Evaluating Performance and Resiliency of Networked Satellite Systems

Robert Richter

June 3, 2024

Master's Thesis Proposal
Chair of **Data-Intensive Internet Computing** at Hasso Plattner Institute

Assessor: *Prof. Dr. Vaibhav Bajpai*
Advisor:*Dr. Vasileios Ververis*

Contents

1 Motivation **2**

2 Research Questions **4**

3 Contributions **5**

4 Outline **6**

5 List of Acronyms **9**

Abstract

The modern internet brought up many different networking technologies. For example, glass fiber has proven as a reliable networking technology. However, it has severe disadvantages, e.g., communication needs to cross country borders, glass fiber infrastructure is highly expensive for sparsely populated areas, and cables are highly vulnerable.

A different possibility is to route communication over satellites. This allows reaching a major part of the earth's population without tedious construction of networking infrastructure. Also, it is less prone to catastrophes, which caused governments to construct networked satellite infrastructure themselves. In addition, private institutions constructed their own networks for business usage, e.g., Starlink, O3b, or Hughesnet.

This proposal describes the approach of the master's thesis *"Evaluating Resiliency and Performance of Networked Satellite Systems"* to analyze different networked satellite systems in terms of resiliency and performance. It will put a special emphasis on routing behavior of networked satellite systems. Additionally, it measures latency and packet loss and builds an approach to determine the impact of distance between satellite and end-user over the course of a connection period.

1 Motivation

The internet plays a major role in our everyday's life. There are many technologies available that allow to connect to the web addressing different use cases (e.g., Wi-Fi for local area networks [5] or Fiber-to-the-home (FTTH) for high-speed wired connections to an end user's home [1]). However, there are several problems with such a setup. First, it requires wired infrastructure, which is quite expensive for networks in the wider area. For single end users, that is not affordable. Second, should the wired infrastructure be in place, it is vulnerable to attacks or natural catastrophes that render the service unusable.

Another emerging technology uses satellites as data transmission node. It is very resilient to human attacks or natural catastrophes as satellites are largely inaccessible. Therefore, governments installed dedicated satellite constellations to maintain communication in any given scenario. A satellite constellation is a group of artificial satellites that serve a specific purpose.

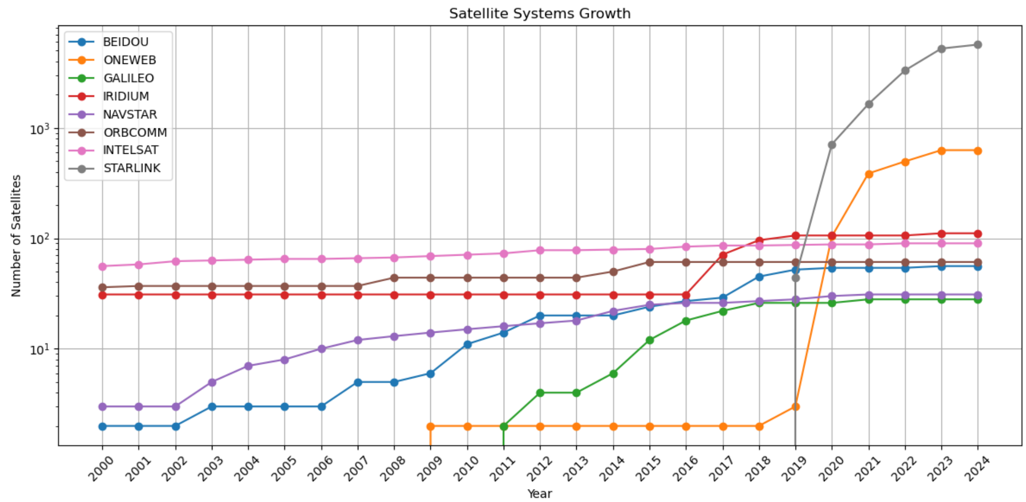

Figure 1: Growth of satellite numbers of different satellite constellations since 2000. Note the logarithmic scale.

Prominent examples of governmental satellite constellations are *Beidou* and *Galileo*.

Aside from crisis intervention, also businesses discovered opportunities. Providing communication over satellite allows users mobile access to information that usually require complex infrastructure. Users can access services like geographical data, radio frequencies, and even web access. Especially the demand for web access is growing, while companies failed at providing acceptable latencies in the past.

However, also the demand for low latency access grew. Practice showed that Geostationary Orbit (GEO) satellites (35'786 km altitude) were not able to achieve the desired latency. However, Low-Earth Orbit (LEO) satellites (200 - 1200 km altitude) were able to provide the desired latency. On the other hand side, LEO satellites cover a smaller part of the earth's surface, which required more satellites to cover the same area.

Therefore, different satellite communication providers (e.g., *Starlink* or *OneWeb*) started constructing their own networked satellite systems. For different satellite constellations, the development of satellite numbers is shown in Figure 1. The numbers originate from N2YO [9], a platform for tracking satellites. It is visible that Starlink has far more satellites than any of its competitors. While Starlink arrives at more than 5500 satellites, its closest competitor, OneWeb, does not even reach 1000 satellites in 2024.

Aside from many earlier business failures [3, 2], it is still in question how well networked satellite systems actually work and whether they offer practical advantages. Previous work reported competitive latencies for LEO systems, accompanied by increased packet loss [8]. Also, it is in question whether networked satellite systems integrate well with existing protocols.

2 Research Questions

RQ: How do networked satellite systems perform in terms of latency and packet loss?

Previous work [8, 7, 10] showed first results for Round-Trip-Time (RTT) (i.e., latency), throughput, and packet loss. However, networked satellite systems are a cutting edge technology that undergo changes frequently. For example, [6] et al. showed a heavily different performance for moving vehicles. Therefore, it is worth taking a look if significant changes occurred. First, we will have a look on the current performance of networked satellite systems regarding latency and packet loss. Eventually, a system displaying current Starlink performance trends could be developed.

Additionally, we will analyze the Starlink user terminal firmware to evaluate resilience and privacy of the system.

RQ: How do networked satellite systems perform efficient routing?

In theory, satellites should integrate well in the existing internet architecture. However, it proved not to be the case. Especially high packet loss [7] poses a problem as a continuous connection cannot be guaranteed. It should be determined how networked satellite systems currently route packets. That includes considering bent pipes and ISLs [4].

Ideally, the firmware also allows assessing whether Starlink guarantees privacy and safe data transfer to modern standard of security. Also, we will explore the limitations of fulfilling the previously mentioned standards in networked satellite systems including Inter-Satellite Links (ISLs) and bent pipes.

RQ: What does the Starlink user terminal firmware reveal about the system's resiliency and privacy?

The user terminal firmware is a key factor for privacy and resiliency of the Starlink networked satellite system. Previous attempts in accessing the terminal's built-in firmware were highly successful, but the firmware was not analyzed in detail.

This thesis wants to explore that topic by describing a way to acquire the firmware, describe its structure, and analyze it in regard to resiliency and privacy.

3 Contributions

This thesis gives an answer to the research questions mentioned in Chapter 2. It uses measurements running on RIPE ATLAS, a platform for performing measurements with probes distributed across the world. RIPE ATLAS also provides a number of Starlink probes that allow performing the following measurements: ping, traceroute, DNS, TLS, HTTP, and NTP. By running ping measurements, we intend to measure RTT and packet loss. The ping measurements runs every five minutes and pings a specific server.

Also other platforms like Cloudflare Radar are used to gather data. This allows to compare data from different sources.

The second research question will integrate the data collected in the ping measurement and compare it to satellite positions collected from N2YO. This allows comparing the relative position of the probe to satellite. In the end, we want to state whether we were able to see a bit rate decrease, when the satellite moved further away from the probe.

Finally, to make a statement about the routing, we will look at firmware from Starlink's user terminals. The firmware is available at different blogs, where people successfully obtained root access. We hope to find information from the firmware that allows to make conclusions about how Starlink performs routing and if it is any different to traditional routing mechanisms.

4 Outline

The proposed structure for the thesis is the following:

1. Introduction
   (a) Motivation
   (b) Research Questions
   (c) Contributions
   (d) Outline
2. Background
   (a) Networked Satellite Systems
   (b) GEO and LEO
   (c) Starlink
   (d) Routing with Bent Pipes and Internet Satellite Links
3. Related Work
4. Methodology
   (a) RIPE ATLAS
   (b) N2YO
   (c) Starlink Firmware
   (d) Measurement Setup
5. Results
   (a) Latency and Packet Loss
   (b) Relative Position of Satellite and Probe
   (c) Starlink Firmware Analysis
      i. Routing Behavior
      ii. Privacy Analysis
6. Limitations and Future Work

   (a) Limitations
   (b) Future Work

7. Conclusion

8. Reproducibility Considerations

   (a) Nix

References

[1] Slaviša Aleksic and Ana Lovric. “Power consumption of wired access network technologies”. In: *2010 7th International Symposium on Communication Systems, Networks and Digital Signal Processing, CSNDSP 2010* (2010), pp. 147–151. DOI: 10.1109/CSNDSP16145.2010.5580441.

[2] David Barboza. “Iridium, Bankrupt, Is Planning a Fiery Ending for Its 88 Satellites”. In: *The New York Times* (Apr. 2000), pp. 1–1.

[3] Sharon Pian Chan. “The birth and demise of an idea: Teledesic’s ’Internet in the sky’”. In: *The Seattle Times* (Oct. 2002).

[4] Yannick Hauri et al. “”Internet from Space” without Inter-satellite Links”. In: *HotNets 2020 - Proceedings of the 19th ACM Workshop on Hot Topics in Networks* (Nov. 2020), pp. 205–211. DOI: 10.1145/3422604.3425938. URL: https://dl.acm.org/doi/10.1145/3422604.3425938.

[5] Paul S. Henry and Hui Luo. “WiFi: What’s next?” In: *IEEE Communications Magazine* 40 (12 Dec. 2002), pp. 66–72. ISSN: 01636804. DOI: 10.1109/MCOM.2002.1106162.

[6] Dominic Laniewski et al. “Starlink on the Road: A First Look at Mobile Starlink Performance in Central Europe”. In: *CoRR* abs/2403.13497 (2024). DOI: 10.48550/ARXIV.2403.13497. arXiv: 2403.13497. URL: https://doi.org/10.48550/arXiv.2403.13497.

[7] Sami Ma et al. “Network Characteristics of LEO Satellite Constellations: A Starlink-Based Measurement from End Users”. In: *IEEE INFOCOM 2023 - IEEE Conference on Computer Communications, New York City, NY, USA, May 17-20, 2023*. IEEE, 2023, pp. 1–10. DOI: 10.1109/INFOCOM53939.2023.10228912. URL: https://doi.org/10.1109/INFOCOM53939.2023.10228912.

[8] François Michel et al. “A first look at starlink performance”. In: *Proceedings of the 22nd ACM Internet Measurement Conference, IMC 2022, Nice, France, October 25-27, 2022*. Ed. by Chadi Barakat et al. ACM, 2022, pp. 130–136. DOI: 10.1145/3517745.3561416. URL: https://doi.org/10.1145/3517745.3561416.

[9] N2YO. *Live Real Time Satellite Tracking and Predictions*. [Online; accessed April 18, 2024]. 2024. URL: https://www.n2yo.com/.

[10] Sascha Segan. “Tested: SpaceX’s Starlink Satellite Internet Service Is Fast, But It’ll Cost You”. In: *PC Mag* (Oct. 2020).

5 List of Acronyms

ISLs Inter-Satellite Links 4

FTTH Fiber-to-the-home 2

LEO Low-Earth Orbit 3

GEO Geostationary Orbit 3

RTT Round-Trip-Time 4