**Simulation and Analysis of Inter-satellite**

**Communication for Real-Time Data**

**Downloading**

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# Introduction

## Motivation

## Background and Problem Statement

## Aim and Objectives

The overall objective is to analyze if the data download deadline can be met given the data on an LEO satellite can be transferred either directly to a ground station or via some other LEO satellite, given a configuration of an LEO satellite constellation and a set of ground stations. The analysis is conducted based on the simulation of the communication behavior between LEO satellites and between an LEO satellite and the ground stations.

There are several sub-tasks to achieve the above objective:

1. Simulation: to simulate the communication behavior
   1. To simulate the position of each satellite in space at a given time, based on which we can evaluate whether two satellites can communicate.
   2. To simulate whether a satellite is in the communication scope of a given ground station, given the related parameters.
   3. To simulate the data transfer latency, either between satellites or between a satellite and a ground station.
2. Optimization

There can be multiple paths for a satellite to download the data to the ground. Based on the simulation capability, an optimization algorithm will be developed to find the shortest communication path and check if the communication along this path can meet the data download deadline.

The simulator simulates the communication between Low Earth Orbit (LEO) satellites and the ground station, including the communications between LEO satellites. It aims to calculate the real-time capabilities of a group of LEO satellites in data downloading by simulating the environment of LEO and referring the existing satellites to obtain data close to reality. Meanwhile, the simulator simulates the LEO environment with space geometry and satellite communication.

The simulator will simulate the real LEO environment by using the real LEO environment feature and the space geometry when calculating the satellite orbit. The LEO satellite visibility modelling and decisions of data transmission will use the existing satellite data to guarantee the result is close to reality.

The outcome of the project will be a simulator to show all the orbits, data transmission path, and transmission delay. The final outcome will allow users to customize the orbit and satellites including the orbit used in the simulation, find out the path of data transmission and show the delay of the transmission.

## 1.1 Background and Problem Statement

Nowadays, thousands of satellites are launched in the Low Earth Orbit (LEO). LEO satellites orbit below 2000 kilometers above the earth. It is expected that in the period from 2014 to 2023 an average of 115 small LEO satellites will be launched per year (Sebestyen et al., 2018). Which is used for communications, military reconnaissance, spying and other imaging applications. The LEO satellites made for communication benefit from the lower signal propagation delay in LEO. The environment in LEO provides lower propagation delay and is able to communicate with Earth-based stations with utmost efficiency (Shustova, 2022), resulting in low-latency, high bandwidth, and universal internet connectivity (Vasisht et al., 2021). Meanwhile, LEO satellites are closer to the earth's surface, so imaging satellites will also be able to capture better and more detailed pictures (Shustova, 2022).

However, the communication coverage of LEO satellites is much smaller than the higheraltitude satellites. Ground stations can communicate with LEO satellites only when the satellite is in their visibility region and the duration of the visibility and the communication vary for each LEO satellite passing over the station since LEO satellites move too fast over the Earth. (Cakaj et al., 2014). As a result, an LEO satellite may fly for many hours to end up in the communication scope of a ground station. Since the number of ground stations on the ground is limited, it takes a long time for an LEO satellite to download the data to the ground. The data satellite must wait at the satellite before it comes in contact with a ground station (Vasisht et al., 2021).

Therefore, inter-satellite communication is hard to meet the strong real-time constraints. A real-time system requires to guarantee events can be completed in a set amount of time. However, cause of the feature of LEO satellites and the distribution is not fixed, it is hard to complete the data transmission in a set amount of time when the path of data transmission is not ensured.

Inter-satellite communication offers a new opportunity to achieve real-time data downloading, even if the number of ground stations is limited. Suppose an LEO satellite has some data to download and cannot find a ground station within a specified deadline. In that case, the satellite can transfer the data to another satellite that can communicate to some ground station. Therefore, the data downloading may probably meet the specified deadline.

In this project, we study the problem of meeting real-time data downloading requirements with inter-satellite communication. When a satellite has data to download, it can either communicate to a ground station (if the satellite is in the communication scope of the ground station) or transfer the data first to another satellite that can communicate to some ground station. We will simulate the communication between an LEO satellite and a ground station and multiple satellites, specifically the communication capability and its delay. As an LEO satellite may have multiple choices in the downloading data path, we will explore if there is at least one path that can meet the download deadline, based on the simulation.

# Project Methodology

## Design

### 2.1.1 Orbit Modeling

### 2.1.2 Visibility Modeling for Observation

### 2.1.3 Visibility Modeling for Communication

## 2.2 LEO satellite space geometry, Visibility, and Communication modeling

In the space geometry modeling, there are mostly using the mathematical algorithm in space geometry. These algorithms will be development with python and using the “NumPy” library to assistance.

Algorithms may use in this section:

* Magnetic
* acceleration, attitude, rotation calculation of satellite
* acceleration of gravity, velocity
* Satellite Helix antenna frequency
* And more

## 2.3 Decision-making algorithm for communication

In this section, algorithms may use to calculate the distance between satellite and making decision of select the next satellite need to transmit the data. It may use algorithms or machine learning method, depends on the ability and efficiency of making the decision.

## 2.4 Experiments and demonstration

To demonstrate the work of this project, we will use the simulator to output the dynamics of the satellites and the potential communication paths for data downloading, and we will also show the

shortest path that is found by the decision-making algorithm.

# Implementation

## 3.1 Resources Estimation

### 3.1.1 Hardware Requirement Estimation

* Computer able to run .py file

### 3.1.2 Software Requirement Estimation

* Python 3.8
* Pip (for install library, e.g. numpy, xlwt)

## 3.2 Project Schedule

|  |  |
| --- | --- |
| **Subject** | **Deadline** |
| LEO satellite space geometry modeling   * Multi orbit calculation * Space Geometry Modeling | 1 Nov, 2022 |
| Visibility Modeling   * Define the detection range of satellite * Successfully the observation target within the detection range | 1 Jan, 2022 |
| Communication Modeling   * Download an image from satellite to satellite * Download an image from satellite to ground station | 1 Feb, 2023 |
| Decision-making algorithm for communication  ⚫ Successfully making path decision of communication | 1 March, 2023 |
| Experiments and demonstration  ⚫ Complete a set of experiments to show the simulation results and the decision-making results | 1 April, 2023 |

# Conclusion

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