Department of Electrical and Electronic Engineering

Simulation of SpaceX's Starlink Optical Intersatellite Network

Saif Anwar   Supervisor: Dr George Kanellos

1. INTRODUCTION

Current high-speed internet is dependent on optical fiber cables connecting nodes that wish to communicate with each other. However, there are drawbacks to using optical fiber, some of which are outlined below:

- Speed of light in optical fiber is 33% slower than in a vacuum [1].
- Requires infrastructure of cables between all communication points.
- Cost of rerouting fiber can be very high.

SpaceX propose a constellation of low Earth orbit (LEO) satellites to provide global network coverage with ultra-low latency and high bandwidth [2]. Compared to optical fiber, intersatellite networks are much more resilient to failures as a new route can be calculated whereas with optical fiber new cables would have to be laid.

2. AIMS & OBJECTIVES

The aim of this project is to develop a simulation of the Starlink constellation network. By doing so, we aim to define a network topology which always provides the path of lowest latency. The following objectives will contribute towards a successful simulation:

- Easily adjustable constellation parameters will allow for quick updates.
- To maintain low latency and resiliency against failures, routing should have minimal delay.
- By developing a data structure of all satellite positions throughout time, it is possible to know all possible routes much further in advance.

Although Starlink has potential for relatively large network capacity, this is too speculative to model whereas latency is limited by topology and speed of light.

2. DEPLOYMENT CHARECTERISTICS

There are currently 1321 satellites in orbit, with approval for up to 12,000 in total. The constellation conforms to the following characteristics:

- Orbital planes are arranged such that they cross the equator at evenly spaced longitudes.
- There are multiple phases of deployment with their respective features outlined in Table 1 below [3].

	Initial Deployment	Final Deployment			
Orbital Planes	32	32	8	5	6
Satellites per plane	50	50	50	75	75
Altitude (km)	1,150	1,110	1,130	1,275	1,325
Inclination	53°	53.8°	74°	81°	70°
Number of Satellites	1600	1600	400	375	450

Table 1: Characteristics of the 5 proposed phases of the Starlink constellation

- To avoid collision of satellites in the same phase, a phase offset is defined as a value between 1 and 0. Figure 1 represents the effect of orbital phase offset between consecutive planes.
- Deployments at 53° and 53.8° inclination have similar inclination and altitude. Therefore, to improve spatial coverage, the 53.8° orbital planes are equidistant between the 53° planes at the equator.

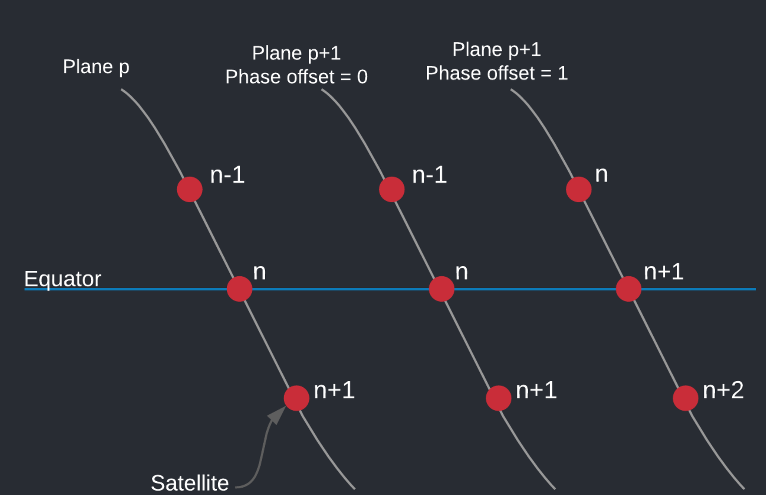


Figure 1: Effect of phase offset on consecutive orbital planes

- All satellites have a mass of 250kg which allows for calculation of the orbital planes in each phase.

3. SIMULATION IMPLEMENTATION

The simulation is developed such that any potential variations in the constellation configuration can be easily transferred. Behaviour can be described in 3 coordinate systems (Cartesian, spherical and geometric) for ease of incorporation with existing standards in both fields of communication and astrophysics.

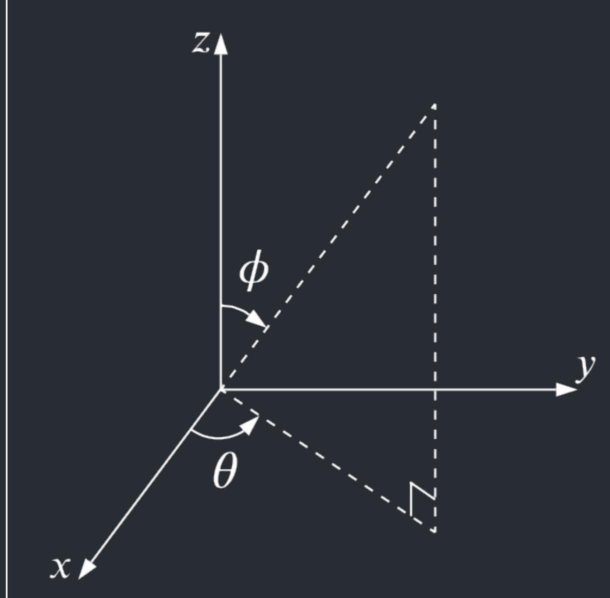


Figure 2: A representation of the Cartesian and spherical coordinate systems

Using the spherical coordinate system allows for ease of representation and conversion between the 3D space and the geographical system. However, the Cartesian system is more widely understood and allows for simpler displacement calculations.

Figures 3 show the developed simulation for all currently proposed deployment phases in the Starlink constellation. It is shown in both a geographical coordinate system as well as a 3D space which can be interpreted as both the spherical and Cartesian systems. The relationship between these is shown in Figure 2.

3. ROUTING CHARACTERISTICS

The shortest path between two points on a sphere is known as the great circle route. Achieving a great circle route is not feasible with optical fiber as it is not always possible to lay cables in an uninterrupted straight line.

The intention with the developed simulation is to specify two locations (via longitude and latitude) and observe the shortest path between them i.e. lowest latency.

- Each satellite is equipped with 5 free space lasers to form communication links with other satellites.
- A satellite is reachable from the ground if it is within 40° from the vertical.

Using these satellite specifications in the simulation, Dijkstra's algorithm can be run over the entire network to minimise link latency with the defined starting position and destination. With each node making 5 possible connections, the time complexity of this algorithm is $O(n \log n)$, therefore it should be quick to perform whenever a route is requested and will not scale poorly as the constellation grows.

5. CONCLUSION AND FUTURE WORK

The developed simulation allows for complex analysis and observation of the Starlink constellation. It provides an accurate representation of all satellite positions throughout time in multiple geometric forms.

Following on from this, shortest path calculations can be implemented to minimse link latency between two locations. To quantify the improvement over optical fiber, latency will have to be observed between specified locations for terrestrial optical fiber and then compared to that of the Starlink network.

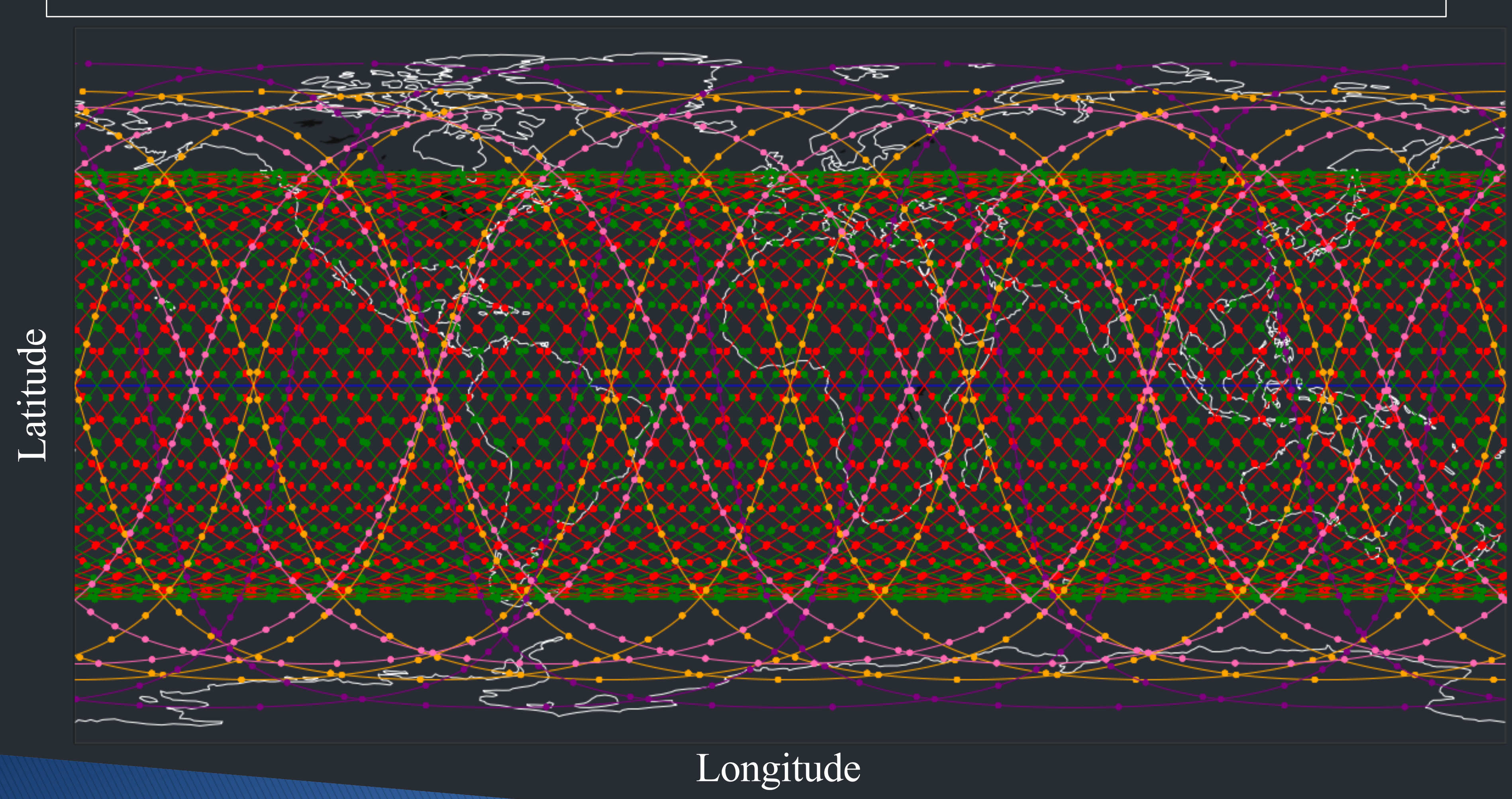
REFERENCES

[1] (https://www.commscope.com/globalassets/digizuite/2799-latency-in-optical-fiber-systems-wp-111432-en.pdf, 2017)

[2] https://fcc.report/company/Space-Exploration-Holdings-LLC

[3] Handley, M. (2018). Delay is not an option: Low latency routing in space. *HotNets 2018 - Proceedings of the 2018 ACM Workshop on Hot Topics in Networks*, 85–91. https://doi.org/10.1145/3286062.3286075

[4] https://www.onlinewebfonts.com/icon/529378



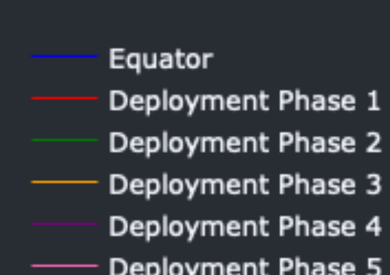
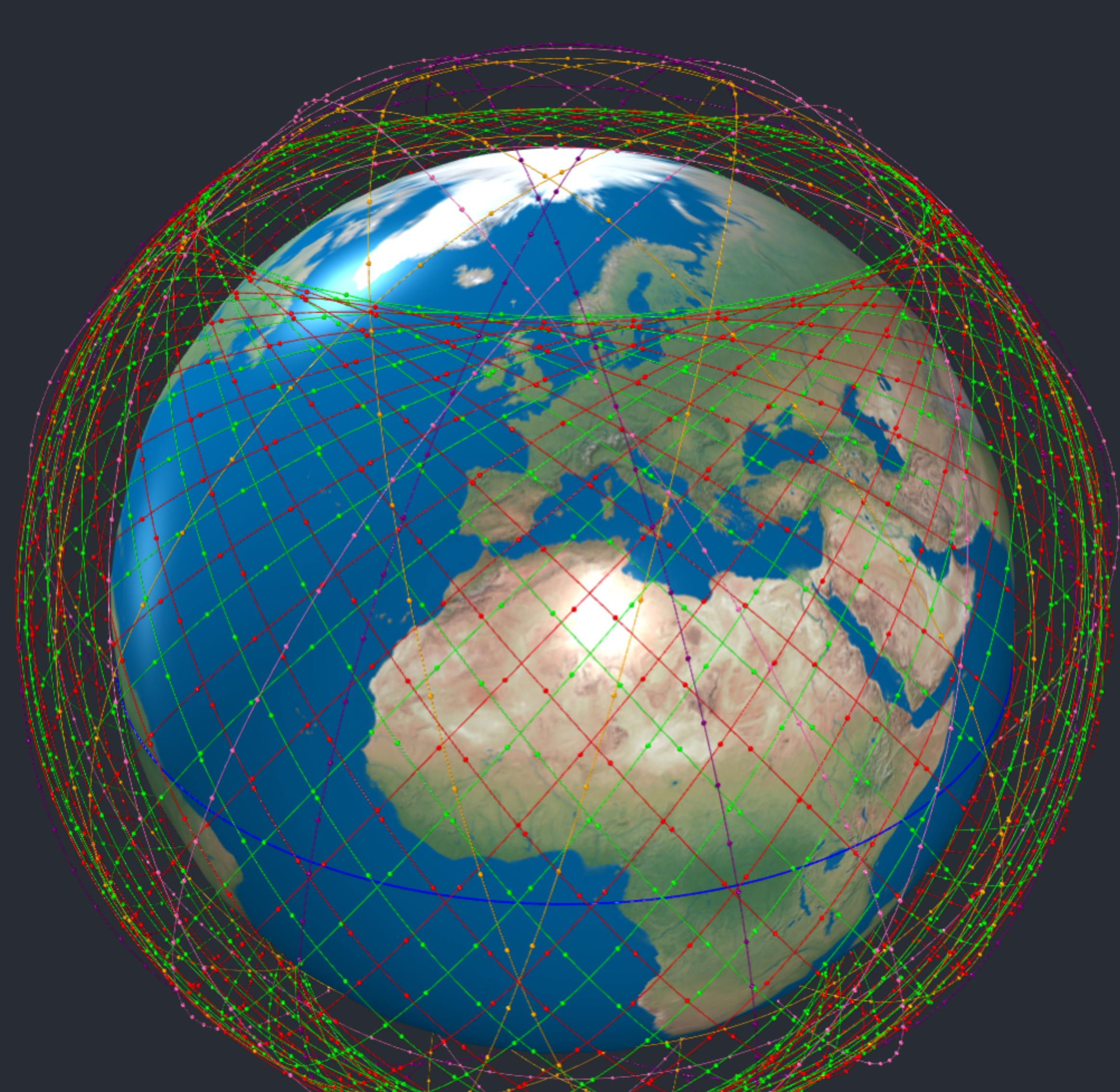


Figure 3: All proposed deployment phases of the Starlink intersatellite network constellation represented in a 2D geographical coordinate system (left) and a 3D space (right).



University of BRISTOL