TUDelft

Frontiers of LEO Space Networks
Understanding the Intricacies of Starlink's Internet Access

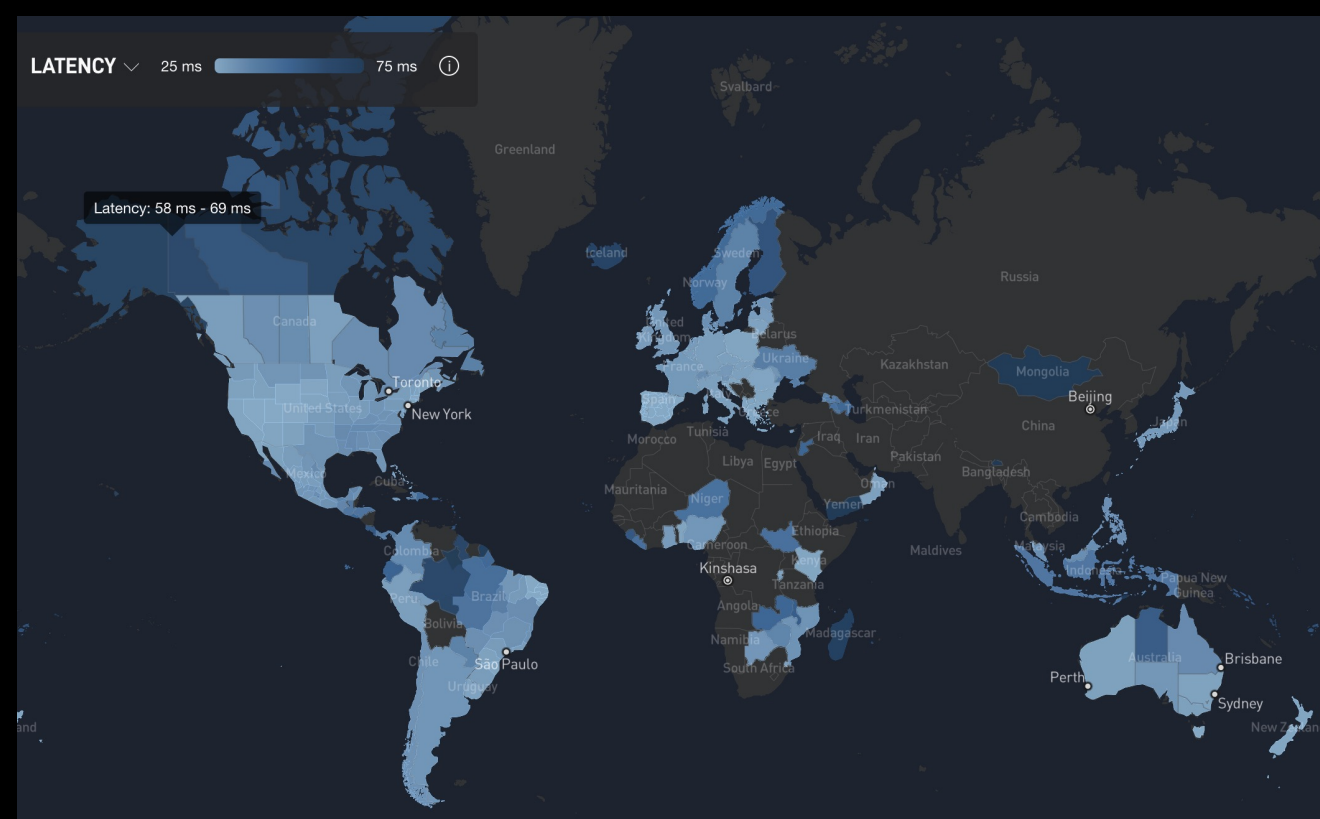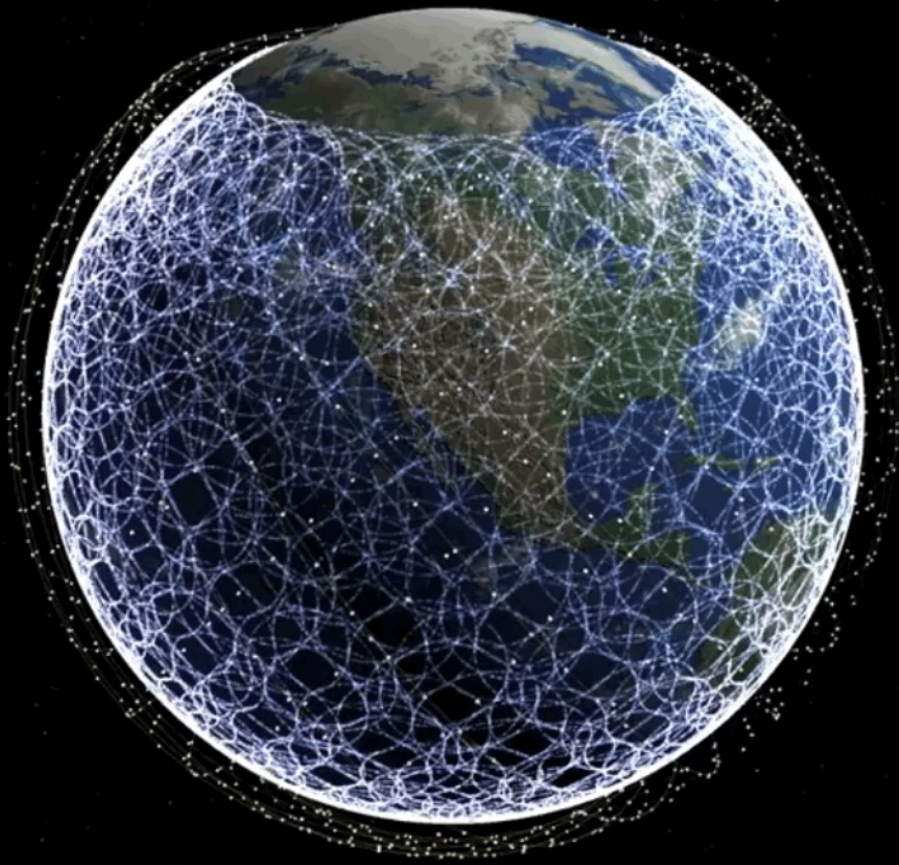### Dr. Nitinder Mohan

Assistant Professor
Delft University of Technology, Netherlands

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https://www.starlink.com/map?view=latency

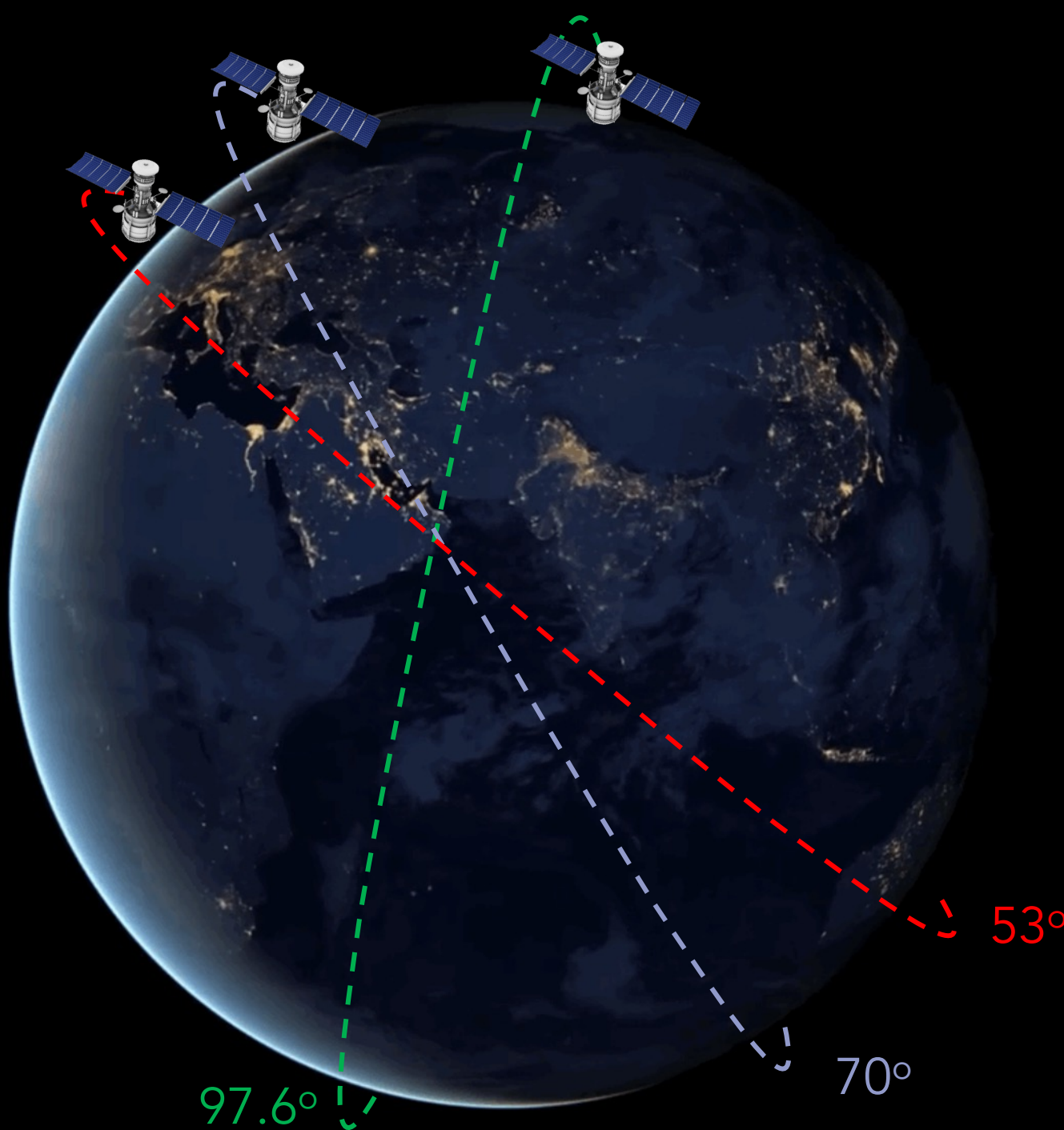# Starlink is emerging as a "global" ISP

- \> 6000 operational LEO satellites

- Plans to deploy 40,000+ satellites

- Satellites orbiting at 300-700 km altitude

- Aims to provide low-latency high-bandwidth connectivity globally

- Competitive performance to many terrestrial providers

Starlink network performance is globally inconsistent due to network design and operation
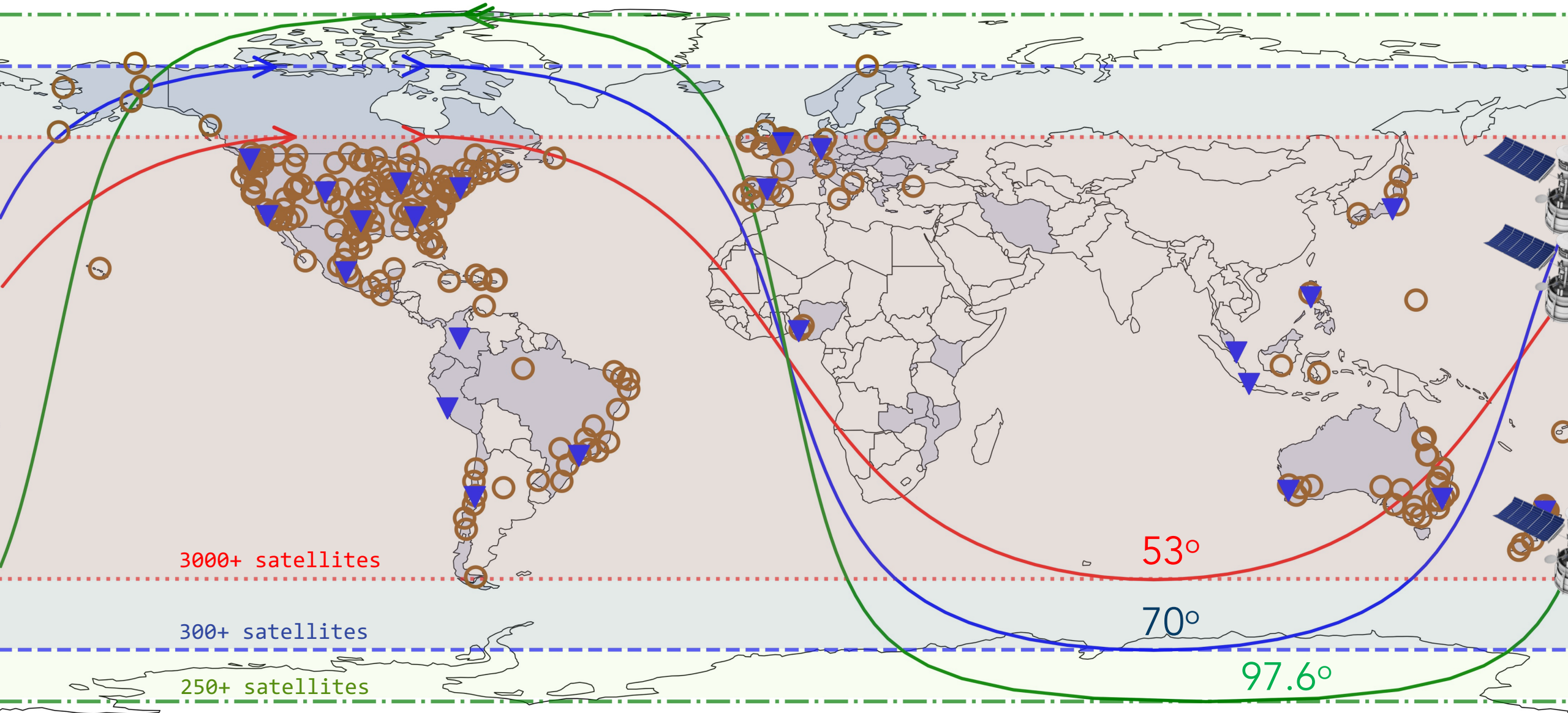
(1)

Starlink satellite fleet is deployed in multiple orbits

Majority of deployed satellites (90%) are in 53° orbital shell

53°

70°

97.6°

Ground Station ▼ Point of Presence

53°

70°

97.6°

3000+ satellites

300+ satellites

250+ satellites

Different regions globally will observe different satellite coverage and frequency
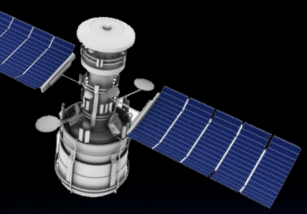
Starlink network performance is globally inconsistent due to network design and operation

(2)

Starlink follows a "bent-pipe" connectivity

Satellites connect Starlink user terminals to Ground Stations

Changes in bent-pipe and ground infrastructure density can impact end-to-end performance
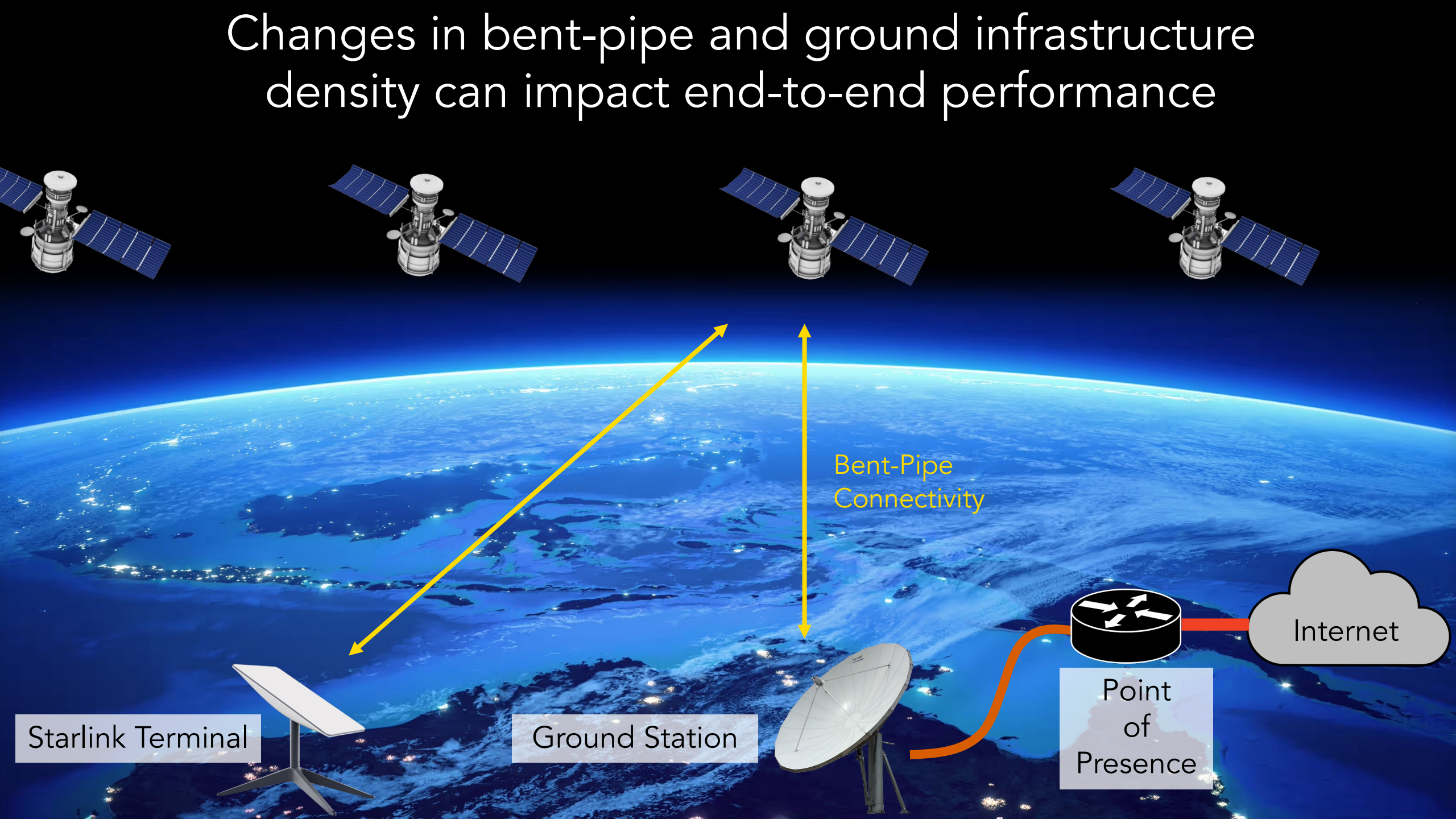
Bent-Pipe Connectivity

Internet

Starlink Terminal

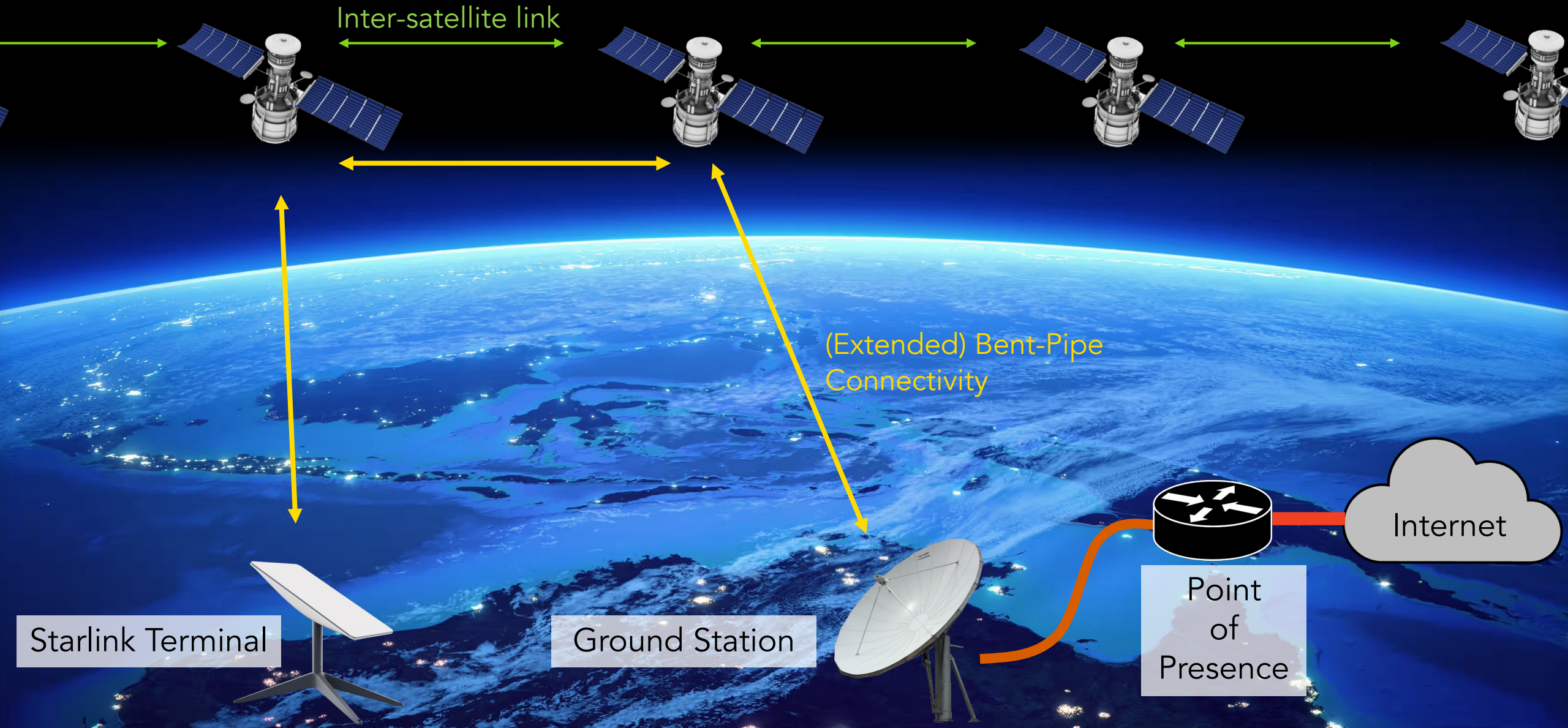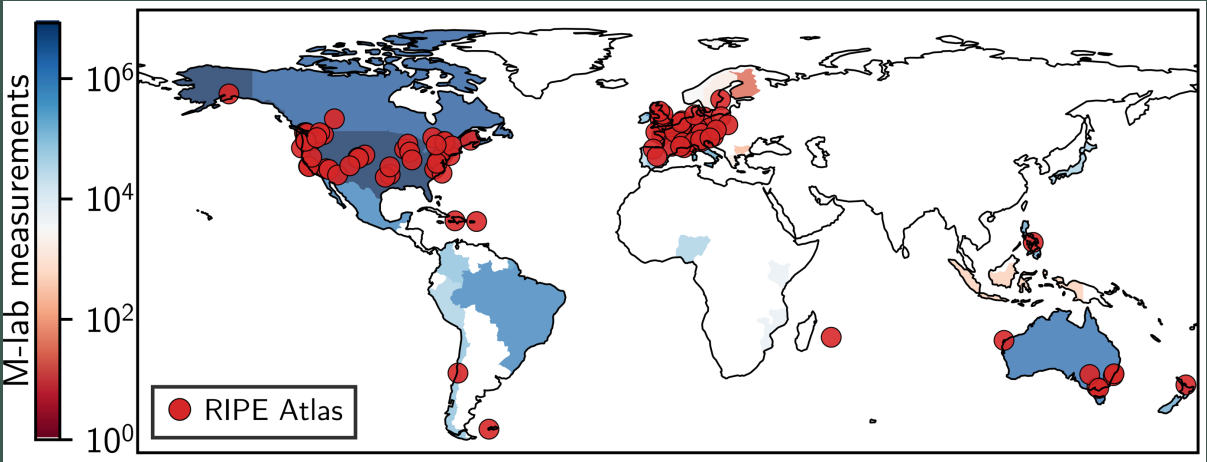Ground Station

Point of Presence

Changes in bent-pipe and ground infrastructure density can impact end-to-end performance

Inter-satellite link

(Extended) Bent-Pipe Connectivity

Starlink Terminal

Ground Station

Point of Presence

Internet

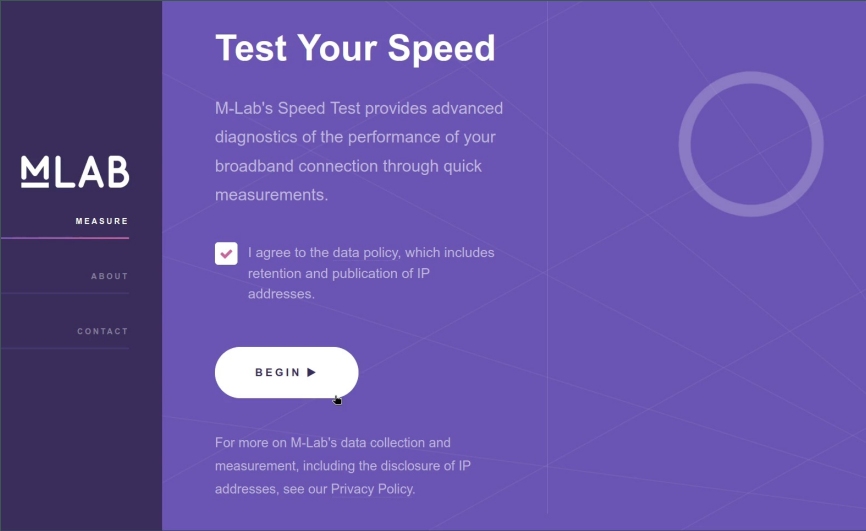We conducted multifaceted comprehensive analysis of Starlink operations and performance

A Multifaceted Look at Starlink Performance
The Web Conference (WWW) 2024

🏆 IETF ANRP Award 2025

Global Performance

1. Crowdsourced M-Lab TCP "speed tests" from Starlink users to the nearest cloud server
   - 19.2 million data points from 34 countries

2. Targeted pings and traceroute measurements from Starlink RIPE Atlas probes
   - 98 probes from 21 countries
   - Endpoints in 145 datacenters from seven cloud operators

We conducted multifaceted comprehensive analysis of Starlink operations and performance

A Multifaceted Look at Starlink Performance
The Web Conference (WWW) 2024

🏆 IETF ANRP Award 2025

Global Performance

Real-Time Web Apps

1. Zoom conferencing
   - Comparison between Starlink and ethernet for supporting low latency videoconferencing
   - RTTs, jitters, bitrate, resolution, …

2. Amazon Luna cloud gaming
   - Comparison between Starlink, ethernet, and 5G
   - Delays, FPS, frame freezes, jitters, throughput, …
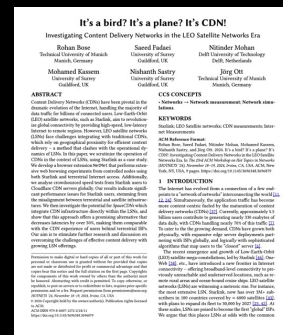
We conducted multifaceted comprehensive analysis of Starlink operations and performance

It's a bird? It's a plane? It's a CDN!

ACM HotNets 2024

It's a bird? It's a plane? It's CDN!
Investigating Content Delivery Networks in the LEO Satellite Networks Era

Rohan Bose
Technical University of Munich
Munich, Germany

Saeed Fadaei
University of Surrey
Guildford, UK

Nitinder Mohan
Delft University of Technology
Delft, Netherlands

Mohamed Kassem
University of Surrey
Guildford, UK

Nishanth Sastry
University of Surrey
Guildford, UK

Jörg Ott
Technical University of Munich
Munich, Germany

Global Performance

Real-Time Web Apps

CDN Performance

I. Cloudflare Aggregated Internet Measurements (AIM)

- Speedtest to Cloudflare CDNs
- 22K+ Starlink measurements from 55 Countries and 800K terrestrial ISPs measurements from 196 countries

II. NetMet Browser Plugin

- Fetch Tranco top-20 popular websites hosted by Cloudflare and Cloudfront CDNs
- 5K+ measurements from Starlink (8 countries) and terrestrial (15 countries)
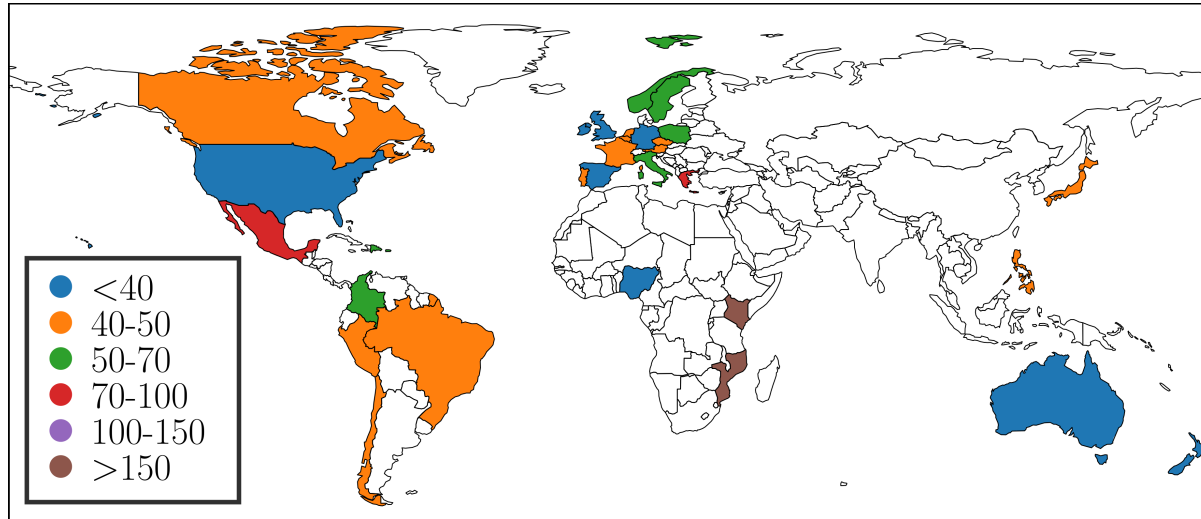
III. LEOScope Testbed

- Controlled measurements from 12 countries
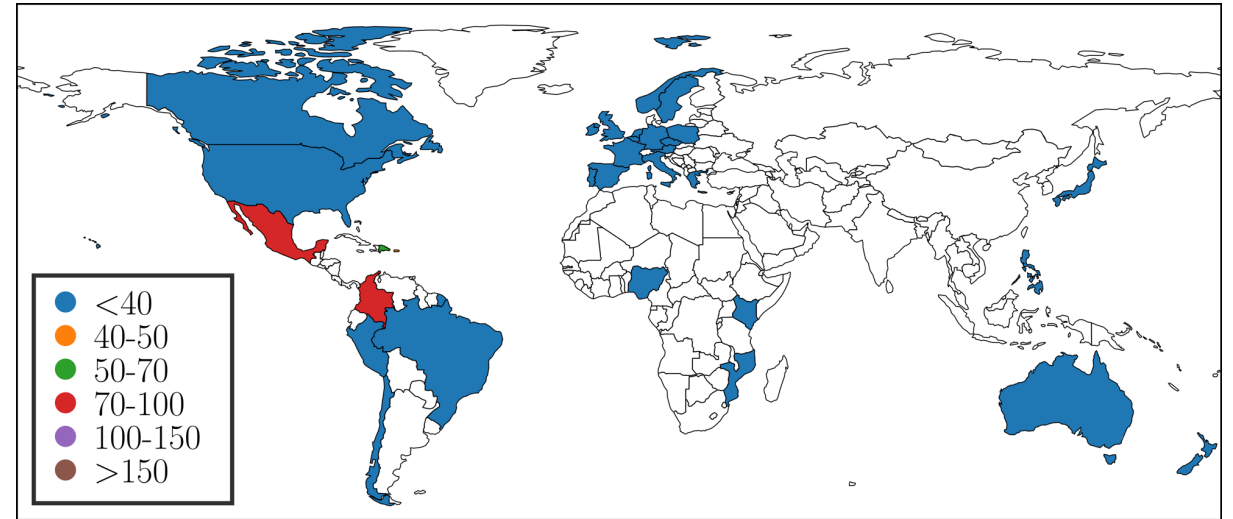- NetMet Docker measurements

CLOUDFLARE

NetMet

Global Performance
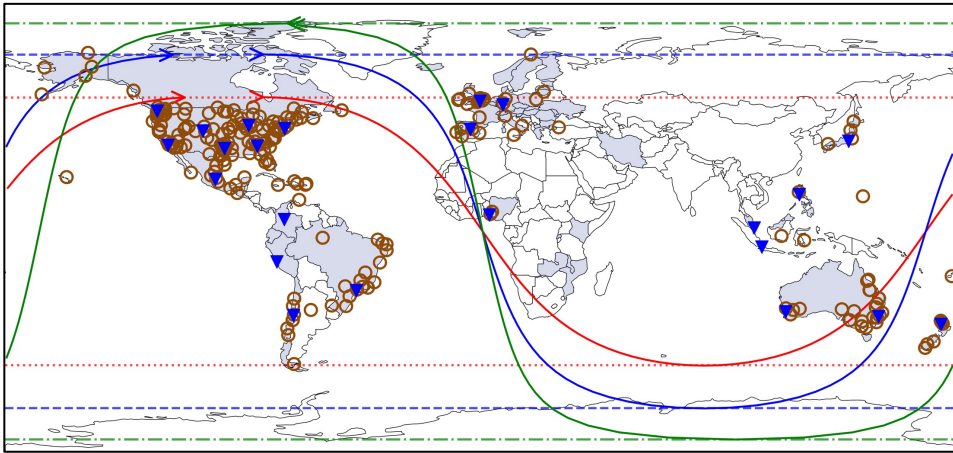
World View of Latencies

Starlink

Top-3 mobile network operators

- Median latencies for Starlink is ~40-50 ms while mobile network latencies are ~30 ms
- Well-provisioned regions (such as NA and EU) enjoy the best Starlink latencies
- Starlink performs poorly in several regions with long tail latencies, e.g. Africa
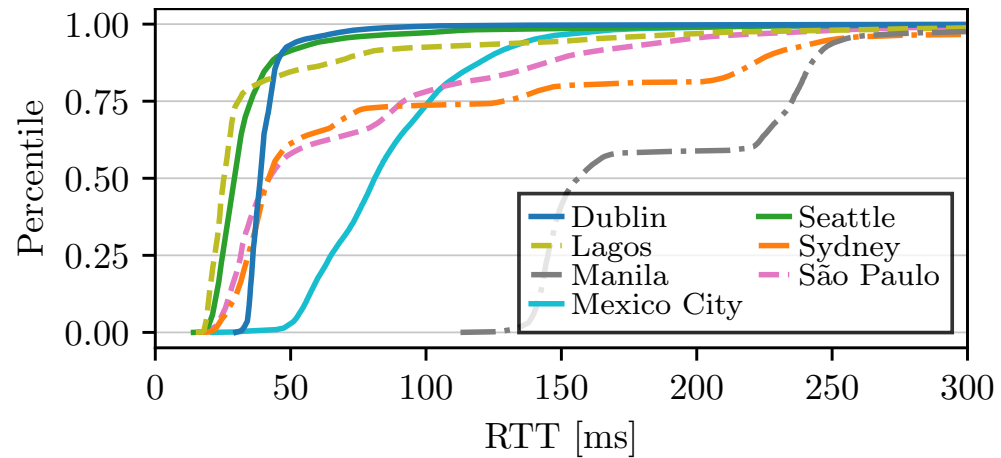- Not many regions where Starlink currently outperforms cellular

A Digital Divide?

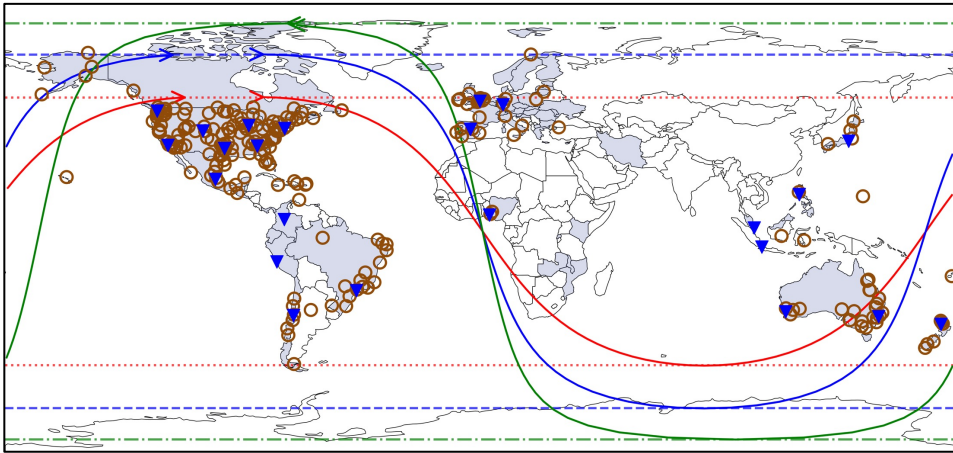## Clear impact of ground station infrastructure

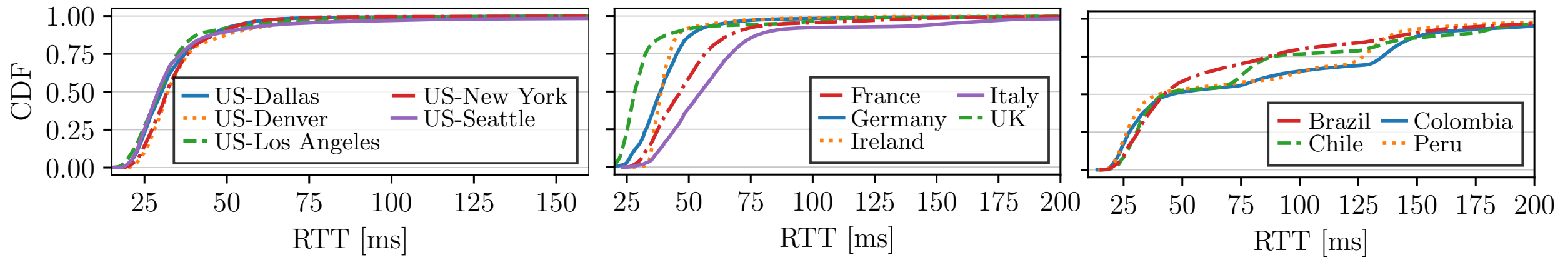- Regions with high ground station and PoP availability get better latencies.
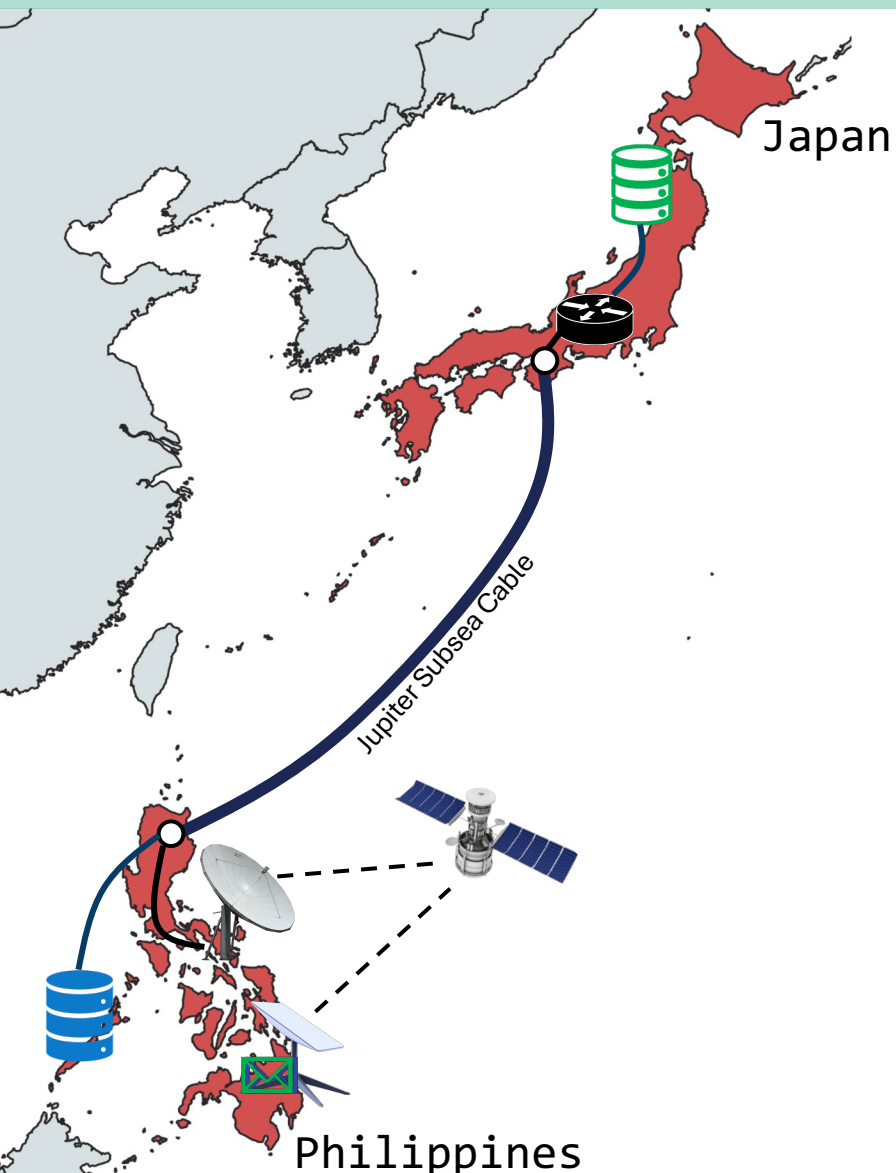
A Digital Divide?

Clear impact of ground station infrastructure

- Regions with high ground station and PoP availability get better latencies.
- Consistent performance across USA due to dense ground infrastructure
- In EU, closeness to PoP means shorter latencies (e.g. Italy connects to PoP in Spain)
- Significantly higher latencies in SA, long distances between GSs and limited PoPs in the region

Impact of ground infrastructure - Philippines

Before May 2023

Starlink only has ground station in Philippines but used nearest PoP in Japan

Client in PH connecting to server in Japan

Client in PH connecting to server in PH

subsea link

PH - PH Pre May'23
PH - JP Pre May'23

CDF

RTT [ms]

Impact of ground infrastructure - Philippines
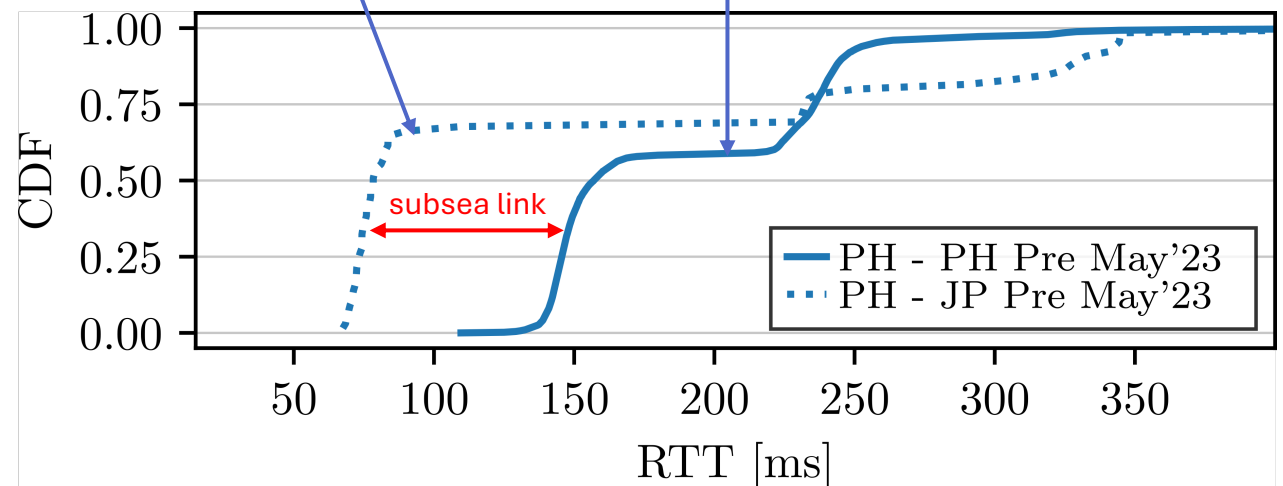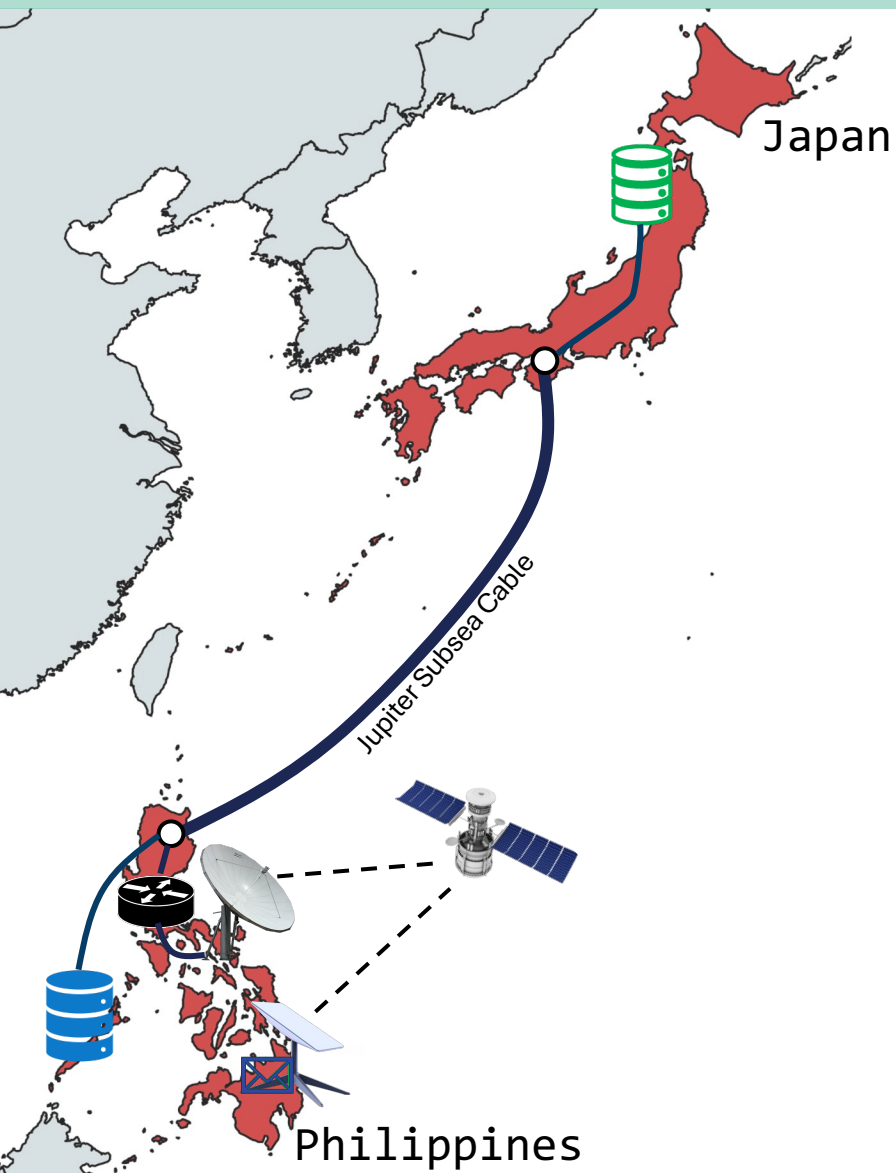

Japan

Jupiter Subsea Cable

Philippines

After May 2023

Starlink only has ground station in Philippines but used nearest PoP in Japan

Client in PH connecting to server in Japan
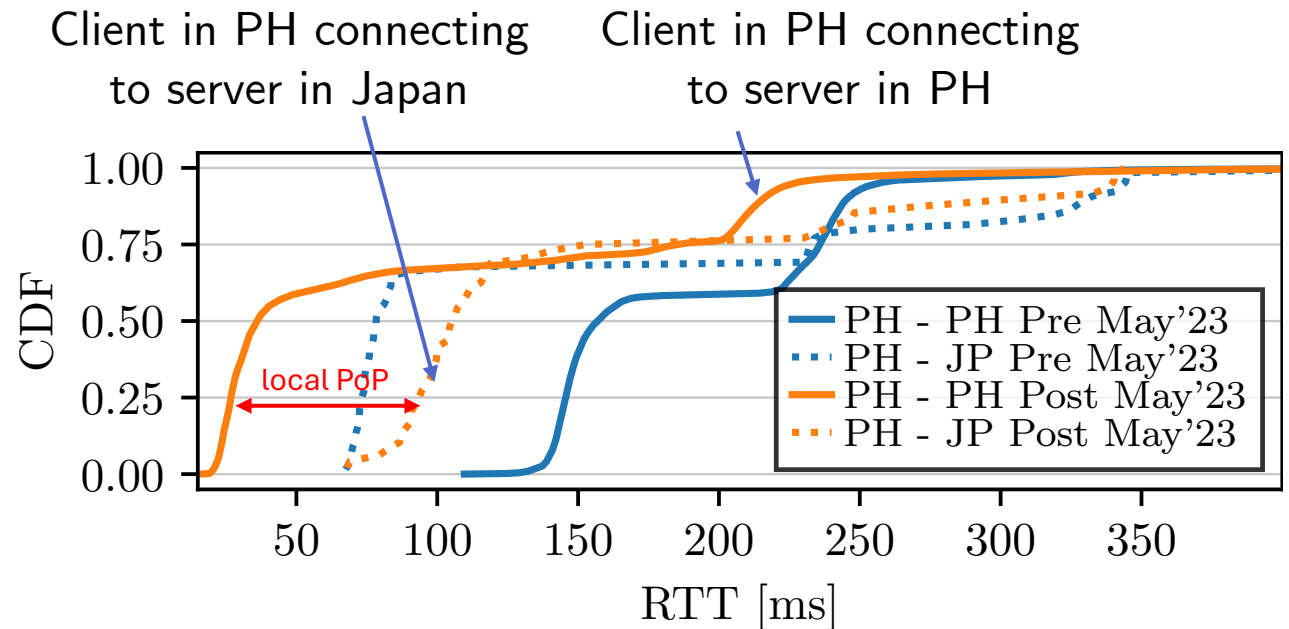
Client in PH connecting to server in PH

local PoP

PH - PH Pre May'23
PH - JP Pre May'23
PH - PH Post May'23
PH - JP Post May'23

CDF

RTT [ms]

Starlink CDN Operations

Global Performance

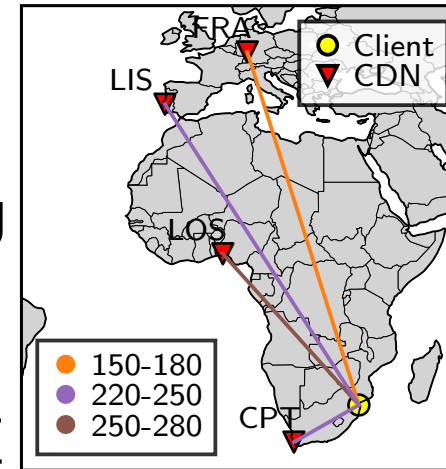| Country	Terrestrial ISP		Starlink	
	Distance (km)	minRTT (ms)	Distance (km)	minRTT (ms)
Swaziland	301	12.8	4731.6	122.7
Kenya	197	16	6310.8	110.9
Zambia	1202	44	7545.9	143.5
Lithuania	168	12.5	1243	40
Spain	375.3	14.3	13.4	33
Japan	253	9	57.0	34

- Terrestrial connections almost always achieve lower latencies to CDNs

- Disparity is more pronounced for Starlink users in many African countries (e.g., Kenya, Mozambique, and Zambia), where latencies are around 120-150 ms higher.

- Even if the distance to CDN server is shorter in Starlink, the latency is still higher due to LEO satellite propagation speed + terrestrial route from PoP to CDN server
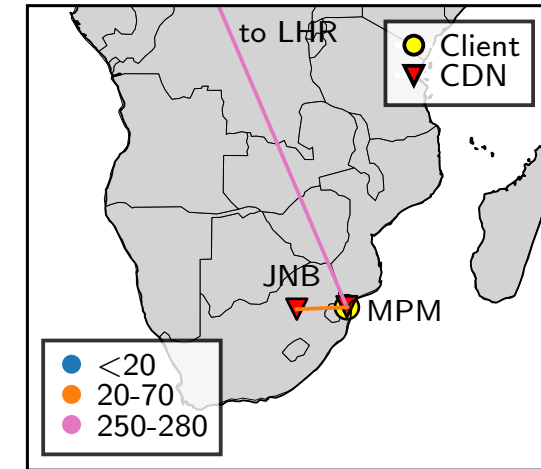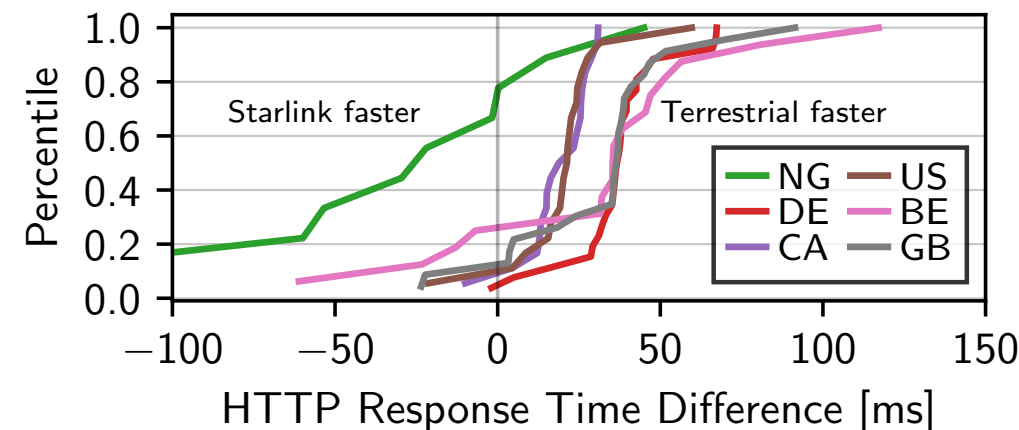
Starlink vs Terrestrial

What's going on?

- From Mozambique, (majority) Starlink users are mapped to CDN in Germany (≈6000 km) hosting the PoP

- If mapped to CDN in Africa, the latencies are higher due to additional terrestrial route from DE

- Problem does not exist in terrestrial ISPs

- Significant degradation in user experience with long tails in performance

- Only exception is Nigeria as it has local PoP and local terrestrial infrastructure deployment is not great
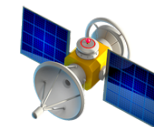

Starlink

Terrestrial

Think about inconsistencies when retrieving <u>locally</u> popular content over Starlink!
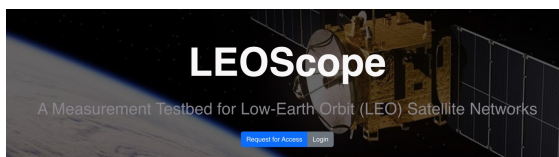
🚀 Towards Space-Friendly Internet Future 🛰️

*The journey to a space-friendly Internet is not just about technology;
it's about inclusion, resilience, and sustainability.*

- There exists a dichotomy between satellite and terrestrial network operations which limits geographical extent

- We need to rethink how Internet content provisioning, cloud services and terrestrially-dependent operations should inter-mingle

- *Satellites as base stations* vs. *Satellites as Internet backbone*?

Interested?

Contribute a
Starlink probe!

RIPE Atlas

arch ID, ASN, Country, IP, Prefix
S14593 (v4) (89)

LEOScope
A Measurement Testbed for Low-Earth Orbit (LEO) Satellite Networks
Request for Access   Login

LEO-NET 2025
The 3rd ACM Workshop on LEO Networking and Communication 2025

Coimbra, Portugal
September 8th, 2025

Co-located with ACM SIGCOMM 2025

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Backup