A Framework for Heterogeneous Satellite Constellation Design for Rapid Response Earth Observations

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Abstract— **Earth Observation (EO) satellite constellation design deserves further investigation for optimizing configurations that enhance space mission performances. In recent years, there has been considerable interest in reducing the System Response Time (SRT) of EO satellites - the interval between request submission and availability of the image product - in order to achieve rapid response in case of natural or man-made disasters or matters involving defense and natural security. This key performance indicates to the user when, after the request submission, the image produced will be available to him.**

The best way to improve this performance metric is using heterogeneous constellations, where two different functional constellations are cross-linked; one is mainly for imaging and the other is a communication constellation that is dedicated to relaying commands delivery from Earth station to imaging satellites and data collection back to Earth. This scheme has been proposed before in the previous work to explore its potential enhancement of system performance, or to evaluate the network performances by comparing candidate relay constellations for servicing remote sensing satellites. However, methods for satellite constellation design of this scheme have not been introduced.

Since the best heterogeneous configuration may require studying several constellation combinations, this paper presents a framework capable of generating thousands of heterogeneous constellation configurations based on predefined Design Variable (DV) ranges and sizing those configurations in terms of the predefined Measure of Performances (MOPs). Using Systems Tool Kit (STK) and its various add-on modules, we introduce multiple solutions to configure both the imaging and relay constellations of the heterogeneous constellation systems that can achieve their objectives and improve the overall system performance by reducing the SRT.

One of these solutions is an imaging constellation of 8 satellites equally distributed in 2 different planes, a Sun-Synchronous Orbit (SSO) and a Mid-Inclination Orbit (MIO). We select this constellation based on the global daily coverage percentage and the satellite optical sensor parameters. In order to reduce the maximum SRT, we select a relay constellation in a Medium Earth Orbit (MEO) on an Equatorial plane and a location of a Ground Station (GS) as a receiving and transmitting Earth site.

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1. INTRODUCTION

In recent years, there has been considerable interest in reducing the System Response Time (SRT) of Earth Observation (EO) satellites in order to achieve rapid response in case of natural or man-made disasters [1] or matters involving defense and natural security [2]. SRT is the interval between request submission and availability of the image product. It depends on both the geometrical configuration of the system (orbit, access area, ground station distribution) and on the time scheduling of the system to handle the request in the first time and then the data on the ground [2].

The scientific literature on planning and scheduling of EO satellite constellations discussed the scheduling optimization problem for minimizing SRT and maximizing the rewards of the images taken and transmitted in a short time [3]–[7]. Although these efforts in previous work of scheduling remote sensing satellites for rapid response to natural disasters, they can only optimize start times and durations of both images acquisition and download activities based on mission constraints and satellite resources. Nevertheless, they could not significantly reduce gaps in connectivity between Earth stations and imaging satellites, which is the root cause of increasing SRT.

Ultimately, reduction of SRT will require the use of Inter-Satellite Links (ISLs) to relay commands to imaging satellites and, possibly, relay data back to the receiving Earth station. The first proposals to use relay satellites to support EO satellites for Telemetry, Tracking, and Control (TT&C) employed Geostationary (GEO) communication satellites [8]. Nevertheless, this method is usually too expensive for small satellites supported by limited budgets, which become of more importance to the scientific and engineering

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community, or for spacecraft that not equipped for long-range communications. Non-GEO infrastructure, namely Low Earth Orbit (LEO) and MEO systems, is a more affordable option due to lower launch costs and shorter link distances. The latter reduces the required antenna sizes and link budget constraints. Satellites in MEO are the best nominated Non-GEO systems for servicing the LEO observing satellites. They have the advantages of the characteristics of both GEO and LEO [9]. LEO/MEO Double Layer Satellite Networks (DLSNs) are frequently proposed in multilayer satellite networks for global satellite communication systems [10]–[14] because they have shorter round trip delays and lower transmission power requirements [15].

Based on current literature, few papers have discussed using MEO satellites for tracking and data relay to remote sensing satellites in LEO and they did not discuss explicitly the improvement of system performance in terms of SRT [16]–[18]. In this work, only single instances have been proposed and simulated and neither their coverage performances nor ISLs properties have been analyzed for realistic remote sensing constellations. The first promising evaluation study that used relay satellites in specific LEO and MEO constellation configurations (Walker delta) has improved data quality of EO satellites by reducing the response time [19]. Nevertheless, it did not explore the optimal configurations of relay satellite constellations and only one level of ISL routing has been considered between layers.

In this paper, using multiple of STK simulations, we achieve trade-offs between Design Variables (DVs) elements and their related Measures of Performances (MOPs) to get a solution that meets specific requirements. We start to design an imaging constellation that achieves global coverage in one day with specific sensor parameters that achieve a 0.5 m spatial resolution. For this constellation, we select a relay constellation and a latitude of a GS to reduce the SRT. Finally, we analyze the heterogonous constellation to evaluate the improvement of SRT compared with the SRT of the imaging constellation alone without relay constellation.

The rest of the paper is organized as follows. Section 2 introduces the SRT components and the need of heterogeneous constellations for remote sensing missions. Section 3 introduces the framework of the methodology used to design the heterogeneous constellations. Section 4 presents and discusses the simulation results of the framework. Conclusions and recommendations for future work are covered in Section 5.

2. CONCEPT

System Response Time (SRT) components

System Response Time (SRT) accounts for delays in getting collection requests to the imaging satellites, delays in transmitting collected data to a receive GS and a number of fixed duration delays in between, which are in orders of seconds or few minutes. An illustration of SRT and the delay time components is shown in Figure 1 [6], [20]. We have modified this figure for more clarifications to the SRT computations in our case study. Definitions of each time component in this figure are listed in the Appendix section.

Most traditional constellation design methods for remote sensing satellite constellations focus on minimizing the revisit time, which is the gap duration in coverage access between targets over a given region. However, excessive SRT still a fundamental problem due to the two dynamic delay times, command uplink delay time (T2) and data downlink delay time (T6).

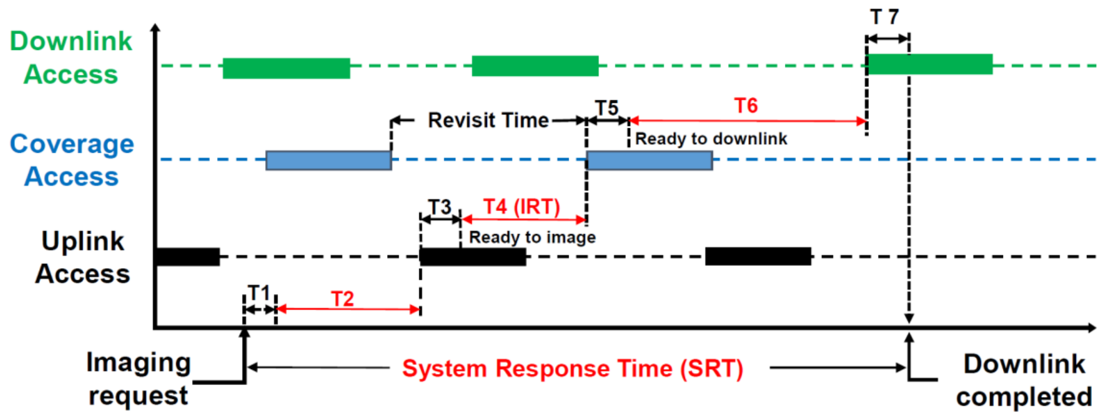
The dynamic value of SRT can be equal to Intrinsic Response Time (IRT) only if all delays are set to zero. Therefore, considering an ideal (optimal) relay constellation configuration will make both delay times tend to approximately zero, the SRT, in this case, will be reduced to be relatively the same as IRT. We show here how using heterogeneous constellations can incredibly reduce the SRT.

Heterogeneous remote sensing constellations

The process of remote sensing constellation design starts from establishing mission objectives and constraints according to mission requirements. Therefore, objectives and constraints of remote sensing missions are the main drivers of development remote sensing sensors, evolving the Figure of Merits of constellation missions, and selection constellation orbital configurations and the number of satellites based on simulation methods and orbital mechanics laws as shown in Figure 2. Selection of orbital parameters for the constellation mission is the most important factor for the fulfillment of the space mission requirements. Practically, straightforward approach for selection of these parameters does not exist. Consequently, it is necessary to follow a complex process that requires trade-offs among the different parameters and the corresponding MOPs such as coverage, revisit time, sensor resolutions (spatial, spectral, and temporal), the capacity of data collected, swath width, spectral ranges of interest for every application, system response time.

Satellite constellation design for remote sensing applications is entering the phase of heterogeneous (nonhomogeneous) constellations that uses ISLs between two different functional constellations, remote sensing constellation and a constellation of small satellites dedicated for command delivery and relay data back to Earth. Since timeliness is valuable, rapid response for Earth Observations and the need for fast data delivery to end users lead to this new level of complexity and opportunity into satellite constellation design. Using bidirectional ISLs between imaging satellites and an upper layer satellite constellation can incredibly reduce the SRT by reducing T2 and T6.

We select satellite systems in MEO layer for servicing the LEO observing satellites for many reasons. They have the advantages of the characteristics of both GEO and LEO systems and they are frequently proposed in multilayer satellite networks for global satellite communication systems



T1 Command preparation Time. T2 Command uplink delay Time. T3 Command time and pre-collect Time. T4 Intrinsic Response Time (IRT). T5 Imaging and post processing Time. T6 Data downlink delay Time. T7 Downlink Time

Figure 1 - System Response Time (SRT) time components

because they have shorter round-trip delays and lower transmission power requirements. From another perspective, with the accumulating space debris, future collisions between large fragmentation debris and other intact objects in the MEO region are less probable than if the same breakup occurred in the LEO region [21] particularly after the recent proposals of deploying thousands of communication satellites in LEO [22]. In this scheme, the imaging satellites in LEO layer are serviced by relay satellites in the MEO layer forming what has been called heterogonous remote sensing constellation.

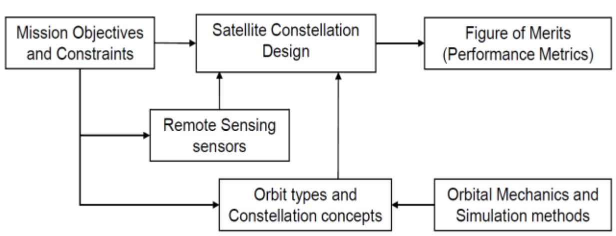


Figure 2 - Design processes of remote sensing satellite constellation mission

3. METHODOLOGY

Our approach in supporting control (command delivery) and data recovery of the LEO remote sensing systems is well suited for AGI STK's analytical capability. We use STK software with some of its modules such as Coverage, Analysis Workbench (AWB) and STK Analyzer, which is used for STK automation, to run a series of parametric studies. For each parametric study, one or two DVs will be run through a sweep of values and at each value, MOP statistics will be collected. Through our analysis, we will see how changing each of these DVs affects the correlated MOPs. A chart shows the trade analysis process is represented in Figure 3.

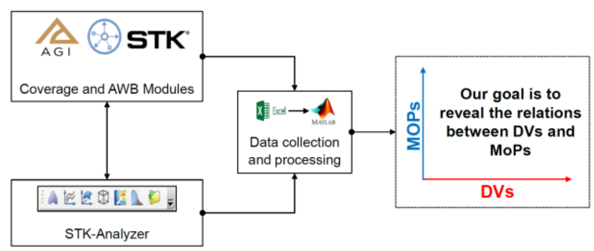


Figure 3 - Data flow of the trade analysis process

In this paper, we present a flow of trade-off design curves to configure heterogeneous satellite constellations for remote sensing missions. Our objectives are to design an optical imaging constellation that achieves daily global coverage, specify their payload parameters required for achieving specific spatial resolution, find the best relay satellite constellation on an Equatorial plane to reduce SRT, and the location of a GS to be a receiving and transmitting Earth site. Ranges of multiple DVs and their relevant MOPs are determined to find out the solutions of each constellation in this configuration that meet the mission requirements. Among all solutions, designers can find out the optimal/suboptimal configuration parameters. In this paper, we use 3 different orbital types, the first 2 types are used for the imaging constellation and the third type is for the relay constellation:

1. Sun Synchronous Orbit (SSO) on LEO
2. Mid Inclined Orbit (MIO) on LEO
3. Circular MEO on an Equatorial plane

Our method to design a heterogeneous satellite constellation for rapid response EOs can be summarized as follows:

1. Design an optical constellation on SSO based on its global coverage percentage at different sensor

parameters such as sensor Field Of View (FOV), sensor focal length (f) and detector pitch (DP).

2. Design and optimize the optical payload parameters and their effects on coverage and spatial resolution.
3. Coverage analysis of the SSO constellation to see how adding an inclined imaging constellation on MIO can improve the constellation revisit time and coverage at mid-latitudes.
4. Based on the selected imaging constellation, which consists of two constellations in two orbital planes SSO and MIO, we introduce a method for configuring a relay constellation to increase the access window durations with the imaging constellation by using ISLs capabilities between relay and imaging satellites. The relay constellation is selected to be on an Equatorial plane. The unknown DVs of the relay constellation will be its number of satellites. This constellation is designed based on specific GS latitudes where a continuous coverage can be achieved.
5. Analysis of the heterogonous constellation performance in terms of SRT compared with the performance of the imaging constellation.

Sun-Synchronous Orbit Constellation

For some remote sensing payloads, the satellite altitude plays a large role in determining the details of information obtained and the total area imaged by the sensor based on its FOV. Sensors at high altitudes typically view a larger area, but cannot provide good spatial resolution. Therefore, our aim here is to generate the design curves for SSO constellations in order to provide designers with some quantitative information about the relationships between orbital altitude, number of satellites, payload FOV and their effects on Earth global coverage. Then, we discussed the sensor parameters impacts on coverage and spatial resolution. From these design curves, we can select SSO constellation altitude, a number of satellites and the sensor parameters that achieve a daily global coverage with 0.5 m Ground Spatial Distance (GSD) as a measure of spatial resolution.

In the beginning, we used a satellite sensor with a fixed rectangular FOV=20º, which is defined according to specified Vertical Half Angle (VHA) and Horizontal Half Angle (HHA) as shown in Figure 4 [20]. These sensor types are typically used with satellites or aircraft for modeling the field of view of instruments such as push-broom sensors and star trackers. Sensor FOV is independent of orbital altitude (h) while the swath width (SW), which is the ground-projected FOV, depends on it. Increasing the sensor FOV increases SW at the same altitude. At a fixed FOV, increasing orbital altitude increases SW as shown in figure 5 based on equation (1).

$$SW = 2 * h * \tan\left(\frac{FOV}{2}\right) \quad (1)$$

We know that for SSO imaging constellation, increasing both the orbit altitude and the sensor FOV will improve coverage capabilities until we run up against the ground sampling resolution constraint for the sensor. Fortunately, we can change sensor parameters to permit greater viewing capabilities at higher altitudes. GSD, as shown in equation (2), is a function of both focal length and detector pitch (DP) of a sensor. For our next step, we will see how changing the focal length will impact coverage for a 2 different sensor FOV to achieve specific GSD resolutions for an imaging constellation on SSO. We select the sensor DP to be 1 μm.

$$GSD = \frac{DP * r}{f * \sqrt{\sin(elev)}} \quad (2)$$

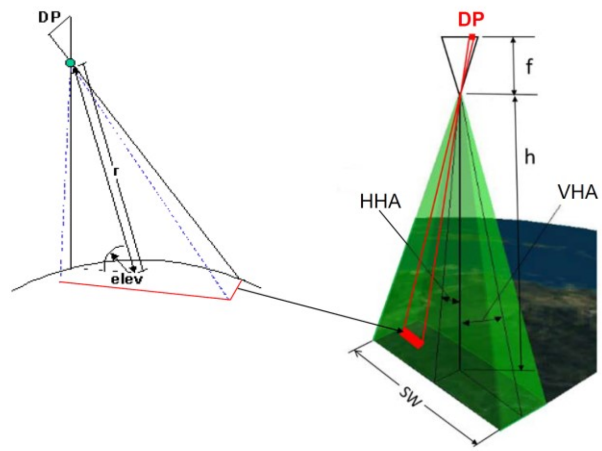


Figure 4 - Rectangular sensor parameters (Source: AGI-STK)

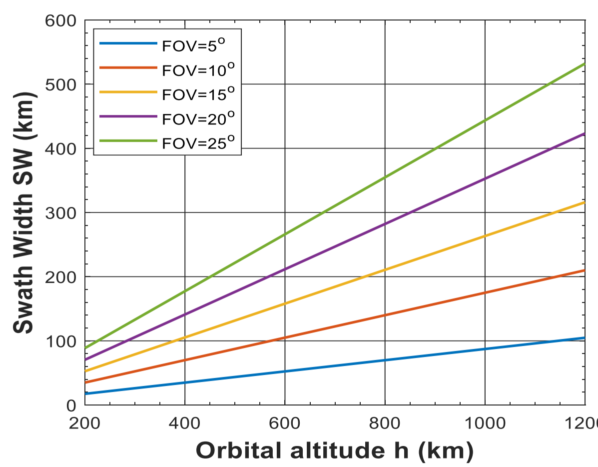


Figure 5 - Sensor swath width (SW) vs. satellite orbital altitude at different Field Of View (FOV)

To define an optical sensor's resolution, we must specify the focal constants shown in Figure 4, f and DP. These parameters and the satellite altitude are used in the computations of the GSD in equation (2) where r is the sensor range and elev is the elevation angle. The low GSD values are the better image resolutions. Therefore, increasing f and decreasing DP will improve GSD. We started with the default values in STK sensor resolution parameters with a sensor FOV=20º to study the effects of orbital altitude, a number of satellites and the FOV on the constellation coverage. Then, we will optimize the sensor parameters to get the required spatial resolution.

We will show the design curves associated with the process of determining if an optical sensor will achieve the required coverage and spatial resolution. Once that is accomplished, the next big step is to decide the best imager parameters that serve mission purposes. Then, we can select the orbital altitude and the number of satellites of a constellation. Since the orbit track spacing varies with latitude, the revisit rate is significantly greater at higher latitudes than at the equator. After setting the SSO constellation parameter, we analyzed its coverage. Results will show that the mid-latitude regions have the most uncovered portions. Therefore, we show through simulations how many MIO satellites and their altitudes required to improve the global coverage and revisit time of these mid-latitude regions. By this step, we can select the imaging constellation altitude, number of satellites/plane and the sensor parameters. The following step is to select the relay satellite constellation to improve the SRT.

MEO relay constellation design

The heterogeneous system configuration and the constellation details have a significant impact on the system availability. The availabilities are dependent on the LEO & MEO constellation characteristics, e.g., altitudes, number of orbital planes & types, number of satellites per plane, etc. The best configuration of a heterogeneous system requires studying several constellation combinations. In this paper, we design a MEO satellite constellation that can deliver commands from a GS to an observing satellite, collect data and storage from an observing satellite, and download it to a GS. It means that a bidirectional Inter-Layer ISLs are involved in our network scheme. We propose using relay satellites on an Equatorial plane for the relay constellation at the minimum altitude of MEO range, which is 8,000 km. Thus, the unknown parameter of the relay configurations will be the number of satellites. Moreover, we select the latitude of the GS, which will be used as a transmitting and receiving Earth site.

STK can compute the Intrinsic Response Time (IRT) for an imaging constellation based on the Time Average Gap (TAG), which is the average length of the coverage gap found if the timeline for target points is sampled randomly [20]. STK can also compute the SRT for the imaging constellations by selecting a command and receiver GS and providing values for the fixed intervals listed in the appendix. Nevertheless, STK does not have the option for SRT computations when using relay satellites neither for command delivery nor for collecting data back from imaging satellites. Therefore, we divide SRT into 3 major dynamic time components, T2 due to coverage gaps between command GS and imaging satellites, IRT that depends on the revisit time of the imaging satellite constellation itself, and T6 due to the coverage gaps between imaging satellites and the receiving GS.

In case of no relay satellites used, the max values of T2 and T6 are equal to the Maximum Gap Duration (Max GD) between the GS and the imaging satellites. This is the worst case where the maximum SRT occurs when the GS has to wait for a Max GD to uplink its command to the imaging satellite and again the imaging satellite has to wait for the same period, Max GD, to download its data to a GS. Max SRT, in this case, depends on the number of imaging satellites, the GS location, and the target locations. Although the high latitudes ground sits are effective and can improve SRT, these stations make contact with the satellite in each revolution, though the transmission time is limited to a few minutes per orbit, which is too small to accommodate all the acquired data. Therefore, we use MEO relay satellites to increase the connectivity durations for data download and to decrease the maximum SRT.

When using relay satellites, the max T2 will be equal to the max GD between a GS and a relay plus the max GD between the relay and the imaging satellite. The same for downlink, the max T6 will be equal to the max GD between the imaging satellite and a relay plus the max GD between the relay and GS. Thus, we first perform multiple simulations in order to find the minimum number of relay satellites at a minimum MEO altitude (8,000 km) that achieve continuous coverage to a GS. IN this case, the daily coverage percentage of a GS is the MOP, which is depending on the two inputs of STK-Analyzer, the latitude of the GS and the number of relay satellites. A minimum 10^{o} elevation angle is applied to the GS as an elevation angle constraint in order to avoid obstacles caused by natural barriers at low elevation [23].

First, we can select the number of relay satellites at 8,000 km altitude and a GS latitude, which has continuous daily coverage. Therefore, the $\max T2 \ and \ \max T6$ will be based on the gap durations between relay satellites and the imaging satellites themselves. Second, using STK access tool, we compute the average of both $\max T2 \ and \ \max T6$ for $\overline{Max\ SRT}$ computations based on equation (3) as a final step.

$$\overline{Max\ SRT} = \overline{IRT} + \overline{\max T2} + \overline{\max T6} + T1 + T3 + T5 + T7 \tag{3}$$

4. Results and Discussion

Imaging constellation

We performed multiple simulations to generate several thousand constellations at altitudes ranging from 200 km to 1200 km with a step size of 5 km for from 2 to 6 satellites. The global coverage percentage is the MOP in this case while SSO altitude and number of satellites are DVs. Since we are using an optical sensor, a daylight constraint is added to the coverage definition in STK scenario for coverage computations. These simulations are based on a sensor FOV of 20^{o}. Figure 6 shows that increasing the SSO altitudes (h_{sso}) and the number of satellites in the SSO plane (SSOSats) increases the global coverage percentage during daylight imaging.

To show the effects on coverage when changing sensor FOV at a different number of satellites, we select an orbital altitude at 600 km as a case study. For a range of a sensor FOV, we analyze how increasing the sensor FOV and the number of satellites affects the daily global coverage percentage during daylight as shown in Figure 7. From Figure 6 we can see that a SSO constellation of 4 satellites at altitude 600 km can achieve about 46% global coverage percentage when using 20° sensor FOV. From Figure 7, we can increase this percentage to be 81.4% by simply increase sensor FOV to be 40° using the same number of satellites. This will be at the expense of the image resolution. Therefore, our aim in the next step is to specify sensor focal length and detector pitch values for both FOVs values, 20 and 40 degrees, that achieve the required coverage and GSD.

We ran simulations using a SSO constellation of 4 satellites at 600 km altitude to show the effects of changing sensor FOV and focal length on coverage and on GSD as a measure of spatial resolution. From these simulations, we can specify the focal length that met the required GSD when using two sensors with FOVs, 20° and 40°. We selected the sensor DP to be 1 μm. Figure 8 and Figure 9 show that increasing the focal length increases the coverage percentage of the SSO constellation until it reaches the maximum global coverage percentage that can be achieved by this constellation. From Figure 8, we can optimize the minimum focal length required to achieve 5 m GSD images while from figure 9, we can get the optimized focal length to achieve 0.5 m GSD. Below these values, this constellation will achieve the same resolution but will reduce its coverage percentage. Results in both figures show that there is no need to increase the focal length values, as they will improve neither coverage time nor GSD.

Based on the previous results, we select a SSO constellation consists of 4 satellites and each has a 40° sensor FOV. This is a solution of multiple solutions that can be obtained from the above trade-offs design curves based on the sensor parameters and mission requirements of coverage and GSD. The maximum global coverage percentage of this constellation is 81.41%. Among the available solutions, a SSO constellation of 6 satellites at altitude 1,200 km, and each has a 20° FOV sensor. This constellation will increase coverage percentage to be 96%. Nevertheless, this constellation needs a very big increase in the sensor parameters. In this case, we need a sensor focal length of around 2.5 m to achieve 0.5 m GSD, which is not practical.

From coverage analysis of the SSO constellation, we concluded that the most of the uncovered portions of Earth are in mid-latitudes region (from -50° to +50° latitude). The other portions are very small portions on Polar Regions. Based on this analysis, we propose another imaging constellation on a Mid-Inclination Orbit (MIO) at an inclination (i=45°) to overcome the coverage limits of the SSO constellation and increase the revisit time of the mid-latitude regions where the bulk of the world's population

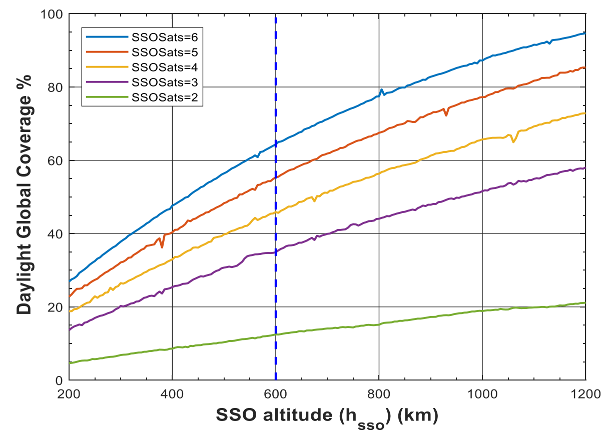


Figure 6 - SSO altitude and daylight global coverage at different number of satellites. Each satellite has a rectangular sensor with 20° FOV

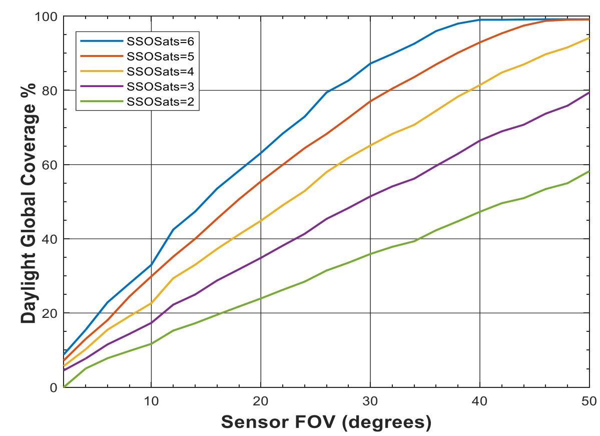


Figure 7 - Daylight global coverage % vs sensor FOV of a SSO constellation at 600 km altitude at different number of satellites

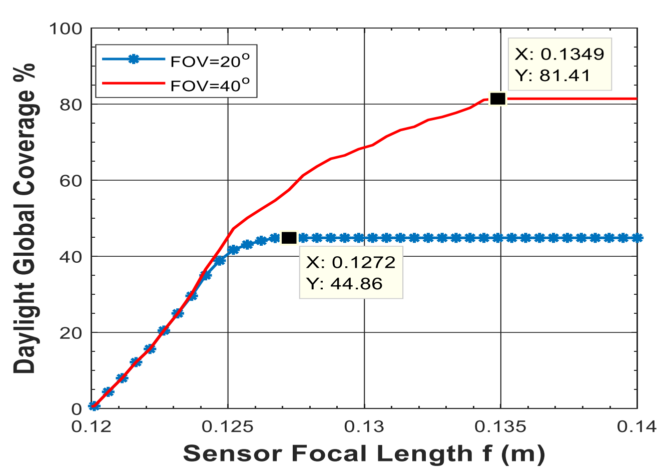


Figure 8 - Optimized Sensor Focal Length (f) required to achieve 5m GSD using 1 μm sensor DP. The global coverage percentage achieved by a SSO constellation of 4 satellites at altitude 600 km.

reside. This constellation will have the same sensor parameters as the SSO constellation.

The objective of the next step from simulations is to know the number of MIO satellites (MIOsats) and the altitude of this constellation that improves the daylight global coverage percentage with the proposed SSO constellation. As shown in Figure 10, MIO constellation of 4 satellites at 575 km altitude with the same sensor parameters as the SSO constellation can improve the coverage percentage to be 98.75%. We applied 0.5 m GSD as a constraint to the coverage definition during these simulations. Therefore, we can see that increasing MIO orbital altitude (h_{mio}) will not improve the coverage due to this applied constraint. Finally, from the above results, we can choose the imaging constellation parameters as summarized in Table 1.

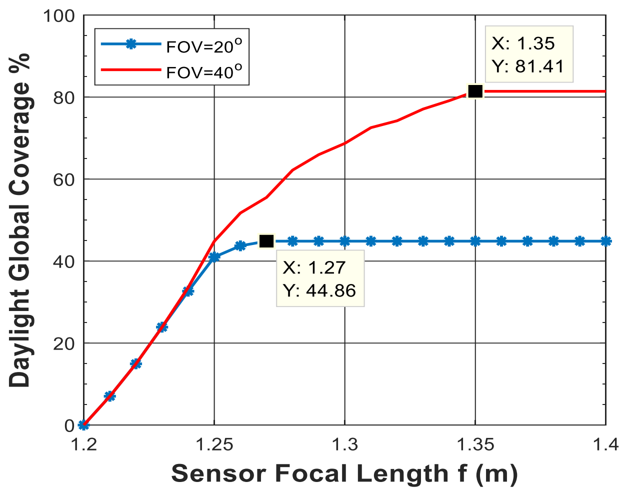


Figure 9 - Optimized Sensor Focal Length (f) required to achieve 0.5m GSD using 1 µm sensor DP. The global coverage percentage achieved by a SSO constellation of 4 satellites at altitude 600 km

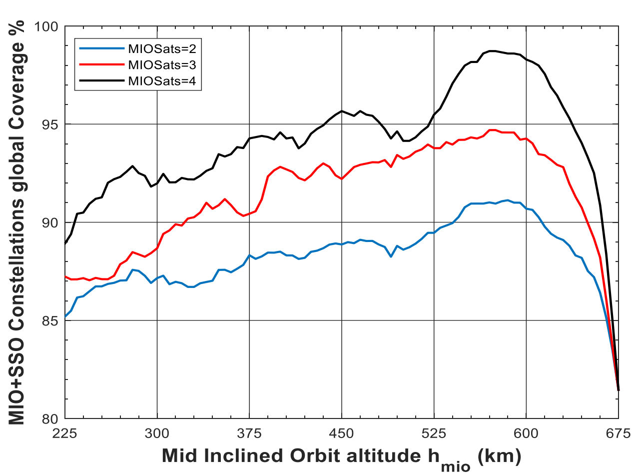


Figure 10 - Mid-Inclination constellation altitude and different number of satellites and their effects to improve coverage with the SSO constellation

Table 1 - Imaging Constellation parameters

Orbit type	SSO	MIO
Orbital altitude	600 km	575 km
Number of satellites	4	4
Sensor FOV	40°	
Swath Width (SW)	437 km	
Sensor Focal length	1.35 m	
Sensor Detector pitch	1 µm	
GSD	0.5 m	
Daylight global coverage %	98.75%	

Relay constellation

The results of this section respond to the following questions:

1. What is the number of satellites on an Equatorial orbit that achieve continuous coverage of a GS?
2. What is the GS latitude?
3. What will be the effect of using this MEO constellation with its GS on the maximum SRT?

We can find the answers to the first 2 questions in Figure 11. Any GS at latitude from 0° to 34° has a continuous coverage from MEO constellations consists of a number of satellites Ns = 4, 5, or 6 satellites. We select the minimum number of relay satellites Ns = 4 satellites and a GS at 30° latitude from these simulations. Using equation (3), figure 12 shows the reduction of average maximum SRT by using the heterogeneous constellation compared with the performance of the imaging constellation only. The same GS latitude, at 30° latitude, has been used to be a command and receiving GS in case of the case of the imaging constellation only too.

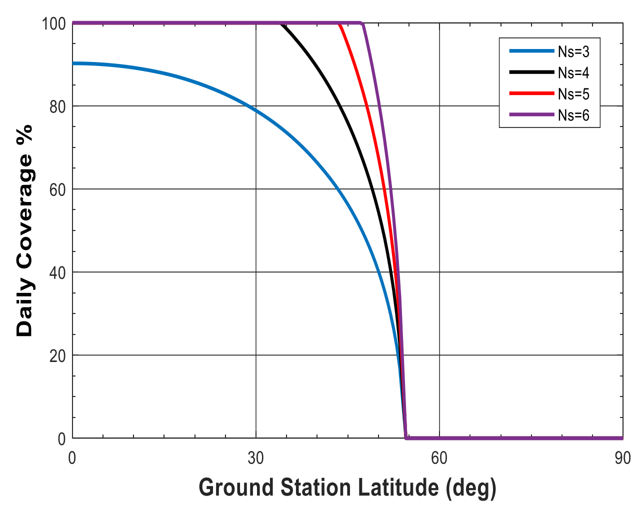


Figure 11 - Daily coverage percentage vs GS latitude for

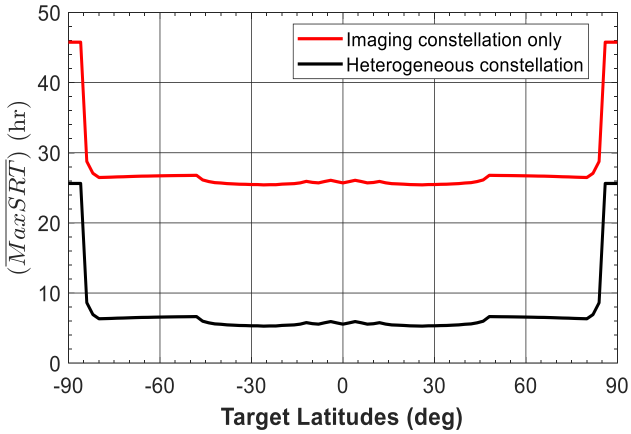


Figure 12 - Average of maximum SRT as a function of ground target latitudes for both the imaging constellation only and the heterogeneous constellation.

5. Conclusions and Future Work

The objectives and constraints of remote sensing missions are the main driver for selection of the constellation orbital configurations. Improving System Response Time (SRT) of Earth Observation satellites is of significant interest for Disaster Risk Reduction (DRR) and national security applications. This performance metric leads to evolve the constellation design methods for remote sensing into a more complex phase of design, a phase of heterogeneous (nonhomogeneous) constellations that uses InterSatellite Link (ISL) between two different functional constellations, remote sensing constellation and a constellation of small satellites dedicated for command delivery and relay data back to Earth.

The heterogeneous system configuration and the constellation details have a significant impact on the system availability. The availabilities are dependent on the imaging and relay constellation characteristics, e.g., altitudes, number of orbital planes & types, number of satellites per plane, etc. The best configuration of a heterogeneous system requires studying several constellation combinations. This paper introduces a framework for heterogeneous constellation system based on tradeoff analysis between different design variables and their related measure of performances.

Appendix

Definition of SRT Components

Time	Definition	Value
Command preparation time (T1)	Specify the amount of time required to generate collection commands prior to the uplink of the commands from GS to imaging satellites. This time includes request/list handling delay, system programming and command compilation.	Fixed
Command Uplink Delay Time (T2)	Time delay until access between imaging satellite and the command GS will occur for command delivery.	**Dynamic**
Commanding time (1st part of T3)	The time required to uplink generated collection commands from the command GS to the imaging satellite.	Fixed
Pre-collection time (2nd part of T3)	Amount of time required to configure access time of the targets after the collection command has been received to perform image acquisition. This time includes the required time for payload switching in the required operative mode.	Fixed
Intrinsic Response Time (IRT) (T4)	The time between a request of coverage of a point and the time at which coverage is achieved. This time completely depends on the revisit time of the imaging constellation.	**Dynamic**
Collection Time (1st part of T5)	Amount of time required for an imaging satellite to perform a collection of the image for the assigned target.	Fixed
Post collection time (2nd part of T5)	The time required to configure a receiving GS for downlink.	Fixed
Data Downlink Delay Time (T6)	Time delay until access between imaging satellite and the receiving GS will be occurred to start data downlink.	**Dynamic**
Downlink time (T7)	Amount of time required to downlink generated data	Fixed

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