X Workshop em Engenharia e Tecnologia Espaciais
7 a 9 de agosto de 2019

Advancements in satellite data collection and relay concepts using small satellites

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Resumo. *CubeSats have become a relevant actor in the space sector, private sector has surpassed academic institutions in the number of spacecraft deployed in orbit. Main payload are used for communications, followed by R&D.*

Case studies of a fly alone Brazilian Data Collection Satellite (SCD-2) and Spire Global Lemur-2 constellation mission, are presented and then compared.

Issues regarding orbital inclinations accessibility and available power for CubeSat challenge the full constellation and spectrum of concepts concerning traditional spacecraft.

Spire has successfully deployed satellites and raised almost 150 MUS$, becoming a relevant actor to be watched as it develops.

Keywords: CubeSats; Data relay; Nano-satellites; Spire Global; SCD-2

1. Introduction

In the past decade, CubeSats (nano-satellites between 1 and 10 kg of mass) have become a relevant actor in the space sector, and many new concepts have been launched into orbit. CubeSats represent 70% of the over 1300 SmallSats[1] launched between 2012 and 2018 (Bryce Space and Technology, 2019). Figure 1 provides an overview of its evolution over the past two decades.

The Union of Concerned Scientists lists around 2000 operational satellites orbiting Earth (UCS, 2019). Hence the number of nanosatellites listed represents a significant actor in number (not in mass).

Of the payloads applications launched on SmallSats, 37% are communications, this is only comparable to R&D (31%) and surpasses Remote Sensing (18%) and Scientific payloads (17%) (Wekerle et al., 2017).

[1] It defines small satellites up to 600 kg mass, and includes both successful and unsuccessful launch attempts.

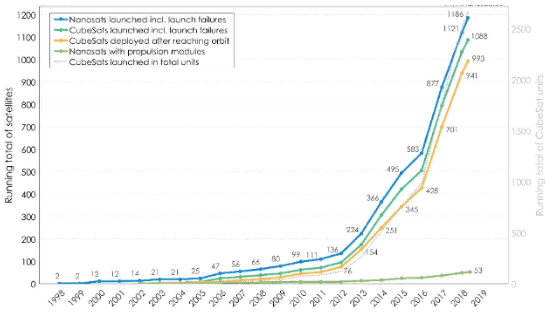

Figure 1 Total Nanosatellites Launched[2] as of June 10th, 2019 (Kulu, 2018)

Under this paradigm shift, new players have emerged, serving needs previously served by "traditional" big spacecraft or not feasible due to a high number of spacecraft required to provide the adequate temporal resolution. Specifically, data collection and relay concepts are addressed by deploying a large number of spacecraft providing short revisit times. One example, Automatic Identification System (AIS) being used for ship and plane tracking by Spire Global Inc. and new concepts are being assessed by deploying R&D proof of concept missions.

The purpose of this study was to perform a case study comparing the fly alone Brazilian Data Collection Satellite 2 (SCD-2), launched in 1998, with the nanosatellite constellation deployed by Spire Global for Automatic Identification System (AIS). The launch mass of SCD-2, 115 kg, accounts for around 30 Lemur 3U CubeSats[3].

Specific objectives of this study where comparing the small satellite concepts with respect to traditional spacecraft and identify constraints.

2. Methodology

Case studies for Spire Global's AIS constellation and SCD-2. First context information of each mission is provided, then an overview of traditional architectures for satellite data relay. Followed by some enabling technologies, as Software Defined Radios (SDR), Satellite AIS, and Small Satellite design philosophies.

Then the two missions are introduced, and respective parameters are synthesized into tables.

3. Results

Satelite de Coleta de Dados 2 (SCD-2)

The spacecraft, see Figure 2, designed in the early 90s, corresponds to INPE's firsts space crafts. Its design lifetime, of 2 years, was operational at least until 2012(eoPortal Directory, 2019).

Its mission was data collection from stations over Brazilian territory, particularly hydrology of the Amazon basin, atmospheric chemistry and was used for other purposes like oceanography and weather forecasting (NASA Space Science Data Coordinated Archive, n.d.).

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[2] For specifics on the database's definition of nanosatellite check https://www.nanosats.eu/#figures

[3] Estimation based on a 4 kg mass per 3U CubeSats, based on (Arash Mehrparvar, 2014)

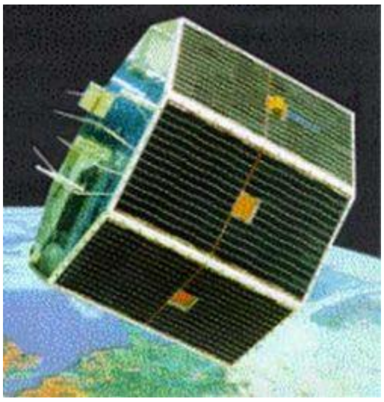

Figure 2 Artist representation of SCD-2 [Source: INPE]

Spire Global Constellation Lemur-2, 2nd generation spacecraft

With over 100 spacecraft launched into orbit, 76 of which are currently in LEO at Equatorial, 51.6°, polar, 83 and 85° inclinations. It has more than 30 active ground stations to provide services with the required temporal resolution (Spire, 2019). Its constellation provides services GPS radio osculation, weather at, AIS and ADS-B (Kulu, 2018).

Second generation Low-Earth Multi-Use Receiver, in short, Lemur-2 CubeSats can be seen in Figure 3, where the “mass production” can be easily observed. They represent the spacecraft to be used for the benchmarking with respect to SCD-2.

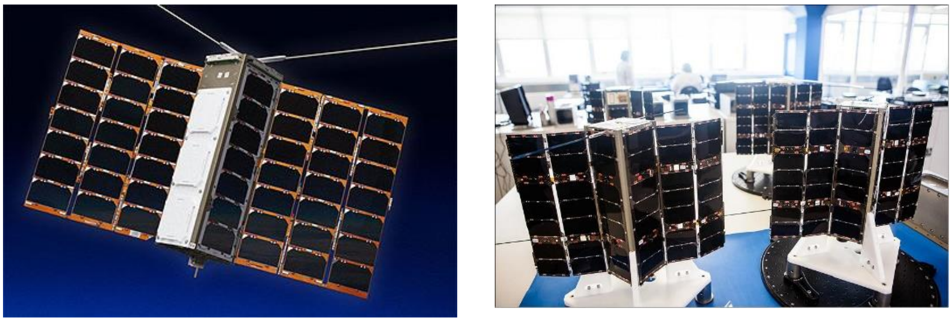

Figure 3 Triple Unit Lemur-2 Second Generation Satellites(Spire, 2019)

The active constellation can provide traffic routes, as seen in Figure 4.

Figure 4 AIS and AIS-B Spire data products (Spire, 2019)

Satellite communications architectures

Due to their vantage point, satellites have been used for data relay since Telstar was launched in 1962. The different architectures consider Geostationary Spacecraft, deployed in an equatorial circular orbit at almost 36.000 km altitude and remaining fixed with respect to a pint on earth, as well as LEO, HEO, and MEO constellations where the spacecraft moves with respect to the ground. Several links between space and ground elements, as described in Figure 5, of which the relay concept is of interest for this study.

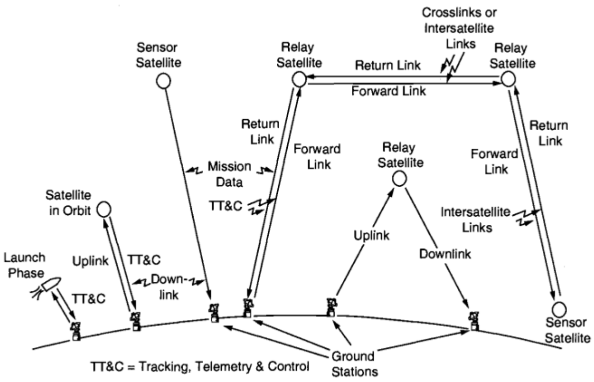

Figure 5 The communications architecture consists of the satellites and ground stations interconnected with communications links (W. J. Larson & Wertz, 1999)

Live communication is feasible if the two points of interest are connected; for several studies, a need to extract data from remote sensors are addressed by store and forward concepts.

Specifically, the cases where no real-time relay is required and data captured can be stored onboard the spacecraft until a relevant ground station come into contact for downloading it.

Nanosatellites are deployed into LEO, as "piggyback" of Earth Observation mission in SSO. Also, some are deployed from ISS supply missions in ~50° inclination. Inclinations can be seen in Figure 6, where they can be grouped mostly into SSO or ISS ones.

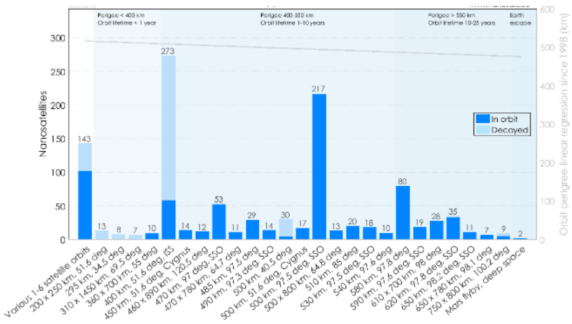

Figure 6 Nanosatellite approximate orbits as of June 10th, 2019 [Source: (Kulu, 2018)**]**

Some Enabling technologies

Some key enablers of the nanosatellite used for communications are Software Defined Radios (SDR), the CubeSat Standard and especially the launch adaptors that allow faster integration in several launch vehicles.

As defined by (Birkeland & Quintana, 2018) SDR are flexible technology that allows generic communications hardware to serve different communications needs just by updating the software. Flexibility, is very relevant for small satellites as it can be used to increase data throughput, changing frequencies, modulation schemes, and others.

Furthermore, nano-satellites have enabled multi-spacecraft constellations concepts in LEO to flourish. Figure 7 provides an overview of announced constellations, where both Planet Labs and Spire have effectively deployed over 450 satellites (Kulu, 2018).

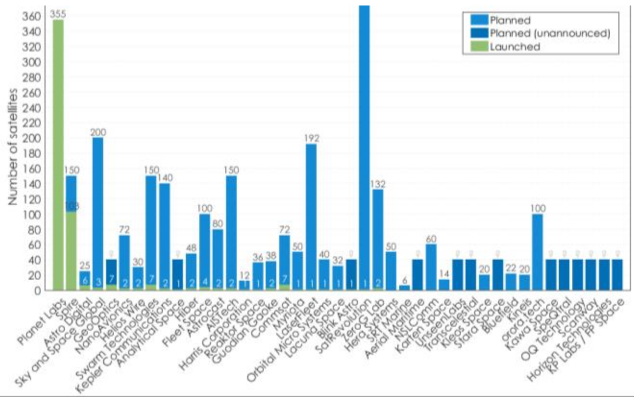

Figure 7 Nanosatellite constellations as of June 10th, 2019 [Source: (Kulu, 2018)**]**

The design approach for this high number relates more to the smartphone evolution than the traditional space industry. Spire deploys new LEMUR spacecraft almost every month, being continuously updated in software and with major hardware upgrade every 2 to 3 years. This times can relate to the period upgrade their smartphones.

Satellite Automatic Identification System (AIS)

AIS is a global standard for ship-to-ship, ship-to-shore, and shore-to-ship communications and contributes to collision avoidance, SAR operations, and others. It has been mandatory since 1974.

AIS was developed as a terrestrial system and therefore never intended to be received by satellites. These design considerations, posed several challenges, like its low power 1 to 12.5 Watts depending on the AIS transmitter); also IAS messages can be transmitted within the same 'slot' by tow units when sufficient physical distance exists. So several vessels could transmit in the footprint of the satellite, especially in high-density routes (Carson-Jackson, 2019)

Satellite AIS picks up signals to increase vessels visibility in remote areas around the world.

Small satellite design philosophies

Some relevant principles and practices for small satellites are outlined above:

- Engineering to cost by carefully trading mission objectives against the cost (Try to achieve 80% performance of conventional satellite at 20% cost)
- Recommended design practices: Keep it simple and stupid (KISS); Minimize moving parts and avoid toxic, volatile or explosive materials; Use previously flown designs and components in essential systems; Be realistic with safety and design margins; Ensure systems are capable of independent operations – avoid chains; Use a layered, failure/resilient system architecture

- Standardization and use on Commercial Off The Shelf (COTS) components when possible

Discussion

Note difference concerning the number of ground stations for INPE's missions and several spacecraft and contacts to be managed per day in the case of Spire's Constellation.

SCD-2 is relevant at its launch is around the first release of the CubeSat standard in the early 2000s (Puig-Suari, 2001). Also, one should consider how many cell phone updates have we had over the past two decades, in terms of hardware and software technological evolution.

Regarding the orbital parameters, see Table 1, the SCD-2 mission is intended to provide coverage above Brazil, in which case near-equatorial orbits is a better fit. On the other end, the business case for Spire relies on global coverage

Table 1 Main orbital elements [Source: Adapted from (Kulu, 2018; NASA Space Science Data Coordinated Archive, n.d.)

	SCD-2 INPE	Lemur-2 Spire
Orbit type	Circular	SSO
Inclination [°]	25.0°	97.5
Altitude [km]	742km x 768 km	500km
Design lifetime	2 year	2 years
Operational lifetime	10 + years	

Power and link budgets of an individual Lemur spacecraft are far inferior with respect to SCD-2. However, the temporal resolution and the size of the active constellation allow for shorter revisit periods, which allow for lower volumes of data need to be stored and relayed.

Table 2 Main Spacecraft parameters (eoPortal Directory, 2019; Kulu, 2018; Spire, 2019)

	SCD-2	Lemur-2 Spire[4]
Payload	RF communications: S-band TT&C for housekeeping. On-board storage capability for TT&C data. A UHF uplink at 401.650 MHz and 401.620 MHz used for data collection.	STRATOS (GPS radio occultation payload), SENSE (AIS payload)
Total mass	117 kg	4 kg
Power	110W	20 W[5]
Manufacturer	INPE	Spire Global
Launched	23/Oct/1998 (on Pegasus)	15/Feb/2017 (PSLV-XL-C37
Launch cost	12 million USD[6]	295 thousand USD[7]

[4] Data provided here corresponds to Lemur-2-23 Spire-Minions (FM24) https://www.nanosats.eu/sat/lemur-2

[5] Estimated for analogous wing solar panels by GomSpace, as data for the spacecraft couldn't be found. https://gomspace.com/UserFiles/Subsystems/datasheet/gs-ds-nanopower-dsp-11.pdf

[6] Estimated at 40 million USD for 375 kg in LEO https://www.nextspaceflight.com/launches/details/240

[7] For a 3U according to http://spaceflight.com/schedule-pricing/#pricing

4. Conclusion

A case study for SCD-2 and Lemur-2 was developed. Challenges in the availability of relevant technical details made it difficult to benchmark each concept in much details. Hence, a generalization of aspects has been provided.

Though some principles of small satellite design philosophy can be observed in the SCD-2 mission, only two spacecraft effectively reached orbit, while over 60 spire spacecraft have been successfully deployed and operated.

Constrains for cost-effective deployment of CubeSat in specific orbital inclinations, different than SSO or Polar and ISS near 50°, yield challenges for missions with specific orbital needs (as the case of Brazilian territory).

Further research

- Satellite internet concepts: One Web, Keppler, Starlink (Space X) and other mega LEO constellations
- Propulsion capabilities for orbital maneuvering or innovative concepts for Nano-satellite deployment will be critical to providing specific orbits to fill in the constellation or replaced decayed or nonoperational spacecraft. For this, the work of (Grönland, Palmer, Bejhed, & Elgaard, n.d.; NASA, 2019; Pascoa, Teixeira, & Filipe, 2018) will provide relevant insights in terms of current technology readiness level and trends.

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