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The Ground Segment: A proposal Framework based on concepts of Dynamic Management of the Space Link Extension Protocol Services.

MSc. Antonio Cassiano Julio Filho[a]*

PhD. Mauricio Gonçalves Vieira Ferreira[b], PhD. Ana Maria Ambrosio[c]

[a,b,c] *National Institute for Space Research (INPE)*
Av. dos Astronautas, 1758 São José dos Campos, São Paulo Brazil.
[a] cassiano.filho@inpe.br, [b] mauricio.ferrreira@inpe.br, [c] ana.ambrosio@cse.inpe.br
* Corresponding Author

Abstract

Nowadays, at the Brazilian National Institute for Space Research (INPE), remote sensing satellites as those of CBERS family and the Amazonia-1, small satellites for educational and technological applications, like the Tancredo-1, and the new mission RaioSat, demonstrate that an increasing number of missions need the service networks of terrestrial components of a Ground Segment to totally meet their requirements. The CBERS program is a partnership between Brazil and China in the space technical and scientific sector for the remote sensing data generation technology, this partnership involves INPE and China Academy of Space Technology (CAST). The images are distributed free over the internet and used in monitoring agriculture, urban growth, and education. Those images are also used in large strategic Brazilian national projects such as Real-Time Deforestation Detection (DETER), and Measurement of Deforestation by Remote Sensing (PRODES). The Amazonia-1, successfully launched in February 2021, is the first remote sensing satellite completely designed, integrated, tested and operated by INPE/Brazil. Its main objective is to observe and monitor vegetation, and the deforestation in the Amazon region with a high revisit rate keeping synergy with the operational programs of DETER and PRODES. Tancredo-1 is a small satellite developed by Brazilian students with support from INPE and successfully placed in Low Earth Orbit, in 2017. RaioSat mission is based in the CubeSat platform aiming to test new technologies. It will use S-band to communicate with ground stations for tracking and controlling of the spacecrafts, and mission data distribution. In this miscellaneous context, the missions posed challenges for the implementation of the Ground Segment. The Ground Segment shall attend the higher rate revisits, satellite controlling and data reception, as well as cross support and interoperability to space agencies, so requiring a robust architecture to support them. The current architecture is based on a Dynamic Management of the Space Link Extension Protocol Services for reception, processing, and distribution of data through the Ground Segment. This paper presents an overview of INPE’s missions and the corresponding ground systems, and describes the Space Link Extension Protocol Services. Moreover, the paper describes the framework based on the concepts of Dynamic Management of the Space Link Extension Protocol Services to address the new requirements supporting different types of satellite missions, ensuring cross support, interoperability and cost reduction of space missions.

Keywords: CCSDS, Framework, Ground Segment, Model-Based Systems Engineering, Space Link Extension (SLE)

Acronyms/Abbreviations

AEB Brazilian Space Agency
ALC Alcântara (Brazilian TT&C Ground Station)
AOCS Attitude and Orbit Control System
BrasilDAT Brazilian Total Lightning Network
CAST China Academy of Space Technology
CBA Cuiabá (Brazilian TT&C Ground Station)
CBERS China-Brazil Earth Resources Satellite
CCSDS Consultative Committee for Space Data Systems
CFDP CCSDS File Delivery Protocol
CGCE General Coordination of Space Engineering, Technology and Science
CGCT General Coordination of Earth Science
CLTU Communications Link Transmission Unit
DETER Real Time Deforestation Detection

ECSS European Cooperation for Space Standardization
ESA European Space Agency
ESOC European Space Operation Center
GS Ground Station
IBS Integrated Baseband System
INPE Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)
JAXA Japan Aerospace eXploration Agency
LM-4B Long-March 4B
MBSE Model-Based System Engineering
MCTI Ministry of Science, Technology and Innovations
MMP Multi-Mission Platform
MUX Regular Multispectral Camera
NASA National Aeronautics and Space Administration
PRODES Measurement of Deforestation by Remote Sensing
PSLV Polar Satellite Launch Vehicle
RAF Return All Frames
RCF Return Channel Frames
SATCS SATellite Control System
SCC Satellite Control Center
SCCS Space Communication Cross Support
SLE Space Link Extension
TC Telecommand
TM Telemetry
TSL C Taiyuan Satellite Launch Base
TT&C Telemetry, Tracking and Command
WFI Wide Field Imager
WPM Multispectral and Panchromatic Wide-Scan Camera

1. Introduction

The different classes of satellites and the increasing number of missions require service networks of terrestrial components implementing a Ground Segment. At INPE, we can cite the remote sensing satellites: China-Brazil Earth Resources Satellite (CBERS) family and Amazonia-1, and the educational and technological application satellites: Tancredo-1 and RaioSat, which are all operated under INPE's responsibility.

These missions posed challenges for the implementation of the Ground Segment which requires an architecture to support them. The current architecture is based on a Dynamic Management of the Space Link Extension (SLE) Protocol Services [1, 2] for the reception, the processing, and the distribution of data through the Ground Segment. The SLE Protocol Services establishes activities for cross support and interoperability according to Consultative Committee for Space Data Systems (CCSDS). The cross support occurs when an organization offers part of its space infrastructure to meet the requirements of data management and transfer of another organization.

Due to the adoption of SLE Protocol Services by several space agencies (non-exhaustive list) CNES, DLR, ESA, ESOC, INPE, JAXA, and NASA and its resulting benefits, there is a great stimulus for dedicating effort in research and development about this topic.

We propose a framework to improve INPE's ground segment. The framework is based on concepts of Dynamic Management of the SLE Protocol Services allowing a new vision of the ground segment and addressing the challenging requirements to comply with different type space missions.

This paper is organized as follows: section 2 presents an overview of missions; section 3 describes the current INPE's Ground Systems; the section 4 presents a proposal Framework based on the concepts of Dynamic Management of the SLE Protocol Services and section 5 shows the conclusions.

2. Missions

The missions CBERS, Amazonia-1, and the small satellites Tancredo-1 and RaioSat have similar terrestrial infrastructure, common elements, but different functions. Concerning the differences among those missions and taking into account the needs for optimization, cost reduction, and performance, it is necessary to analyze and review the architectures and solutions for the INPE's Ground Segment. In the following subsections, we present the programs, satellites and segments of the referred missions.

2.1. CBERS Program

CBERS program is a family of remote sensing satellites CBERS-1 & 2, CBERS 2A, CBERS-3 & 4 and CBERS4-A. It is a partnership, which involves the INPE and China Academy of Space Technology (CAST). According to ref. [1], INPE using the CBERS-4 has distributed free over the internet 90,000 images. Those images are used in monitoring sugarcane areas, water resources, agriculture, urban growth, land use, and education. These images, also, are used in large strategic Brazilian national projects such Real Time Deforestation Detection (DETER), which uses Landsat images, and Measurement of Deforestation by Remote Sensing (PRODES) [1, 2]. The last satellite of CBERS family is the CBERS-4A satellite, which is described below.

2.1.1. CBERS-4A Satellite

The CBERS-04A satellite accommodates a new Chinese Imager camera that has superior quality in geometric and spectral resolution and optical payloads operating in the visible spectrum with resolutions in the range of 2 to 60 meters. It has 1980 kg of the total mass and body dimension are 1.8 x 2.0 x 2.6 meters.

The satellite, shown in Figure 1, comprises a service module and a payload module, which houses image cameras and recording equipment and transmission of image data. The satellite takes on board two Brazilian cameras Regular Multispectral Camera (MUX) and Wide Field Imager (WFI) camera and the Chinese camera Multispectral and Panchromatic Wide-Scan Camera (WPM). MUX generates images of 16 meters resolution, with revisit of 31 days. WFI has a resolution of 55 meters and revisit 5 of days while WPM, has resolution of 2 meters in panchromatic and 8 meters in RGB [1].

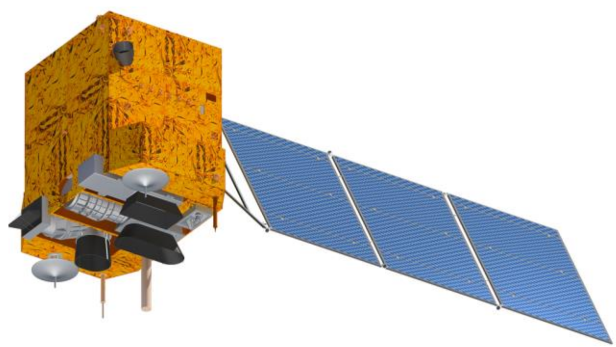

Fig. 1. CBERS-4A Artistic Conception

The satellite was successfully launched in December 2019 from Taiyuan Satellite Launch Base (TSL C), located in Shanxi province, 700 km southwest of Beijing, through the launch vehicle Long-March 4B (LM-4B). It operates in a sun-synchronous orbit and frozen applicant with the following main nominal parameters: Altitude: 628.6 km; Inclination: 97.9 degrees; Local time at descending node: 10:30 am; Repetition Cycle: 31 days; Revolutions/day: 14 +25/31.

2.1.2. CBERS Segments

The CBERS-4A, Figure 2, is composed of the following segments (only Brazilian segments in detail) [1]:

a) Space Segment is comprised of the spacecraft with the service module and the payload;

b) Ground Control Segment is configured to: control the satellite, monitor and analyze its on-orbit operation is relying in the use of the two INPE Telemetry, Tracking, and Command (TT&C) Ground Stations and Satellite Control Center (SCC);

c) Application Segment is comprised by INPE Reception and Recording Station, and by the Mission Center, and also comprising the Remote Sensing Data Center, in Cachoeira Paulista, São Paulo state, which collects, processes and stores the images received, making them available to the users;

d) Launch Segment is responsible for placing the satellite in orbit.

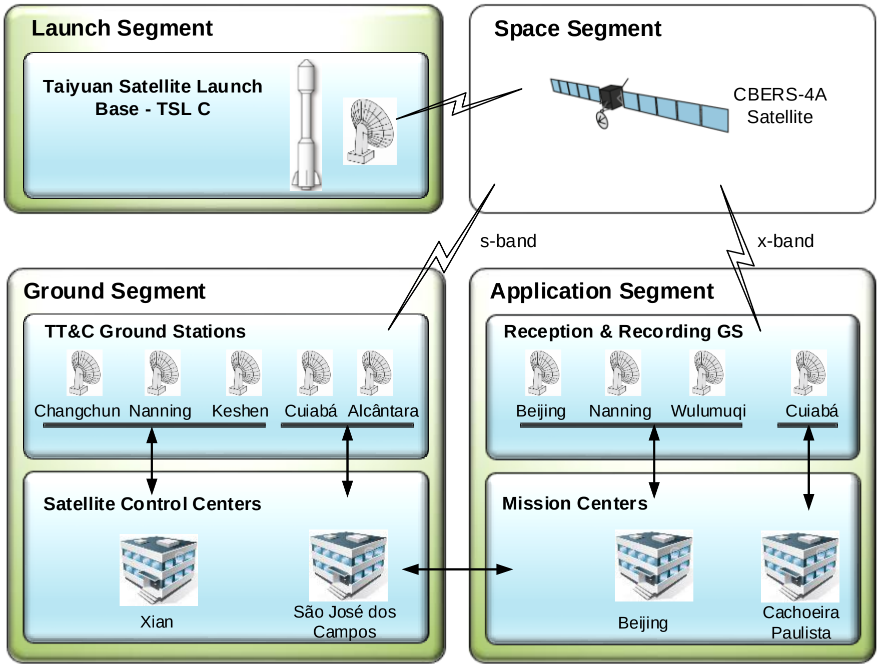

Fig. 2. CBERS-4A Segments overview

2.2. Amazonia-1 Program

Amazonia-1 is the first remote sensing satellite completely designed, integrated, tested and operated by Brazil. It is a development coordinated by the Ministry of Science, Technology and Innovations (MCTI) and conducted by the INPE/MCTI in partnership with the Brazilian Space Agency (AEB/MCTI). Its aim is of providing remote sensing to observe and monitor vegetation, especially deforestation in the Amazon region, for use by the scientific community and governmental agencies [2].

In the scope of the Earth Observation, Amazonia-1 satellite is an important source of information for two of INPE operational programs for the monitoring of the Brazilian Amazon region: DETER, PRODES [1, 2].

2.2.1. Amazonia-1 Satellite

The satellite, Figure 3, is based on the Brazilian multi-purpose three-axis stabilized service module, called Multi-Mission Platform (MMP), and the Payload which houses image cameras - optical imager is a WFI camera model as the one used in the CBERS program - and recording equipment and transmission of image data.

MMP is a generic platform for satellites of up to 500 kg aimed to provide all the necessary resources of different payloads of up to 280 kg. The MMP [2] is comprised by Mechanical Structure and Service Module, Attitude and Orbit Control System (AOCS), On Board Data Handling (OBDH), Propulsion; Telemetry, Telecommand and Control (TT&C), Thermal Control and Energy Supply. The satellite has 640 kg of the total mass and body dimension are 1.0 x 1.0 x 2.5 meters.

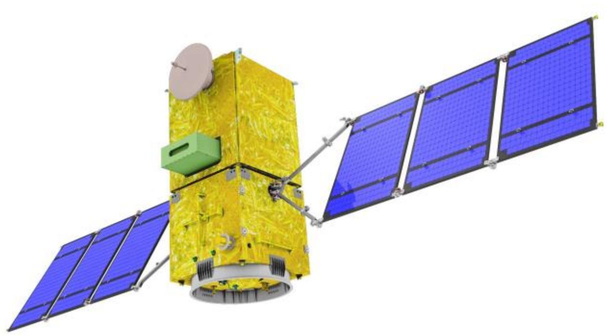

Fig. 3. Amazonia-1 Satellite Artistic Conception

Amazonia-1 successfully launched in February 2021 from Satish Dhawan Space Centre SHAR, Sriharikota, India, through the Polar Satellite Launch Vehicle (PSLV-C51). It is placed in a sun-synchronous Low Earth Orbit in order to provide an Earth surface imaging with a swath of 830 km, spatial resolution at nadir better than 70 m, and with the following main nominal parameters: Altitude: 752 km; Inclination: 98.51 degrees; Local time at descending node: 10:30 am; Repetition Cycle: 5 days; Revolutions/day: 14.40.

2.2.2. Amazonia-1 Segments

The existing terrestrial infrastructure used to support the Amazonia-1 mission [2] is the similar infrastructure of CBERS-4A, and it is composed of the following segments: Ground Control Segment, Application Segment and Launch Segment. The Amazonia-1 segments and their inter-relationship are shown in Figure 4.

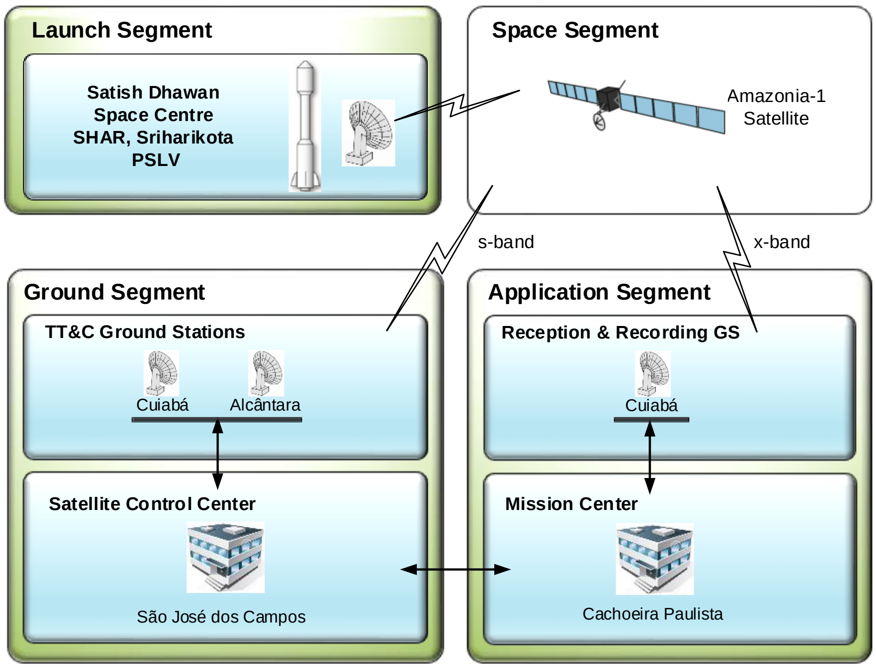

Fig. 4. Amazonia-1 Segments Overview

2.3. Tancredo-1 Program

Miniaturized satellite projects are of great interest to many space organizations and companies due to cost savings, and shortened project cycle times, and the possibility of validating several technologies.

2.3.1. Tancredo-1 Satellite

Tancredo-1 [3] is a picosatellite developed by Brazilian high school students from “Tancredo de Almeida Neves” school, located in the city of Ubatuba (São Paulo state), with support from INPE. This satellite was an experiment to conduct new scenarios to search for solutions in the Ground Segment and motivate students in the integrated approach of the disciplines of Science, Technology, Engineering and Mathematics (STEM).

An educational voice recorder and an INPE Langmuir probe comprise the payloads of this small satellite. The domain of these space artifacts evolves with extensive use of nanotechnology and microelectronics and it has received special attention in missions for satellites. The Langmuir probe contributing to the research and new knowledge concerning the ionosphere plasma irregularities over Brazil, which affects the Telecommunications and Global Positioning Systems.

Tancredo-1, Figure 5, has 0.8 kg of mass, diameter of 92.5 mm, length of 127 mm. It was successfully placed in Low Earth Orbit, in 2017, from the Kibo module of the International Space Station (ISS) using the H-IIB launcher and the robotic cargo Kounotori spacecraft, all from JAXA/Japan.

Fig. 5. Tancredo-1 Satellite

2.3.2. Tancredo-1 Segments

The terrestrial infrastructure used to support the Tancredo-1 operation was composed of two segments: Ground Segment and Application Segment. The communication between the satellite and the ground segment occurs within the UHF band of amateur radio that is not fully compatible with INPE's ground stations, so it was necessary to include new requirements for the small satellites like Tancredo-1, such as the S-band hardware module, specific antenna, and a new embedded software.

2.4. RaioSat Mission

The RaioSat mission, in development, is a partnership between two groups at INPE, the General Coordination of Earth Science (CGCT) and the General Coordination of Space Engineering, Technology and Science (CGCE), besides another INPE's area to support the multidisciplinary activities.

The RaioSat intends to integrate, for the first time, a sensor for detecting the intra-cloud and cloud-to-ground lightning flashes simultaneously over the Brazilian territory, with the development of national technology for detecting lightning from space [4, 5]. The information collected from the lightning detection it is useful for predicting extreme weather phenomena – tropical cyclone, tornados, supercell storms - complementing the data for the high-resolution Numerical Weather Prediction models and the Brazilian meteorological networks, called Brazilian Total Lightning Network (BrasilDAT) [5].

2.4.1. RaioSat Satellite

The satellite is based on the CubeSat platform, an open-source satellite architecture that has a volume of one liter (10 cm cube, stated as one unit, 1U), and it uses commercial off-the-shelf electronics components.

The RaioSat satellite is being planned for a CubeSat 3U (10 x 10 x 30 cm) in a Low Earth Orbit (LEO) about 650 km altitude with inclination between 70° and 98°. In addition to meet the scientific mission requirements, it has the objective of testing new technologies using the S-band to communicate with ground stations for tracking and controlling of the spacecrafts, and the distribution of mission data [4].

RaioSat satellite, Figure 6, comprises the service module and the payload module. The service module contains an Onboard Computer (OBC), a Communications Subsystem, an Attitude and Orbit Control System (AOCS), and an Electric Power Subsystem (EPS). The Payload Module comprises a Spectral Imaging Camera with 2048 x 1536 pixels of resolution, a VHF Receptor with a Passive Antenna in a frequency from 80 to 200 MHz, and includes and a Global Position System (GPS) receiver.

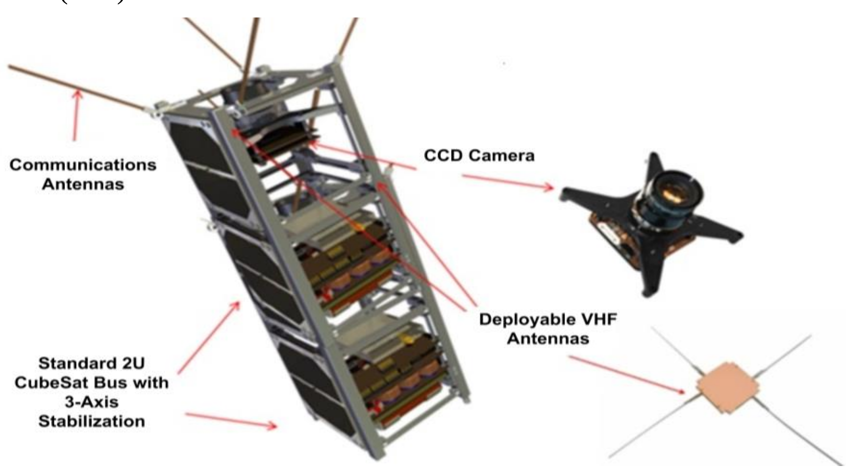

Fig. 6. RaioSat, payload and service modules

2.4.2. RaioSat Segments

The terrestrial infrastructure, Figure 7, that will be used to support the RaioSat [4] is composed of the following segments: Ground Control Segment, Application Segment and Launch Segment. Concerning small satellites, it is beneficial that the communication between the satellite and the ground segment occurs within the UHF band of amateur radio. In this case, an S-band system will be added for communication between satellite and ground stations.

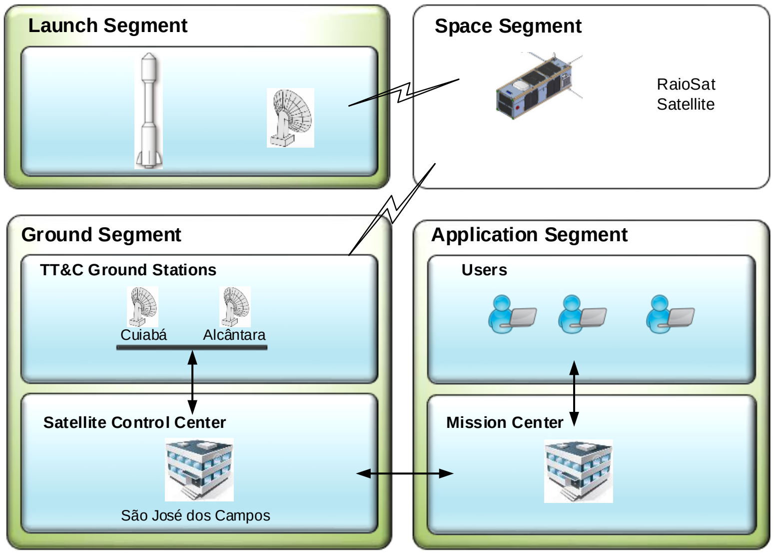

Fig. 7. RaioSat Segments Overview

3. INPE's Ground Systems

3.1. Reception and Recording Station

Brazil was one of the first countries to receive and use data from Earth Observation Satellites. In 1973, INPE started the activities of satellite tracking and data reception from the first remote sensing satellite, the Earth Resources Technology Satellite-1 (ERTS-1) of the Landsat Series [2].

Nowadays the current Reception and Data Recording Station are located in Cuiabá, Mato Grosso State, Brazil, as shown in Figure 8. This station, operating in X-Band, receives and continuously records the images transmitted by Amazonia-1, CBERS satellites, Landsat-5 and 7, SPOT-4, ERS-2, and Radarsat-1. The data are transferred to the Remote Sensing Data Center in Cachoeira Paulista, in São Paulo State, for further processing and dissemination to end users from all Brazilian country.

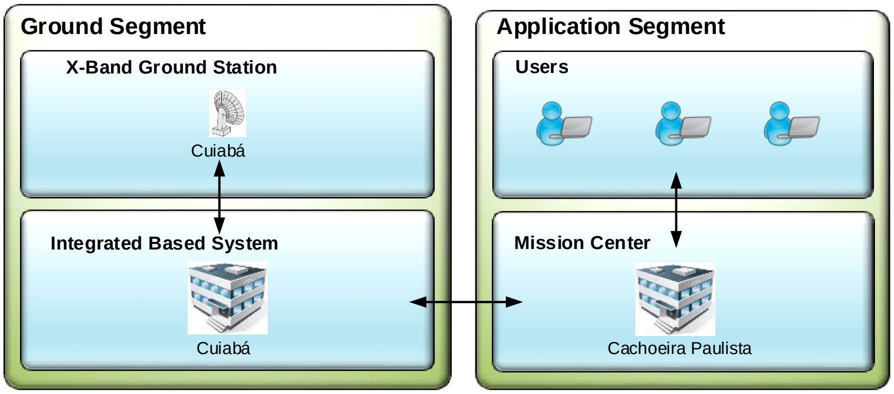

Fig. 8. X-Band Payload Reception and Recording Station

3.2. TT&C Ground Stations and Satellite Control Center

Telemetry, Tracking and Command (TT&C) Ground Stations (GS) of INPE provide the link between the control personnel and the satellites [1, 2, 6]. The Ground Stations operate in S-band and, are located in the cities of Cuiabá (Mato Grosso state) and Alcântara (Maranhão state) in Brazil.

TT&C GS, shown in Figure 9, comprises a RF Front End, an Antenna Control Unit, and a Time & Frequency. The functions of TM, TC, Ranging Data, Range Rate and are based on Integrated Baseband System (IBS). IBS is a Commercial Off-the-Shelf (COTS) baseband processor. It also allows the implementation of SLE services (SLE Provider) for cross support and interoperability between space agencies.

Satellite Control Center (SCC) [2], Figure 9, is located in the city of São José dos Campos, (São Paulo, Brazil). SCC is the entity responsible for planning and executing all activities related to satellite control, and also the rapid reaction in case of anomalies of a satellite. The SCC’s main functions are orbit and attitude control, maneuvers calculation, operational payload configuration, real-time monitoring of the satellite health. The SCC structure includes a software system named SATellite Control Systems (SATCS). SATCS was developed by a specialized team from the General Coordination of Space Engineering, Technology and Science (CGCE) at INPE. It was designed to be an easily configurable and personalized system.

This ground segment infrastructure was initially designed to support operations of the first Data Collection Satellite (SCD-1) launched in 1993. The basic infrastructure has been updated along the years.

In 2013, it was incorporated the SLE protocol. The acceptance tests for the SLE protocol were performed in cooperation with the European Space Operation Center (ESOC). On having the SLE protocol operational, INPE can count on the support of other tracking stations distributed around the world to track its own satellites, and in the same way, it provides tracking services to other international agencies. The current segment, shown in figure 9, includes, nowadays, the function SLE user.

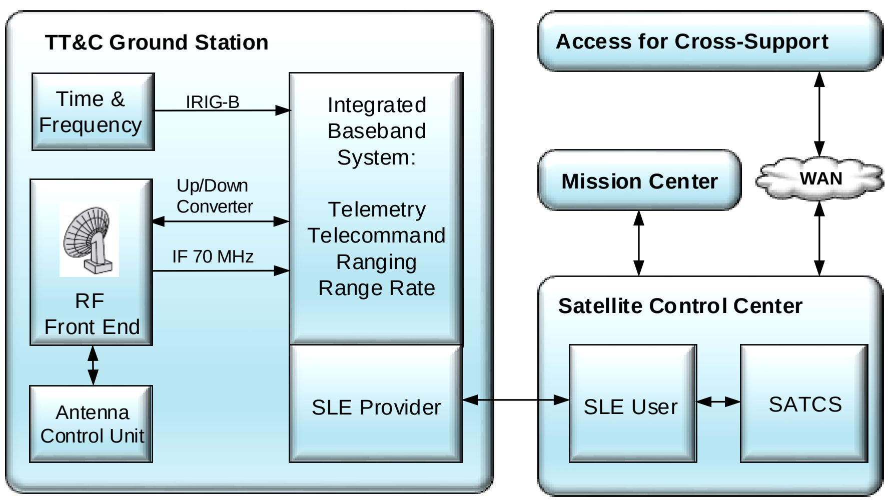

Fig. 9. INPE's Ground Station and Satellite Control Center

3.3. Space Link Extension

Space Link Extension (SLE) Protocol Services are services resulting of the CCSDS normalization for Telecommand and Telemetry [7, 8, 9]. The SLE Protocol Services extending the Space Link services [10, 11] in distance, in time, and by adding information, of the systems onboard the spacecraft to ground systems, for Local Area Networks and Wide Area Networks enabling processing, control and storage of data in one or more intermediate points. These SLE Protocol Services are CCSDS recommendations for cross support and interoperability.

3.3.1. Space Communication Cross Support

Space Communication Cross Support [12, 13] is a generalization of SLE. The SCCS defines two services types: data transfer services and management services, and it also defines a framework for the user and the provider to configure the parameters of space link, transfer services and set up ground stations. The SLE data transfer services are based on client/server architecture; the client is called SLE User and the server is called SLE Provider.

According to ref. [13], the terminology in the SCCS is derived in part from other cross support service documents, such as the Cross Support Reference Model [14], therefore new terminology has been required.

Figure 10 illustrates the attributes needed to instantiate a data transfer service: identifier, user/provider, service type, start and end time, port identifier and configuration [1, 2].

CCSDS recommends the Internet SLE Protocol One (ISP1) [15, 16, 17] for transfer of the SLE Protocol Data Units and the transfer services are: Communications Link Transmission Unit (CLTU) [7], Return All Frames (RAF) [8] and Return Channel Frames (RCF) [9].

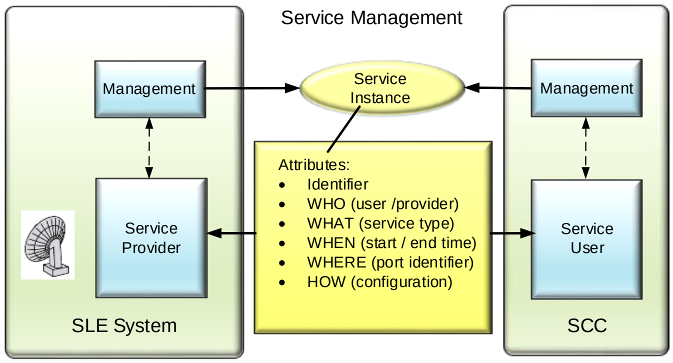

Fig. 10. Overview of SCCS

4. Proposed Framework based on concepts of Dynamic Management of the SLE Protocol Services

The proposed framework will improve INPE's ground segment joining strongness to **Dynamic** Management of the SLE Protocol Service.

4.1. *Architecture for Dynamic Management of the SLE Protocol Services*

The current architecture is based on a Dynamic Management of the SLE Protocol Services [18]. The architecture aims to simplify access to ground stations, allow the detection dynamic for redundancy between provider and user; the automatic switching, meeting interoperability and cross support requirements and as consequence, a greater ability to tracking the spacecraft, and sharing resources of TT&C Ground Stations and Ground Systems.

Figure 11 shows the ground segment for the satellite operation, which embeds the function of Dynamic Management of the SLE Protocol Services. INPE's SCC contains the Gateway SLE User, Satellite Control System itself, and the Dynamic Management of the SLE Protocol Services. In the Ground Stations, the SLE function are composed by the SLE Provider. In ref. [18] the Dynamic Management is discussed in detail.

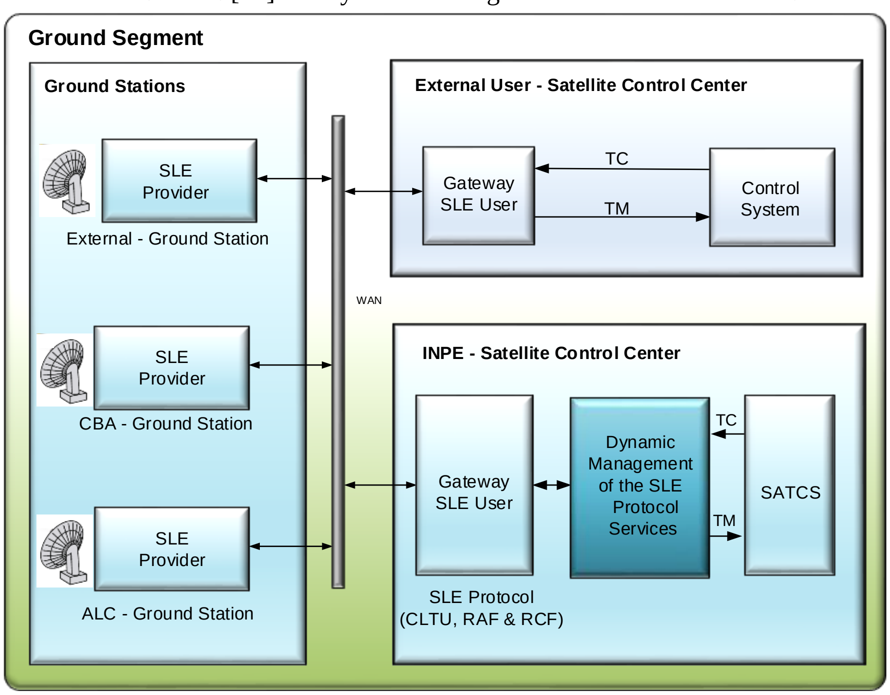

Fig. 11. Ground Segment for satellite operation with the Dynamic Management of the SLE Protocol Services

4.2. Framework

According to ref. [19] "a framework includes specific concepts, terminology, artifacts, and taxonomies for describing the architecture of a system". A framework contributes to defining a consistent logical architecture, analyzing alternative design solutions, and defining verification and validation criteria for the system elements.

The proposed framework is based on the concepts of the Dynamic Management of the SLE Protocol Services and allows a new vision of the ground segment. This new vision addresses the challenging requirements to support different types of space missions. We can cite as drives for the new solution: simplification access to ground stations, dynamic detection, automatic switching, interoperability, cross support and greater ability to tracking the spacecraft.

The requirements of the INPE's different missions, shown in Table 1, involve definitions as communication band, data (uplink and downlink) rate, protocols, onboard processing, remote reconfiguration of service and payload modules, and classically, determine the design and development of missions.

Table 1. Missions and main requirements

Mission	Type	Band	Data Rate	Protocols	Cross Support	Onboard Processing	Remote Configuration
CBERS-4A	Remote Sensing	S, X	High	SLE, CFDP*	Yes	Yes	Yes
Amazonia-1	Remote Sensing	S, X	High	SLE	Yes	Yes	Yes
RaioSat	Scientific, Technology	UHF, S	Low	No	No	No	Yes
Tancredo-1	Technology	UHF, S	Low	No	No	No	No

* CFDP = CCSDS File Delivery Protocol

We propose the development of a new application function, called Framework Application, that performs the bidirectional interface between systems that are incompatible with SLE Protocol Services. The space segment maintains its requirements, as much as possible, and the Framework Application standardizes the parameters (band, data rate, protocol, onboard processing, remote configuration) exchanged between provider and user.

Furthermore, the framework shall allow an analysis of the ground segment requirements aligned with the space segment. The analysis results collaborate to define and refine requirements for space systems architecture and to ensure the fulfillment of mission objectives with efficiency and reduced cost. Examples of requirements that can be implemented into the space segment include the improvement of onboard image processing or the addition of a CCSDS module for payload remote configuration.

The Framework Application must be implemented on the Dynamic Management of the SLE Protocol Services (SCC) and on the SLE Provider (Ground Station) as illustrated in Figure 12.

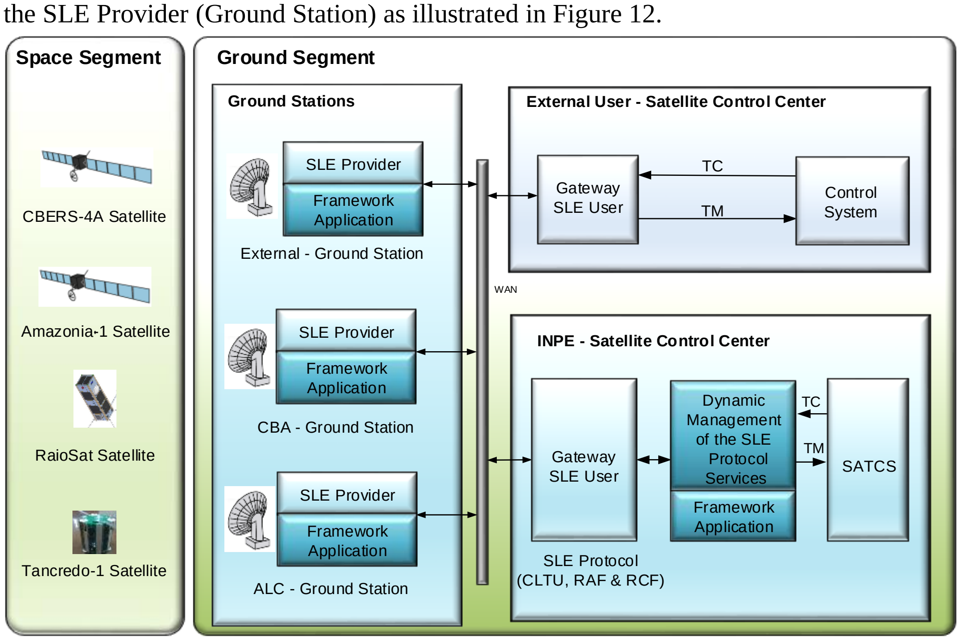

Fig. 12. Proposal Framework based on concepts of Dynamic Management of the SLE Protocol Services

We intend that the implementation follows in accordance with the guidelines of the European Cooperation for Space Standardization (ECSS) [20] and NASA [21] concerning the systems engineering discipline; follows the references [19, 22] about the Model-Based Systems Engineering (MBSE) area; and the references Fortescue et al. [23], Larson and Wertz [24] for space systems. It should also comply with the CCSDS recommendations in the aspects of: a) SLE Protocol Services for Cross Support and Interoperability [7, 8, 9, 10, 11]; b) Space Communication Cross Support [13, 14, 15, 16]; c) CCSDS File Delivery Protocol (CFDP) [25, 26].

5. Conclusion

CBERS satellites, Amazonia-1, Tancredo-1 and RaioSat missions present different requirements. The design of Ground segment to comply these missions lead to the design and implementation of a practical evaluation of the framework based on Dynamic Management of the SLE Protocol Services as a spin off project.

The Framework improves the space systems design, in the perspective of the Ground Segment, with a strong standardization of the procedures for systems engineering, management, and implementation of the Ground Segment projects and their interface with the Space Segment.

The proposal will provide an evaluation of the framework with the elaboration of models for services, payload, and ground segment. These models must represent the scenarios, which will help: (i) the evaluation of the framework, (ii) the implementation of the algorithms, (iii) the interaction of mechanisms, and the (iv) conformance to ECSS and NASA guidelines for System Engineering, and CCSDS recommendations, notwithstanding not limited to these entities.

Future works include the use of ground segment ontology, and models defined on the basis of the Model-Based Systems Engineering (MBSE).

Acknowledgements

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References

[1] Julio Filho, A. C., Ambrosio, A. M., Ferreira, M. G. V., Loureiro, G., "The China-Brazil Earth Resources Satellite - CBERS-4A: A proposal for Ground Segment based on the Space Link Extension Protocol Services", in: International Astronautical Congress, 70ª IAC. Washington D.C., United States, 2019.

[2] Julio Filho A. C., Ambrosio, A. M., Ferreira, M. G. V., Bergamini, E. W., "New Challenges for Dynamic Management of the Space Link Extension Protocol Services: The Amazonia-1 Satellite Ground Segment". In: Spaceops Conference, Marseille, France. Proceedings...2018. DVD.

[3] Tikami, A. "Uma metodologia para re-engenharia de sistemas espaciais aplicada a um picossatélite". 2016. 395 p. Dissertation (Master's degree in Space Systems Engineering and Management) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil,, 2016. URL:http://urlib.net/rep/8JMKD3MGP3W34P/3LMMJCH

[4] Julio Filho, A. C., Tikami, A., Paula E. S. F., Murcia Piñeros J., Fernandes G. F., Camargo L. A. P.; Santos, C. A. M. B., Dos Santos W. A., Naccarato K. P. "CubeSat Development for Lightning Flashes Detection: RaioSat Project". Journal of Aerospace Technology and Management, JATM, v. 12, 2020. http://dx.doi.org/10.5028/jatm.cab.1161.

[5] Naccarato KP, Pinto Junior O. "Lightning detection in Southeastern Brazil from the new Brazilian Total Lightning Network (BrasilDAT)". Paper presented 2012 International Conference on Lightning Protection (ICLP). IEEE; Vienna, Austria. https://doi.org/10.1109/ICLP.2012.6344294

[6] Julio Filho, A. C., Ambrosio, A. M., Ferreira, M. G. V., "A proposal an innovative framework for the conception of the ground segment of space systems". In: International Astronautical Congress, 71.Online Proceedings...2020. <http://urlib.net/rep/8JMKD3MGP3W34R/43FSFEB>.

[7] CCSDS Space Link Extension - Forward CLTU Service Specification. Recommended Standard. CCSDS 912.1-B-4. Blue Book. Issue 4. Washington, D.C., August 2016.

[8] CCSDS SpaceLink Extension - Return All Frames Service Specification. Recommended Standard. CCSDS 911.1-B-4. Blue Book. Issue 4. Washington, D.C., August 2016.

[9] CCSDS Space Link Extension - Return Channel Frames Service Specification. Recommended Standard. CCSDS 911.2-B-3. Blue Book. Issue 3. Washington, D.C., August 2016.

[10] CCSDS Cross Support Concept - Part 1: Space Link Extension Services. Informational Report. CCSDS 910.3-G-3. Green Book. Issue 3. Washington, D.C., March 2006.

[11] CCSDS Cross Support Reference Model - Part 1: Space Link Extension Services. Recommended Standard. CCSDS 910.4-B-2. Blue Book. Issue 2. Washington, D.C., October 2005.

[12] Pietras, J. V., Barkley, E.J., Crowson, A. "CCSDS Space Communication Cross Support Service Management", International Conference on Space Operations (SpaceOps), Huntsville, Alabama, USA. 2010. URL:http://arc.aiaa.org/doi/pdf/10.2514/6.2010-2283.

[13] CCSDS Space Communication Cross Support – Architecture Description Document - Informational Report. CCSDS 901.0-G-1. Green Book. Issue 1. Washington, D.C., November 2013.

[14] CCSDS Space Communication Cross Support - Service Management - Operations Concept. Informational Report. CCSDS 910.14-G-1. Blue Book. Issue 1. Washington, D.C., May 2011.

[15] CCSDS Space Link Extension - Internet Protocol for Transfer Services. Recommended Standard. CCSDS 913.1-B-2. Blue Book. Issue 2. Washington, D.C., September 2015.

[16] CCSDS Space Link Extension - Application Program Interface for Transfer Services - Summary of Concept and Rationale. Informational Report. CCSDS 914.1-G-1. Green Book. Issue 1. Washington, D.C., January 2006.

[17] CCSDS Space Link Extension - Application Program Interface for Transfer Services - Application Programmer's Guide. Informational Report. CCSDS 914.2-G-2 Green Book. Issue 2. Washington, D.C., October 2008.

[18] Julio Filho, A. C., "An Architecture for Dynamic Management of the Space Link Extension Protocol Services". 213 p. Dissertation (Master's degree in Space Systems Engineering and Management) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil, 2015. URL:http://urlib.net/8JMKD3MGP3W34P/3HP2P7P (accessed August 2015).

[19] Friedenthal, S.; Moore, A.; Steiner, R. (2009) "Practical guide to SysML: the systems Modeling Language". Amsterdam, The Netherlands: Morgan Kaufmann. ISBN 978-0-12-378607-4.

[20] EUROPEAN COOPERATION FOR SPACE STANDARDIZATION (ECSS). "Space Engineering System Engineering General Requirements". 3. ed. Noordwijk, The Netherlands : ECSS-E-ST-10C, 2009.

[21] NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA). "NASA Procedural Requirements – NPR 7123.1B. Systems Engineering Processes and Requirements". Washington, DC, 2013. 157 p.

[22] International Council on Systems Engineering (INCOSE) (2020) "Systems Engineering Vision 2020, version 2.03". Seattle, WA: International Council on Systems Engineering, Seattle, WA, INCOSE-TP-2004-004-02.

[23] FORTESCUE, P.; STARK, J.; SWINERD, G. "Spacecraft Systems Engineering 3". Chichester, UK : John Wiley, 2003. ISBN: 678 ISBN 0-471-61951-5.

[24] LARSON, W.J.; WERTZ, J. R. (Ed). "Space Mission Analysis and Design 3. Dordrecht, Netherlands : Kluwer Academic, 1999. ISBN: 969306936 ISBN 1-881883-10-8.

[25] C. R. Haddow, M. Pecchioli, E. Montagnon and F. Flentge "File Based Operations – The Way Ahead". ESA/ESOC, Robert-Bosch-Str 5, 64293 Darmstadt, Germany.

[26] D. Evans, A. Lange, "OPS-SAT: Operational Concept for ESA'S First Mission Dedicated to Operational Technology," Proceedings of the 14th International Conference on Space Operations (SpaceOps 2016), Daejeon, Korea, May 16-20, 2016, paper: AIAA 2016 2354, URL: http://arc.aiaa.org/doi/pdf/10.2514/6.2016-2354