A New Model Proposal for Integrated Satellite Constellation Scheduling within a Planning Horizon given Operational Constraints

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Abstract: The operational use of satellite systems has been increasing due to technological advances and the reduced costs of satellites and their launching. As such it has become more relevant to determine how to better use these new capabilities which is reflected in an increase in application studies in this area. This work focuses on the problem of developing the scheduling of a constellation of satellites and associated ground stations to monitor different types of locations (targets) with different priorities for a given planning horizon. In order to address this problem we will propose a new model that considers explicitly the operational requirements of Brazilian relevant scenarios for a given planning horizon and target priority list. The methodology to be developed to solve this model will also be discussed.

1 INTRODUCTION

The rapid rate of technological advances in the area of spaceflight and sensors combined with the reduced costs of satellites and their launch yield potential for applications in many areas like navigation, communication, weather forecasting, and also defense, safety and security, e.g. detecting oil spilling, monitoring borders, etc. (IPIECA, 2006; Brekke and Solberg, 2005; Gagne, 2017). As such there is an increasing need for support during the acquisition phase and planning of the use of these new technologies.

As Brazil is in an emerging stage in terms of management and development of satellite systems technologies, there is a need for research focusing on this context seeking a better management of satellite services and products to increase the autonomy and sovereignty of the country. Remote sensing using satellites to acquire information on given areas of the Earth´s surface are particularly interesting given Brazil´s vast territory of more than 8.5 million square kilometers. In order to contribute to this challenge, this work focuses on the development of a realistic optimization model that, given a planning horizon and the specifications of different satellites/sensors, can support the decision making process on the best planning to monitor different types of targets (high and low priority ones) taking the mission requirements into account in a Brazilian context.

As the mission requirements determine the type of satellites/sensors that should be used, it is important to define scenarios with logical requirements. Brazil is confronted with several environmental and security issues like drought, deforestation, floods, landslides, dam ruptures, oil spilling along the coast, border monitoring issues, etc. For some of these situations satellite remote sensing is an interesting option as sensors on-board of such satellites can scan vast areas during day and night and download this data to ground stations for further processing and usage. However, the satellite orbit and characteristics of the on-board sensor as well as the location of the ground stations yield limitations on the number of times and the duration that a given area can be scanned by a particular satellite and the time at which the collected information can be downloaded to the ground station. In this paper we will consider mostly scenarios for which, regular monitoring can increase the situation awareness and enable both early detection of disasters and/or mitigation actions, like:

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- → Deforestation in the Amazon: a very extensive inland region of difficult access that is often victim of deforestation attempts. The detection of small areas of deforestation at an early stage will permit authorities to take mitigation measures to contain this deforestation.
- → Oil spilling along the extensive Brazilian coast line: the extraction and transport of oil in this vast area, which lies adjacent to some natural reserves, poses environmental challenges. It is of the utmost importance to detect oil spilling at an early stage to contain any environmental disaster.
- → Monitoring Brazil's border: this border incorporates parts of the world's largest rainforest, which are difficult to access. Therefore remote sensing of this vast area is required in order to identify activities like the construction of alternative roads for smuggling or transportation of drugs.

Figure 1 provides an idea of the location and area extension of the scenarios described above, and the positions of the Brazilian ground stations as well.

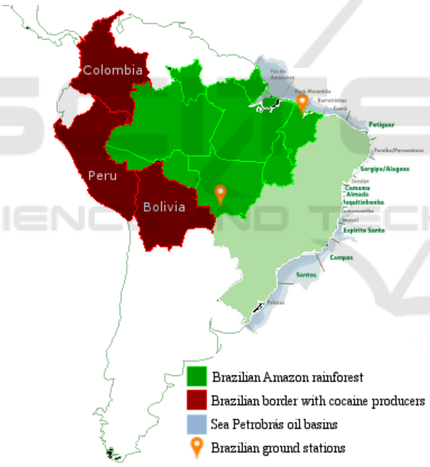

Figure 1: Brazilian scenarios information based on Petrobrás (2007), Gagne (2017) and DPI (2017).

This paper is organized as follows. In Section 2, we introduce the problem and provide a review of related models proposed in recent literature. Next the operational background on satellite remote sensing as well as the MATLAB program that has been developed to compute the satellite coverage is described in Sections 3 and 4. This coverage will be input to the optimization model that will be discussed in Section 5. Section 6 presents further research possibilities.

2 DATA ACQUISITION AND DOWNLOAD SATELLITES SCHEDULING PROBLEM

This section introduces the Data Acquisition and Download Scheduling Satellite Problem (DADSSP) and discusses related proposed models.

DADSSP considers the planning problem of assigning a set of different data requests (targets) with different values (priorities) to a constellation of heterogeneous satellites and ground stations in such a way that the value of the collected data is maximized (as not all the targets might be addressed), while dealing with time-windows constraints and different operational restrictions. DADSSP also takes mission requirements constraints into account, like revisit time (the time interval between successive observations of the same target) and due time (the latest time for reception at the ground station of the acquired new imagery of the same target). This problem is related to the heterogeneous fleet routing problem with time window and capacities (Toth and Vigo, 2014).

Most of the existing literature takes only the acquisition problem into account in a static (Sundar et al., 2016) or dynamic way (Zhai et al., 2015; Niu et al., 2015). Also literature can be found related to the scheduling problem of downloading the acquired imagery by a satellite constellation to several ground stations (Marinelli et al., 2011). However, in this paper we will focus on literature that addresses problems similar to DADSSP (Wang and Reinelt, 2011; Wang et al., 2011; Kim and Chang, 2015). These papers handle both the acquisition and the download planning but report few or no details about the data and do not devote attention to operational constraints (related to orbit/sensors characteristics like inclination, altitude, resolution, etc) and/or to mission requirement constraints.

Wang and Reinelt (2011) consider the acquisition and download planning aiming to maximize the summed rewards of serviced requests subject to acquisition/download constraints and visibility time-windows constraints, taking transition time between consecutive acquisitions/downloads into account. The precedence of the acquisition and the download of the same request and the capacity of the satellite memory level are also modelled. Their modelling approach has been tested considering satellites from the First Chinese Environment Monitoring Constellation and ground stations from China, in a two-days planning horizon.

Wang and Reinelt (2011) randomly generated the input and it is not clear how the satellite related data was modelled. Wang et al., (2011) provided more details about the satellite system and energy capacity constraints are included in a nonlinear model. As this model is not easy to apply in practice and since, according to the author, the acquisition planning plays a more decisive role than the download planning, a priority-based heuristic with conflict-avoidance and a decision support system based on the model is provided. The methodology was tested using the same set of satellites of Wang and Reinelt (2011) but considering spot and/or polygon targets, uniformly positioned inside and/or outside the mainland of China. The target rewards were again randomly generated. Their paper presents another version model of DADSSP and takes into account relevant space operational concepts like the sensor agility (capability in both roll and pitch axes, i.e., it can look to the left and to the right and image targets ahead and behind). However, requirements like due and revisit time are not considered in the model.

Kim and Chang (2015) also considered the acquisition and download problem, but their objective was to reduce the system response time defined as the time between the image data request and its final distribution (including on-orbit imaging, download and image processing on Earth). A genetic algorithm is proposed to solve the problem. The paper shows that the mission planning using the scheduler reduces the system response time. It also shows that an increase in the number of satellites decreases both the revisit time and the response time yielding an increase of the overall mission cost. Moreover, a higher number of satellites does not result in a significant decrease in revisit time nor response time. They considered a horizon planning of two months and a 50 × 50 km arbitrarily selected target area on the Korean Peninsula. Their paper considers several details about the satellite system but not in a generic way as only Synthetic Aperture Radar (SAR) sensors are included in the constellation; in particular, agile SAR sensors with automatic change detection for abnormal activities, strip map mode for a large coverage and, after, spotlight mode for high resolution.

The above literature review has shown different types of models (concerning associated variables, constraints and/or objectives) and that the DADSSP has not yet been tackled before. It also showed the importance of deriving models that are operationally relevant and that take into account the space operations concept (orbit/sensors characteristics) and the requirements of the scenario.

3 OPERATIONAL CONCEPTS

This section will summarize basic elements of the concept: satellite orbits, imagery sensors and ground stations.

3.1 Satellite Orbit

Satellite orbits depend largely on the altitude above the Earth surface and can be categorized as Geosynchronous Earth Orbits (GEO), Medium Earth Orbits (MEO) and Low Earth Orbits (LEO).

GEO satellites orbit Earth at an altitude of about 35,800 km, and are known to cover about one-third of the surface of Earth, which is a great advantage. However, as a consequence of the large distances involved, the resolution of remote-sensing pictures taken from such a position is typically limited. LEO satellites (at altitudes up to 1500 km) do offer excellent resolutions, but their coverage area is restricted, and because of the inherent motion of the spacecraft with respect to Earth, they can observe specific targets on Earth only with limited durations (a so-called pass may take up to 15 minutes, depending on altitude and other geometrical aspects). Depending on the requirements of a particular mission, a combination of GEO and LEO satellites is used (Wertz and Larson, 1999).

3.2 Imagery Sensors

Two main categories of imagery sensors can be identified: passive and active. Passive sensors measure sunlight that is reflected by the targets or radiation emitted by the target itself. Active sensors have its own source radiation and its sensor measures reflected energy. Examples of each sensor with respective satellites (Reuner, 2017a) are:

a) Active: ASAR (ENVISAT); SAR (ERS-2, RADARSAT-1 and RADARSAT-2).

b) Passive: OSA (IKONOS); ETM (LANDSAT-7).

The imagery collected by a given sensor is the result of a combination of the area observed and the sensor characteristics in terms of its spatial, temporal and spectral resolutions. Spatial resolution specifies the pixel size of satellite images covering the Earth surface. Temporal resolution specifies the revisiting frequency of a satellite for a specific location. Spectral resolution specifies the number of spectral bands in which the sensor can collect radiation and its width that is related to the position of bands in the electromagnetic spectrum (Reuner, 2017a).

In general, the field of view (FOV) and the sensor altitude above the ground determine the size of the imaged area (swath width). FOV describes the opening angle of the sensor, as shown in Figure 2.

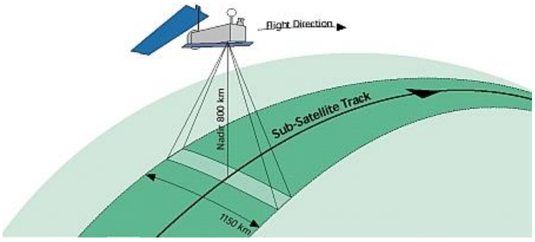

Figure 2: Illustration of FOV and sensor swath. Reuner (2017b).

3.3 Ground Stations

Most satellites have a limited storage capacity and therefore it is essential to download the information collected to ground stations when possible (i.e. within the associated visibility window).

The contact options depend on the relative motion of the two elements involved: the ground station (which is at a fixed position on Earth, and which is rotating 360 degrees in a day), and the satellite which is going about in its orbit around Earth (for a LEO satellite, a full revolution takes about 100 minutes or slightly more). Contact is possible whenever the two players are in direct view (starting with the handshake process), i.e. when the satellite appears above the effective horizon of the ground station. Ideally, this horizon could be the true horizon at zero degrees elevation, but in practice the viewing options will be limited by trees, buildings, hills, etc., so a more realistic minimum elevation of about 5º is required. The download capacity depends on a large number of aspects, both at the satellite and at the ground station such as broadcast power, frequency of signal, size and shape of antenna, beam width, size of picture (Wertz and Larson, 1999).

The Brazilian ground tracking system of INPE (National Institute of Space Research) is named Satellite Tracking and Control Centre (CRC) and is composed of the Satellite Control Centre (SCC), located in São José dos Campos, and two S-Band ground stations located in Cuiabá and Alcântara (Chiaradia et al., 2013), as shown in Figure 1.

4 OPTIMIZATION PROBLEM INPUT

Before exploring the model for the DADSSP we will first address how to derive the input for this model. For this, a MATLAB program has been developed to evaluate the coverage of a given satellite and associated sensor and a more detailed description of the scenarios will be presented to identify relevant requirements.

4.1 Scenarios and Detection Characteristics

This section will elaborate on the required input in terms of the characteristics of the satellites and sensors taking the scenarios requirements and their detection characteristics into account.

4.1.1 Oil Spill Detection

Accidents at sea-based oil platforms can yield huge environmental damage, as most of the Brazilian oil reserves are in marine fields, in deep and ultra-deep waters far away from the coastline. Since this monitoring process needs to be done for a large area, remote sensing offers a good option to uncover possible oil spilling. When the surveillance area has been reduced, other platforms can be deployed to identify the polluter, the extent and the type of spill.

In order to distinguish a possible oil spilling the following oil characteristics need to be considered (Brekke and Solberg, 2005; IPIECA, 2006):

- absorbs solar radiation and re-emits a portion of this energy as thermal energy;
- emits stronger microwave radiation than the water and appears as bright objects on a dark sea
- at night, a thick spill can appear cooler than the water since it releases heat quicker than its surrounding water;
- can have strong surface-emissivity signatures.

As such, the detection of any oil spill will depend on oil type, thickness of the spill, wind speed, sea temperature and the target dimensions.

In terms of dimensions and locations we will consider two Brazilian oil basins: Campos and Santos Basins. Santos basin is the largest basin in the country, with an area of more than 350,000 km^2, extending from Cabo Frio (RJ) to Florianópolis (SC). Campos basin is the main area already explored on the Brazilian coast, extending from Vitória (ES) to Arraial do Cabo (RJ) with an area of approximately 100,000 km^2. Figure 1 provides an idea of the Petrobrás Oil Basins location.

According to literature, this type of application requires regular monitoring, preferably daily in order to detect potential oil spills. The desirable spatial resolution will depend on the needs of the mission. For a general response, medium-to-high resolution imagery will be required to distinguish different slicks (IPIECA, 2006). SAR sensors are considered as the best and most efficient satellite sensor for this application (Brekke and Solberg, 2005).

4.1.2 Deforestation

The Amazon rainforest has been subject of deforestation which is endangering this natural reservoir. The Amazon covers an area of over 6.5 million square kilometers in the northern part of South America that spreads across nine countries. Brazil has 85% of this region (5.217.423 km²) which occupies 61% of the national territory (see Figure 1). According to Butler (2017) on average 15,000 km² of the Amazon forest are deforested every year.

As the Amazon area is huge, dangerous and quite inaccessible, remote sensing to monitor it offers an efficient tool to provide early detection of deforestation areas in order to be able to act and stop the process. Deforestation detection requires the following capabilities:

- monitoring a large area;
- detection of very small areas in a forest region;
- coping with cloudy and forested areas.

INPE in collaboration with the Ministry of the Environment (MMA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) uses DETER/PRODES systems to monitor deforestation and forest degradation in the Amazon. DETER uses data from the MODIS Terra satellite sensor, with a 250 m spatial resolution that makes it possible to detect deforestation polygons with an area larger than 25 hectares. The high revisiting time of MODIS of two days is used to quickly inform deforestation to surveillance authorities (INPE, 2012). PRODES monitors clear-cut deforestation and has produced annual deforestation rates for the region since 1988 (Global Forest Watch, 2017). This system historically used LANDSAT-5 images, but now is capable of showing small clearings (larger than 6.25 hectares) because it also incorporated imagery from LANDSAT-7, LANDSAT-8, CBERS-2, CBERS-2B, Resourcesat-1 and UK2-DMC. More information (in Portuguese) about the PRODES/DETER systems can be found on the INPE website on *Amazonia* (INPE, 2017).

In this type of scenario both the spatial and the temporal resolution are important because daily information reduces the time to prevent the deforestation and high resolution can be easier to detect small-size deforestation areas. So our constellation will contain the PRODES satellites (LANDSAT-8, CBERS and UK2-DMC) and SENTINEL. LANDSAT-8 and UK2-DMC have good resolution and small revisit times and CBERS is considered a Brazilian satellite because it was born from a partnership between Brazil and China. SENTINEL presents better resolution than the others and could detect smaller areas in comparison to what is now detected by Brazilian systems.

4.1.3 Illegal Border Activities

Brazil has a more than 6,500 km border with all three major production sources of cocaine Colombia, Bolivia and Peru, as shown in Figure 1. Remote sensing provides an alternative to monitoring and identifying drug smuggling activities along this large area (which in some regions is quite inaccessible). As intelligence reports indicate possible transportation routes and border crossing points, these areas can be monitored in order to collect high-quality imagery. Moreover, by regularly comparing imagery on border areas, it will be possible to identify the opening of new smuggling routes.

The above suggests that a high-resolution imagery and a regular revisit times should provide a good view of what is happening on the ground and improve the surveillance efficiency (SatCen, 2017).

4.2 Satellites Constellation

Considering satellites and sensor data available and the requirements related to the detection characteristics in each scenario, our constellation (sensors and respective satellites) will be probably: SAR (TERRASAR-X, SENTINEL 1, RADARSAT-1 and RADARSAT-2), OLI+TIRS (LANDSAT-8), DMC (UK-DMC2) and WFI (CBERS).

4.3 Satellite Coverage Modeling

The input for the optimization model will be derived using a MATLAB program that computes for given satellite/sensor parameters the target coverage over different time periods.

A mathematical formulation is required to assess the visibility options between a spacecraft and a location on Earth (irrespective whether this is a target or a ground station). Here, the satellite position is described with respect to a uniformly rotating Earth and a fixed location position. The coverage model for the (circular) satellite orbit is based on the so-called dual-axis description. A summary of the essential expressions is given below, full details can be found in Wertz (2009).

$$\sin(\delta_{sc}) = \sin(i)\cos(\varphi_{2,0} + nt) \tag{1}$$

$$\alpha_{sc} = \varphi_{1,0} - \omega_E t + \mathrm{acos2}\left[\frac{-\cos(i)\sin(\delta_{sc})}{\sin(i)cos(\delta_{sc})}, H\left(\varphi_{2,0} + nt\right)\right] \tag{2}$$

where t is the independent parameter time, which samples the spacecraft (index sc) position with an arbitrary step size (e.g. once every second). The latitude (measured with respect to the equator) and longitude of the instantaneous satellite position are expressed by δ_{sc} and α_{sc}, respectively. Parameter i is the inclination of the orbit, n its mean motion, and ω_E the rotational velocity of Earth. Parameters $\varphi_{1,0}$ and $\varphi_{2,0}$ are arbitrary initial values of the satellite position and Earth orientation at the reference epoch, respectively. H is the so-called hemisphere function, needed to provide the proper four-quadrant answer for the acos function (hence acos2, see Wertz, 2009).

Taking a location gs with position (δ_{gs}, α_{gs}) as an arbitrary target for contact, the distance D between the satellite and this target can be obtained from:

$$D^2 = R^2 + a^2 - 2Ra[\sin(\delta_{sc})\sin(\delta_{gs}) + \cos(\delta_{sc})\cos(\delta_{gs})\cos(\alpha_{sc} - \alpha_{gs})] \tag{3}$$

where R is the Earth radius, and a the semi-major axis of the satellite orbit.

Knowing D, one can readily determine the elevation angle ε. This is the angle with respect to the local horizon with which the satellite can be observed from the target (for ε equal to 90°, the satellite is at zenith, i.e. directly above the target, and for ε equal to 0° it is exactly on the horizon).

$$\frac{\sin(90 + \varepsilon)}{a} = \frac{\sin(\lambda)}{D} \tag{4}$$

where λ is the angle between the direction to the satellite and to the target, as seen from the center of Earth.

A direct link between the satellite and the target is possible when the elevation is above a certain minimum threshold (for communication with the station, a representative value for ε_{min} is 5°, whereas for remote-sensing observations larger values are typically required). When ε is negative, the satellite is below the horizon as seen from the ground component and it is invisible, obviously.

Basically, the coverage model uses the input:

- Satellite/sensor parameters: altitude; inclination; spatial, temporal and spectral resolution; swath width; field of view (FOV)
- horizon planning (time frame)
- target parameters: location; type (point or area)

Working our way through (1)-(4) for a series of time-steps t will provide the time-window of contact opportunities between the satellite and one target/ground station. The resulting time-windows can be represented in a coverage histogram for ease of interpretation, as shown in Figure 3. For a 3-days horizon planning, three targets (T1, T2, T3), two satellites (S1, S2) and one ground station (GS), 16 time-windows are derived: 11 acquisition time-windows (A1 to A11) and 5 download time-windows (D1 to D5).

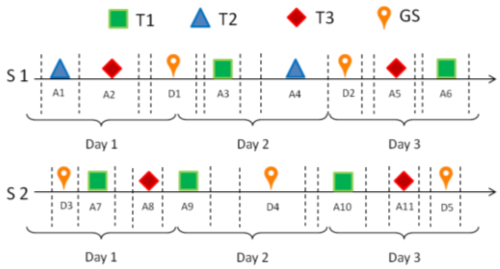

Figure 3: Coverage histogram showing time-windows.

This coverage histogram and the scenario requirements will define the input to the optimization model. For instance, if satellite S1 has a spatial resolution of 50 m and the requirement of the target T2 is at most 30 m, then the acquisition time-windows (A1 and A4) will not be considered as input for the optimization model.

Results for the MATLAB analysis specifying the Brazilian scenarios requirements in interaction with required decision makers will be presented in a follow-up paper.

5 OPTIMIZATION MODEL

We formulate the DADSSP as follows. Let H be the planning horizon; T the set of targets; $p_i \geq 0$ the priority of target i; S the set of heterogeneous satellites in the constellation; S_i the set of satellites that can acquire target i; G the set of ground stations; G_j the set of ground stations that satellite j has a visibility contact with; A_{ij} the set of acquisition time-windows wherein target i can be acquired during the planning horizon H by satellite j; D_{jg} the set of download time-windows wherein the acquired data by satellite j can be downloaded to the ground station g during the planning horizon H. We are assuming that for a satellite its acquisition/download time-windows do not overlap, as the satellite will have to dedicate its time to a single activity. Furthermore, let $[a_t, \bar{a}_t]$ be the start and the end time of t-th acquisition time-window and $[b_d, \bar{b}_d]$ the start and the end time of d-th download time-window ($a_t, \bar{a}_t, b_d, \bar{b}_d \in \mathbb{N}$); $RT_i \geq 0$ the required revisit time of target i (which implies that in the given planning horizon H the target i will be revisited at most $AD_i = \left\lceil \frac{H}{RT_i} \right\rceil$, $AD_i \in \mathbb{N}$); $DT_{ik} \geq 0$ the required due time for the k-th download of target i data. In order to address the satellite processing time capacity, let V_i be the volume of data of the target i (in MB); AP_j the acquisition processing time of satellite j (in MB/sec); DP_{jg} the download processing time of satellite j to the ground station g (in MB/sec); C_j the maximum processing time capacity of satellite j during the planning horizon H. Assuming that acquisition and download of target data depends mostly on the data size, the satellite acquisition and download processing time as well as of the ground station processing time, the acquisition and download time will be defined, respectively, as $M_{ij} = V_i/AP_j$ and $S_{ijg} = V_i/DP_{jg}$.

Consider the following decision variables: $x_{ikjt} \in \{0,1\}$ indicates whether satellite j will be used for the k-th acquisition of target i in the acquisition time-window t; $y_{ikjgd} \in \{0,1\}$ indicates if satellite j will download the k-th data acquired on target i to the ground station g in the time-window d. We will also define the variables $AW_{ikj} \geq 0$ as the start time of the k-th acquisition of target i by satellite j; $DW_{ikjg} \geq 0$ as the start time of the k-th download of target i by satellite j to ground station g.

$$Max \sum_{i \in T} p_i \sum_{k=1}^{AD_i} \sum_{j \in S_i} \sum_{t \in A_{ij}} x_{ikjt} \tag{5}$$

s.t.:

$$\sum_{j \in S_i} \sum_{t \in A_{ij}} x_{ikjt} = \sum_{j \in S_i} \sum_{g \in G_j} \sum_{d \in D_{jg}} y_{ikjgd} \leq 1, \quad i \in T, k = 1, \dots, AD_i \tag{6}$$

$$\sum_{j \in S_i} \sum_{t \in A_{ij}} x_{i,k+1,j,t} \leq \sum_{j \in S_i} \sum_{t \in A_{ij}} x_{i,k,j,t} \quad i \in T, k = 1, \dots, AD_i - 1 \tag{7}$$

$$\sum_{t \in A_{ij}} a_t x_{ikjt} \leq AW_{ikj} \leq \sum_{t \in A_{ij}} (\bar{a}_t - M_{ij}) x_{ikjt} \quad i \in T, k = 1, \dots, AD_i, j \in S_i \tag{8}$$

$$\sum_{d \in D_{jg}} b_d y_{ikjgd} \leq DW_{ikjg} \leq \sum_{d \in D_{jg}} (\bar{b}_d - S_{ijg}) y_{ikjgd} \quad i \in T, k = 1, \dots, AD_i, j \in S_i, g \in G_j \tag{9}$$

$$\sum_{r \in S_i} AW_{i,k+1,r} - AW_{ikj} \geq RT_i \sum_{t \in A_{ij}} x_{ijkt} \quad i \in T, k = 1, \dots, AD_i - 1, j \in S_i \tag{10}$$

$$DW_{ikjg} + S_{ijg} \leq DT_{ik} \quad i \in T, k = 1, \dots, AD_i, j \in S_i, g \in G_j \tag{11}$$

$$AW_{ikj} + M_{ij} \sum_{t \in A_{ij}} x_{ijkt} \leq \sum_{g \in G_j} DW_{ikjg} \quad i \in T, k = 1, \dots, AD_i, j \in S_i \tag{12}$$

$$\sum_{i \in T} \sum_{k=1}^{AD_i} \sum_{t \in A_{ij}} M_{ij} x_{ikjt} + \sum_{i \in T} \sum_{k=1}^{AD_i} \sum_{g \in G_j} \sum_{d \in D_{jg}} S_{ijg} y_{ikjgd} \leq C_j, j \in S \tag{13}$$

The objective of DADSSP (5) is to maximize the sum of the priorities of the target requests for which all the required data was collected and downloaded. Constraints (6) ensure that each target request will be addressed at most once (by one satellite and in one acquisition time-window). These constraints also ensure that the target request is completed only if the target data has been acquired and downloaded to the ground station. Constraints (7) enforce that targets that need to be revisited will either be fully revisited or not at all. Constraints (8) and (9) guarantee that the full acquisition and download time required needs to fall within the respective time-windows. Constraints (10) ensure that for the targets that need to be revisited the revisit time is respected. Constraints (11) ensure that the acquired target data will be downloaded before the required due time. Constraints (12) enforce the acquisition/download precedence, i.e., the target data can only be downloaded to a ground station if it was fully acquired before by the same satellite. Finally, Constraints (13) ensure that the satellite total processing time will not exceed the satellite capacity in the planning horizon.

To the best of our knowledge, revisit time and due time have not yet been considered in the literature. As these operational time scenario requirements are extremely important in practice we believe that they need to be addressed in order to derive a model that can work in practice.

6 FINAL REMARKS

This paper proposes a new mathematical model to DADSSP to find an optimal planning to acquire different target data with different priorities taking into account several operational constraints. Some of these have not been addressed in literature before but are required to realistically model mission requirements. The model can be tackled with optimization tools. Given its complexity heuristic approaches should also be explored.

Further research also includes the extension of the proposed model to consider polygon areas and to model other constraints such as agility, storage capacity and inherent uncertainties in the scenario.

Finally, if the considered satellite constellation does not fulfill the scenario requirements it is important to determine the best orbit/sensor parameters to fill the identified gaps. The result is expected to help Brazilian decision makers in future acquisitions.

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