Data Rich Architecture for Future Space Applications and Computing

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Data Rich Architecture for Future Space Applications and Computing

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Space applications play an important role in technological advancements. This is because satellites are useful in existing applications like earth observations and future computing (hosting space based data centres). In these applications, satellites increase the amount of space debris as they reach their end of life. Therefore, the reduction of space debris for hosting future space application is crucial. The discussion in this paper considers that increasing space debris limits the deployment of additional earth observation satellites and future space based data centres. This challenge is addressed in this paper that proposes the use of non–earth's orbital locations for hosting earth observation satellites and siting space data centres in regions having low debris. In addition, the proposed solution aims to identify regions in space with low space debris for hosting space based data centres. The performance metric is the rate of space debris generation (RSDG). The proposed solutions presents a framework to enable the acquisition and aggregation of data for RSDG computation in a given space region. Regions in non–earth orbital locations are utilized when the RSDG in a given earth's orbital location exceeds a pre–defined threshold. In addition, the RSDG is formulated via the adaptation of the Shannon relation utilized to formulate the channel capacity in wireless communications. The result of evaluation shows that the RDSG is reduced by 50% on average due to the use of the proposed mechanism.

Keywords: Data Processing, Cloud Platforms, Intelligent-Systems, Satellites, Wireless Computing

1. Introduction

Earth observations and space based computing are important aspects of next generation space applications. The acquisition of meteorological data by satellites is important for earth observation. The use of a significant number of earth observation satellites increases the space debris risk as satellites reach their end of life [1–4]. This has necessitates the development of space debris removal technologies [5–7] and realizable via satellite re–entry [8–10]. Space debris removal is important due to the emergence of mega–constellation projects [11–13]. This increases space debris risks in the low earth orbit [14–15]. Furthermore, the increased launch of low cost small satellites in mega–constellations results in a higher volume of space based data requiring processing to enable decision making. The transfer of this big data to the terrestrial data centres for processing and analysis incurs a high latency. The use of space based data centres reduces the observed high data transfer latency thereby making it possible to achieve low latency space data acquisition. The computing payload aboard space based data centres is suitable for processing the concerned big data.

However, deploying satellites results in the generation of significant space debris when these satellites reach their end of life. The resulting space debris can be reduced by reducing the number of satellites required in earth observation missions. The reduction can be realized via a new paradigm for realizing space applications. This paradigm is realized by re–formulating the earth observation problem. In our consideration, earth's climate and weather can be inferred from meteorological data acquired from non–earth orbital locations.

In addition, it is important to determine the suitable locations for hosting space based data centres. These locations should ensure that space based data centres have a low exposure to space debris. The space debris being considered arises from low cost small satellites at their end of life. In this regard, it is important to design solutions enabling the identification of locations in space with low debris. This should be done for the low earth orbit, middle earth orbit and the geostationary earth orbit.

Contribution:

The discussion in the paper recognizes that the emergence and proliferation of low cost small satellites increases space debris in earth's orbit. This space debris arises when low cost small satellites reach their end of life. Space debris can collide with other space assets i.e. satellites leading to damage and loss of functionality. This challenge is recognized to arise because of satellites make use of certain locations in space. The solution being proposed is the use of previously unexplored locations for hosting space assets i.e satellites. This is recognized to reduce the number of satellites in previously utilized locations thereby limiting the debris arising from fewer satellites reaching their end of life.

The paper proposes an architecture enabling the reduction of space debris with relation to earth observation satellites. Earth observation satellites are considered as meteorological data acquisition nodes. In the consideration, earth observation satellites are placed in earth's orbital locations and non–earth's orbital locations. This reduces the number of earth observation satellites placed in earth's orbital locations. The reduction results in fewer satellites reaching their end of life. Hence, a low amount of space debris arises. In the proposed solution, the acquired meteorological data is suitable for use in computation associated with making inferences on earth's climate and weather. In addition, the proposed architecture aims to identify locations in space with low space debris and suitable for hosting future space based data centres. This is deemed necessary due to the increased interest in executing space based computation. In this regard, it is important to be capable of siting space based data centres in regions with low space debris.

The performance of the proposed architecture is formulated by using the rate of space debris generation (RSDG). The RSDG is given in space debris generated per second. It is formulated by using the Shannon model that is commonly used to describe the channel rate in information systems. In the formulated model, the important variables are rate of launch of new satellites, number of in–orbit existing satellites, rate at which satellites approach their end–of–life, number of satellites reaching their end–of–life and rate of satellite collision with existing space debris. The RSDG plays two roles.

In the first case, the RSDG is influenced by executing the earth observations and meteorological data acquisition. This is due to the novel consideration of earth observation satellites as meteorological data acquisition nodes. The RSDG plays an equally important role in the second role where it is used to describe the suitability of a space region for hosting space based data centres.

The RSDG is formulated for the existing approach and proposed approach. In the existing approach, large number of satellites is deployed in earth's orbit for space based earth observations to acquire meteorological data. The proposed approach is one in which the proposed architecture acquires meteorological data.

Organization:

The discussion is structured as: Section 2 describes existing work. Section 3 presents problem description. Section 4 focuses on the proposed paradigm from a space perspective. Section 5 focuses on data related aspects of the proposed paradigm. Section 6 formulates the performance model. Section 7 discusses performance benefit. Section 8 is the conclusion.

Table 1: List of Acronyms

S/N	Acronym	Meaning
1	GEO	Geostationary Earth Orbit
2	LEO	Low Earth Orbit
3	LIDAR	Light Detection and Ranging
4	MEO	Middle Earth Orbit
5	RSDG	Rate of Space Debris Generation

2. Background and Existing Work

The discussion here presents research with focus on use of space orbital resources, applications and space with a view to determining the role of new technologies.

The discussion in [16] examines the effects of space debris with relation to space applications. Rose in [16] recognizes that increased space debris arises due to the conduct of more activities via satellites. The discussion identifies the role of mitigation guidelines from the United Nations. These guidelines focus on limiting the amount of generated debris. The debris reduction is done with the aim of enhancing the safety and sustainability of the outer space environment in the long term. Nevertheless, increased participation of NewSpace actors in space exploration and application development increases launched low cost small satellites. This makes it important to pay attention to space debris occurrence in outer space. The discussion in [16] does not describe how the guidelines influence debris removal due to the emergence of mega–constellations.

The role of technology proliferation and ease of adoption of new space technologies with regards to space debris receives consideration in [17]. The factor enhancing technology proliferation and ease of adoption is the reducing cost of small satellites. The discussion in [17] like that of [16] recognizes that the reducing cost of small satellites spurs their use in future space applications. The perspective being considered here is that small satellites should be based at near earth altitudes to aid re–entry and burn–up. However, the approach of relying on re–entry and burn- up is insufficient for small satellite mega–constellations. This is because of the limited number of suitable orbital locations.

The discussion in [16] and [17] recognises that technological advancements increases small satellite deployment but does not consider space debris removal. This is considered in [18]. Mamani *et al.* [18] recognize the risk posed by space debris and importance of space debris removal. The study identifies different methods and technologies suitable to realize space debris removal. Examples of suitable technologies are laser ground station, laser space station and light detection and ranging technologies. The space debris removal technology is launched into the concerned small satellite orbit. This approach is beneficial in the long term. However, launching debris removal technology requires developing a space debris population model. The light detection and ranging (LIDAR) technology is utilized for debris removal. However, the usefulness of the proposed LIDAR technology has not been examined from the perspective of scalability. From the discussion in [18], the question of the number of LIDAR technology payloads to be deployed with an increasing number of satellites in mega–constellations arises. However, this question has not been considered.

The influence of non–trackable objects in space is examined in [19]. Maclay *et al.* [19] recognize the threat posed by lethal space non–trackable objects. These objects constitute debris that is too small to track and catalogue. However, small sized debris has a high velocity and can damage a satellite on impact. The discussion in [19] proposes space traffic management for limiting the lethal effects of non–trackable debris. It is also recognized that limiting the population of lethal non–trackable objects is a feasible solution for reducing space debris. This can be achieved by reducing the potential of new missions to become sources of debris. The reduction of small sized non–trackable debris can also be realized by removing massive derelict objects in the low earth orbit (LEO).

The proposed space management approach aims to enhance and not worsen the space environment. An alternative way to reduce the complexity of the space traffic management is to limit the number of objects in space. However, this perspective has not been considered in [19].

The need to re–design and enable the emergence of a new space era is recognised by the European Space Agency [20]. The discussion in [20] recognises that reducing the orbital congestion necessitates designing solutions suited for enabling the emergence of a new era. It is recognized that collaboration is important to address the risks posed by space debris. In addition, the space sustainability rating and metric is recognized in [20]. The use of the space sustainability rating is suitable for promoting the sustainable use of orbital resources by organizations involved in space application deployment.

Space debris is also recognized to pose threats to new initiatives such as Space 4.0. Bohlmann *et al.* [21] recognize the risks and challenges that space debris pose to Space 4.0. The space 4.0 initiative is the next step in the evolution of space exploration and applications. It proposes reducing the effect of space debris by limiting the: (i) released debris, (ii) probability of accidental orbital collision, (iii) long term presence of launch vehicle and associated fragments in the low earth orbit, (iv) post–mission breakup potential and (v) long term spacecraft interference.

In [21], the use of active debris removal technologies is proposed for removing space debris and mitigating against the effect of space debris.

The discussion in [16–21] assumes that earth's orbital zones should be accessible to all actors requiring access to space's orbital resources. This is observed to result in an orbital commons paradigm. In this case space actors are able to freely access and use space's orbital resources. The use of this orbital commons paradigm results in space congestion with the generation of space debris being a negative consequence.

The observed challenge of space congestion can also be addressed by introducing license fees as a pre–requisite for the use of orbital fees. The use of orbital fees is proposed as an alternative approach in [22–24].

This is a feasible approach because it reduces the number of satellites that are launched into space and constrains space service providers to re–think accessing space resources.

However, the introduction of orbital fees can induce space winter i.e. reduce innovation in the design and development of future space applications. A space winter can occur when orbital use fees of up to $235k [22, 24] is levied on each satellite in the low earth orbit. The space winter occurs when regulatory policies limit the ability of capital constrained organizations to deploy satellites for applications.

The introduction of an annual charge of $235k orbital fees as proposed in [22] increases the challenges associated with deploying satellites for capital constrained space organizations. It limits the prospects of deploying applications requiring small satellite mega–constellations. It is important to avoid a scenario where satellite orbital use fees induce a space winter. However, the occurrence of a potential space winter has not been identified in the existing consideration for introducing orbit use fees as seen in [22–24].

The use of small satellites is increasing in different applications [25–27]. However, the introduction of orbital use fees can limit the benefits derivable from applications due to the use of small satellites.

Space exploration focuses on earth's orbital region and locations [22]. Earth's orbital locations comprise the low earth orbit, middle earth orbit and geostationary earth orbit. This perspective has not considered using non earth orbital locations for future space applications. However, the use of non-earth orbital locations in space applications is feasible. This can be seen in applications such as inter–planetary communications [28–29]. The realization of inter–planetary communications makes use of non–earth orbital regions. In interplanetary communications, nodes are located around different planets. The satellites used in interplanetary communications do not result in space debris in earth's orbit at their end of life.

The realization of inter–planetary communications presents the notion that satellites located out of the earth's orbit zones i.e LEO, MEO and GEO can deliver useful applications. This shifts the focus on the use of earth's orbital resources to non-earth's orbital resources for hosting satellites. The use of space technology for inter–planetary communications has also received significant research attention as seen in [30–31]. However, the discussion in [28–31] focuses on communications and not earth observations.

Earth observations via deployed satellites host payload having sensors that acquire meteorological data. The observed data are used to make inferences about earth's weather and climate. Earth observation satellites make use of earth's orbital locations. These are the low earth orbit (LEO), middle earth orbit (MEO) and geostationary orbit (GEO). The emergence of commercial earth observation start–ups [32–33] that use small satellites increase the number of satellites in earth's orbital locations. These deployed small satellites acquire meteorological data required for different applications that derive value from earth observations. This results in an increased earth orbital load. The introduction of orbital use fees for space access to capital constrained space organizations launching small satellites can induce space winter. However, it is important to design a mechanism that limits space debris arising from using large number of small satellites without inducing space winter.

In addition, space is being recognized as a suitable location for hosting computing entities. The emergence of new initiatives in the enterprise recognizes the capability of computing to transform space applications [34–36]. The discussion in [34–36] considers the use of edge computing nodes to transform space applications and is being pioneered by Hewlett Packard. The use of space based data centres with computational capacity exceeding edge computing nodes is expected to enable the low latency transfer and processing of space based data. This is expected due to the increased launch of small satellite related mega–constellation networks. In this case, a significant use of orbital resources is leading to increased orbit debris generation when these satellites reach their end of life.

The use of orbital resources for hosting data centres is recognized to have significant future applications [37]. This is especially important due to the increased interest in space exploration leading to acquiring more data from space. Space based data centres are useful in enabling the processing of data arising from space exploration. However, the occurrence of increased space debris is not beneficial to deployed space based data centres. This necessitates the conduct of research to ensure that the increased deployment of space based assets with increased space debris does not pose risks to future space based data centres. The proposed research should enable the identification of regions in space with low orbital debris. In such regions, space based data centres have a low exposure to space debris. This is important to ensure that a space induced winter does not limit the launch of initiatives seeking to place data centres in LEO, MEO or GEO.

3. Problem Description

The problem being described considers that a space organization seeks to deploy satellites (used in remote sensing) in different earth's orbits. The notations and parameters used in this paper are presented in Table 2.

Table 2: List of Parameters and Notations.

S/N	Parameter	Meaning
1	β	The set of operators seeking to deploy satellites
2	$\beta_j, \beta_j \epsilon \beta$	The set of satellites deployed by the j^{th} operator
3	$\beta_j^a, \beta_j^a \epsilon \beta_j$	The a^{th} satellite deployed by the j^{th} operator
4	ς	The set of terrestrial computing platforms comprising data centres
5	$\varsigma_k, \varsigma_k \epsilon \varsigma$	The k^{th} terrestrial data centre.
6	t	The set of epochs in the consideration
7	$t_y, t_y \epsilon t$	The y^{th} epoch
8	$\mathscr{b}(\varsigma_k, t_y)$	Computing resources aboard the k^{th} terrestrial data centre at the y^{th} epoch
9	$\mathscr{v}(t_y)$	The computing resource demanded by terrestrial applications
10	$\mathscr{v}(\beta_j^a, t_y)$	The amount of computing resources demanded by a^{th} satellite deployed by the j^{th} operator at the y^{th} epoch
11	$C_{thresh}(\beta_j, t_y)$	Threshold cost associated with launch and orbital use by the j^{th} operator at epoch t_y
12	$C_1\left(l_1(\beta_j^a, t_y)\right)$	The launch cost for the by a^{th} satellite deployed by the j^{th} operator at the y^{th} epoch
13	$C_2\left(l_1(\beta_j^a, t_y)\right)$	The orbit use cost for the by a^{th} satellite deployed by the j^{th} operator at the y^{th} epoch
14	ξ	The set of channels in the wireless network
15	$\xi_m, \xi_m \epsilon \xi$	The m^{th} wireless channel
16	$P_{tr}(\xi_m, t_y)$	The transmit power on the m^{th} wireless channel at the y^{th} epoch
17	$h_{tr}(\xi_m, t_y)$	The transmit channel gain for the m^{th} wireless channel at the y^{th} epoch
18	$P_{int}(\xi_m, t_y)$	The interferer power on the m^{th} wireless channel at the y^{th} epoch
19	$h_{int}(\xi_m, t_y)$	The interferer channel gain for the m^{th} wireless channel at the y^{th} epoch
20	$B(\xi_m)$	The bandwidth of the m^{th} wireless channel
21	F	The information rate
22	V	The set of satellites in our consideration
23	V_{eo}	The set of satellites in earth's orbit locations
24	V_{neo}	The set of satellites in non – earth orbital locations
25	$V_{eo}^k, V_{eo}^k \epsilon V_{eo}$	The k^{th} satellite in the earth's orbit locations i.e. LEO, MEO or GEO.

26	$V_{neo}^{q}, V_{neo}^{q} \epsilon V_{neo}$	The q^{th} satellite in the earth's non–orbital locations.
27	ℓ_1	Location associated with the low earth orbit
28	ℓ_2	Location associated with the middle earth orbit
29	ℓ_3	Location associated with the geostationary earth orbit
30	$N_{tr}(V_{eo}, \ell_1, t_y)$	The number of satellites in the low earth orbit in the y^{th} epoch
31	$N_{tr}(V_{eo}, \ell_2, t_y)$	The number of satellites in the middle earth orbit in the y^{th} epoch
32	$N_{tr}(V_{eo}, \ell_3, t_y)$	The number of satellites in the geostationary earth orbit in the y^{th} epoch
33	$N_{in}(V_{neo}, t_y)$	The number of satellites in the non–earth orbital locations in the y^{th} epoch
34	$ƒ_{in}(V_{eo}, \ell_1)$	The rate of launching satellites into the low earth orbit
35	$ƒ_{in}(V_{eo}, \ell_2)$	The rate of launching satellites into the middle earth orbit
36	$ƒ_{in}(V_{eo}, \ell_3)$	The rate of launching satellites into the geostationary earth orbit
37	$ƒ_{tr}(V_{neo}, t_y)$	The rate of launching satellites into non–earth's orbital locations in the y^{th} epoch
38	$N_{int}(V_{eo}, \ell_1, t_y)$	The number of satellites in the low earth orbit reaching their end of life in the y^{th} epoch
39	$N_{int}(V_{eo}, \ell_2, t_y)$	The number of satellites in the middle earth orbit reaching their end of life in the y^{th} epoch
40	$N_{int}(V_{eo}, \ell_3, t_y)$	The number of satellites in the geostationary earth orbit reaching their end of life in the y^{th} epoch
41	$N_{int}(V_{neo}, t_y)$	The number of satellites in non–earth orbital location reaching their end of life in the y^{th} epoch
42	$ƒ_{int}(V_{neo}, t_y)$	The rate at which satellites in non–earth orbital location reaching their end of life in the y^{th} epoch
43	κ	Set of regions in outer space
44	$\kappa_e, \kappa_e \in \kappa$	The e^{th} region in outer space
45	$ђ_1^{th}(\kappa_e)$	Threshold space debris in the e^{th} outer space region in the low earth orbit
46	$ђ_2^{th}(\kappa_e)$	Threshold space debris in the e^{th} outer space region in the middle earth orbit
47	$ђ_3^{th}(\kappa_e)$	Threshold space debris in the e^{th} outer space region in the geostationary earth orbit
48	$ђ_1(\kappa_e, t_y)$	The amount of space debris in the e^{th} region in the low earth orbit at the y^{th} epoch
49	$ђ_2(\kappa_e, t_y)$	The amount of space debris in the e^{th} region in the middle earth orbit at the y^{th} epoch
50	$ђ_3(\kappa_e, t_y)$	The amount of space debris in the e^{th} region in the geostationary earth orbit at the y^{th} epoch
51	$L_{tr}(V_{eo}, \ell_1)$	Number of planes hosting earth observation satellites in the low earth orbit
52	$L_{tr}(V_{eo}, \ell_2)$	Number of planes hosting earth observation satellites in the middle earth orbit
53	$L_{tr}(V_{eo}, \ell_3)$	Number of planes hosting earth observation satellites in the geostationary earth orbit.

These satellites are used to deliver applications to subscribers. Let β denote the set of operators seeking to deploy satellites such that:

$$\beta = \{\beta_1, \beta_2, \beta_3, \dots, \beta_J\}, \quad (1)$$

where

J is the index of the last satellite operator.

The set of satellites $\beta_j, \beta_j \epsilon \beta$ deployed by the j^{th} operator, is given as:

$$\beta_j = \{\beta_j^1, \beta_j^2, \beta_j^3, \dots, \beta_j^A\}, \quad (2)$$

where

A is the index of the last satellite deployed by the j^{th} operator.

In addition, let ς denote the set of terrestrial computing platforms comprising data centres such that:

$$\varsigma = \{\varsigma_1, \varsigma_2, \dots, \varsigma_K\}, \quad (3)$$

Where $\varsigma_k, \varsigma_k \epsilon \varsigma$ is the k^{th} terrestrial data centre.

The amount of computing resources aboard ς_k at the epoch $t_y, t_y \epsilon t, t = \{t_1, t_2, \dots, t_Y\}$ is denoted $ƀ(\varsigma_k, t_y)$. In addition, let $\mathscr{v}(t_y)$ and $\mathscr{v}(\beta_j^a, t_y), \beta_j^a \epsilon \beta_j$ denote the computing resource demanded by terrestrial applications and the a^{th} satellite from the j^{th} operator at the epoch t_y, respectively. Satellite data requiring processing is challenging for terrestrial computing platforms when:

$$\sum_{y=1}^{Y}\sum_{a=1}^{A}\sum_{j=1}^{J}\left(\mathcal{v}(t_y)+\mathcal{v}(\beta_j^a,t_y)\right) \geq \left(\sum_{y=1}^{Y}\sum_{k=1}^{K}\mathcal{b}(\varsigma_k,t_y)\right), \mathcal{v}(\beta_j^a,t_y) > v(t_y). \tag{4}$$

The challenge in (4) describes a context in which the total size of data from the space segment comprising multiple satellites exceeds that from terrestrial applications. The total data requiring processing exceeds t terrestrial computing platform capacity. In (4), the data requiring processing exceeds terrestrial computing platform capacity due to the increasing number of deployed small satellites.

Let the launch and orbit use costs for satellite β_j^a at the epoch t_y be $C_1\left(l_1(\beta_j^a,t_y)\right)$ and $C_2\left(l_1(\beta_j^a,t_y)\right)$, respectively. Let $C_{thresh}(\beta_j,t_y)$ be the threshold cost associated with launch and orbital use by the j^{th} operator at epoch t_y. High costs pose a limitation to satellite deployment when:

$$\sum_{a=1}^{A}\left(\sum_{y=1}^{Y}C_1\left(l_1(\beta_j^a,t_y)\right)+C_2\left(l_1(\beta_j^a,t_y)\right)\right) \geq C_2\left(l_1(\beta_j^a,t_y)\right), C_2\left(l_1(\beta_j^a,t_y)\right) > C_{thresh}(\beta_j,t_y), \tag{5}$$

$$\sum_{a=1}^{A}\left(\sum_{y=1}^{Y}C_2\left(l_1(\beta_j^a,t_y)\right)\right) \geq \sum_{a=1}^{A}\left(\sum_{y=1}^{Y}C_1\left(l_1(\beta_j^a,t_y)\right)\right), C_2\left(l_1(\beta_j^a,t_y)\right) > C_{thresh}(\beta_j,t_y). \tag{6}$$

The challenges in (5) and (6) imply that the orbital use costs exceed the launch costs and threshold costs. Hence, the high orbital use cost can limit space exploration and application deployment.

Furthermore, the set of satellites in β_j can be deployed in an application to serve as space based data centres. The role of space based computing via space based data centres is becoming important as seen in initiatives such as Hewlett Packard's Spaceborne computing project [34–36]. Space debris can arise in the region hosting the space based data centres. Given that space has multiple regions with the number of regions being in the set κ such that:

$$\kappa = \{\kappa_1, \kappa_2, \dots, \kappa_E\} \tag{7}$$

In addition, let threshold space debris in the e^{th} space region $\kappa_e, \kappa_e \in \kappa$ for LEO, MEO and GEO be denoted as $\hbar_1^{th}(\kappa_e), \hbar_2^{th}(\kappa_e)$ and $\hbar_3^{th}(\kappa_e)$, respectively. In addition, the amount of space debris is time varying and is denoted as $\hbar_1(\kappa_e,t_y), \hbar_2(\kappa_e,t_y)$ and $\hbar_3(\kappa_e,t_y)$ for LEO, MEO and GEO, respectively. The regions in LEO, MEO and GEO are unsuitable for hosting space based data centres due to space debris when:

$$\left(\left(\frac{1}{Y-1}\right)\left(\sum_{y=1}^{Y}\hbar_i(\kappa_e,t_y)\right)\right) \geq \hbar_i^{th}(\kappa_e), i = \{1,2,3\} \tag{8}$$

An entire orbit i.e. LEO, MEO or GEO has a high amount of space debris when:

$$\left(\left(\frac{1}{Y-1}\right)\left(\sum_{y=1}^{Y}\sum_{e=1}^{E}\hbar_i(\kappa_e,t_y)\right)\right) \geq \left(\sum_{e=1}^{E}\left(\hbar_i^{th}(\kappa_e)\right)\right), i=\{1,2,3\} \tag{9}$$

4. Data Driven Earth Observation Paradigm

The discussion in this section presents the proposed earth observation paradigm. The description of the proposed paradigm is done in two parts. The first part presents the space aspects and relations in the proposed earth observation paradigm. The second part focuses on the underlying data driven architecture that supports the proposed earth observation paradigm.

4.1 Space Assets, Aspects and Relations

The proposed solution i.e the data driven earth observation paradigm is presented in this section. The solution addresses the challenges presented in the relations (4), (5) and (6) alongside the challenges in (7), (8) and (9). The proposed paradigm addresses earth observation using a two partition satellite system. It utilizes satellites that are located in non–earth orbital and earth orbital locations (LEO, MEO and GEO). In this case, earth's non–orbital locations are the space locations lying beyond the GEO. In the proposed paradigm, the satellites in earth's locations pose threats of space debris at their end of life and are temporally deployed. The satellites in non–earth orbital locations are deployed for a longer duration.

The data driven earth observation paradigm aims to acquire training data useful for predicting earth's weather and climate outcomes. In this case, satellites in earth's orbital locations and non–earth's orbital locations acquire meteorological data. The acquired meteorological data is used in a machine learning application that predicts earth's meteorological data (output) utilizing non–earth orbital location related meteorological data as input. This is feasible considering the advances in cloud platforms and data driven machine learning algorithms.

In the proposed data driven earth observation paradigm, small satellites are deployed in earth and non – earth orbital locations. The satellites in earth orbital locations are deployed for a shorter duration with the aim of acquiring training data to be used in the aforementioned machine learning application. This is different from the existing perspective where commercial earth observation service providers deploy satellites to continuously acquire earth's meteorological data. In the proposed mechanism, the satellites are deployed with the aim of acquiring training data.

A smaller number of satellites in LEO orbiting the earth are used to acquire earth's meteorological data. In a similar manner, mobile satellites are deployed in non–earth's orbital locations and also acquire meteorological data for pre–determined locations beyond GEO. This is feasible because of advances in launch vehicle technology making it possible to launch meteorological data acquisition nodes into beyond GEO locations. This can be realized by hosting meteorological data acquisition payload aboard vehicles capable of reaching beyond GEO locations as seen in [38–39].

Reilly *et al.* [38] identifies and discusses technologies enabling the realization of beyond earth orbit applications using small satellites. The identified technologies comprise electrostatic, electro-thermal and electromagnetic propulsion.

Walker in [39] also recognize the demonstrated usefulness of small satellites i.e. nano-spacecraft in inter-planetary applications. Given that the altitudes associated with inter–planetary locations exceed GEO altitude. In [39], the context of inter-planetary locations involves executing missions in Mars. The technology concerned can be used in the context of beyond GEO altitudes which falls short of the Earth-Mars distance. Furthermore, different launch vehicles and their reachable final destinations are also presented in [39]. The presented launch destinations exceed GEO altitude values. Hence, it is feasible to utilize these launch vehicles in placing meteorological data acquisition nodes into beyond GEO altitudes. Examples of the launchers presented are: PSLV/Ariane 6, Soyuz/Ariane 6 and Proton/Atlas V. These launchers host different spacecraft that can carry meteorological data acquisition nodes (i.e. satellites) as the comprising entities. The final destination concerned lie beyond GEO making it feasible to realize meteorological data acquisition in beyond GEO locations. However, these locations are not in the interplanetary path. Furthermore, the use of moon–based earth observation processes is recognized to be suitable for realizing beyond GEO earth observation and meteorological data acquisition. This can be seen in [40–44].

The evolution of earth observation satellites are discussed in [40]. In this case, fifth generation of satellites are recognized to be used in earth observations. Fifth generation earth observation satellites are expected to be highly intelligent with integrated earth observation sensors, data processing and communication capabilities. In addition, fourth generation earth observation sensors are expected to incorporate high resolution and hyper-spectral imaging sensors that are still evolving in resolution capability. The moon is also expected to be an ideal remote sensing platform in [40]. The discussion in [41] also recognizes the capability and technical feasibility of using moon based meteorological sensors to realize earth observations. The moon is recognized to be advantageous because it enables earth observation with spatial continuity and temporal consistency. In addition, the moon presents a surface suitable for hosting several sensors that can be used to obtain meteorological data from the earth. The use of locations beyond GEO is feasible via the launch vehicles enabling the realization of moon based earth observations. This is because the beyond GEO altitudes of up to 60,000 km fall short of the earth–moon distance of 380,000 km. A similar discussion on the benefits of using the moon is also presented in [42–45].

In the proposed solution, a lesser number of satellites are deployed in LEO in comparison to the number of satellites beyond GEO. In this case, a smaller number of satellites can be deployed in LEO. This is because satellites now act as temporal nodes that acquire meteorological data. The use of a small number of satellites reduces the space debris threat and risk.

The flowchart showing the proposed mechanism is presented in Figure 1. In Figure 1, it is assumed that satellites in earth's orbital locations (LEO, MEO and GEO) and non–earth's orbital locations have been deployed. The non–earth's orbital locations are not in the path of interplanetary travel for realizing earth applications. These satellites host meteorological data acquisition payload that acquire meteorological data. In this case, satellites in non–earth's orbital locations are deployed to pre–defined locations outside of GEO. A significant number of satellites are deployed and hosted in non–earth's orbital locations.

The total number of satellites that is normally used in earth's orbital locations equals the sum of satellites in our proposed mechanism. In our consideration, the sum is the total of the satellites in non – earth and earth's orbital locations. The number of locations hosting satellites in the non–earth's orbital locations is equivalent to the number of locations being visited by satellites in earth's orbital locations. The acquired meteorological data is transmitted to the cloud platform for storage and proposing to meet the requirements of the machine learning application.

The machine learning application is intended to determine earth's meteorological variables (output) given the meteorological data from non–earth's orbital locations as inputs. A threshold size of data is required from satellites in earth's orbital locations. In the event that the threshold size of data has been acquired, the development of the machine learning application proceeds. The trained machine learning application uses only data observed from satellites in non–earth's orbital locations after training.

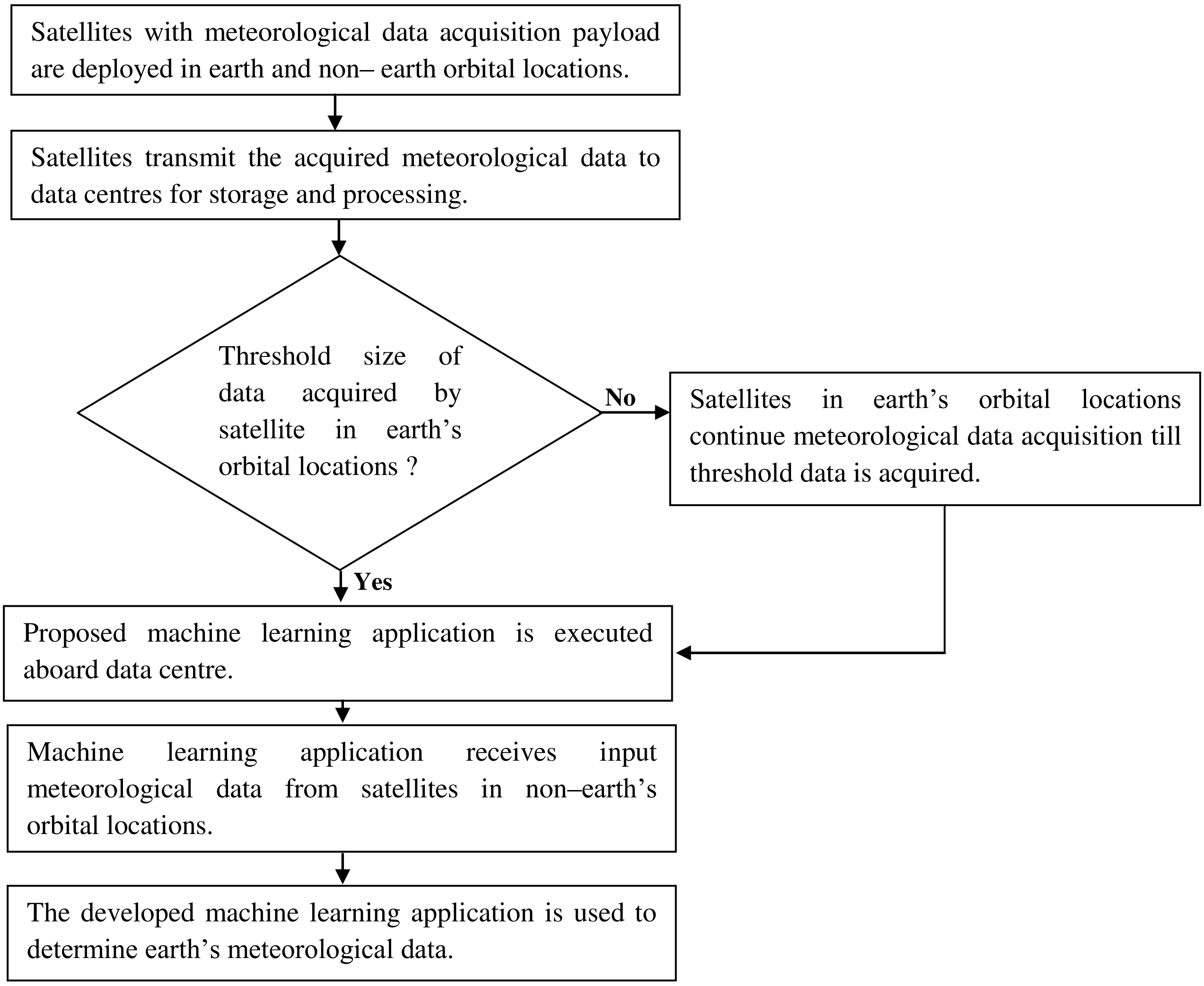

Figure 1: Flowchart showing the computational steps in the proposed mechanism.

4.2 Underlying Data Driven Architecture

The presented research also proposes a data framework to acquire the parameters enabling the computation of the RDSG in the proposed mechanism. The process of data acquisition and aggregation is related to in–orbit satellites and satellites approaching their end of life. The access and aggregated data is obtained from databases hosting satellite data. The use of internet based satellite data crawlers is also proposed to search the web for the acquisition of unstructured space application and satellite related data.

In the data acquisition process, two types of information sources are considered. These are: (1) Structured Information obtained from databases such as [1–5] and (2) Unstructured information from internet satellite data crawlers. The acquired data is held in a cloud computing platform and used to compute the RDSG. This computation is done aboard the cloud computing for different regions in earth's orbital locations i.e. LEO, MEO and GEO. The regions in this case are determined by the altitude, coverage (footprint) and inclination. A region has values for these parameters within a pre–defined range of values.

Figure 2 presents the relation between the data hosting methods and databases. In Figure 2, structured and unstructured data are utilized for RDSG related computation. The acquisition of structured data is done from databases holding satellite and space orbit utilization related data. The satellite and space orbit utilization related data is defined for each orbital plane that hosts launched satellites being used in existing applications i.e. space exploration, earth observations and communications. In Figure 2, there are B databases that hold plane specific space utilization related data. Furthermore, unstructured data is obtained from web sources via logical crawler entities. There are C web sources with each having a logical crawler entity. Data obtained from the databases and web sources are processed by data refining entity structured (DREs) and data refining entity unstructured (DREu).

The DREs sends the acquired data to the data aggregator entity (DAE). This is also done by the DREu. The DAE aggregates data from the DREu and DREs. The aggregated data serves as an input to the parameter extraction entity (PEE) that extracts data from the DAE output. The RDSG is computed from the data extracted from the PEE. The RDSG data is used to rank regions in space for the orbital locations of LEO, MEO and GEO. This is done to identify the region with the lowest RDSG i.e. most suitable region in space in each orbit and for an entire orbit to host satellites being launched.

In the architecture presented in Figure 2, a threshold RDSG is also pre–defined. In the case that the RDSG (computed) exceeds the threshold RDSG, satellites are launched into non–earth orbital locations. In the proposed mechanism, the use of earth's orbital locations receives more preference than non–earth's orbital locations. This is because of the low launch costs associated with utilizing earth's orbital locations of LEO, MEO and GEO.

The proposed architecture being presented in Figure 2 enables the acquisition of information useful in determining the suitability of a space region to host data centres. The information used to determine the suitability of a region for hosting data centres is the output of the RCE. This is used to evaluate (8) and (9) and determine the space regions suitable for siting space based data centres. The architecture presented in Figure 2 is set in the context of multiple mega–constellation satellite networks. These networks are owned by different satellite network service providers or operators. This context is feasible due to the increasing use and adoption of small satellites and identified space applications.

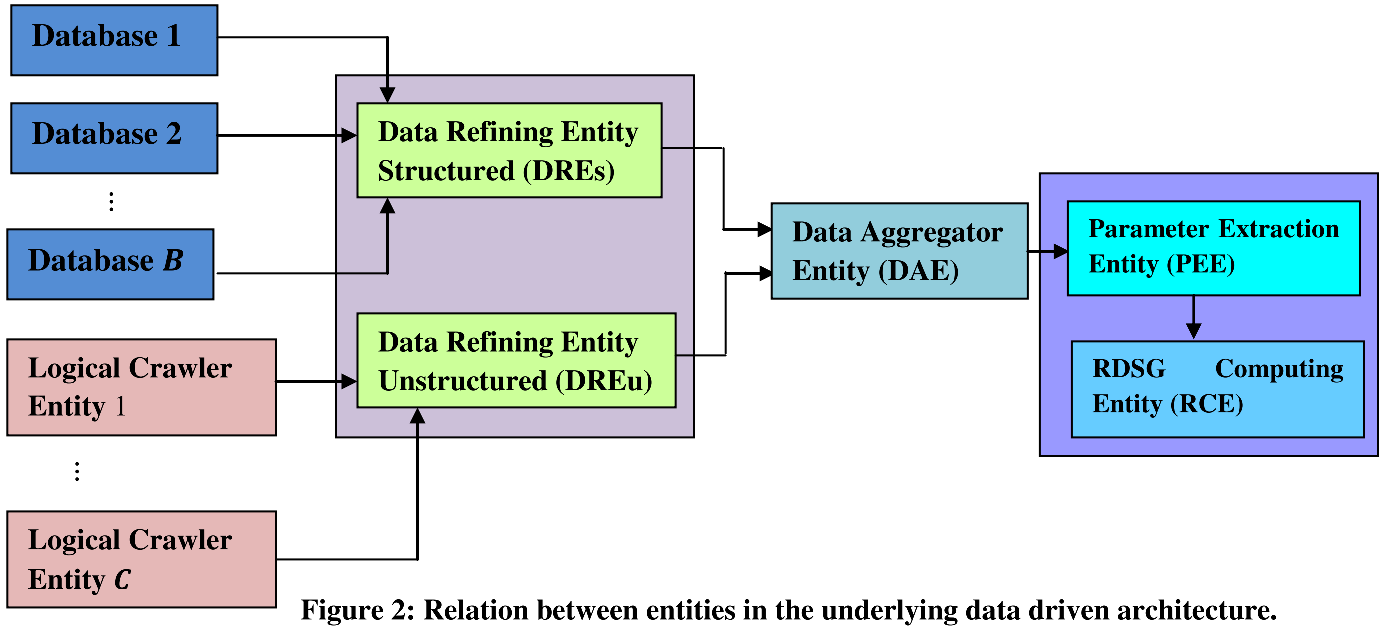

Figure 2: Relation between entities in the underlying data driven architecture.

5. Performance Formulation and Modelling

The performance model is formulated in this section. The metric being formulated is the rate of space debris generation (RSDG). The RDSG is formulated using an adaptation of the Shannon channel capacity relation. The Shannon channel capacity relation comprises variables that describe the information rate of a wireless channel. This is done considering variables and parameters such as the transmit power on the channel, interfering power on the channel; transmit channel gain, interferer channel gain and the noise on the concerned wireless channel.

Let ξ denote the set of channels such that:

$$\xi = \{\xi_1, \xi_2, \dots, \xi_M\}. \qquad (10)$$

The transmit power, transmit channel gain, interfering power and interferer channel gain associated with the m^{th} channel $\xi_m, \xi_m \epsilon\, \xi$ at the epoch t_y are denoted as $P_{tr}(\xi_m, t_y), h_{tr}(\xi_m, t_y), P_{int}(\xi_m, t_y)$ and $h_{int}(\xi_m, t_y)$, respectively. Given that the bandwidth of the m^{th} channel ξ_m is denoted as $B(\xi_m)$, the information rate, F is:

$$\mathrm{F} = \sum_{y=1}^{Y}\left(\sum_{m=1}^{M}\left(B(\xi_m)\log_2\left(\frac{P_{tr}(\xi_m, t_y)\left|h_{tr}(\xi_m, t_y)\right|^2}{P_{int}(\xi_m, t_y)\left|h_{int}(\xi_m, t_y)\right|^2}\right)\right)\right). \qquad (11)$$

In a similar manner, an adaptation of the information rate relation is used to formulate the RDSG metric. The RDSG is formulated using the variables of: (1) Number of in–orbit new satellites (equivalent to transmit power), (2) rate of launch of new satellites (equivalent to transmit channel gain), (3) Number of satellites reaching their end of life (equivalent to interferer power) and (4) rate at which satellites approach their end– of–life (equivalent to interferer channel gain).

The assigning of variables has been done considering parameters influencing the access to space orbital resources. In this regard, the number of in–orbit new satellites and rate of launch of new satellites are important. These are the parameters influencing space orbital resource access. Furthermore, variable assignment is also done considering parameters influencing space debris generation in space. The concerned parameters in this case are the number of satellites reaching their end of life and rate at which satellites approach their end of life. These are the parameters influencing space orbital resource debris related congestion. Parameters influencing space orbital resource access influence space (channel) access. The parameters influencing space orbital resource debris related congestion constitute risk (interference) due to space debris on launched satellites.

Furthermore, let V denote the set of satellites such that:

$$\mathrm{V} = \{\mathrm{V}_{eo}, \mathrm{V}_{neo}\}, \tag{12}$$

$$\mathrm{V}_{eo} = \{\mathrm{V}_{eo}^{1}, \mathrm{V}_{eo}^{2}, \dots, \mathrm{V}_{eo}^{K}\}, \tag{13}$$

$$\mathrm{V}_{neo} = \left\{\mathrm{V}_{neo}^{1}, \mathrm{V}_{neo}^{2}, \dots, \mathrm{V}_{neo}^{Q}\right\}, \tag{14}$$

where

V_{eo} and V_{neo} are the set of satellites in earth's orbit locations and non–earth's orbit locations, respectively.

K and Q are the indexes of the last satellite in earth's orbit locations and non–earth's orbit locations, respectively.

V_{eo}^{k} , $\mathrm{V}_{eo}^{k} \epsilon\, \mathrm{V}_{eo}$ is the k^{th} satellite in the earth's orbit locations i.e. LEO, MEO or GEO.

V_{neo}^{q} , $\mathrm{V}_{neo}^{q} \epsilon\, \mathrm{V}_{neo}$ is the q^{th} satellite in the earth's non–orbital locations.

In addition, let $N_{tr}(\mathrm{V}_{eo}, \ell_1, t_y), N_{tr}(\mathrm{V}_{eo}, \ell_2, t_y)$ and $N_{tr}(\mathrm{V}_{eo}, \ell_3, t_y)$ be the size (i.e. number of satellites) in LEO (ℓ_1), MEO (ℓ_2) and GEO (ℓ_3), at the epoch , t_y respectively. The size of satellites in earth's non–orbit location at the epoch t_y is denoted $N_{in}(\mathrm{V}_{neo}, t_y)$. The rate of launch associated with $N_{tr}(\mathrm{V}_{eo}, \ell_1, t_y), N_{tr}(\mathrm{V}_{eo}, \ell_{2,t_y})$ and $N_{tr}(\mathrm{V}_{eo}, \ell_3, t_y)$ are denoted as $\not{f}_{in}(\mathrm{V}_{eo}, \ell_1), \not{f}_{in}(\mathrm{V}_{eo}, \ell_2)$ and $\not{f}_{in}(\mathrm{V}_{eo}, \ell_3)$, respectively. The rate of launch associated with $N_{tr}(\mathrm{V}_{neo}, t_y)$ is given as $\not{f}_{tr}(\mathrm{V}_{neo}, t_y)$.

Furthermore, the number of satellites reaching their end of life and associated with $N_{tr}(\mathrm{V}_{eo}, \ell_1, t_y), N_{tr}(\mathrm{V}_{eo}, \ell_2, t_y)$ and $N_{tr}(\mathrm{V}_{eo}, \ell_3, t_y)$ are given as $N_{int}(\mathrm{V}_{eo}, \ell_1, t_y), N_{int}(\mathrm{V}_{eo}, \ell_2, t_y)$ and $N_{int}(\mathrm{V}_{eo}, \ell_3, t_y)$, respectively. In a similar manner, the number and rate of satellites reaching their end of life and associated with $N_{tr}(\mathrm{V}_{neo}, t_y)$ and $\not{f}_{tr}(\mathrm{V}_{neo}, t_y)$ are denoted as $N_{int}(\mathrm{V}_{neo}, t_y)$ and $\not{f}_{int}(\mathrm{V}_{neo}, t_y)$, respectively.

The RDSG is formulated for the existing case in which the proposed network architecture and mechanism is not used. The RDSG φ_1 is:

$$\varphi_1 = \sum_{i=1}^{3}\left(\sum_{y=1}^{Y} \log_{\mathrm{o}}\left(\frac{N_{tr}(\mathrm{V}_{eo}, \ell_i, t_y)\not{f}_{tr}(\mathrm{V}_{eo}, \ell_i)}{N_{int}(\mathrm{V}_{eo}, \ell_i, t_y)\not{f}_{int}(\mathrm{V}_{eo}, \ell_i)}\right)\right), |\mathrm{V}_{eo}| = K, \tag{15}$$

where o is the number of satellite orbiting paths in the space environment.

The RDSG in the case of the proposed mechanism is denoted φ_2 and given as:

$$\varphi_2 = \sum_{i=1}^{I}\sum_{y=1}^{Y} \log_{\mathrm{o}}\left(\frac{N_{tr}(\mathrm{V}_{eo}, \ell_i, t_y)\not{f}_{tr}(\mathrm{V}_{eo}, \ell_i) + N_{tr}(\mathrm{V}_{neo}, t_y)\not{f}_{tr}(\mathrm{V}_{neo}, t_y)}{N_{int}(\mathrm{V}_{eo}, \ell_i, t_y)\not{f}_{int}(\mathrm{V}_{eo}, \ell_i) + N_{int}(\mathrm{V}_{neo}, t_y)\not{f}_{int}(\mathrm{V}_{neo}, t_y)}\right),$$

$$|\mathrm{V}_{eo}| + |\mathrm{V}_{neo}| = K, |\mathrm{V}_{neo}| \geq |\mathrm{V}_{eo}|, \tag{16}$$

The number of satellite orbiting paths influences the feasible propagation paths of space debris emerging from space debris (for end of life satellites). A large number of orbiting paths implies that space debris can travel in more directions without experiencing collision with functional and in–orbit satellites. A smaller number of satellite orbiting paths implies that emerging space debris can travel in a lesser number of directions with an increased risk of colliding with in–orbit satellites. The case of a large and small number of paths for the case in which satellites are hosted in one orbital plane is considered in this research. This is done assuming that space debris travelling from one orbital plane into another orbital plane arrives into the destination orbital plane at low speed. The arrival at low speed into the destination orbital plane results in transiting debris having a low incident kinetic energy on space assets that are deployed in the destination orbit. In this case the space assets are space based data centres and earth observation satellites.

Scenarios illustrating the influence of space debris and number of propagation paths are presented in Figure 3 and Figure 4. In presenting and discussing the scenarios in Figures 3 and 4, the focus is on considering the number of space debris propagation paths. This is done without placing emphasis on location of satellites in either an earth or non–earth orbital locations. The scenarios presented in Figure 3 and Figure 4 presents feasible directions of debris propagation. In this case, the aggregated small space debris being considered are capable of colliding with earth observation satellites or deployed space based data centres. This is challenging as it can influence the capability of earth observation satellites to acquire meteorological data; and limit the ability of space based data centres to execute data storage and processing.

The scenario in Figure 3 shows the case in which there are six space debris fragments and seven satellites at different altitudes (executing earth observations). The space debris being considered has emerged due to the aggregation of three smaller space debris fragments. Each space debris fragment can travel in four directions each i.e. up, down, left and right in translational motion. Therefore, the case in Figure 3 with the higher number of space debris fragments has a total of 24 feasible propagation paths.

Figure 4 shows a scenario where the seven earth observation satellites with altitudes similar to the satellites in Figure 3. However, there are three collections of aggregated small space debris fragments that can also travel in four directions i.e. up, down, left and right in translational motion.
Therefore, there are 12 feasible propagation paths of the concerned space debris. The consideration of more types of motion i.e. the inclusion of non–linear motion direction increases the number of feasible propagation paths. Given that each debris aggregate is capable of executing bi–directional circular motion, the number of feasible propagation paths in Figure 4 increases from 12 to 18. The new number of feasible propagation paths i.e. 18 is less than the 24 which is the number of feasible propagation paths in Figure 3. This shows the dominating effect of the number of feasible propagation paths.

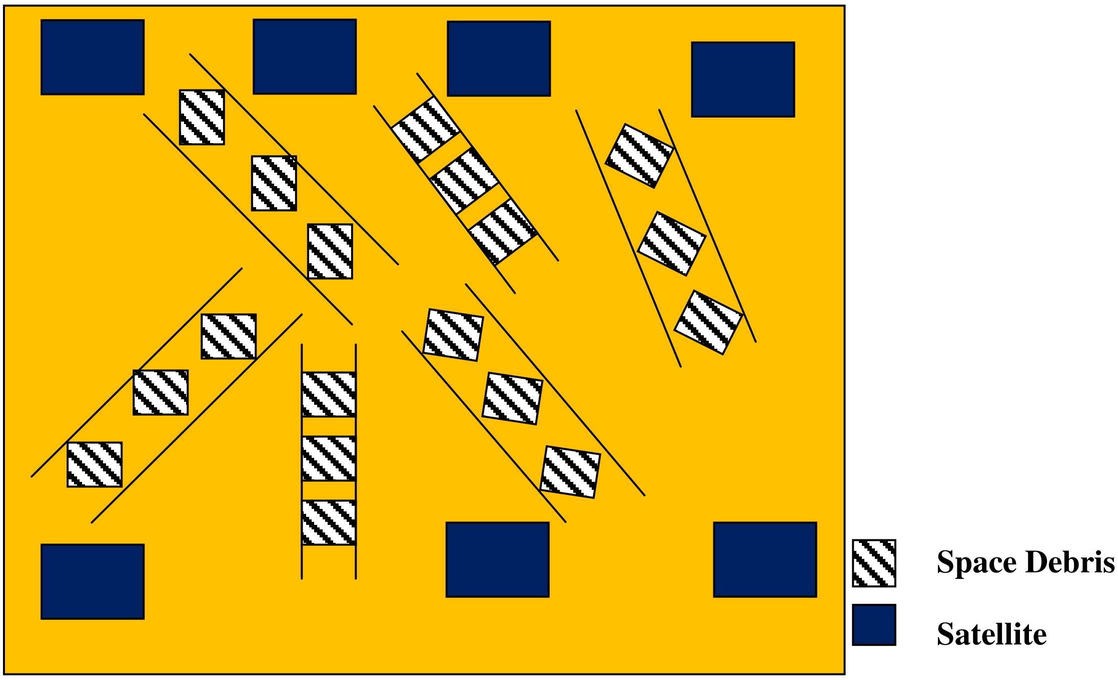

Figure 3: In–orbit satellites with 24 feasible propagating paths for space debris.

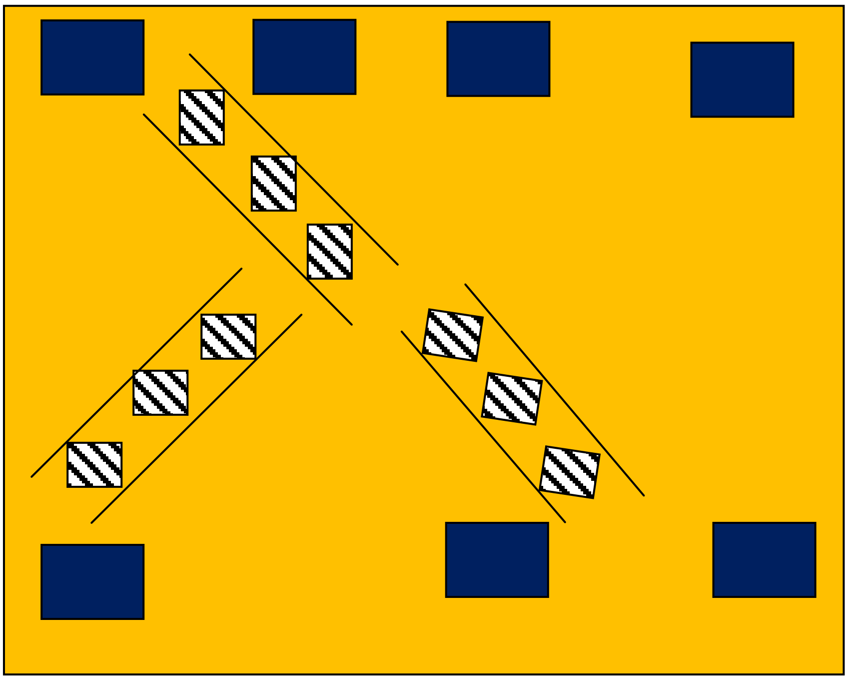

Figure 4: In–orbit satellites with three propagating paths for space debris.

6. Performance Evaluation

The performance evaluation is presented in this section. This is done by investigating the RDSG before and after using the proposed solution proposed mechanism. The RDSG gives the number of space debris generated per second. A low RDSG is more beneficial than a high RDSG. The former indicates a lower occurrence of space debris while a high RDSG indicates a higher occurrence of space debris for the same region in space. The occurrence of a low RDSG in a given space region implies that assets such as earth observation satellites or space based data centres are subject to collision with a lower number of space debris particles in the considered region. This arises in the case when there is a large number of existing space assets in a given space region are approaching their end of life.

A high RDSG implies that space assets being deployed i.e. earth observation satellites and space based data centres are subject to collision from a large amount of space debris. This arises when there is a large number of existing space assets approaching the end of life in a given space region.

The performance evaluation parameters for one orbital plane are presented in Table 3. The parameters used in the performance evaluation and shown in Table 3 have been randomly selected considering that the number of satellites, their launch rates and how they approach end of life are orbital independent. In this context, orbital independence implies that satellites can reach their end of life state in different times across the earth's orbital regions. Furthermore, non–earth's orbital satellites are placed in their location using launch vehicles. In addition, the launch of satellite with meteorological data acquisition payload is considered as being continous.

Satellites are launched into the considered locations in a manner that they do not function toward realizing a single objective. Instead, the performance evaluation considers that multiple space organizations deploy satellites into the considered earth's orbital locations and non–earth's orbital locations.

The application of interest in this case is that of earth observation. Earth observation is conducted with the aim of acquiring meteorological data. The simulation result of the RDSG before and after the use of the proposed solution is presented in Figure 5 and Figure 6, respectively. The case of the existing mechanism is presented in the discussion by Rao *et al.* [22]. However, the case here differs from [22] because it does not consider the inclusion of orbital use fees and the use of non–earth orbital locations as proposed here. Hence, the existing work being considered is [22].

Table 3: Performance Evaluation Parameters.

S/N	Parameter	Value
1	Number of satellites in LEO (maximum , mean and minimum)	[147.7, 79.6, 12.3]
2	Number of satellites in MEO (maximum , mean and minimum)	[163.5, 88.6, 3.5]
3	Maximum, Mean and Minimum rate of satellite launch into LEO	[93.9% , 52.6%, 8.3%]
4	Maximum, Mean and Minimum rate of satellite launch into MEO	[94.2% , 58.4%, 23.9%]
5	Maximum, Mean and Minimum rate of satellite launch into GEO	[86.7% , 45.2%, 11.3%]
6	Maximum, Mean, and Minimum Number of satellites reaching end of life in LEO	[31.8, 14.5, 3.9]
7	Maximum, Mean and Minimum Number of satellites reaching end of life in MEO	[34.5. 10.2 , 0.06]
8	Maximum, Minimum and Mean Number of satellites reaching end of life in GEO	[39.5, 19.4, 5.8]
9	Maximum, Mean and Minimum rate of satellite reaching end of life in LEO	[96.2 %, 45%, 0.74%]
10	Maximum, Mean and Minimum rate of satellite reaching end of life in MEO	[89 % , 56.4%, 21.8%]
11	Maximum, Mean and Minimum rate of satellite reaching end of life in GEO	[91 % , 59%, 3.3%]
12	Maximum Number of Satellites in Non–Earth's Orbital Locations	243.6
13	Mean Number of Satellites in Non–Earth's Orbital Locations	130.2
14	Minimum Number of Satellites in Non–Earth's Orbital Locations	16.6
15	Maximum rate of satellite launch into Non–Earth's Orbital Locations	76.2%
16	Mean rate of satellite launch into Non–Earth's Orbital Locations	43.6 %
17	Minimum rate of satellite launch into Non–Earth's Orbital Locations	0.12%
18	Maximum rate of satellite approaching end of life in Non–Earth's Orbital Locations	76.2%
19	Mean rate of satellite approaching end of life in Non–Earth's Orbital Locations	41.5 %
20	Minimum rate of satellite approaching end of life in Non–Earth's Orbital Locations	9.2 %

From the results in Figures 5 and 6, it can be seen that an increase in the number of paths results in a reduced RDSG. This is because of the reduced risk of satellite–space debris collision when resulting space debris can travel in more orbital locations (that do not host satellites). In Figure 6, the use of the proposed mechanism utilizing non–earth's orbital locations is solely considered between the epochs 6 and 10. Hence, there is a significant reduction in the RDSG between these epochs.

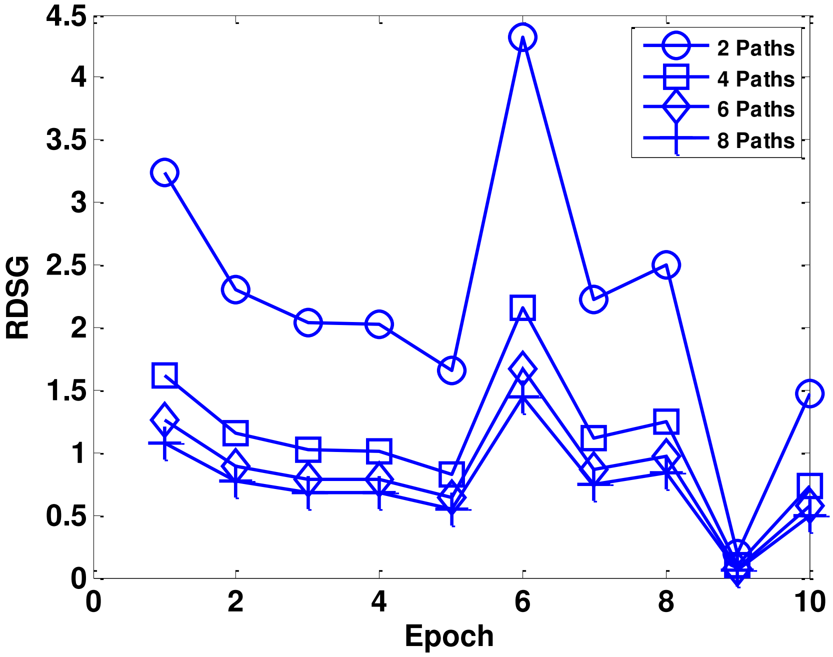

Figure 5: Simulation showing the values of the RDSG for 2, 4, 6 and 8 space debris propagation paths in the case of the existing approach (without the use of non–earth orbital locations as found in [22]).

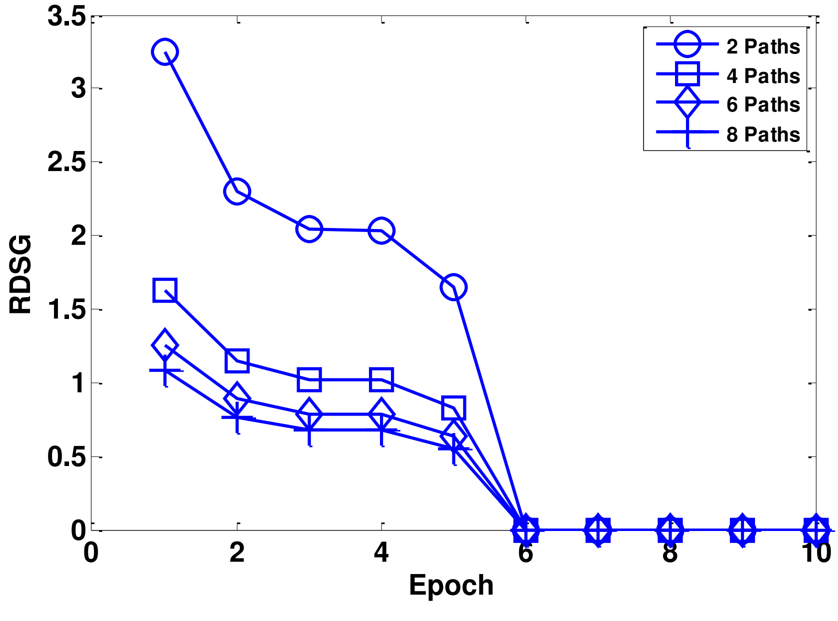

Figure 6: Simulation showing the values of the RDSG for 2, 4, 6 and 8 space debris propagation paths in the case of the proposed approach (while using non–earth orbital locations).

Analysis shows that increasing the number of paths by 50%, 66.7%, 75%, 33%, 50% and 33% reduces the RDSG by an average of 50%, 61.3%, 66.7%, 22.6%, 33.3% and 16.1%, respectively. The mean lowering of the RDSG value in this case applies to the existing case and proposed case. This shows that the number of space debris propagation paths significantly influences the RDSG.

In addition, the evaluation investigates the benefit of the proposed mechanism over the existing mechanism in [22] given the same number of paths. Analysis shows that the proposed mechanism and reduces the RDSG by 50% on average. It is observed that the performance benefit of 50% is noted for all number of paths i.e. {2, 4, 6, 8} that are considered in the simulation.

The analysis shows that the use of the proposed mechanism that includes using non–earth orbital locations reduces the threat posed by an increasing amount of space debris. In this case, the risk posed by the presence of space debris in earth's orbital location is reduced by 50 %. Hence, the proposed mechanism reduces space debris effects (deleterious) in earth's orbital locations (LEO, MEO and GEO) by half (50 %).

7. Conclusion

The discussion in the paper proposes a new paradigm for conducting space applications with the focus on earth observations. An increasing conduct of space–based earth observations is recognized to necessitate satellite deployment. The increased participation of commercial earth observation providers also results in increasing number of launched satellites. This can increase the space debris when these earth observation satellites reach their end of life. The occurrence of space debris limits the number of available and accessible space orbital locations. This limits the future conduct of space applications. The proposed research presents a mechanism that addresses the challenge arising from the occurrence of increased space debris. The solution being presented proposes the use of non–earth's orbital location for hosting future earth observation satellites. The non–earth's orbital location being considered lie beyond the geostationary earth orbit and can be used due to advances in launch vehicle technology. In addition, the paper identifies and discusses how advances in cloud computing platform technology, artificial intelligence and machine learning can be used to realize earth observation in the considered context. Advances in artificial intelligence and machine learning are recognized to play a significant role in determining earth's meteorological data. The earth's meteorological data is determined via prediction using the meteorological data obtained from observation satellites deployed in the non–earth's orbital locations. The considered context is one in which earth observation satellites are hosted in the earth's orbital locations and non–earth's orbital locations. Furthermore, the discussion formulates the rate of space debris generation as the performance metric. Analysis shows that 50% less debris is generated by using the proposed mechanism.

Declaration

Availability of data and material – The required and utilized data is enclosed within the body of the paper.
Competing interests – There are no competing interests.
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Authors' contributions – AA Periola conceptualized and formulated the research problem, executed formal analysis and initial write up alongside system emulation and evaluation. AA Alonge contributed in formal analysis and project management and provided critical technical review. KA Ogudo undertook critical technical review, contributed in formal analysis and project management.
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