Breaking Through the Clouds: Performance Insights into Starlink's Latency and Packet Loss

Hasso Plattner Institut
Digital Engineering · Universität Potsdam

IFIP Networking 2025

May 27, 2025

Download Paper

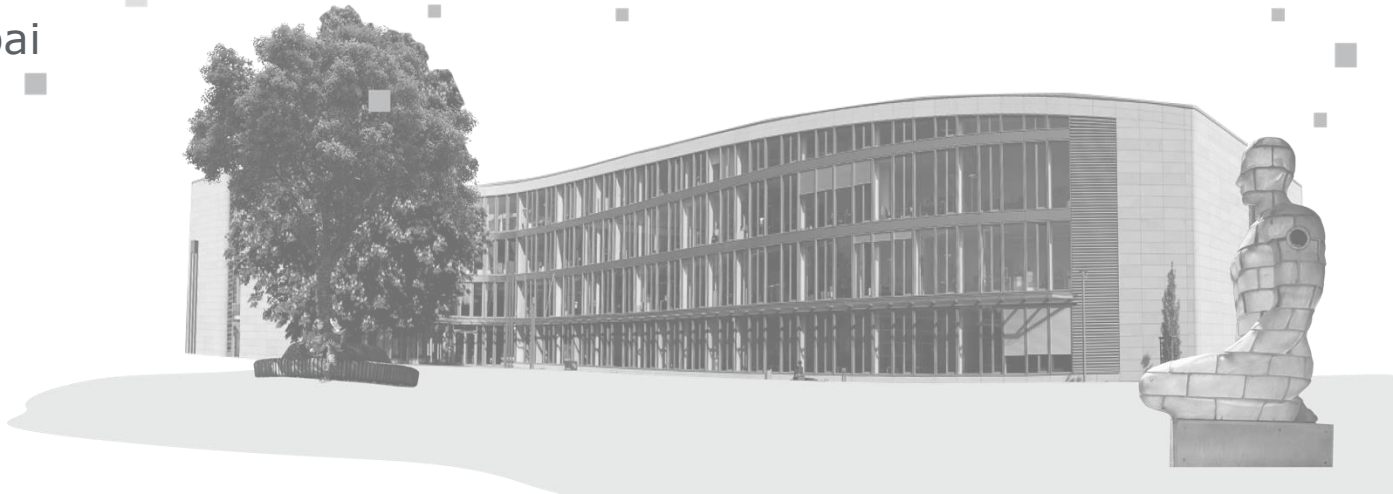


Robert Richter Vasilis Ververis Vaibhav Bajpai

Hasso Plattner Institute, Potsdam, Germany

Design IT.
Create Knowledge.

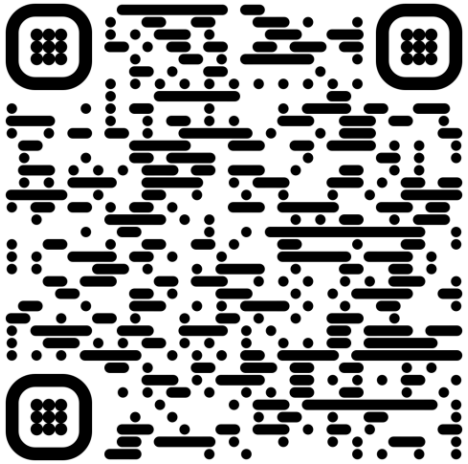
www.hpi.de



Agenda

1. Low-Earth Orbit Satellite Constellation Background
2. Related Work
3. Research Questions
4. Longitudinal View 01/2022 – 06/2024
   - Latency
   - Packet Loss
5. Latency and Packet Loss Correlation
6. Traceroute Analysis

Download Paper



Low-Earth Orbit Satellite Constellation Background

Satellite Network Operator	Altitude	# of Satellites
Starlink	≈ 550 km	6,396
OneWeb	≈ 1,200 km	628
O3B	≈ 8,062 km	20
Intelsat	≈ 35,767 km	74

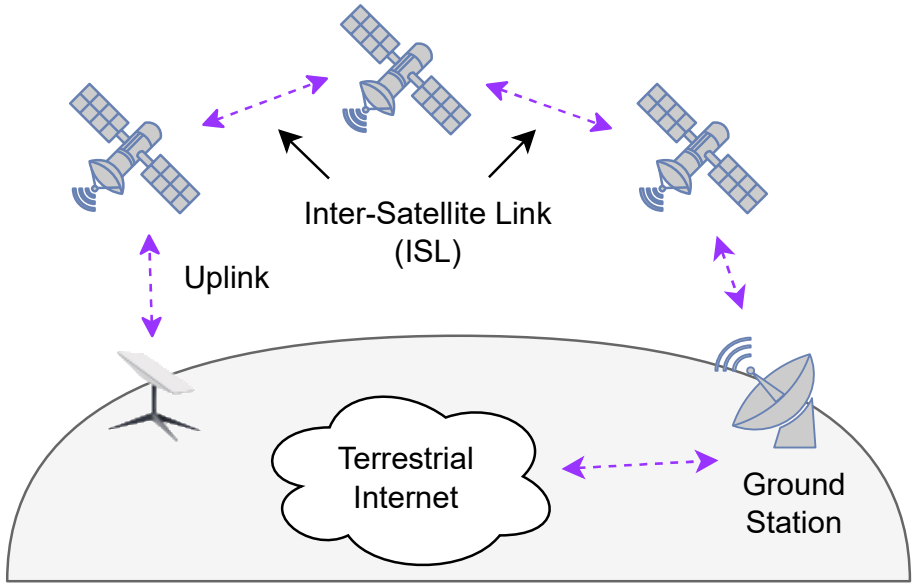


Figure 1: SNO satellite count since 2000 to 06/2024

Low-Earth Orbit Satellite Constellation Background: Influence of Altitude

Starlink	OneWeb	IntelSat
$\frac{550\ km \cdot 2}{300m000\frac{km}{s}} \approx 0.004\ s$	$\frac{1{,}200\ km \cdot 2}{300{,}000\frac{km}{s}} \approx 0.008\ s$	$\frac{35{,}767\ km \cdot 2}{300{,}000\frac{km}{s}} \approx 0.240\ s$

- Lower altitude ⇒ Better latency & more satellites required
- Higher altitude ⇒ Worse latency & fewer satellites required

- **Constellations try to find a sweet spot**

Related Work

- Performance measurements
  [Ma23, Raman23, Garcia23]
  - High Packet Loss at ≈ 2 %
  - Latency in lab conditions at ≈ 40 ms
- Mobility & weather impact performance negatively [Laniewski24, Laniewski25]
- LEO simulators did not reflect reality
  [Lai20, Kassing20]

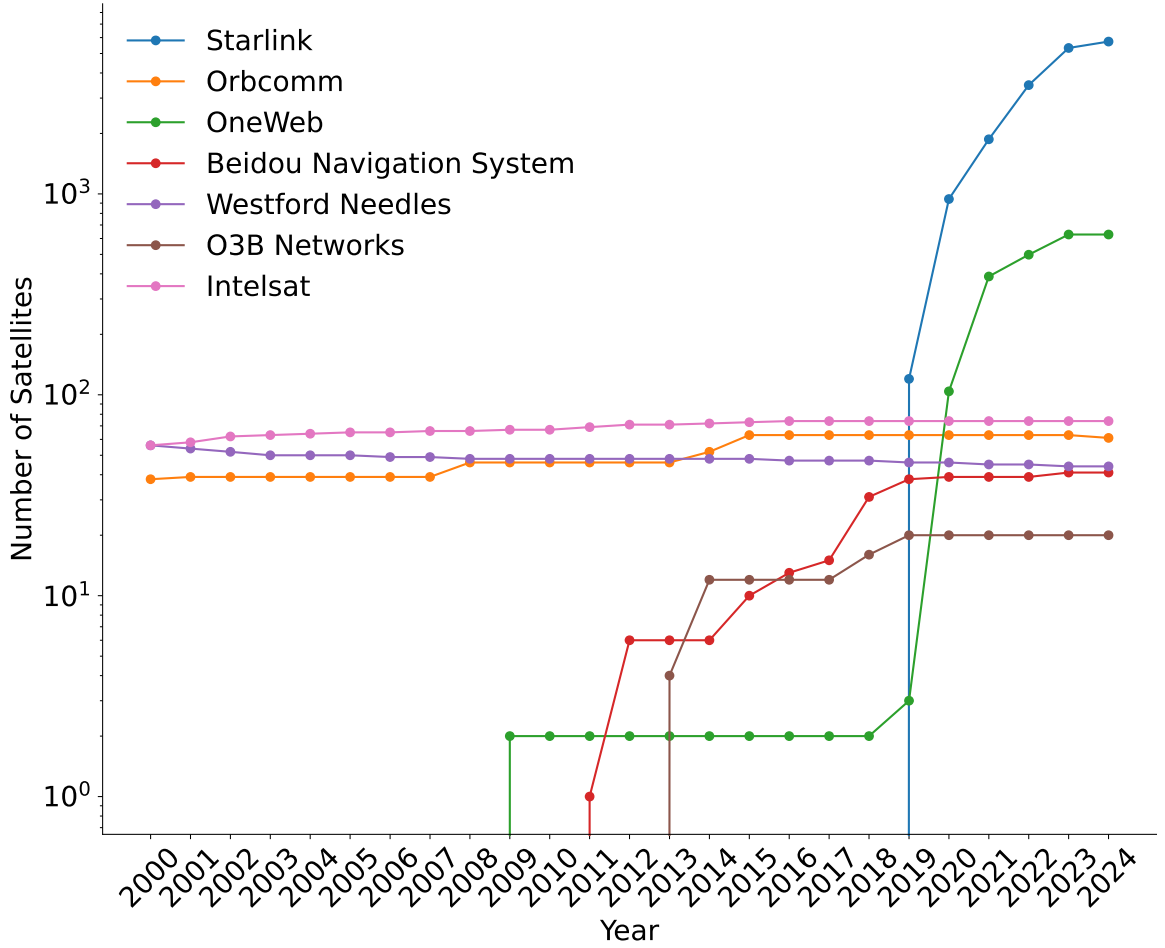


Figure 2: SNO satellite count since 2000 to 06/2024

Research Questions

1. How has latency and packet loss evolved since 2022?
2. In the case of Starlink, do latency and packet loss correlate?
3. What happens to latency when routing to the Starlink constellation?

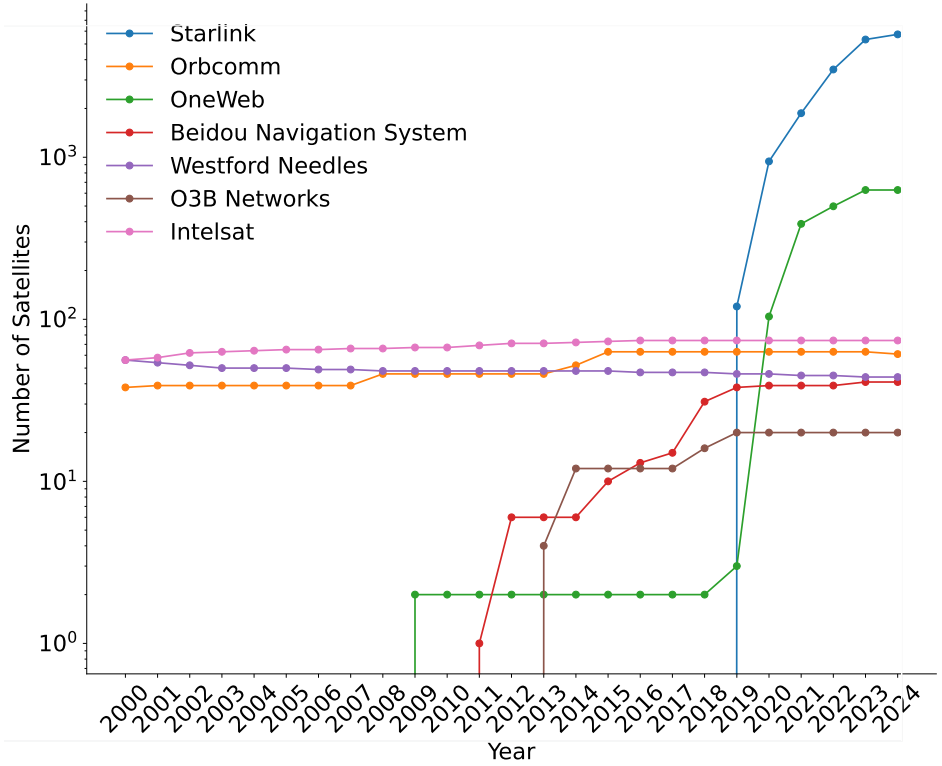


Figure 2: SNO satellite count since 2000 to 06/2024

Figure 3: Starlink ground station placement in Europe as in Unofficial Starlink Global Gateways & PoPs Map

Methodology

- Timeframe 01/2022 – 06/2024
- RIPE Atlas built-in measurements from ≈ 150 probes (AS14593)
- TLS (for latency), Ping (for packet loss), and Traceroute (for routing) measurements to *k.root-servers.org*
- Data made publicly available[1]

[1] DOI 10.5281/zenodo.15303863

Country	Number of Probes
United States	53
France	18
Canada	11
United Kingdom	11
Germany	10
Australia	8
Austria	4
Italy	4
Spain	4
Haiti	3
Philippines	3
Belgium	2
Benin	2
Kiribati	2
Netherlands	2
Czechia	1
Falkland Islands	1
Greece	1
Honduras	1
Poland	1
Réunion	1
Sweden	1
Switzerland	1
Virgin Islands, U.S.	1

How does Starlink perform in terms of TLS latency?

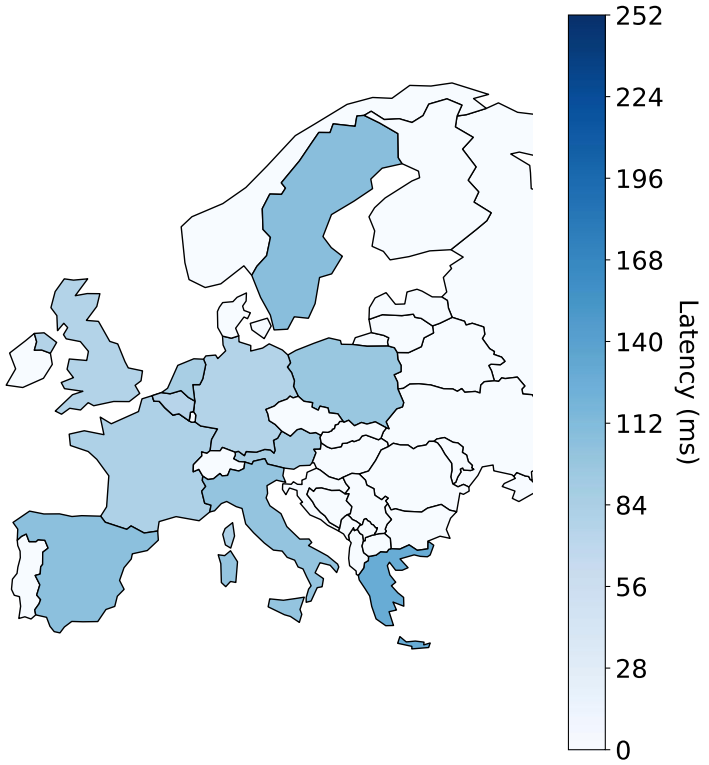


Figure 4: Median TLS Latencies in Europe in 2024

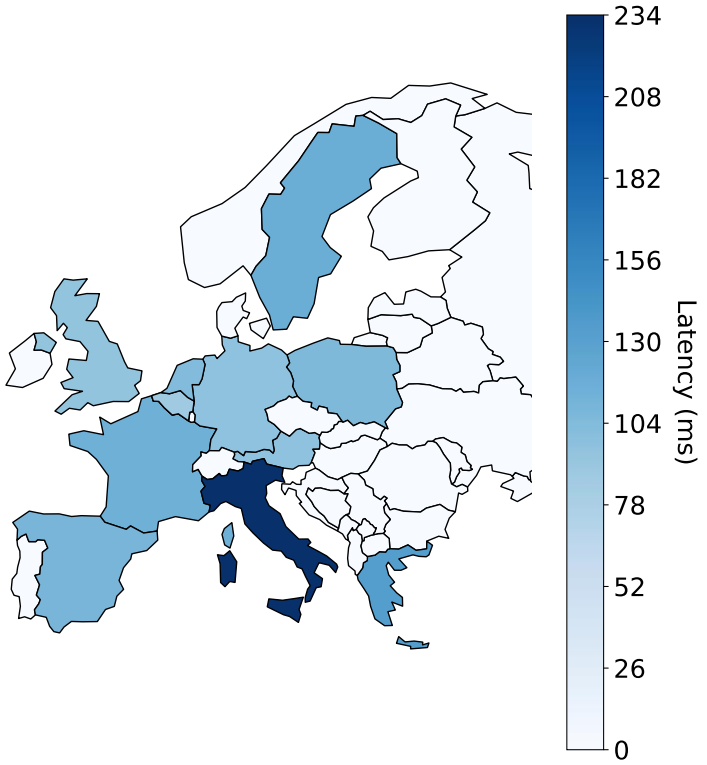


Figure 5: Average TLS Latencies in Europe in 2024

Figure 3: Starlink ground station placement in Europe as in Unofficial Starlink Global Gateways & PoPs Map

How has latency and packet loss evolved since 2022?

- Median Latencies have been much worse in 2023, compared to 2022 and 2024
- Minimum Latencies improved from 2022 to 2023
- Possible reasons:
  - Growth of Starlink satellite constellation
    - Dec. 2022: 3,481 satellites
    - Dec. 2023: 5,326 satellites
    - June 2024: 6,396 satellites
  - More ground stations
  - Improved Inter-Satellite Links (ISLs)

Ideal Starlink Latency

$$\frac{550\ km \cdot 2}{300{,}000 \frac{km}{s}} \approx 0.004\ s$$

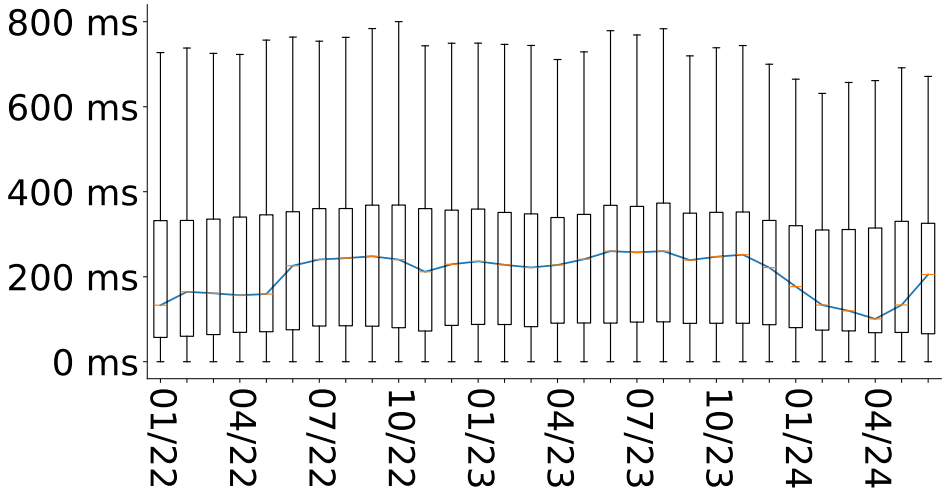


Figure 6: TLS Latencies in the USA

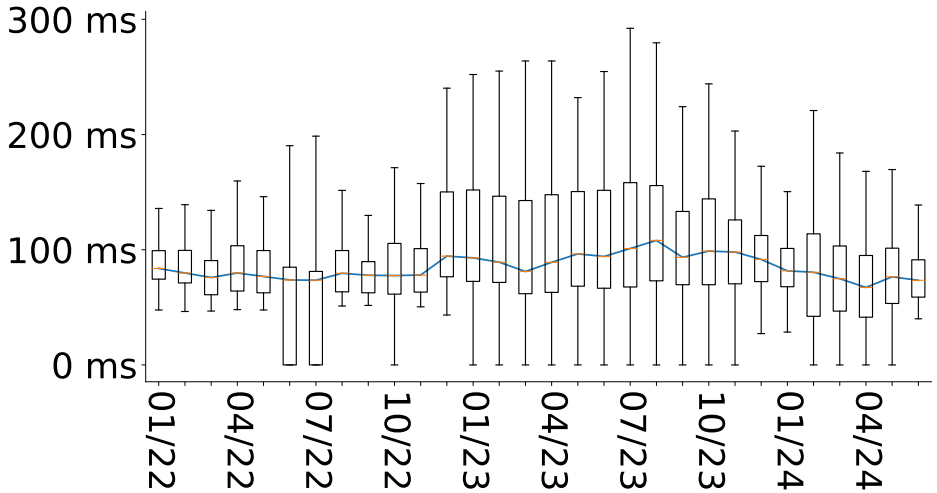


Figure 7: TLS Latencies in Germany

How does Starlink perform in terms of packet loss?

- Packet loss from Ping measurements
- Packet loss has improved consistently in 2023 across many countries
  - Worse in 2022 and 2024
  - In June 2024, consistent packet loss reduction
- Possible reason:
  - Constellation growth compared to user numbers (→ *no reliable numbers on users*)

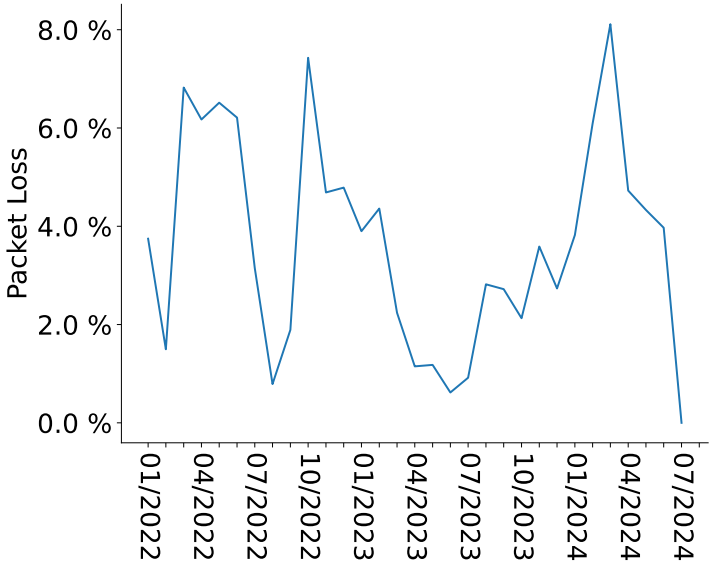


Figure 8: Packet Loss in the **USA**

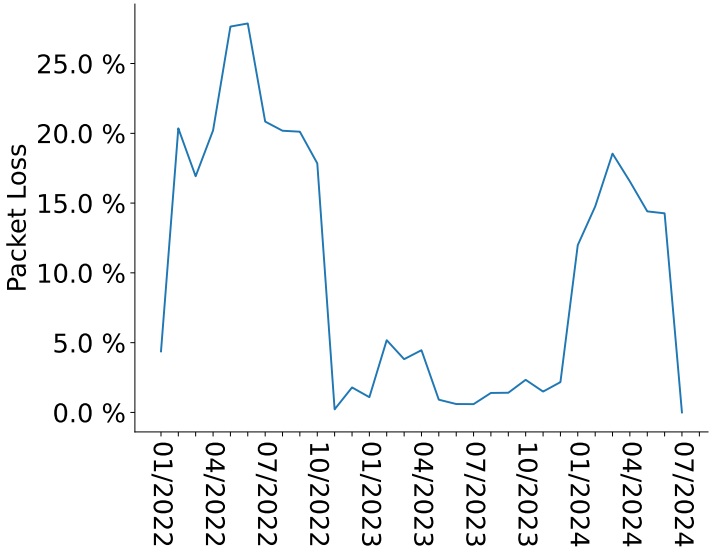


Figure 9: Packet Loss in **Germany**

Do latency and packet loss correlate?

- Pearson, Spearman, and Kendall correlation on median latency & overall packet loss per month
  - 1 or -1: Variables correlate
  - 0: Variables are orthogonal (i.e., do not correlate)
- Values scattered across the interval (-1, 1)

⇒ Cannot make a statement about correlation from the data

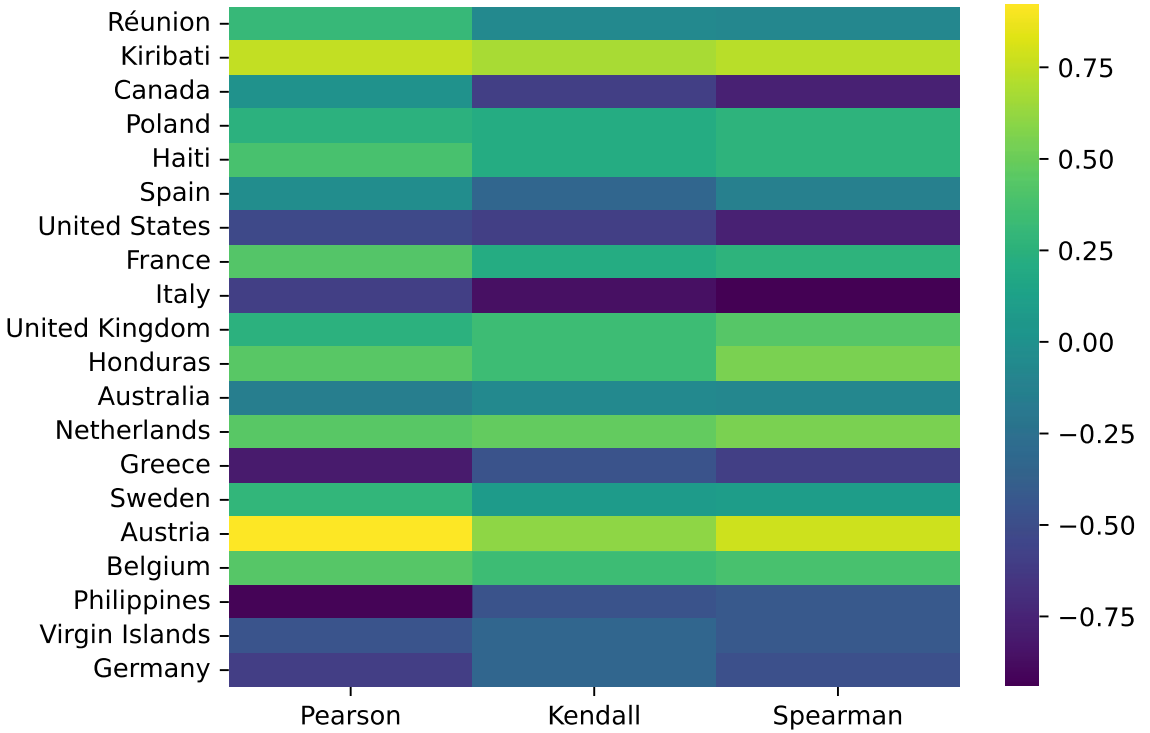


Figure 10: Statistical correlation results by country

What happens to latency when routing through the Starlink constellation to DNS root server?

- Two jumps in latency
- First jump related to routing through satellite constellation
- Second jump outside Starlink network

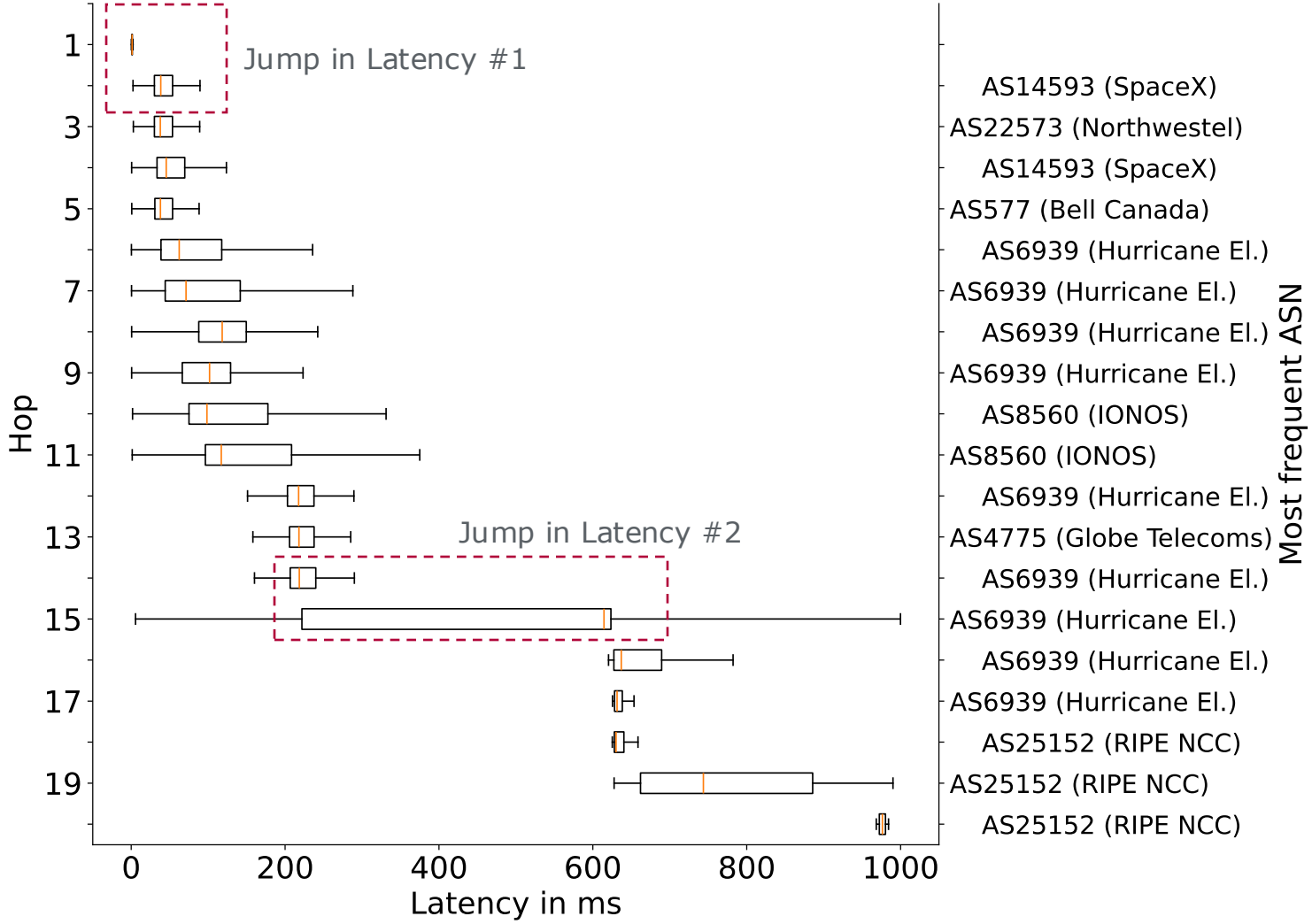


Figure 11: Starlink latency change per hop in Canada to *k.root-servers.org*

Limitations

- Starlink is a Black Box
  - Little is known about Starlink technology and software
  - Hard to find explanations for the data
  - Similar problems for other vendors

- Missing a theoretical model for satellite constellations

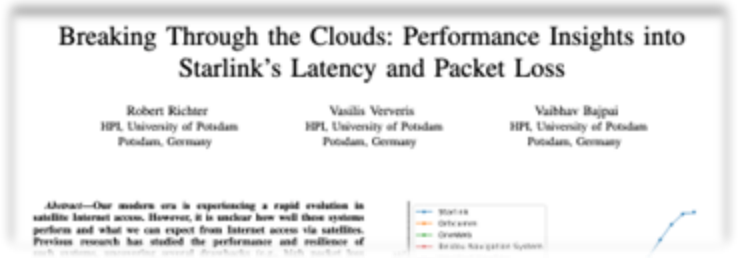
- Little probe numbers available
  - e.g., 10 probes in Germany (> 80 million population)
  - Only Starlink probes; no other SNOs present
  - Remaining question: How does Starlink compare to other SNOs?

Conclusion

Contact me: robert.richter@hpi.de

- Residential Starlink latencies ≈ 100–250 ms
- Packet loss may exceed 20% median
- Correlation between latency & packet loss not discoverable (different per country)
- Traceroute shows two latency jumps
  - First one after routing through the satellite constellation, which operates below IP layer

There's more in the paper!


Breaking Through the Clouds: Performance Insights into Starlink's Latency and Packet Loss

Robert Richter, HPI, University of Potsdam, Potsdam, Germany
Vasilis Ververis, HPI, University of Potsdam, Potsdam, Germany
Vaibhav Bajpai, HPI, University of Potsdam, Potsdam, Germany

- Diurnal variation
- Bimodal distribution of Starlink latencies
- Latency & Packet loss across various countries on different weekdays
- Solar magnetic storm intensity not influencing latency

Download Paper

Interested in PhD or Postdoc position?
⇒ vaibhav.bajpai@hpi.de

References

[Ma23] "Network characteristics of LEO satellite constellations: A starlink-based measurement from end user", Ma et al., (May 2023)

[Raman23] "Dissecting the performance of satellite network operators", Raman et al. (November 2023)

[Garcia23] "Multi-Timescale Evaluation of Starlink Throughput", Garcia et al. (October 2023)

[Laniewski24] "Starlink on the Road: A First Look at Mobile Starlink Performance in Central Europe", Laniewski et al. (March 2024)

[Laniewski25] "Measuring Mobile Starlink Performance: A Comprehensive Look", Laniewski et al. (February 2025)

[Lai20] "StarPerf: Characterizing Network Performance for Emerging Mega-Constellations", Lai et al. (November 2020)

[Kassing20] "Exploring the "Internet from space" with Hypatia", Kassing et al. (October 2020)

Download Paper

Interested in PhD or Postdoc position?
⇒ vaibhav.bajpai@hpi.de

Influence of Solar magnetic storms

- Correlation of Kp-index with TLS latency
- Results:
  - Pearson: ≈ 0.03
  - Kendall: ≈ 0.01
  - Spearman: ≈ 0.01

- Values very close to 0 indicating that both variables (Kp-index and TLS latency) are orthogonal (i.e., not correlated)
- Opposing popular research