Evaluating Resiliency and Performance of Networked Satellite Systems

Evaluierung der Resilienz und Leistung von vernetzten Satelliten Systemen

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Abstract

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1 Introduction

1.1 Satellite Network Simulators

Amongst concrete measurements, one can also simulate networked satellite systems. This became increasingly interesting when the constellations were composed of many more satellites compared to traditional Geostationary Orbit (GEO) satellite constellations. For example, Low-Earth Orbit (LEO) constellations comprise hundreds to thousands of satellites, which implies a highly complex system.

Sadly, measurements are often highly difficult as they either require acquiring satellite hardware or recruiting users that already posses the required hardware. Simulation would tackle both problems, while maintaining low cost. To the best of our knowledge, we found two networked satellite simulators for LEO constellations.

1.1.1 StarPerf

StarPerf[1] [LLL20] is a mega-constellation performance simulation platform. It specifically aims at measuring the impact of the movements of satellites. Also, it measures performance in different areas. However, setting it up required, amongst others, Matlab and STK. This made the project difficult and expensive to test. Therefore, we did not advance in trying out *StarPerf*.

1.1.2 Hypatia

Hypatia[2] [Kas+20] is another LEO network simulation framework, released in 2020 just like *StarPerf*. It aims at a low-level simulation on packet-level and visualizes the data. Unlike *StarPerf*, it only requires a Python3 installation. Sadly, running simulations with Hypatia is highly complex as it requires the user to define, amongst others, the satellites, ground stations, and points of presence. This information is hardly available, which renders the simulations barely usable.

1 SpaceNetLab/StarPerf_Simulator
2 snkas/hypatia

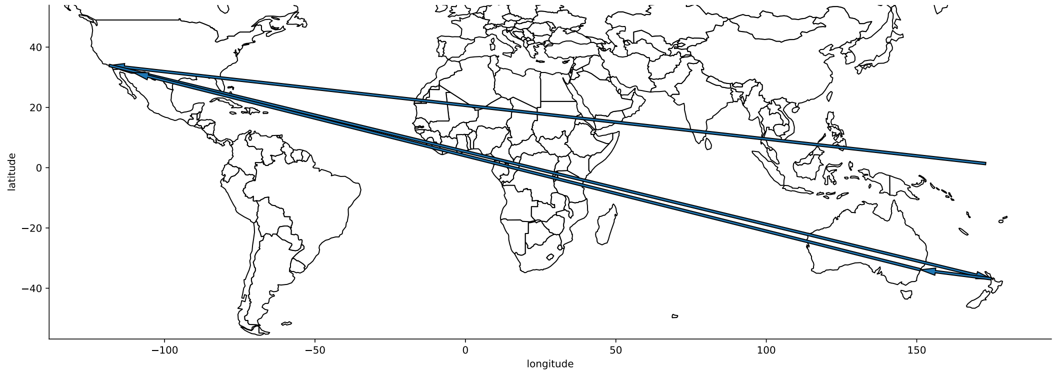

Figure 1.1: Visualization of a Traceroute from Kiribati

1.1.3 Problems of Network Simulators

To the best of our knowledge, research has stopped relying on simulators since 2020. There is proper hardware available that allows testing in the real world. Testing in the real world has the advantage as it takes more variables into account. Crucial factors for the performance of a networked satellite system are the weather, congestion, solar magnetic storms, material failure, and many more. Those cannot be ideally tested with simulations and will eventually produce wrong results. Therefore, for further research of this thesis, simulations will not be used.

1.2 Traceroute Analysis

Looking at traceroute results, we can make conclusions about the routing behavior of Starlink network devices. In the data we gathered more than forty million traceroute measurements. Those include primarily built-in measurements from RIPE Atlas probes to **.root-servers.net* for Starlink probes (Autonomous System Number (ASN) 14593).

Routing Behavior

First, we found that the satellite hops are likely invisible to the traceroute. We conclude that as there are no hops visible above water, even for probes located in remote regions, e.g., Kiribati in the Pacific Ocean. In Figure 1.1, one can see a visualization of a traceroute result from Kiribati to *f.root-servers.net*. One can see that the first visible hop is located in New Zealand or an island to the north of

New Zealand. However, if satellites were visible, we'd be able to observe more satellites.

Coming from the first insight, we can also conclude that Inter-Satellite Links (ISLs) are enabled. If they were not, we would likely not be able to see a successful traceroute from Kiribati to a location. The next closest known Point of Presence (PoP) is on Hawaii. However, the distance between both is 4000 km, which is more than a single satellite can cover. Aside from that, we do not observe the usage of the PoP in Hawaii, but in more distant locations, which just strengthens the argument. Therefore, we conclude that ISLs are enabled. This is special interest, as it was not clear in recent research [Hau+20].

1.2.1 Privacy Concerns in Traceroute Data

One of the most important responsibilities of an Internet Service Provider (ISP) is to ensure the privacy of its users. This also includes to route traffic only in trusted countries. In the case of Starlink, we were able to observe a different behavior. We looked at a slice of the built-in traceroute measurements from German Starlink probes and analyzed their most common targets. We filtered for anycasted servers (e.g., *.root-servers.net) and bogon IPs (i.e., IPs that cannot be associated with metadata).

In Table 1.1, the top twenty most frequent hits of IP addresses are shown. The IP addresses are joined with data from IPInfo. As traffic goes from a German probe to an anycasted server, located in Germany, one would expect little traffic outside Germany, and none outside Europe. The top five IP addresses are located within or close to Germany, but the next five already involve traffic to the United States. Here, we observe an unexpected behavior. Assuming that the data is not flawed, this is a clear violation of guiding privacy principles.

Table 1.1: IP Hitlist for Built-In Traceroute Measurements

Hits	City	Country	Organization	IP Address
10634	Frankfurt am Main	Germany	AS1299	62.115.37.20
8202	Offenbach	Germany	Unknown	80.81.192.154
6207	Amsterdam	Netherlands	Unknown	193.239.116.217
5582	Frankfurt am Main	Germany	AS2914	213.198.72.18
5257	Frankfurt am Main	Germany	AS3257	89.149.137.14
4932	Chicago	United States	AS14593	206.224.65.178
4916	Chicago	United States	AS14593	206.224.65.180
4850	Chicago	United States	AS14593	206.224.65.182
4755	Chicago	United States	AS14593	206.224.65.184
4358	Miami	United States	AS49791	81.31.213.126
4333	Zürich	Switzerland	Unknown	185.1.147.30
4256	Tokyo	Japan	Unknown	210.173.176.242
4179	Chicago	United States	AS14593	206.224.65.186
4035	Chicago	United States	AS14593	206.224.65.192
4014	Frankfurt am Main	Germany	AS6762	213.144.184.30
4010	Chicago	United States	AS14593	206.224.65.190
4005	Chicago	United States	AS14593	206.224.65.188
4002	Frankfurt am Main	Germany	AS1299	62.115.124.118
3990	Singapore	Singapore	AS2497	202.232.1.69
3827	Frankfurt am Main	Germany	AS6939	72.52.92.70

2 Conclusions & Outlook

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2.1 List of Acronyms

ISLs Inter-Satellite Links 3

ISP Internet Service Provider 3

LEO Low-Earth Orbit 1

GEO Geostationary Orbit 1

ASN Autonomous System Number 2

PoP Point of Presence 3

Declaration of Authorship

I hereby declare that this thesis is my own unaided work. All direct or indirect sources used are acknowledged as references.

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