Satellite Placement Optimization Using Quantum Computing

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Introduction

The space industry is expanding rapidly because of the intuitive nature of humans to explore and with technological developments accomplished by both government and private players. Currently, the space industry is generating a revenue of $350 billion and Morgan Stanley estimates that 'the global space industry could generate revenue of more than $1 trillion or more by 2040'. At the moment most of these developments and advancements by the private players are happening particularly at Low-Earth-Orbit (LEO). LEO is and will be an important zone for Satellite internet providers.

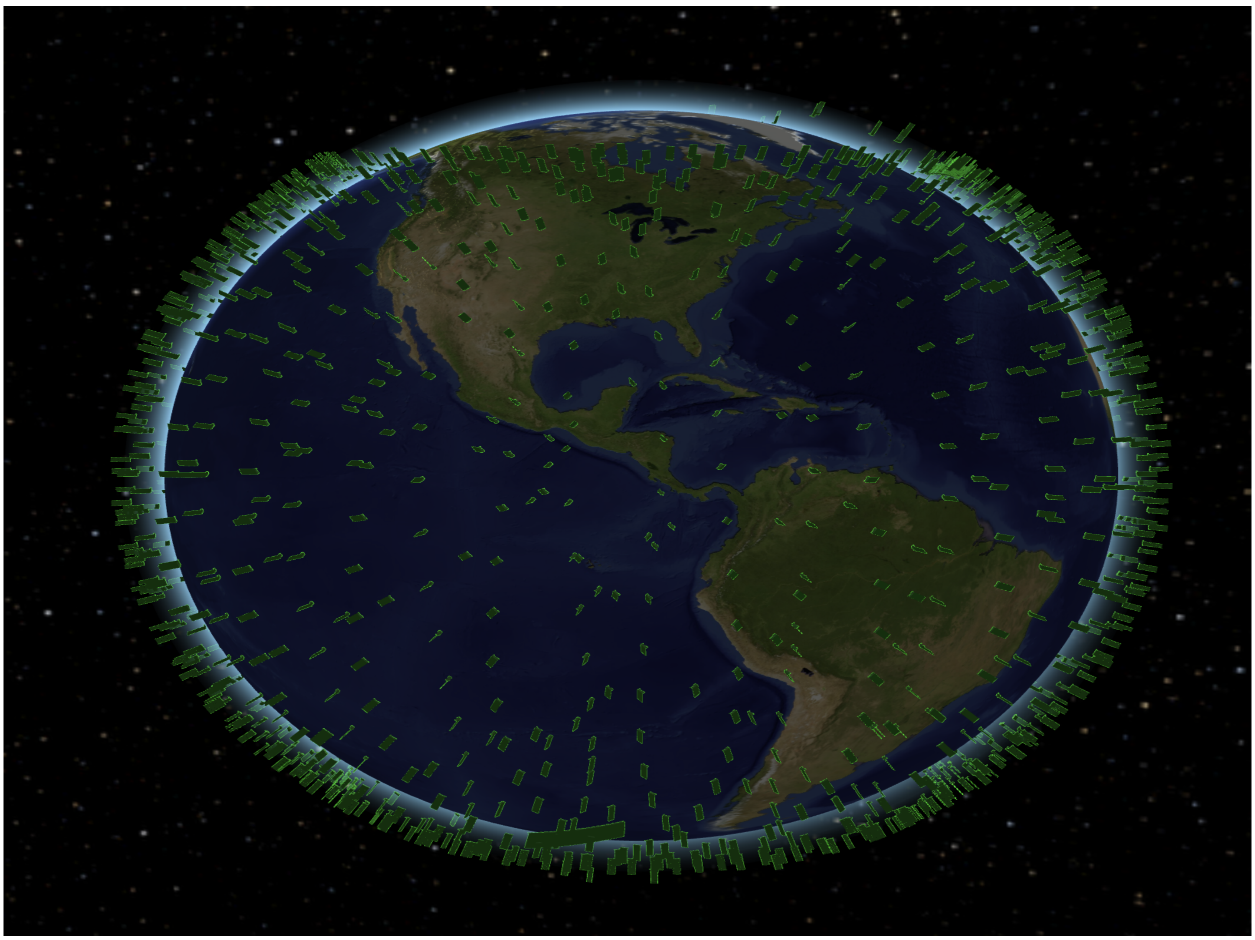

Fig 1: This figure displays the mega constellation of satellites in Low Earth Orbit (Image source: https://platform.leolabs.space/visualization)

LEO satellites revolve in an altitude range of 200 km to 2000 km from the earth's surface. Since they are at low altitude, they would take nearly 128 mins to complete one revolution of the earth, making 10 to 15 revolutions a day. Starlink, OneWeb, and Kuiper are three of the major players trying to build LEO satellite constellations to provide internet connectivity. The least possible Internet latency of geostationary satellites would be 250 milliseconds, they are positioned at 35,000 km from the ground. And internet latency of LEO satellites would be around 50 milliseconds, they are positioned at 600 km from the ground. The altitude range of LEO satellites is very significant for all major internet providers because if the altitude of satellites increases, the internet latency also increases.

Coordination and placement of satellites are very crucial in providing continuous uninterrupted connectivity with low latency. There are so many parameters that are required to provide services through LEO satellites. Satellite placement optimization can play a solid role in improving the overall connectivity area and limiting the number of satellites and other resources.

The number of LEO satellites is increasing exponentially due to an influx of more players competing to provide internet coverage and other services. As of January 2022, the total number of active LEO satellites in space is 4500. And the number is expected to reach 100,000 in the following years.

Why are these numbers concerning?

As the number of satellites increases, this can create a lot of space traffic, and space debris, and most importantly it does have a huge negative impact on the Ozone layer. Scientists warn ‘Chemicals released as defunct satellites burn in the atmosphere could damage Earth's protective ozone layer if plans to build mega-constellations of tens of thousands of satellites, such as SpaceX's Starlink, go ahead as foreseen’ and ’could cause problems for science missions, human spaceflight, the Hubble telescope, and ground-based telescopes that look for asteroids that might hit the Earth’. Space industries will have to find solutions to avoid space traffic, and space debris and reduce the number of satellites to reduce their impact on the environment.

‘More than 100,000 more satellites have been proposed, with nearly 40,000 proposed to the U.S. Federal Communications Commission in November 2021 alone’. These numbers are expected to increase drastically.

The lack of advancement in technologies to bring non-functioning satellites and space debris back to the earth makes more complications for space companies to achieve their outcomes as well as increases the possibility of collisions between satellites and space debris.

How Satellite Placement Optimizations for LEO satellites can help reduce the chaos?

At the very moment in time, it is a necessity to consider Satellite Placement Optimization for all the current existing players as well as those about to enter space, which is a crowded zone without consideration of the seriousness of its impact.

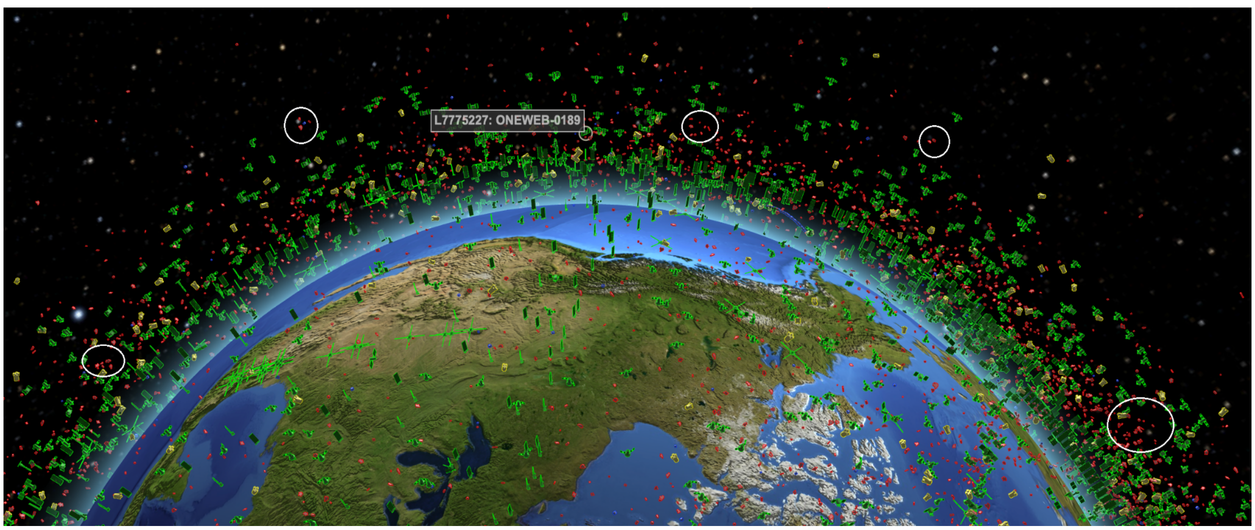

Fig 2: This figure displays the proximity of Space Debris and satellites in Low Earth Orbit. (Image source: https://platform.leolabs.space/visualization)

From Fig. 2, we can examine the seriousness of the problem. Space debris is mutually orbiting the earth in their respective direction with the satellites in their orbits. With the existence of space debris and non-functioning satellites, there is always a probability of risk to active satellites.

The amount of space debris in LEO altitude has been approximated at 4000 objects. In reality, the debris might not be as big as shown in Fig. 3 and are small objects but still, have a potential threat to the environment and to active satellites. As of November 2021, there is 36,500 space debris that is larger than 10 cm.

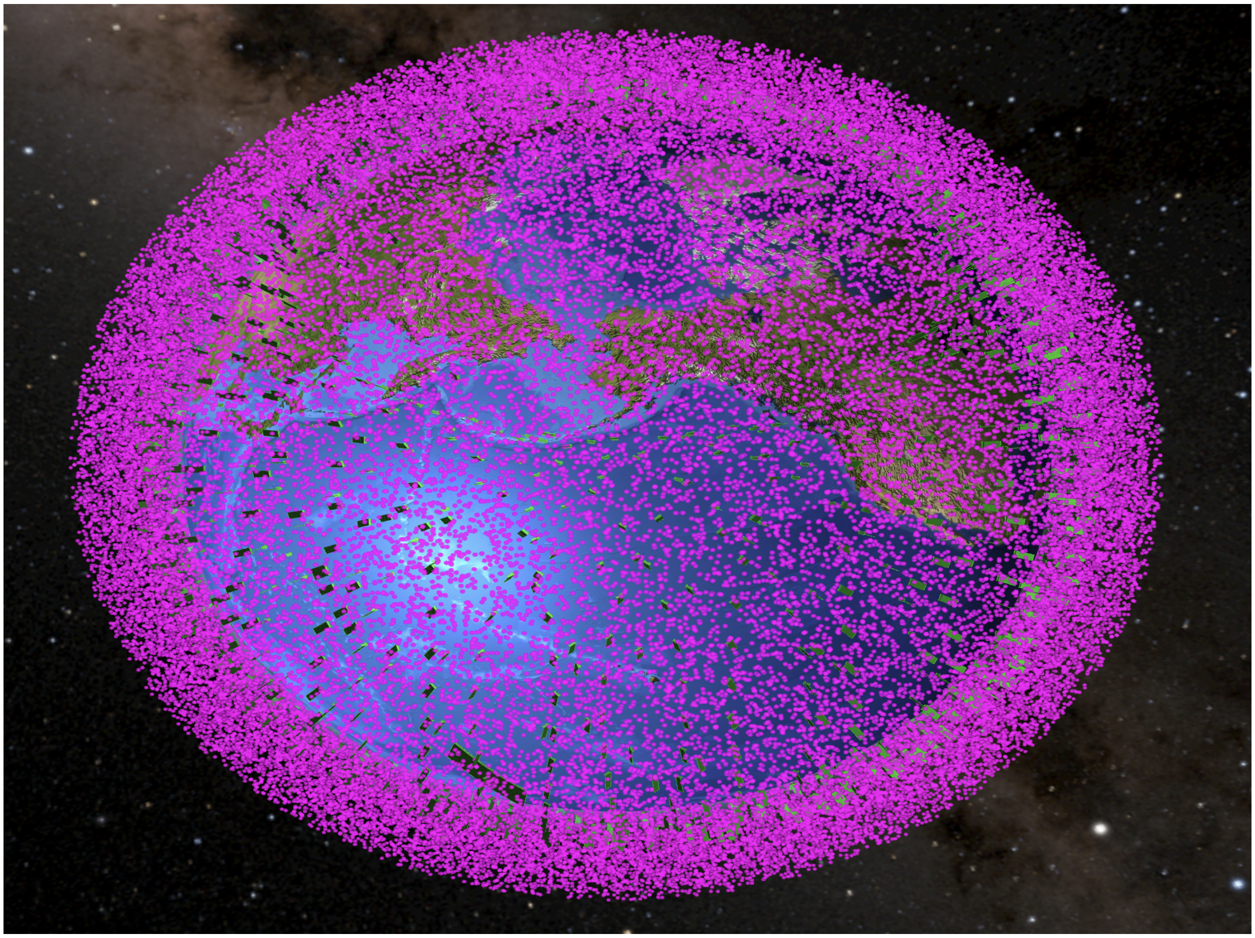

Fig 3: Space Debris in Low Earth Orbit (Image source: https://platform.leolabs.space/visualization)

Considering the fact that space traffic and space debris are drastically increasing (Fig. 4), Satellite Placement Optimization models can pave the way to,

- Maximize the efficiency of the service with limited resources. With these orbital optimization models, we can limit the number of satellites without affecting the coverage.
- In achieving the best orbital path by reducing contact with space debris and operating at low space traffic altitudes and zones without compromising the efficiency of the service provided by the satellites.

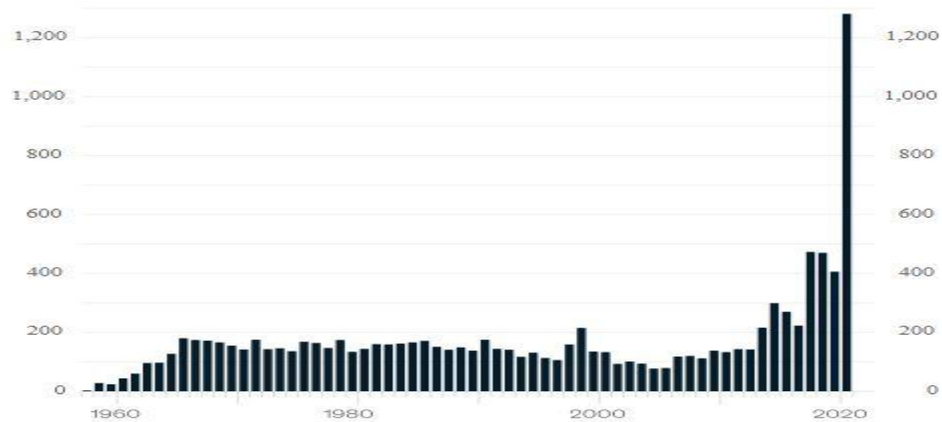

Fig 4: The chart illustrates the rapid increase in the number of space debris in recent years. (Image source: McKinsey & Company - Look out below: What will happen to the space debris in orbit?)

Satellite Placement Optimization using Quantum Computing

Satellite Placement Optimization can be formulated into a combinatorial optimization problem. As the finite set of feasible placements in this optimization problem is discrete and large, these properties are similar to what combinatorial optimization problems are defined.

Combinatorial optimization is the process of searching for maxima (or minima) of an objective function ***'F'*** whose domain is a discrete but large configuration space. This combinatorial optimization contains the characteristics of NP problems which are hard to solve using classical computers when it comes to big-size problems.

What makes Satellite Placement Optimization an NP-hard problem?

To create an efficient Satellite Placement Optimization model, in general, we need to consider the four main elements (**'Points of Interest', 'Orbital mechanics', 'Space debris',** and **'Space traffic'**) that have a direct influence on the placement of satellites and henceforth, to maximize coverage of the internet services.

- The **'Points of Interest'** describe locations on the ground, and at what locations the satellites can be placed to provide internet services. For example, an internet-provider company ABC (A Satellite Internet Provider), is required to provide maximum coverage of internet services in New Delhi, Cape Town, London, Milan, and Denver. Now, these locations are considered ***points of interest*** along which the satellites can be placed.
- The **'orbital mechanics'** will provide information on the possible paths with altitude along which the given specific satellites can orbit.
- The **'Space debris'** and **'Space traffic'** contains the information of all the space objects (which can be possible threats to satellites) while placing new satellites along the possible orbital paths.

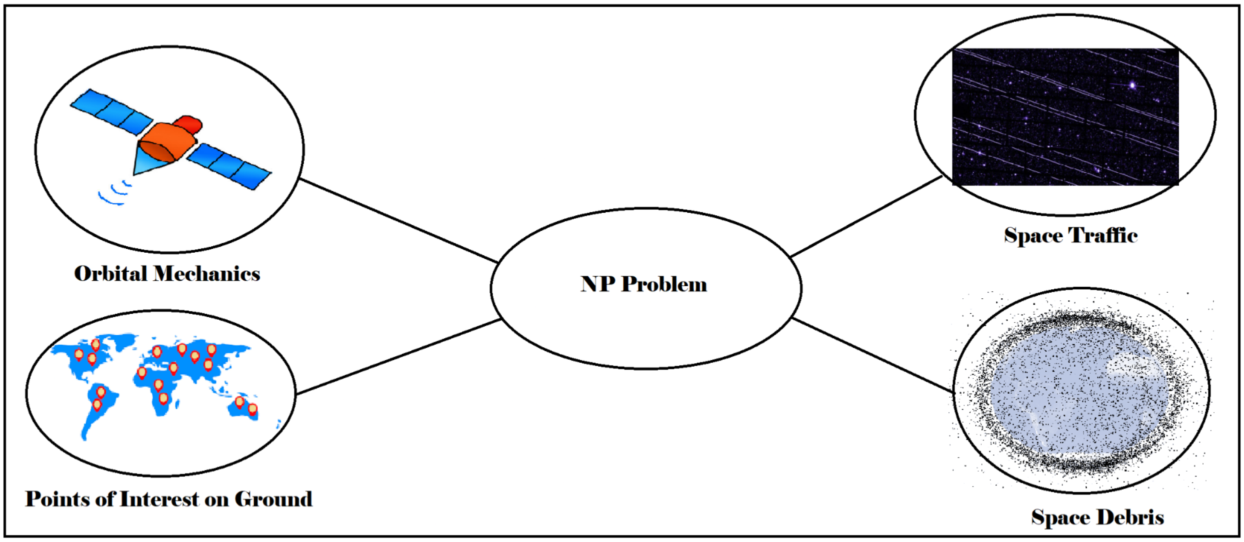

Fig 5: Schematic diagram which displays the parameters that make the Satellite Placement Optimization model an NP-hard Problem.

As there are a large number of parameters and variables to compute and possible solutions to have exponential increase with an increased number of variables, these characteristics make Satellite Placement Optimization an NP-hard problem.

It is not always possible to balance between the possibility of threats to the satellites and their functioning to provide the optimum satellite placements. The optimization model has to come with the best satellite placements where the portability of the collision in their orbitals with other space bodies is reduced and the functioning and service provided by satellites are not affected. In order to do this, we need to explore all possible paths, and the number of possible paths increases exponentially with the addition of new variables.

The model can be dealt with in two main segments:

- **Pre-Placement Optimization:** We consider where and at what particular time the satellites are required to provide their service on their desired positions on the ground, and with the number of satellites, the company can afford to accomplish this task. In an ideal case, inputs to the model are the number of satellites and points of interest on the ground. With an orthodox placement optimization model, we can achieve the best orbital path to accomplish the task in an ideal case.

Since we know that earth space is very dynamic and with the increasing number of space debris and space traffic, we cannot neglect these variables. We require a model that considers the complexity and behavior of space debris and space traffic that are a potential threat to satellites.

- **Post-Placement Optimization:** With the increasing number of LEO satellites and space debris, there is always a possibility of threat in the form of collision, with the existing satellites in the earth's space. A universal model must be capable of providing solutions, solutions as in Risk Mitigation Maneuvers (RMMS), which can be performed to reduce the probability of collision with other space objects.

  Risk Mitigation Maneuvers (RMMS) are maneuvers performed by satellites or spacecraft to avoid collisions with other space objects such as space debris, satellites, and other unknown space objects.

Apart from generally considering variables like orbital mechanics, points of interest on the ground, space debris, and space traffic, we also need to consider natural events occurring in space. Natural events can have catastrophic impacts on large numbers of satellites, e.g. in February 2022, a geomagnetic storm brought down 40 Starlink satellites. It is possible that such events will occur in the future.

A Satellite Placement Optimization model shouldn't only work for ideal conditions rather, it should also consider natural and other infrequent events. All of these increase the complexity of the model.

As the characteristics of this optimization problem demand a large computational space, computing using a hybrid quantum-classical model can provide us with the best orbital placement positions and solutions when satellites are at risk of colliding with space debris and other space objects.

In the space industry, time is of the essence and the ability to provide accurate solutions on time determines the efficiency of the solution. Approaching the problem using a hybrid model of utilizing quantum computers and classical computers together can provide coherent results. State-of-the-art quantum computers can compute the problem with large computational space and classical computers can be utilized to converge the list of solutions acquired from quantum computation, to achieve a practically applicable solution.

Utilizing quantum properties of qubits (quantum bit) such as superposition, entanglement and interference can help us achieve solutions in real-time even to the most complex problems. Satellite Placement Optimization is a complex model as the problem demands a large number of parameters. Using the inherent nature and properties of quantum computers, we can compute the objective function in a short span of time. The characteristics of this combinatorial optimization model make it naturally well-suited to be solved by quantum computing.

Therefore, a hybrid (quantum + classical) algorithm can be a possible algorithm to be adopted for efficient Satellite Placement Optimization that uses quantum computers to compute a large set of parameters to achieve all possible solutions and classical methods for converging the solution to an optimal solution.

The solution to the Satellite Placement Optimization problem could be an extension of the proposed Hybrid Algorithm by our team using Quantum Computing and Genetic Algorithms for the EV Charging Stations Placement Optimization problem and in other ongoing location optimization problems. This type of hybrid algorithm may be able to solve and provide efficient and optimized solutions to the present major problems in the space industry and particularly for better placement of LEO satellites.

References:

Kosambe, Santosh. "Overview of Space Debris Mitigation Activities in ISRO." *Journal of Aircraft and Spacecraft Technology* (2019).

Legge Jr, Robert S. *Optimization and valuation of reconfigurable satellite constellations under uncertainty*. Diss. Massachusetts Institute of Technology, 2014.

Boley, Aaron C., and Michael Byers. "Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth." *Scientific Reports* 11.1 (2021): 1-8.

Kaplan, Marshall H. *Modern spacecraft dynamics and control*. Courier Dover Publications, 2020.

Chandra A, Lalwani J, Jajodia B. "Towards an Optimal Hybrid Algorithm for EV Charging Stations Placement using Quantum Annealing and Genetic Algorithms." *arXiv preprint arXiv:2111.01622* (2021).

Maneuver Types

Look out below: What will happen to the space debris in orbit? | McKinsey

Volkswagen optimizes traffic flow with quantum computers

Kessler Syndrome and the space debris problem

Air pollution from reentering mega constellation satellites could cause ozone hole 2.0 | Space

4 threats posed by Elon Musk's Starlink satellites

Megaconstellation Satellites Reentering Puts a Hole in Ozone Layer, Increases Atmosphere Pollution, and Uncontrolled Geoengineering | Science Times

Loads of New Satellites Joining Earth's Orbit Amid Space Junk Crisis

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