

# Evaluating Resiliency and Performance of Networked Satellite Systems

Master's Thesis Midterm Presentation

*An excerpt of what happened so far*

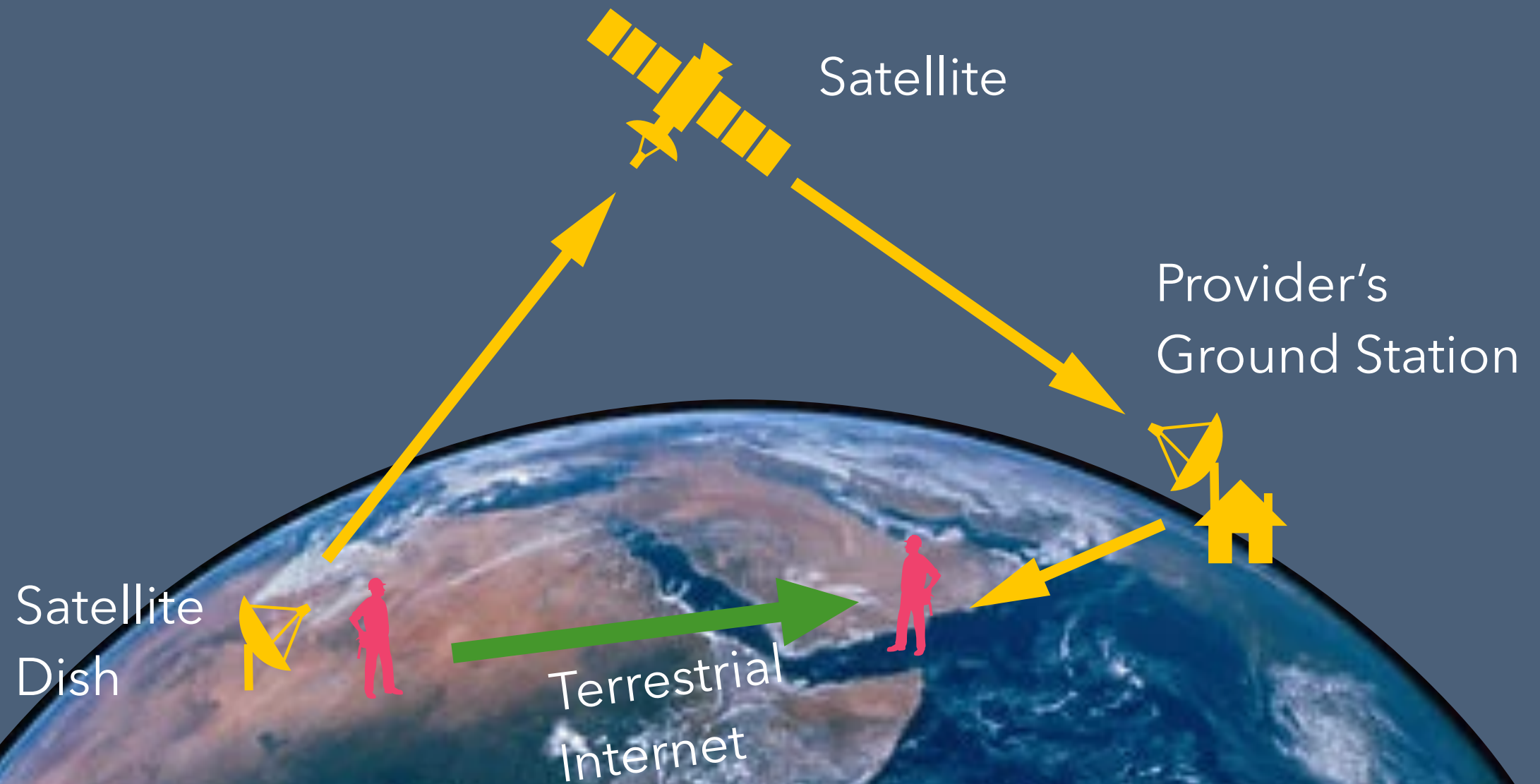
# Motivation for Networked Satellite Systems

Why do we even do that?

- **Remote Regions** difficult to support
- Resilience against **catastrophic situations**
  - earthquakes or tornadoes might destroy infrastructure
- You might **not want specific countries** to be part of the routing
- Solution: Communication over satellites
- Problem: We need to learn how to do that well.



# How well does „Satellite Internet“ work?



# Research Questions

- What do performance metrics state?
  - Packet Loss
  - Latency
- How does routing work?
- Do ISLs work well?
  - *I applied to present that at RIPE RACI*

# Methodology

- Data collection<sup>1</sup> from RIPE Atlas, Cloudflare Radar, N2YO, and (in the future) OONI
- Includes data for the following<sup>2</sup>:
  - **Ping** (for packet loss)
  - **TLS** (for latency)
  - **Traceroute**
  - HTTP
  - DNS
  - Disconnect Events of RIPE Atlas probes
  - RIPE Atlas Probes (for ASN14593, 146 probes in 23 countries)
  - All Satellites ever
- IP Info data for analysis (not included in the database)

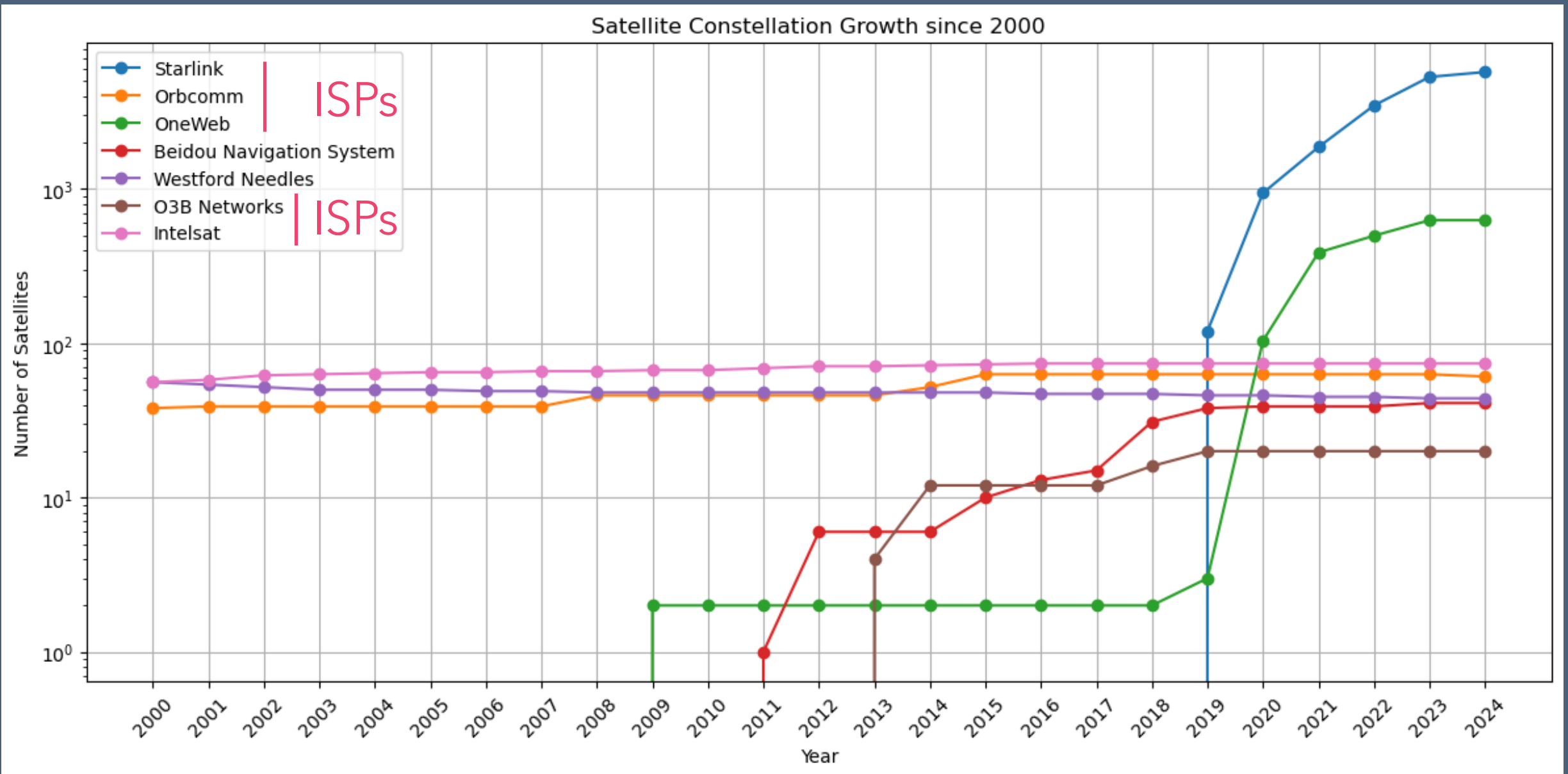


[1] ER-Diagram for database in appendix.

[2] Currently, only Starlink is considered as other providers are not on those platforms.

# Satellite Constellations

How many satellites do different constellations have?



Note the logarithmic scale

- Starlink: 5732
  - OneWeb: 628
  - Intelsat: 74
- } Constellations closer to earth



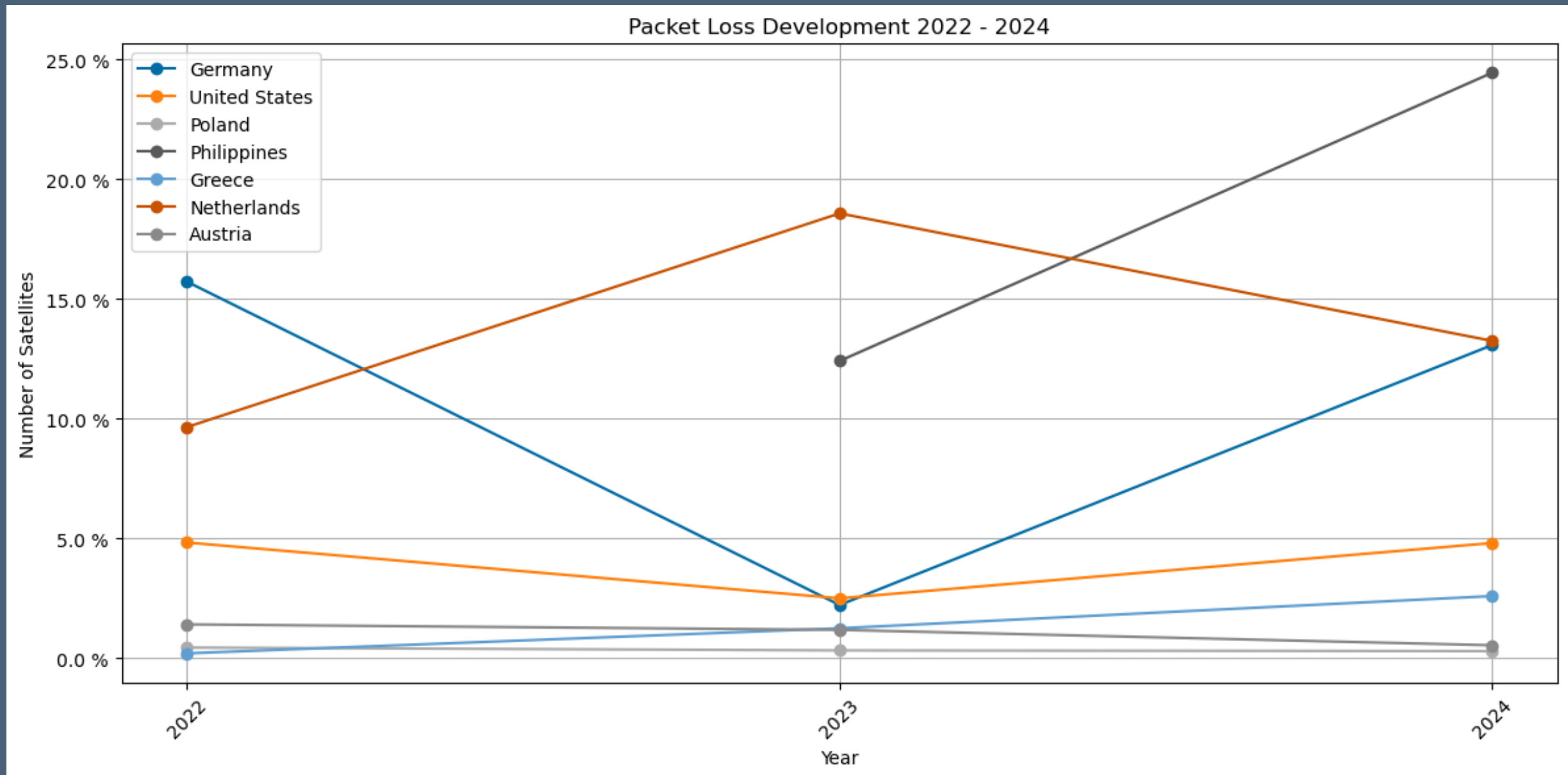
# Packet Loss

For ASN14593 from RIPE Atlas Probes

	Packet Loss in 2022 in %	Packet Loss in 2023 in %	Packet Loss in 2024 in %
country			
Germany	15.71	2.21	13.06
United States	4.82	2.49	4.80
Poland	0.43	0.31	0.28
Philippines	NaN	12.40	24.43
Greece	0.19	1.24	2.58
Netherlands	9.64	18.56	13.24
Austria	1.40	1.17	0.53

Correlate with latency

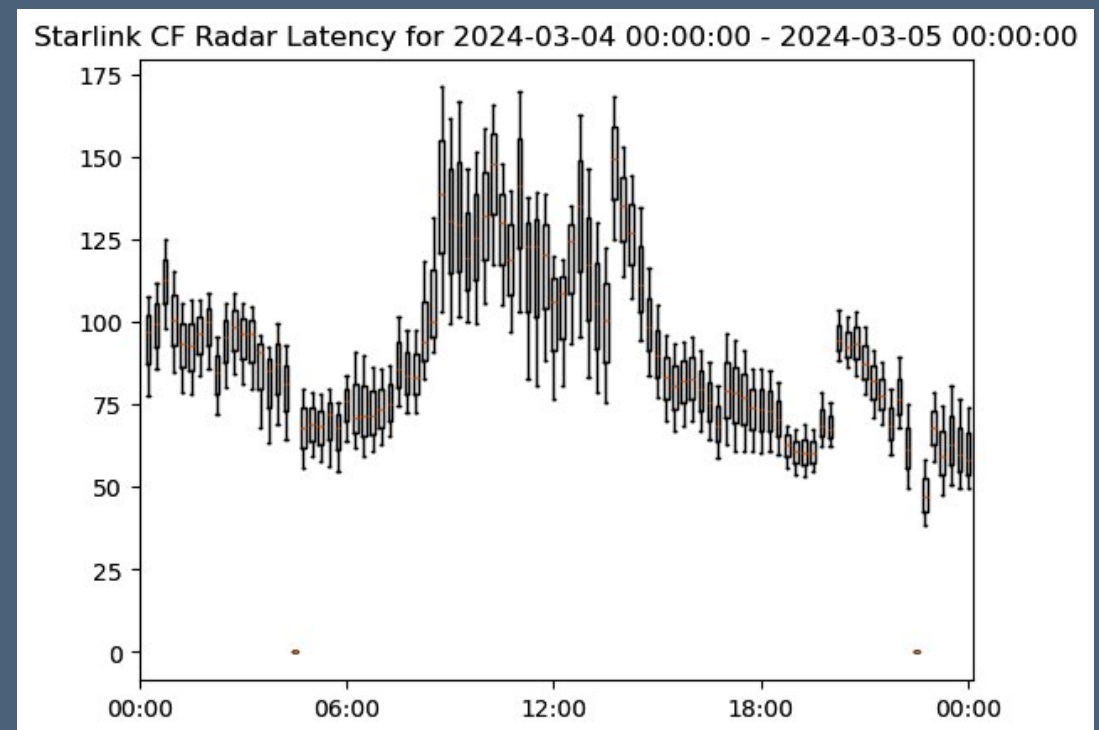
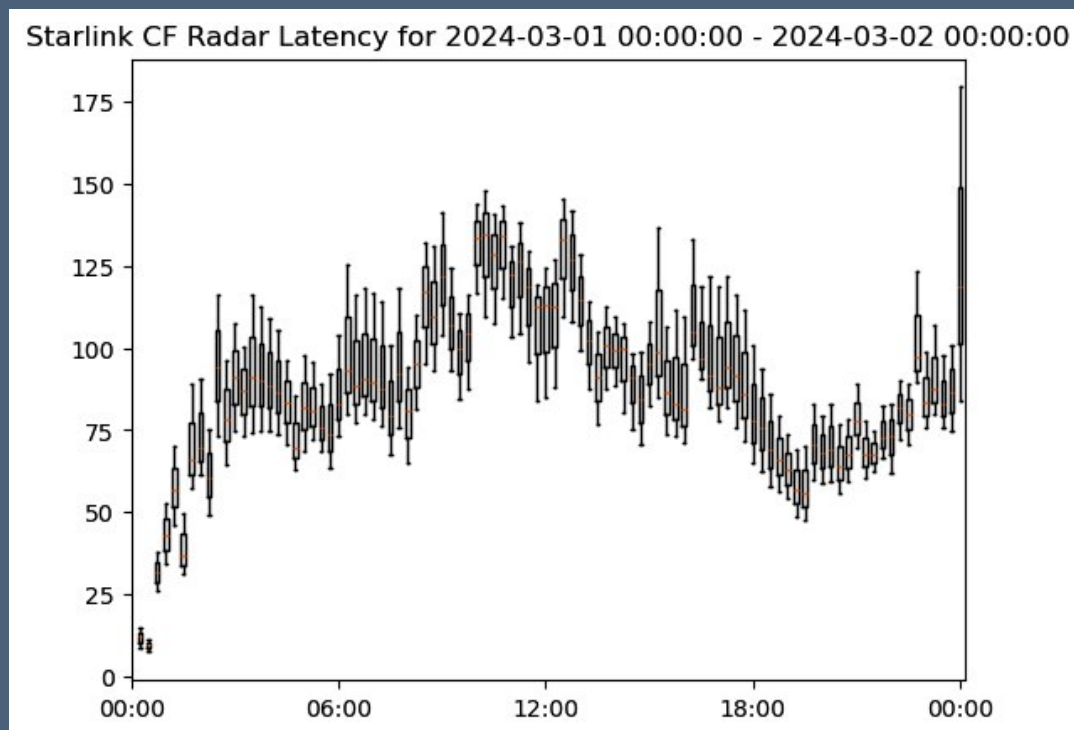
Boxplot, more points



# Latencies: A Single Day

## For Cloudflare Radar Data

- Spikes in the classical worktime (9 - 5)
- Lowest in the night (past midnight) and during dinner (19 - 20)

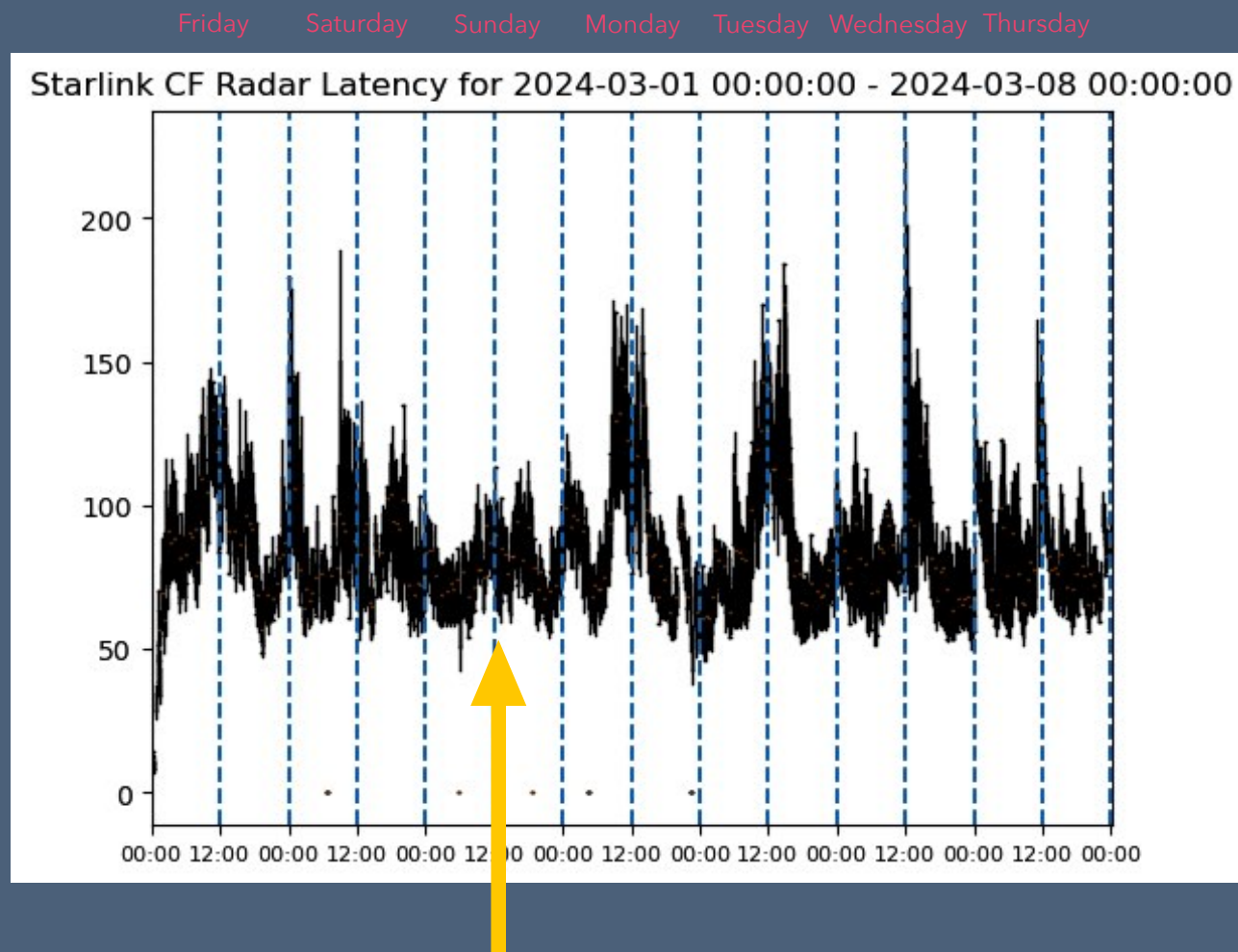


Why this day?  
More general behavior

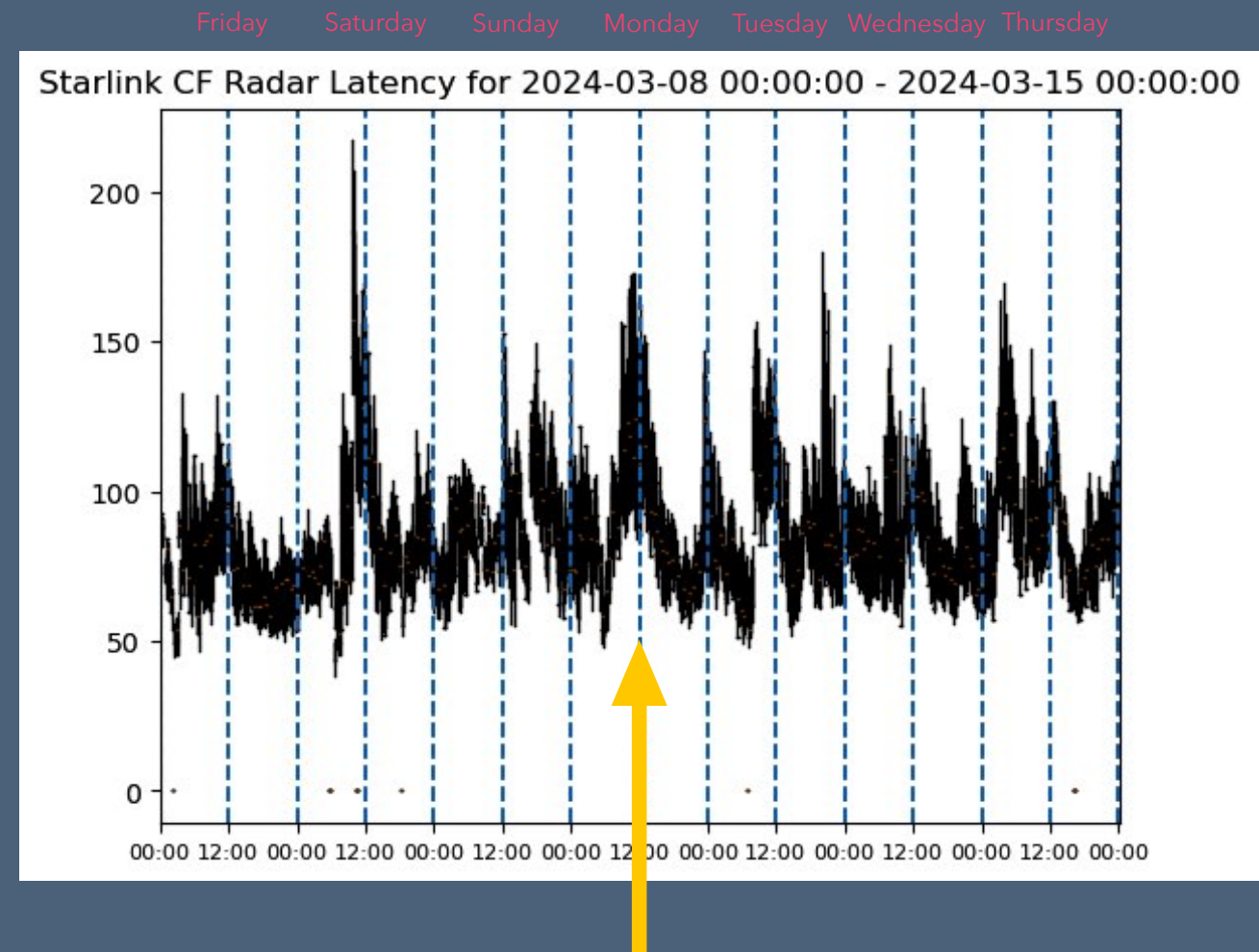


# Latency: A Week

For Cloudflare Radar data



No spike on Sunday



Spike on Monday

# Routing in Starlink


From RIPE Atlas probes and IP Info data

ISP should get data fast out of their network?

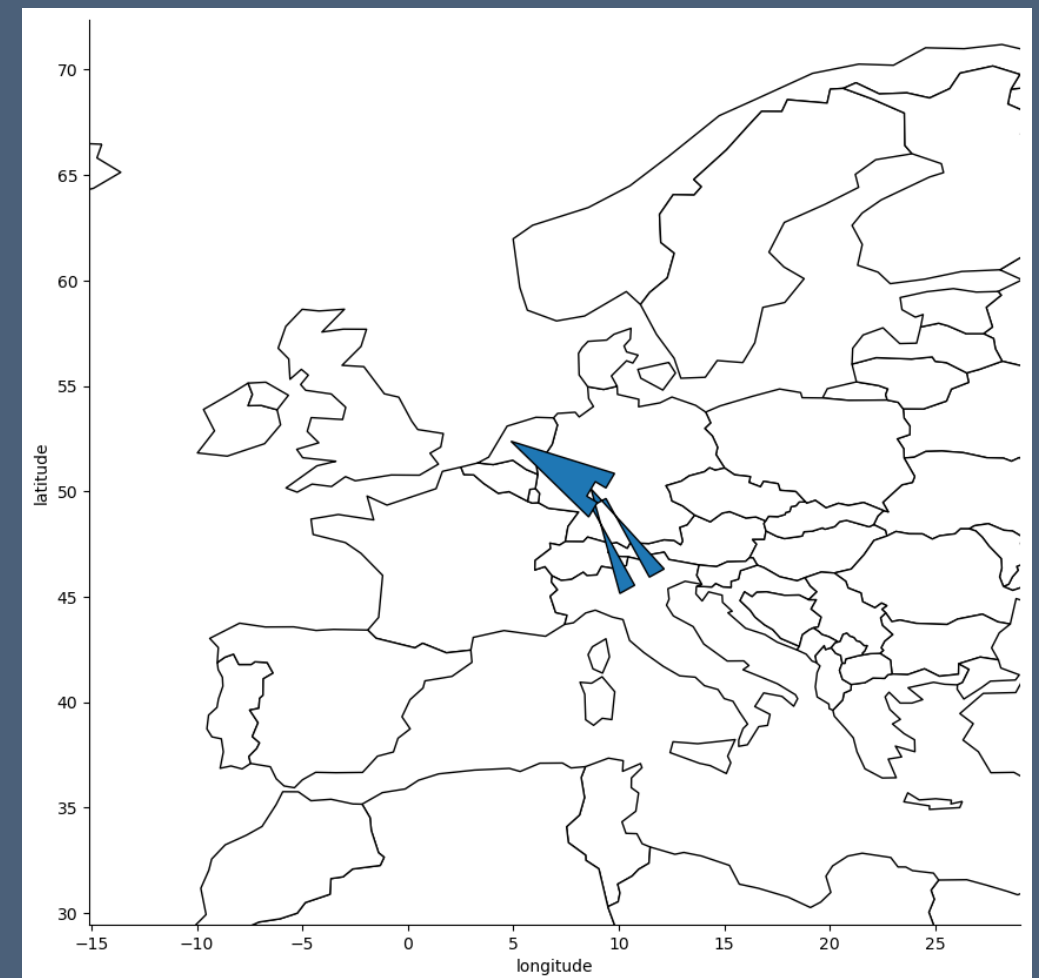
ISL relationship with traceroute

- Measurement setup: Traceroute from German probe to (mostly anycasted) \*.root-servers.net
- It seems, Starlink will enter the terrestrial internet as soon as possible.
- However, ISLs are still activated (looking at probes from Kiribati).
- *Not clear: Do they yield a performance improvement?*

Research is not sure [Hauri2020, Mohan2024, Li2023, Tanveer2023, ...]

IP Address	Hits	City	Flag	Country	Organization
193.239.116.217	13821	Amsterdam		Netherlands	Unknown
80.81.192.154	9528	Frankfurt am Main		Germany	Unknown
62.115.37.20	9050	Frankfurt am Main		Germany	AS1299
72.52.92.70	8546	Frankfurt am Main		Germany	AS6939
184.104.197.186	7301	Amsterdam		Netherlands	AS6939
206.224.65.178	7270	Chicago		United States	AS14593
206.224.65.184	7182	Chicago		United States	AS14593
206.224.65.182	7178	Chicago		United States	AS14593
206.224.65.180	7101	Chicago		United States	AS14593

Top Hit IPs



Traceroute Visualization of a Single Traceroute

# Next steps

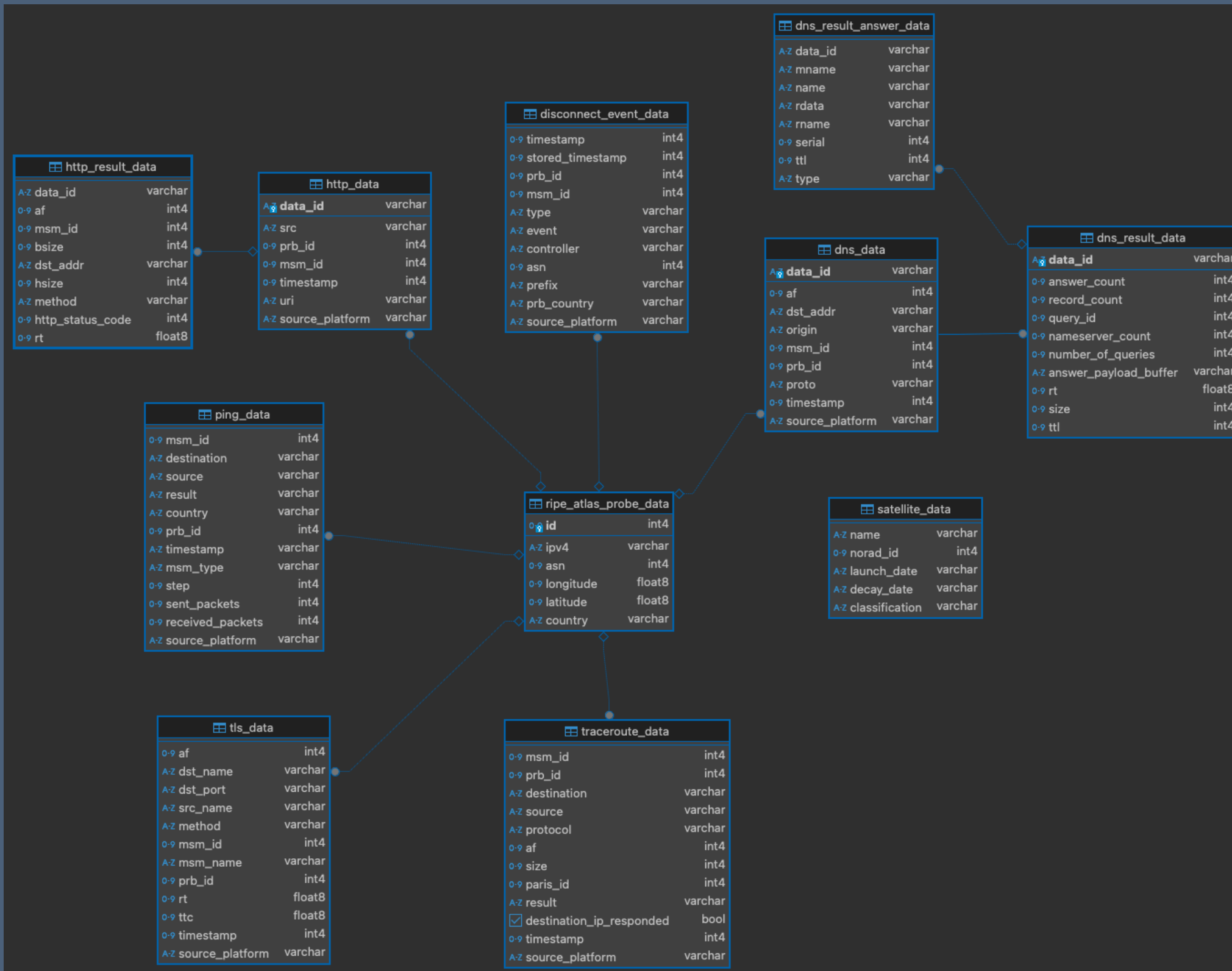
- Latency analysis:
  - RIPE Atlas TLS Data
  - For the whole range of data (2022 to July 2024)
  - For individual countries
- Finalize Routing Analysis
- ISL analysis: mostly about „Do ISLs improve performance?“
- Look at the other data: DNS, HTTP, ...
- Bonus: The influence of satellite position on performance.
  - Correlate latency & packet loss with the position of a satellite.

# Appendix

# Destinations for Traceroutes

A-Z destination ▼
104.237.152.132
139.162.27.28
170.247.170.2
192.203.230.10
192.33.4.12
192.36.148.17
192.5.5.241
193.0.14.129
193.0.19.59
193.0.19.60
198.41.0.4
198.97.190.53
199.7.83.42
199.7.91.13
199.9.14.201
202.12.27.33
213.133.109.134
45.33.72.12
78.46.48.134

# ER Diagram for DB





# Packet Loss 2022 - 2024

	country_long	Total Packet Loss (complete interval in %)	Packet Loss in 2022 in %	Packet Loss in 2023 in %	Packet Loss in 2024 in %
0	Austria	1.084669	1.399670	1.171061	0.527815
1	Australia	4.173753	1.997390	6.352580	1.223839
2	Belgium	2.329525	1.114463	1.988446	5.541626
3	Benin	0.221743	NaN	NaN	0.221743
4	Canada	3.280974	0.347290	2.113378	5.067781
5	Switzerland	0.386915	0.386915	NaN	NaN
6	Czechia	0.228482	NaN	0.228482	NaN
7	Germany	9.377228	15.706816	2.208954	13.063105
8	Spain	3.671932	0.160163	12.720470	1.260941
9	Falkland Islands (Malvinas)	3.235828	NaN	3.235828	NaN
10	France	6.591610	1.281551	9.274813	10.648189
11	United Kingdom	3.456526	4.022389	5.251026	0.559071
12	Greece	1.626359	0.189618	1.236970	2.582672
13	Honduras	2.612991	0.386609	0.269018	5.987934
14	Haiti	1.431330	NaN	0.675566	1.966914
15	Italy	3.733627	3.070874	4.833069	2.443725
16	Kiribati	9.268443	NaN	NaN	9.268443
17	Netherlands	14.242005	9.639804	18.561993	13.237323
18	Philippines	19.425088	NaN	12.398919	24.432945
19	Poland	0.352452	0.430861	0.312574	0.282865
20	Réunion	1.136504	NaN	1.009948	1.253406
21	Sweden	0.429436	NaN	0.350376	0.513379
22	United States	3.649459	4.817592	2.487545	4.796999
23	Virgin Islands, U.S.	0.606871	NaN	0.728809	0.461274

# Packet Loss in 2022

	sent	rcvd	country_long	packet loss ratio in %
0	9922841	9783954	Austria	1.399670
1	16102564	15780933	Australia	1.997390
2	7003101	6925054	Belgium	1.114463
3	7651535	7624962	Canada	0.347290
4	2843	2832	Switzerland	0.386915
5	36112602	30440462	Germany	15.706816
6	1456642	1454309	Spain	0.160163
7	123678219	122093219	France	1.281551
8	32378420	31076034	United Kingdom	4.022389
9	819543	817989	Greece	0.189618
10	7019233	6992096	Honduras	0.386609
11	7023213	6807539	Italy	3.070874
12	7604968	6871864	Netherlands	9.639804
13	7011766	6981555	Poland	0.430861
14	118776840	113054657	United States	4.817592

# Packet Loss in 2023

	sent	rcvd	country_long	packet loss ratio in %
0	15348212	15168475	Austria	1.171061
1	33335844	31218158	Australia	6.352580
2	10996525	10777865	Belgium	1.988446
3	41194762	40324161	Canada	2.113378
4	8119682	8101130	Czechia	0.228482
5	49620855	48524753	Germany	2.208954
6	3969303	3464389	Spain	12.720470
7	432934	418925	Falkland Islands (Malvinas)	3.235828
8	125414257	113782319	France	9.274813
9	33504135	31744824	United Kingdom	5.251026
10	6998473	6911904	Greece	1.236970
11	4216453	4205110	Honduras	0.269018
12	6910646	6863960	Haiti	0.675566
13	23524764	22387796	Italy	4.833069
14	8660029	7052555	Netherlands	18.561993
15	10390188	9101917	Philippines	12.398919
16	6939482	6917791	Poland	0.312574
17	3350074	3316240	Réunion	1.009948
18	4113295	4098883	Sweden	0.350376
19	273239956	266442989	United States	2.487545
20	9408505	9339935	Virgin Islands, U.S.	0.728809

# Packet Loss in 2024

	sent	rcvd	country_long	packet loss ratio in %
0	7859953	7818467	Austria	0.527815
1	12563741	12409981	Australia	1.223839
2	3839451	3626683	Belgium	5.541626
3	340484	339729	Benin	0.221743
4	38776617	36811503	Canada	5.067781
5	35183290	30587260	Germany	13.063105
6	12746508	12585782	Spain	1.260941
7	78380584	70034471	France	10.648189
8	26821264	26671314	United Kingdom	0.559071
9	3910175	3809188	Greece	2.582672
10	7589412	7134963	Honduras	5.987934
11	9839576	9646040	Haiti	1.966914
12	16118265	15724379	Italy	2.443725
13	2768534	2511934	Kiribati	9.268443
14	3897495	3381571	Netherlands	13.237323
15	14488495	10948529	Philippines	24.432945
16	3929081	3917967	Poland	0.282865
17	3675666	3629595	Réunion	1.253406
18	3936270	3916062	Sweden	0.513379
19	156085789	148598355	United States	4.796999
20	7756556	7720777	Virgin Islands, U.S.	0.461274

# Average Latencies

Measured using TLS

	rt	ttc
country		
AT	118.850359	54.394441
AU	351.590379	170.134380
BE	125.520766	61.742852
BJ	228.271898	101.329514
CA	215.809948	99.034965
CZ	133.999878	63.192864
DE	93.809640	44.151585
ES	122.126862	53.210413
FK	595.722619	204.381250
FR	96.110162	41.677666
GB	106.095100	48.741139
GR	155.620069	67.035563
HN	217.569390	95.554923
HT	231.495170	112.509270
IT	198.296704	51.132900
KI	406.407002	197.538679
NL	102.960952	48.174512
PH	317.627217	159.056267
PL	137.449773	58.849454
RE	350.715318	172.095539
SE	132.986852	61.065885
US	231.757526	101.421170
VI	242.613436	114.935840

- ttc = time-to-connect
- rtt = round-trip-time
- No extreme outliers (max about 4000ms)