

Measuring Anycast Routing:

An open, collaborative tool for Internet measurement

IJ Seminar, Tokyo, Japan, Sep'26

Remi Hendriks

**UNIVERSITY
OF TWENTE.**

Who am I?

- PhD student at University of Twente UT (Netherlands)



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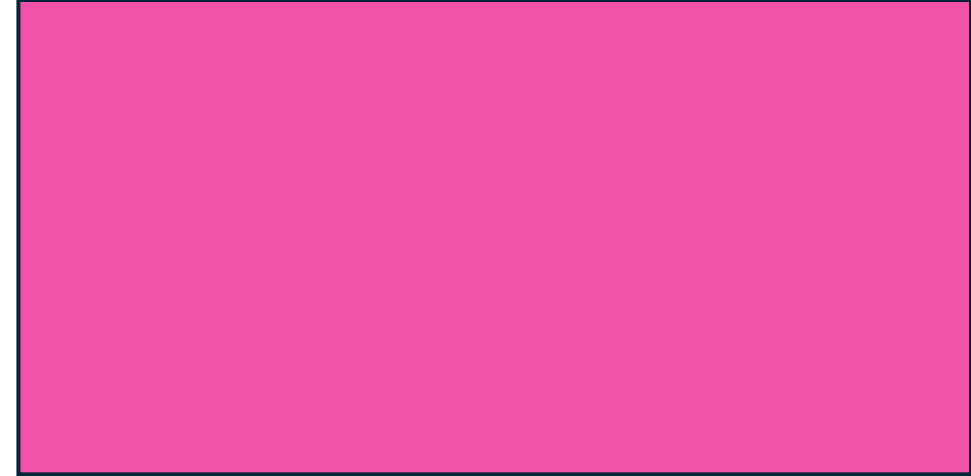
- PhD student at University of Twente UT (Netherlands)
- I grew up in Twente
- Did both my bachelor and masters at the UT
 - Whilst taking care of 10+ german shepherds :)
- Now at IIJ for a research visit (3 months)
 - Supervised by Romaine, Christoff, Malte
 - First time living abroad

Goal of today's talk

- Make you aware of MAnycastR
 - Our collaborative anycast measurement tool
 - And share how we may enable/facilitate anycast measurements for you
- Highlight its usefulness
 - Academic use cases
 - Anycast census
 - Value for operators

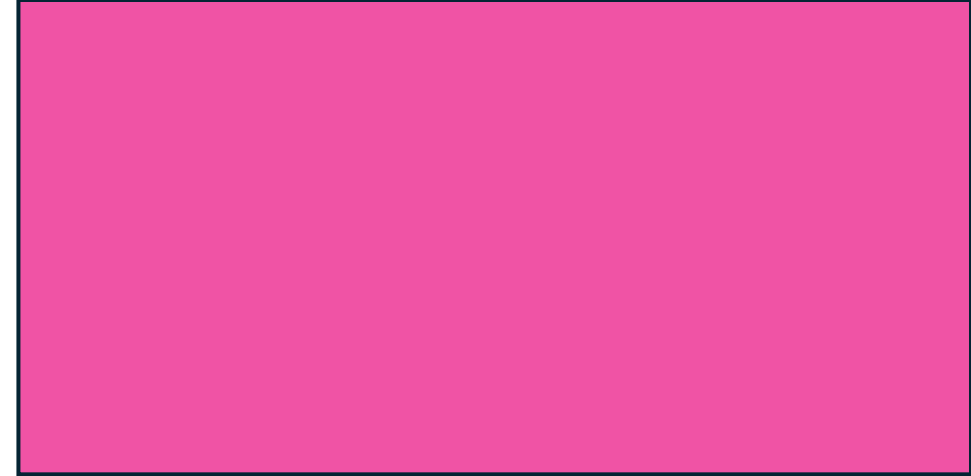
Outline

- Introduction
 - What is anycast? Why measure it?
- Background
 - More on anycast measurement tools
 - How MAnycastR was started
- Methodology
 - System design & requirements & implementation details
- Usage by operators
- Usage by academics and collaborative outreach
- Conclusion



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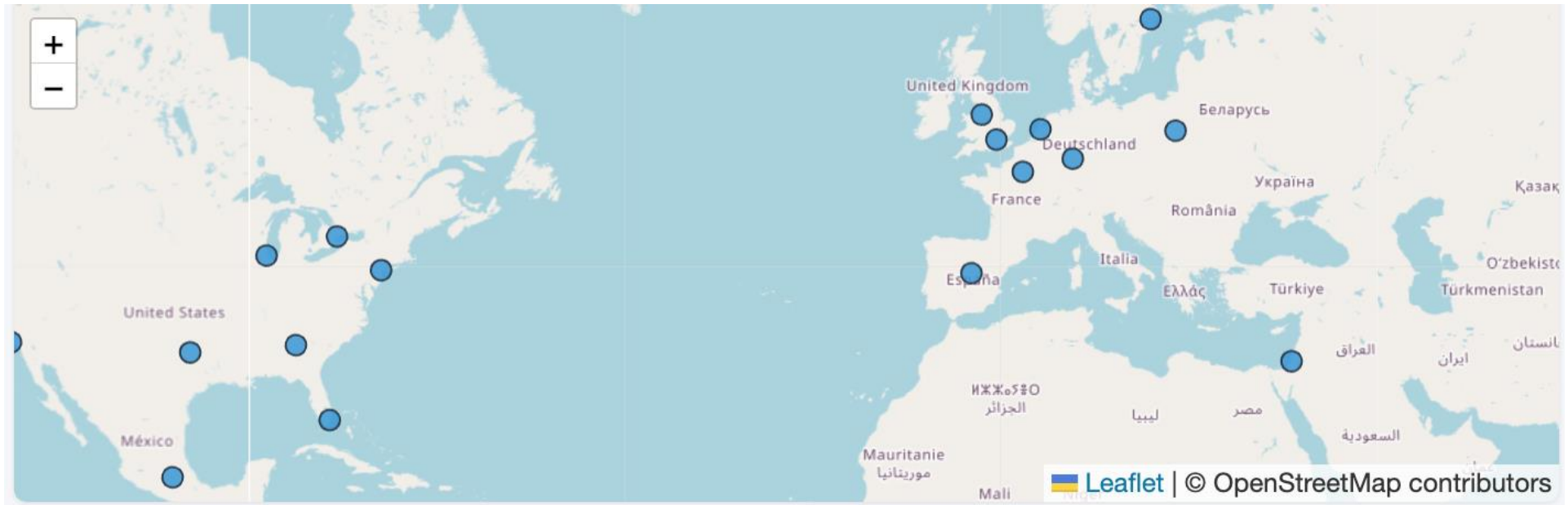
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Introduction

What is anycast?

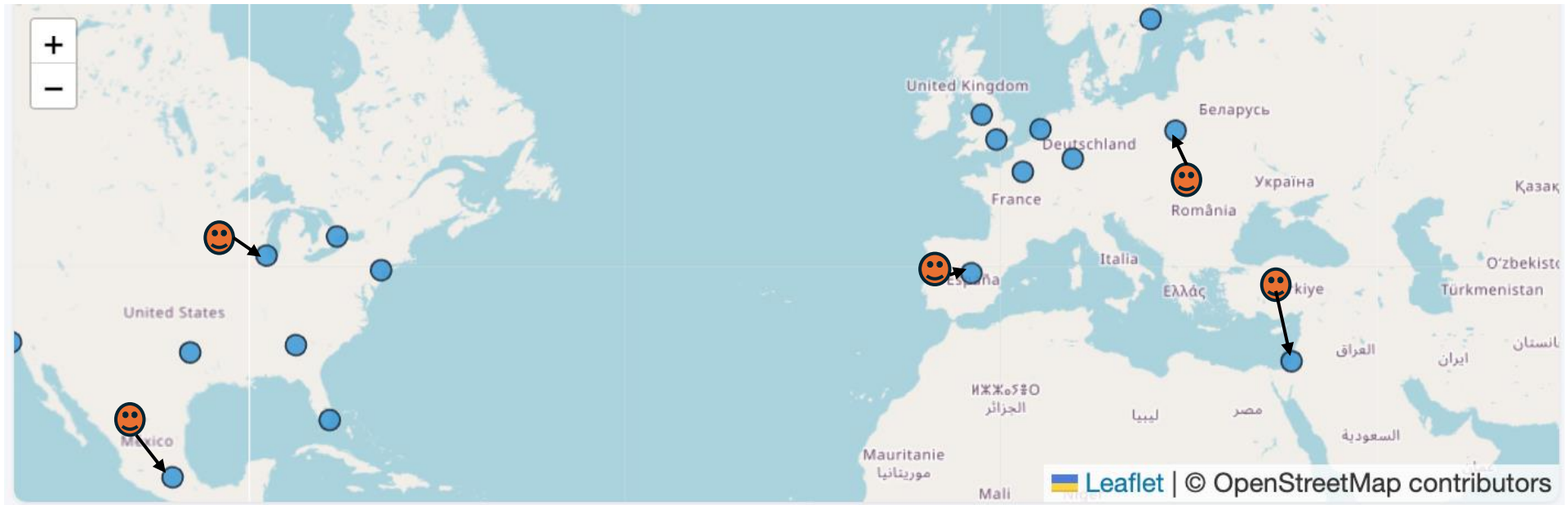
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 - *How?* - Announcing an IP prefix at multiple locations using BGP



Introduction

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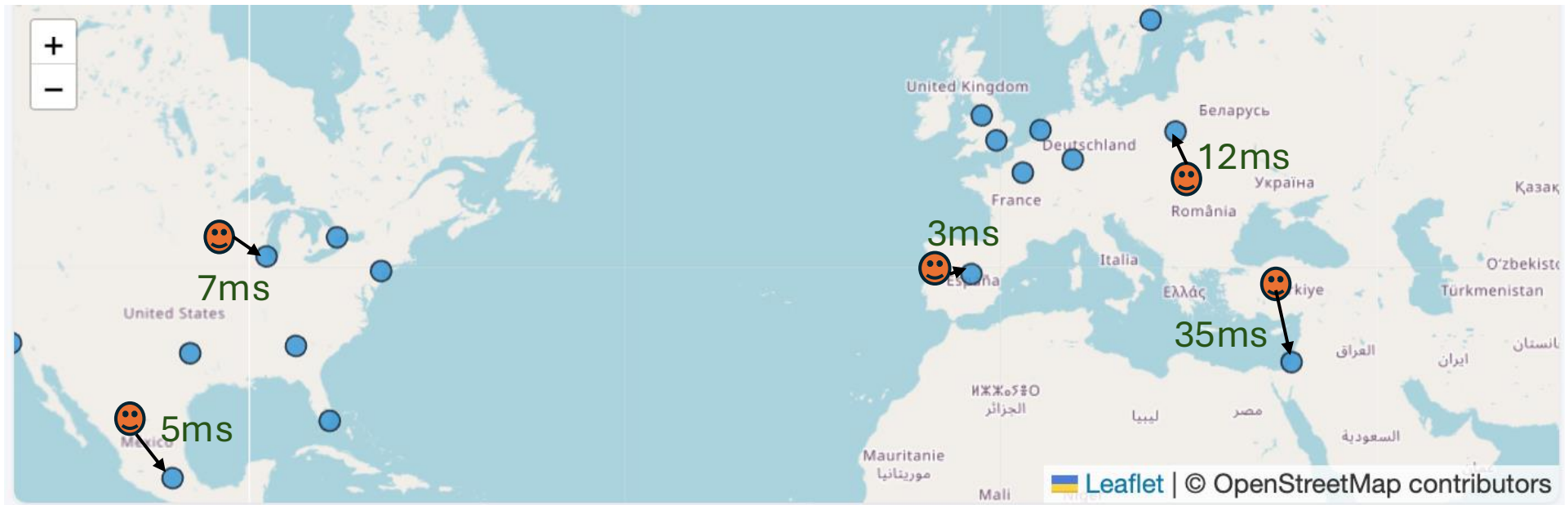
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 - *How?* - Announcing an IP prefix at multiple locations using BGP
 - *Why?* - **Distribute load**



Introduction

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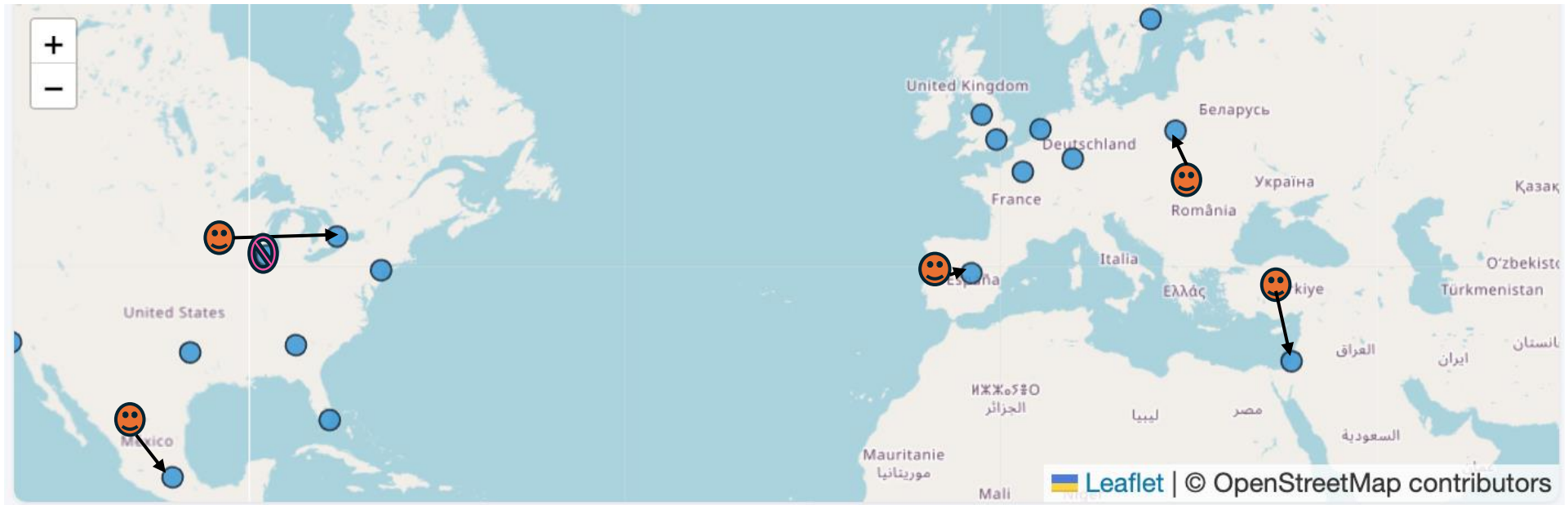
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 - *Why?* - Distribute load, **reduce latency**



Introduction

What is anycast?

- Anycast: Making an IP address available in multiple Points of Presence (PoPs)
 - *How?* - Announcing an IP prefix at multiple locations using BGP
 - *Why?* - Distribute load, reduce latency, **resiliency**



Introduction

Anycast usage

- Anycast is widely used
 - Over 1,000 ASes deploy anycast

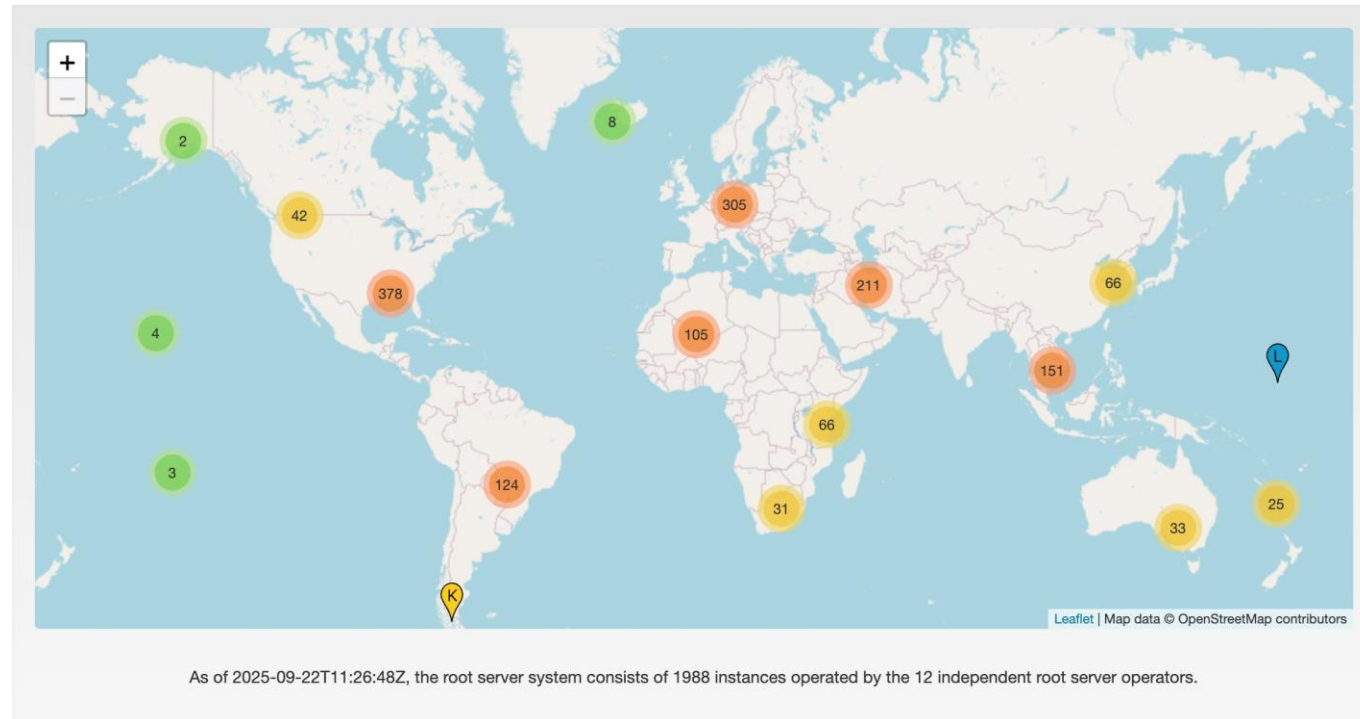
NETWORK STATISTICS (HIGH CONFIDENCE) – 2026-04-16			
	IPv4	IPv6	Union
Anycast ASes ⓘ	1,082	580	1,235
Unique BGP prefixes (backing_prefix) ⓘ	5,385	2,889	8,273
MOAS prefixes ⓘ	220	313	533

Statistics from manycast.net

Introduction

Anycast usage

- Anycast is widely used
 - Over 1,000 ASes deploy anycast
- Critical infrastructure
 - All DNS root letters



Source: root-servers.org

“All 12 DNS root-letters are deployed using anycast; combined totaling 1,988 sites”

Introduction

Anycast usage

- Anycast is widely used
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 - All DNS root letters
 - ccTLD servers (e.g., **.jp**)

JP - TLD
Census: latest · Resolved via Google Public DNS
① DNS records reflect today's resolution and may differ from the selected census date.
Click a row to look up the prefix in detail.

NS RECORDS **MIXED**

g.dns.jp **ANYCAST**

IP address	Prefix	ASN	Anycast
203.119.40.1	203.119.40.0/24	AS24252	high · 2 PoPs

h.dns.jp **ANYCAST**

IP address	Prefix	ASN	Anycast
161.232.72.25	161.232.72.0/24	AS12041	high · 4 PoPs
2a01:8840:1bc::25	2a01:8840:1bc::/48	AS12041	high · 3 PoPs

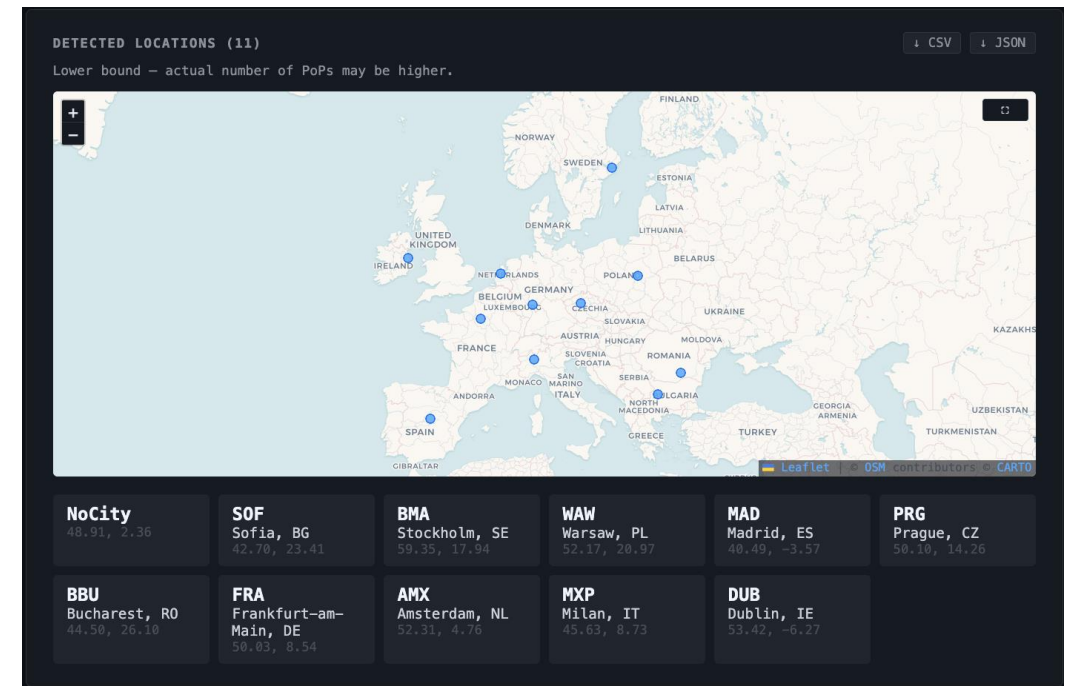
e.dns.jp **ANYCAST**

IP address	Prefix	ASN	Anycast
192.50.43.53	192.50.43.0/24	AS23634	high · 3 PoPs
2001:200:c000::35	2001:200:c000::/48	AS23634	high · 3 PoPs

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Anycast usage

- Anycast is widely used
 - Over 1,000 ASes deploy anycast
- Critical infrastructure
 - All DNS root letters
 - ccTLD servers (e.g., **.jp**)
 - Public DNS resolvers



Source: <https://manycast.net/?q=86.54.11.1>
“Example: DNS4EU public DNS resolver locations”

Introduction

Anycast usage

- Anycast is widely used
 - Over 1,000 ASes deploy anycast
- Critical infrastructure
 - All DNS root letters
 - ccTLD servers (e.g., **.jp**)
 - Public DNS resolvers
 - Time synchronization (NTP) infrastructure
 - And much more ...

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- The Internet would not function without these services
 - Hence, they deploy using anycast for its resiliency

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- The Internet would not function w
 - Hence, they deploy using anycast for its resiliency
- Also used by `hypergiants` (e.g., Google, Amazon, Cloudflare)
 - Web caching, content delivery, etc...
 - Mostly to bring services geographically closer to users (performance)


50ms
To 95% of the
world's Internet
users

Cloudflare Global Network

One of the world's largest networks —
running every service in every data center for
unmatched performance, security, and reliability.

55 cities
North America —
the densest
concentration of
Cloudflare data
centers on the
planet.



Introduction

Motivation

- Anycast plays a key role in today's Internet
- This motivates Internet measurements of anycast

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- **Barrier:** anycast infrastructure is expensive
 - Smallest prefix size that can be anycasted is a /24
 - IPv4 is scarce and expensive!
 - Not realistic for most of us academics

/24 block (256 IPs) RIPE LEGACY	Transferable to: RIPE, ARIN, APNIC, LACNIC
PRICE PER IP € 22,00 (~\$ 25,39)	PURCHASE PRICE € 5.632,00
COUNTRY OF SELLER  The Netherlands	Buy now >>

/24 block (256 IPs) RIPE ASSIGNED PI	Transferable to: RIPE, ARIN, APNIC, LACNIC
PRICE PER IP € 35,00 (~\$ 40,39)	PURCHASE PRICE € 8.960,00
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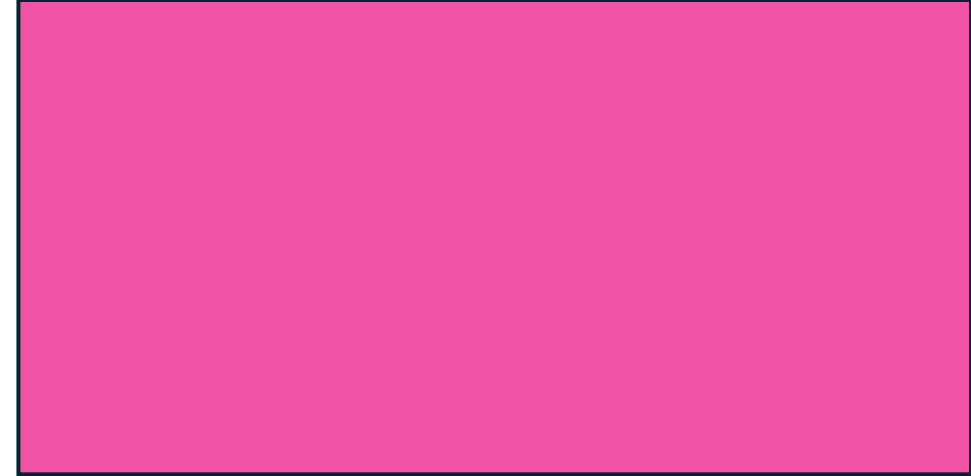
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- **Barrier:** anycast infrastructure is expensive
 - Smallest prefix size that can be anycasted is a /24
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- Our goals
 - Develop tooling that facilitates anycast experiments
 - Provide datasets that maps Internet resiliency
 - Enable an open & accessible measurement interface

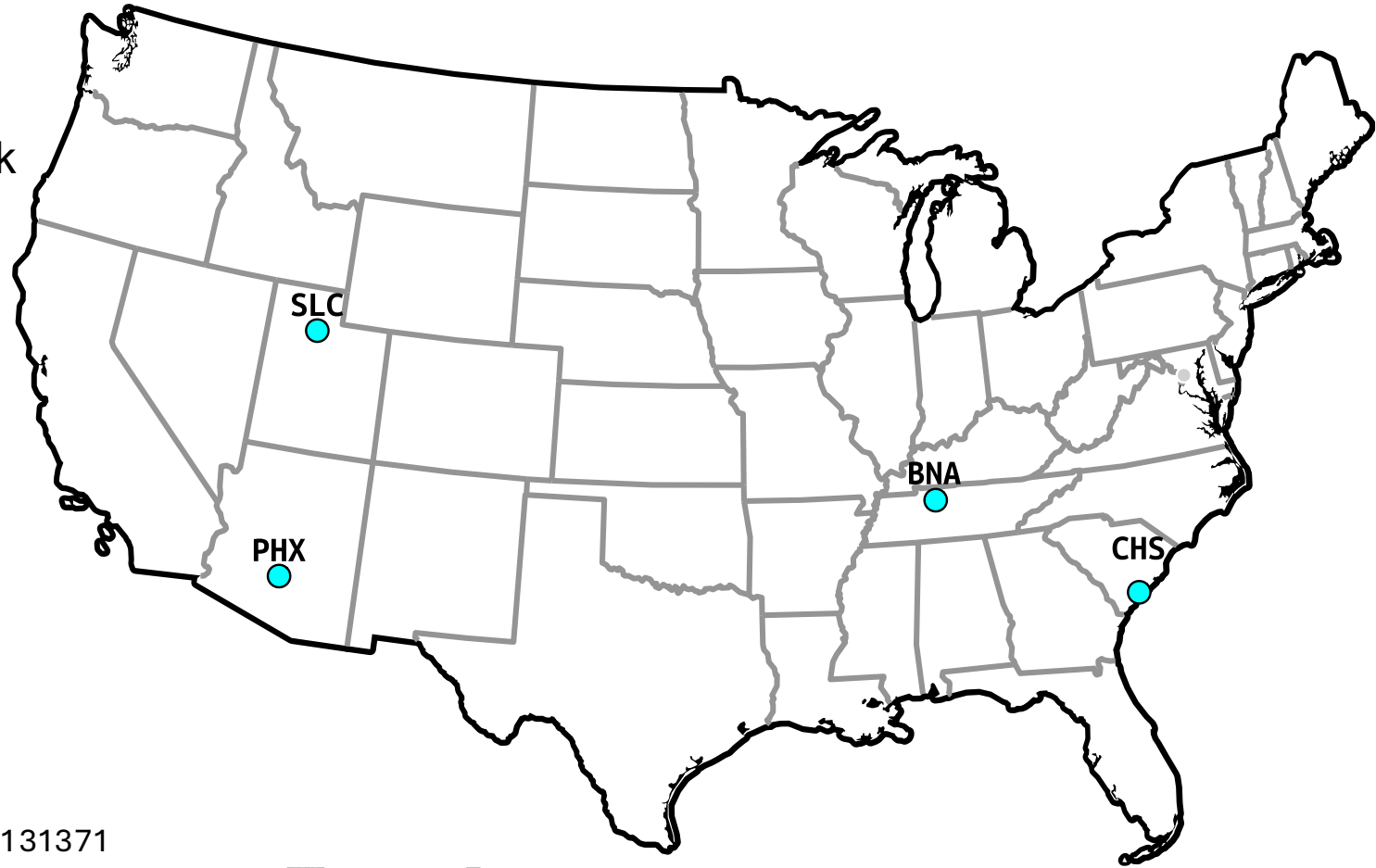
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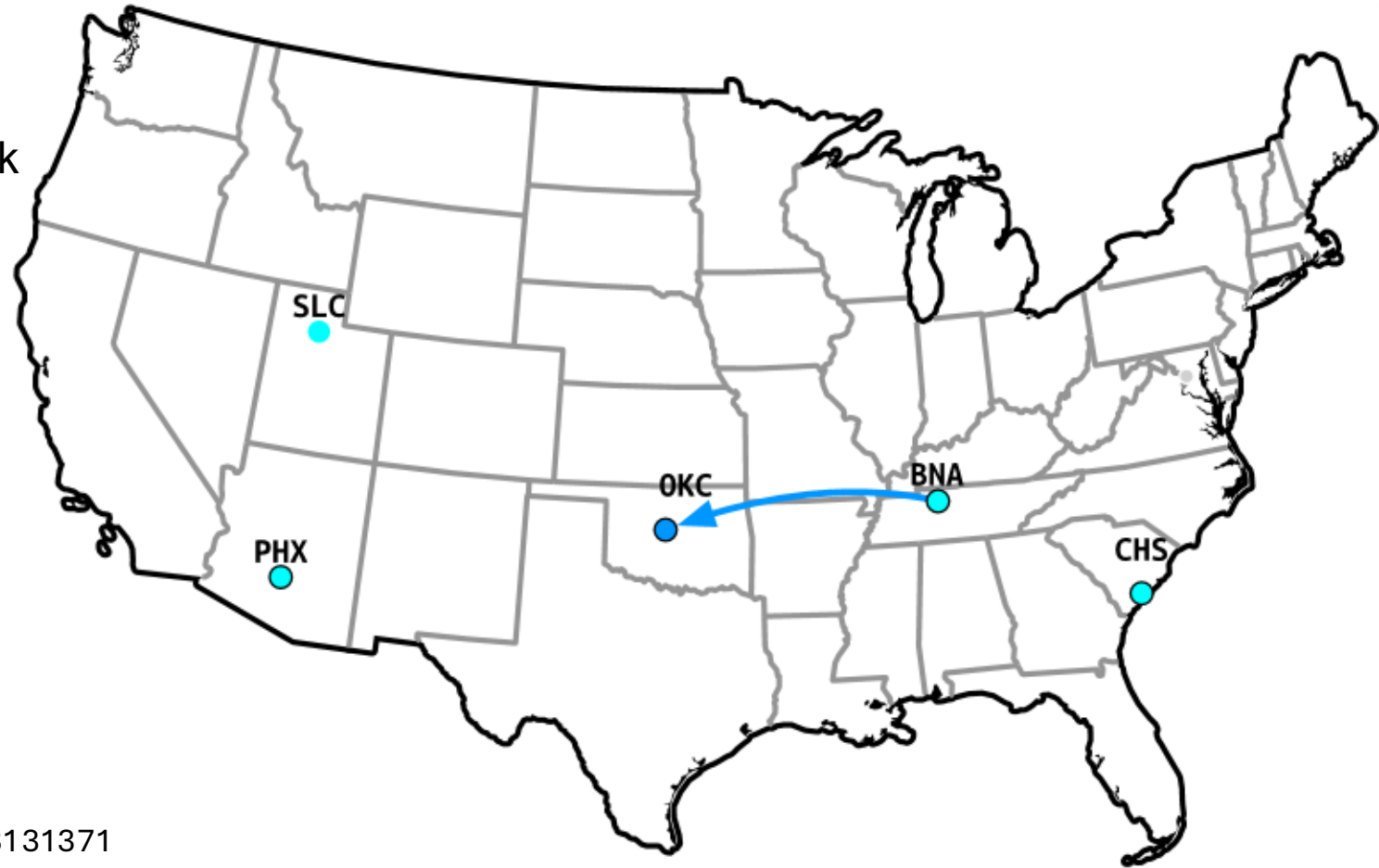
Background Verfploeter

- Verfploeter maps anycast catchments [1]
 - I.e., which anycast site 'catches' which traffic
- How?
 - Ping host with anycast source IP
 - See where the ping reply comes back



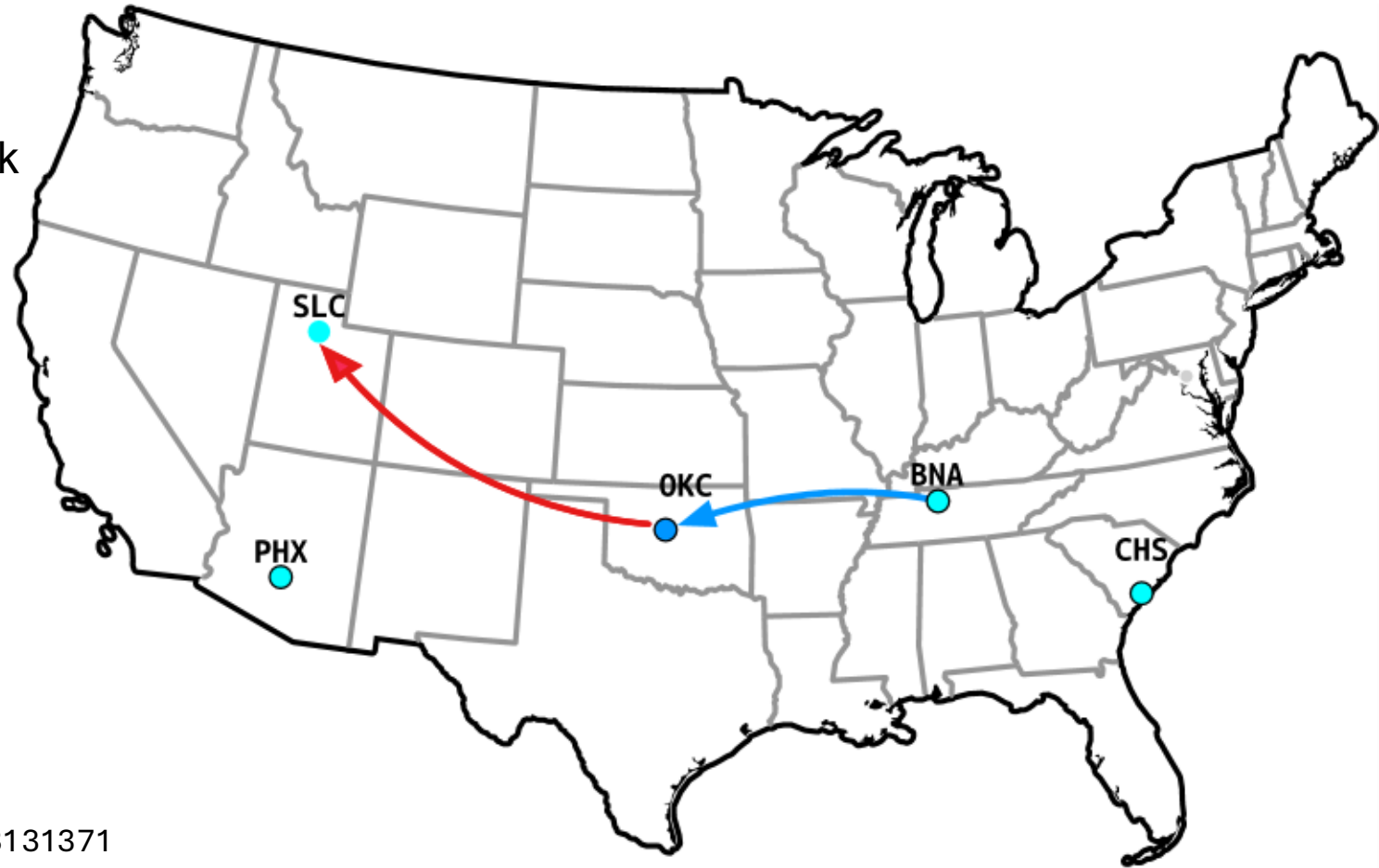
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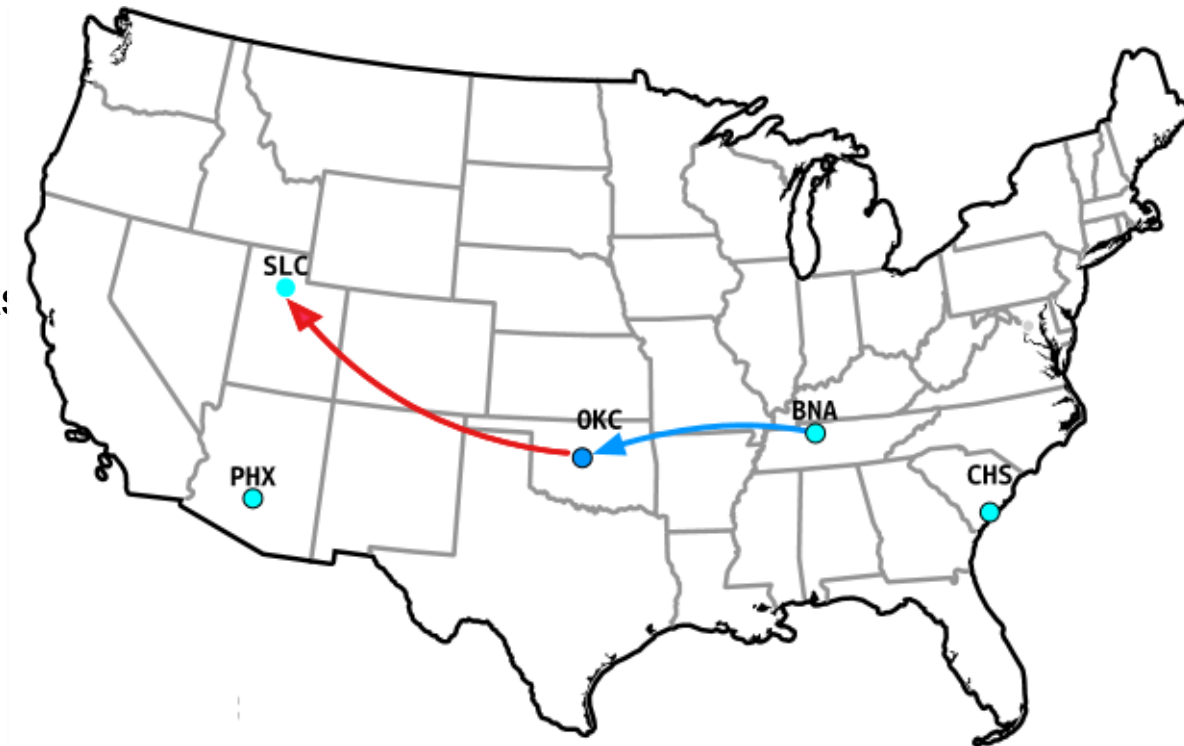
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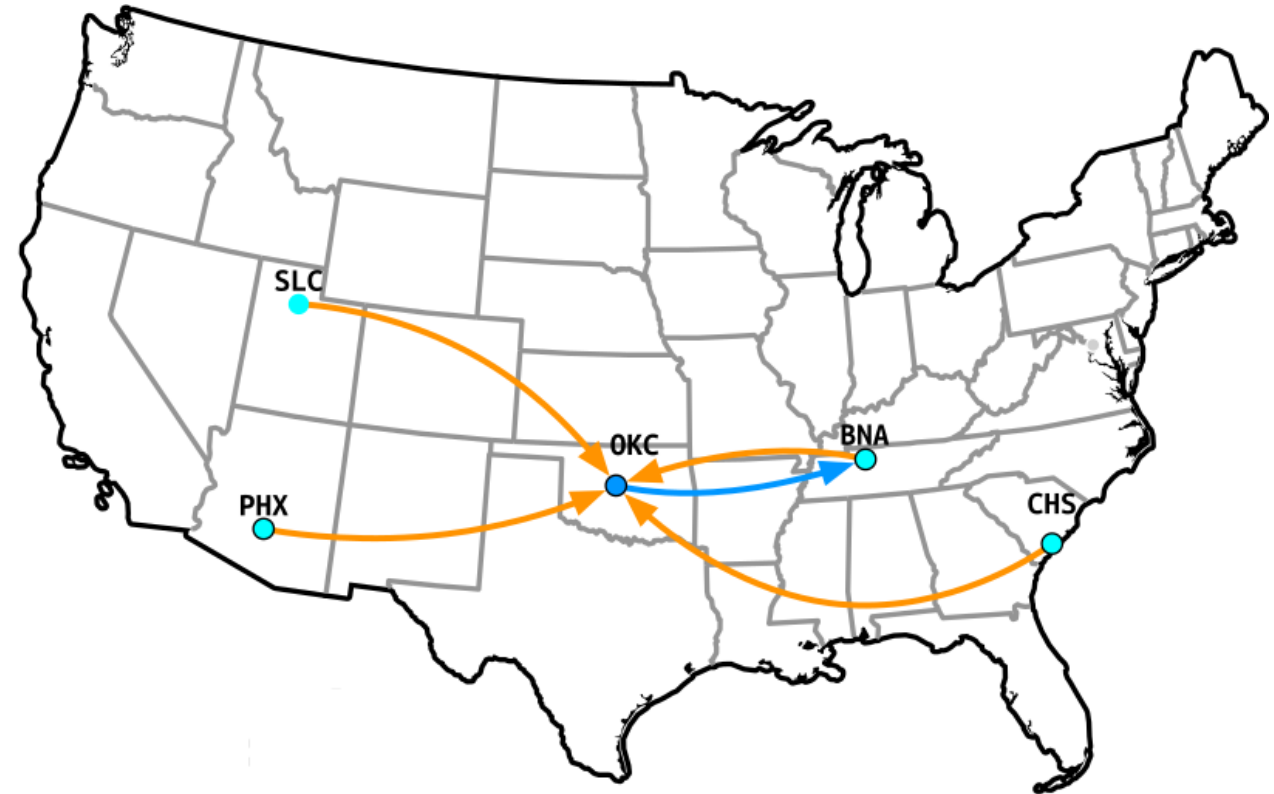
- Verfploeter maps anycast catchments [1]
 - I.e., which anycast site 'catches' which traffic
- How?
 - Ping host with anycast source IP
 - See where the ping reply comes back
- Advantages
 - Covers 4.5 million /24s with ICMP responsive hosts:
 - 70k+ ASes
 - Measures on-demand
 - Experimental prefixes, traffic changes, ...



Background

MAnycast2

- Detect anycast using anycast
- Uses Verfploeter's technique
 - With one key difference
 - Probing from all locations
- Normal behavior
 - OKC receives 4 pings
 - All pings go to the closest anycast replica (BNA)



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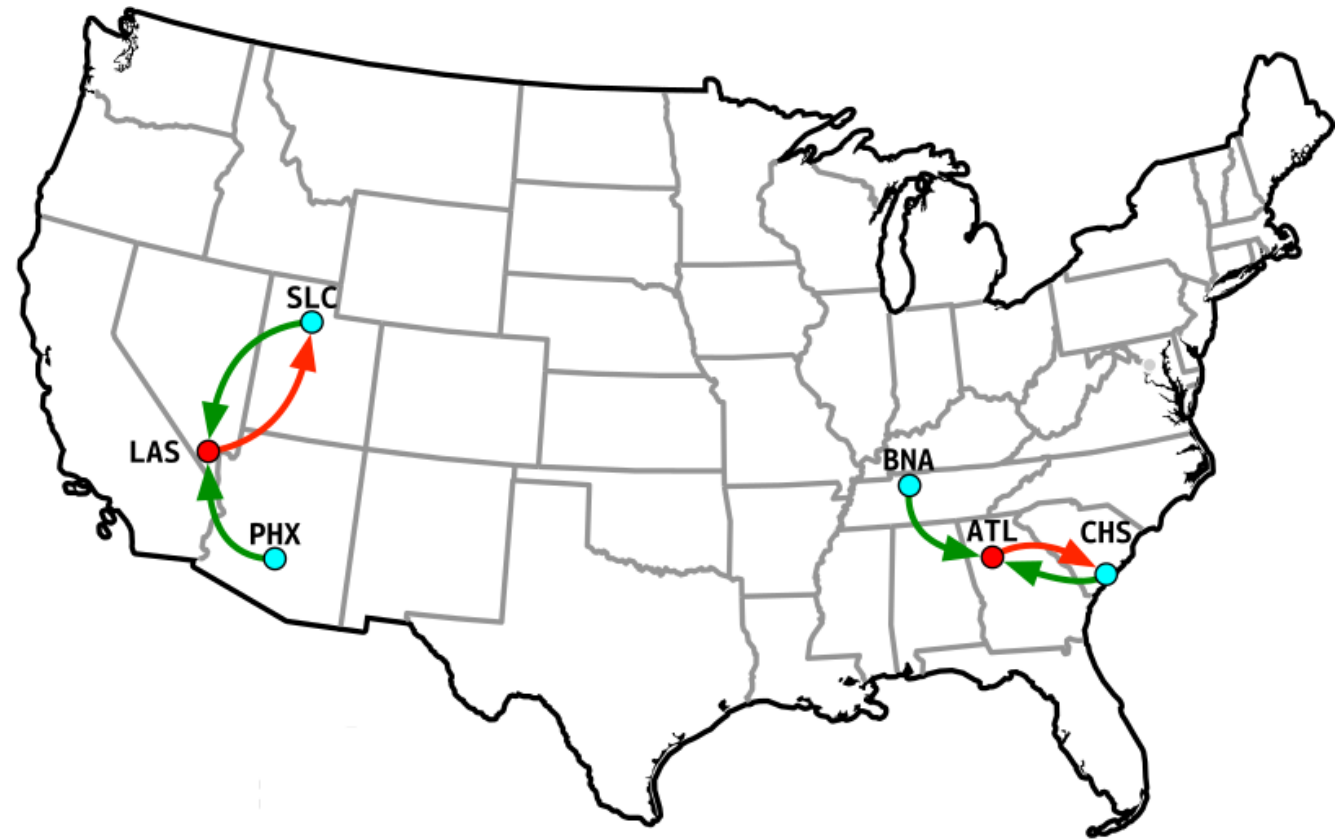
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- Things get weird when probing anycast
 - I.e., probing anycast using anycast
- Red an external anycast deployment
 - Our probes reach different sites (LAS, ATL)
 - Each site responds to their nearest replica of ours
 - > 1 replicas receive replies -> anycast



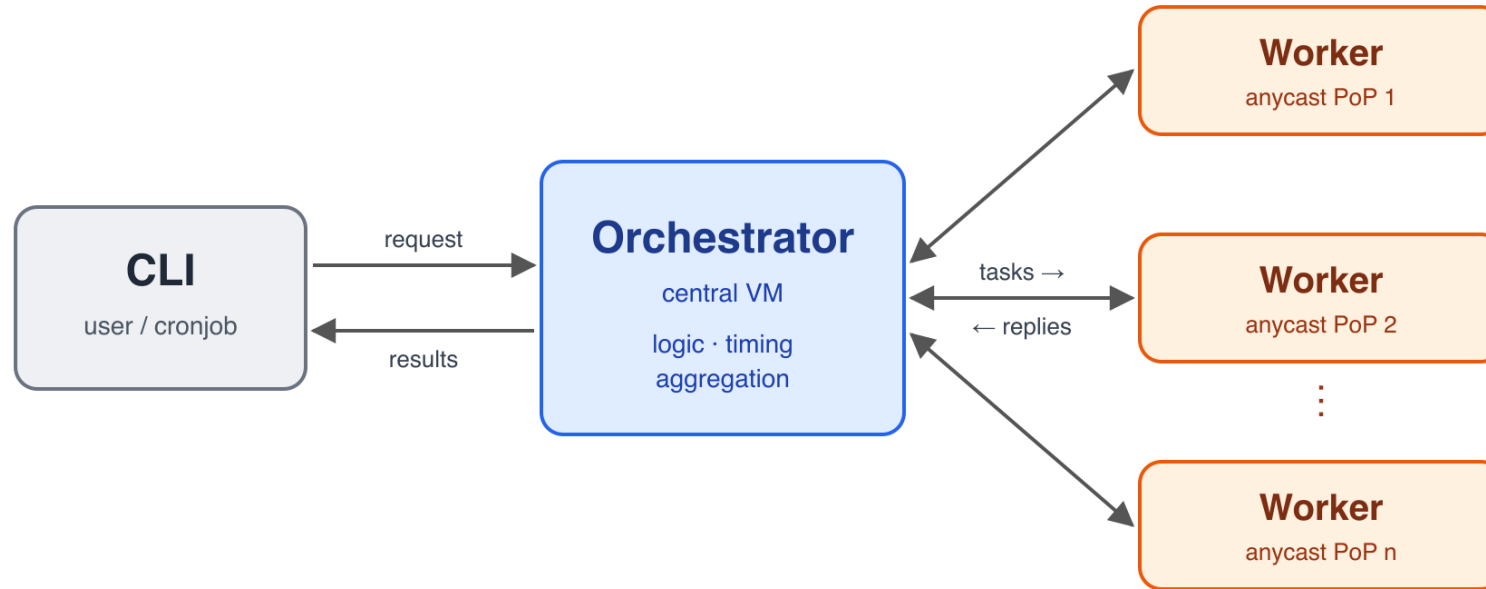
Extending previous work

- MAnycast2 was published as a proof-of-concept paper
 - Stitched together Verfploeter measurements
- Initial goal was to create a tool for daily anycast censuses
 - Available at manycast.net
- Designed to be versatile, started to be used for other use-cases
- Extended from performing anycast censuses to:
 - Measuring anycast performance (for our ccTLD partner)
 - Measuring the Internet at large using anycast's routing properties
- Thus, Measure Anycast Routing (MAnycastR) was created

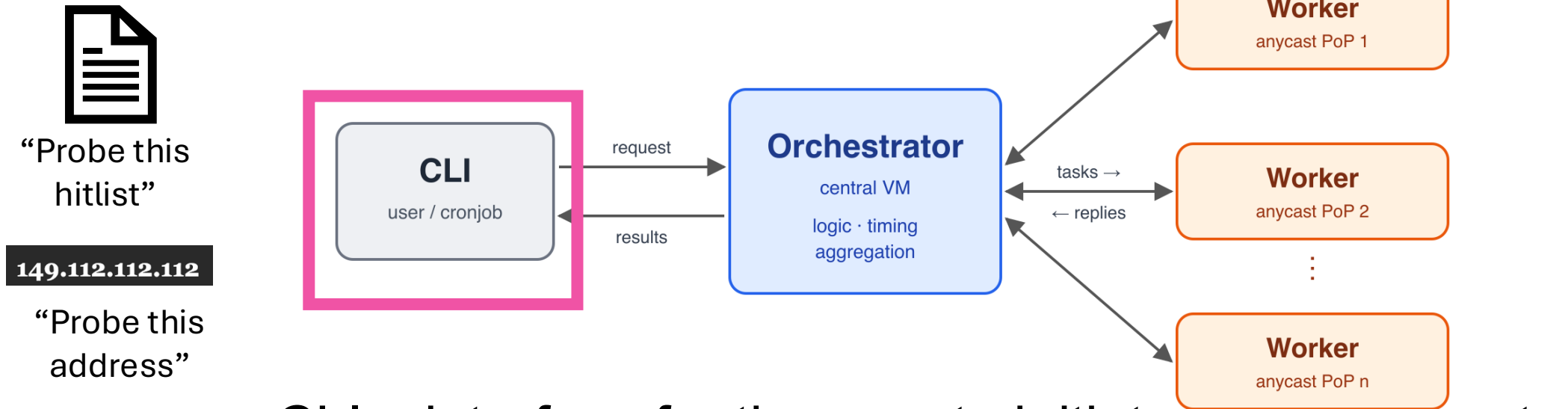
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Modular design

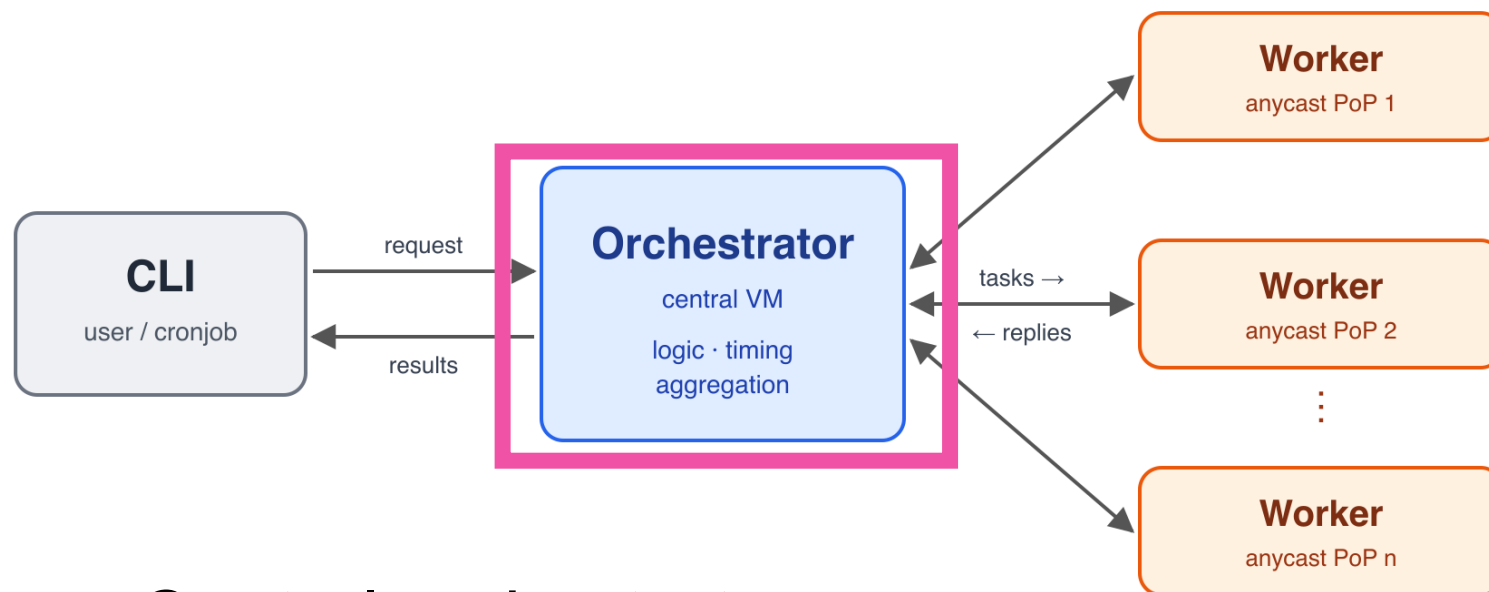


Modular design



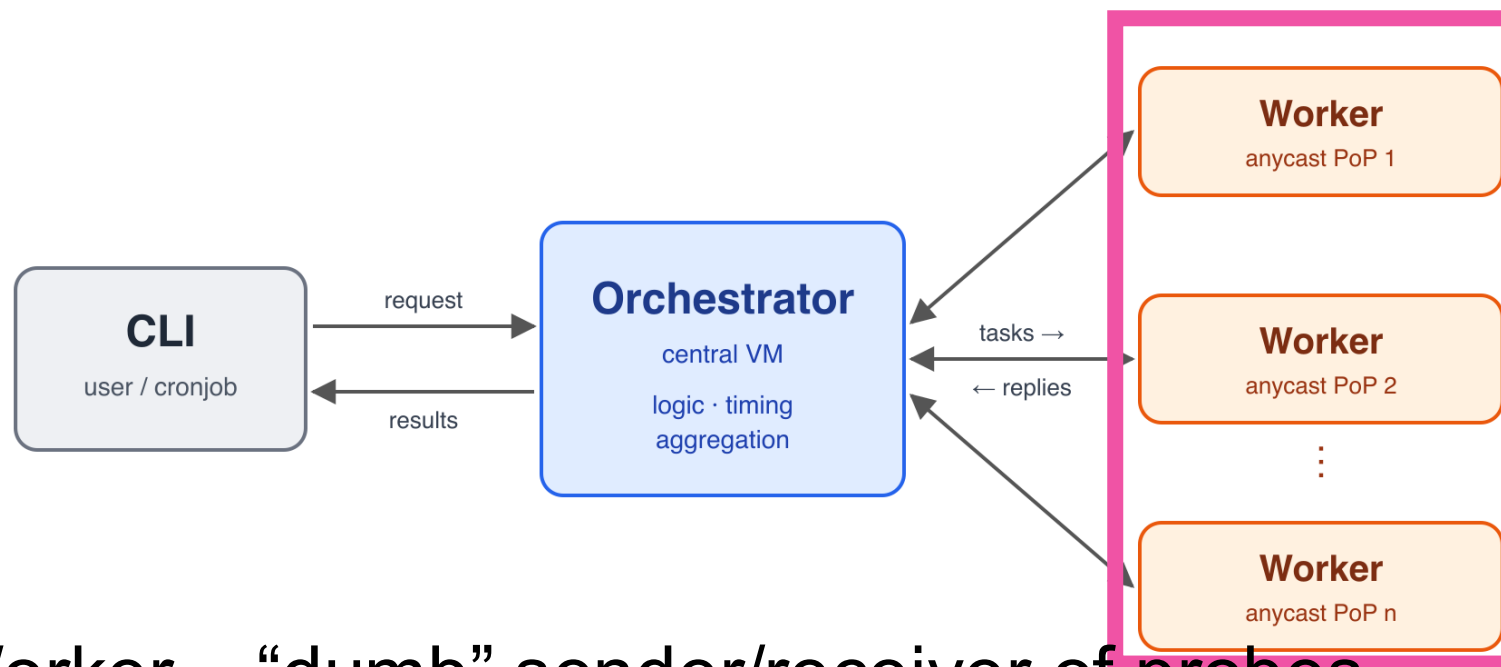
- CLI – interface for the user to initiate measurements
 - Locally, cronjob, stdout pipe (reactive), etc...
- Sends measurement requests to Orc
 - Supports individual / stdout of tasks
- Receives stream of aggregated results

Modular design



- **Orc – Central orchestrator**
 - Implements most logic, deployed at central VM
- Instructs Workers to send probes at timed intervals
- Aggregates Worker replies
 - Handles more complex follow-up logic

Modular design



- Worker – “dumb” sender/receiver of probes
 - Low resource usage
- Receive probe tasks and sends probes
- Listens for probe replies which are streamed back

System requirements

- Many features added based on “I need this for my experiment”
 - From both myself and other academics
 - Also require easy set-up/access (mostly for my own sanity)
- Also, sophisticated requirements from discussions with large operators (including commercial operators)
 - Very concerned with security
 - Variety of environments in which to deploy
 - Want no interference with production software
- Need to accommodate totally different groups!



Requirements

Versatile

- MAnycastR must maximize usefulness and coverage by supporting different measurement types
- Supports:
 - Catchment mappings (improved version of Verfploeter)
 - MAnycast2 (anycast census)
 - Measuring anycast RTTs (more on this later)
 - And much more
- IPv4/IPv6, ICMP/TCP/DNS

Requirements Configurable

- We allow users freedom to define their own measurements
 - Allows for satisfying both academics and operators
- At the same time we provide sensible default values
 - Users do not need to read a manual to get started

Requirements

Plug-and-play, scalable, secure

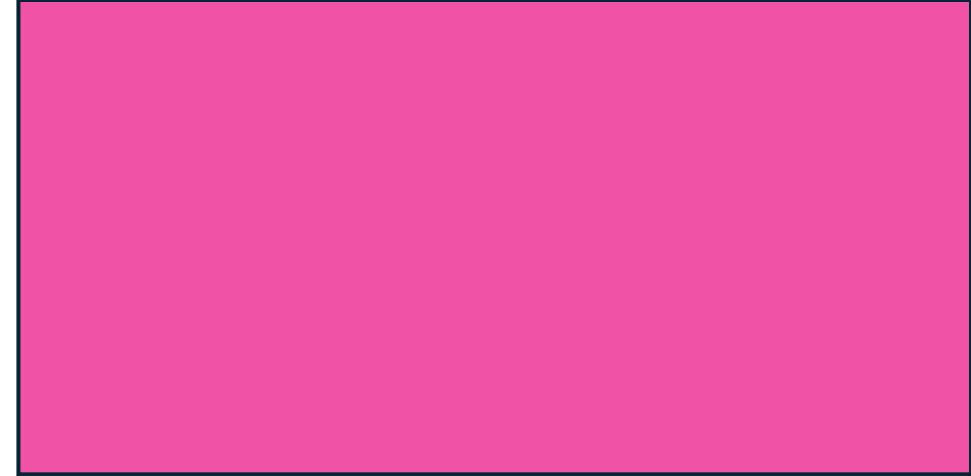
- We make deployment easy, portable
 - Allow deployment on variety of operator infrastructure
- Deployment can be containerized (e.g., Docker) to enable security constraints
- Inter-component communication using TLS
- Our system works for both small and large deployments
 - Verified working on a deployment of 150 PoPs :)

Main uses of MAnycastR

- As mentioned, MAnycastR is used by researchers and operators
- Following slides highlight its usefulness for both groups
- For operators
 - Measuring performance and optimal performance
- For academics
 - Providing an anycast census
 - Enabling Internet measurements

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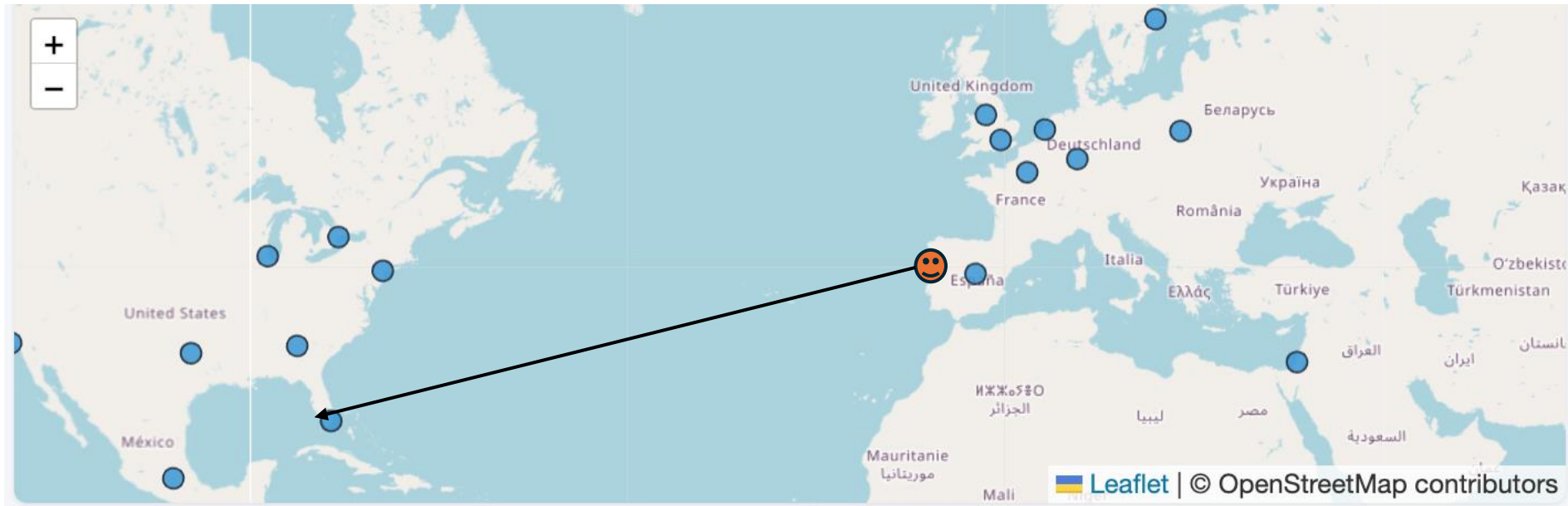


Measuring anycast performance

- Anycast routing can be sub-optimal
 - Clients reaching distant replicas
 - High latencies, long paths, congested links, increased packet loss, ...
 - Poor load distribution amongst replicas
- Performance metrics help with
 - Infrastructure (expansion) planning
 - Making traffic engineering decisions
- MAnycastR assists in getting these metrics
- Used by root-letter, ccTLD, and commercial operators

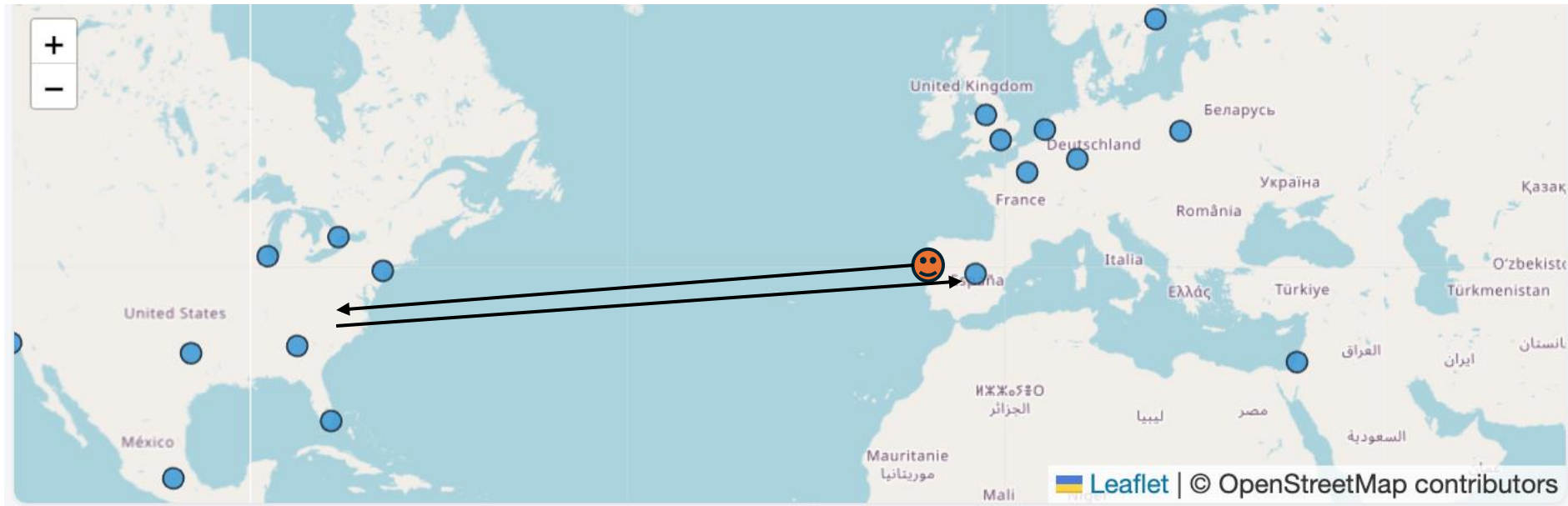
Anycast routing problems

- Anycast relies on BGP to route clients
- But.. BGP routes based on shortest path -> not performance
- Case A) Client routes to a distant PoP



Anycast routing problems

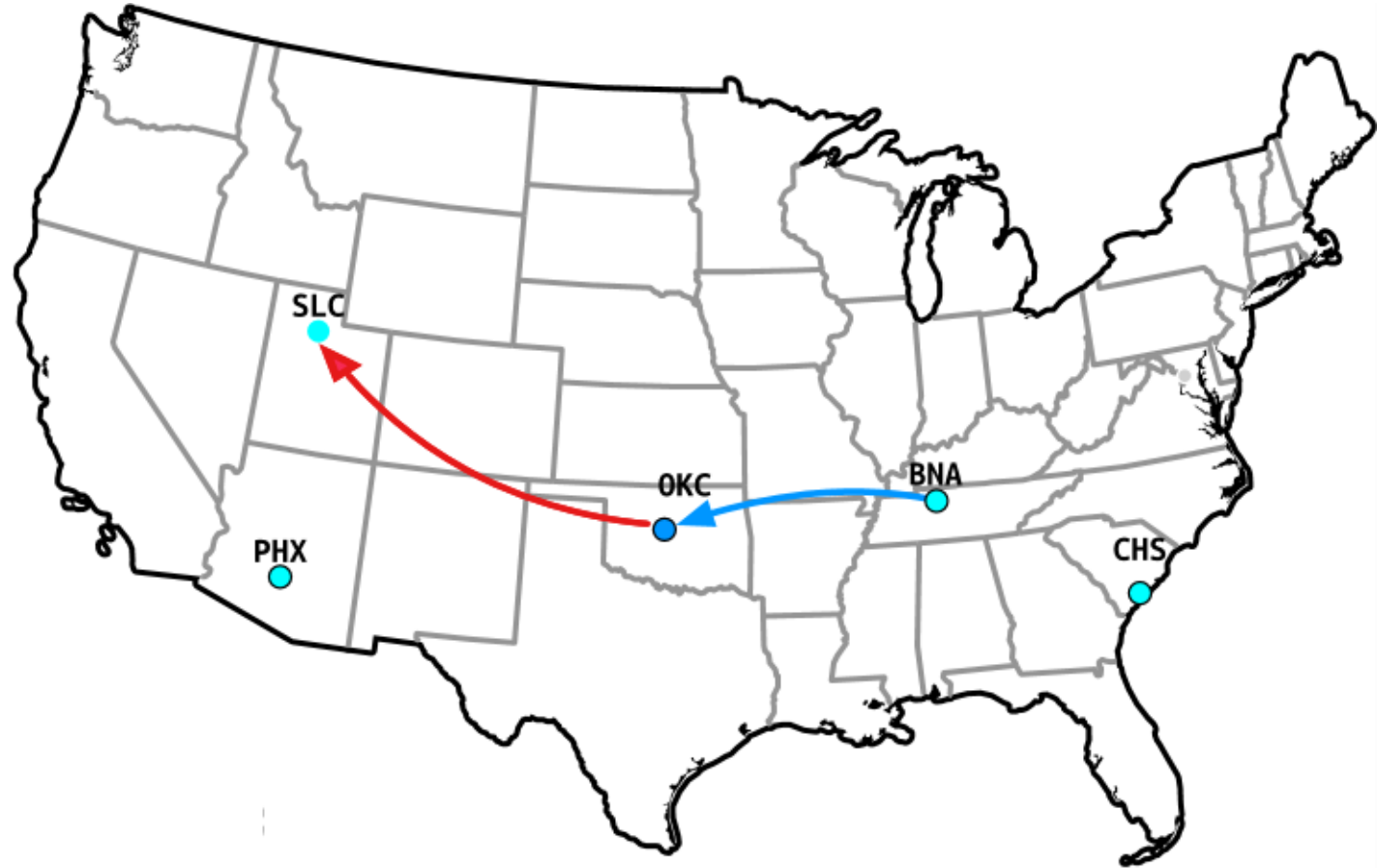
- Anycast relies on BGP to route clients
- But.. BGP routes based on shortest path -> not performance
- Case B) Client routes to a nearby PoP, with a long/slow path
 - *E.g., boomerang routing*



Measurement type

Anycast RTT

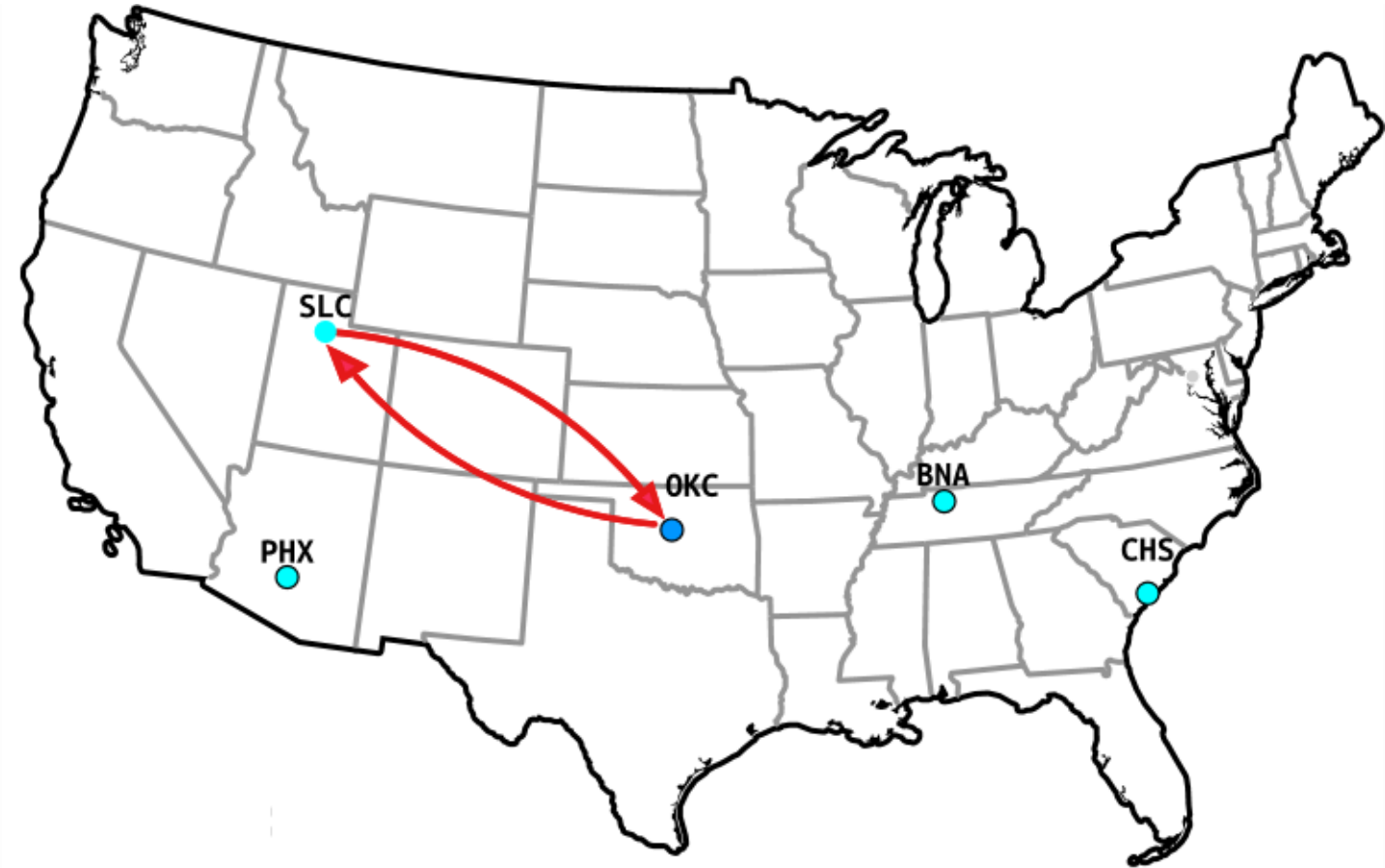
- **Probe 1: assess catchment (discovery probe)**
- Probe 2: probe from catcher (measurement probe)
 - $RTT = \text{receive time} - \text{transmit time}$



Measurement type

Anycast RTT

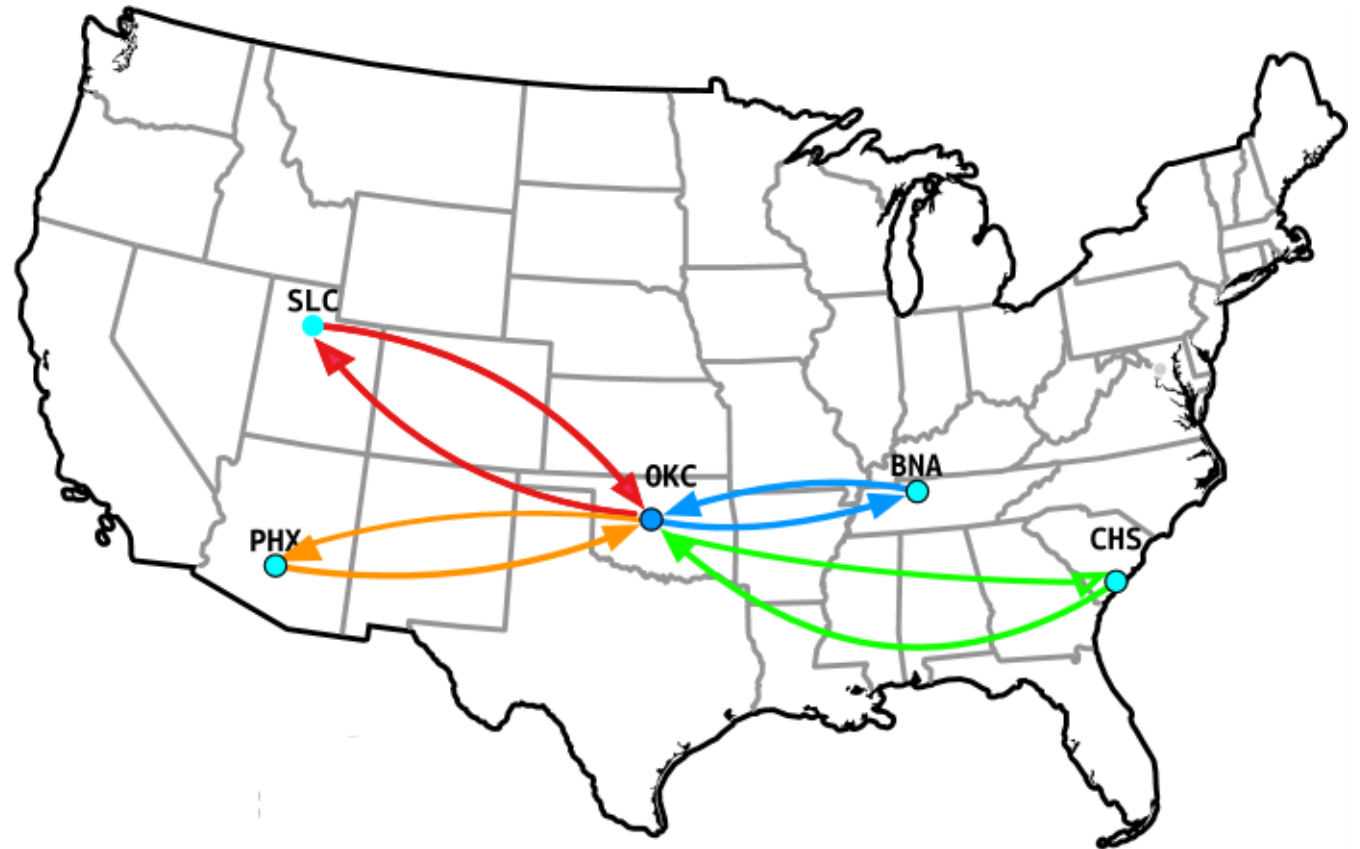
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Measurement type

Unicast broadcast

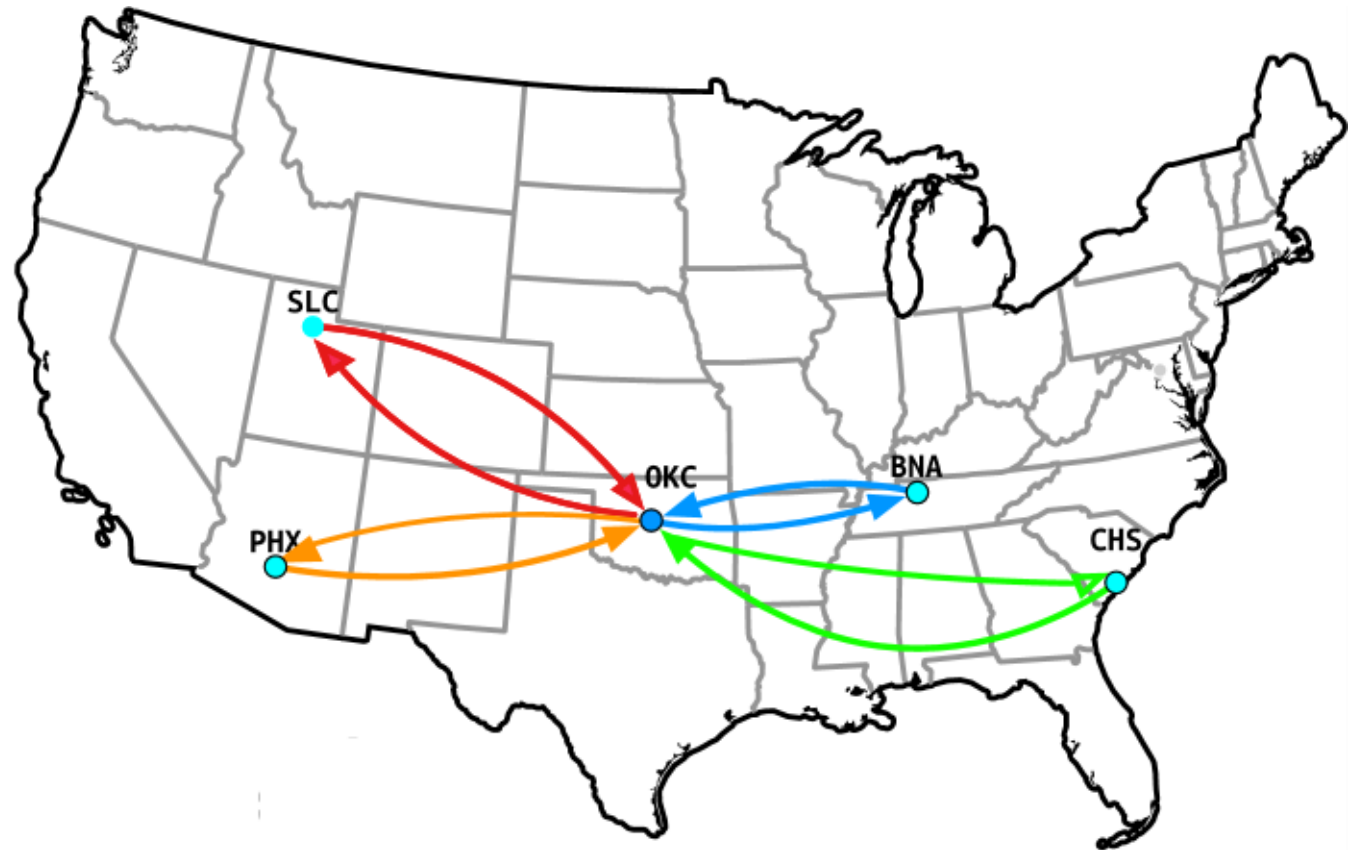
- Probe target from all VPs using unicast IPs
 - Measures RTT with all possible sites
 - Site with lowest RTT -> 'optimal' site



Measurement type

Unicast broadcast

- Probe target from all VPs using unicast IPs
 - Measures RTT with all possible sites
 - Site with lowest RTT -> 'optimal' site
- Allows for:
 - Identifying best site
 - Quantifying possible RTT improvement



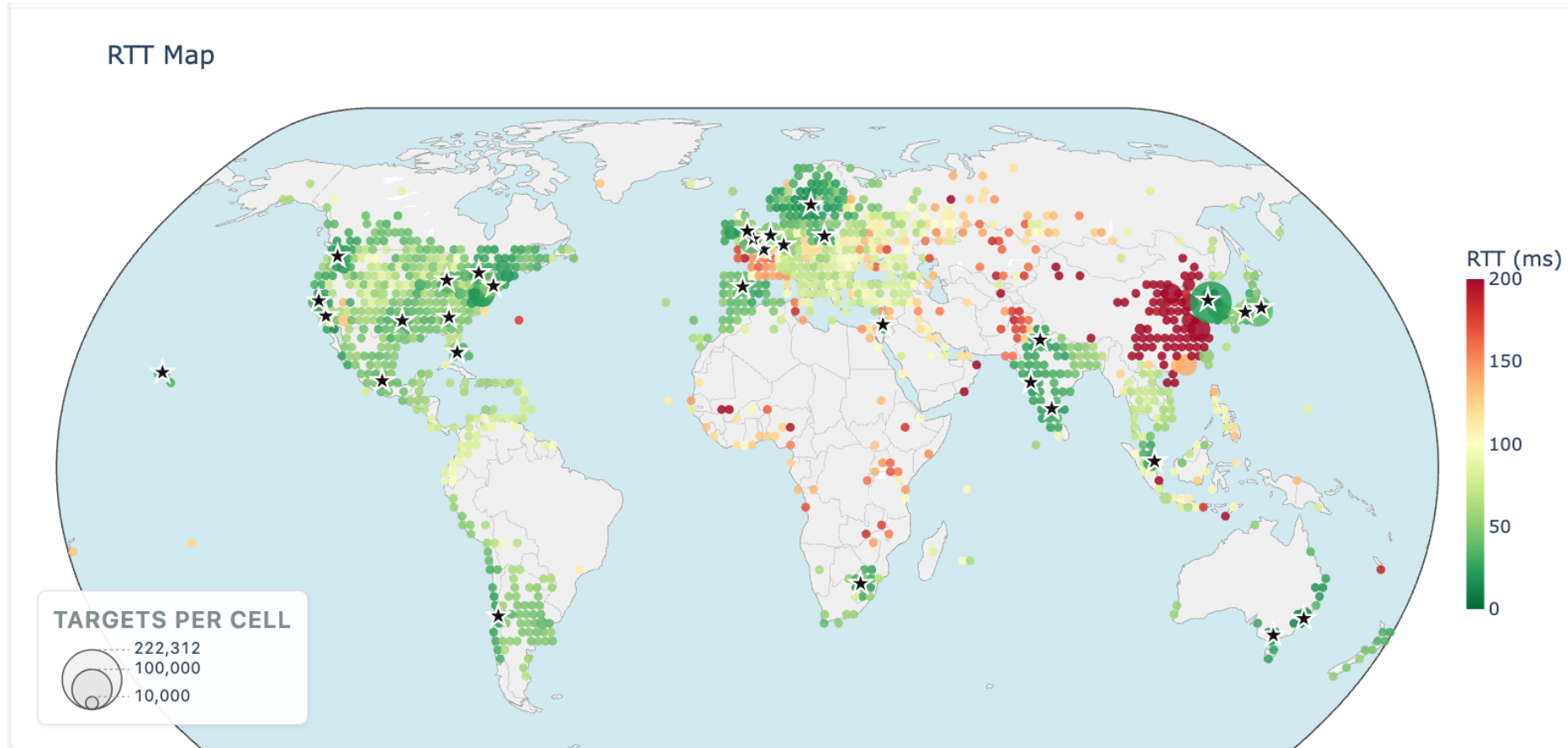
Results

- Measurement results for our anycast testbed
 - Deployed with Vultr (32 PoPs)



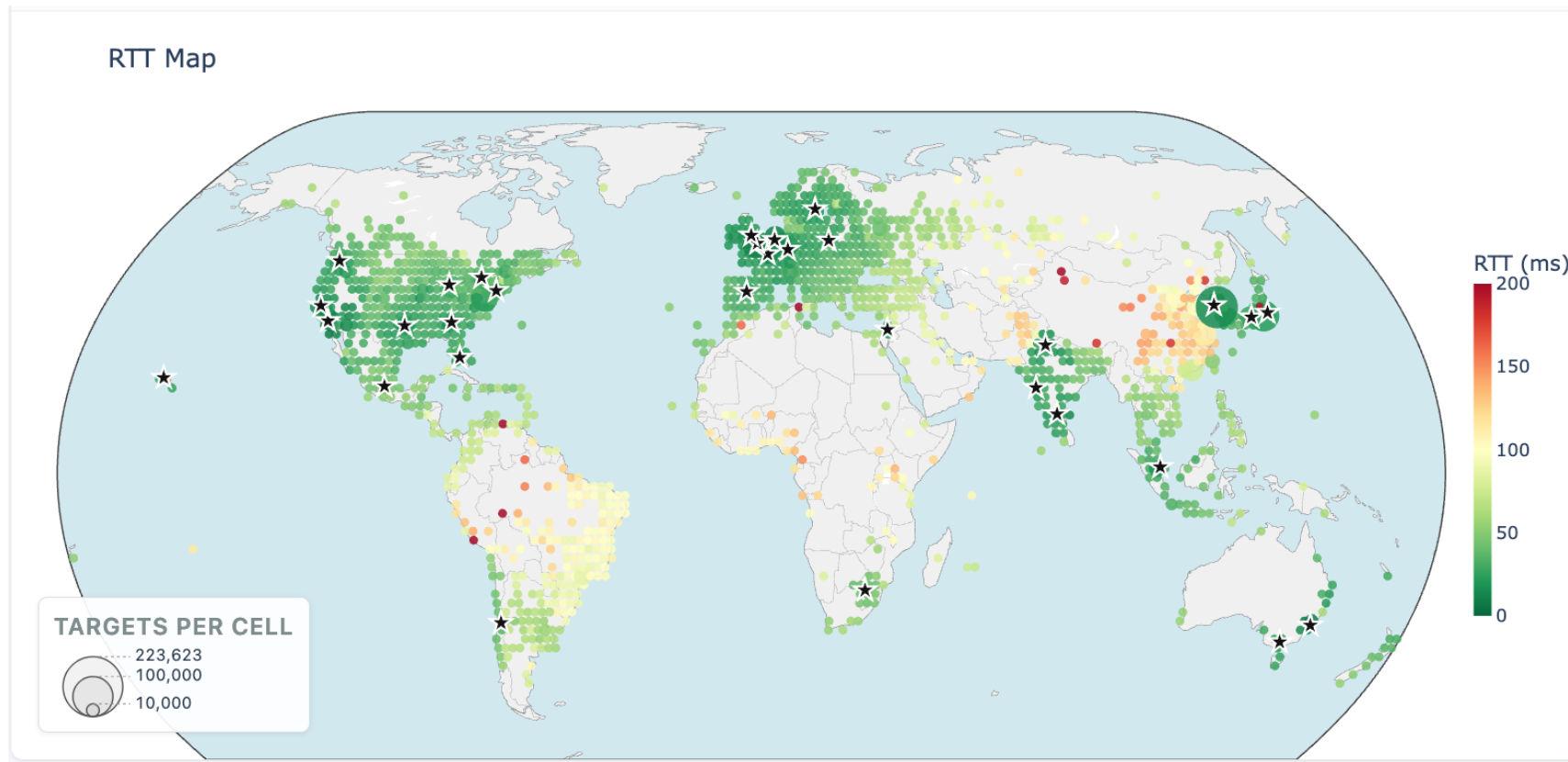
RTTs

- Latencies experienced by networks connecting to our testbed



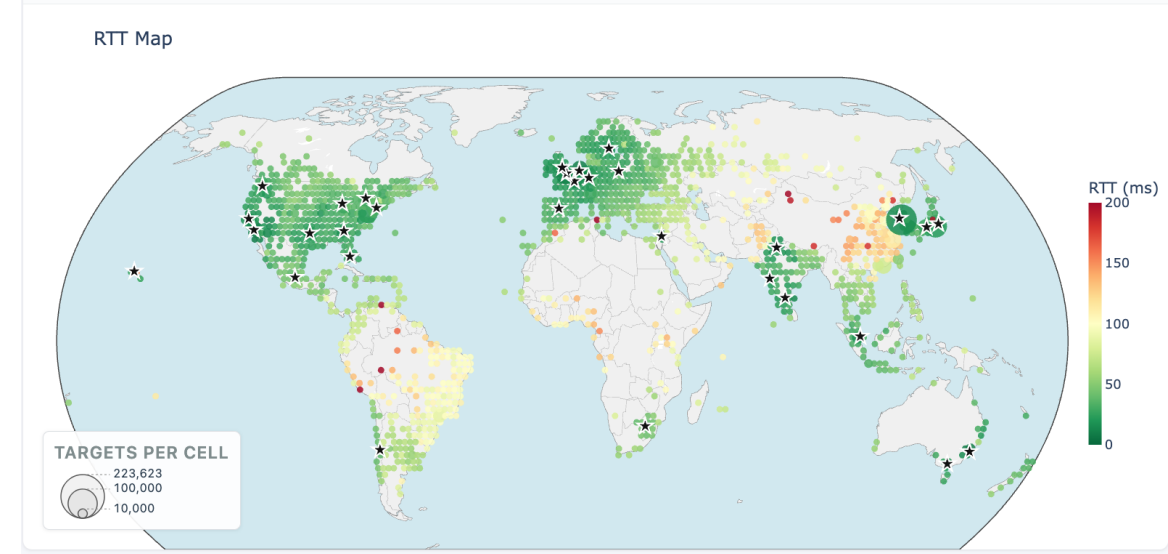
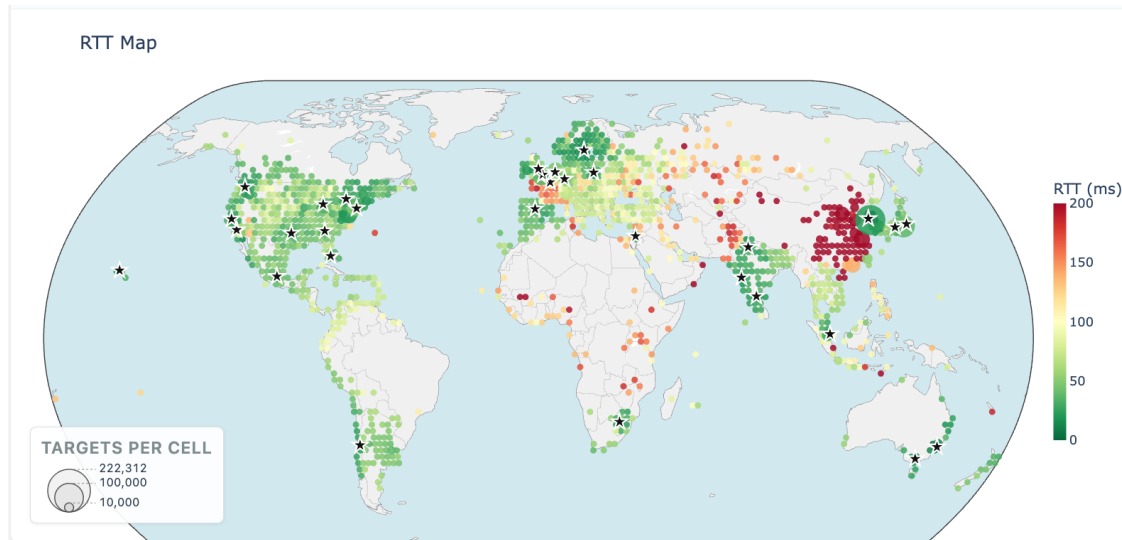
RTTs

- Optimal latencies for networks towards our testbed



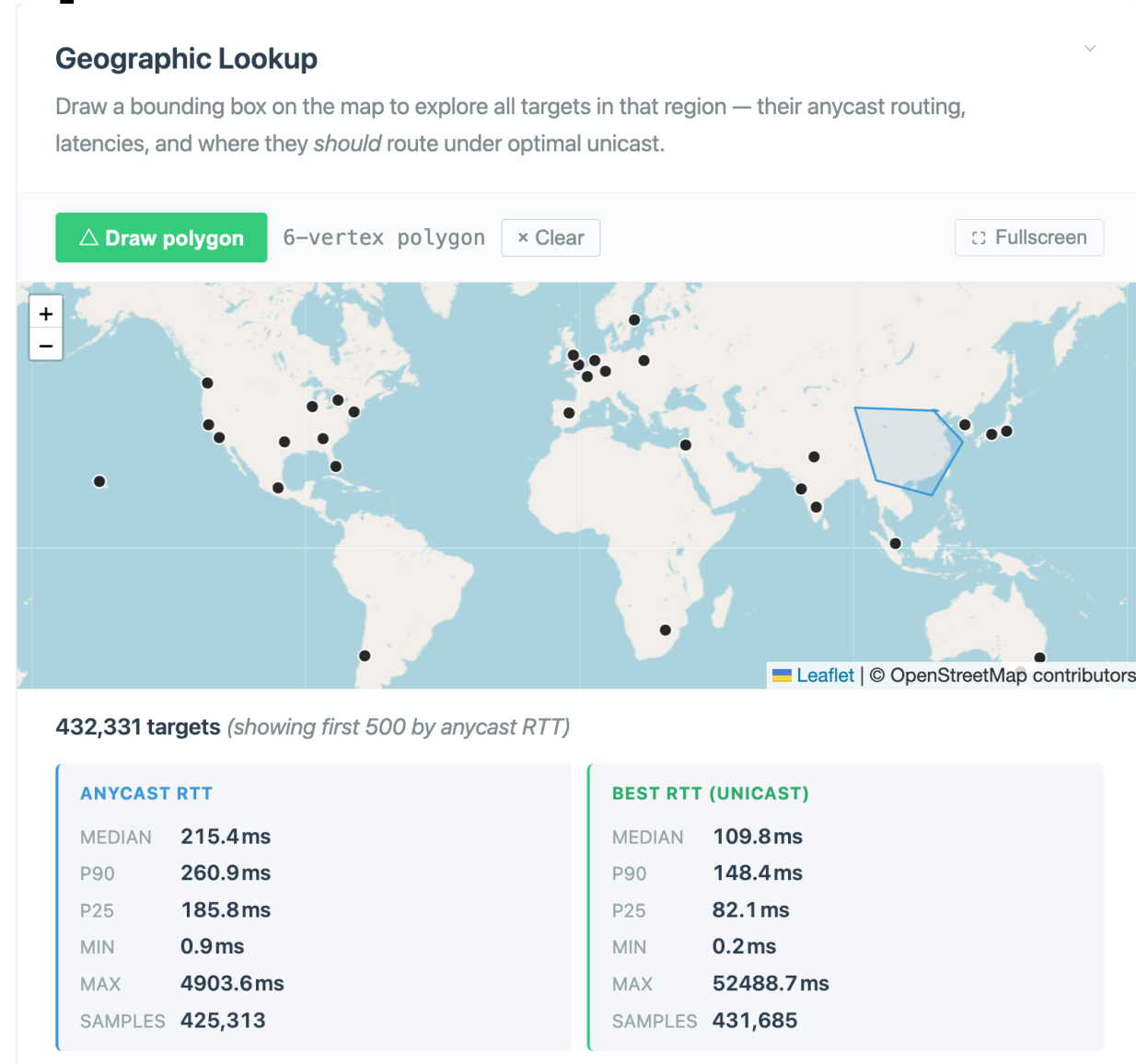
RTTs

- Takeaways:
 - Latencies shows who routes good, who routes bad
 - Optimal latencies show who 'could' route good -> TE needed
 - And who 'cannot' route good -> PoP placement needed



Quantifying Improvement

- Zooming in on China
 - Horrible median RTT (215)
 - Optimal can lower it to 110
 - Still bad however..
- Suggests lacking PoPs in China



Quantifying Improvement

- Zooming in on China
 - Horrible median RTT (215)
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▼ ASNs 200						
ASN	OPERATOR	TARGETS	TOP POP	ANYCAST RTT	BEST RTT	
AS4134	CHINANET-BAC...	111,647	de-fra-manycast	228.4ms	134.0ms	
AS4837	CHINA169-BAC...	90,880	de-fra-manycast	219.0ms	90.3ms	
AS37963	ALIBABA-CN-N...	24,915	gb-lhr-manycast	218.1ms	97.8ms	
AS9808	CHINAMOBILE-...	21,340	gb-lhr-manycast	237.9ms	129.6ms	
AS45090	TENCENT-NET-...	17,739	de-fra-manycast	217.9ms	123.3ms	

24/29

Geographic Lookup

Draw a bounding box on the map to explore all targets in that region — their anycast routing, latencies, and where they *should* route under optimal unicast.

△ Draw polygon

6-vertex polygon

× Clear

Fullscreen



432,331 targets (showing first 500 by anycast RTT)

ANYCAST RTT

MEDIAN 215.4ms
P90 260.9ms
P25 185.8ms
MIN 0.9ms
MAX 4903.6ms
SAMPLES 425,313

BEST RTT (UNICAST)

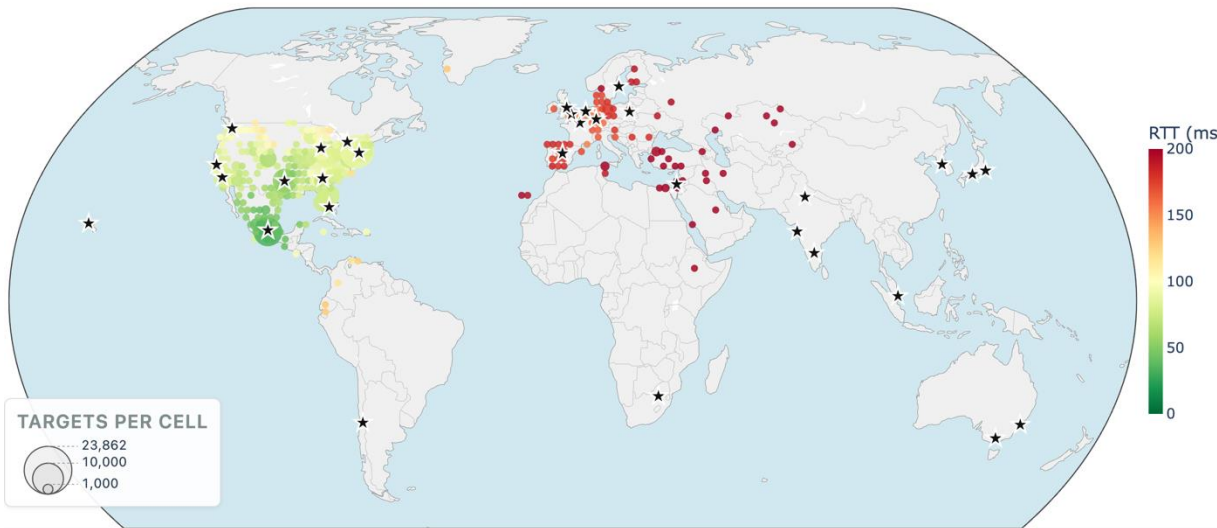
MEDIAN 109.8ms
P90 148.4ms
P25 82.1ms
MIN 0.2ms
MAX 52488.7ms
SAMPLES 431,685

RTTs

mx-mex

- Actual (left) and optimal (right) RTTs for our second-largest PoP by catchment
- RTTs are optimal for Mexican networks
- But south US networks have good RTTs
 - RTT gain probably not worth the traffic engineering

RTT Map

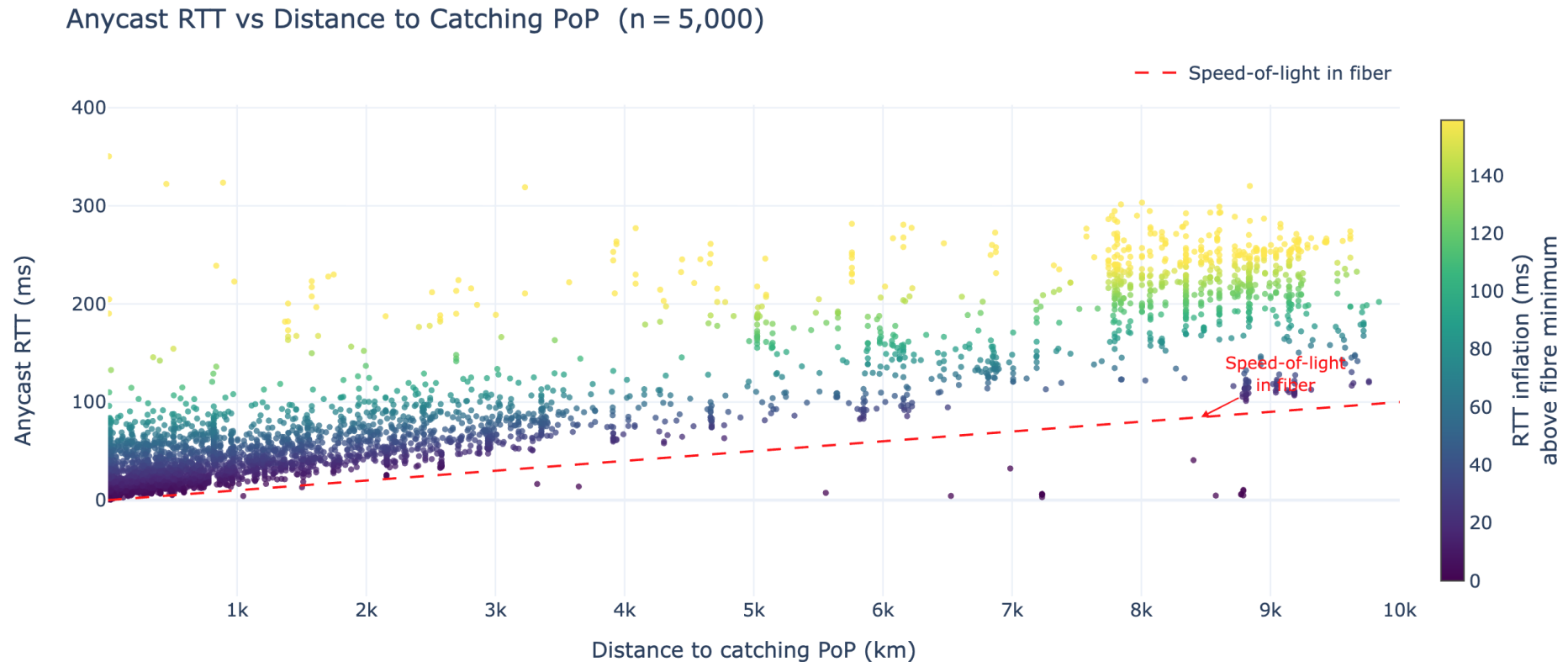


RTT Map



RTT against Catchment

- Measured anycast RTTs (y-axes)
- Distance from catching PoP (x-axis)
 - Using IPInfo

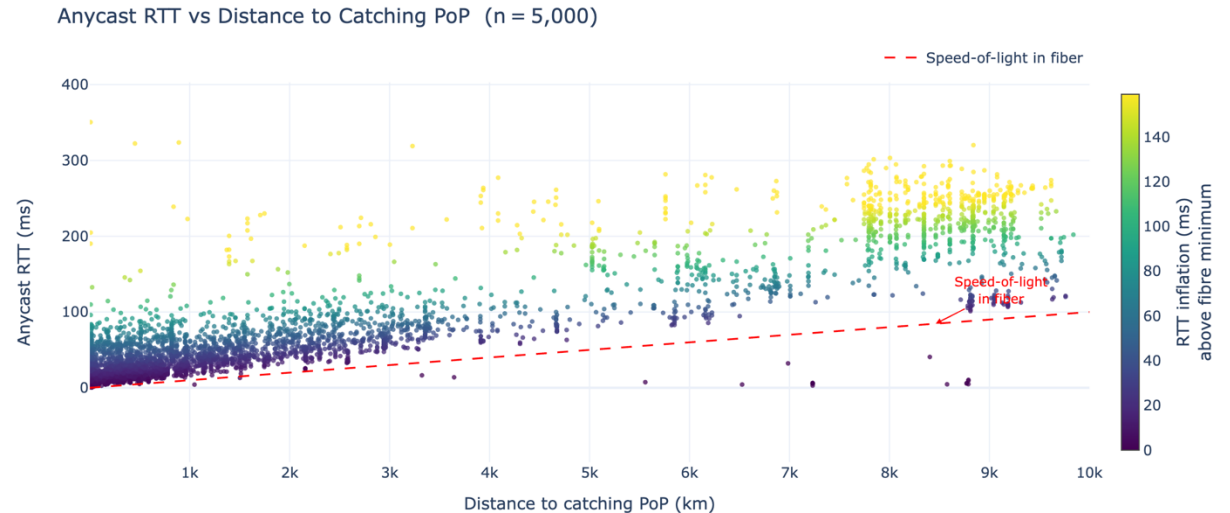


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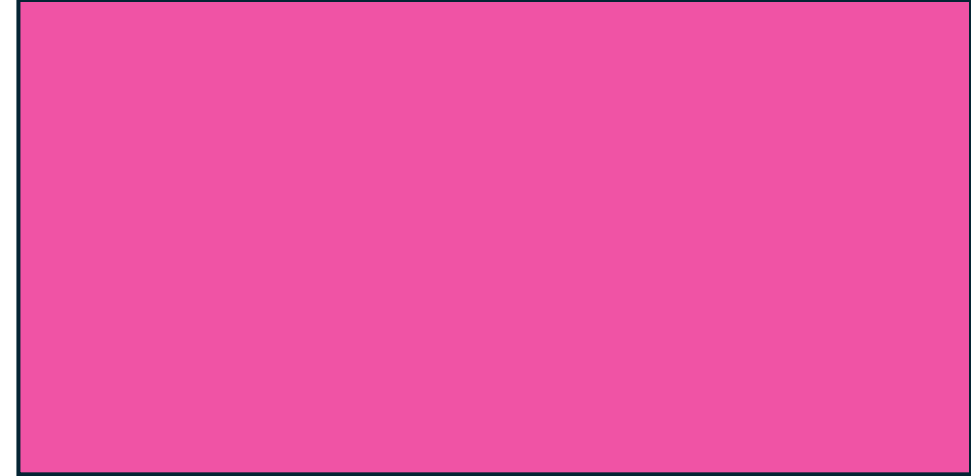
Takeaways

- Catchments can be misleading
 - Catchment inferred distance $\neq$ path length
 - *E.g.*, boomerang routes
- RTT is a better indicator of performance
 - Accounts for congested links
 - Accounts for long paths (to nearby targets)



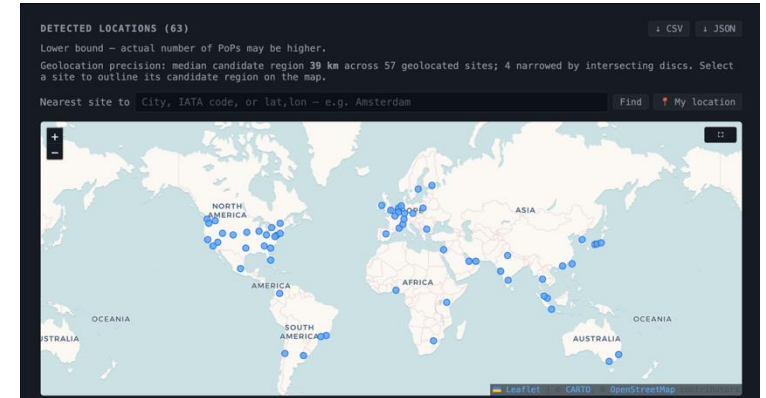
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Daily anycast census

- We use MAnycastR to publish a daily census
 - Available at manycast.net
- Provides detection of anycast
 - Covering both IPv4 and IPv6
- Also geolocates anycast
 - Counting the number of replicas behind an anycast IP
 - And geolocating each replica
- Useful for
 - Resilience assessment
 - Understanding anomalous routing behavior in measurements
 - Making better routing decisions for operators



Anycast census use-cases

Resilience assessment

- Used our dataset to see which anycast deployments have presence in Taiwan

**When Submarine Cables Go Dark:
Understanding and Preparing for the
Risks of Taiwan's International Internet
Disconnection**

Anycast census use-cases

Resilience assessment

- Used our dataset to see which anycast deployments have presence in Taiwan
- Examples of academia using our dataset to assess resiliency of infrastructure

Critical BGP Prefixes: A Measurement-based Investigation of Critical Infrastructure Security

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BigTime: Characterizing Large Time Service Providers

Technical Report SIDN Labs 2025-12-01

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Country-in-the-Middle: Measuring Paths between People and their Governments

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Anycast census use-cases

Resilience assessment

- Used our dataset to see which anycast deployments have presence in Taiwan
- Examples of academia using our dataset to assess resiliency of infrastructure
- Used by Internet2 to make better routing decisions

Internet measurements

- MAnycastR enables anycast measurements
- Anycast has unique routing properties
 - Clever measurement design can utilize them
 - *E.g.*, measuring churn of IP prefixes

A First Look at Starlink's Geofeeds: On Discrepancies between Feeds and Routing

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Internet measurements

- MAnycastR enables anycast measurements
- Anycast has unique routing properties
 - Clever measurement design can utilize them
 - *E.g.*, measuring churn of IP prefixes
- Measuring anycast routing properties - -
 - Convergence time
 - Catchment stability
 - Load-balancers vs. anycast
 - Remote peering latency inflation
 - And many more

An Empirical Characterization of Anycast Convergence Time

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Load-Balancing versus Anycast: A First Look at Operational Challenges

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Too Remote to Be Local: Latency Inflation in Anycast due to Remote Peering

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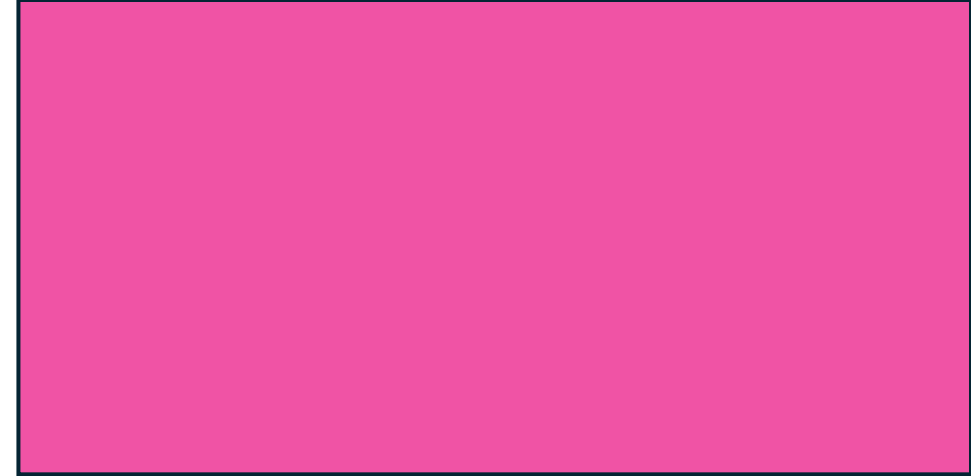
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Measurement platform

- Researchers cannot use MAnycastR without an anycast testbed
- Currently working on a measurement interface to our testbed (similar to RIPE Atlas) (currently a manual process)
- Unique properties:
 - BGP collector at Worker VMs -> correlate probes with BGP events
 - Anycast + unicast measurements enabled
 - Access to BGP (perform prepends, add communities, withdraw, announce, etc..)
 - Live anycast detection (e.g., DDoS mitigation detection)
 - Feed based measurements (e.g., based on BGP events)

Outline

- Introduction
 - What is anycast? Why measure it?
- Background
 - More on anycast measurement tools
 - How MAnycastR was started
- Methodology
 - System design & requirements
- Usage by operators
- Usage by academics and collaborative outreach
- **Conclusion**



Conclusion

- We built MAnycastR (publicly available at github.com/rhendriks/MAnycastR)
- Originally designed for research purposes
 - Anycast census
- Currently used by operators
 - Measure deployment performance
- Also used by researchers
 - Large variety of research
- We are open to collaboration and welcome you to use our open measurement platform

Q&A