Towards a Non-Binary View of IPv6 Adoption

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Where Does IPv6 Adoption Stand Today?

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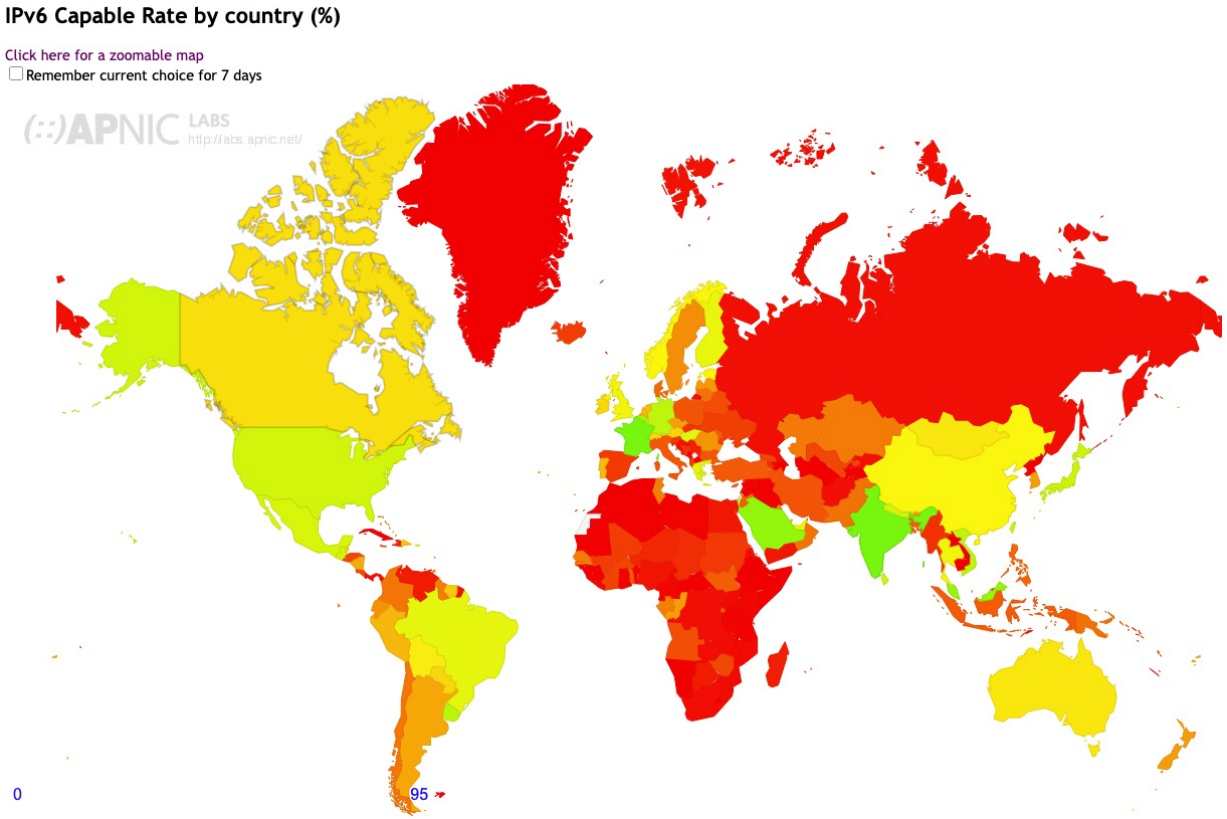

APNIC IPv6 Capable/Preferred
[https://stats.labs.apnic.net/ipv6/]

- APNIC shows whether a user is *v6-capable* or *v6-preferred*
- NOT: how much IPv6 traffic is *actually used*

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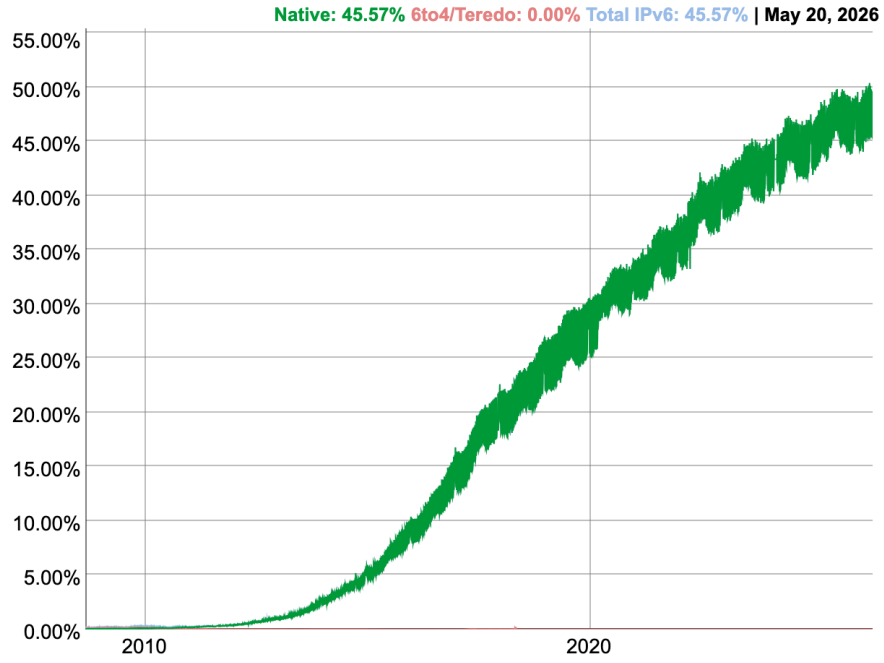

Google IPv6 Adoption Tracker
[https://www.google.com/intl/en/ipv6/statistics.html]

- Google shows users' IPv6 *traffic fraction*
- but, for a *single organization*

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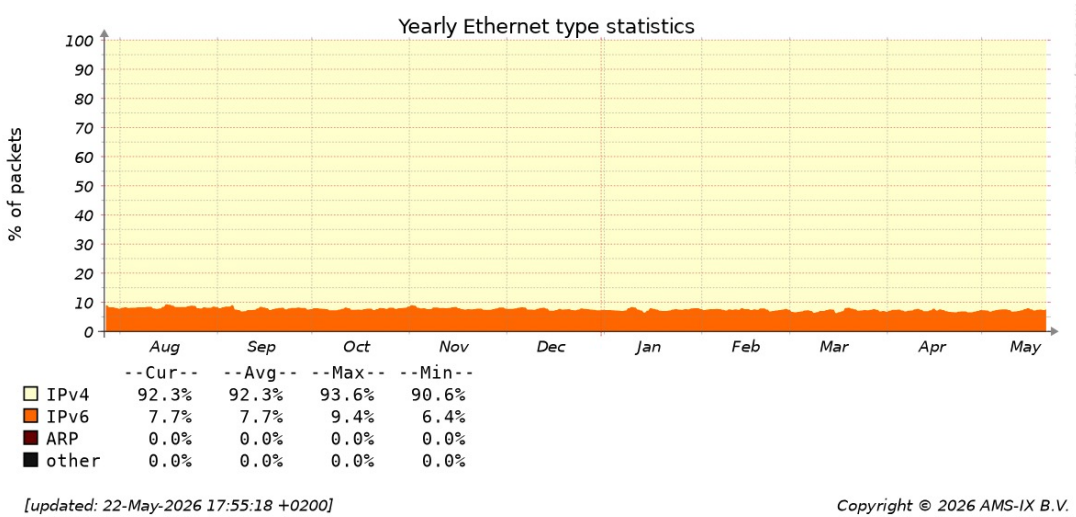

AMS-IX Ether Type Statistics
[https://stats.ams-ix.net/sflow/ether_type.html]

- AMS-IX shows use by *multiple orgs*
  - (at one IXP)
- but, Google is at 50% vs AMS-IX at 8% !
- why the *huge difference?*

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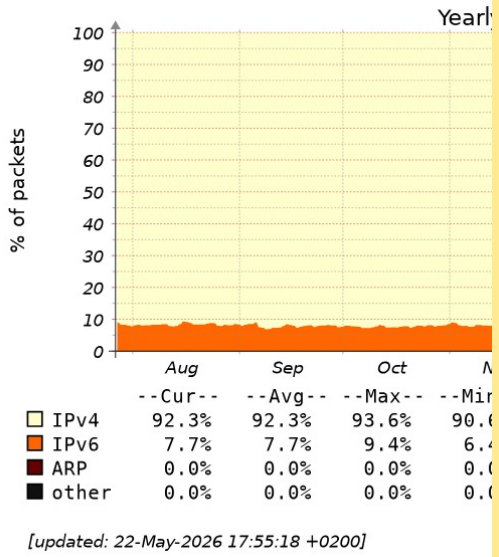


AMS-IX Ether Type Statistics
[https://stats.ams-ix.net/sflow/ether_type.html]

- going forward, we need metrics that tell us
  - how *much* IPv6?
    => "non-binary" view
- so we can ask
  - what are the *causes*?
  - where is *intervention* most useful?

multiple orgs

s AMS-IX at 8% !

e?

Contributions

- we reframe IPv6 adoption in *non-binary* terms
  - from: is IPv6 possible?
  - to: *how much IPv6? why?*

- answers from measurements as a
  - client
  - server
  - cloud
- recommendations for how to improve IPv6 adoption at each

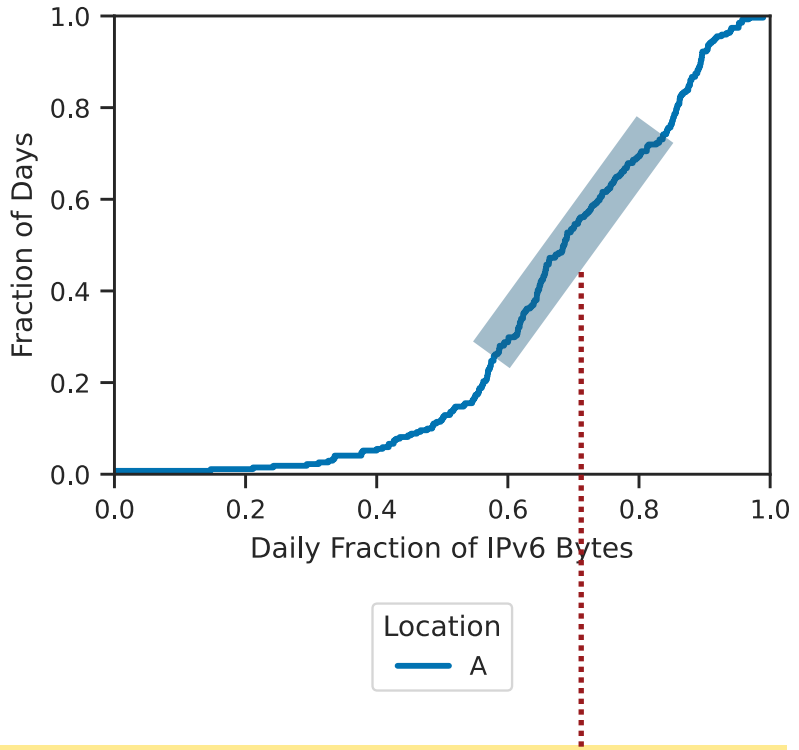
- introduction
- **client-side IPv6 adoption**
- server-side IPv6 adoption
- cloud IPv6 adoption
- conclusions

Client-side IPv6 Adoption

- Q: How much IPv6 do clients use? why?

- we observe 9 months of traffic at 5 dual-stacked LA residences
  - ISPs: Spectrum, Frontier (large U.S. broadband providers)
  - total 17 individuals
  - mix of devices (smartphones, computers, TVs, consoles..)
  - for privacy, we only capture flow information (no payload)

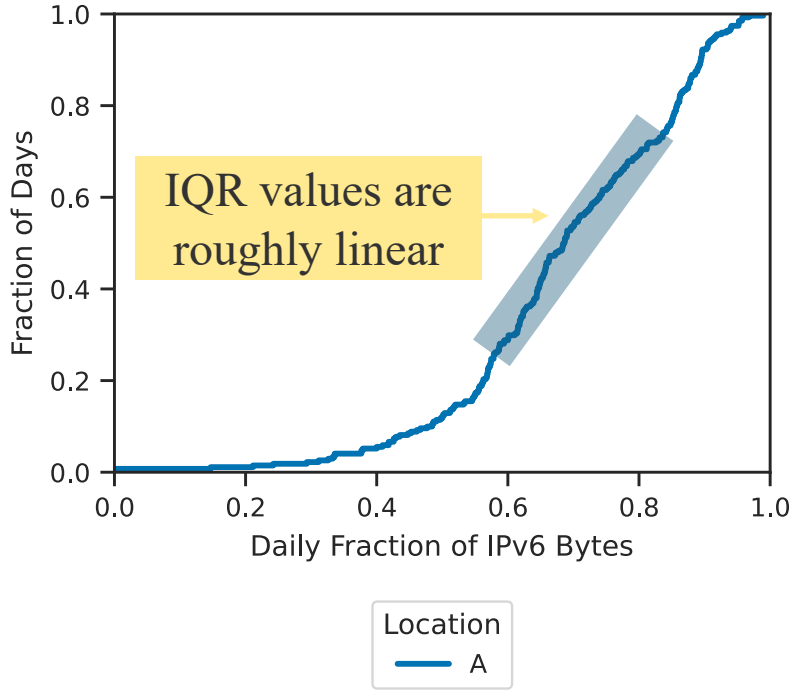
CDF of Daily IPv6 Fraction



Interquartile range (IQR)
(middle 50% of days fall here)

Everyday IPv6: Variation by Day

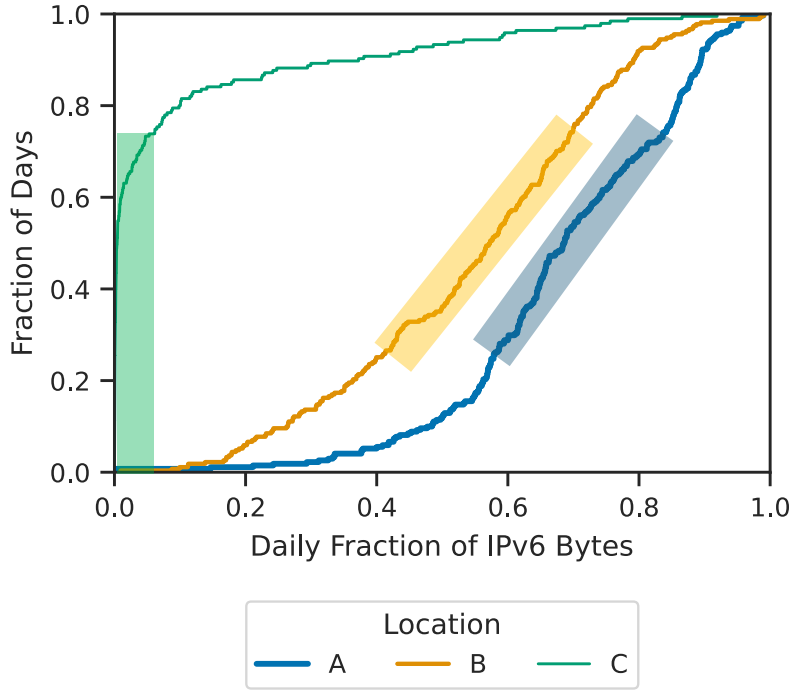
- IPv6 traffic volume (bytes) fraction
  - large day-to-day variation



(shaded: Inter-Quartile Range)

Everyday IPv6: Variation by Site

- IPv6 traffic volume (bytes) fraction
  - large day-to-day variation
  - medians vary considerably by site



(shaded: Inter-Quartile Range)

(Residences A, B & C account for 20.8 TB / 21.5 TB of all observed traffic)

What Causes Outlier Days?

- a single app can shift the day!
  => need to identify apps that "lead" or "lag"

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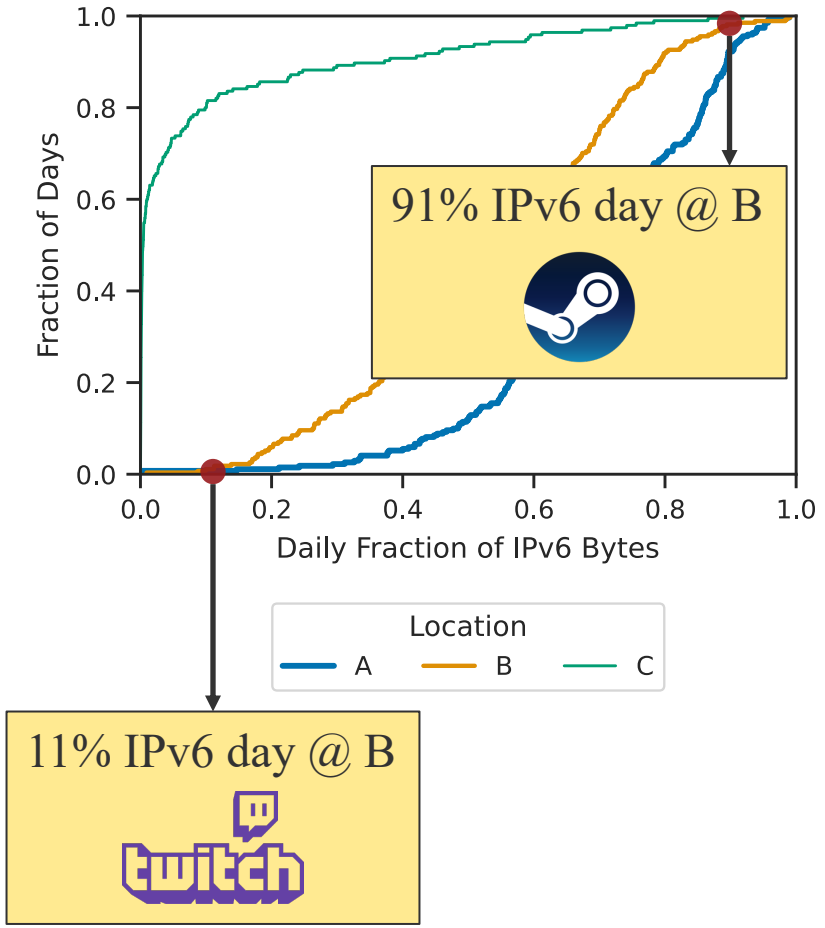


Which Services Lead and Lag in IPv6?

Leading

Lagging

Which Services Lead and Lag in IPv6?

Lagging

some *essential* services lag!

Observations and Takeaways

large variation in IPv6 usage ⇒ non-binary view matters

everyone has their IPv6-lagging application ⇒ next step: add IPv6 to long tail of applications

- introduction
- client-side IPv6 adoption
- **server-side IPv6 adoption**
- cloud IPv6 adoption
- conclusions

Server-side IPv6 Adoption

- are all “v6-enabled” websites fully v6-loadable?
  - no, many pages have IPv4-only dependencies!

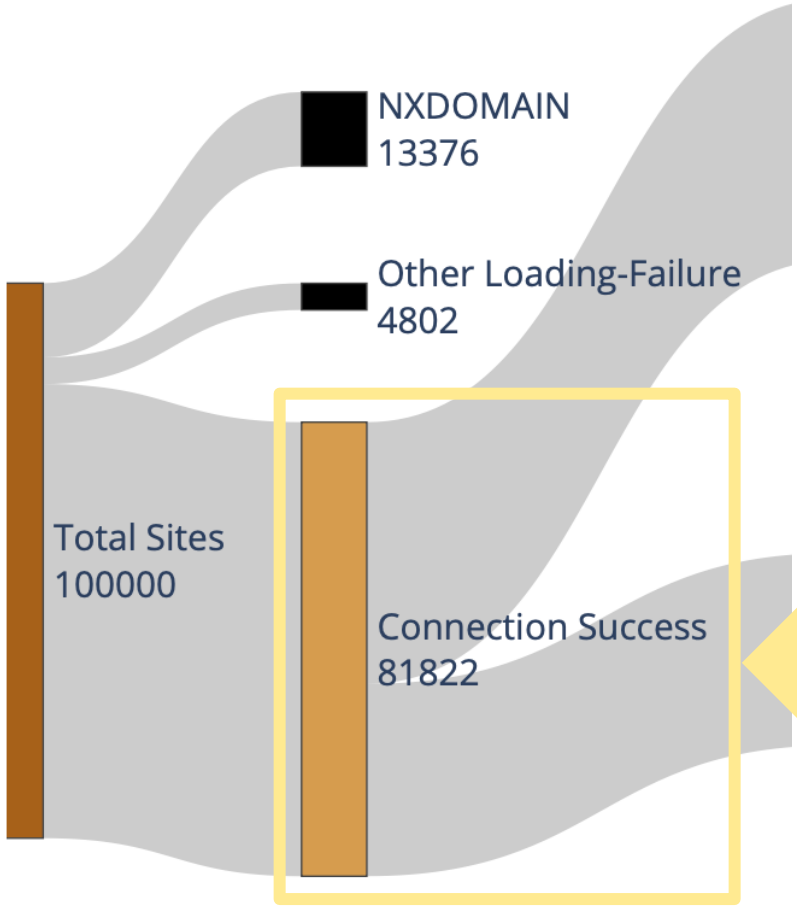
- => what is the non-binary view of *servers*?

Server-side IPv6 Adoption

- we crawl the Tranco top 100k sites using OpenWPM
- look *deeper* for IPv4-only resources
  - load the website using a browser

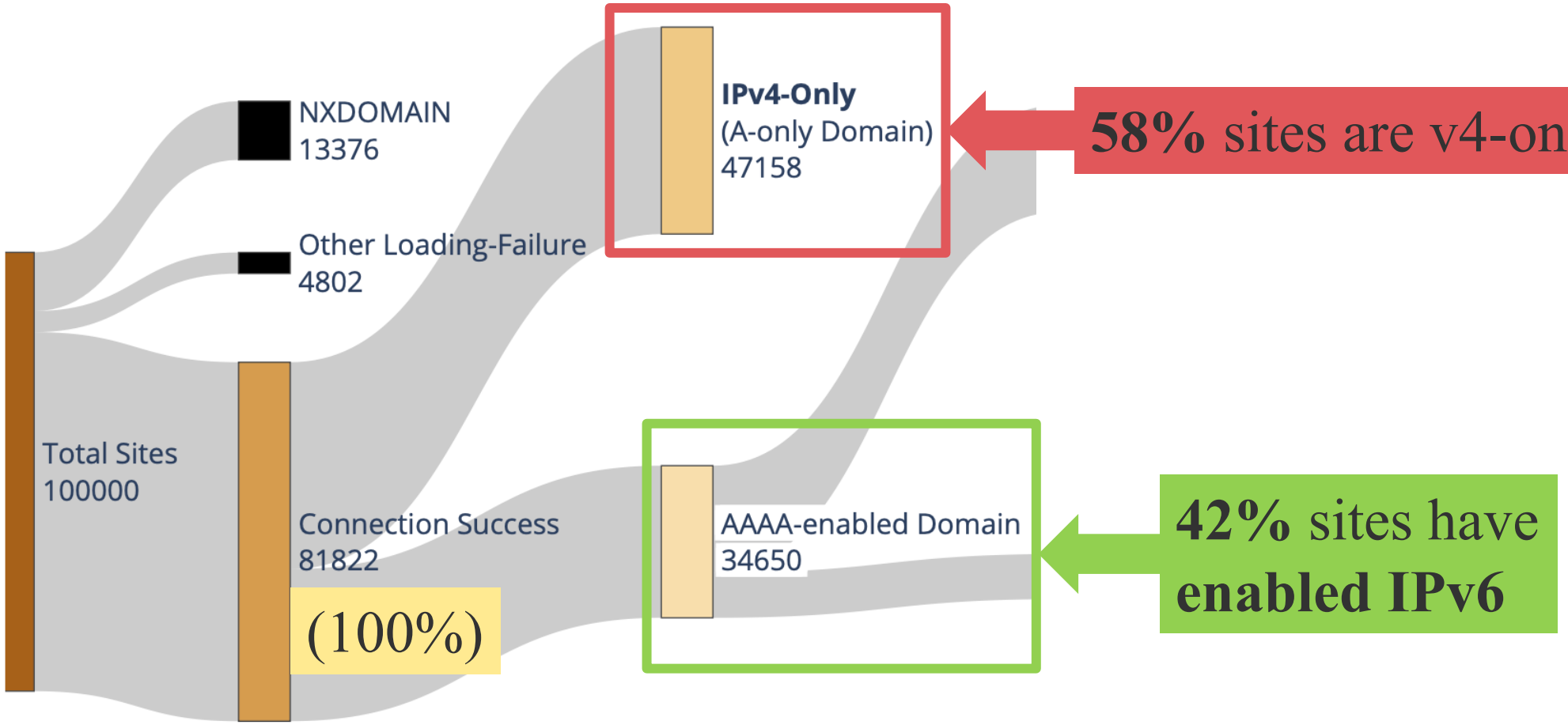
    => resolves dependencies to arbitrary depth
  - click on 5 randomly chosen “internal” links (same eTLD+1)
- 3 measurements over 9 months to identify trends

To what extent do websites support IPv6?

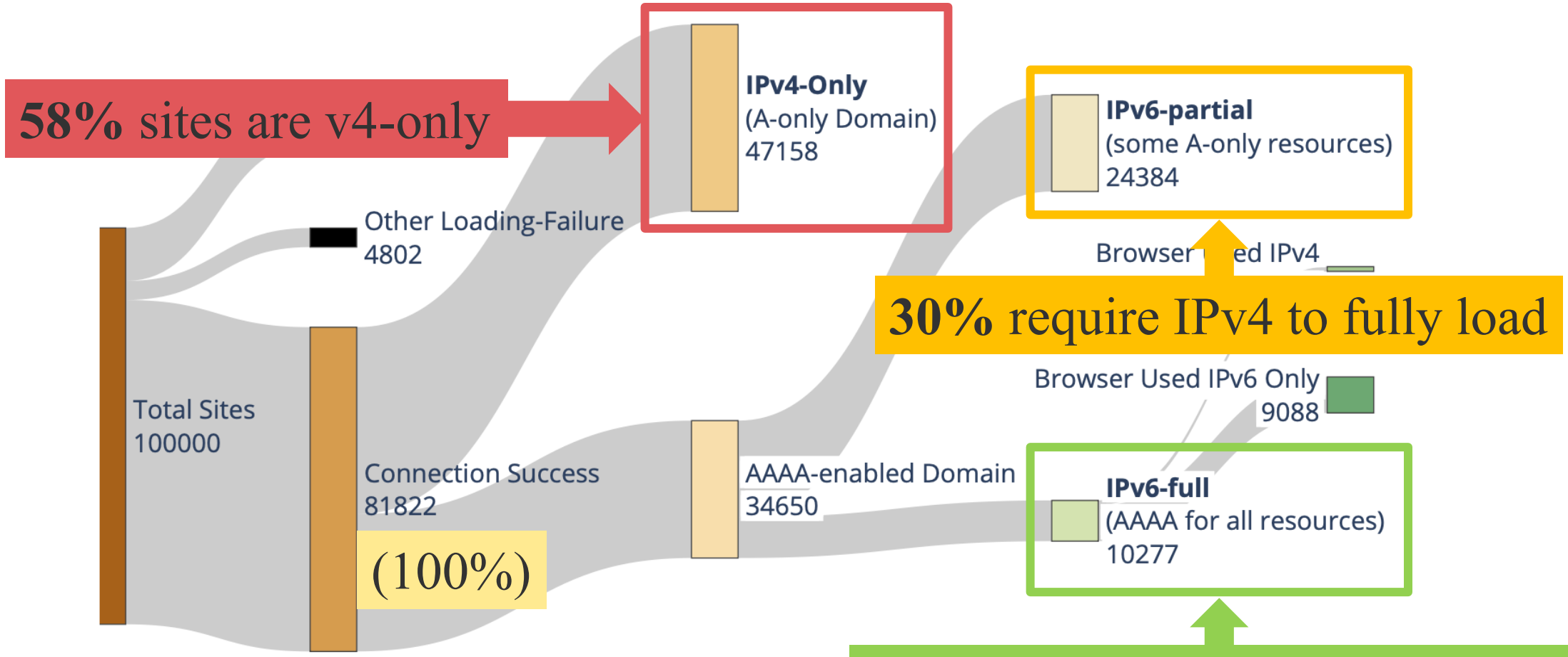


82k out of 100k sites are loadable

The Binary View



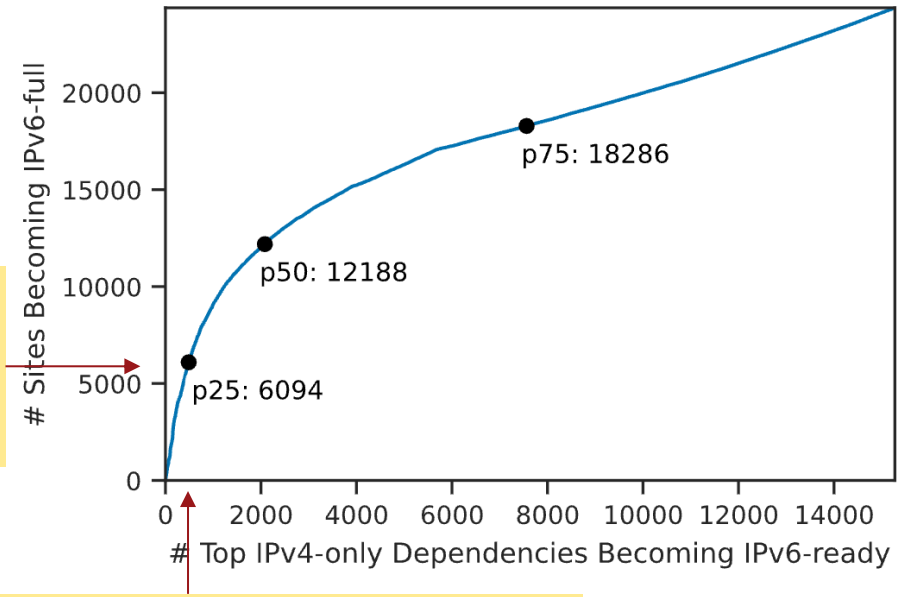
The Non-Binary View



IPv4-Partial: Held Back by v4-only Resources

- adding IPv6 to *few highly popular resources* would help a lot!

fix over 25% (6k) IPv6-partial sites…



by fixing top 5% (500) v4-only resources

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- client-side IPv6 adoption
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Cloud IPv6 Adoption

- most servers today are hosted in the cloud
- all major clouds support IPv6 today
- why does server-side IPv6 adoption still lag?

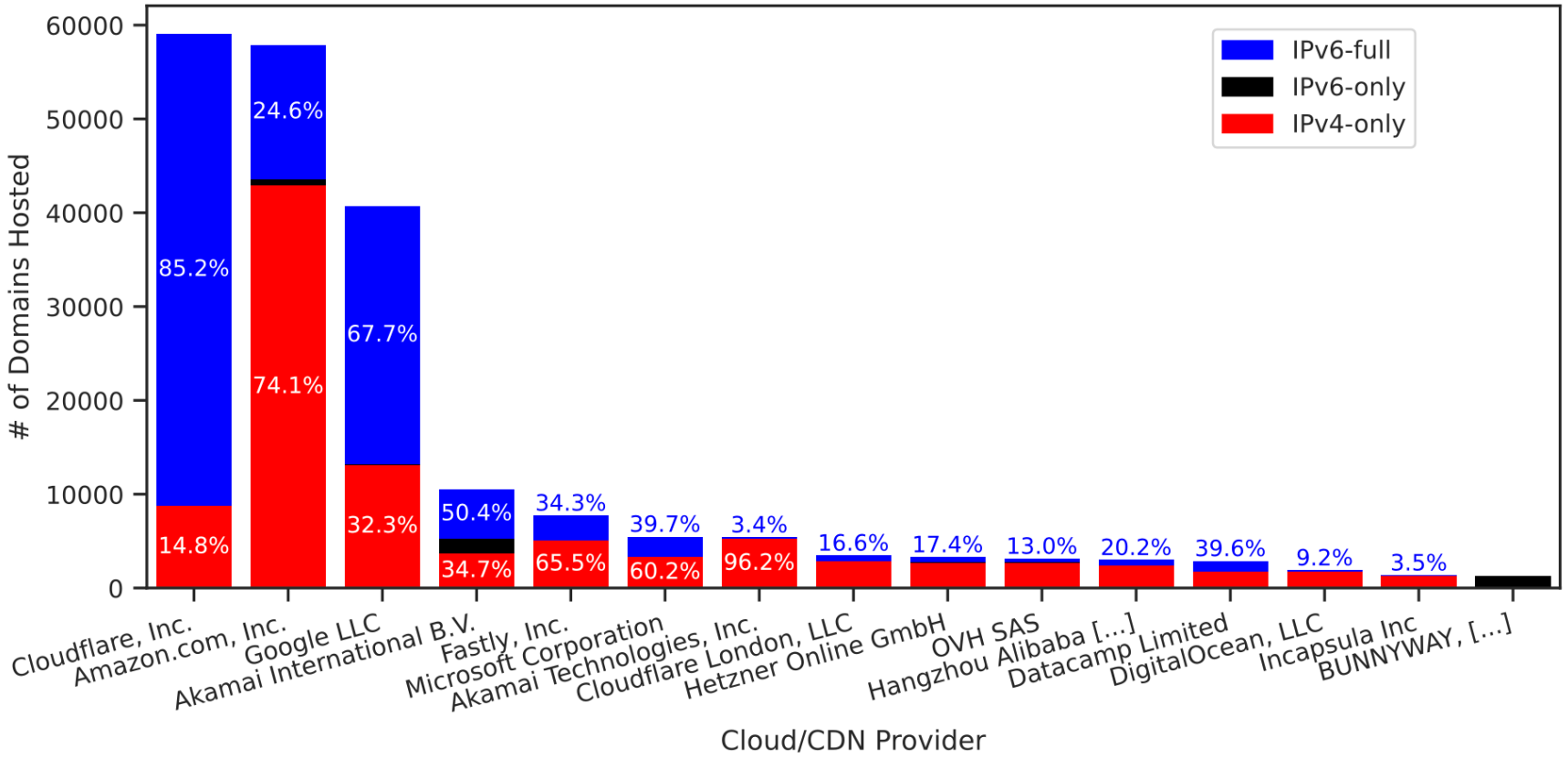
=> what is the non-binary view of *clouds*?

Are some clouds IPv6-heavy?

- evaluate clouds from our server data
  - about 256k FQDNs of servers
  - map: domain → IP address → origin AS → cloud

- we consider both cloud providers and CDNs as *clouds*
  - since the two increasingly overlap
    (many traditional CDNs now offer cloud compute and vice versa)

Are some clouds IPv6-heavy?



IPv6 support varies widely across clouds!

(blue IPv6-full varies from 3% to 85%!)

Do IPv6 barriers vary across clouds?

- some clouds are IPv6-heavy, but *why*?
- how do we separate
  - *cloud IPv6 support*
  - from *tenant choices* ?

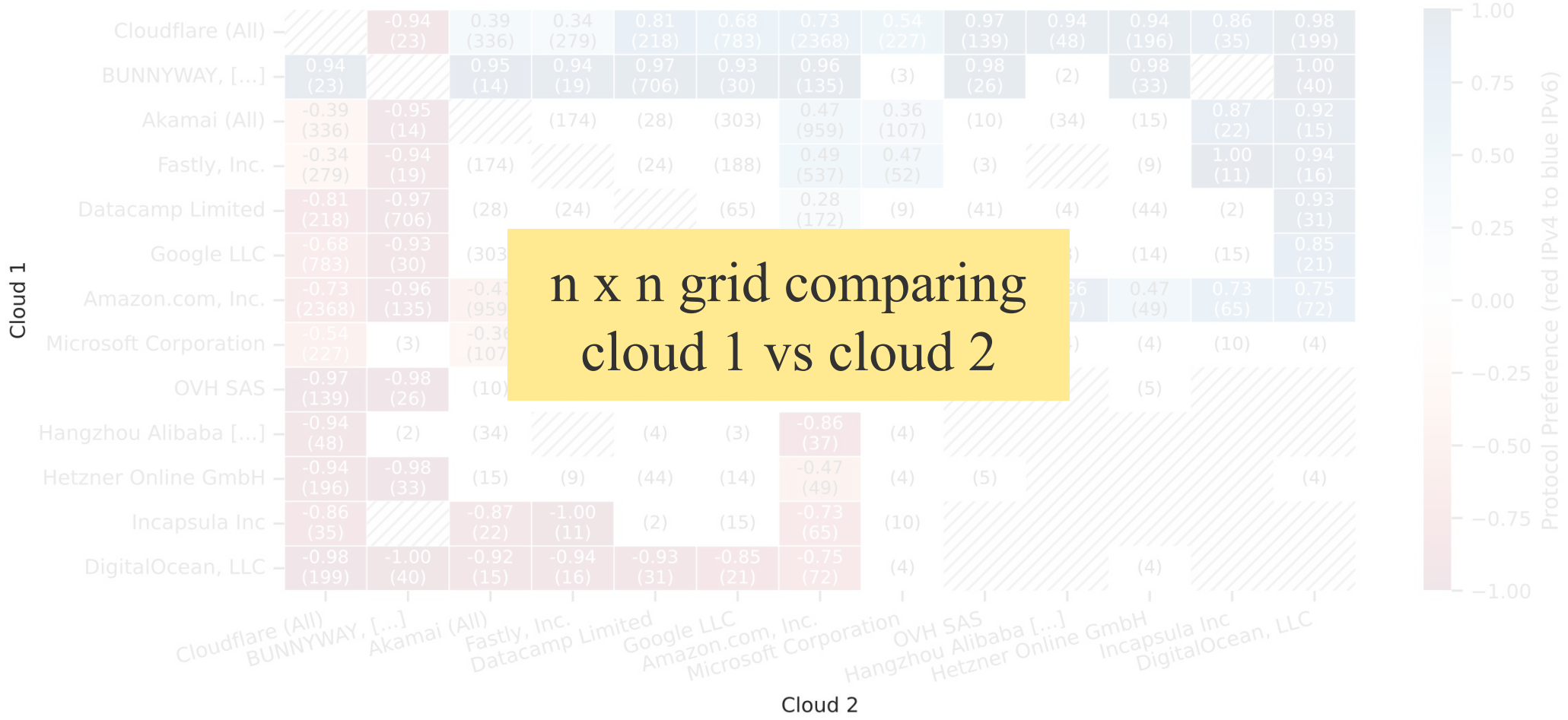
Do some clouds make IPv6 harder?

- to separate *cloud support* from *tenant choice*,
- compare the *same* tenant across two clouds

- test: two-sided Wilcoxon signed-rank test
  evaluating all tenants that use the same pair of clouds

- example:
  - `apnic.net` uses both Cloudflare *and* Amazon
  - Cloudflare subdomains: all IPv6-full; Amazon: all IPv4-only
    => Cloudflare: 1.0, Amazon: 0.0 (for this shared tenant)

Do some clouds make IPv6 harder?



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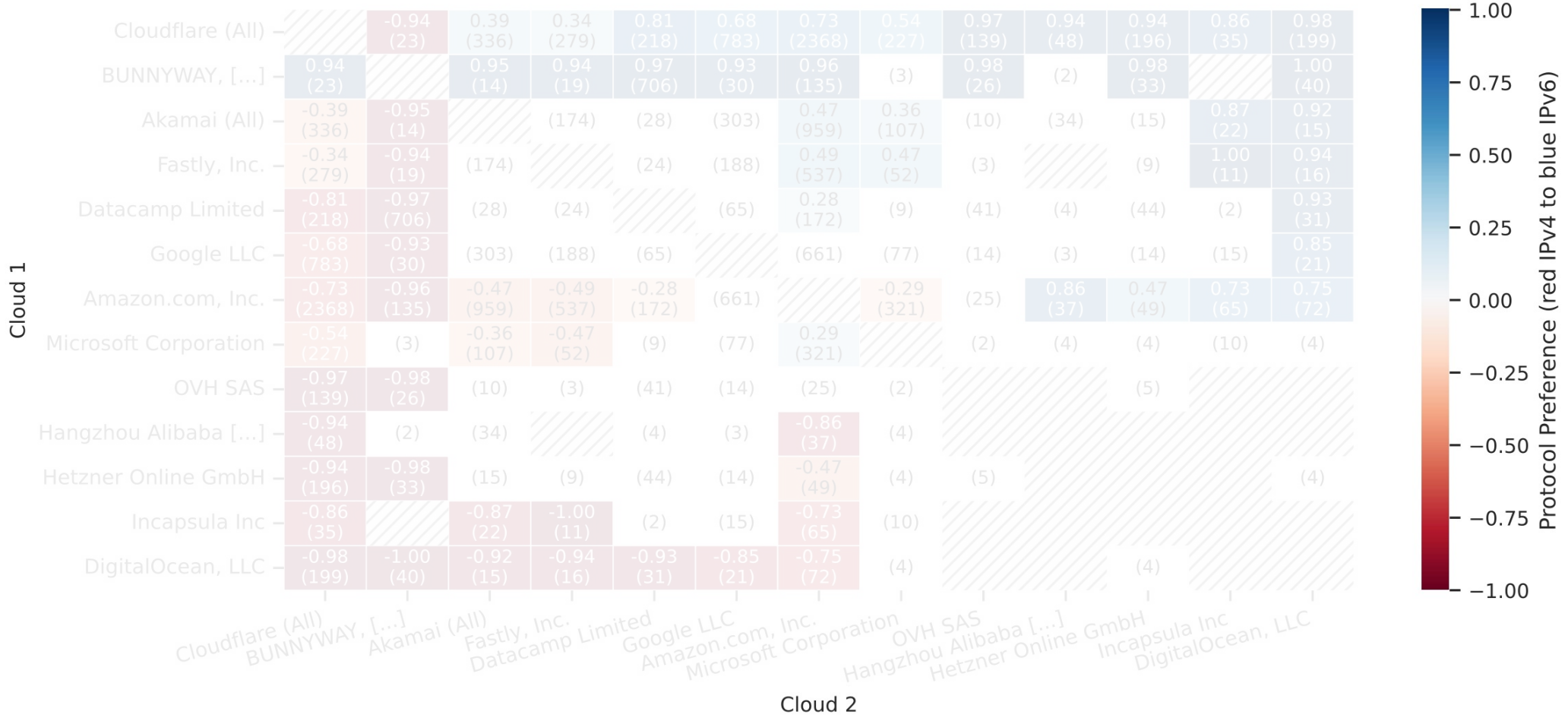

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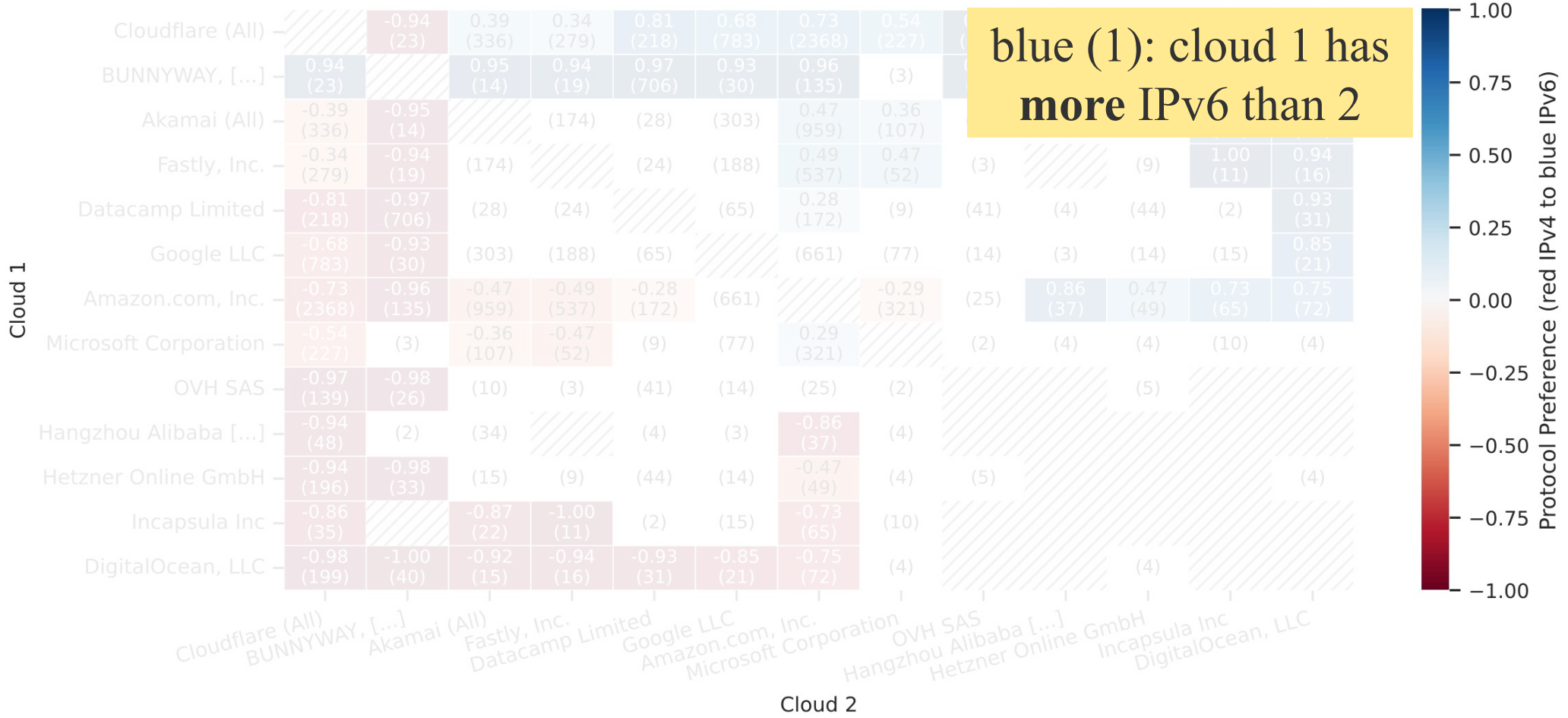

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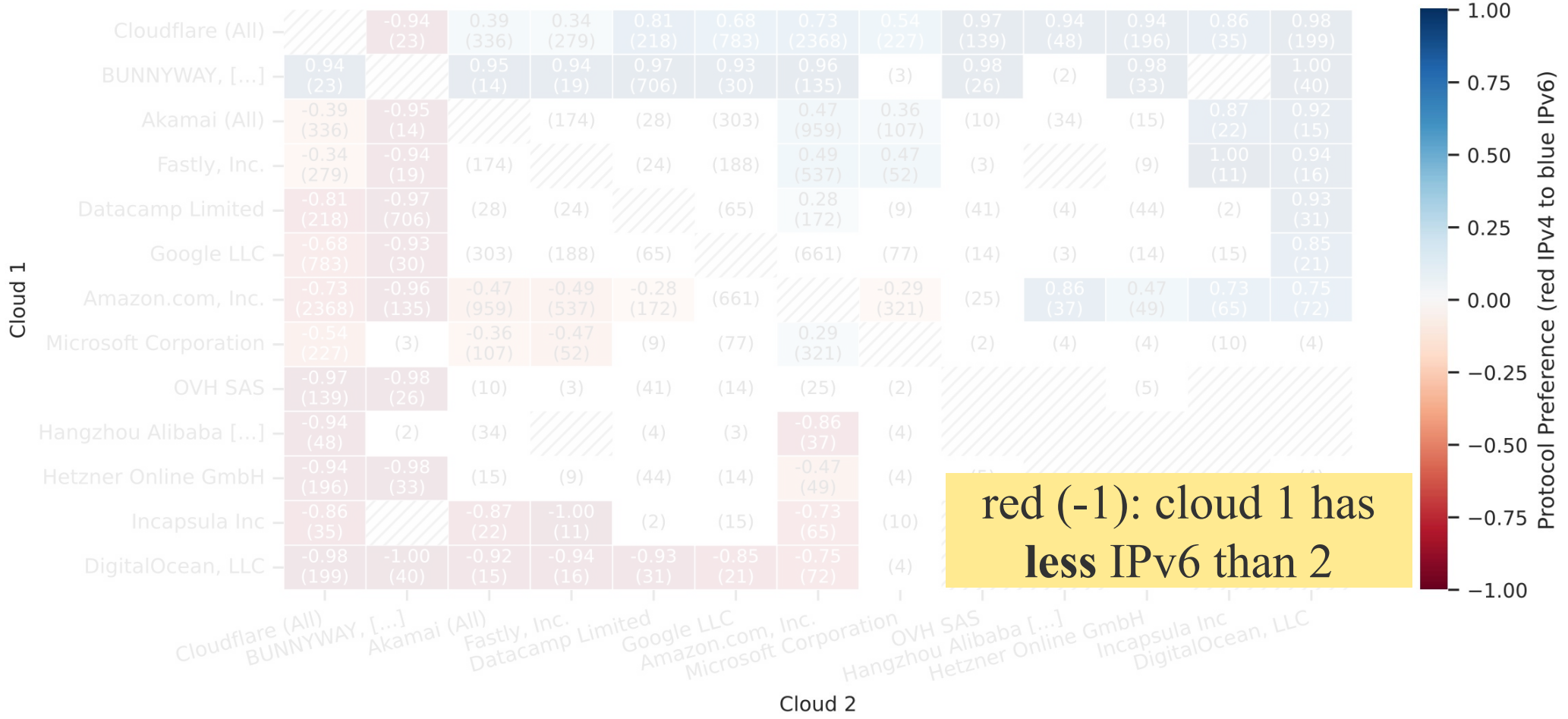

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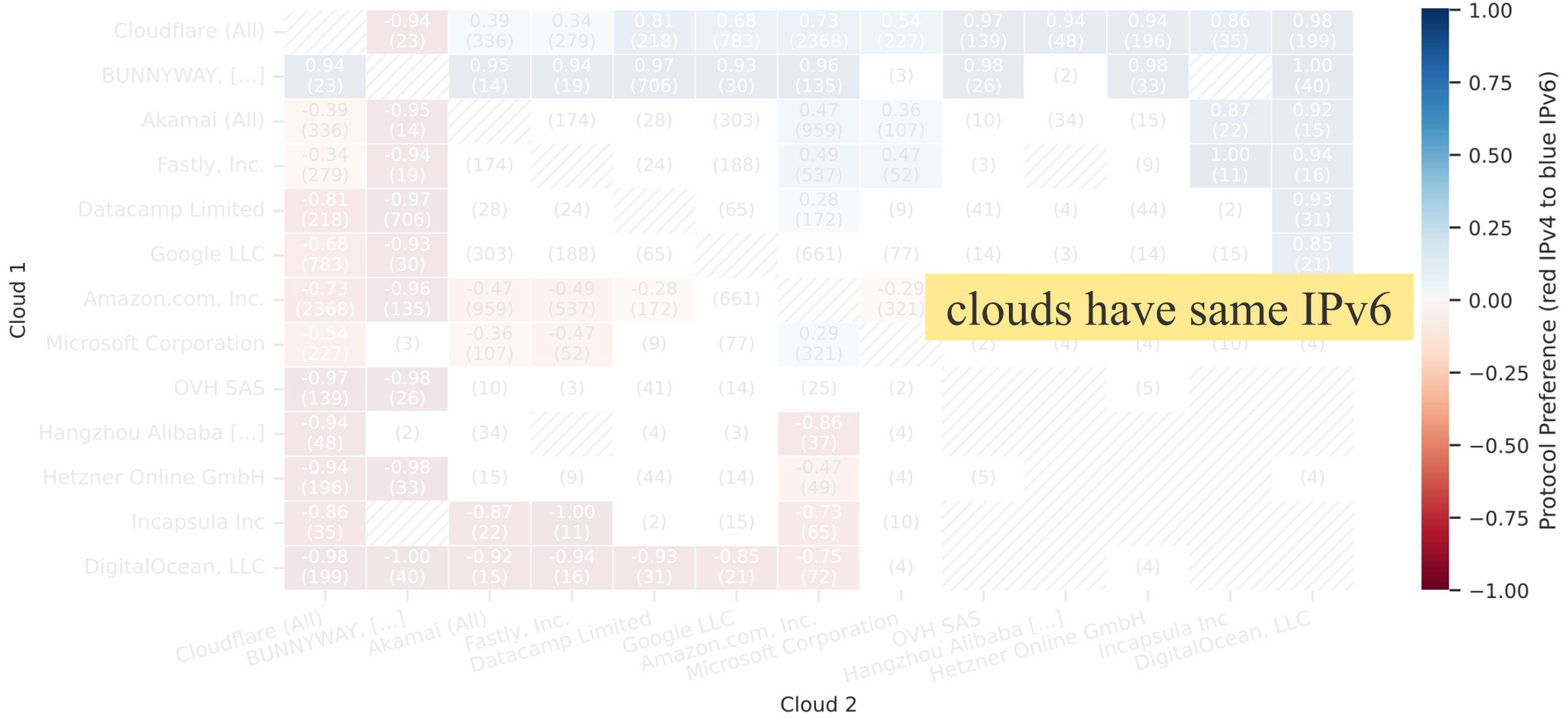

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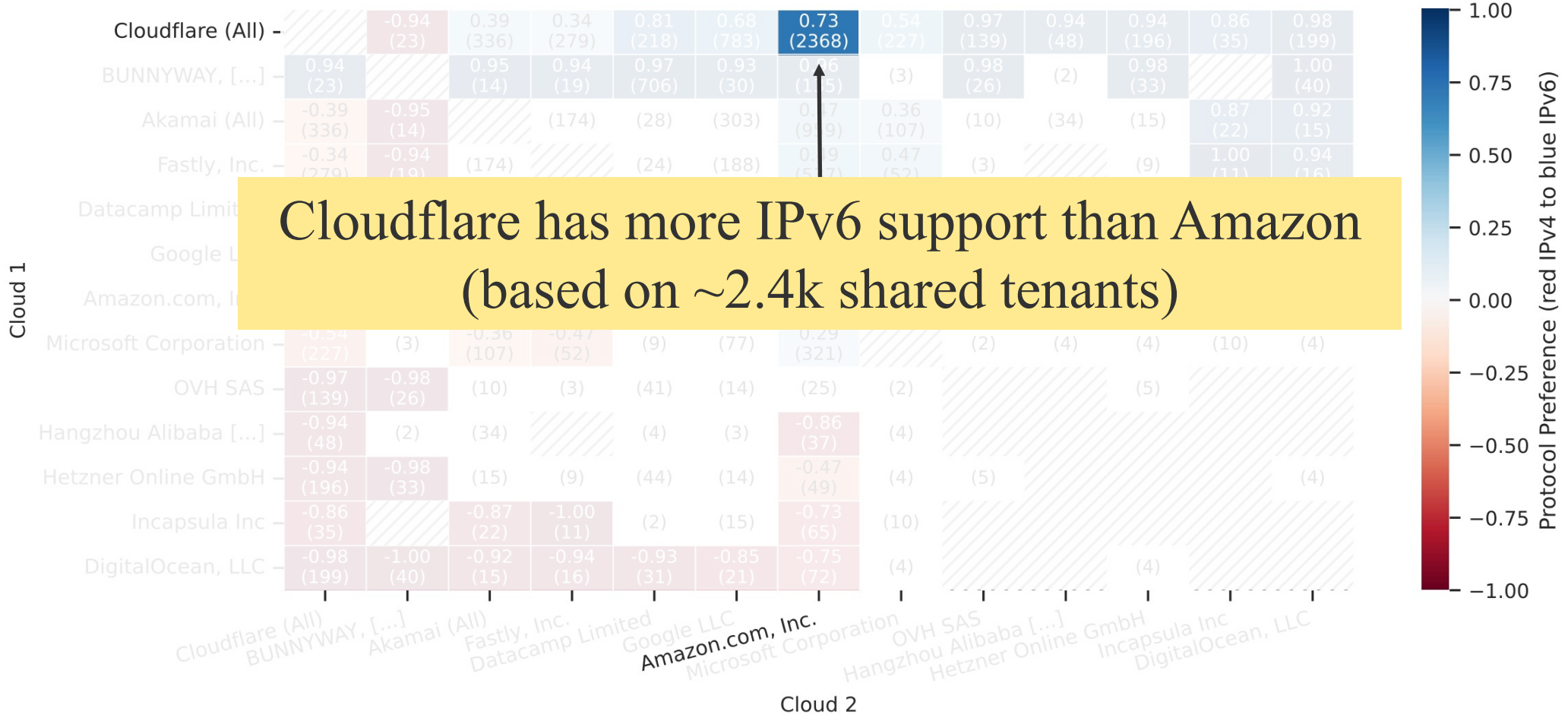
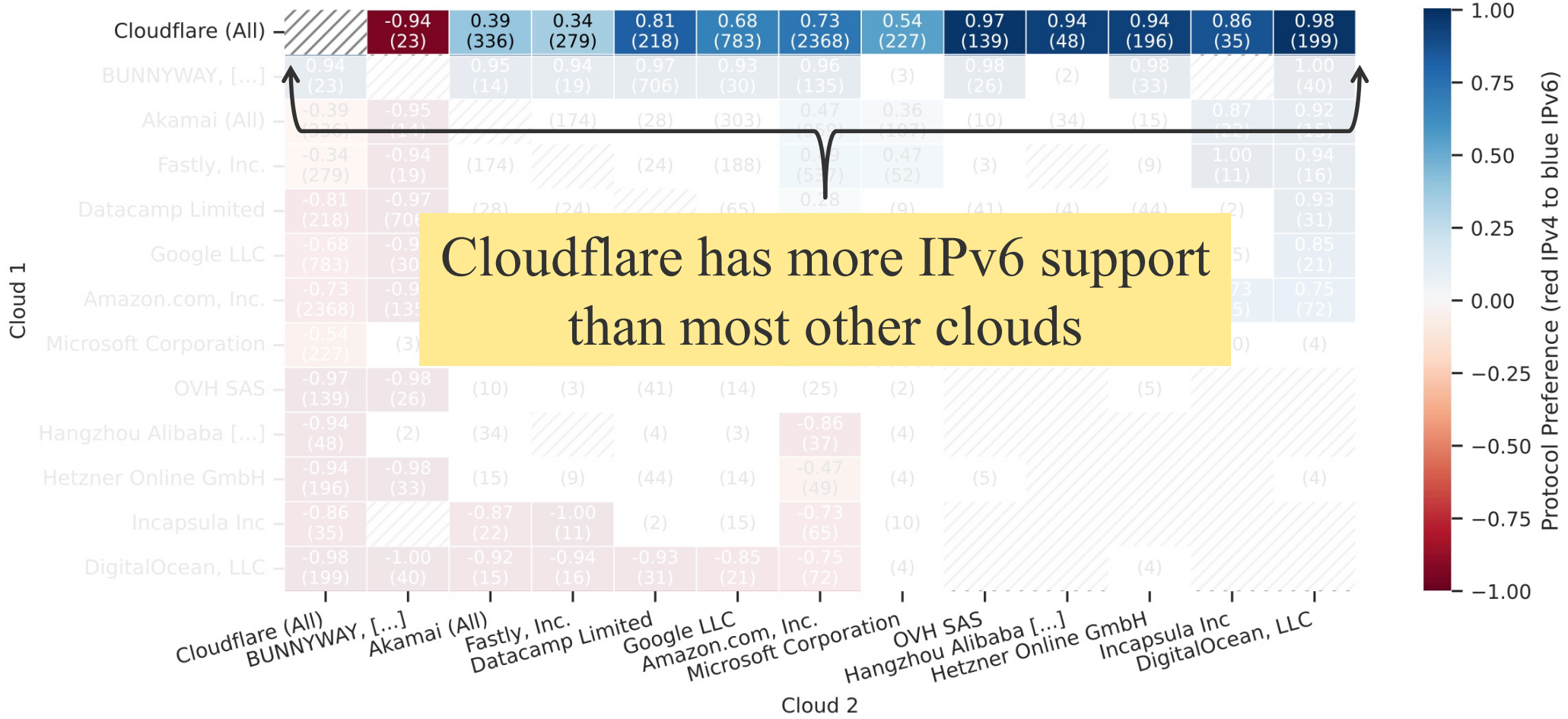


Cloudflare has more IPv6 support than Amazon (based on ~2.4k shared tenants)

Do some clouds make IPv6 harder?



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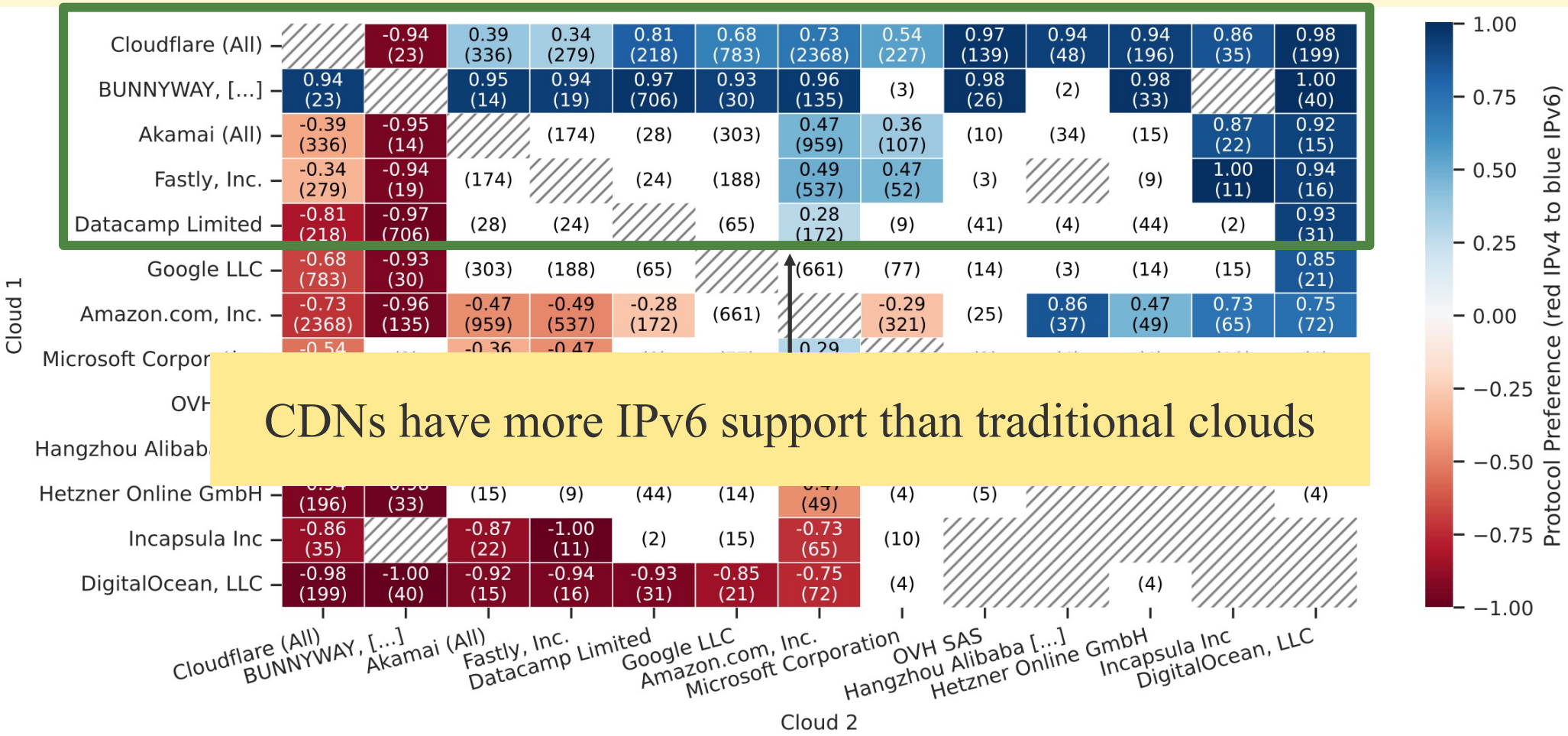
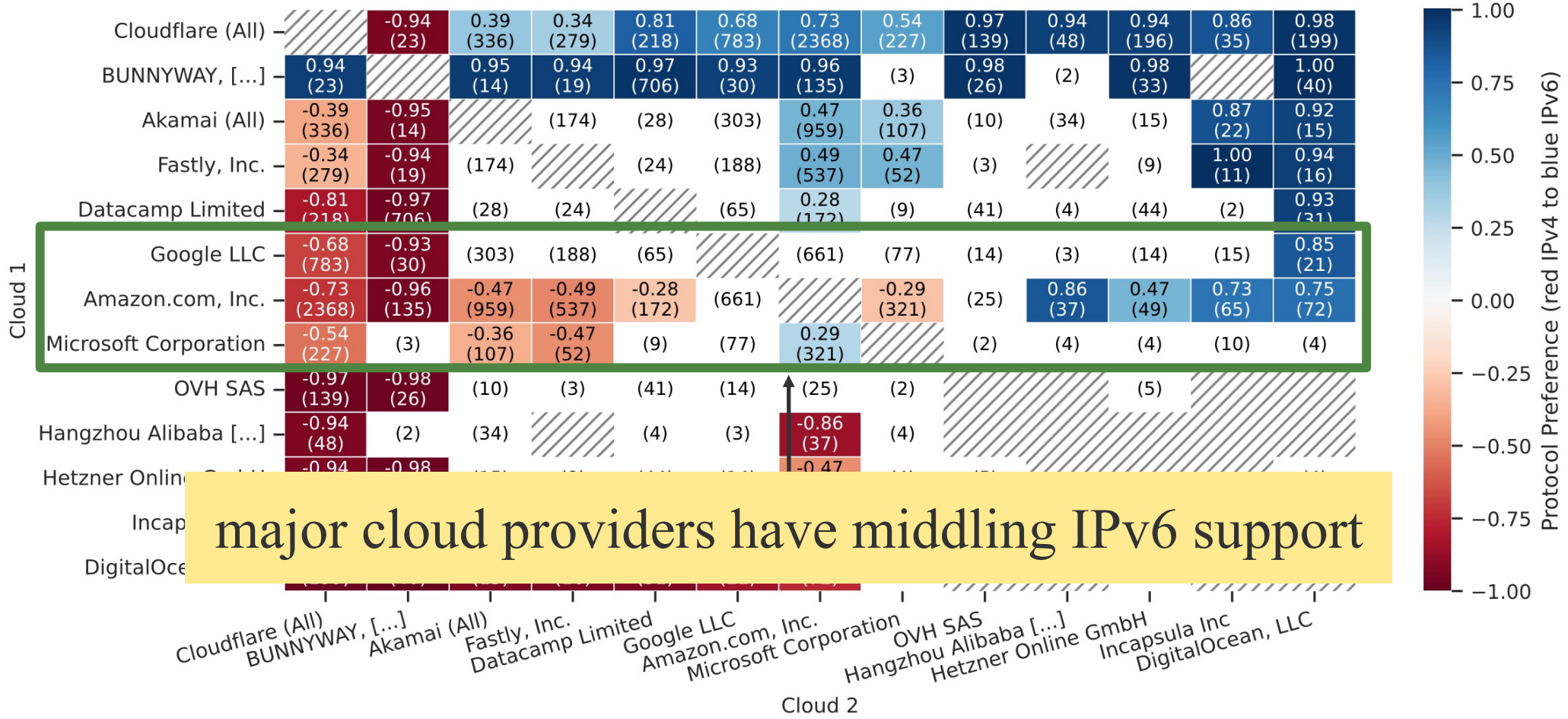


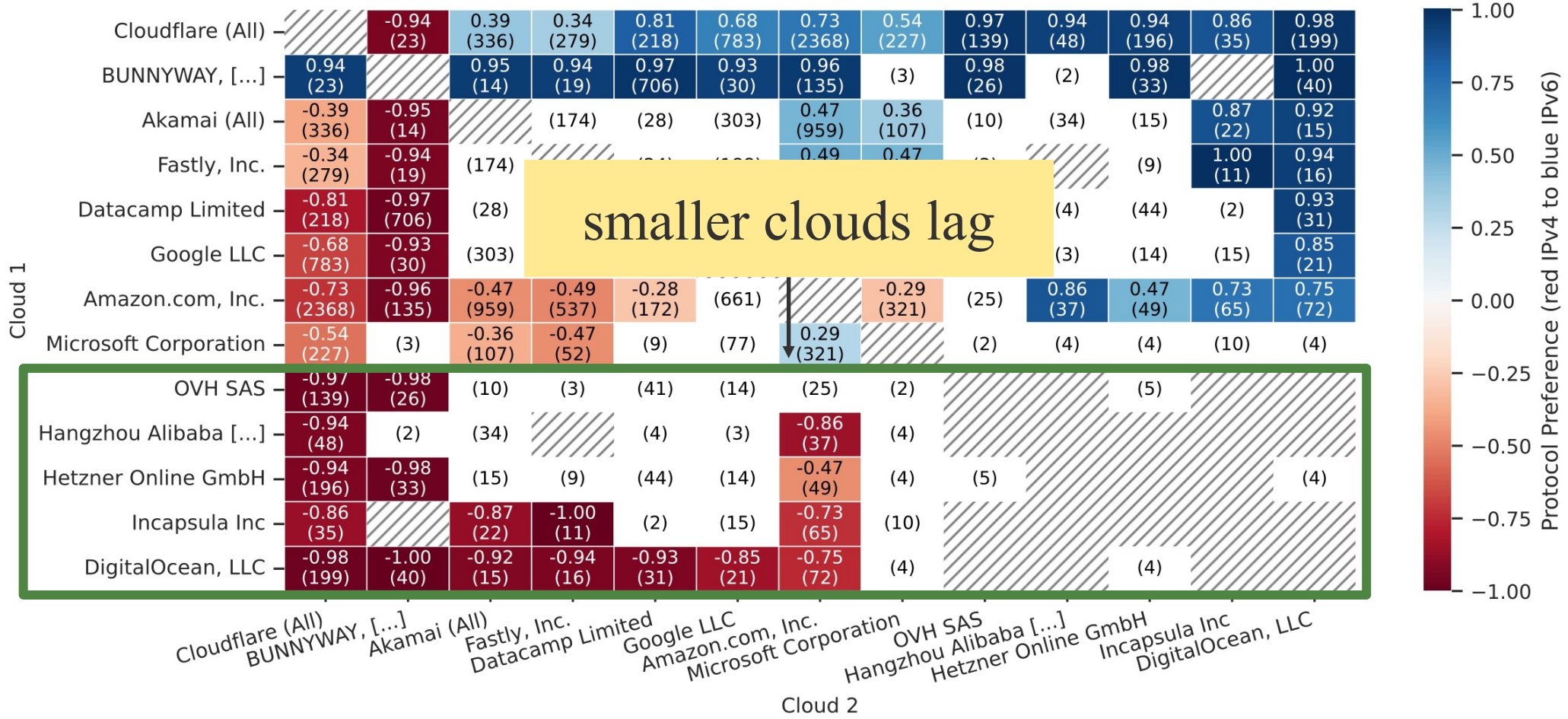
CDNs have more IPv6 support than traditional clouds

Do some clouds make IPv6 harder?



major cloud providers have middling IPv6 support

Do some clouds make IPv6 harder?



Why do Clouds Differ?

- tenant changes are hard
  - both Amazon S3 and CloudFront added IPv6 in 2016
  - CloudFront: automatic IPv6 deployment => *71% IPv6-ready*
  - S3: bucket users must change URLs => *0.4% IPv6-ready (!)*

```
<bucketname>.s3.<aws-region>.amazonaws.com
```

vs

```
<bucketname>.s3.dualstack.<aws-region>.amazonaws.com
```

Recommendations

- clouds should deploy IPv6 *transparently*
  - rather than requiring opt-in or code changes
- is opt-out really needed?
  - Azure Front Door shows that no-opt-out is possible (100% IPv6)

Conclusion

- today, IPv6 is non-binary
  - not *capable or not?*
  - but *how much is it used?*
- recommendations:
  - some client-essential services are IPv4-only; need to come forward
  - services need to move forward key third-party resources
  - clouds should add IPv6 transparently

Scan for full paper!