cannot reach some regions, among others. Disadvantages of narrowband include lower data transfer rates and lower availability of electromagnetic spectrum [1], [2], [3], [4], [6].

In this context, the Alpha Crux Mission of the University of Brasilia (UnB) emerges as an embryo of a constellation of narrowband communication satellites, aiming to provide critical communications beyond radio targeting without interruption, and enabling a M2M/IoT data network in remote regions with little infrastructure.

This paper presents an overview analysis of the communication architecture of the Alfa Crux space mission, highlighting the relevant aspects of the use of narrowband inherent to its mission objectives.

MISSION ANALISYS

Mission Purpose

The main purpose of the Alfa Crux nanosatellite is to provide narrowband fixed and mobile communications link for periodic time interval operations. It is a university space mission that will assist Brazil in having a more efficient way of communicating data and voice in remote or hard-to-reach areas. The main objectives of the Alpha Crux mission are:

- Improve communication in remote regions beyond the line of sight of the radio with a communication system less susceptible to attenuation caused by rain, tree canopy foliage or metal structures;
- Get lighter terminals compared to equipment used in Super High Frequency (SHF)/Extremely High Frequency (EHF) satellite communications system
- Assist communication between M2M/IoT devices and data interaction and exchange to take internet connectivity to a broader level.

Proposed Orbit

As mentioned above, although satellites with GEO orbit cover a larger geographical area, their signals must travel a greater distance compared to LEO orbit, resulting in longer time and attenuation of signals. In this way, using LEO orbits would reduce the transmission power requirements of the terminals, allowing for smaller ground terminals to be used. With the need for a coverage area, especially for LEO orbits, there would be a need for an increase in the number of satellites resulting in greater coverage, with greater connectivity, reliability and resilience [1].

The nanosatellite Alfa Crux will be placed in LEO which contributes to decrease signal delay and attenuation. LEO orbit also reduces the transmitter power requirements of satellite by contributing to their reduction in size, weight and cost, which makes it also cheaper to launch [6]. Figures 1 and 2 show the ground track of the satellite over the Brazilian territory. A near Sun-Synchronous orbit of approximately 500 km altitude with 97° inclination is selected, where the nanosatellite antenna footprint on the ground is expected to have a radius of approximately 2500 km, which equals an area of 36 million km².

The Alfa Crux nanosatellite will also provide a data collection system to contribute to IoT technology. Even though a single satellite on a Sun-Synchronous does not offer continuous coverage of a specific region, it provides global coverage, favoring IoT connectivity with a constellation of CubeSats around the planet [10].

Figure 1. Nanosatellite Alfa Crux orbits proposed.

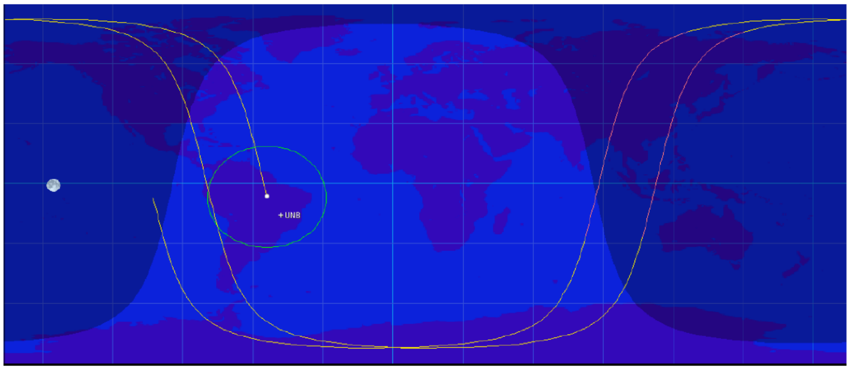

Figure 2. Nanosatellite Alfa Crux land tracking with coverage area in Brazil.

Spectrum Use

The use of the frequency spectrum is controlled by national and international agencies. These functions are performed by the ITU (International Telecommunication Union) at the international level and by ANATEL (National Telecommunications Agency) at the Brazilian national level, which is responsible for controlling the electromagnetic spectrum range from 8.3 kHz to 3000 GHz. In Brazil, Resolution No. 697, of August 28th, 2018, allocates and assigns radio frequency bands to the Amateur Radio Service and approves the Regulation on Conditions of Use of Radio Frequencies by the Amateur Radio Service, according to the transmission and reception frequencies of the satellite. Within the scope of the ITU, the Radiocommunication Regulation, 2016 edition, contains the complete texts of the Radiocommunication Regulation, adopted by the World Radiocommunication Conference (Geneva, 1995), which were subsequently revised and approved by several other successor conferences.

In the administration of the radio spectrum, the assignments of the bands, defined in international treaties and agreements, are approved by the ITU and issued annually in the Frequency Band Allocation and Distribution Plan in Brazil. Such document contains the details of the use of radio frequency bands associated with various telecommunications services and activities [12].

Bus

The Alfa Crux bus will be a 1U CubeSat with total dimensions of a 10 cm cube and a total mass of approximately 1,3 kg.

The main subsystems are a Ultra High Frequency (UHF) transceiver, the Telemetry, Tracking, and Control (TT&C) subsystem, the on-board computer for satellite data control and management development process, and an electrical power system (EPS) composed by: (i) control storage, distribution and power; ii) batteries for energy storage; iii) solar panels for recharging the batteries; iv) power distribution network to the different satellite subsystems.

Payload

The main feature of Software Defined Radios (SDR) is their versatility, since they can operate several wireless communication protocols through software, that is, without the need to update hardware to change the frequency [13]. Thus, for the Alfa Crux mission, the SDR TOTEM platform is proposed, which is a COTS component. The motherboard of this platform constitutes the main processing and an external front end can be connected to adapt the signal to the application of interest. The technical specifications of the TOTEM platform are as follows:

- SDR + UHF front end platform;
- 5 W at 30 dBm at 437 MHz;
- Tunable SDR from 70 MHz to 6 GHz;
- UHF front end as a piggyback board;
- Unregulated voltage supply from EPS and 3V3;
- Several GPIOs and DACs available;
- Embedded Linux;
- Multiple interfaces: CAN, UART, Ethernet;
- PC/104 standard;
- Physical properties:
  - Mass: 131 g (shields included);
  - Dimensions: 89.3 mm x 93.3 x 13.9 mm;
  - Power:
    - ~ 5 W @ 30 dBm output power
    - <2 W in RX mode
    - 1.36 W with front end off.

The Alfa Crux SDR will provide three critical functions:

- Relay between users within the antenna footprint;
- Data store and forward to any ground station in cooperation with the mission;
- Communication with the satellite command and control station.

The communication payload will also be SDR based, which allows sharing of electrical and logical interfaces and the same concept of operation. Integrating front-end RF circuits with the TOTEM platform, along with the antennas required for each of the bands of interest, enables the complete payload to be implemented, including physical (radio) leveling, modulation and demodulation, information processing, storage and data retrieval.

The payload is also capable of receiving Automatic Dependent Surveillance Broadcast (ADS-B) signals and decode the packets transmitted in the 1090MHz (L band) range with information needed for tracking. The IoT/M2M system, on the other hand, implements a low-rate, two-way, short message-based store and forward communication system between terrestrial and satellite terminals.

User Segment

It is proposed a communication device developed for the exchange of short messages, therefore very favourable for the applications of IoT and M2M technologies. The IoT/M2M terminal technical specifications are:

- Single mini-USB port connector;
- RF SMA connector;
- RF output power up to +30 dBm: Configurable from +24 dBm in 3dB steps;
- Power: TX Mode: <3W @ 30 dBm;
- USB interface: 9600 bps;
- KISS Protocol.

Ground Station

The ground station to be installed will be for UHF and S-band amateur satellite bands. A possible configuration considered is as show in Table 1.

Table 1. Ground station specifications.

Band	Antenna	Low Noise Amplifier
UHF	Yagi Crusade (2x18 elements) (linear polarization) 14.95 dBi	G = 10-25 dB NF = 0.7 - 1.0 dB
S	Helicoidal (polarization RHCP) 16 dBi	G = 25 dB NF = 1.2 dB

LOSSES AND ATTENUATION

In addition to the losses inherent in the propagation of electromagnetic waves in free space, other important obstacles to attenuate the signal from the nanosatellite Alfa Crux present on Earth must be considered in the case of the Alfa Crux mission. In the area of a tropical forest such as that of the Amazon region, narrowband is a better option compared to higher frequency bands since the region is characterized by large humidity and a high density of foliage.

Loss of Free Space

Considering an altitude of 500km for the Alfa Crux nanosatellite, the longest distance between the satellite and the ground station (r = 2573.13 km) is calculated according to scheme shown in Figure 3, where φ is the elevation angle, d is the distance between the ground station and the satellite, h is the altitude from the center of Earth, R_E is the Earth radius and θ is the angle between the ground station and center of Earth calculated from the position of satellite.

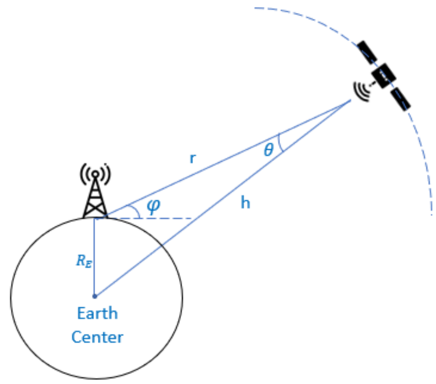

Figure 3. Distances and angles between the satellite and the ground station. Adapted from [6].

Although their orbits are different, the frequency of the nanosatellite Alfa Crux (~ 437 MHz) and the frequency of the Brazilian Defense and Strategic Communications Geostationary Satellite (SGDC) operating in the Ka band (17.7 GHz) are compared in order to identify the pros and cons of the two different solutions. Using Equation (1) the loss in free space for the two frequencies is calculated and shown in Table 2, where r is distance in km between the satellite and the ground station and f is the frequency in GHz, [12].

$$L_s = 92{,}45 + 20\ log_{10}(r) + 20\ log_{10}(f) \quad (1)$$

Table 2. Frequencies and respective losses in free space.

Frequency (GHz)	Space Loss (dB)
0,437	153,47
17,7	185,62

As the distance r varies according to the satellite orbit, it is also possible to obtain the various losses in free space according to the satellite trajectory. Figure 4 illustrates these losses according to the variation of the elevation angle and, consequently, to the distance r for the two frequencies analyzed. Note that with φ = 90 °, there is the shortest distance between the satellite and the ground station, one has the least loss for both frequencies [6].

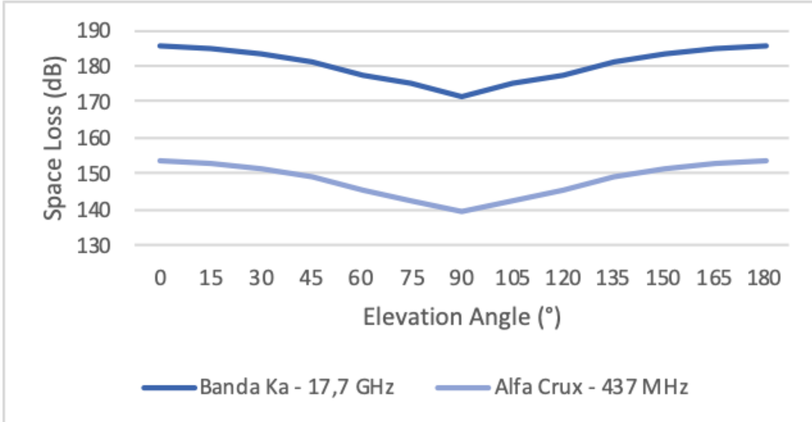

Figure 4. Space loss by elevation angle (altitude 500 km).

Link Budget

As is known, one of the first steps in a communication space mission is the link budget analysis, necessary to provide technical specifications to guarantee the correct functioning of the TT&C system and data transmissions with other terrestrial segments [12]. Table 3 presents a first link budget analysis for the Alfa Crux nanosatellite according to its characteristics and objective. It is worth mentioning that some technical issues related with the communication hardware are still being analyzed, thus some values may change in the final solution.

Table 3. Link budget.

Item	Symbol	Unit	Value
Frequency	f	MHz	437
Wavelenght	λ	m	0,69
Miscellaneous Losses	L_M	dB	5
Receiver Antenna Gain	G_a	dBi	15
Equiv. Isotropic Radiated Power	EIRP	W	1
Equiv. Isotropic Radiated Power	EIRP	dBW	0
Propagation Path Length	S	km	2573,13
Space Loss	Ls	dB	153,47
System Noise Temperature	Ts	K	450
Data Rate	R	bps	9600
E_b/N_o	E_b/N_o	dB	18,78
Carrier-to-Noise Density Ratio	C/N_o	dB-Hz	58,6
Bit Error Rate	BER	-	10^{-3} to 10^{-4}
Required Eb/No	Req E_b/N_o	dB	5

Rain Attenuation

The Amazon rainforest is in a tropical region, characterized by a high amount of rain in the summer. As rains have a great influence on the attenuation of satellite signals, it is important to carry out a preliminary analysis. Attenuation causes a higher energy requirement for the transmitting units and increases the cost per transmission bit. The rain leads to a great attenuation of the signals from satellites to bands of higher frequencies such as those above 10 GHz [14].

In order to determine the specific attenuation through the rainfall rates, Equation (2) is applied where the parameters k and α were calculated for frequencies between 1 and 100 GHz. The specific attenuation γ_R (dB/km) is obtained from the rain rate R (mm/h) and coefficients k and α, [15],

$$\gamma_R = kR^{\alpha}. \tag{2}$$

Therefore, considering the values recommended by the ITU for the polarization coefficients k and α, the specific attenuation due to rain is calculated according to the corresponding frequency considering the rainfall index (R) of the Amazon region of 2300mm/year. The attenuations calculated for frequencies between 1 and 50 GHz are shown in the Figure 5 demonstrating that the attenuation due to rain also increases with increasing frequency. Consequently, the use of narrowband for communication in a rainy environment is preferred.

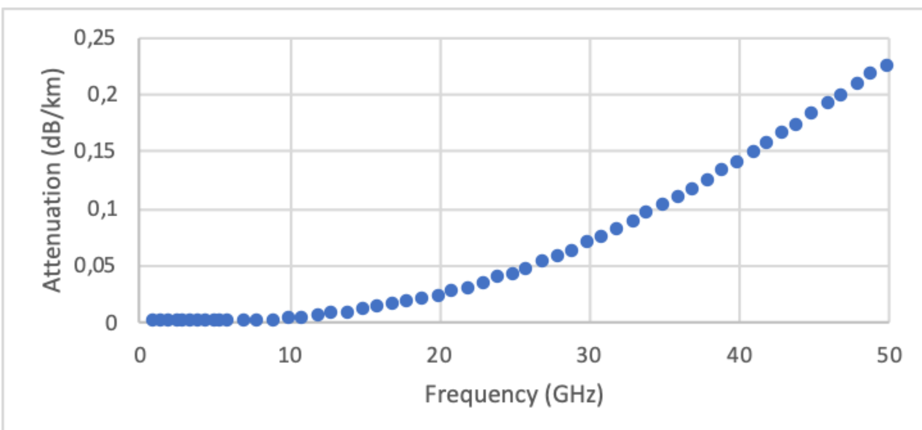

Figure 5. Frequency by rain attenuation

Foliage Attenuation

Foliage is another important obstacle in the propagation of electromagnetic waves in the communication field. They should also be considered for the properties of the nanosatellite Alfa Crux to have its application in remote and difficult to access areas such as the region of the Amazon rainforest.

For the calculation of the attenuation due to the foliage, Equation (3) presented in [16] is considered, where L is the attenuation in dB, f the frequency in GHz and d represents the depth of the vegetation in meters. The trees, depending on the regions, have different species and even growth characteristics. However, the leaf condition will be assumed constant for the current analysis, and the values for the parameters A, B and C in Equation (3) fixed as 1.43, 0.721 and 0.356, respectively.

$$L = A\, d^{B} f^{C}. \quad (3)$$

Considering a vegetation depth of 2 meters, Equation (3) was applied in order to calculate the attenuations due to the trees for a wave propagation at 437 MHz and 17.7 GHz. Figure 6 illustrates the result.

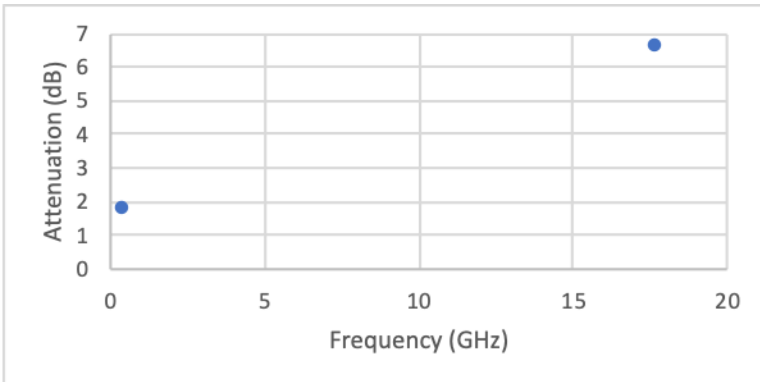

Figure 6. Frequency by foliage attenuation.

Taking into account the losses in free space and the attenuations due to rain and foliage, it is possible to notice that the nanosatellite Alfa Crux, working at a frequency around 437MHz, has relevant properties when compared to higher frequencies. The lower data rate and the lower loss in free space of its narrowband provide greater energy efficiency with the positive consequence of lighter terminals in order to facilitate displacements in the forest, what is related with the Alfa Crux mission. It is also possible to notice through the previous analyses that the penetration of the narrowband signals is favorable in an environment of high density of trees and high rainfall index like that of the Amazon rainforest. Lighter terminals and greater reliability in the arrival of signals in the user segment are relevant points for the purpose of this mission.

CONCLUSION

This work presented an overview of the Alfa Crux CubeSat mission for narrowband communication. In particular, the main aspects taken into account for hardware and software specification was pointed out. Considering the proposed payload, user segment and ground station hardware for the mission, as well as the losses and attenuation analysis, it is possible to conclude that Alfa Crux nanosatellite contains the necessary technical characteristics to succeed in providing a communication link in areas of difficult access as well as in harsh environments for RF communication.

The analyzes presented showed that the losses in free space and the attenuations due to rains and foliage is lower for the Alfa Crux communication band compared to higher frequency solutions. Although some technical issues are still being defined, the presented link budget provided a better understanding of the propagation characteristics in the entire path between the nanosatellite and the ground station.

As future work, in order to improve coverage aspects such as revisit time, cumulative coverage time, gap durations, among others, a constellation analysis should be carried on helping improve and extend the capability of the Alfa Crux system. This would allow to provide different types of communications services quickly and at an affordable cost, under conditions where other technological solutions are still not available or are very expensive.

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