Cover Sheet (for draft)

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Title of Project	Modelling Low Earth Orbit Constellations for Networking
Date of submission	
Will Human Participants be used?	No
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Modelling and Visualisation of Networking in Low Earth Orbit Constellations

Project Proposal

Introduction

SpaceX are planning to launch a constellation of 4,425 low Earth orbit communication satellites in the next few years. The objective of this constellation, called Starlink, is to provide low-latency internet connection across the world.

The satellites in this network will be in constant motion, not just relative to the ground, but relative to one another, creating a network with a constantly changing topology and associated latencies. The question of how to route signals across such a network has not been thoroughly explored, but it will become increasingly relevant as more and more companies build similar constellations.

My goals are:

1. To develop multiple routing algorithms for this network.
2. To compare these algorithms on latency, fault tolerance, and response to high demand.
3. To create visualisations of these routing algorithms at work.

In order to achieve goals (1) and (2) I will have to do extensive research into routing algorithms, and then translate the strategies I find into an unfamiliar context. To do (2) I will need to create a model of SpaceX's constellation of satellites, and for (3) that model will have to be visualised. To achieve this I will be using a games engine to create a simulation of SpaceX's constellation. While this will sacrifice some precision, a precise model of so many intersecting orbits at different altitudes and the connections between them is exteremely difficult, and a games engine will allow me to create visualisations that can be ran on any device.

The visualisation should be able to take any two points on the Earth and show the path of a data packet between them, as well as showing the network under high demand, under different routing algorithms. The results produced can then be used in (2). In order to achieve (3), my model will have to be clear and well designed, and I will use design principles in its construction.

Ultimately, all three of my goals shall feed into one another, as (2) and (3) open up new insights into the network, that can help inspire (1).

Further Details About SpaceX's Network

As my example constellation I will be using the constellation planned by SpaceX. Theoretically, I could have used any constellation, and focusing my attention on SpaceX's runs the risk of creating algorithms that are specific to it, which might not perform as well on other networks. However, the vast amount of legislation on satellites makes it hard to know what a "normal" network would look like. By using SpaceX's constellation we get a confirmed legal and physically possible network, on which we can build our routing algorithms.

There is a lot we do not know about this constellation, but this is what we can infer from SpaceX's application to the FCC[1]:

- 4,425 satellites will orbit in 83 different orbital planes at altitudes ranging from 1,150km to 1320km. We know exactly how many satellites will be in each plane.
- For our purposes these satellites are identical.
- Connections will be made with lasers, which require line-of-sight.
- Base stations can only communicate with satellites at an elevation degree of at least 40 degrees.
- One base station can receive signals from 4 different satellites simultaneously without interference, each satellite can send two signals to a base station simultaneously. Which means that a base station can receive 8 total signals at once.
- The satellites have an expected lifespan of 5-7 years.

Criteria for Success

This project will be deemed a success if I can test three different algorithms, producing meaningful data about their latency, fault tolerance, and response under high demand along with informative visualisations of their operations.

Starting Point

The initial inspiration for this project comes from a talk given my Mark Handley on Sep 25th, 2018, however I will not be using any of the code that he used in his talk. My primary reference point will be SpaceX's reference point to the FCC, though this will only be used for deciding on variables in my model. In principle, my model should be applicable to any constellation of satellites.

When I am developing algorithms, I will research a wide variety of texts on routing algorithms. As far as I know, there are no public algorithms for a network with these properties, and if I encounter one in my research I will endeavour to create my own.

[1] licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-289550&f_number=SATLOA2016111500118

Timeline

19th Oct	Proposal Submitted	
2nd Nov	Satellites Modelled	By this point I should be able to model the orbit of my satellites around the Earth, and know when two satellites are able to communicate to one other or to a base station.
16th Nov	Connections Modelled	At this point I should be able to efficiently model and visualise a connection between two satellites, or between a satellite and base station.
30th Nov	Data Flow Modelled	At this point I should be able to efficiently model and visualise a data packet moving between two base stations through the network through a given path.
14th Dec	Routing on a Static Network	By now I hope to have designed a simple test algorithm, working on static satellites, that can be visualised in operation.
28th Dec	Random Routing on a Moving Network	Now, by adding back in orbits, I should be able to visualise a random routing algorithm operating on this moving network.
11th Jan	Tests Designed	By this point I should have a series of pre-programmed tests to apply to a routing algorithm. I can then use these on my static and moving cases to demonstrate they are effective.
25th Jan	Iterate on Visualisations	Part of the success of my project relies on my visualisations being clear and informative. To ensure I achieve this, I’m going to dedicate some time to reviewing and iterating on my visualisation.
1st Feb	PROGRESS REPORT DUE	
8th Feb	Selection of Algorithms	At this point I should have completed three proposals for algorithms to test.
22nd Feb	Algorithms Written in	I will design each algorithm individually. One algorithm will most likely be much more involved than the others,

		and writing that algorithm will consume the bulk of my time.
8th Mar	Algorithms Tested	By now my algorithms will have been fully tested and data will have been produced.
22nd Mar	Iterate on Visualisations	Once again I will iterate on my visualisations, considering design principles and asking if my visualisations are still clear and informative when applied to my more advanced algorithms.
5th Apr	Model and Algorithms Complete	By this point my model should be fully functional. These two weeks are dedicated to bug testing.
26th Apr	PROJECT WRITTEN	At this point I the code of my project should have been completed and all the relevant data should have been collected, and my dissertation should have been fully written. The next two weeks will be dedicated to publishing and editing my completed dissertation.
10th May	PROJECT COMPLETE	This date, a week before the deadline, is when I plan to have sent my dissertation to my overseers.
17th May	FINAL DEADLINE	

Resources Declaration

For the modelling of this system I will be using the games engine Godot on my personal laptop. Using a games engine will allow me to create real-time 3D models of the constellation in motion, and Godot is free, open-source, intuitive and well-supported. Godot has two supported languages, it’s native language GDScript and C#. GDScript, which is weakly typed, will be used for the visualisation, while the strongly-typed C# will be used for the bulk of the simulation, where precision is more important.

I will be using my own laptop. To mitigate the risks of this, I will back up my code to github every day.