The AMSAT® Journal

Editor-in-Chief
Joe Kornowski, KB6IGK

Assistant Editors
Bernhard Jatzeck, VA6BMJ
Douglas Quagliana, KA2UPW/5
Paul Graveline, K1YUB

Volume 43, Number 4 — July/August 2020

In this issue —

Periodicals
POSTAGE PAID
At Kensington, MD
and at additional
mailing offices

AMSAT
10605 Concord St., Suite 304
Kensington, MD 20895-2526

attacks to satellites. It is very important to secure ground stations that have Internet connectivity because it would be one of the primary targets for a cyber-attack, but as revealed in the NASA case study, there is still much to be done on security issues in IP networks.

SpaceX is currently the world's largest low-orbit satellite operator, with plans to have 42,000 satellites in space over the next 10 years. This number of satellites is intended to provide satellite Internet services around the world. However, SpaceX and other rival companies are under pressure to achieve this goal by accelerating the production of their satellites at low cost, which could result in a lack of security in their construction and operation. These types of actions are the ones hackers are currently looking for to infiltrate while the satellite service companies are worried to be first in space by sacrificing costs and security in their systems.

Finally, no matter what actions the satellite industry and governments take on cybersecurity in satellite systems, only one thing is sure: something must be done about it, and soon. It will be a serious mistake to continue developing satellites that do not satisfy minimum security standards, making it easy for hackers to gain control of commercial or amateur satellites to put human lives in danger or to damage space and ground segment services or infrastructure.

REFERENCES

• Akata, W. (2020). Hackers could shut down satellites — or turn them into weapons. Astronomy Magazine. Available at astronomy.com/news/2020/02/hackers-could-shut-down-satellites--or-turn-them-into-weapons.

• Alshaer, M. K. (2013). Cyber Attacks On Satellites Review & Solutions. Available at www.academia.edu/18156391/Cyber_attacks_on_satellites_Review_and_solutions.

• Constantin, L. (2014, April 18). Satellite communication systems are rife with security flaws, vulnerable to hackers. Computer World.

• Fritz, J. (2013). Satellite Hacking: A guide for the perplexed. Culture Mandala: The Bulletin of the Center for East-West Cultural and Economic Studies. Vol 10, No.1.

• Klotz, I. (2013). NASA Steps Up Security After Arrest of Former Contractor. Available from www.reuters.com/article/us-space-espionage-idUSBRE92J1FR20130320.

• Laurie, A. (2009). Satellite Hacking for Fun and Profit. Retrieved from www.securitytube.net/video/263.

• Leyden, J. (2011). Inside the mysterious U.S. satellite hacking case. Available from www.theregister.co.uk/2011/11/21/us_sat_hack_mystery/print.html.

• Malik, W. (2019). Attack Vectors in Orbit: The Need for IoT and Satellite Security. RSA Conference, San Fco. USA.

• Martin, P. (2012). NASA Cybersecurity: An Examination of the Agency's Information Security. Available from oig.nasa.gov/congressional/FINAL_written_statement_for_%20IT_%20hearing_February_26_edit_v2.pdf.

• Pollock, R. (2013). NASA Chief Failed to Tell Congress of 118 Chinese Nationals Working in IT. Available from washingtonexaminer.com/nasa-chief-failed-to-tell-congress-of-118-chinesenationals-working-in-it/article/2525324.

• Prime: Cybersecurity Risk Management Strategies for SATCOM Networks. (2012). Available from www.milsatmagazine.com/cgi-bin/display_article.cgi?number=1142237172.

• Steinberger, J. (2008). A Survey of Satellite Communications System Vulnerabilities. Available from www.dtic.mil/dtic/tr/fulltext/u2/a487592.pdf.

• USCC. (2010). Report to Congress of the US-China Economic and Security Review Commission. Available from www.uscc.gov/sites/default/files/annual_reports/2010-Report-to-Congress.pdf.

• USCC. (2011). Report to Congress of the US-China Economic and Security Review Commission. Available from **origin.**www.uscc.gov/sites/default/files/annual_reports/annual_report_full_11.pdf.

• U.S. Department of Homeland Security (DHS). (2003). The national strategy to secure cyberspace. Washington, D.C.

Integration of a Distributed Ground Station Network Based on Amateur Radio Infrastructure for Scientific Space Missions

M.A.Mendoza-Bárcenas (SWL); Rafael Prieto-Meléndez (SWL); Alejandro Padrón-Godínez (SWL); Gerardo Calva-Olmos (SWL), Omar Álvarez-Cárdenas, XE1AO; Margarita G. Mayoral-Baldivia XE1BMG; Alfonso Tamez-Rodríguez, XE2O

1. Abstract

The rapid increase of scientific and low-cost experimental satellite missions has made it necessary to develop new proposals for the integration of space platforms and ground stations for telemetry control and data downloading from sensors onboard. In recent years, the number of radio amateurs around the world with technological capabilities for downloading satellite data has grown significantly, becoming a fundamental part of international communications. In this work, a novel proposal for the integration of a network of ground stations distributed worldwide, based on Amateur Radio Infrastructure for Scientific Space Missions, is shown.

2. Introduction

The relationship between ham radio and space technology dates back from 1961 when the OSCAR-1 satellite (acronym of Orbiting Satellite Carrying Amateur Radio) was launched. Until January 2018, near 92 satellites of all sizes, carrying amateur radio and several related experiments, have been launched and successfully operated by hams in countries around the world according to AMSAT (2018).

In the context of the architecture of a typical space mission, and according to the general scheme shown in SMAD (1999), this is integrated by three main segments: space segment (SS), ground segment (GS) and launch segment (LS). The SS is integrated

Figure 1 — Scheme for communication between GS and SS (Maini, Agrawal 2014).

mainly by the spacecraft and all the hardware on-board, meanwhile, the GS is integrated by the communications equipment on-ground and all the technological and computer resources for the storage and distribution of the downloaded data from the spacecraft in-orbit.

According to Maini (2014), an Earth station (ES) is a terrestrial station mainly located on the Earth's surface. The ES is intended for communication with one or more manned or unmanned spacecraft in orbit, or with one or more terrestrial stations of the same type via one or more reflecting satellites or other objects in space, as depicted in Figure 1.

In the context of the design of GS, it is important to consider the footprint coverage and the available time for the uplink and downlink of data during each pass of the spacecraft over the GS. Undoubtedly that, having a high number of GS that allow covering the largest surface during the orbit of the spacecraft, will be the better scenario. A good idea is the implementation of a Distributed Ground Station Network (DGSN).

Some advantages of DGSN integration are the rapid installation, the ease of adaption to hard and hazardous geographical conditions, the use of fixed, semi-fixed or portable equipment for handling, storage, and the automation of the data are easy transported and distributed. The uplink/downlink to the satellite uses low transmission power, and it is the antenna systems that avoid loss of data caused by long distances between their links. Additionally, it is possible to reuse frequencies in different geographical areas of the world, allowing DGSN to be more effective compared to the performance of one o more fixed stations operating individually. Of course, we must consider the disadvantages among which we can mention spectrum congestion by disabled systems in the use of radio frequencies. Each of the stations in the network must carry out procedures and payment of fees for the use of the spectrum. There are effects due to environmental conditions and the possibility of interference by third parties and the potential risk of interception of data. All equipment requires maintenance and often needs lines of sight for links to exchange data among participating stations.

As it is established in (AMSAT, 2018), amateur radio provides access to a variety of frequencies from shortwave to microwave for amateur satellite use. Once in orbit, a satellite for amateur radio users becomes more than a simple telemetry and telecommand link for radio experimenters, students, and academics around the world, of all ages, specialties and academic levels becoming in powerful technological tools for increasing the availability and participation in the STEM education scheme. In addition, as students and academics obtain their amateur licenses, they gain valuable expertise in communication techniques that can be applied to a variety of space-related projects in spacecraft and ground station design, as well as terrestrial communications.

It is possible to take advantage of the strength of both worlds — ham radio and the scientific academic environment — with a proposed project such as the Integration of a Distributed Network based on the infrastructure of radio amateurs, which allows boosting the integration of a distributed ground station for communication with scientific satellites along with the potential as an alternative communication network in case of natural disasters or emergencies. TEPEU-1 mission is a project dating back from 2015, boosted by educational institutions in Mexico such as IPN, UNAM, University of Colima, among others. The main objectives of TEPEU-1 are the development and launch of the first experimental Mexican satellite for dual purposes: technological validation of amateur radio experiments and scientific exploration of the relationship between the ionosphere and space weather. On the side of technological validation, TEPEU-1 seeks to boost the design and integration of a space payload compatible with CubeSat standard for technological demonstration of radio communications based on amateur radio experiments and, on the other hand, the scientific studies based on the alterations of the ionosphere related with events of space weather and its impacts on the communications technologies.

The first potential client for the Distributed Ground Station Network based on Amateur Radio Infrastructure (DGSN) is the TEPEU-1 mission.

3. Importance of the GS in a space mission

Once you have all the requirements for the ground station such as the frequencies, types of antennas, transmission power, modulation schemes and data coding, then it is possible to evaluate the availability and performance of the GS for the mission. In addition to equipment such as antennas, radios, etc., the design of the point-to-point links is important to ensure a successful space mission.

The GS is responsible for monitoring and controlling the complete space mission, giving facilities and services including the generation and provision of raw-data acquisition and auxiliary data to the main investigation group. The complexity of the GS depends on the satellite orbit and the

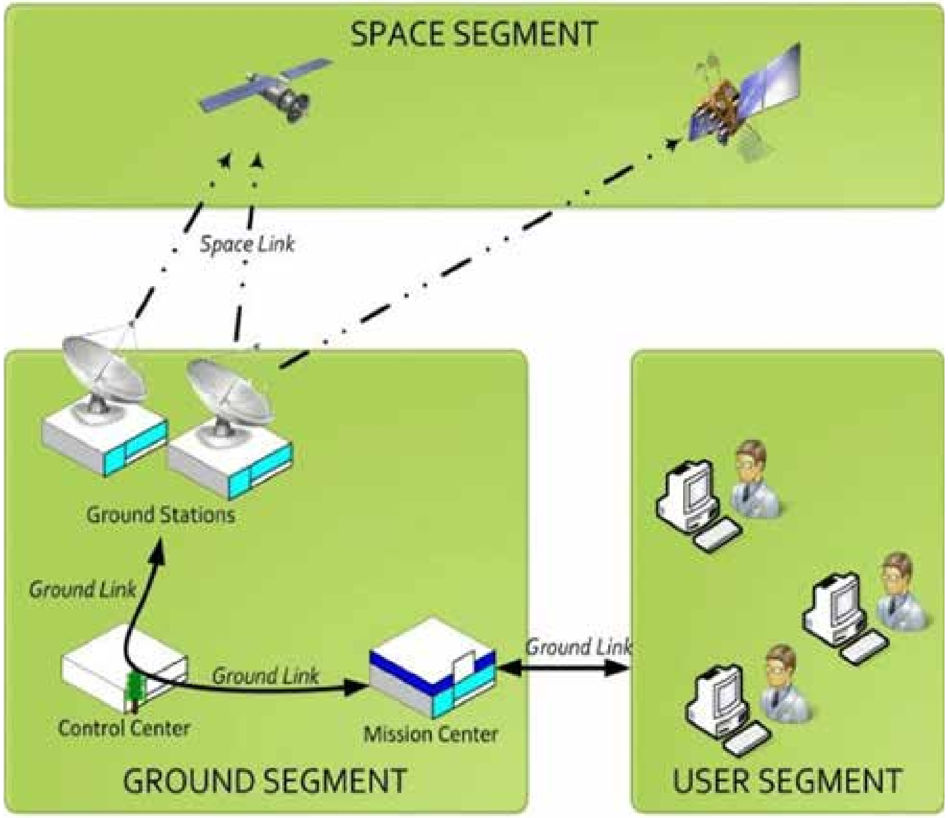

Figure 2 — Ground segment elements (Cerqueira, Do Santos and Ambrosio, 2013).

experiments onboard. Typically, the GS is subdivided into four elements as shown in Figure 2 (ECSS, 2008):

1. Ground Stations to handle the unidirectional or bidirectional communication link with the Space segment.
2. Control Center. Handles operation control, simulation, flight dynamics, data handling and distribution.
3. Mission Center is responsible for the mission concept, evaluation, analysis, mission exploration and payload data.
4. Network. Handles the interconnection of centers, GS, and SS, using terrestrial and space links.

When we use a LEO (Low Earth Orbit) satellite, is possible to use a low-cost ground station based on commercial off-the-shelf (COTS) products, both in terms of software and hardware components. The use of COTS integration is part of one of the technological objectives of this mission: to develop and demonstrate the coordinate interconnection among several GS for the operation of small satellite projects. Likewise, with the use of COTS elements the objective is to provide high-performance operation of the GS to ensure accurate and error-free data received from the satellite. (Gil et al, 2001).

Many LEO missions underestimate the importance of the GS and focus on the SS. However, the GS should be seriously considered from the beginning of the design of the mission, because once the satellite is in orbit it is the only link we have with the satellite, and therefore the only way to get evidence that the LEO satellite is operating properly. However, it is not only important to have an operative GS also is necessary to have trained and distributed operators who can communicate with it effectively. Typically, the LEO satellite only passes a few times a day through a specific GS location and can only establish communication with it for a few minutes, so an essential requirement to ensure the success of the mission is to have a background human team capable of establishing such communication (Duarte, 2016).

4. Amateur GS station model

For the DGSN, the GS is a key piece in the TEPEU-1 mission proposal; therefore, collaboration with the FMRE is established, so that satellite ham radio operators become the first receiving stations in Mexico. In addition to the invaluable cooperation of Mexican radio amateurs, a proposal for a semi-fixed GS (SFGS) is shown in Figure 3.

Considering that a GS will operate in the frequency range of 435 to 438 MHz and that the TEPEU-1 satellite will have an estimated power between 100 mW and 500 mW, the SFGS must include computer equipment to execute the software for automatic azimuth and elevation tracking as well as Doppler frequency correction (SatPC32). To have the station automated, an intermediate hardware stage is added to the SatPC32 based on Fox Delta Tracker model ST2-USB equipment, which handles the information exchange protocol for Yaesu® model G-5500 rotors, which would be the recommended rotor model for the SFGS. With this configuration in the SatPC32, the fixed earth station could receive all the information from the space segment, without need of human intervention, even in night orbits or on weekends.

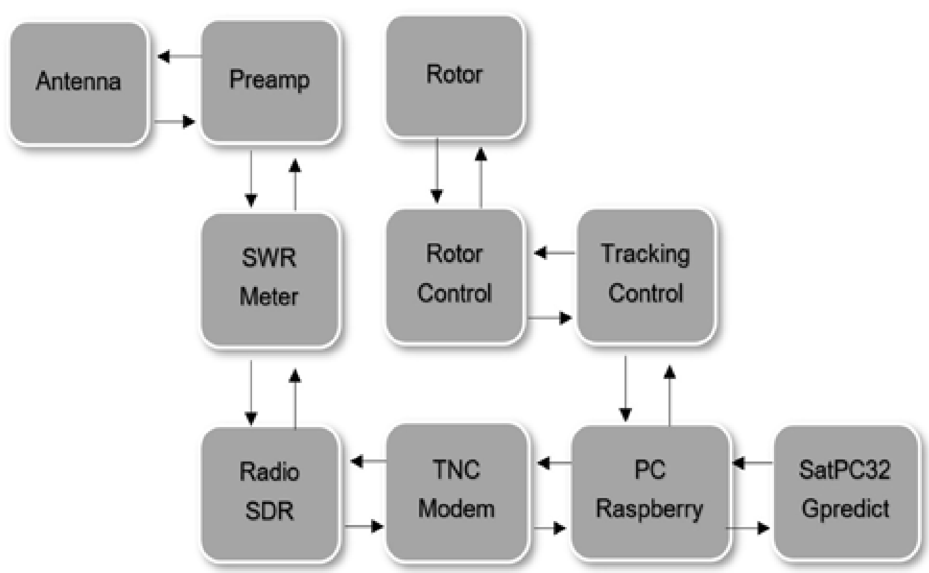

Figure 3 — Fixed Ground Station.

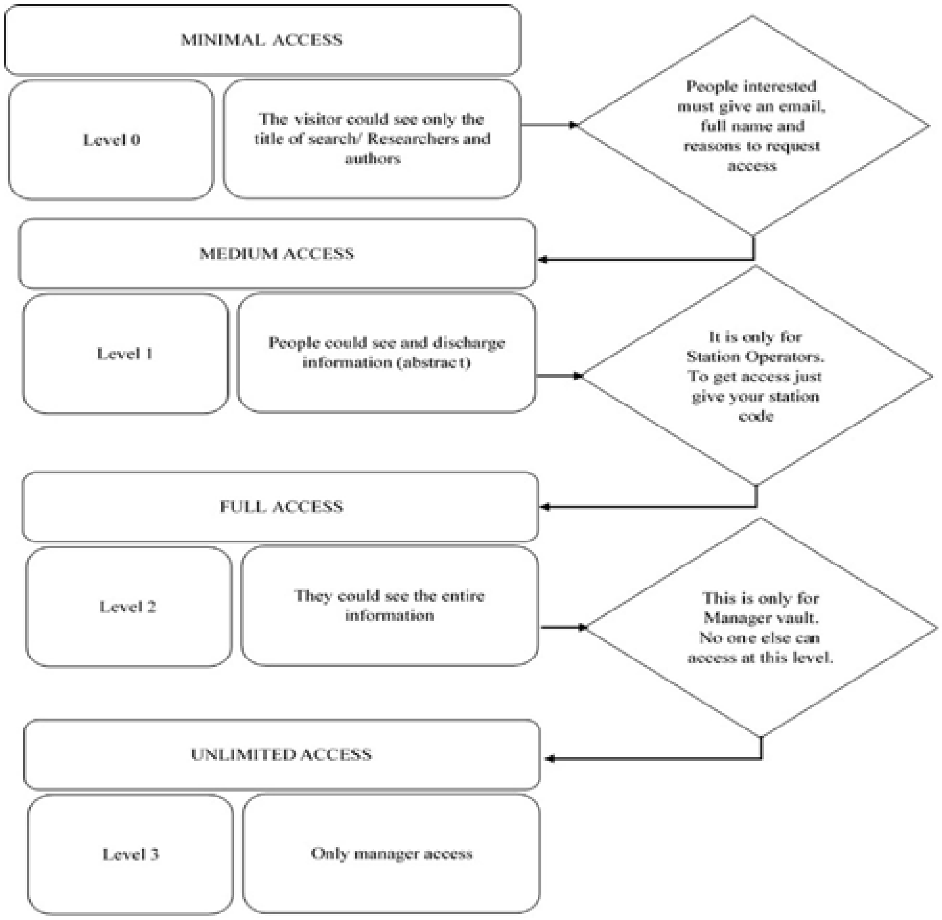

Figure 4 — Block Diagram of a proposal for a station link.

For the receiver system, circular polarized directional antennas with at least 15 horizontally polarized elements and 15 vertically polarized elements are recommended. One proposal is the 436CP30 model of the M2 brand which offers a gain of 15.50 dBi. It is advisable to support the antenna system with preamplifiers installed directly on the antennas; however, if coaxial cable no longer than 15 m and with low loss is recommended for use, then it would be possible to omit the preamplifiers. The coaxial line could be the LMR-400 as a minimum, or the LMR-600 to ensure low loss on the receiving line.

Portable Ground Station

For the Portable Ground Station (PGS), some elements represented in Figure 3 are not necessary or are replaced by other elements shown in the functional blocks that make up the structure of the SFGS. In the first place, the suitable PC is replaced by a Raspberry Pi using a Linux operating system. This proposal offers adequate computing power, portability and low power consumption, essential characteristics for portability. The use of Gpredict® is proposed to calculate the orbits of the LEO satellites, which provide all the functional characteristics of the SatPC32.

For the reception system, the PGS will use an SDR (software defined radio) instead of the VHF / UHF radio used in fixed stations. The SDR is useful in places where there is no electricity supply (it can be powered by a power bank). The specifications described so far mean that the PGS does not require an interface, modem or TNC used for the fixed station. The SDR has a USB connection port that is fully compatible with the Raspberry Pi card. Another advantage of the portable station is not needing the Fox Delta Tracker model ST2-USB interface because there are no rotors for tracking the satellite orbit, instead, a circular polarization non-directional antenna will be used. This type of antenna has the characteristic of receive signals when the satellite's orbit is more than 25 degrees of elevation without the need to track the trajectory of the satellite. The only requirement is to put the antenna at a low height (no more than 3 meters) and a place free of obstacles such as trees, buildings, etc. This configuration is recommended to have a low signal loss due to having a short coaxial line, which requires a male SMA and a SO-239 female adapter to connect the SDR

5. Feasibility of developing a network of ground stations based on amateur radio communications

A good way for data interchange is by an internet link among all stations. Maybe, this is less attractive but more convenient to ensure data in a central vault. The vault could be the H.D. computer of one station (member); keeping its information in each computer´s station in a star configuration design for this. Figure 4 shows an arrangement for linking stations.

Security Levels

All information is available, but not all people can access complete information. This means that members or the station operator (SO) have a free pass for the entire information. Visitors are welcome but just in the first level. The security levels and their descriptions are shown in Figure 4.

6. Data control and distribution scheme

The "Cloud Distributed Storage Platform" or CDSP is an essential component for the operation flow of the TEPEU project. As can be seen in Figure 4, once the data from the TEPEU sensor have been downloaded by the GS, they must be sent to the CDSP. The CDSP is composed of two main elements: the client and a set of distributed storage nodes. Each of the reception stations located throughout the planet must have an authorized CDSP client for the distribution of the captured data. Each of the reception stations located throughout the planet must have an authorized CDSP client for the distribution of the captured data. To ensure the secure flow of information among the receiving stations and the cloud storage system, each client will need to have a unique “token” for access to the CDSP. Moreover, the "core" of the CDSP, consists of a set of storage servers (elastic scaling), whose task is to store the information sent by the general coordinator. The general coordinator is responsible for validating the credentials (token) of the clients, once this is done, the processes divide and store the data together with the storage nodes (SS01, SS02, SS03), thus guaranteeing redundancy, security, and availability of information for end-users (Figure 5).

To avoid generating a bottleneck on the side of the coordinator, the use of an elastic load balancing system has been proposed, that is, the greater the number of requests from customers, the more resources from the coordinator are made available. It is important to note that the storage nodes

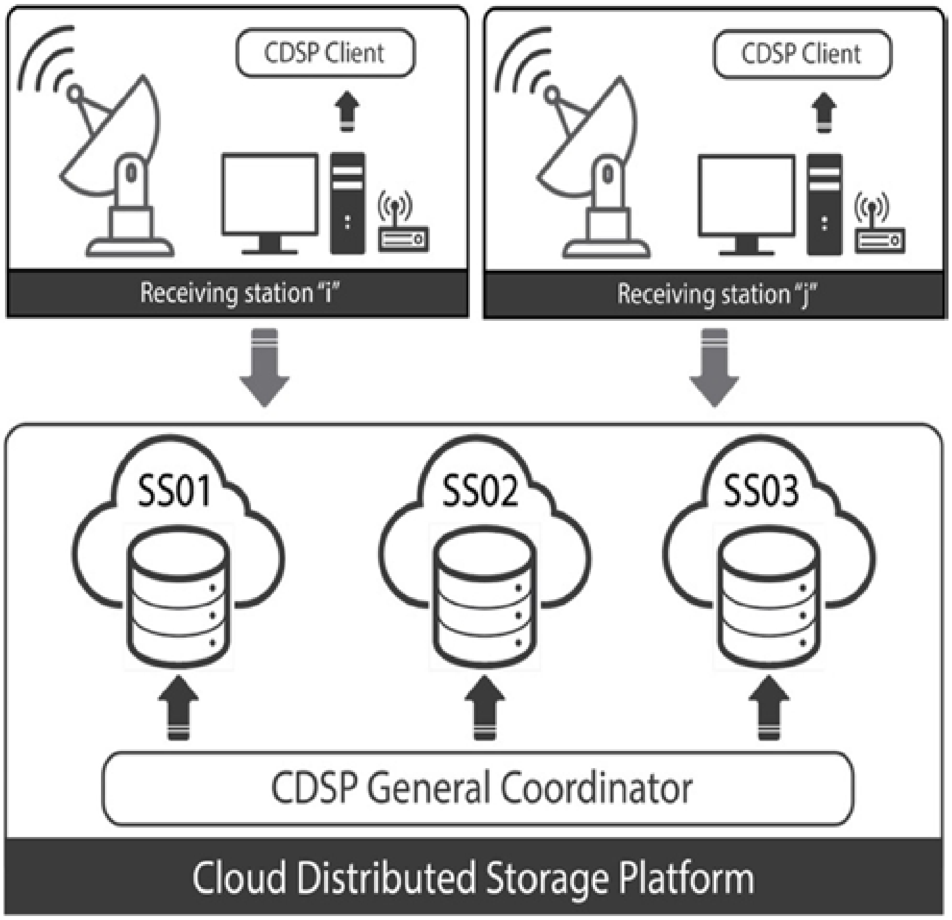

Figure 5 — Cloud Distributed Storage Platform (CDSP).

are not redundant, since they do not contain exact copies of each other; instead, a data partition scheme is used that allows distribution of various sections of the files (slices) throughout the storage nodes. Therefore, only a subset of these nodes is necessary to retrieve the original information thus increasing the robustness of the CDSP (Gonzalez-Compean et al., 2018).

7. Conclusions

In this work, a novel proposal has been presented for the integration of a network of telemetry control stations and data downloading for scientific and low-cost experimental satellite missions. The feasibility of integrating amateur radio associations around the world as part of that network has been analyzed as well. The rapid growth of technological skills and abilities by these groups positions them as a viable alternative for data download tasks. The design of a platform for distribution and storage of high availability data has also been analyzed. The partition of the information into slides will allow a high fault tolerance while optimizing the space and bandwidth required for the storage and distribution of the data, achieving a perfect interaction between the monitoring and download centers with the data centers distributed around the world.

For the mission's scientific team, the DGSN based on amateur radio is considered a major element in this study. The FMRE satellite operators are the core of the proposed DGSN. Their participation as SFGS and PGS guarantee the reception of the TEPEU-1 measurements over Mexico. However, the scientific group invites all satellite operators to join the DGSN. If anyone is interested in participating to increase this infrastructure, please contact the scientific leader:
Mario Alberto Mendoza Barcenas, Ph.D.
Email: mmendozab@ipn.mx.

8. References

AMSAT. (2018). FCC Part 97 "Amateur Radio Licensing for CubeSats." Available at www.amsat.org/wordpress/wp-content/uploads/2018/04/AMSAST_CubeSat_Licensing.pdf.

Cerqueira, C., Dos Santos, W. & Ambrosio, A. (2013). "Development of an Interface to a Spacecraft Simulator Empowered by Virtual Reality." *SBC Journal on 3D Interactive Systems*. 3. 37-44.

Duarte, C. (2016). Hacia el Espacio. México: "Estaciones Terrenas para CubeSats." Available haciaelespacio.aem.gob.mx/revistadigital/articul.php?interior=247.

ECSS "European Space Agency Members". (2008). *European Cooperation for Space Standardization. New Zealand: Ground systems and operations.* Available at ecss.nl/standard/ecss-e-st-70c-ground-systems-and-operations/.

Gill, E., Montenbruck, O., Kayal, H. & Briess, K. (2001). "A Concept for an Autonomous Space and Ground Segment Applied to the BIRD Satellite Mission." *19th AIAA International Communications Satellite Systems Conference*; April 17-20, Toulouse.

Gonzalez-Compean, J. L., Sosa-Sosa, V. J., Diaz-Perez, A., Carretero, J., & Marcelin-Jimenez, R. (2018). "FedIDS: a federated cloud storage architecture and satellite image delivery service for building dependable geospatial platforms." *International Journal of Digital Earth*, 11(7), 730-751.

Maini, A. & Agrawal, V. (2014). *Satellite Technology: Principles and Applications*. Third Edition. Wiley.

M.A. Mendoza-Bárcenas, et al. "Tepeu-1: Misión espacial mexicana con fines científicos y de validación tecnológica," SOMI XXXIV Congreso de Instrumentación. Año 6, no.1, Octubre, 2019. ISSN 2395-8499.