Pulse Research Week ‘25

On Centralization of IP Layer

Country-Level Consolidation of IP Addresses

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Why studying Centralization is important?

- Multiple layers of the Internet are increasingly getting centralized
- Higher centralization
  - ➡Internet disruptions, single points of failure
  - ➡Easier implementation of censorship, security measures
  - ➡Directly impacts Internet Resilience
- Prior work: DNS, Web infrastructure, Hosting Providers
- **IP layer?**

Why should we study the IP layer?

Identify organizations responsible for critical operations:

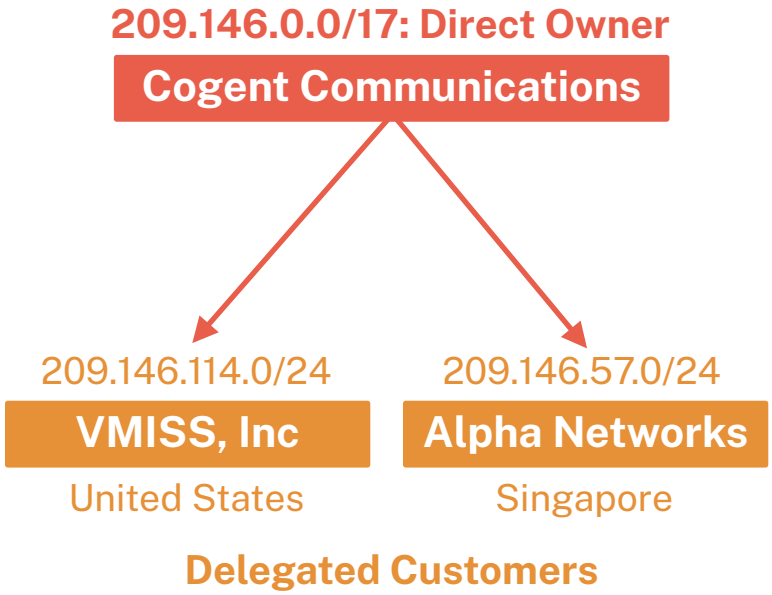
- Connectivity [Resilience]
- Sub-allocation of addresses [Fair Access]
- Routing security measures [Security]
- Deploying services, responsible for traffic [Utilization, Availability]

Datasets

Prefix2Org (ACM IMC ‘25):

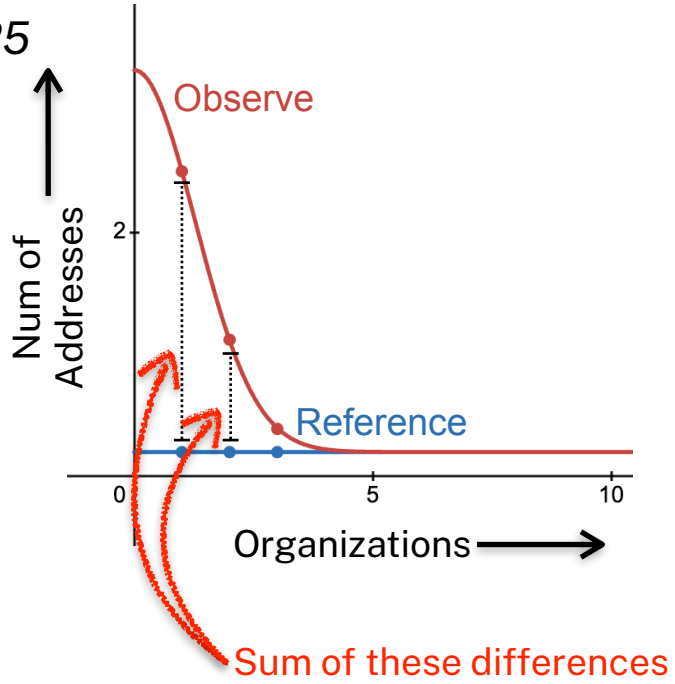
- Authoritative Organization:
  - Connectivity
  - Further allocations
  - Routing security measures
- End-user Organization:
  - Deploying services
  - Traffic

Geolocation: IPinfo (Country-level)



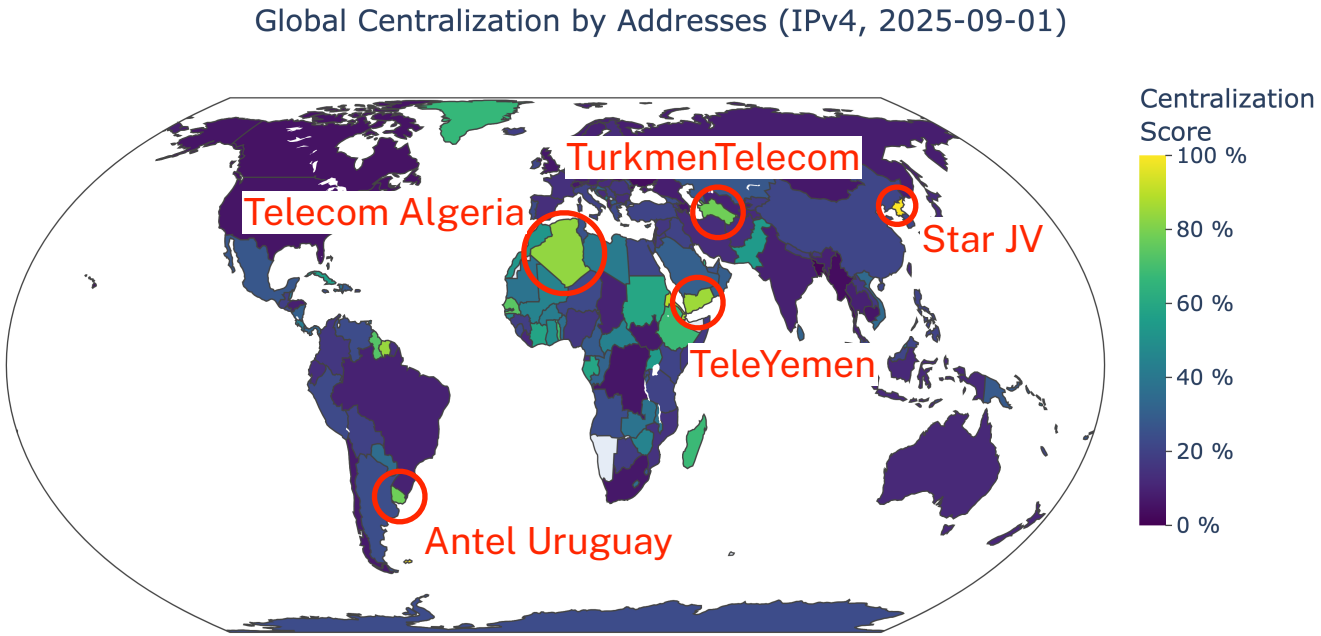
Centralization Metric

- Centralization metric defined in *"Formalizing Dependence of Web Infrastructure", SIGCOMM 2025*
- Effort required to convert an observed distribution → truly decentralized distribution
- Mathematically, similar to Herfindahl–Hirschman index (HHI)
- **Lower Score ⇒ Better!**



Results

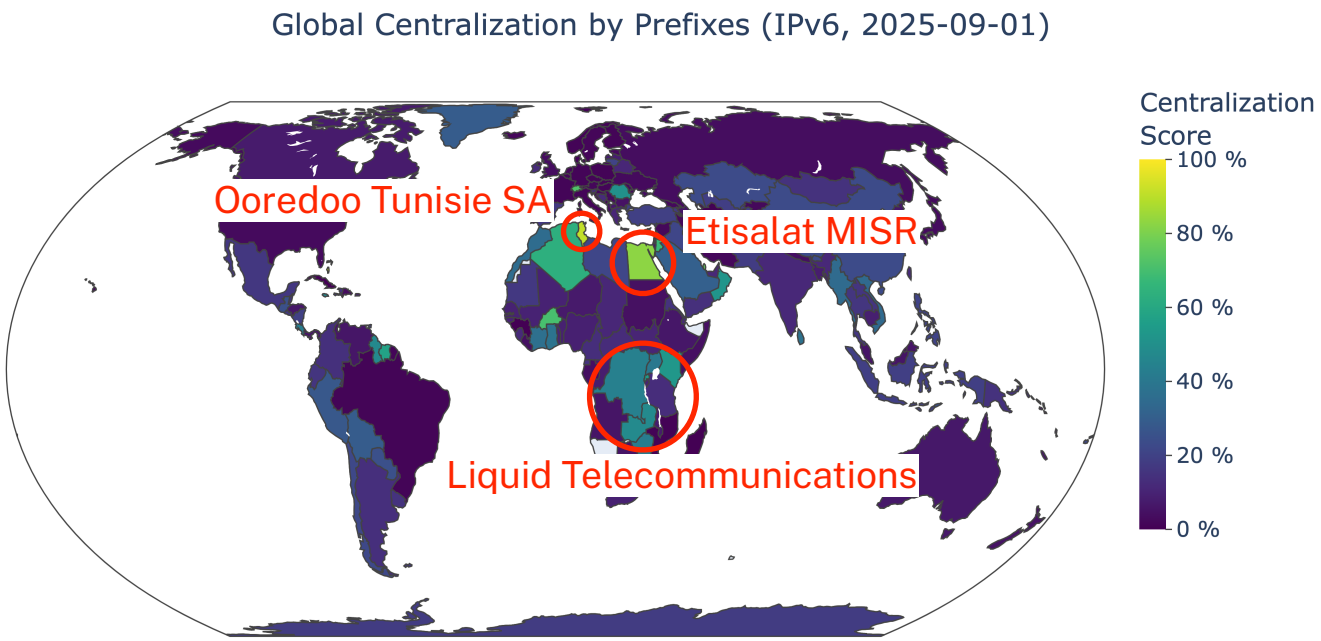
Country-Level Centralization (IPv4)



State-owned telecom providers

In some cases, only one licensed provider!

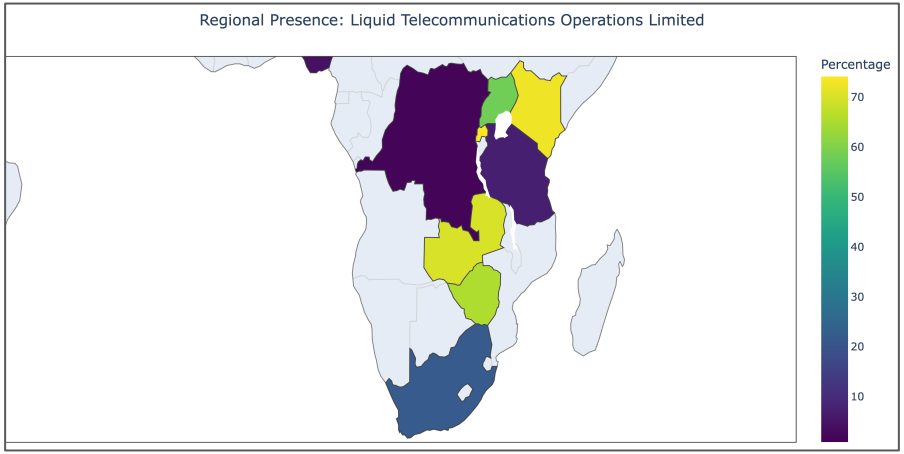
Country-Level Centralization (IPv6)



Not state-owned providers!

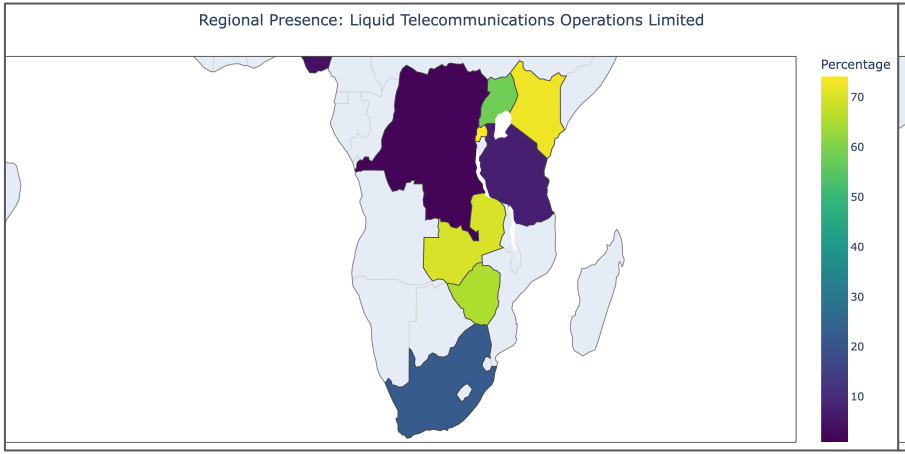
Private organizations with multi-national presence

Organizational Footprint - Regional (IPv6)

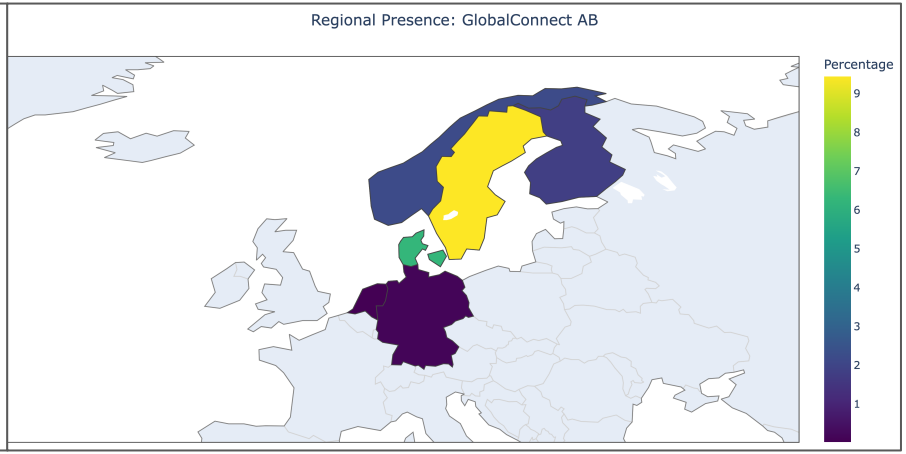


Liquid Telecommunications

Organizational Footprint - Regional (IPv6)

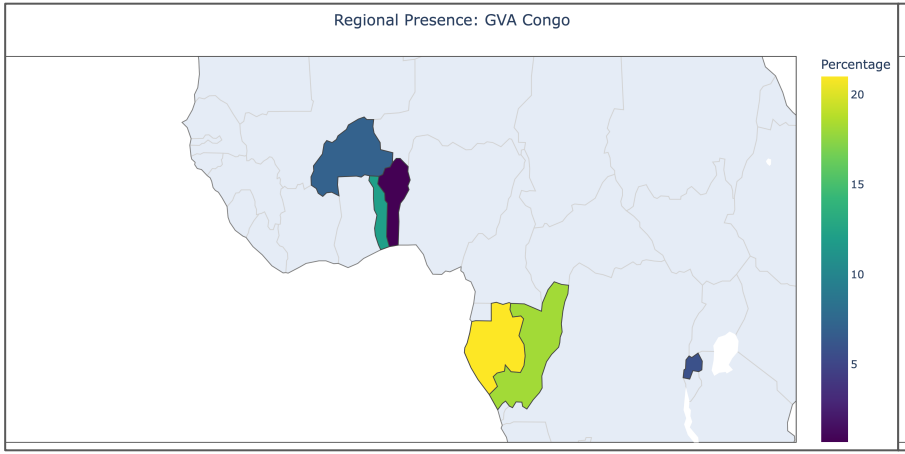


Liquid Telecommunications

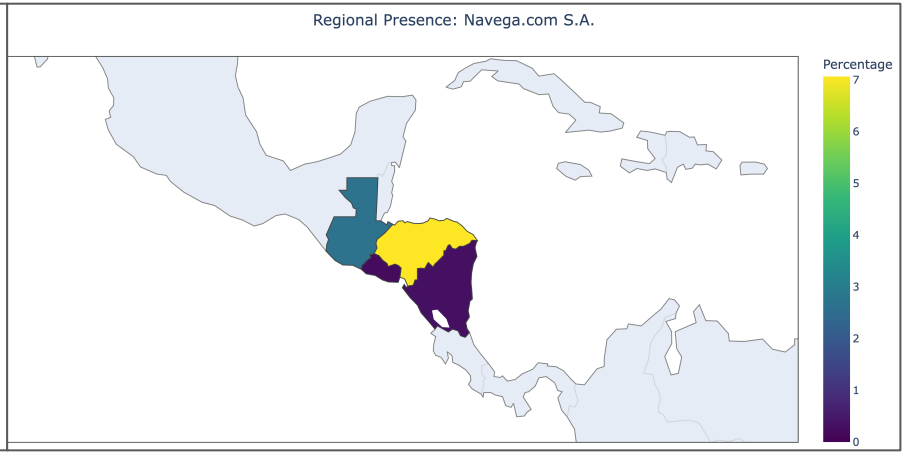


Global Connect AB

Organizational Footprint - Regional (IPv4)

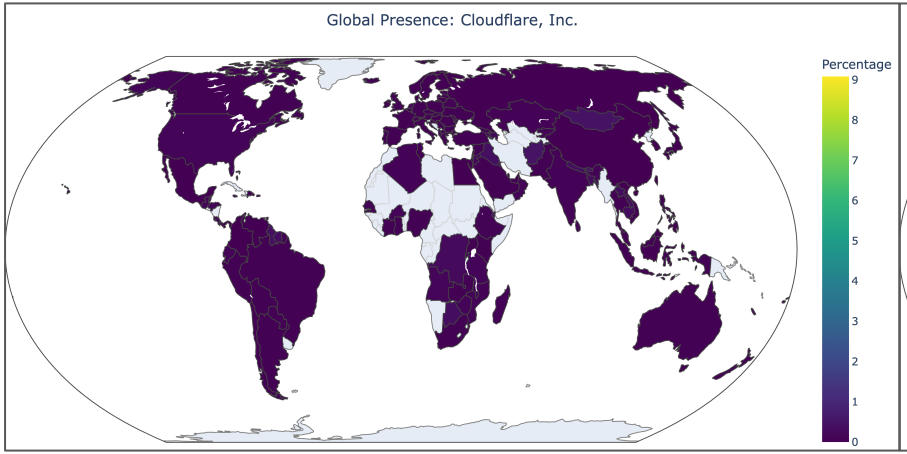


GVA Congo

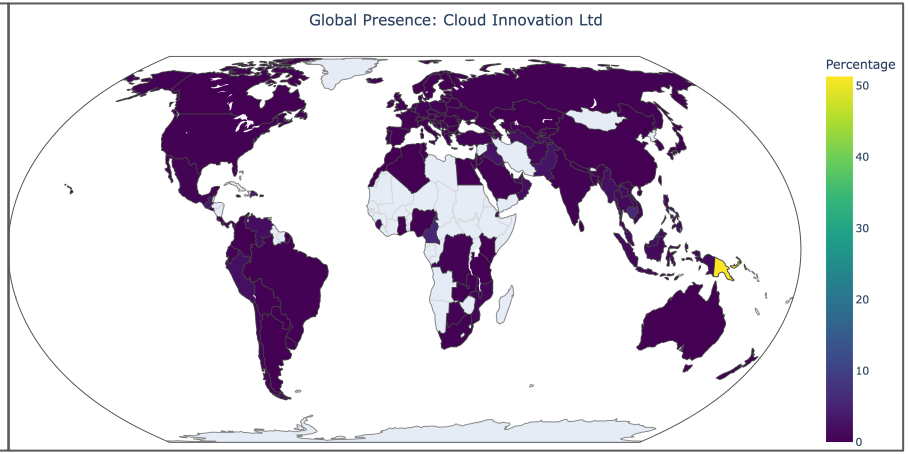


Navega.com SA

Organizational Footprint - Global



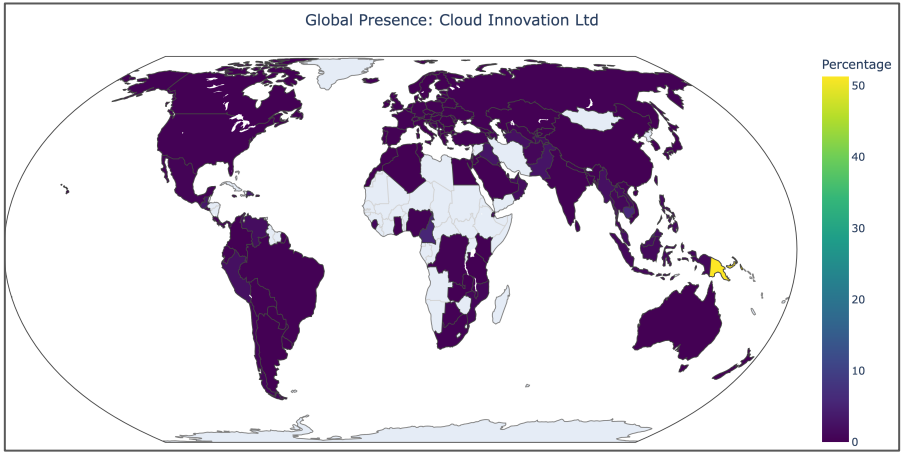
Cloudflare, Inc.
(139 countries)



Cloud Innovation Ltd
(123 countries)

Organizational Footprint - Cloud Innovation Ltd

- 10.6K IPv4 prefixes
- ~100% from AFRINIC
- Operationally:
  - Geolocated in 123 countries
  - Reallocated to ~400 customers
  - BGP Origin → 479 ASNs
- None of these ASNs are managed by Cloud Innovation!

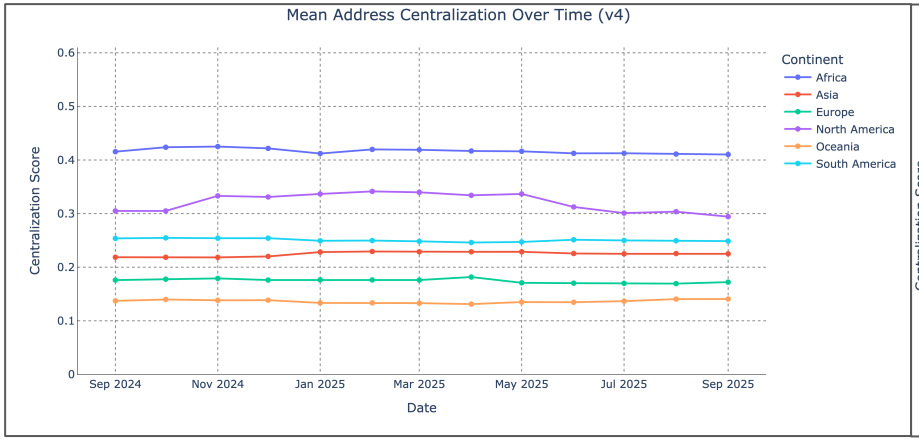


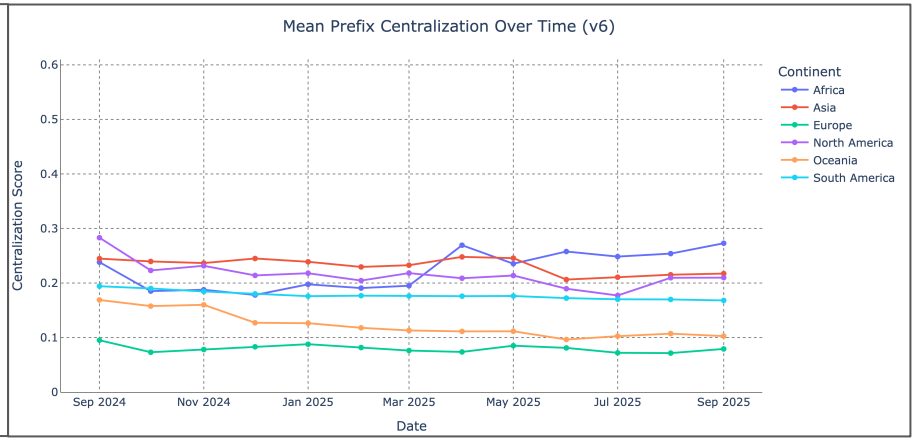
Cloud Innovation Ltd

- Does not appear in BGP, DNS, Hosting Provider studies

Centralization Trends over Time

Longitudinal Trend

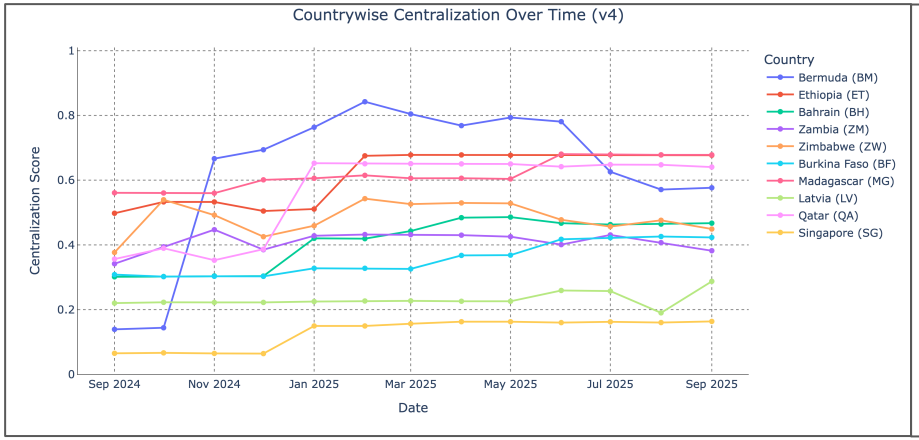


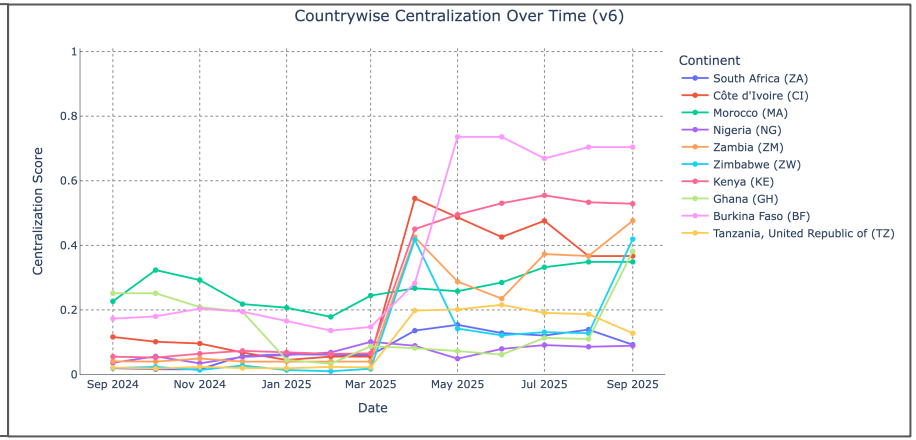


Macro scale: Centralization trend is stable

Centralization Score : IPv4 > IPv6

Longitudinal Trend





Country scale: Increasing in several countries

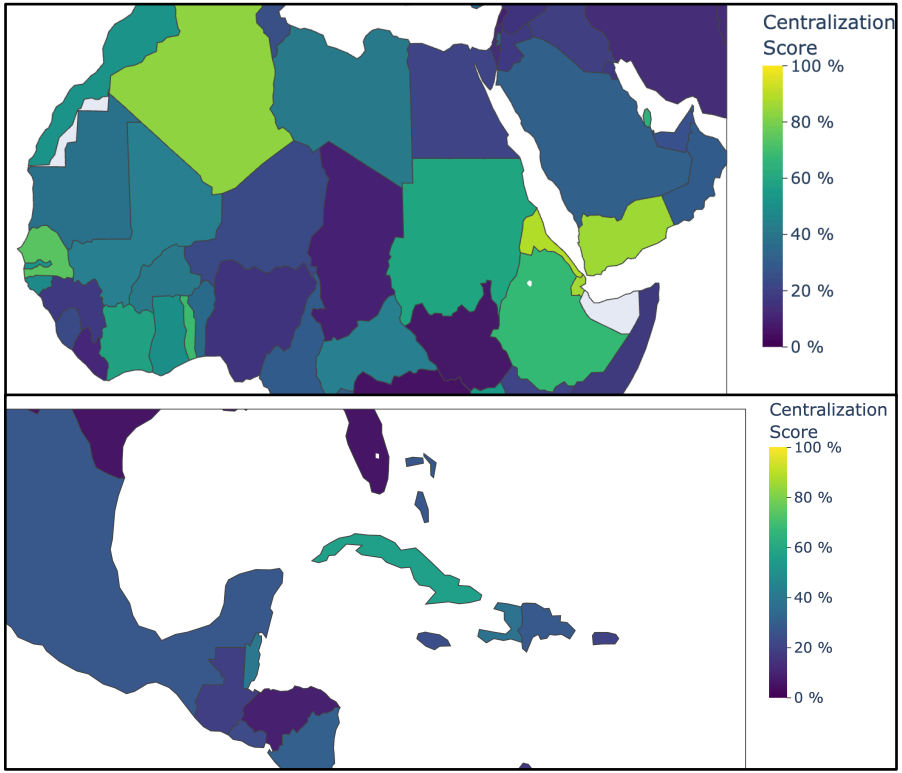
One reason: Organizations start routing new prefixes

Centralization Across Layers

Comparison with other layers - Similarities

- North and east African nations have higher centralization - *Hosting provider ecosystem, (ACM SIGCOMM 2025)*

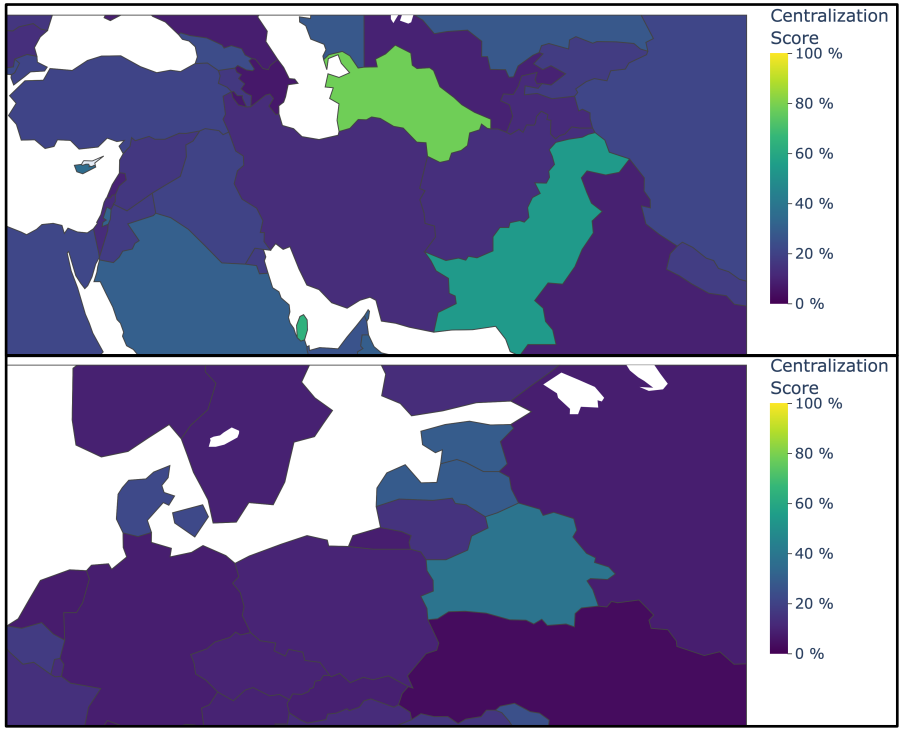
- Countries like Ethiopia, Cuba, Libya and Yemen overwhelmingly rely on the state for IP access - *ASN Transit Influence, (PAM 2022)*



Comparison with Previous Work

- **Turkmenistan:**
  - Low DNS, TLD centralization ⬇
  - High IP centralization ⬆

- **Eastern Europe:**
  - Belarus, Latvia, Estonia
  - Less than average DNS, TLD centralization ⬇
  - Higher than average IP centralization ⬆



Takeaways

- IPv4 Ecosystem:
  - More centralized than IPv6
  - State-owned orgs dominate in countries with high centralization
- IPv6 Ecosystem:
  - easier allocations ⇒ more organizations ⇒ lesser centralization
- Clusters of regional presence in Central Africa, Carribean, Northern Europe
- Countries exhibit centralization across multiple layers
- Next step: prefix-level traffic information

Questions!

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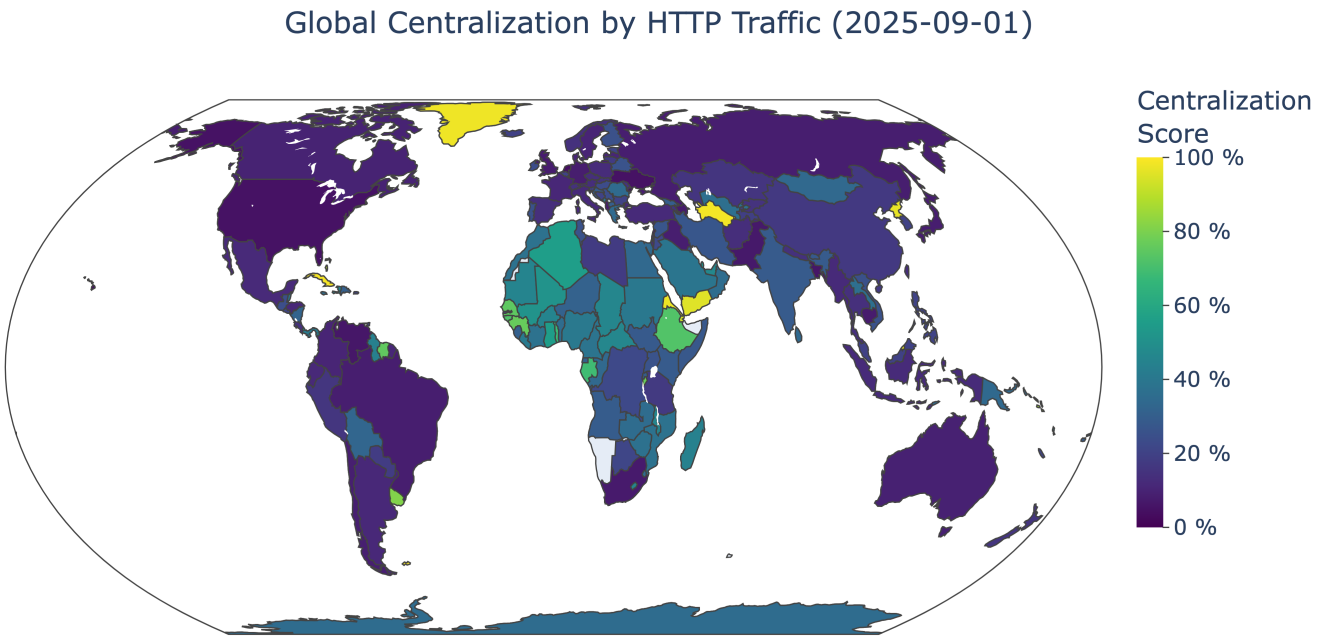
Backup Slides

Centralization of Traffic originated from ASNs



✳ Traffic data from Cloudflare Radar