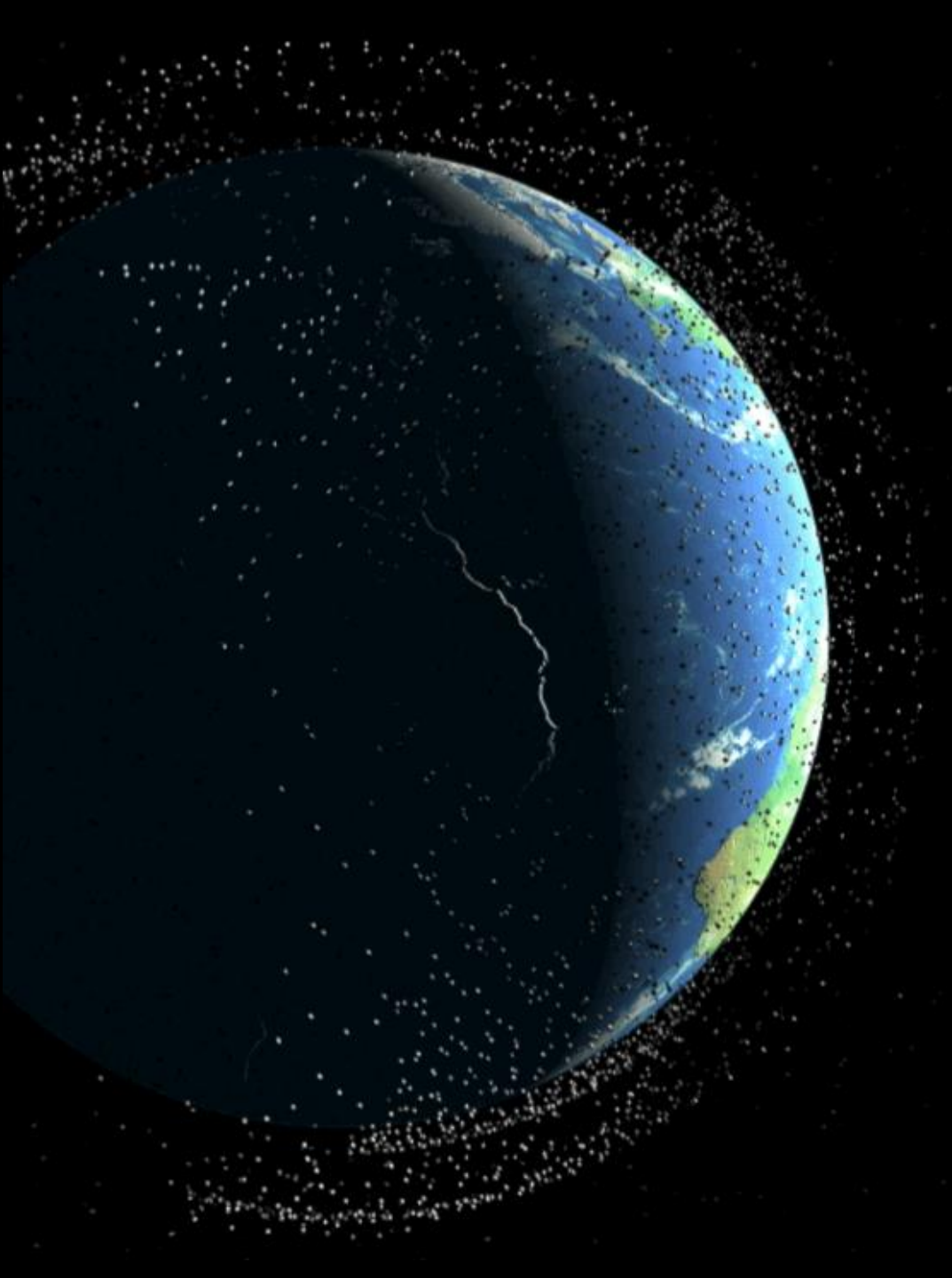

It's a bird? It's a plane? It's CDN!

Investigating Content Delivery Networks in LEO Satellite Networks Era

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Asst. Prof.

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LEO Sat Network Operators (LSNs) == Global ISPs

No longer alternative Internet access → 4.3M+ subscribers from 113 countries

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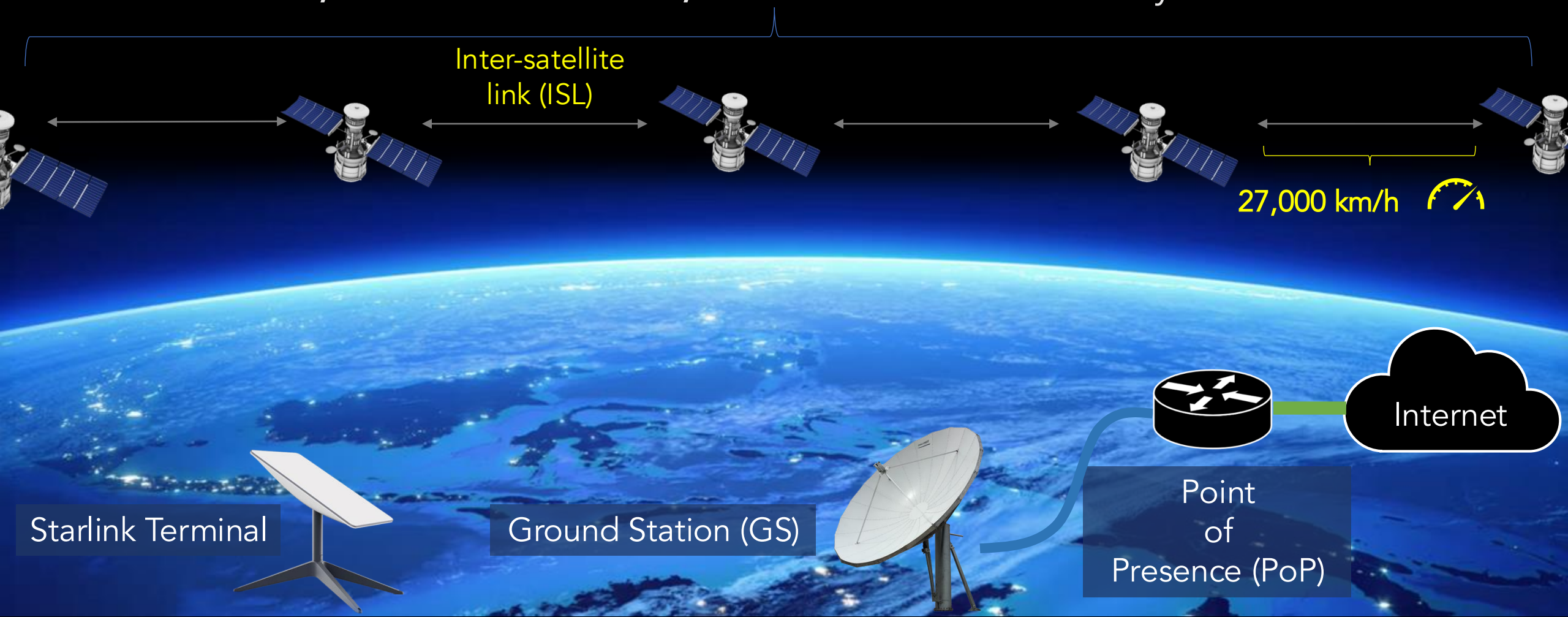

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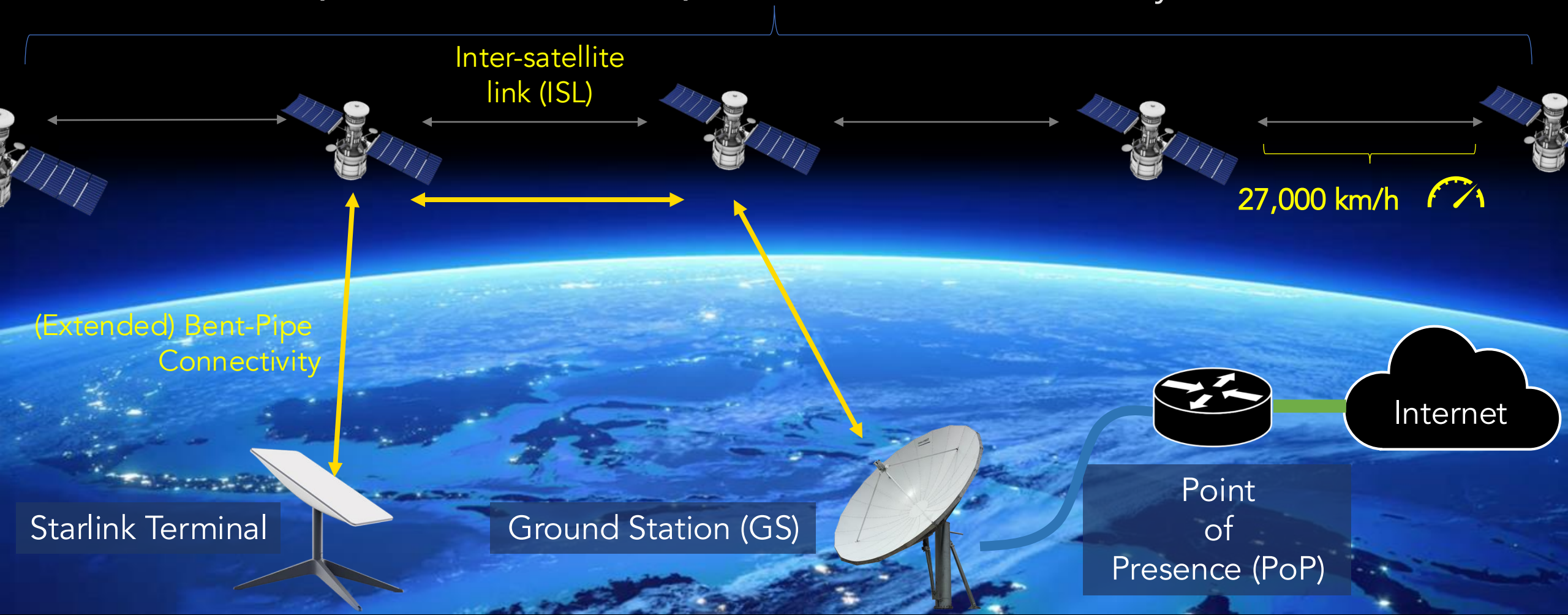

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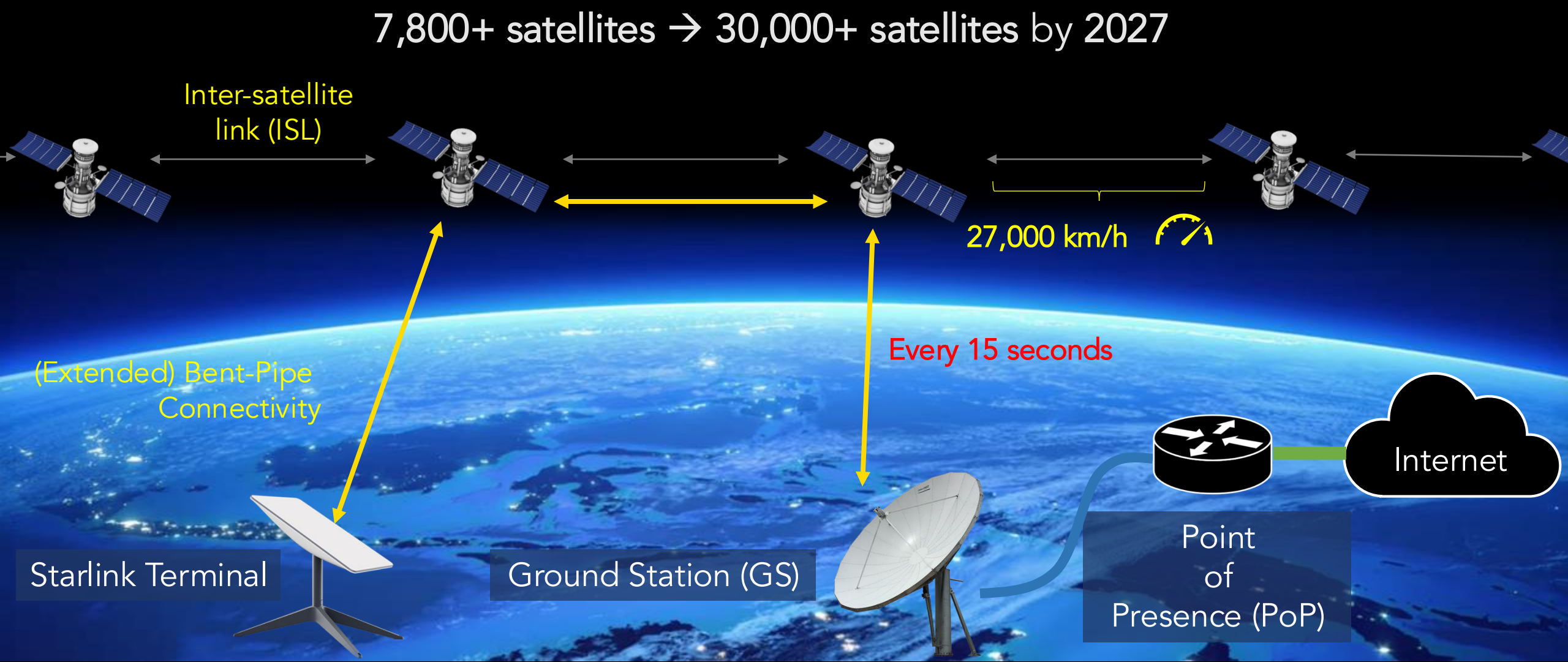

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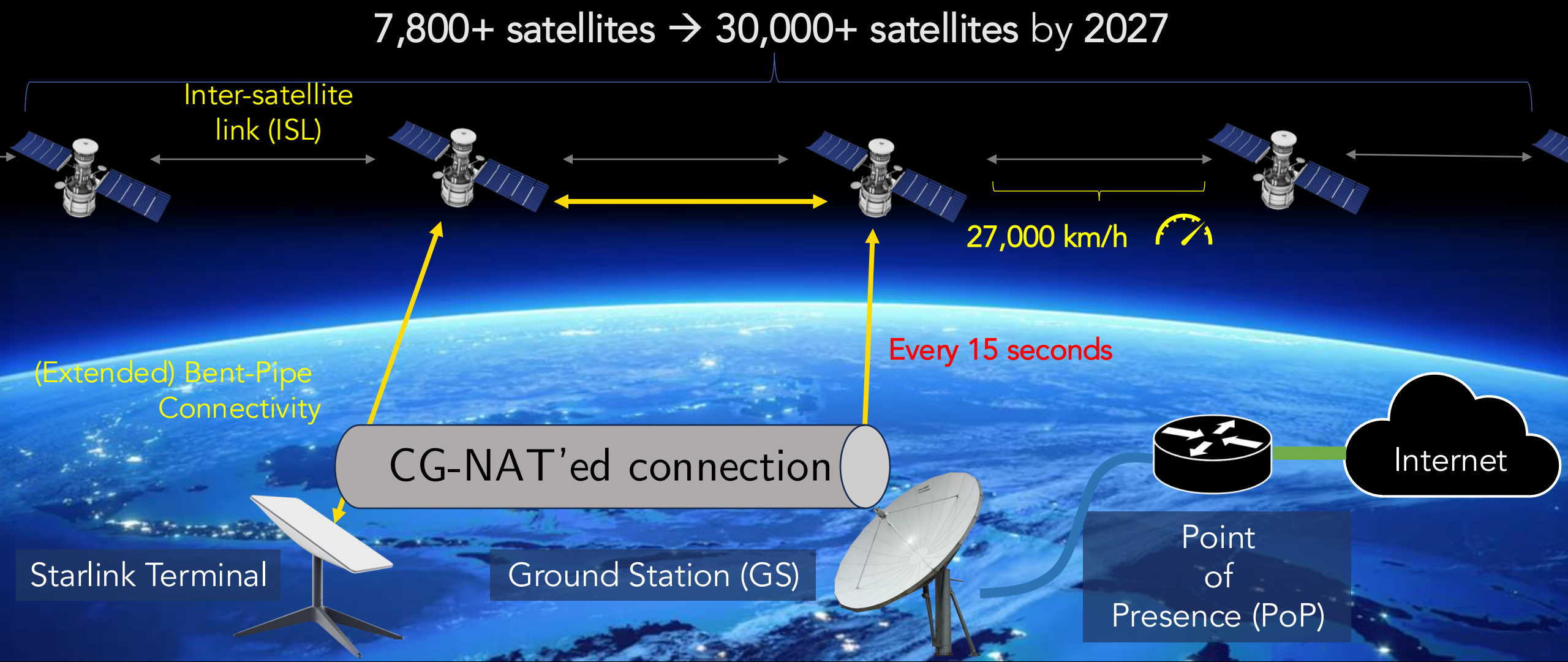
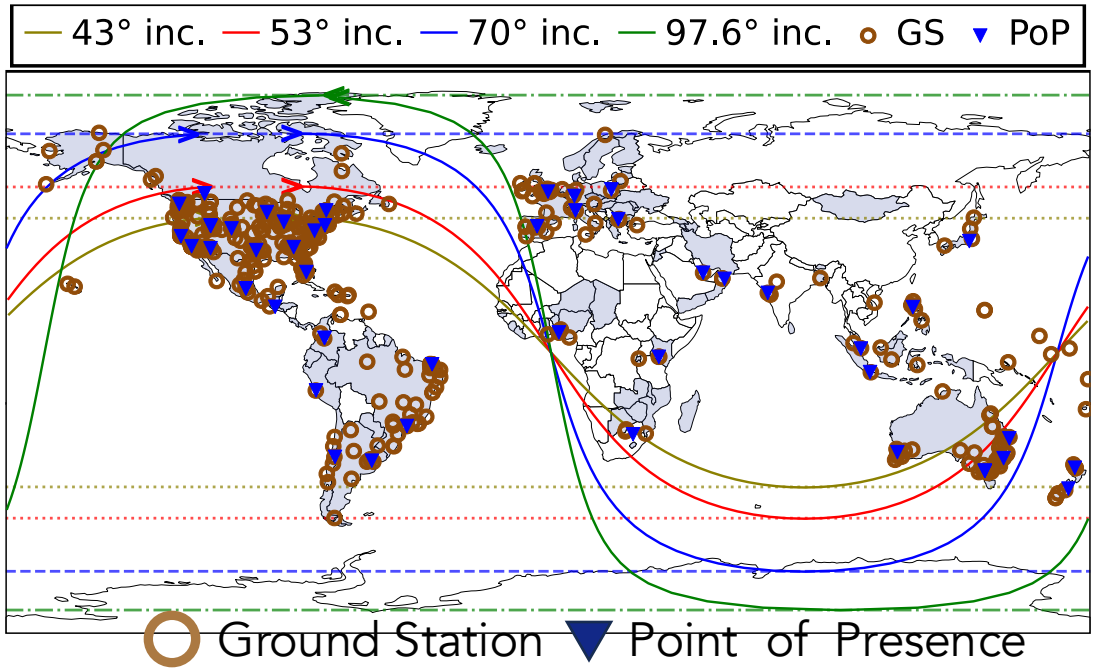
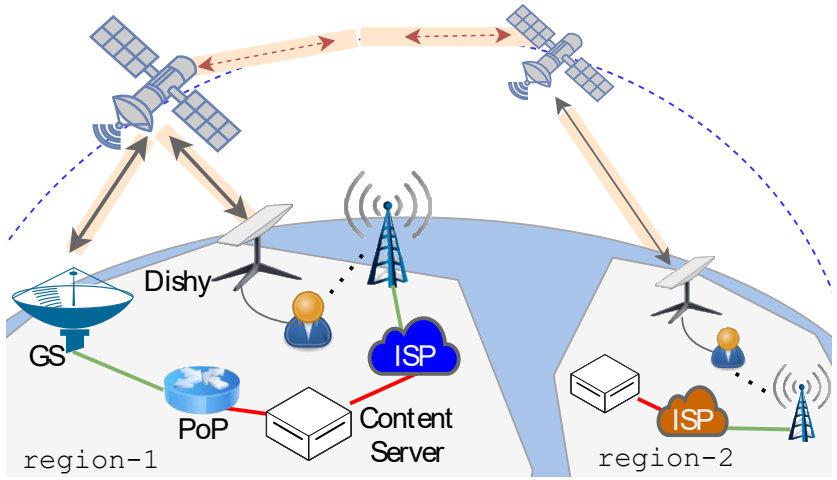


How do CDN services perform over Starlink?

- Majority portion of Internet traffic is handled by CDNs
- Unlike terrestrial networks, geo-location of LSN connections is dependent on PoP instead of user
- Recent research shows that users are mapped to PoPs in different countries and even continents (using ISLs)[1]
- CDNs "estimate" optimal server through geolocation/anycast routing → which may be problematic in LSNs





[1] Mohan et al. 2024. A Multifaceted Look at Starlink Performance. In ACM Web Conference 2024 (WWW '24).

How do CDN services perform over Starlink?

We performed extensive Internet-wide measurements

I. Passive Measurements

- Crowdsourced speedtest measurements to
  - Cloudflare CDNs (Cloudflare AIM)
  - Google datacenters (MLAB)
- 175K+ Starlink measurements from 122 (out of 125) countries and 800K terrestrial ISPs measurements from 196 countries

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- Custom Chromium plugin fetches Tranco top-20 popular websites hosted by Cloudflare and Cloudfront CDNs
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3. **Controlled nodes (especially in Africa)**

How do CDN services perform over Starlink?

We performed extensive Internet-wide measurements

I. Passive Measurements

- Crowdsourced speedtest measurements to
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- 22K+ Starlink measurements from 55 Countries and 800K terrestrial ISPs measurements from 196 countries

II. Active Measurements

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- 5K+ measurements from Starlink (8 countries) and terrestrial (15 countries)

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

ABSTRACT

Content Delivery Networks (CDNs) have been pivotal in the dramatic evolution of the Internet, handling the majority of data traffic for billions of connected users. Low-Earth-Orbit (LEO) satellite networks, such as Starlink, aim to revolutionize global connectivity by providing high-speed, low-latency Internet to remote regions. However, LEO satellite networks (LSNs) face challenges integrating with traditional CDNs, which rely on geographical proximity for efficient content delivery – a method that clashes with the operational dynamics of LSNs. In this paper, we scrutinize the operation of

CCS CONCEPTS

• Networks → Network measurement; Network simulations.

KEYWORDS

Starlink; LEO Satellite networks; CDN measurements; Internet Measurements

ACM Reference Format:

Rohan Bose, Saeed Fadaei, Nitinder Mohan, Mohamed Kassem, Nishanth Sastry, and Jörg Ott. 2024. It's a bird? It's a plane? It's CDN!: Investigating Content Delivery Networks in the LEO Satellite

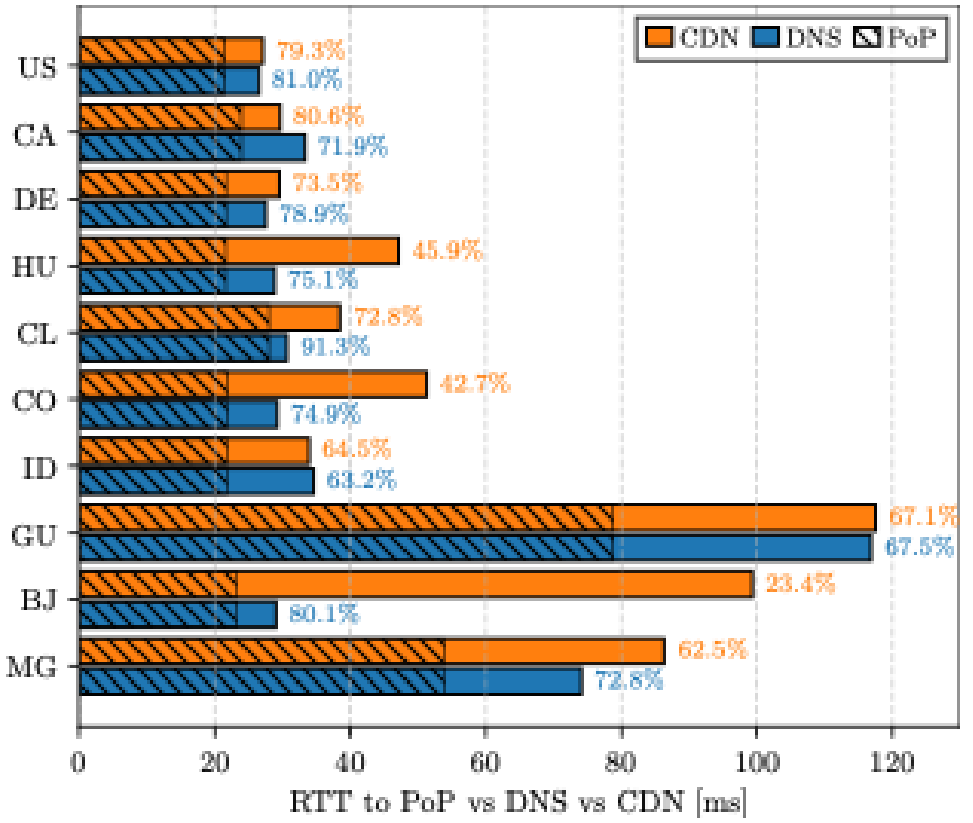
It's a bird? It's a plane? It's CDN!: Investigating Content Delivery Networks in the LEO Satellite Networks Era.
Rohan Bose, Saeed Fadaei, Nitinder Mohan, Mohamed Kassem, Nishanth Sastry, and Jörg Ott.

In ACM HotNets 2024

+ more results

User-to-Content Performance

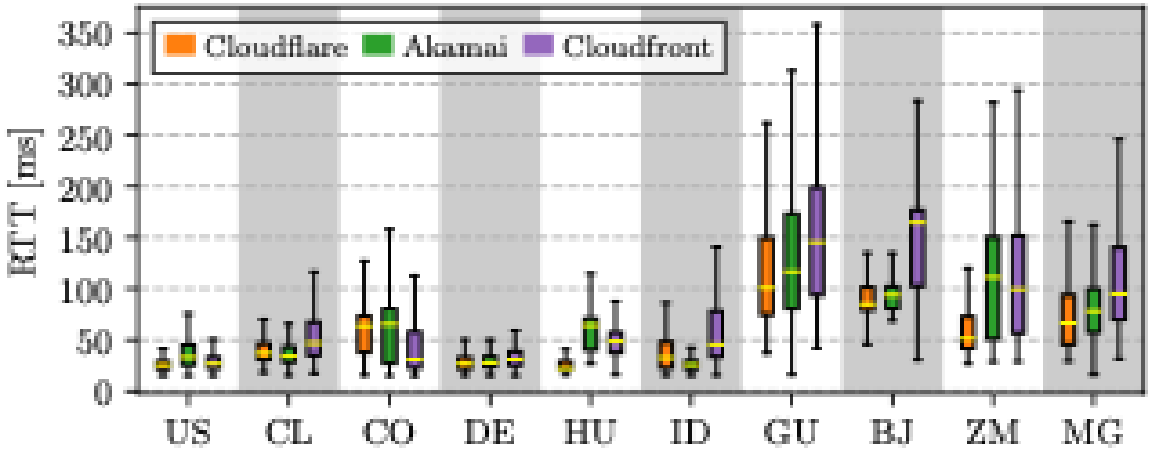
- Latency-to-DNS/CDN dominated by latency-to-PoP in regions with mature Starlink ground infrastructure (US,CA,DE,CL)
- **Low latency-to-PoP ≠ Low latency-to-DNS ≠ Low latency-to-CDN** (HU,CO,ID,BJ) likely due to less developed terrestrial infrastructure
- Higher Latency-to-PoP (GU,MG) can drive latency-to-CDN/DNS to **> 100 ms**



CDN Provider Showdown

Latencies to CDN server

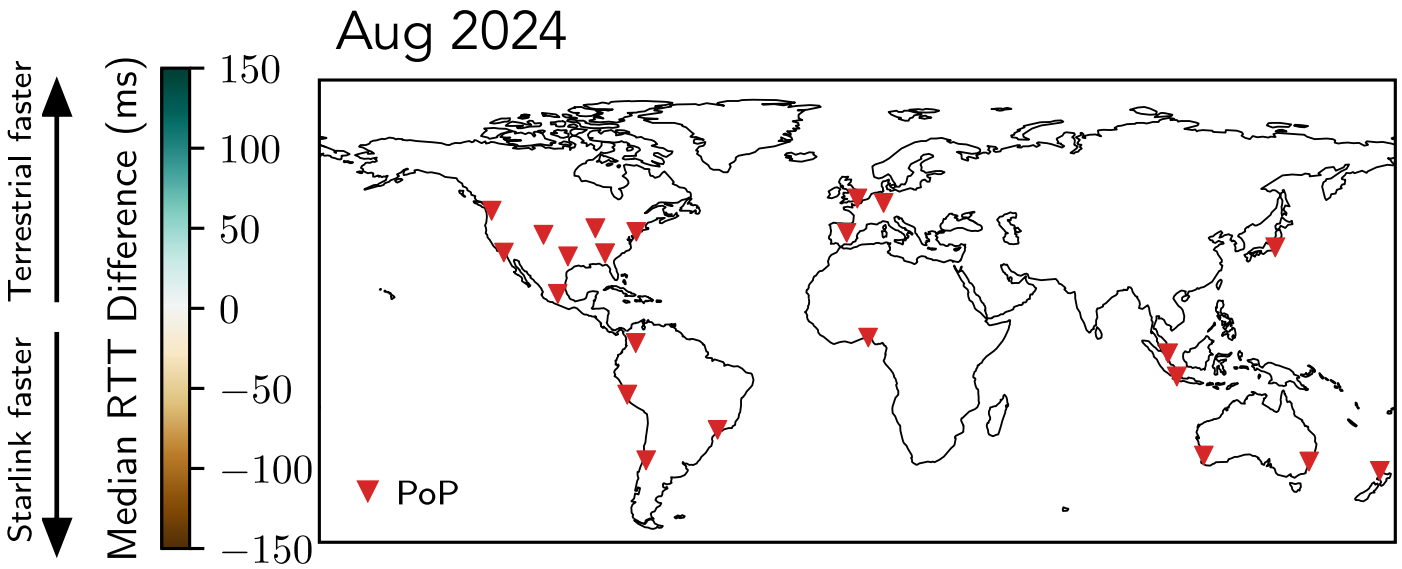
- Latency to different CDN providers (**< 50 ms**) mostly similar where Starlink PoPs are located in well-peered regions (US,CL,DE)
- Starlink to Cloudflare CDN (anycast) exhibit the lowest latencies – CDN servers mostly colocated with Starlink PoPs in well-peered locations

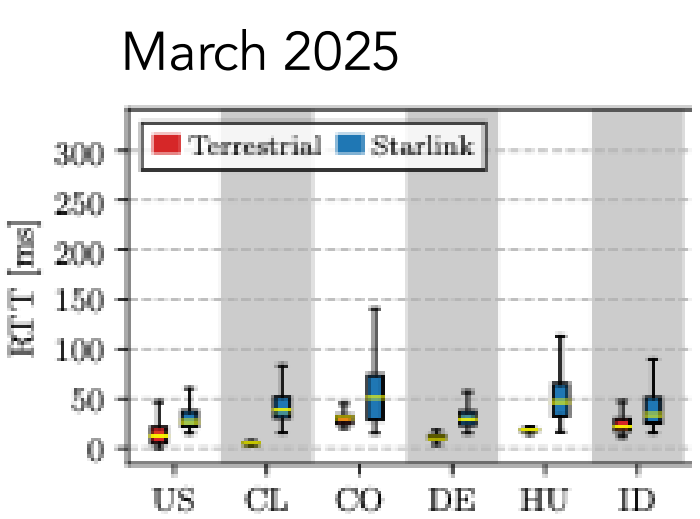


- Akamai CDN (DNS-based) latencies often higher likely due to DNS resolver mis-localization
- Cloudfront CDN latencies are the highest – due to lower global footprint
- Significantly higher CDN latencies for countries in Africa

CDN Performance

Starlink vs Terrestrial



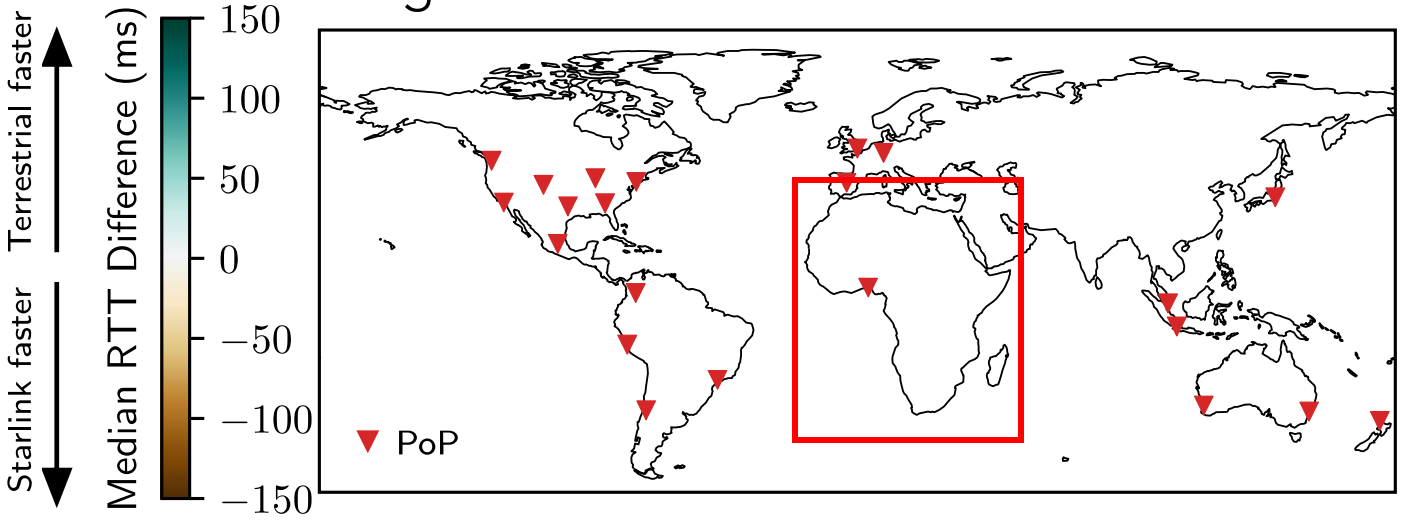


- Terrestrial connections almost always achieve lower latencies to CDNs
  - Terrestrial user to CDN ≅ **19-20 ms** (median)
  - Starlink user to CDN ≅ **50 ms** (median)

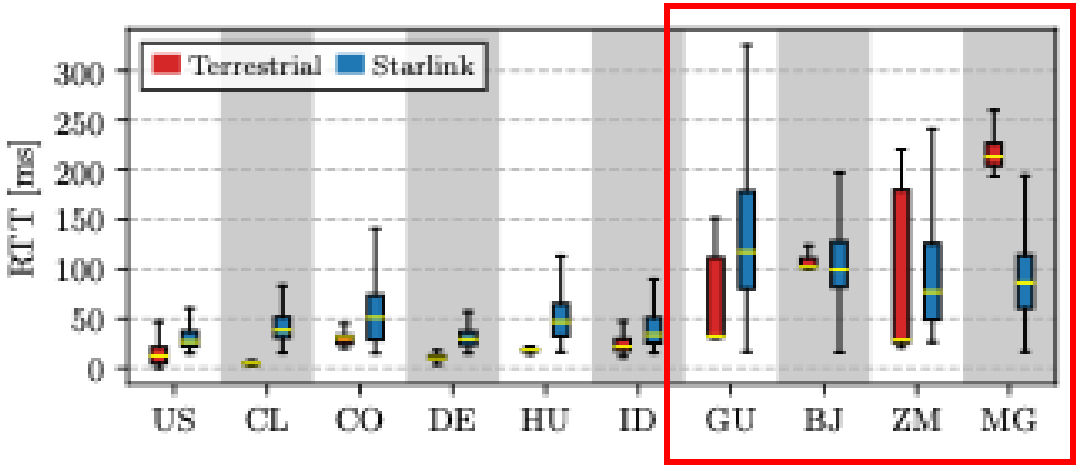
CDN Performance

Starlink vs Terrestrial

Aug 2024



March 2025

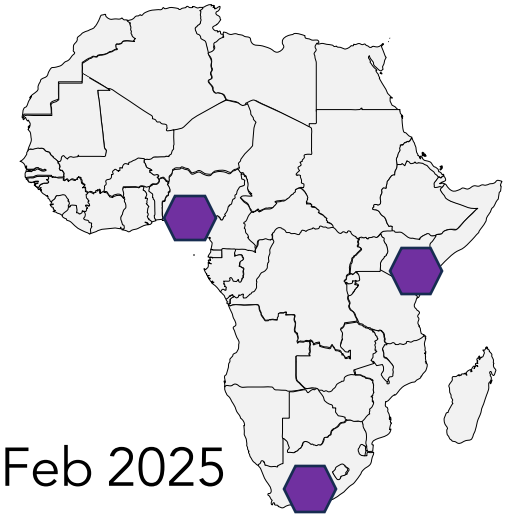


- Terrestrial connections almost always achieve lower latencies to CDNs
  - Terrestrial user to CDN ≅ **19-20 ms** (median)
  - Starlink user to CDN ≅ **50 ms** (median)
- Starlink outperforms terrestrial connections in Madagascar (MG) by ≅**120 ms** and Benin (BJ) by ≅ **10 ms**
  - This wasn't the case 6 months ago when terrestrial was significantly better than Starlink in AF

CDN Performance

Infrastructure Evolution

Aug 2024



Feb 2025

Several new PoPs and GS deployments in Africa that started becoming active starting Jan 2025

CDN Performance

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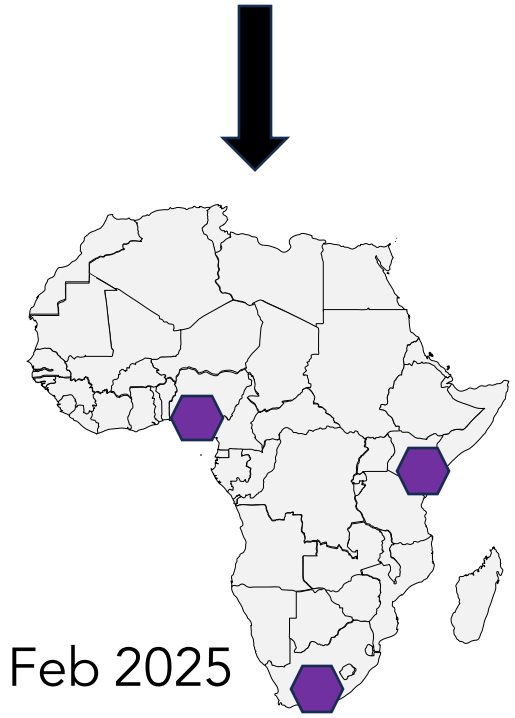

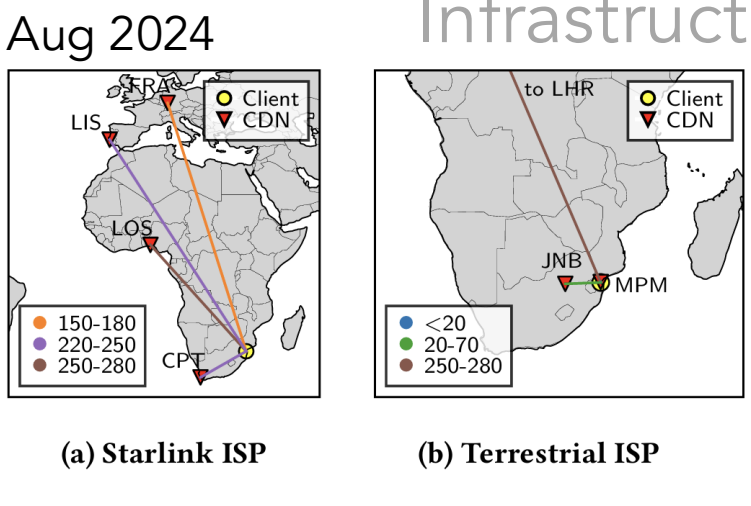

(a) Starlink ISP

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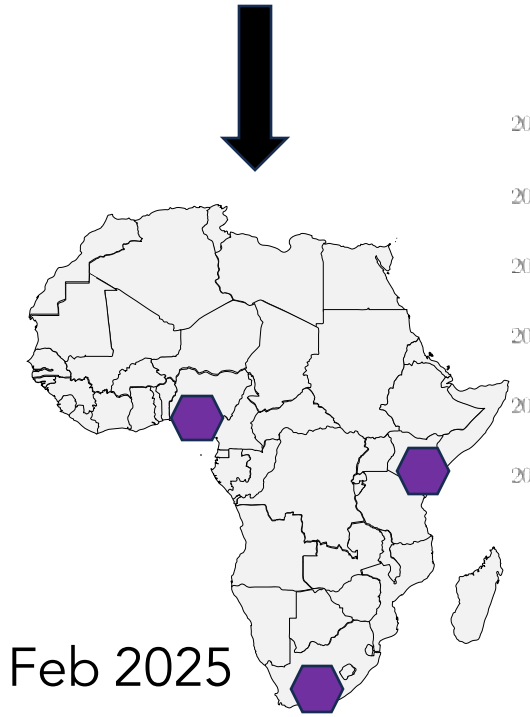

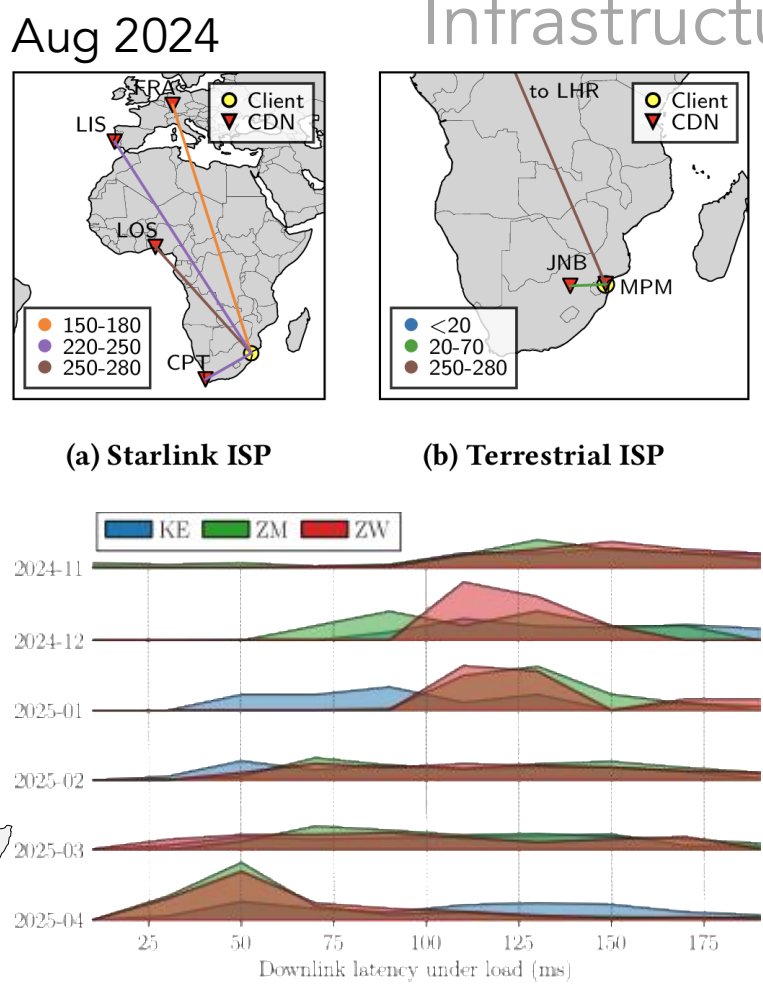

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CDN Performance

Infrastructure Evolution

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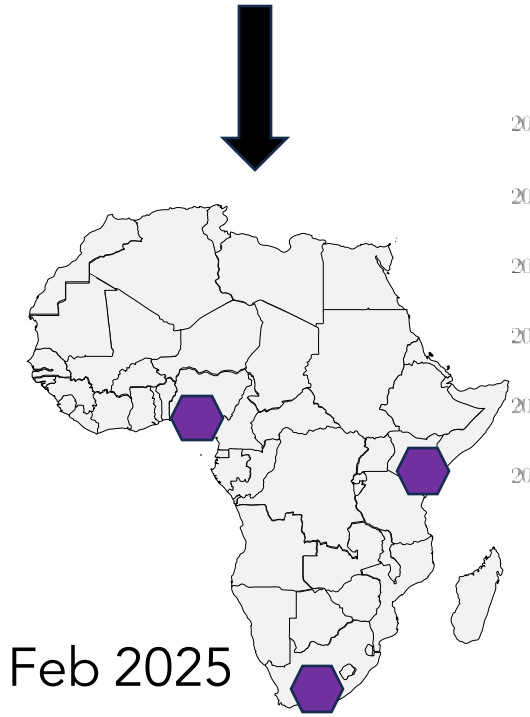

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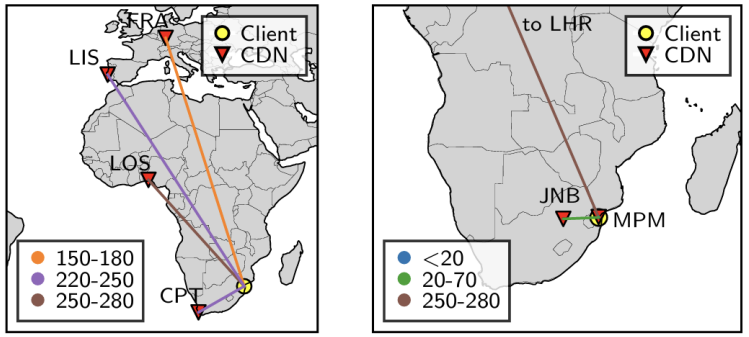

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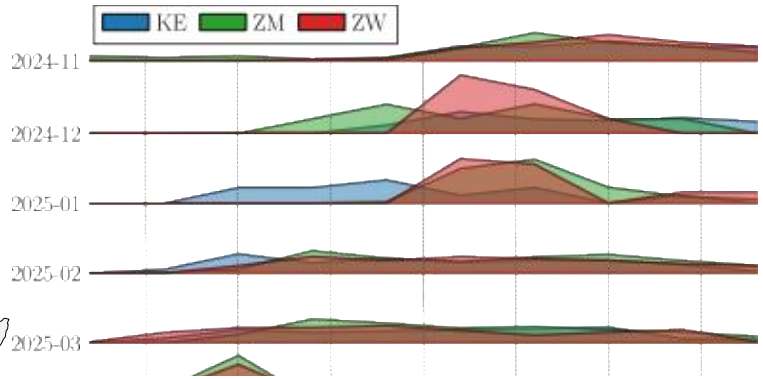

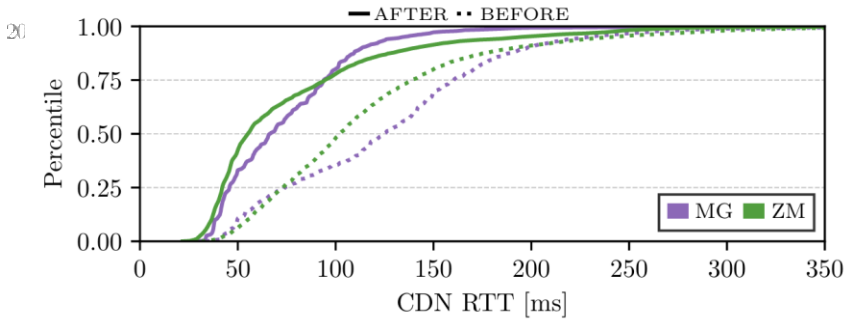

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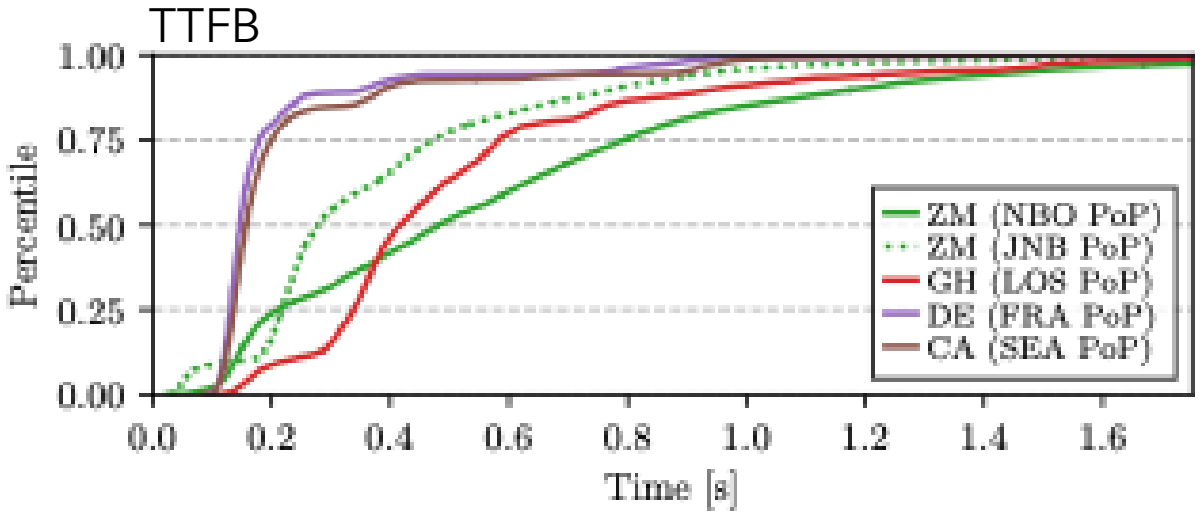
  - DL loaded latencies reduced by almost 3x (≅ 50 – 60 ms)

CDN Performance

Infrastructure Evolution



- Median TTFBs are much lower for Starlink users in DE and CA ≅ **120 -150 ms**
- Median TTFBs for users in GH and ZM ≅ **400 – 500 ms**
- After PoP reassignment for ZM users from Nairobi to Johannesburg, median TTFBs reduce by **2x**

CDN Performance

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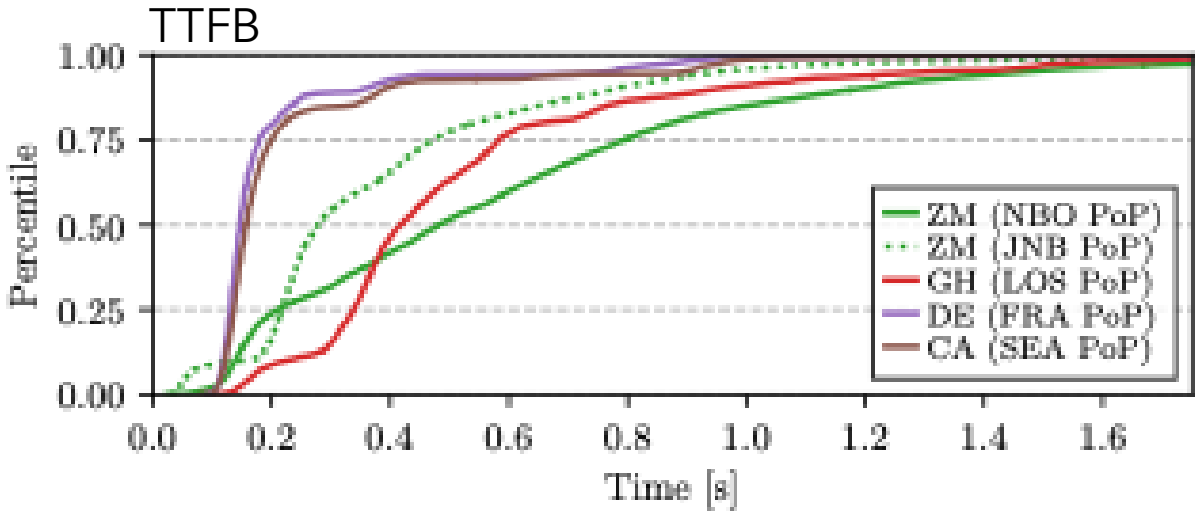

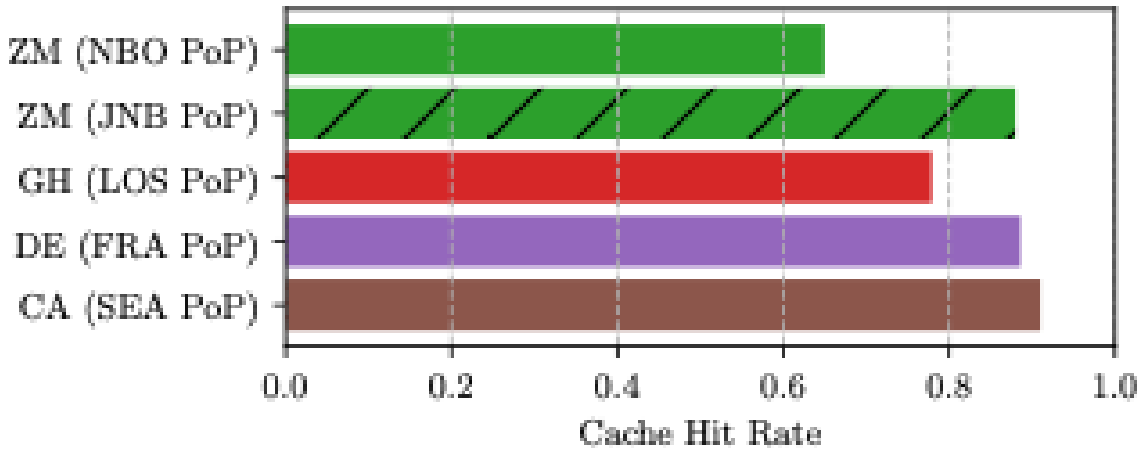

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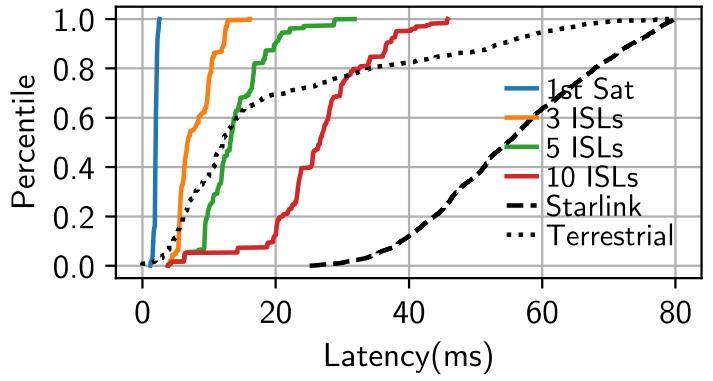
- Also significant improvement in cache hit rates, rivaling EU performance

Content Delivery over LEO is an Open Problem

- Internet is designed for terrestrial subscribers, and we need to find the right way on how we can incorporate LEO Internet users
- PoP availability near users is essential for ensuring good performance
- However, having high PoPs also defeats the purpose of LEO satellite networks and their capabilities to interconnect vast regions through ISLs
- The concept of "edge" requires a grounds-up rethinking
  - SpaceCDN?



Nitinder Mohan

n.mohan@tudelft.nl www.nitindermohan.com

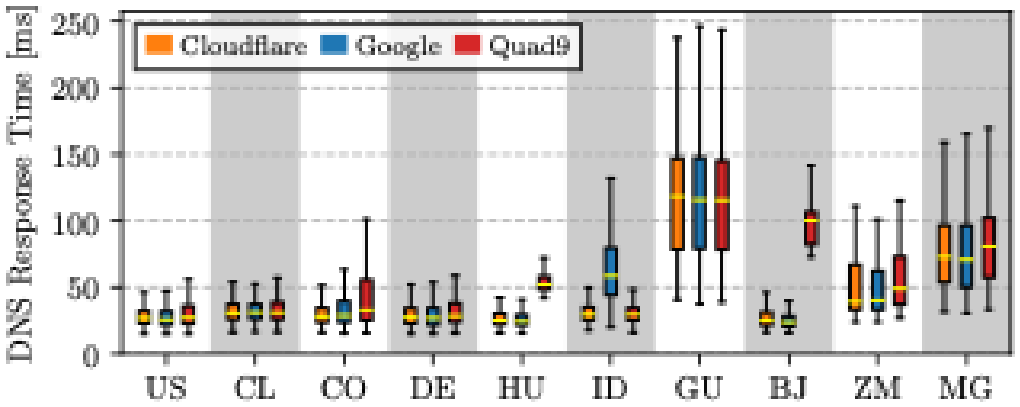
Backup slides

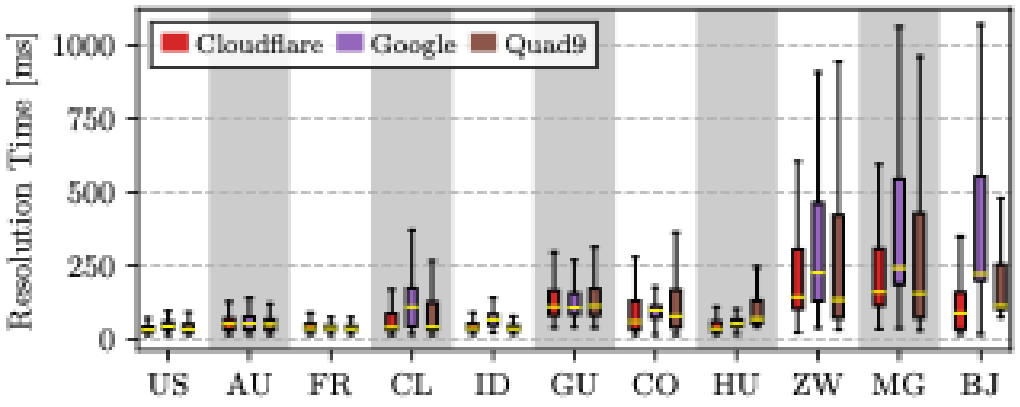
Target Website Domains and Coverage

CDN	Platform	Domains
Cloudflare	RIPE Atlas + Controlled Nodes	www.broadcom.com, www.comodoca.com, www.epicgames.com, www.apnic.net, www.riskified.com, www.wiley.com, www.vmware.com, www.sportskeeda.com, www.garmin.com, www.fao.org, www.n-able.com, www.linkedin.com
	Controlled Nodes	www.roku.com, www.sourceforge.net, www.namecheap.com, www.openai.com, www.cpanel.net, www.zendesk.com, www.17track.net, www.quora.com, www.temu.com, www.constantcontact.com, www.fanfiction.net, www.fao.org, www.matterport.com, www.techtarget.com
Akamai	RIPE Atlas + Controlled Nodes	www.microsoft.com, www.apple.com, www.bing.com, www.icloud.com, www.intuit.com, www.unity3d.com, www.samsung.com, www.ebay.com, www.webex.com, www.cisco.com
CloudFront	RIPE Atlas + Controlled Nodes	www.soundcloud.com, www.zynga.com, www.doi.org, www.booking.com, www.brave.com, www.tycsports.com, www.logitech.com, www.checkpoint.com, www.goodreads.com, www.surveymonkey.com

DNS Performance

DNS Provider Showdown

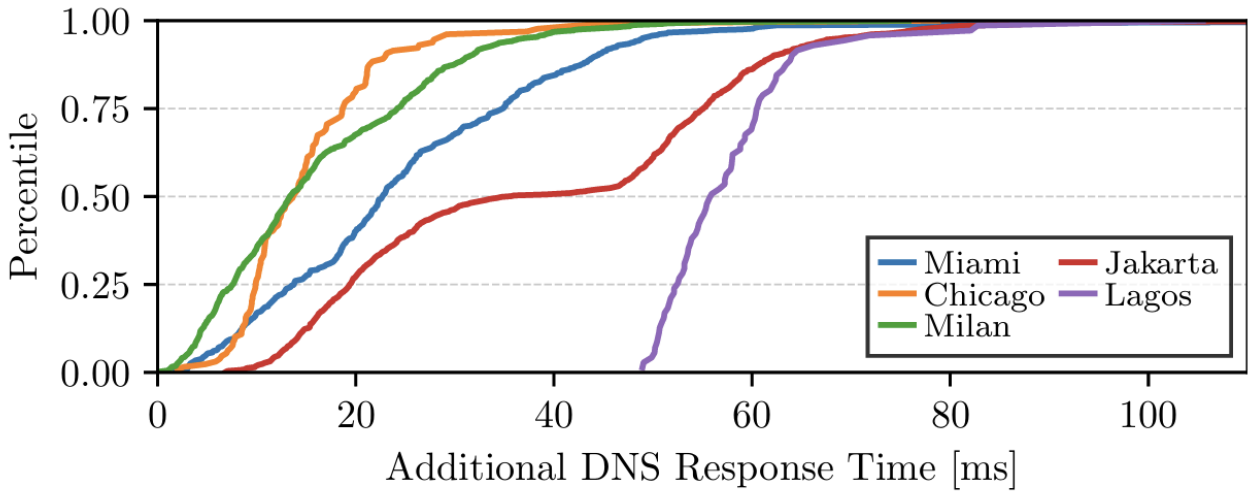




- Cloudflare and Google DNS resolvers provide lowest median latencies ≅ **45 ms**
- Starlink users assigned to PoPs located in immature terrestrial infrastructure may experience higher DNS latencies
  - Indonesia → Google (Singapore DNS resolver) > **50 ms**
  - Hungary → Quad9 (Frankfurt DNS resolver) > **50 ms**
  - Benin → Quad9 (Paris DNS resolver) > **100ms**
- Resolution times are significantly higher in AF, likely due to cache-misses in DNS resolvers

Latency to DNS Resolvers

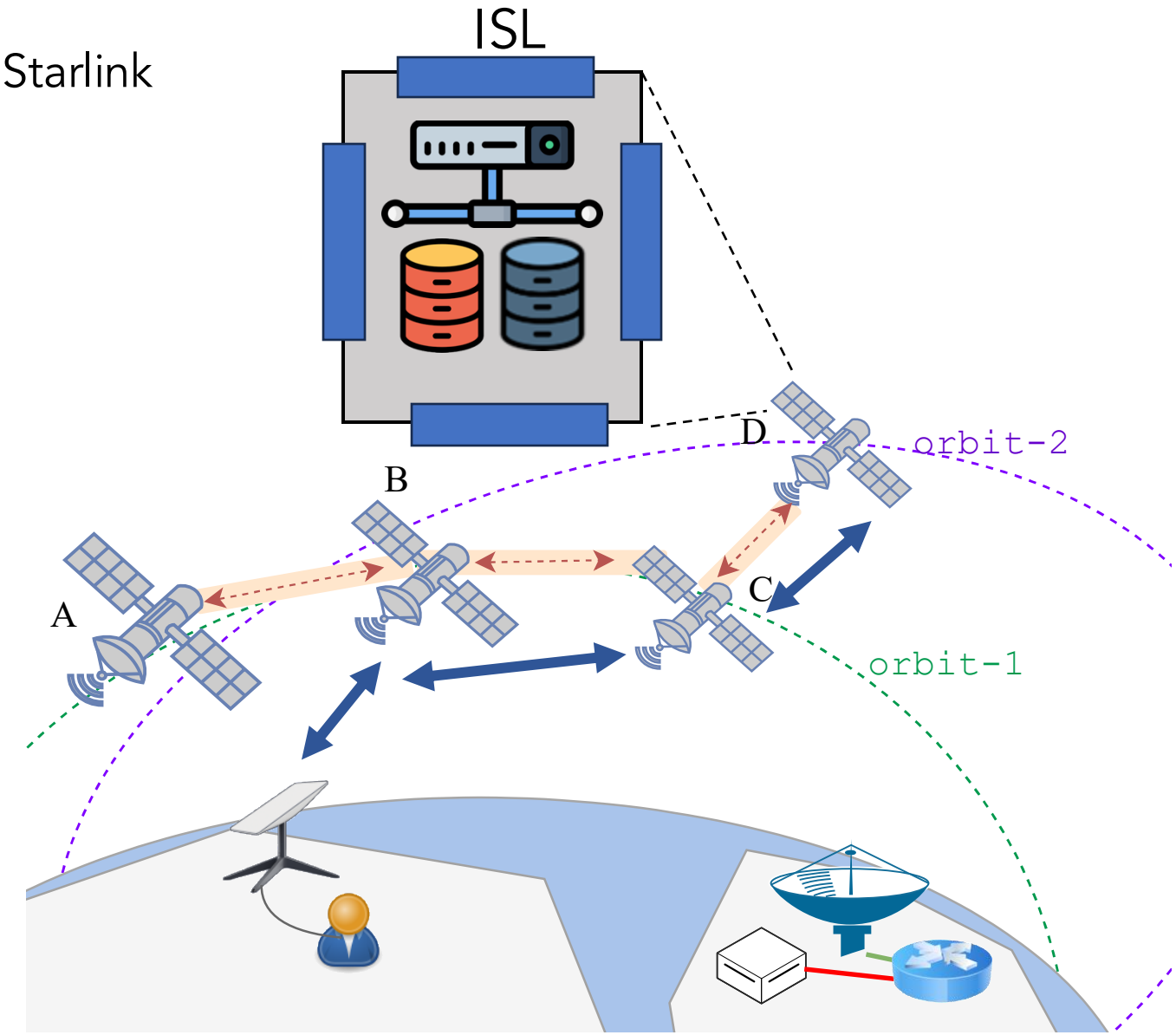
DNS response time = Latency UE-to-PoP + **Latency PoP-to-DNS resolver**



Satellites + CDNs: A Match Made in Space

- Install CDN caches in satellites
  - Total capacity can be around 900 PB in Starlink

- Content can be retrieved in:
  1. (At best) a few ISL hops



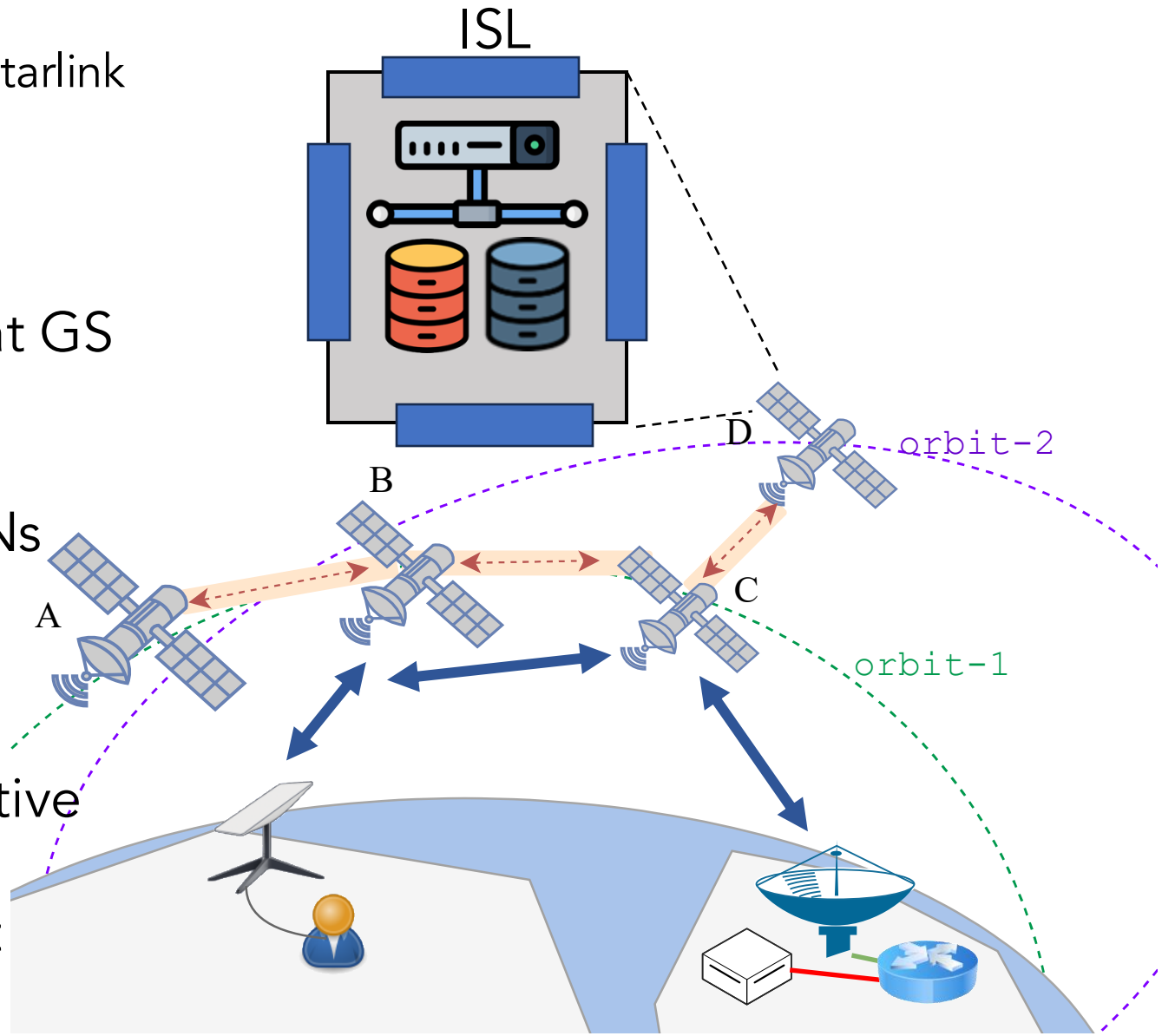
SpaceCDNs: A Match Made in Space

- Install CDN caches in satellites
  - Total capacity can be around 900 PB in Starlink

- Content can be retrieved in:
  1. (At best) a few ISL hops
  2. (At worst) from terrestrial server at GS

- In addition to serving regular CDN content, you can also use SpaceCDNs to store critical content, e.g. BGP tables

- Satellites movement is highly predictive which can be leveraged with "*content striping*" – storing different chunks of content on satellite train



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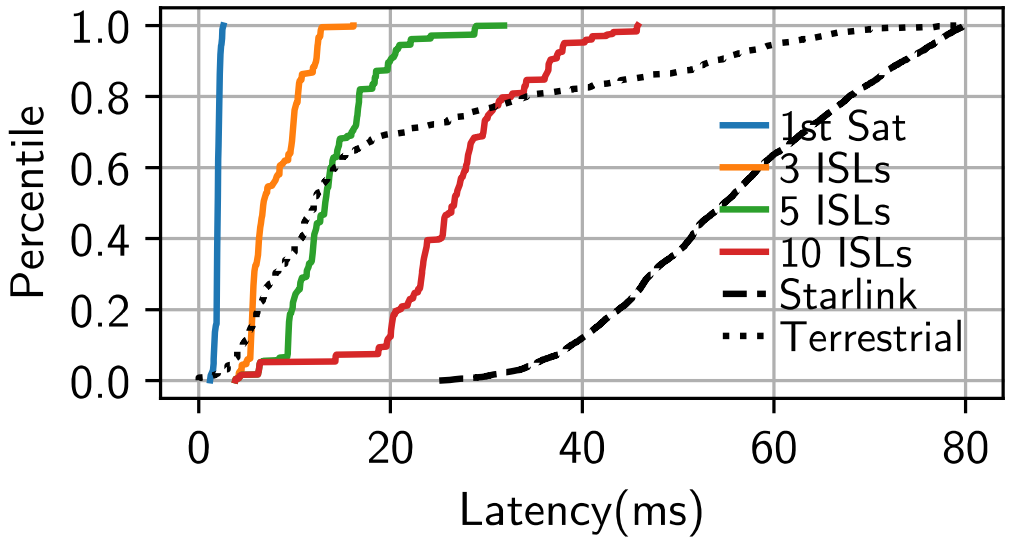

[1] Kassem M. & Sastry N.. xeoverse: A Real-time Simulation Platform for Large LEO Satellite Mega Constellations. IFIP Networking 2024.

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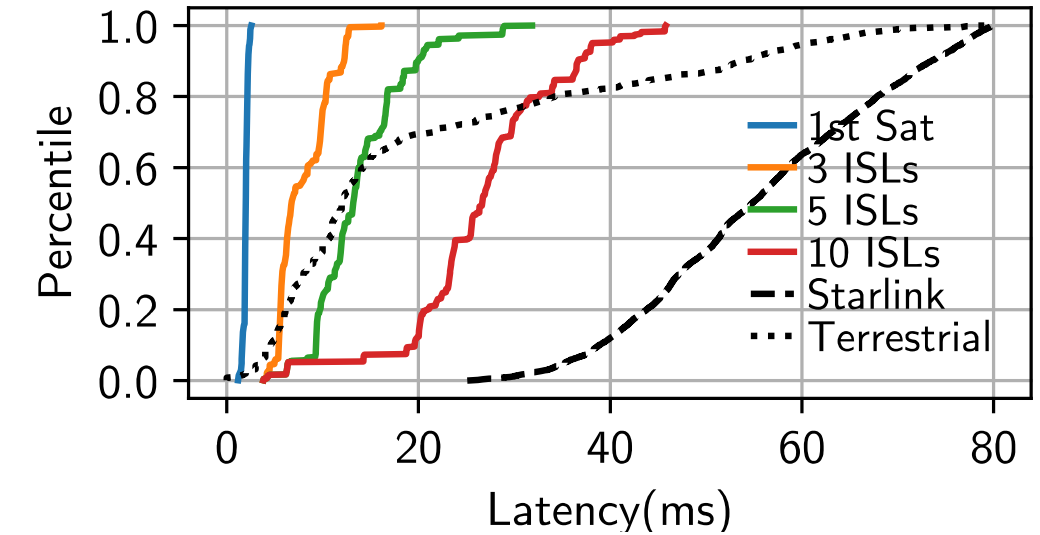
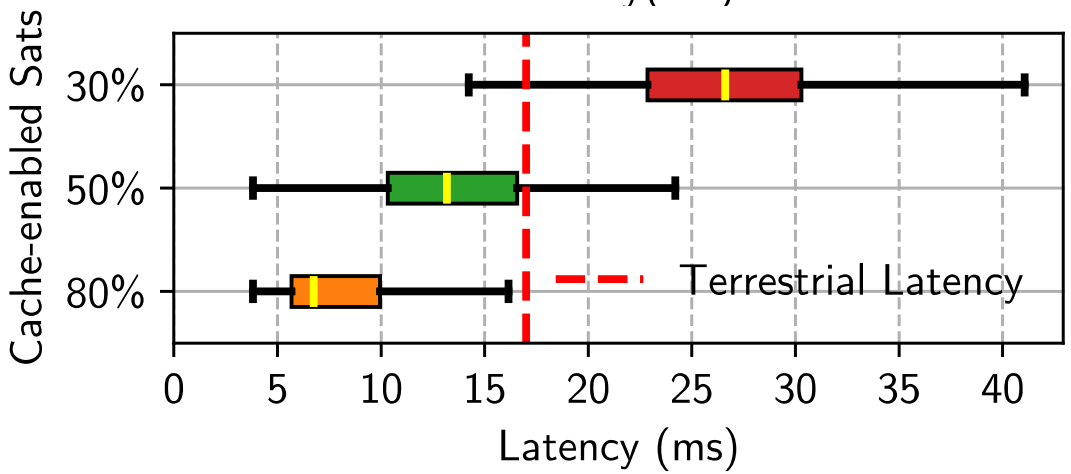
- Even fetching within 10 ISLs, the performance is better than the terrestrial long tail due to under-served regions
- Aggressive power management with active duty cycling
  - SpaceCDNs are still competitive with terrestrial if on 50% of fleet is active





[1] Kassem M. & Sastry N.. xeoverse: A Real-time Simulation Platform for Large LEO Satellite Mega Constellations. IFIP Networking 2024.