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The Amazonia-1 Satellite's Ground Segment - Challenges for implementation of the Space Link Extension Protocol Services

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Abstract

Amazonia-1 is the first Remote Sensing Satellite entirely developed at Brazil by National Institute for Space Research (INPE) and it is expected to be concluded in 2018. Amazonia-1 is a polar orbit satellite that will generate images with a 5 days revisit period. To do this, has a wide sight optical imager, called Wide Field Imager (WFI), able to observe a range of 700 km with 70 meters of spatial resolution. Its rapid revisit feature will enable Amazon deforestation alert data to improve in real time by maximizing the acquisition of useful images in the face of cloud cover in the region. The Amazonia-1 will also provide frequent images of Brazilian areas, and may be useful in other environmental monitoring applications, such as the coastal zone, water reservoirs, forests of other biomes and natural disasters. The Amazonia-1 satellite is based on the Multi-Mission Platform (MMP), which was also developed by INPE and other Brazilian industries as a part of the National Program of Space Activities (PNAE), coordinated by the Brazilian Space Agency (AEB). The MMP is generic platform to 500 kg class satellites. With 250 kg mass, it provides the necessary resources, in terms of power, control, communication and others to operate, in orbit, a payload of up to 280 kg. The requirement of high rate of revisits and the need of controlling and data reception of other remote sensing satellites available in Brazil, for example, the CBERS (26 days to revisit) impose new challenges for the ground segment, related to control system of orbit and attitude and consequently in the reception, processing and distribution of data through the ground segment using the Space Link Extension (SLE) Protocol Services. The SLE protocol services establish activities, based on the Consultative Committee for Space Data Systems (CCSDS) for cross support recommendations, including Management Services for Data Transfer and SLE protocol services related to Telemetry and Telecommand. These services standards have been adopted by the different space agencies, such as: ESA, NASA, CNES, DLR, ASI, JAXA, INPE, to performing tracking and controlling of the spacecrafts. This paper presents an overview of the Amazonia-1 satellite's ground segment, its objectives, the satellite design based in the Multi-Mission Platform (MMP) and also the preparation of the ground segment for the operation with the SLE Protocol and allow for efficient operations with cross support.

Keywords: Amazonia-1, Remote Sensing Satellite, Space Link Extension (SLE) Protocol, Satellite Control System, Space Mission Cost, CCSDS.

Acronyms

AEB	Brazilian Space Agency
ALC	Alcântara (Brazilian TT&C Ground Station)
API	Application Program Interface
CBA	Cuiabá (Brazilian TT&C Ground Station)
CBERS	China-Brazil Earth Resources Satellite
CCSDS	Consultative Committee for Space Data Systems
CLTU	Communications Link Transmission Unit
CM	Complex Management
DCP	Data Collection Platforms
DDR	Digital Data Recorder
DETER	Real Time Deforestation Detection
DSS	Divisão de Desenvolvimento de Sistemas de Solo (Ground Systems Development Division)
ESA	European Space Agency
FOP	Fly Operation Plane
GS	Ground Station
IBS	Integrated Baseband System
INPE	Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)
ISP1	Internet SLE Protocol One
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
MMP	Multi-Mission Platform
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
RAF	Return All Frames

RCF Return Channel Frames
RF Radio Frequency
RG Ranging Data
RR Range Rate
RTU Remote Telemetry Unit
PRODES Measurement of Deforestation by Remote Sensing
SATCS SATellite Control System
SCC Satellite Control Center
SCCS-SM Space Communication Cross Support - Service Management
SCD1 Satélite de Coleta de Dados 1 (Data Collecting Satellite 1)
SICF Service Instance Configuration File
SL Space Link
SL-DU Space Link Data Units
SLE Space Link Extension
SLE API SLE Application Program Interface
SLE FG SLE Functional Groups
SLE-PDU SLE-Protocol Data Units
SLE-SDU SLE-Service Data Units
TC Telecommand
TM Telemetry
TT&C Telemetry, Tracking and Command
UM Utilization Management
WFI Wide Field Imager

1. Introduction

One of the main environmental problems in Brazil in relation to biomes is the deforestation in the Amazon region. The government and other agencies have undertaken many efforts to monitor this phenomenon. One of these initiatives is DETER (Real Time Deforestation Detection). The DETER system is a contribution of the INPE to the action plan of the Ministry of Science, Technology, Innovation and Communications of Brazil to reduce deforestation rates in the Amazon. The DETER uses data with spatial resolution of 250 m, and can identify only areas of deforestation over 25 hectares, from the MODIS (Moderate Resolution Imaging Spectroradiometer).

Other operational programme dedicated to monitoring deforestation in the Amazon region is the PRODES (Measurement of Deforestation by Remote Sensing). This system is based on Landsat type data and aims to measure the deforested area using satellite data. As it involves the measurement of area, uses data with better spatial resolution (Landsat, CBERS).

Both systems DETER and PRODES are affected by the high frequency of clouds over the Amazon region. So, to ensure that the monitoring and measurement of deforestation is feasible, it is necessary to have remote sensing data in spatial and temporal resolutions compatible with these phenomena.

The Brazil has an important role as a supplier of food in the world. Some of the main products in this sector are: coffee, soybeans, sugarcane, corn, cotton and citrus fruits, requiring a greater temporal resolution for remote sensing systems are more useful as operational base for agricultural applications.

In addition, it is expected that the data of the Amazonia-1 may be useful for other applications, such as monitoring of coastal zone, water reservoirs, forests of other biomes and natural disasters.

The requirement of high rate of revisits and the need of controlling and data reception of other remote sensing satellites available in Brazil, for example, the CBERS (26 days to revisit) impose new challenges for the ground segment, related to control system of orbit and attitude and consequently in the reception, processing and distribution of data through the ground segment using the Space Link Extension (SLE) Protocol Services. In this scenario, the CCSDS recommends normalizing cross support services [1-9] between the space agencies aiming at interoperability and standardization of data transfer services that are based on client-server architecture [10-12].

This paper is organized as follows: section 2 explains the Mission and Project Description, section 3 presents the INPE`S Ground Station, section 4 provides the Space Link and Space Link Extension Concepts, section 5 presents an proposed Architecture for Dynamic Management of the SLE Protocol Services to The Amazonia-1 Satellite's Ground Segment, and section 6 the Conclusions.

2. Mission and Project Description

2.1. Mission

The Amazonia-1 objective is to provide remote sensing images to observe and monitor vegetation especially deforestation in the Amazon region, with a high revisit rate and considering the synergy with the existing programs.

The Amazonia-1 aims to provide relevant data to both scientific community and governmental agencies.

The overall system development related to the mission shall be used to enhance the advancement and qualification of Brazilian industry in space engineering and technology, through its engagement in design, development, and manufacturing of the Amazonia-1 Space System.

2.2. Project Description

The Amazonia-1 space system is conceived to provide:

a) an Earth surface imaging with swath of 700 km and a 5 (five) days revisit period. The images shall be provided in 4 (four) spectral bands in the visible (blue, green, red) and a near infra-red band. The spatial resolution at nadir will be better than 70 m for the VIS/NIR (Visible/Near Infra-red) bands;

b) data for monitoring deforestation, agricultural planning and other applications such as monitoring of coastal zones, water reservoirs, natural and cultivated forest, disasters, etc. Besides, it will provide relevant information for the already established DETER system operation.

In order to fulfill the requirements a) and b), a remote sensing satellite is placed in a sun-synchronous Low Earth Orbit (LEO) to meet the requirements in terms of coverage, revisit, and resolution. The Amazonia-1 satellite design uses the Brazilian multi-purpose three-axis stabilized service platform Multi-Mission Platform (MMP). Therefore, the validation of the entire cycle of a space program, taking into account the system design, testing and operation, will be achieved, with a significant technological contribution to the Brazilian Space Program. The payload module is designed considering modularity, independent design and construction, and allowing separated integration and test of payload instruments, before the payload-to-MMP integration and final compatibility tests.

The existing Brazilian ground infrastructure for Telemetry, Tracking, and Command (TT&C) functions and for image processing and archiving will be used at maximum extent.

The Amazonia-1 System is composed by the following segments:

a) ***The Space Segment***, comprising the Amazonia-1 spacecraft, which is designed to be a three-axis stabilized satellite placed into a LEO, carrying instruments for Earth observation.

b) ***The Ground Control Segment,*** which controls the satellite, monitors and analyzes its on-orbit operation. The Ground Segment comprises:

- Satellite Tracking and Control Center;
- Telemetry, Tracking, and Command (TT&C) Stations.

c) ***The Application Segment,*** comprising:

- Image Receiving Station;
- Mission Center (CMCD); which plans image payload satellite acquisitions and coordinates operations for acquisition of images;
- Remote Sensing Data Center (CDSR): which collects, processes and stores the images received, making them available to the users.

d) ***The Launch Segment,*** responsible for placing the Amazonia 1 satellite in orbit.

The system elements and their inter-relationship are depicted in Figure 1. The Amazonia1-1 receives and decodes telecommands from the Satellite Tracking and Control Center, in São José dos Campos, SP, through the TT&C Station located in Cuiabá, MT. For Launch and Early Orbit Operations (LEOP) and in-orbit emergencies, a secondary ground station will be required.

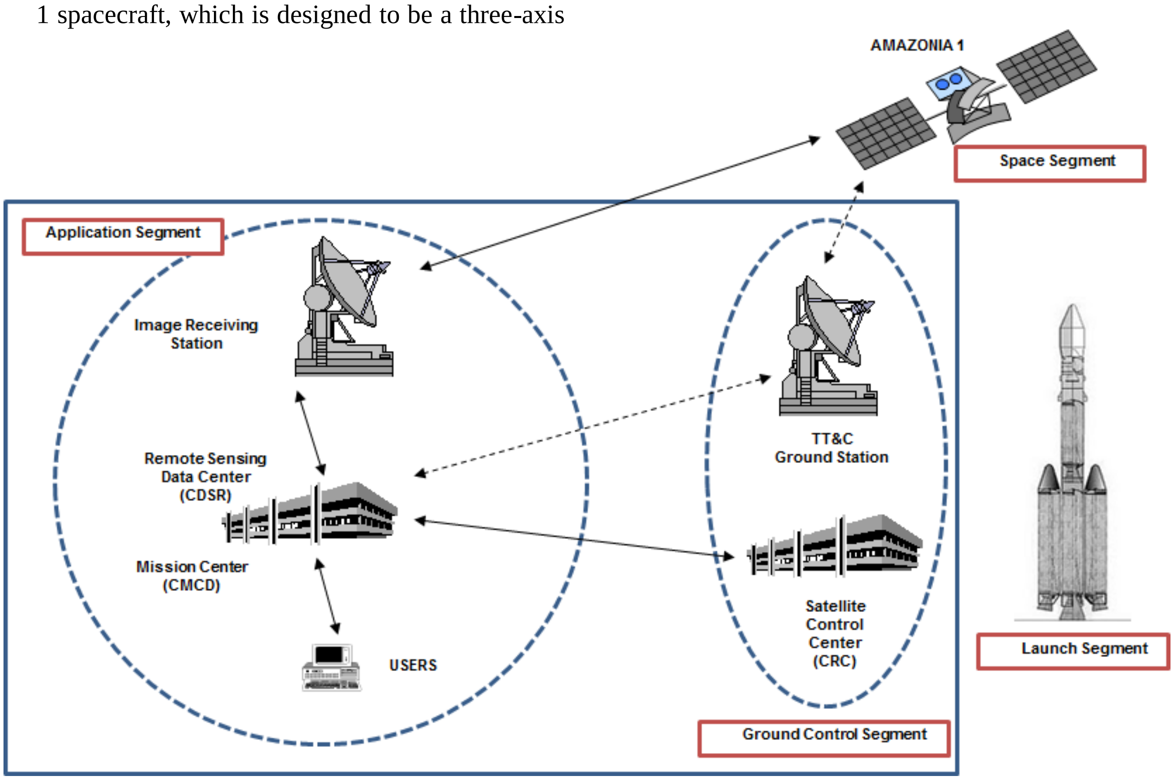

Figure 1. Amazonia-1 System Elements.

Image data received from the Amazonia-1 by the X-Band Image Receiving Station, in Cuiabá, MT, will be forwarded to the Remote Sensing Data Center (CDSR), located in Cachoeira Paulista, SP. In the CDSR the image data will be recorded, processed, archived, and distributed to the users.

Finally, the Mission Center receives requests from users and schedules, along with the Control Center, image acquisition and recording.

2.3. Spacecraft

The Amazonia-1 satellite, figure 2, consists of two independent modules: a service Module, which is a Multi-mission Platform (MMP), and a Payload module, which houses image cameras and recording equipment and transmission of image data

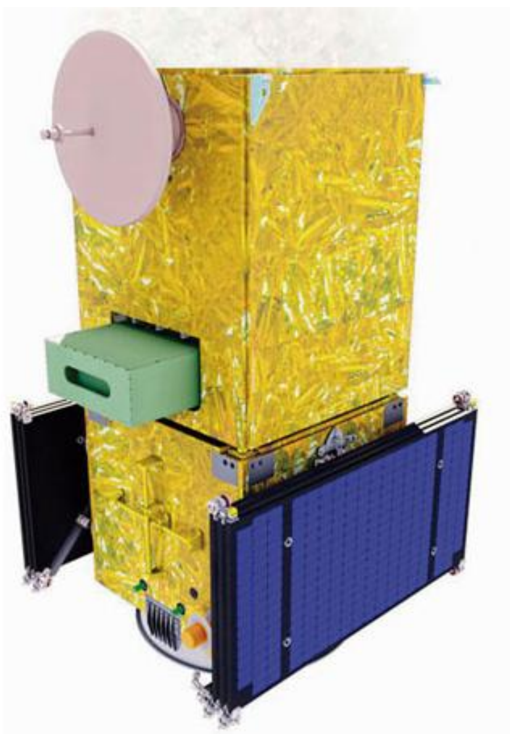

Figure 2. Amazonia-1 Satellite

2.4. Multi-mission Platform -*MMP*

The MMP represents a modern concept of satellite architecture, which aims to bring together in a single platform all equipment performing functions necessary to the survival of a satellite, regardless of the type of orbit: power generation, thermal control, data management, and telecommunication service. It is a generic platform (Service Module) for satellites in the 500 kg. With 250 kg mass, it provides all the features needed to support the operation in orbit, of different payloads of up to 280 kg

Its proposal and design were carried out on the initiative of the Brazilian Space Agency (AEB), which also led to the contracting of the development of the system with national companies, and INPE acted as technical agent with these companies.

2.4.1. MMP Subsystems

The MMP consists of its subsystems, each one of them in charge of performing a specific function to ensure the operability of the satellite in orbit. The main subsystems are:

- Mechanical structure and Service Module;
- Attitude and Orbit Control System (AOCS);
- On Board Data Handling (OBDH);
- Propulsion;
- Telemetry and Remote Control (TT&C);
- Thermal Control;
- Supply of energy.

2.5. Payload

The Payload module houses the imaging camera and recording equipment and data transmission.

The optical imager of Amazonia-1 is a camera model WFI used in the CBERS program, therefore, an equipment with inheritance in flight. The images captured by the imager as well as the ancillary data of the subsystem are processed in a processing unit and sent to the Digital Data Recorder subsystem (DDR) to be written or to be transmitted to the ground via transmission subsystem camera data.

The interface of telemetry and remote control of Camera WFI is performed via a Remote Telemetry Unit (RTU), which requires the power supply voltages governed through a DC/DC Converter. These two, RTU and DC/DC Converter, specific to WFI Camera operation.

The figure 3 illustrates the Amazonia-1 satellite with his two-coupled modules: Multi-mission Platform (Service Module) and the Payload module (upper satellite). Closing panels are separated to illustrate the internal layout of the equipment and subsystems. The solar panel is shown in your collected position (setting the launch phase).

Figure 3. Amazonia-1 satellite with his two-coupled modules

3. INPE`S Ground Station

The Telemetry, Tracking and Command (TT&C) Ground Stations [13] (GS) of INPE were built in 1988 to support the Data Collecting Satellite-1 (SCD1), which was launched 1993. They operate in S-band and are located Brazilian cities of Cuiabá (Mato Grosso state) and Alcântara (Maranhão state). TT&C GSs are in charge of establishing communication between the ground control system and the satellites monitored during the visibility periods [14].

Figure 4 shows the INPE's ground system including SCC and the main systems of the GS: RF Front End, Receiver, Antenna Control Unit (ACU) and Time & Frequency. The functions of TM, TC, Ranging Data (RG), Range Rate (RR) and the SLE Provider are based on the Integrated Baseband System (IBS). These functions are performed following the Flight Operation Plans (FOP) [15]. The TT&C GS receives, demodulates and records spacecraft data telemetry, transmits telecommand to satellite and performs measurements of distance (RG) and speed of satellites [16] (RR), and receives payload telemetry from Data Collection Platforms (DCP).

The SCC is responsible for plan and executes all activities related to the satellites control and is also the administrative headquarters. The SCC is located in the city of São José dos Campos (São Paulo state), Brazil. The main functions of a SCC are: orbit and attitude control, maneuvers calculation, operational payload configuration, real-time monitoring of the satellite health, rapid reaction in case of anomalies of the satellite.

Over the structure of the SCC is embedded a software system, **SATellite Control System** (SATCS); developed by the Ground Systems Development Division (DSS) of coordination of Space Engineering and Technology at INPE. The SATCS is designed to be easily configurable and customized to meet different kind of satellites [17,18].

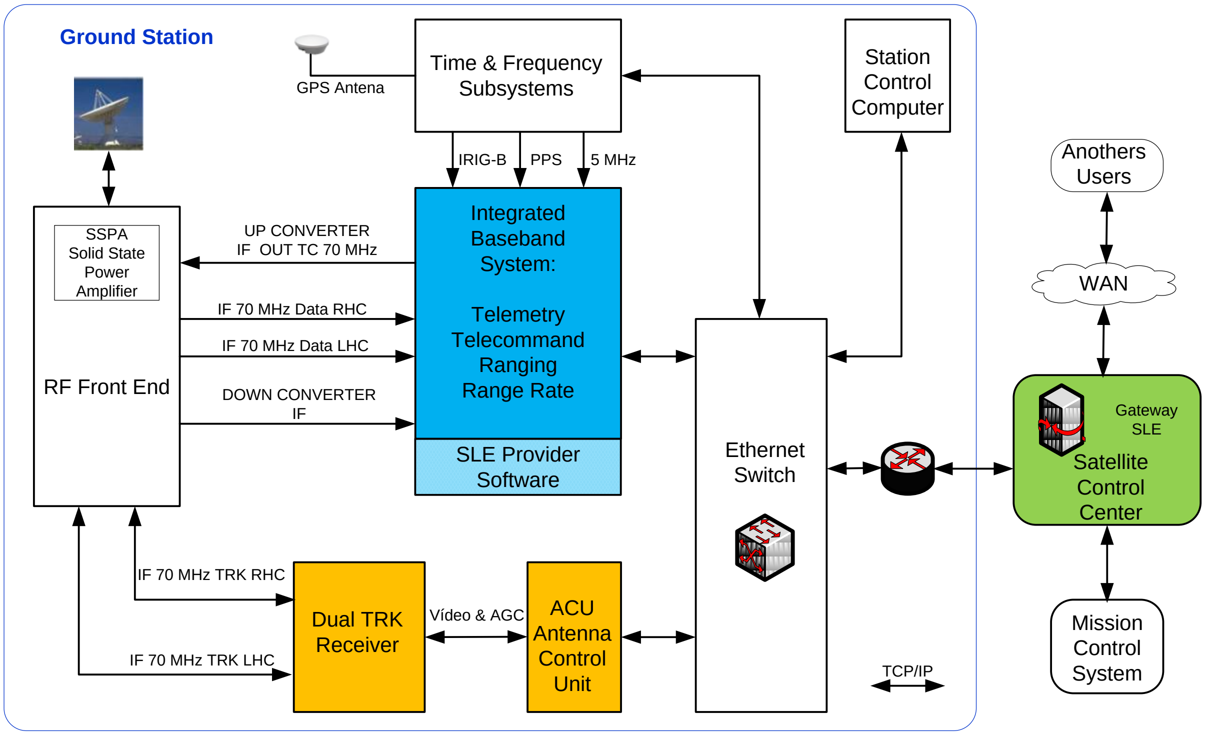

Figure 4. INPE's Ground System.

4. Space Link and Space Link Extension Concepts

4.1. Space Link

Space Link is the communication link between the spacecraft and ground systems, or between two spacecrafts, as described in Ref. [19-21]. The Space Link Extension protocol services extending the Space Link service 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.

4.2. Space Link Extension protocol services

The definition of **Space Link Extension protocol** services [1] is a result of the effort undertaken by the CCSDS for the normalization of the cross support for transferring telecommand and telemetry. There are two categories of services: (i) data transfer services, category responsible for space link data transfer between the ground stations, control center, and the end user; and category (ii) management services that controls the planning and provision of data transfer services.

The **SLE data transfer services** are based on client/server architecture [10]. The client is usually located at SCC side and called SLE User. The server, on the other hand, generally located in the GS, is called SLE Provider.

4.3. Space Communication Cross Support - Service Management

Space Communication Cross Support - Service Management (SCCS-SM) [2,7] is the generalization of SLE. The SCCS-SM includes the data transfer services and management services, and provides a framework for the user and the provider to:

- Set the values of the parameters of space link and transfer services.
- Set up ground stations for the establishment of space link.
- Organize, in time, the transfer services.

Two entities are defined in the SCCS-SM:

- The Utilization Management [8] (UM), on the server side, coordinates requests from users to the space link.
- The Complex Management [6,9] (CM), on the provider side, performs, for example, the negotiate the types, number of instances and duration of services.

4.4. Internet SLE Protocol One

CCSDS recommends the Protocol referred to as Internet SLE Protocol One [22-27] (ISP1) for transfer of the SLE Protocol Data Units (SLE-PDU) using the Internet Protocols. The ISP1 is represented by a layered architecture model.

5. Architecture for Dynamic Management of the SLE Protocol Services to the Amazonia-1 Satellite's Ground Segment

The proposed architecture allows a solution to new challenges for the ground segment, related to control system of orbit and attitude and consequently in the reception, processing and distribution of data through the ground segment using the Space Link Extension (SLE) Protocol Services.

The dynamic management allows agility to access to the spacecraft increasing the ability of tracking and controlling and enables a continuous tracking (in operational routine, contingency or emergency phases) according the number of providers involved and the negotiation of services between agencies that adopt the cross support recommendation.

This proposed architecture follows the layered structure recommended by CCSDS – ISP1, and were included Provider Application Control layers in the Provider Side and User Application Manager and Control layer the User Side.

On the Provider Side, SLE Provider layer is responsible for the transfer services RAF, RCF, and CLTU and sends/receives data to/from the Provider Application Control layer and this, in turn, performs the functions (management services) for the Management Complex.

On the User Side, SLE User layer is responsible for requesting a transfer service, and the User Application Manager and Control layer is responsible for the dynamic management of SLE protocol services and management services (Utilization Management) and finally the Satellite Controller layer controls the user interface for TM and TC request.

5.1. High level requirements

In order to built the proposed architecture we established a set of high level requirements to be accomplished, which are:

- REQ.01: it shall allow the consistency of the point-to-point connection from the user to the SLE provider in the ground station;
- REQ.02: it shall allow the configuration from the SLE user to the SLE provider in the ground station.
- REQ.03: it shall allow redundancy Return SLE services.
- REQ.04: it shall allow interoperability for cross support.
- REQ.05: it shall allow backward compatibility.
- REQ.06: it shall allow automatic switching between ground stations (SLE providers) and the SCC (SLE user).

5.2. The Architecture

The Architecture is distributed between the SCC (user) and the network of ground stations involved (providers). In the Satellite Control Center the architecture is composed of a Gateway SLE User, Satellite Control System and the Dynamic Management. In the Ground Station the architecture consists of a SLE Provider for each station belonging to the network.

The SLE Provider contains minimally three Functional Groups defined in CCSDS recommendations: (i) Return Space Link Processing, (ii) Return Frame Processing and (iii) TC Space Link Processing.

The Gateway SLE User corresponds to the interface between the Dynamic Management and SLE providers, their functions are: (i) enable communication between Dynamic Management and SLE providers and (ii) the execution of the services of management (UM).

With respect to the Satellite Control System, the minimum set of functions is: (i) request the sending of telecommand for dynamic management functional module and (ii) receive the telemetry from the functional module of dynamic management.

Figure 5 illustrates the environment for satellite operation with dynamic management of the SLE protocol services as proposed in Ref. [28, 29]. This architecture allows:

- The dynamism for redundancy between ground stations.
- The transparency in switching stations.
- The reduction of possible failures in the connection between the provider and the user of the services.
- The management services related to negotiation, configuration and scheduling.

5.3. Implementation of the Architecture

The architecture was developed in Java, by building **a set of prototypes** of the architecture's elements and **simplified simulators**. This implementation includes the CLTU, RAF and RCF transfer services and management services.

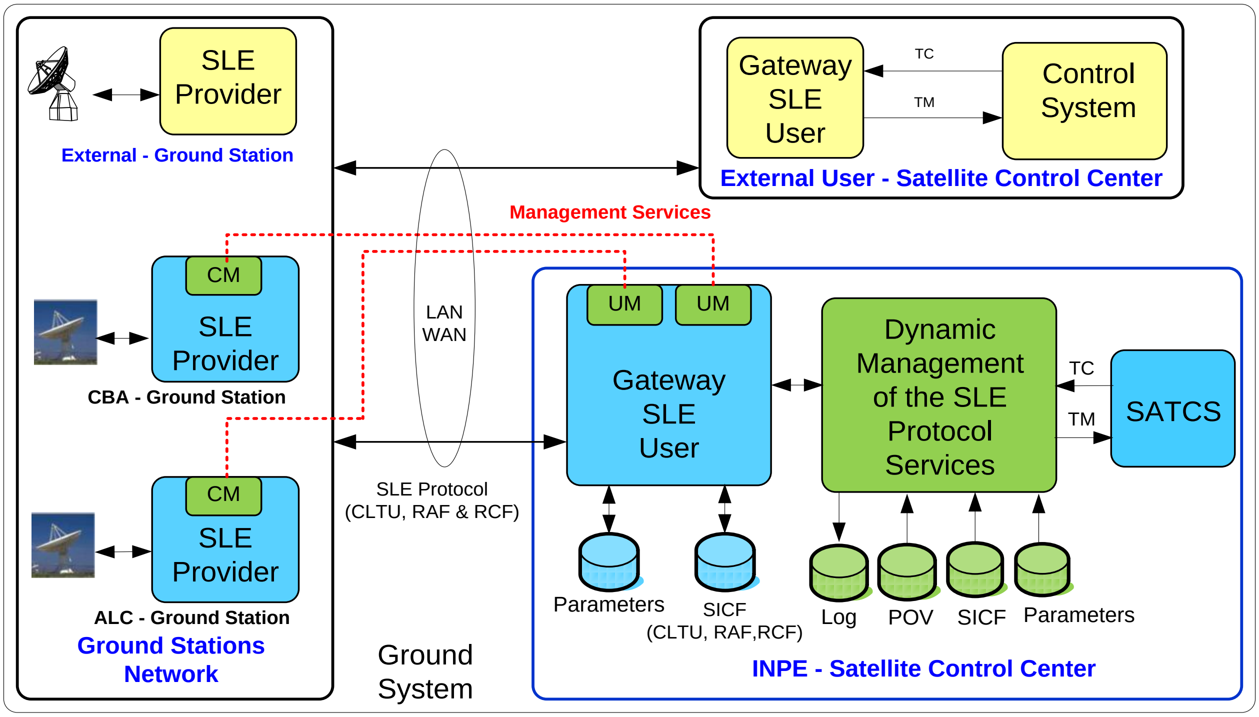

Figure 5. Environment for satellite operation with the dynamic management of the SLE protocol services.

5.4. Architecture Evaluation

For the architecture evaluation we created operational scenarios to cover different aspects of sending telecommand, telemetry reception and automatic switching between two stations during an orbit. Orbit data are obtained from the Operational Flight Plan, specifically the identification of the orbit and the start and end of the passage.

The architecture evaluation is based on the Data Collecting Satellite-1 (SCD1), which was launched 1993 and in operation. The Orbit data and the Operational Flight were provided by Satellite Control Center of INPE.

We present one operational scenario for the evaluation of architecture:

- **Operating scenario 1**: Request reception of the Telemetry via CBA ground station.
  In this scenario the Control System Simulator must allow:
  - The selection of an orbit, obtained from the flight operational plan.
  - The request the telemetry reception.
  - The gateway SLE User should send the request (RAF) to provider.
  - The SLE Provider (CBA ground Station) must receive and process the request and these actions are monitored by the prototype for dynamic management of SLE protocol services.

Figure 6 illustrates the evaluation scenario regarding the FOP and region of the visibility associated the each ground station, provided by the Satellite Control Center of INPE and adapted from the Satellite Toll Kit (STK10 free version).

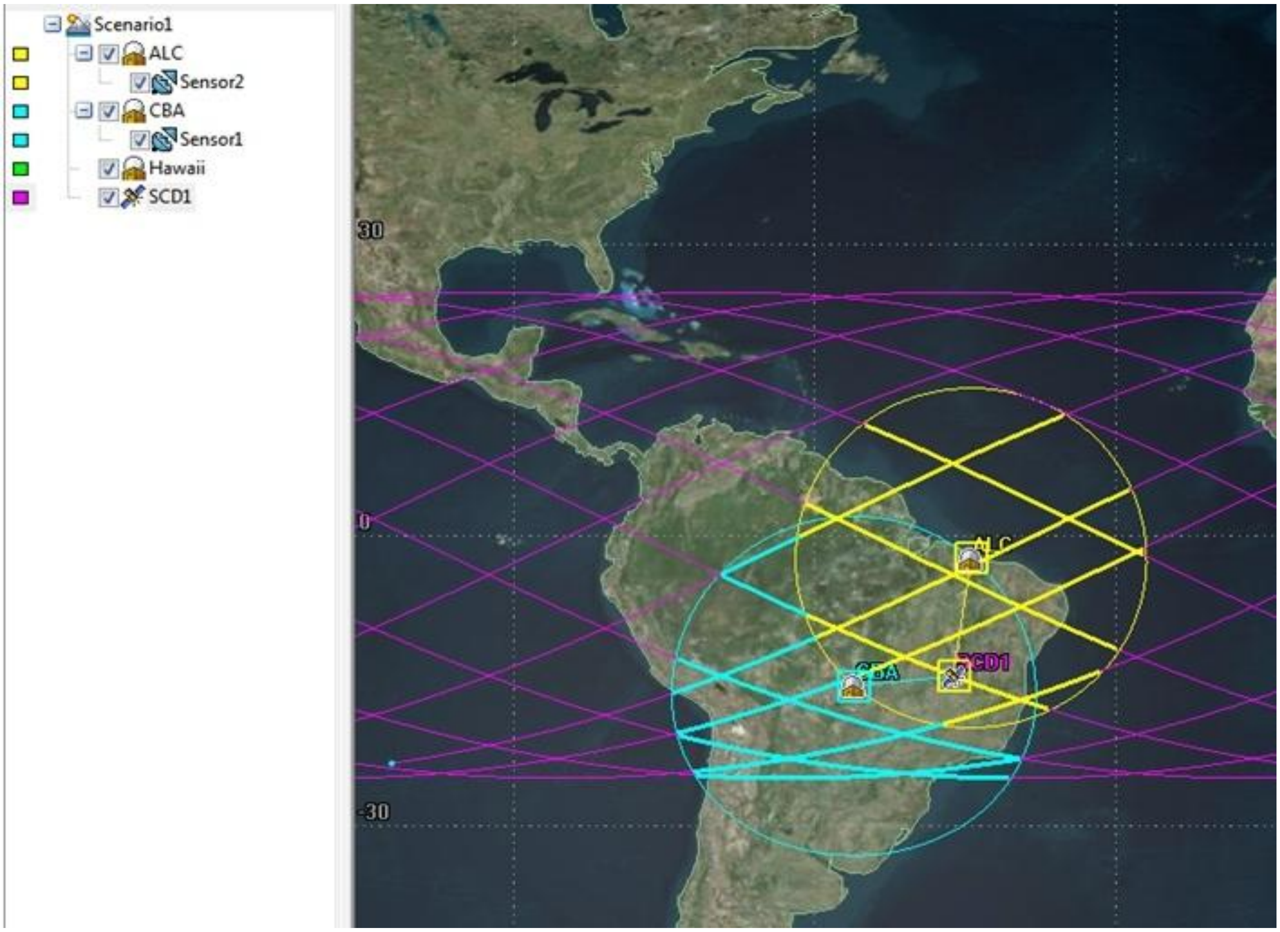

Figure 6. Regions of visibility of CBA and ALC Ground Stations.

5.4.1. Result of Operation scenario

Figure 7 shows the SICF, the type of service selected, in this case RAF; indicates evolution of tracking for CBA and ALC ground station, start time for each station; and events area shows the event log that occurred between the SLE User and SLE Provider.

In summary the scenario 1 shows how relevant aspects under normal tracking:

- The additional time on the duration of the passage of time calculation total tracking, tracking of the CBA ground station (primary station), sum up over time about the ALC ground station (secondary station).
- The continuous tracking with automatic switching between these two stations, via the dynamic management of SLE protocol services.
- The reception of data TM via ALC ground station.

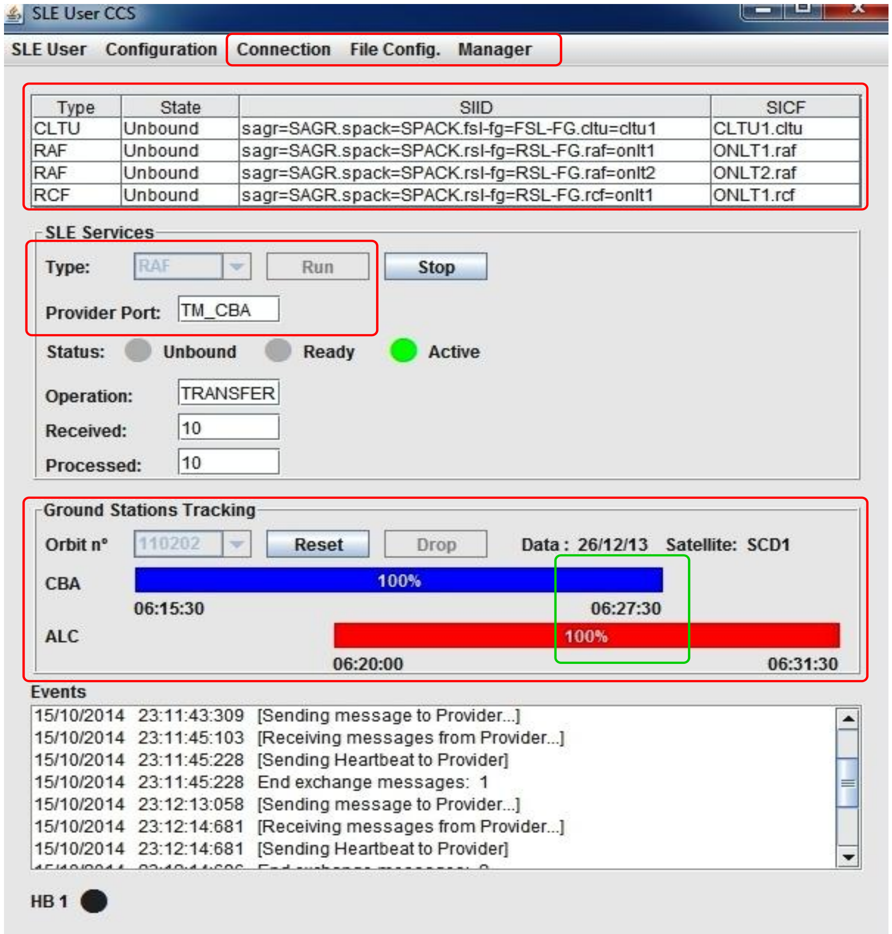

Figure 7. SLE User CCS: RAF Service.

6. Conclusions

This paper presented the Amazonia-1, the first Remote Sensing Satellite entirely developed at Brazil by National Institute for Space Research (INPE). It is a polar orbit satellite that will generate images with a 5 days revisit period using a wide sight optical imager. This satellite is based on the Multi-Mission Platform and a new architecture for the ground segment is proposed.

The proposed architecture allows a solution to new challenges for the ground segment, related to control system of orbit and attitude and consequently in the reception, processing and distribution of data through the ground segment using the Space Link Extension (SLE) Protocol Services. The solution was based on the CCSDS recommendations to cross support for data transfer.

The dynamic management allows agility to access to the spacecraft increasing the ability of tracking and controlling and enables a continuous tracking (in operational routine, contingency or emergency phases) according the number of providers involved and the negotiation of services between agencies that adopt the cross support recommendation.

The main technological gains arising from Amazonia-1 Mission are: the validation of the Multi-mission Platform, generating system reliability and significant reductions of deadlines and costs for the development of future missions based on the platform Multi-mission; the consolidation of knowledge of Brazil in the complete development cycle of 3-axis stabilized satellites, gaining maturity in satellite integration and testing; the country's capacity to carry out initial operations post launch and the consolidation of knowledge in satellite launch campaign of greater complexity.

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Biography

Antonio Cassiano Julio Filho is graduated at Analysis and Development of Systems from Faetec, Brazil and Master's (2015) at Space Engineering and Technology from Brazilian National Institute for Space Research (INPE). Has 32 years of the work at INPE in the Space Engineering and Technology in the area Ground Systems Development Division in the design, development and integration of the ground segment for the tracking and control of satellite and the dissemination of environmental data. Also is INPE Observer Member to the Cross Support Transfer Services Working Group of the CCSDS and Member of the Commission of Study CE:08.010.70/ABNT, to the review and the development of Space Data and Information Transfer Standards, derived from CCSDS Recommendations.

Ana Maria Ambrosio: Bachelor's at Computer Science from Universidade Federal de São Carlos (1984), master's (1988) and doctorate (2005) at Computer Science from Instituto Nacional de Pesquisas Espaciais (INPE). She works at INPE since 1985. She has been involved in the following space missions: Missão Espacial Completa Brasileira (MECB), French-Brazilian Microsatellite (FBM) and China-Brazil Earth Resources Satellites (CBERS). Since 2008 acts as teacher in the Space Engineering and Technology pos-graduation Program at INPE, from 2012 to 2014 acted as Head of Space Systems Management and Technology area of the post-graduation of the Space Technology and Engineering Course. Her areas of research are: satellite verification and validation techniques and methods, model-based approaches for space applications, automatic test generation from state models and satellite simulation.

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