Development of a Framework for Retrieval of Parameters of the Starlink Dish

Final talk for the IDP by

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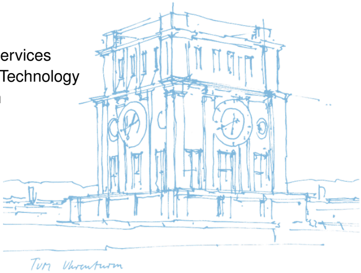

What is Starlink?

- Starlink is a Low Earth Orbiting (LEO) Satellite Constellation
- Brings Internet connection to remote areas
- 4000+ satellites with plans to launch more
- End users have a Dish to connect to satellites in sight
- Performance is higher compared to geostationary satellites (GEOSAT) based connections
- Satellites are orbiting at 550 km in height vs GEOSAT’s 35,000 km
- Average latency is 35 ms
- Download bandwidth is $>$ 100 MBps

Starlink 101

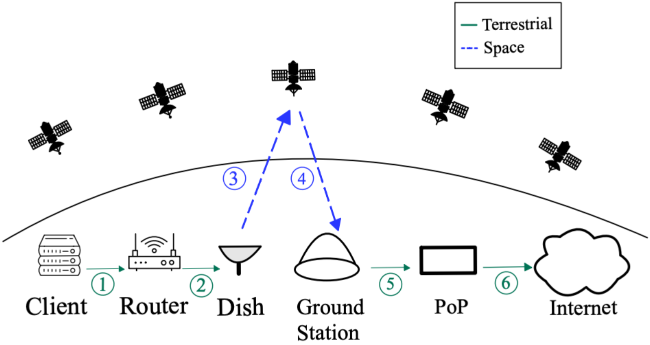

Figure 1: Starlink in a nutshell (ignoring Inter Satellite Links), from [1]

Our Dish

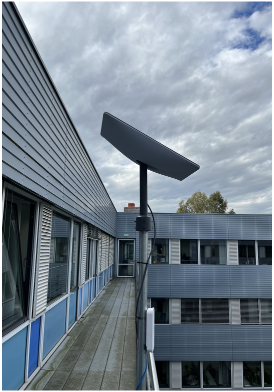

Figure 2: Our Starlink Dish

Problem Statement

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- Documenting gRPC API
- Measuring Latency to Point of Presence
- Understanding Routing Decisions
- Visualize Visible Satellites and patterns in their appearance
- Physical Layer Influences on Performance
- Retrieval of Obstruction Maps
- Satellite Handovers detection based on Obstruction Maps
- Correlation between Satellite Handovers and Bandwidth Drops

Documenting the gRPC API

We started by documenting the gRPC API running on the Dish

- We started by documenting the gRPC[1] API running on the dish
- API is reachable at `192.168.100.1:9200`
- The dish exposes a gRPC API with "Server Reflection"[2]
- 55 Endpoints are available
  - Majority of them do not work
  - 2 categories of errors: `Uninmplemented`, `PermissionDenied` and a some other errors
- Most interesting working Endpoints [3]:
  - `reboot`
  - `get_status`
  - `get_obstruction_map`

[1] `https://grpc.io` is a RPC framework from Google

[2] "Runtime construction of requests without having stub information precompiled into the client." `https://github.com/grpc/grpc/blob/master/doc/server-reflection.md`

[3] `https://gist.github.com/rcastellotti/e20630366dfeaeada6cc2680f562f6ac`

Measuring Latency to the Point of Presence

Can we measure Latency to the Point of Presence (PoP)?

- In short: we don't have to
- The `get_status` endpoint contains a `pop_ping_latency_ms` field
- We started polling the endpoint to gather latency to the Point of Presence
- Latency is pretty stable, averaging 35 ms with some irregular peaks
- Data reported by the API seems to be consistent with traceroutes

Measuring Latency to the Point of Presence

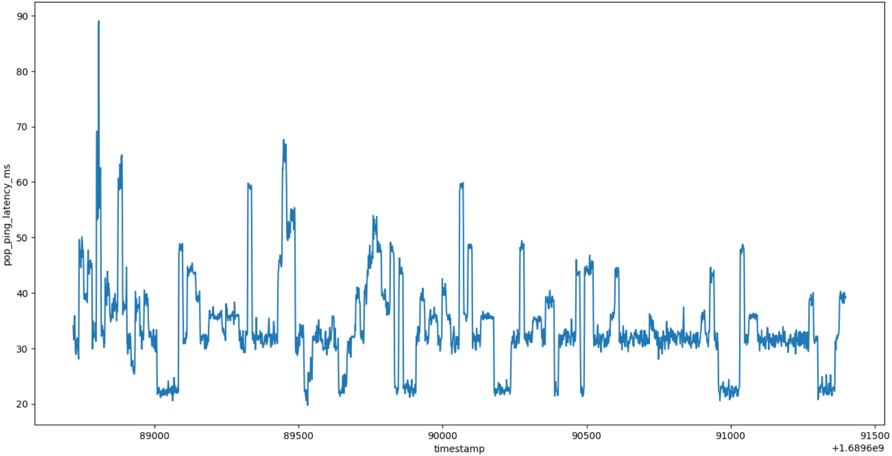

Figure 3: Visualizing latency to the Point of Presence.

Understanding Routing Decisions

Can we gather additional information about routing inside AS14593 [4]?

- Retrieved IP address blocks from major cloud providers (AWS, Azure, Oracle), position already known [5]
- Chose five geographically sparse targets around the globe, i.e., for aws:
  - `ap-northeast-2` Asia Pacific (Seoul)
  - `us-east-1` US East (N. Virginia)
  - `ap-south-1` Asia Pacific (Mumbai)
  - `sa-east-1` South America (São Paulo)
  - `me-south-1` Middle East (Bahrain)
- Tracerouted the targets over several days and saved data to later visualize it

[4] The Autonomous System SpaceX opearates; https://www.peeringdb.com/net/18747

[5] does not necessarily mean the last hop will be in that area (little information around what happens inside data centers), but a good enough approximation

Understanding Routing Decisions

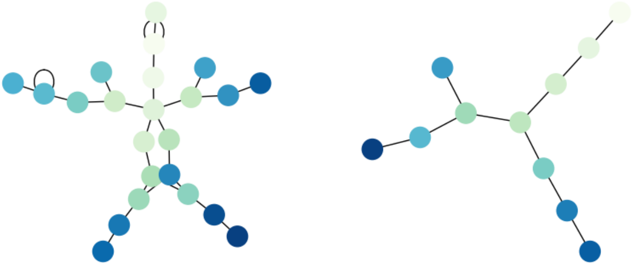

Figure 4: First seven hops of traceroutes to 5 AWS datacenters using ICMP; left is Starlink, right is cabled connection

Visualize Visible Satellites

Can we visualize visible satellites?

- Two-line element sets (TLE)[6]:
  - A data format encoding information abbout Earth-orbiting object for a given point in time
  - Allow for estimation of position and velocity at any point in past or future
- Downloaded a list of Starlink's satellites TLEs from celestrak.org
- Wrote a Python script to calculate visible satellites[7]
- Gathered information about satellite position
- Visualized patterns in satellite appearances.

[6] https://en.wikipedia.org/wiki/Two-line_element_set

[7] https://gitlab.lrz.de/netintum/teaching/tumi8-theses/idp-castellotti/-/blob/main/common.py?ref_type=heads#L132

Visualizing Patterns in Visible Satellites

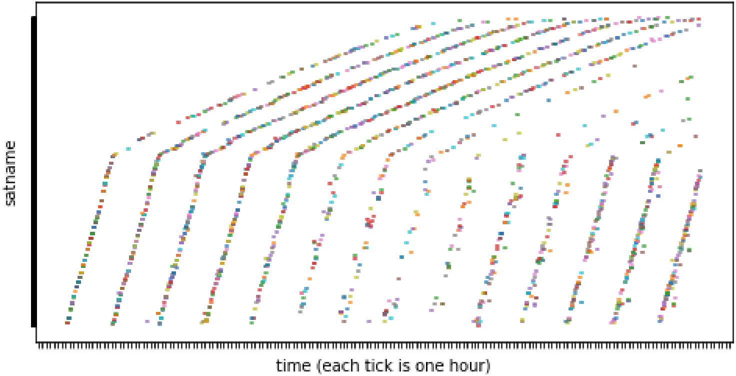

Figure 5: Visualizing patterns in Visible Satellites, we add a dot whenever we see a satellite

Physical Layer Influences on Performance

Does the physical layer have any influences on performance?

- We wanted to understand whether the physical layer influences RTT
- The Dish may decide to send a packet only when it fills a buffer
- Sent packets to a host we control with iPerf to create traffic on the interface, varying the payload size
- Downloaded Debian ISOs from 5 different mirrors (to neutralize upload speed differences)
- Measured RTTs

Physical Layer Influences on Performance

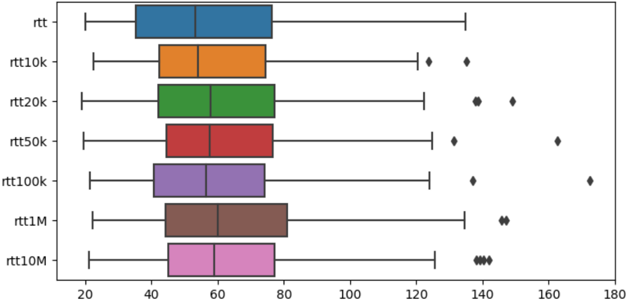

Figure 6: Physical Layer Influences on Performance

the dish_get_obstruction_map Endpoint

Can we use a side channel to extract satellite handovers from obstruction maps?

- An Obstruction Map captures the position where the Dish has seen satellites
- Designed to provide a way to report whether the dish positioning is optimal
- Following the approach described by Izhikevich et al. [1], we retrieved maps
  - Reboot the Dish to clear the Obstruction Map (`api.reboot`)
  - Poll the endpoint frequently enough to see satellite traces (`api.get_obstruction_map`)
  - Save the maps to visualize them later

Querying the `dish_get_obstruction_map` Endpoint

```
"apiVersion":"9",
"dishGetObstructionMap":{
    "minElevationDeg":10.0,
    "numCols":123,
    "numRows":123,
    "snr":[-1.0,-1.0,-1.0,-1.0,...,1.0,1.0,-1.0,-1.0]
}
```

- Interpret the `"snr"` field as a matrix, it contains 15129 (123*123) items
- Export this as images using Matplotlib, adding a timestamp for each map

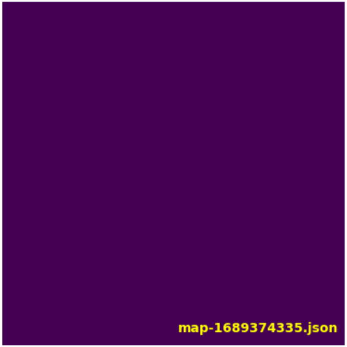

Figure 7: An Obstruction Map

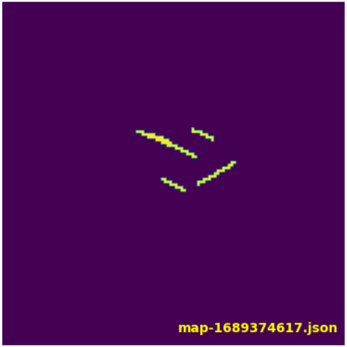

Figure 8: An Obstruction Map

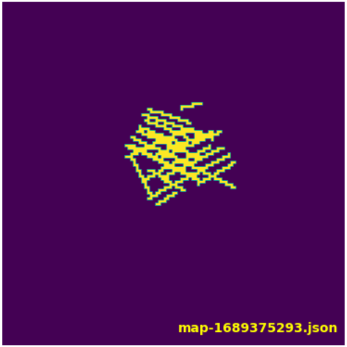

Figure 9: An Obstruction Map

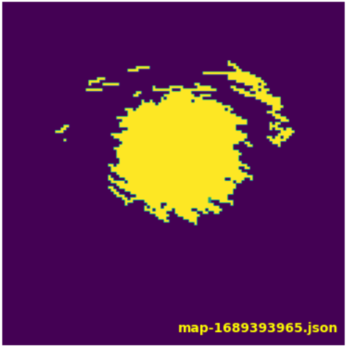

Figure 10: An Obstruction Map

Detecting Handovers Algoritmically

- Going through visualizations frame by frame is not feasible (1000s of frames)
- Following the map matrix interpretation, we assume:
  - "1" means a satellite was detected in that position
  - "-1" means no satellite was detected in that position
- Iterate through matrices two by two and sum them
- Check if, in the sum matrix, a "0" entry is "near" a "2" entry (inside a 3*3 matrix)
  - If it is "near" no handover was performed
  - If it is in complete different position an handover must have been performed

Obstruction Maps as Matrices (No Handover)

$$\begin{bmatrix} -1 & 1 & -1 & -1 \\ -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 \end{bmatrix} + \begin{bmatrix} -1 & 1 & -1 & -1 \\ -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & 1 \\ -1 & -1 & -1 & -1 \end{bmatrix} = \begin{bmatrix} -2 & 2 & -2 & -2 \\ -2 & -2 & 2 & -2 \\ -2 & -2 & -2 & 0 \\ -2 & -2 & -2 & -2 \end{bmatrix}$$

Obstruction Maps as Matrices (Handover)

$$\begin{bmatrix} -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & 1 \\ -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 \end{bmatrix} + \begin{bmatrix} -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & 1 \\ -1 & -1 & -1 & -1 \\ 1 & -1 & -1 & -1 \end{bmatrix} = \begin{bmatrix} -2 & -2 & 2 & -2 \\ -2 & -2 & -2 & 2 \\ -2 & -2 & -2 & -2 \\ 0 & -2 & -2 & -2 \end{bmatrix}$$

Correlating Satellite Handovers and Bandwidth Drops

Is there any correlation between satellite handovers and drops in bandwidth?

- We now have an algorithm to detect handovers
- We run two scripts in parallel:
  - 1st: Retrieves an obstruction map every second
  - 2nd: Gathers Bandwidth data
- We visualize Bandwidth data and Satellite Handovers

Correlating Satellite Handovers and Bandwidth Drops

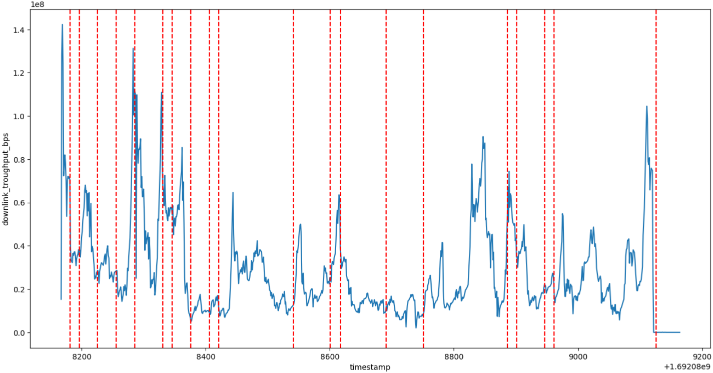

Figure 11: Correlating Satellite Handovers and Bandwidth Drops, blue is bandwidth, red vertical dashes are satellite handovers

Similar Technologies

- Eutelsat operates a LEO constellation, Oneweb [8], mainly serving Enterprises ar ments
- Amazon is currently launching its own LEO constellation: Project Kuiper [9], wit launch 3,236 satellites, with secured lanches (BlueOrigin)
- The China Aerospace Science and Technology Corporation plans to deploy satellite constellation [10]
- The increasing number of LEO satellites might cause problems, mainly:
  - Overall sky brightness increases (impacts astronomical observation)
  - Proliferation of debris

[8] https://oneweb.net

[9] https://www.aboutamazon.com/what-we-do/devices-services/project-kuiper

[10] https://spacenews.com/china-to-begin-constructing-its-own-megaconstellation-later-this-year/

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Final Remarks

We conclude that:

- Majority of the Endpoints on the gRPC API are not accessible
- PoP Latency is remarkably stable
- Physical layer has no remarkable influences on Performance
- Bandwidth is sustained consistently, even in the presence of satellite handovers
- Getting insights into inner routing is hard

Bibliography

[1] L. Izhikevich, M. Tran, K. Izhikevich, G. Akiwate, and Z. Durumeric.
Democratizing leo satellite network measurement, 2023.