Distributed system for agile development of advanced and specific Earth Observation solutions

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Abstract

Small satellite mission architectures pose new challenges to traditional Earth Observation systems. This paper describes a system composed by several interfaces and processing units distributed across three segments: mission segment, big data node and client segment. Each component is capable of acquiring, exchanging and processing data, making decisions and communicating the results to others, exploiting different instruments and devices from satellites and other platforms and also increasing the system configurability to adapt to diverse configurations, rapidly changing scenarios and advanced applications. The agile development of advanced and specific solutions is based on the flexibility of the proposed system, with a distributed and scalable design.

1. INTRODUCTION

Since the early 2010's, there has been an increase in the number of minisatellite, microsatellite and nanosatellite missions. During 2016, the number of small satellite missions surpassed the 600 mark, one third of which are devoted to Earth Observation (EO) and related applications[1]. This ratio might increase or decrease in the future years, but the number of small satellites dedicated to EO in orbit will grow for sure, as most of the ongoing and newly planned missions rely on several satellite platforms, each carrying one or more instruments, i.e. a constellation. The common goal is to offer imagery with broad world coverage and short revisit times. Fine tuning of spectral, spatial and radiometric resolution is typically performed during mission planning to match requirements from specific applications, and standard products and services are provided to end-users.

To address the high volume of data generated by these new missions it is mandatory to develop robust systems. But to better exploit their architectures in conjunction with the use of arising technologies and data science, flexibility should be considered a primary aim for these new systems, hence the need for a distributed and scalable design. This paper describes such a system - adaptable to diverse small satellite mission configurations and scenarios.

2. DISTRIBUTED SYSTEMS AND POTENTIALITY FOR EO

2.1 Trends and challenges

Traditionally, EO satellite missions were comprised of a flight segment including one or a few service platforms with payloads consisting of one or more remote sensing instruments, a ground segment with a centralized mission control and one or a few ground stations (to optimize downloads), and a user segment with static products and services. Each mission could combine several satellite platforms and thus form a constellation.

The current trend is to simplify - and multiply or diversify - the components of a satellite constellation, so it comprises several microsatellites or minisatellites. The next step is to add communication between the platforms, on-board data processing and real-time or near real-time decision-making to maximize each satellite usage. What we fancy is an expansion of the scope of these interactions to further increase the capabilities of a mission, exploiting different instruments and devices from satellites and other platforms and also increasing the system configurability to adapt to rapidly changing scenarios and advanced applications.

From an end-user perspective, we find that the results of the processing of remote sensing data are usually more useful than the data itself. Therefore, the exponential increment in available data should be met by the usage of processing techniques that can ingest large amounts of data and come up with the needed results in a reasonable time, i.e. Big Data. Nonetheless, data acquisition and processing capabilities as well as system configurability amount to little if there is no mean for the generated information to reach the end-user in a suitable and timely fashion.

2.2 Proposed architecture

Drawing from the experience of traditional EO missions, we propose a system composed by several interfaces and processing units distributed across different segments[2], as seen of Figure 1. Each component is capable of acquiring, exchanging and processing data, of making decisions and communicating the results to the other components, thus providing valuable features such as on-board data processing, inter-satellite links and cross-cueing between the platforms.

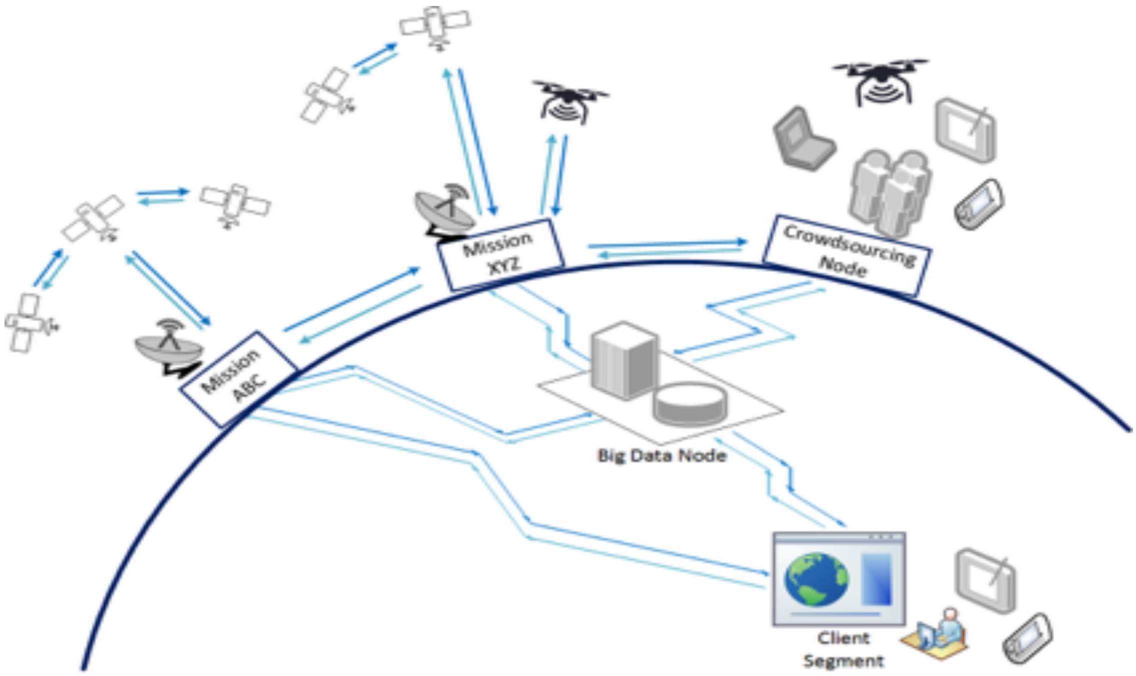

Figure 1. General scheme of the proposed system.

3. SYSTEM SEGMENTS

The components are spread through three segments, with these main functions:

- **Mission Segment**:
    - Data acquisition (from satellite and airborne platforms, and crowdsourcing devices).
    - Multi-mission command & control.
    - Calibration/validation (including crowdsourcing).
    - On-board processing.

- **Big Data Node**:
    - Data storage and backup.
    - Product generation (high volume, high performance data processing).

- **Client Segment**:
    - Access to specific solutions.
    - Data distribution (to end-users).
    - Application modeler.

Each segment is explained below.

3.1 Mission Segment

Service platforms and EO payloads (a traditional flight segment), ground stations and the crowdsourcing nodes and devices conform the Mission Segment.

3.1.1 EO mission scheme

Figure 2 presents a scheme of the Mission Segment components of an EO mission, and their relationships.

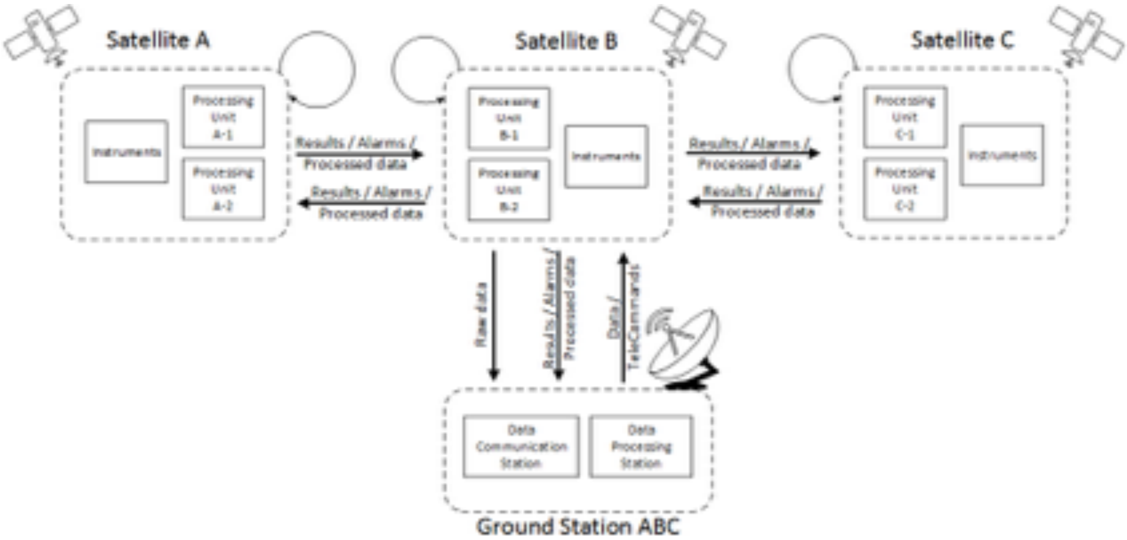

Figure 2. Mission Segment for a generic EO constellation ABC.

Each EO mission consists of several ground stations and platforms with remote sensing instruments and embedded processing units capable of processing data acquired by the said instruments in real-time or near real-time.

The ground stations establish periodic and time-limited data links with platforms to receive raw and processed and perform command & control and calibration/validation operations. Ground stations can also send and receive data from other ground stations dedicated to other missions, enriching the capabilities of their own mission.

The platforms on each mission do not necessarily have to be of the same kind, e.g. a satellite could synchronize data acquisition with an Unmanned Aerial Vehicle (UAV). One particularly appealing feature of this scheme is the ability to receive and transmit data by using the constellation satellites as relays, e.g. in the scheme shown in Figure 2, Satellite B can be used as relay for Satellite A to transmit data to Satellite C or to receive data from the Ground Station ABC.

On-board processing units can be physically separated by using technologies appropriate to the computational load and tasks to be performed, or can be logically designed as different processors embedded in the same on-board platform. Processing units also can be invoked and configured according to specific needs. Table 1 shows examples of typical sensors found on small satellites [1,3], and the derived information that could be generated on-board for quick decision-making.

Sensor technology	Spatial resolutions	Derived product
Reflective panchromatic	Very high/High	Object detection
Reflective multispectral/ superspectral	High/Medium	Vegetation/Environmental indexes Cloud detection
Emissive (thermal)	Medium/Low	Hot spot detection Cloud detection
SAR	High/Medium	Object detection Vegetation/Environmental indexes
RGB video	Very high/High	Object tracking

Table 1. Real-time or near real-time data processes for specific needs according to sensor.

This information can be used to trigger certain actions on instruments or other processing units in the same platform or via direct or indirect links to other platforms operating in tandem or sequentially in the same constellation, resulting in chained schemes. The resulting concatenated logic would allow for an efficient use of the payload or the service platform resources - e.g. the maximization of useful data acquisition or the optimization of energy consumption and downlink bandwidth usage.

In the proposed architecture, ground stations are also able to pre-process the received data, and to use results to trigger certain actions or to switch between different logic schemes or update the status of a proposed task. The inherent limitation of this exchange is the round trip time of the link between the platforms and the ground.

3.1.2 Crowdsourcing scheme

Figure 3 presents a scheme of the Mission Segment components dedicated to crowdsourcing: devices and nodes, and their relationships. In this scheme, crowdsourcing must be understood in a broader sense to include data manually or automatically ingested from several devices such as sensor networks, weather stations, precision farming equipment, mobile phones, etc. i.e. Internet of Things (IoT).

These data sources are equivalent to the flight segment of an EO mission as described before, with the main difference of having multiple remote users who decide which data acquire or generate as well as which data require or consume. In such a context, it is imperative to centralize and analyze the provided data and the requests, in order to validate both. The crowdsourcing node is in charge of managing data exchange with the different sources in order to ensure efficiency, coherency and security of the intended operations. The rules for determining the validity of the requests and the provided data are set according to each specific solution.

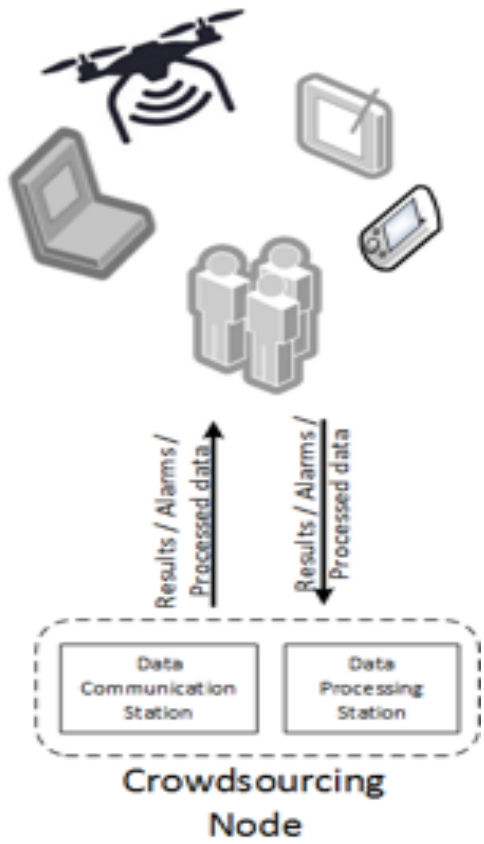

Figure 3. Mission segment for crowdsourcing.

Crowdsourcing nodes can also send and receive data from ground stations and other crowdsourcing nodes.

3.2 Big Data Node

The Big Data node receives the data from ground stations and crowdsourcing nodes and it is where the main mission products would be generated. This node also functions as a safe data repository and catalog for all the data that is exchanged and generated in the system, providing traceability of data and processes, and backup and recovery.

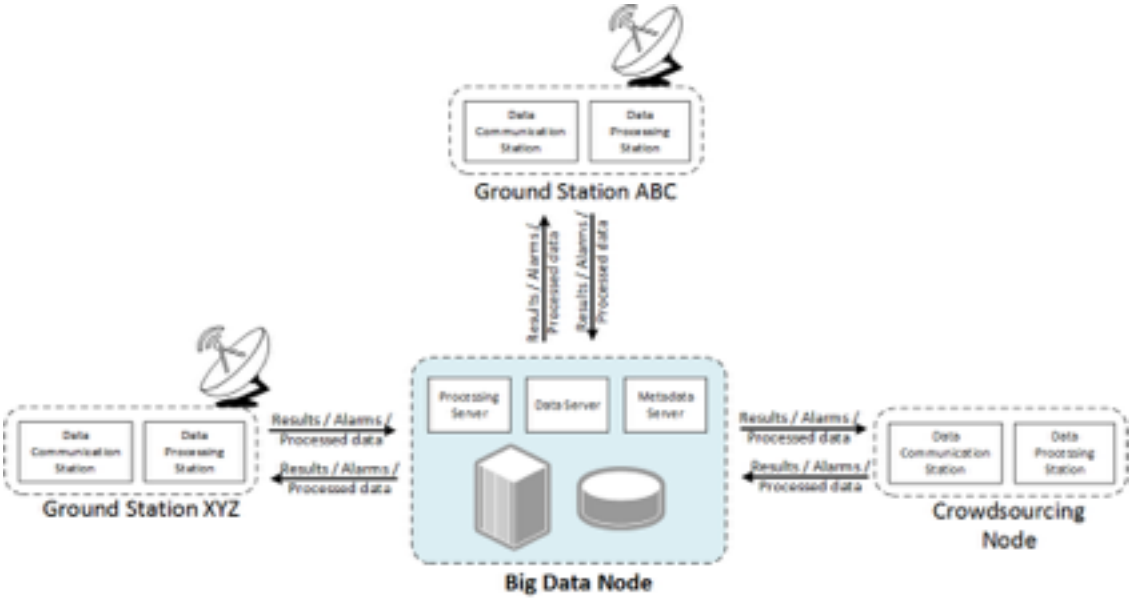

Figure 4. Big Data Node

As it is schematized in Figure 4, this central node is provided of three main servers engaged in different tasks:

- **Processing server**: Capable of performing complex computations on high volumes of data to generate advanced products - useful for providing specific services to end-users over several applications. This server is responsible for orchestrating processes generated manually (i.e. users requests) or automatically (i.e. requests from other processing units).

- **Data server**: Manages all the data received by trusted sources, and the products generated by the processing server.

- **Metadata server**: Provides cataloguing of all the above data by managing the metadata associated to it.

Information from the Big Data Node can be used as feedback for processes on other segments.

3.3 Client Segment

The Client Segment is basically a multi-format interface to handle requests from end-users and make the relevant information available when, where and how it is needed. It should rely in desktop and web access, mobile applications and customized solutions. Human-readable data such as alerts and notifications must be provided as needed. A plus would be using modern technologies such as virtual/augmented reality to enhance the experience.

Besides customary user profile and order management, this segment might have an application modeler to build advanced products and services seizing the processing units distributed across the different system components and their data exchange capabilities.

4. AGILE DEVELOPMENT OF EO SOLUTIONS

Having a distributed system with the specified features eliminates the set-up of an EO mission and provides the basic blocks to build a solution. The steps for the agile development of a successful solution would be:

1. Analyzing the problem/situation and the solution requirements.
2. Checking the availability of components that can be used for the specific application.
3. Weighting of possible solutions within the restrictions of the system.
4. Selecting the best fitting solution, or adding new components if needed (go to 2).
5. Configuring the system (the system propagates the configuration to each of the components to meet the requirements).
6. Presenting the relevant products and services to end-users.

The capabilities of the proposed system would be better showcased using as an example a specific application with advanced requirements, such as Search & Rescue. As it is unfortunately demonstrated by the ongoing search for the Malaysia Airlines' flight MH370/MAS370 - a Boeing 777-200ER which was lost on March 8th 2014 with 239 persons on board and presumably crashed on the southern Indian Ocean with little debris recovered, the (then) current EO satellite missions were not well suited for providing a solution, especially on offshore operations. There are several reasons for this.

Firstly, there is a high demand for spatial coverage: the initial search areas for a ship wreckage or an airplane crash landing on open waters tend to be huge. Besides, the search area expands over time, as marine currents and weather events can spread debris and any survivors even further. This leads to urgency in the need for coverage - and more so if survivors are expected. Life expectancy on waters under 21 ºC (without proper isolation) is measured in hours. Other conditions that usually pose a strong restriction to the use of satellite imagery in search and rescue are the spatial resolution of sensors and presence of clouds/mist over the area of interest.

New small satellite constellations (when fully operational) would meet the nominal requirements in pixel size, spatial coverage and revisit time for search and rescue operations, but any effective solution based on satellite imagery would need a distributed system to make an efficient use of the resources dedicated to the task.

In regards to the acquisition programming, the proposed system would allow an intelligent schedule over the search area - coordinated between different platforms or missions, but also dynamic to allow for a response to a changing scenario. Inputs ingested in advance would include the latest meteorological information from different agencies and the most recent positions of the rescue vessels and any findings as well.

If the satellite has the required on-board processing capability, automatic object detection over the sea would be performed. The coordinates and time of the detected pixels, would be sent in real-time or near real-time to the situation room and the nearest rescue vessels. Even if the satellites are not on-sight from a ground station, acquired scenes, and any derived products, would be relayed via inter-satellite links to the nearest station, thus minimizing the delay in the use of the information.

The whole operation of the constellation and the system could be monitored 24/7 from the situation room. Pre-requested data could be made available to other systems. Alerts and other notifications can be configured to be sent to mobile phones.

5. CONCLUSIONS AND FUTURE WORK

There are multiple active and planned EO missions based both on established and arising technologies. The world will be scrutinized as never before in the years to come. There are countless applications that could potentially emerge from the large amount of versatile data that would be generated on a daily basis - from direct visual interpretation to multi-variable environmental monitoring, business intelligence and emergency response.

We believe that, through the combination of the components and capabilities presented in this distributed system we can configure it to serve most needs in a resource-effective way. We have proposed to lower the time and complexity required to deploy custom-based solutions by incorporating data from multiple EO platforms and crowdsourcing, identifying reusable components and making them available on the same framework, and allowing users to configure the interactions between them, promoting the synergy between data of varied sources. Besides, each time a new Mission Segment is incorporated, new opportunities for combinations of components would arise.

The agile development of advanced and specific solutions would allow more people to benefit from geospatial data and technologies. The proposed system aims to be the nexus between EO-based products and services, applications and end-users. As such, to make realistic estimates of performance and restrictions of this system, a next step would be to model the required data bandwidth and processing load of advanced solutions built over the specifications of current and planned commercial constellations.

REFERENCES

[1] Federal Aviation Administration (FAA) Office of Commercial Space Transportation, The Annual Compendium of Commercial Space Transportation: 2017, Washington, USA (2017).

[2] K. Beckett, UrtheCast second-generation Earth Observation sensors. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives, 1069-1073 (2015).

[3] Gabriel Fusca, Emiliano Castañeda, SuriNG: Plataforma de trabajo geoespacial colaborativo. 6TH International Symposium on Innovation and Technology, Mar del Plata,Argentina (2015).