

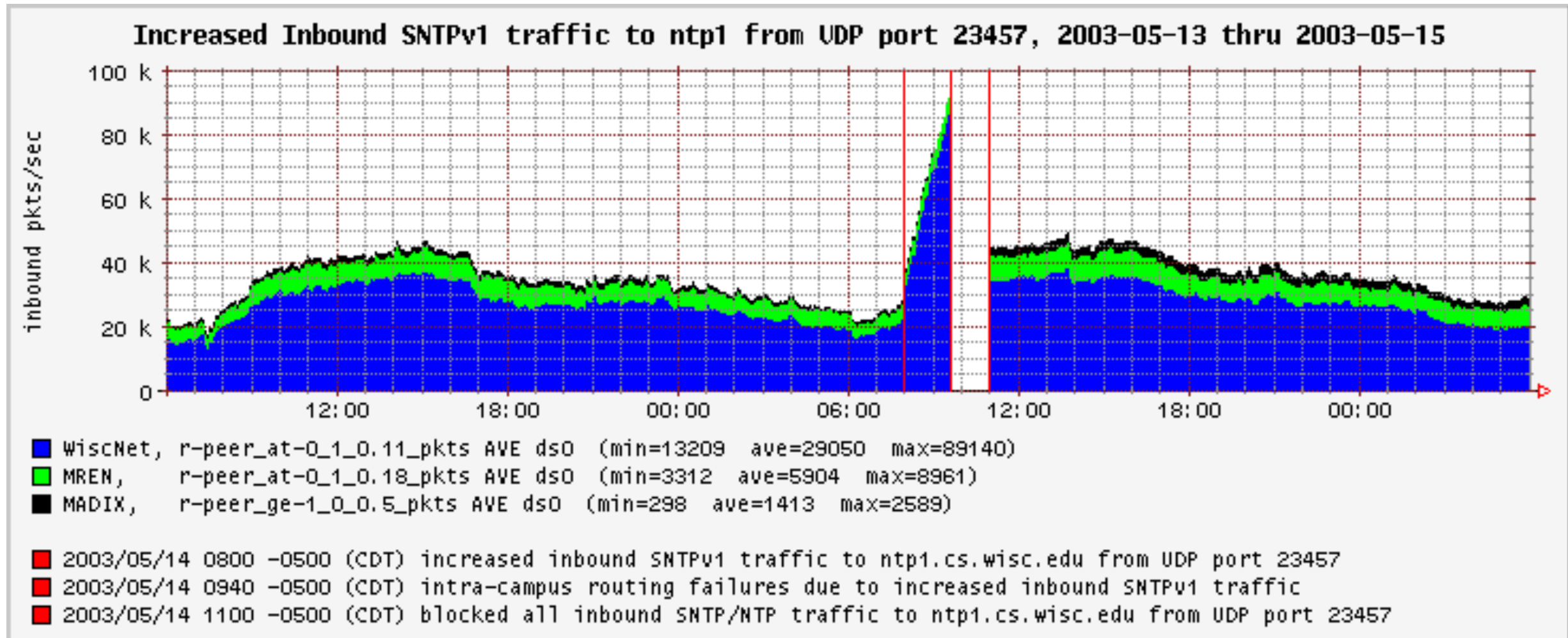
Seeing Things: Measuring IoT, IPv6, and Privacy

Network Traffic Measurement and Analysis Conference (TMA)
Vienna, 29 June 2018

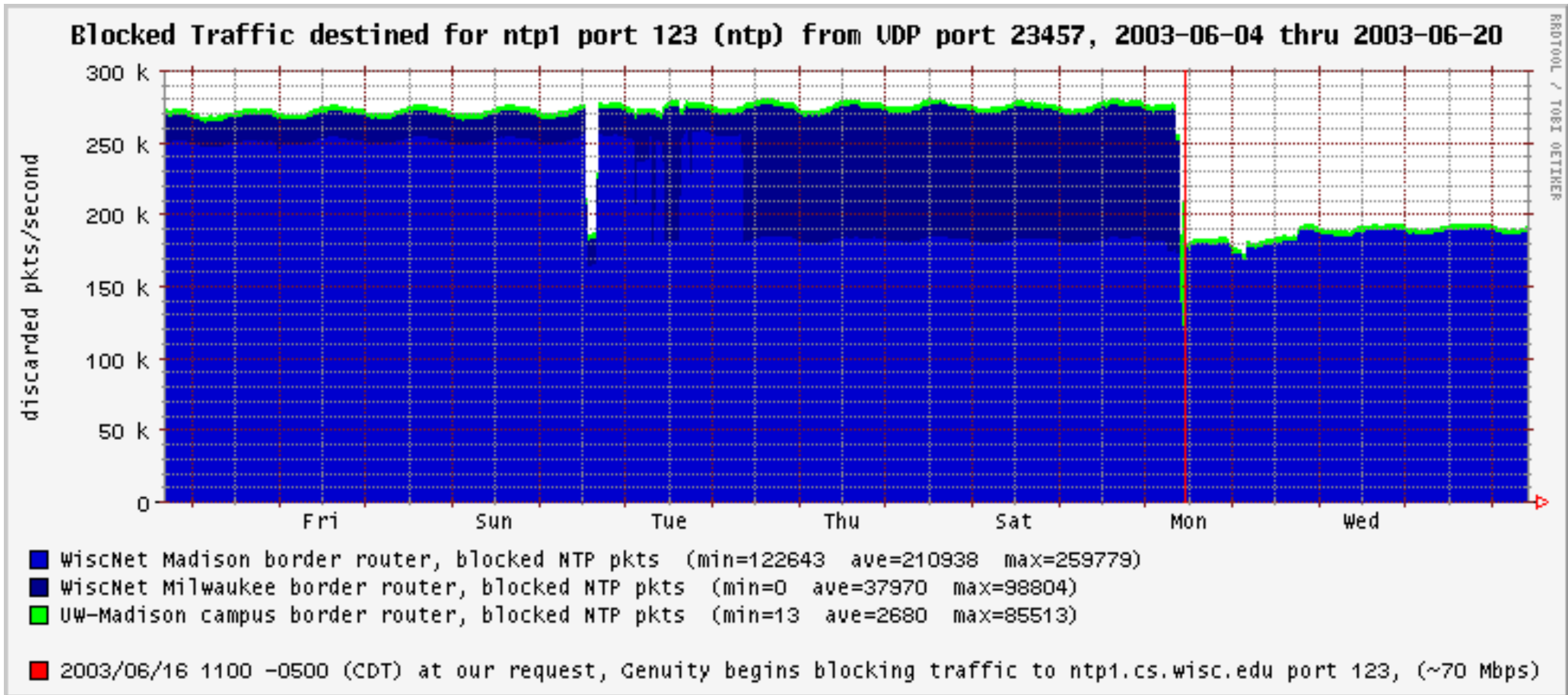
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Measuring IoT: Accidentally and Otherwise

The flood arrives, May 2003



The flood continues, June 2003



Rendezvous: Which devices talk to whom and why?

Affected Products

RP614v2, RP614: 4-Port Cable/DSL Router with 10/100 Mbps Switch

C-NET Editors' Choice, July 2002

RP614v2: upgrade to v5.13, released 2003/07/11

RP614: upgrade to v4.14, released 2003/08/20



MR814: 802.11b Cable/DSL Wireless Router

Innovations International CES, Design & Engineering Showcase Honors, 2003

MR814: upgrade to v4.13, released 2003/08/20



DG814: DSL Modem Internet Gateway

Macworld Editors' Choice

DG814: upgrade to v4.8, released 2003/07/09



HR314: 802.11a Cable/DSL High-Speed Wireless Router

HR314: upgrade to v1.4.2, released 2003/09/05



How is this IoT?

- *What is IoT?*

These things are devices with **homogenous configuration** that are typically rapidly designed, manufactured, and deployed and that ***depend on the Internet*** [where such devices did not, previously.]

- In this case, these CPE switches/routers/access-points are curious in that they **are *Internet devices*** rather than merely network devices.
- We are not usually informed about the arrival and **presence** of these things. IoT presents performance, reliability, and security challenges.

How is this IoT?



The screenshot shows a web browser window displaying a US-CERT alert. The browser's address bar shows the URL <https://www.us-cert.gov/ncas/alerts/TA18-145A>. The page header includes the US-CERT logo and the text "UNITED STATES COMPUTER EMERGENCY READINESS TEAM". A navigation bar contains links for HOME, ABOUT US, CAREERS, PUBLICATIONS, ALERTS AND TIPS, RELATED RESOURCES, and C* VP. The main content area features the alert title "Alert (TA18-145A) Cyber Actors Target Home and Office Routers and Networked Devices Worldwide" and the original release date of May 25, 2018. Social sharing buttons for Print, Tweet, Send, and Share are visible. The "Systems Affected" section lists SOHO routers, networked devices, and NAS devices. The "Overview" section provides details about the VPNFilter malware and the recommendation to power cycle routers.

Cyber Actors Target Home and Office Routers and Networked Devices Worldwide

Original release date: May 25, 2018

[Print](#) [Tweet](#) [Send](#) [Share](#)

Systems Affected

- Small office/home office (SOHO) routers
- Networked devices
- Network-attached storage (NAS) devices

Overview

Cybersecurity researchers have identified that foreign cyber actors have compromised hundreds of thousands of home and office routers and other networked devices worldwide [1] [2]. The actors used VPNFilter malware to target small office/home office (SOHO) routers. VPNFilter malware uses modular functionality to collect intelligence, exploit local area network (LAN) devices, and block actor-configurable network traffic. Specific characteristics of VPNFilter have only been observed in the BlackEnergy malware, specifically BlackEnergy versions 2 and 3.

The Department of Homeland Security (DHS) and the Federal Bureau of Investigation (FBI) recommend that owners of SOHO routers power cycle (reboot) SOHO routers and networked devices to temporarily disrupt the malware.

Affected Products

RP614v2, RP614: 4-Port Cable/DSL Router with 10/100 Mbps Switch

C-NET Editors' Choice, July 2002

RP614v2: upgrade to v5.13, released 2003/08/11

RP614: upgrade to v4.14, released 2003/08/11



**2002. Are these
still around?**

MR814: 802.11b Cable/DSL Wireless Router

Innovations International CES, Design & Engineering Showcase Honors, 2003

MR814: upgrade to v4.13, released 2003/08/20



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Macworld Editors' Choice

DG814: upgrade to v4.8, released 2003/07/09



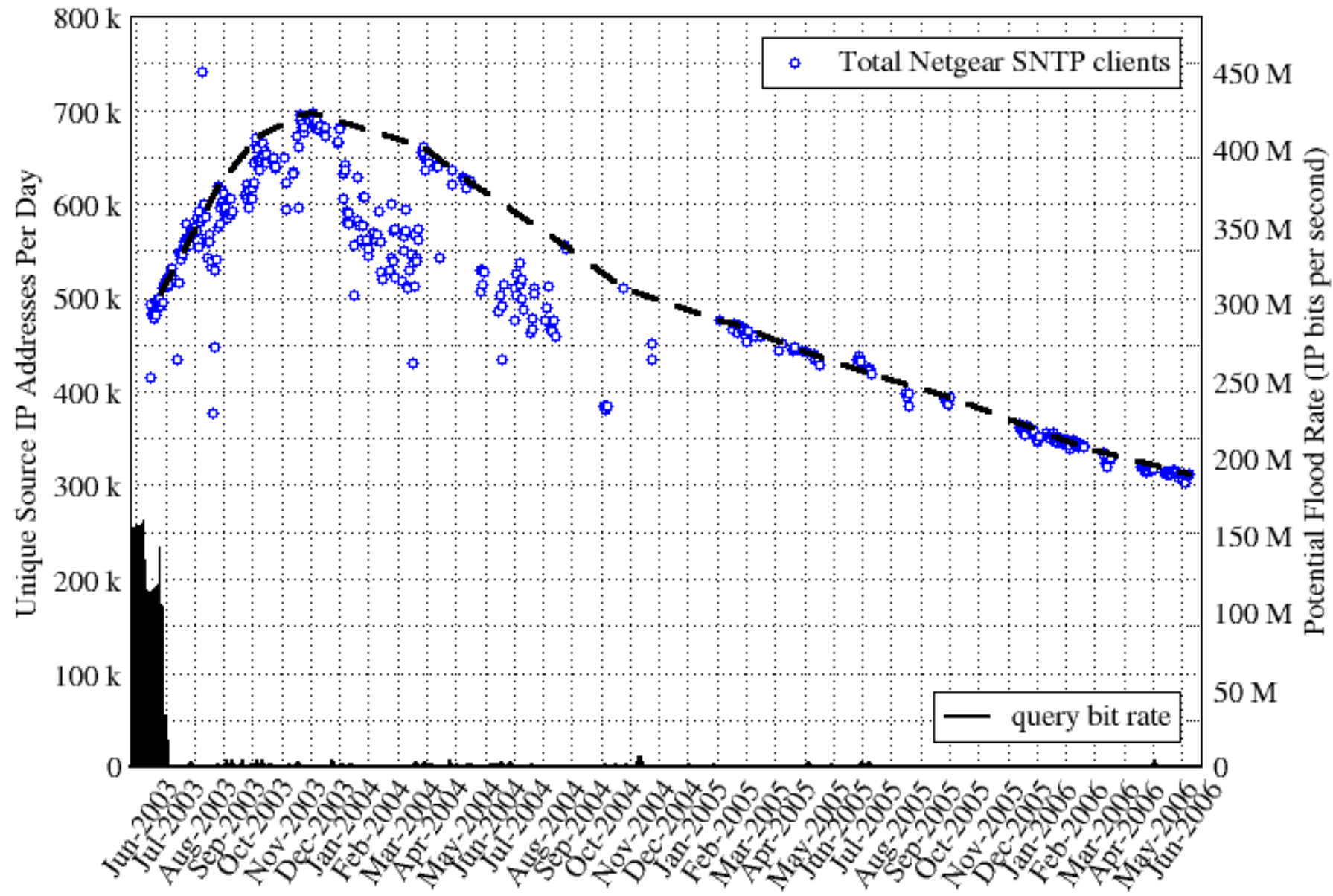
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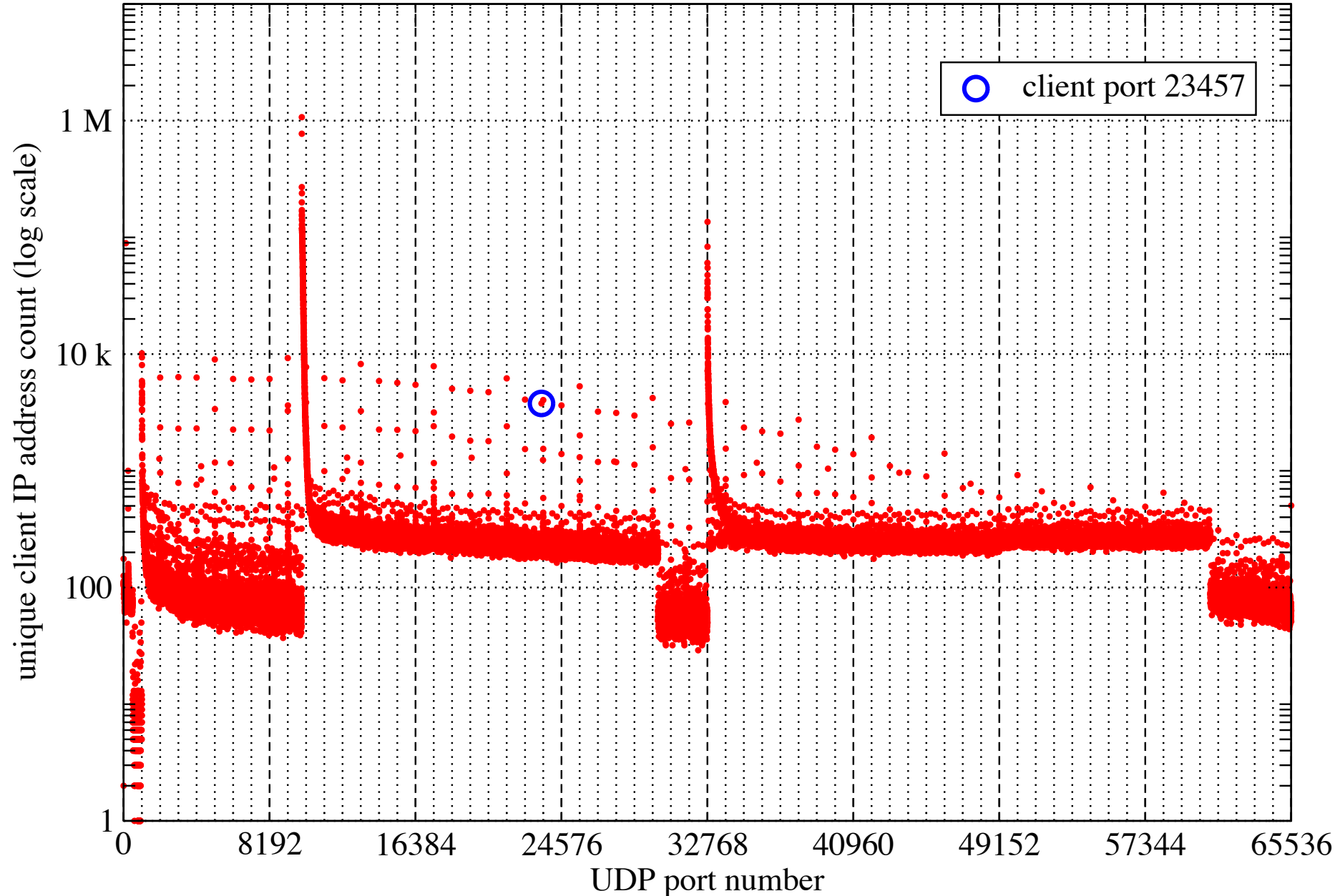


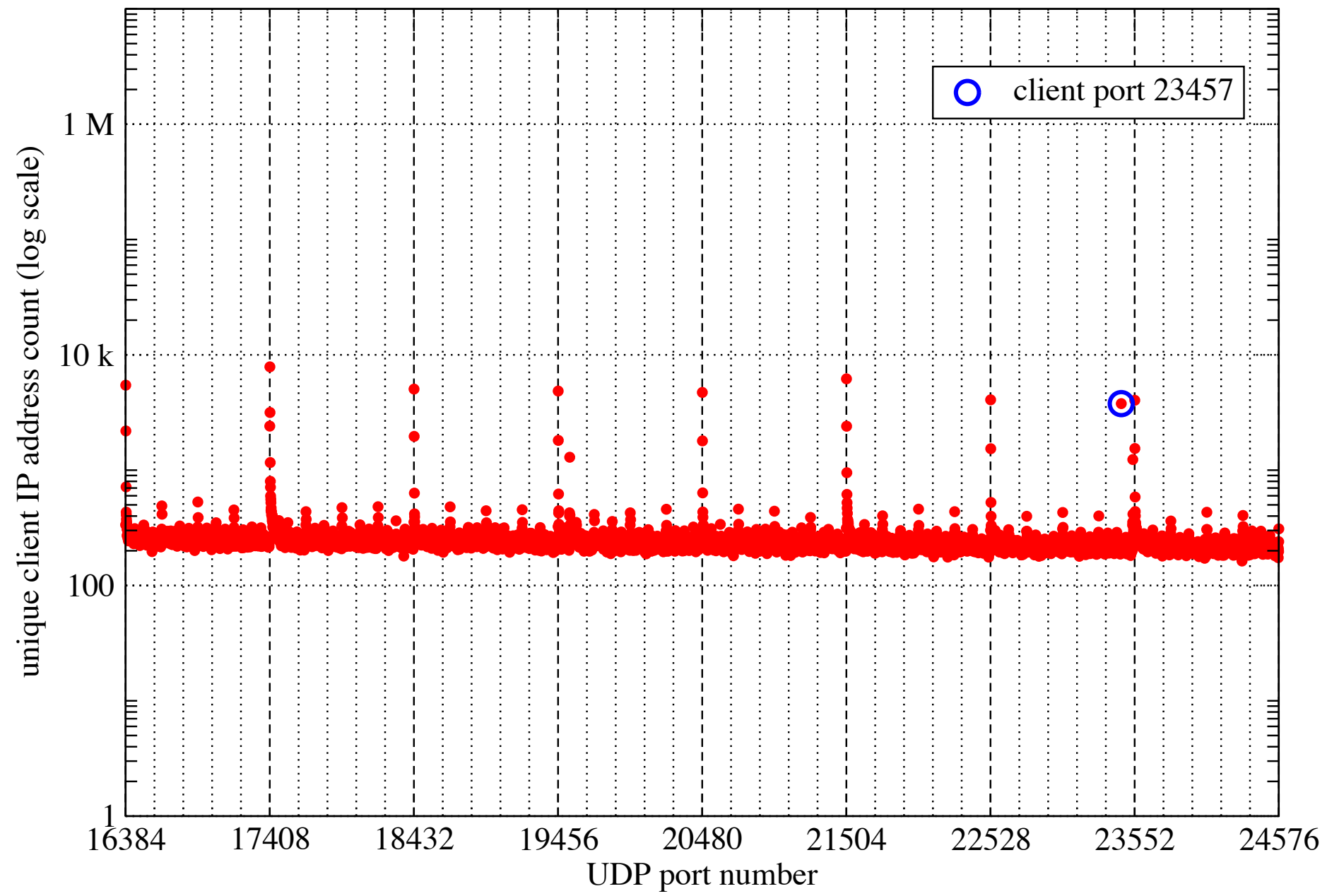
Active “thing” count, through June 2006

Counted at UW-Madison NTP Server, June 2003 through June 2006

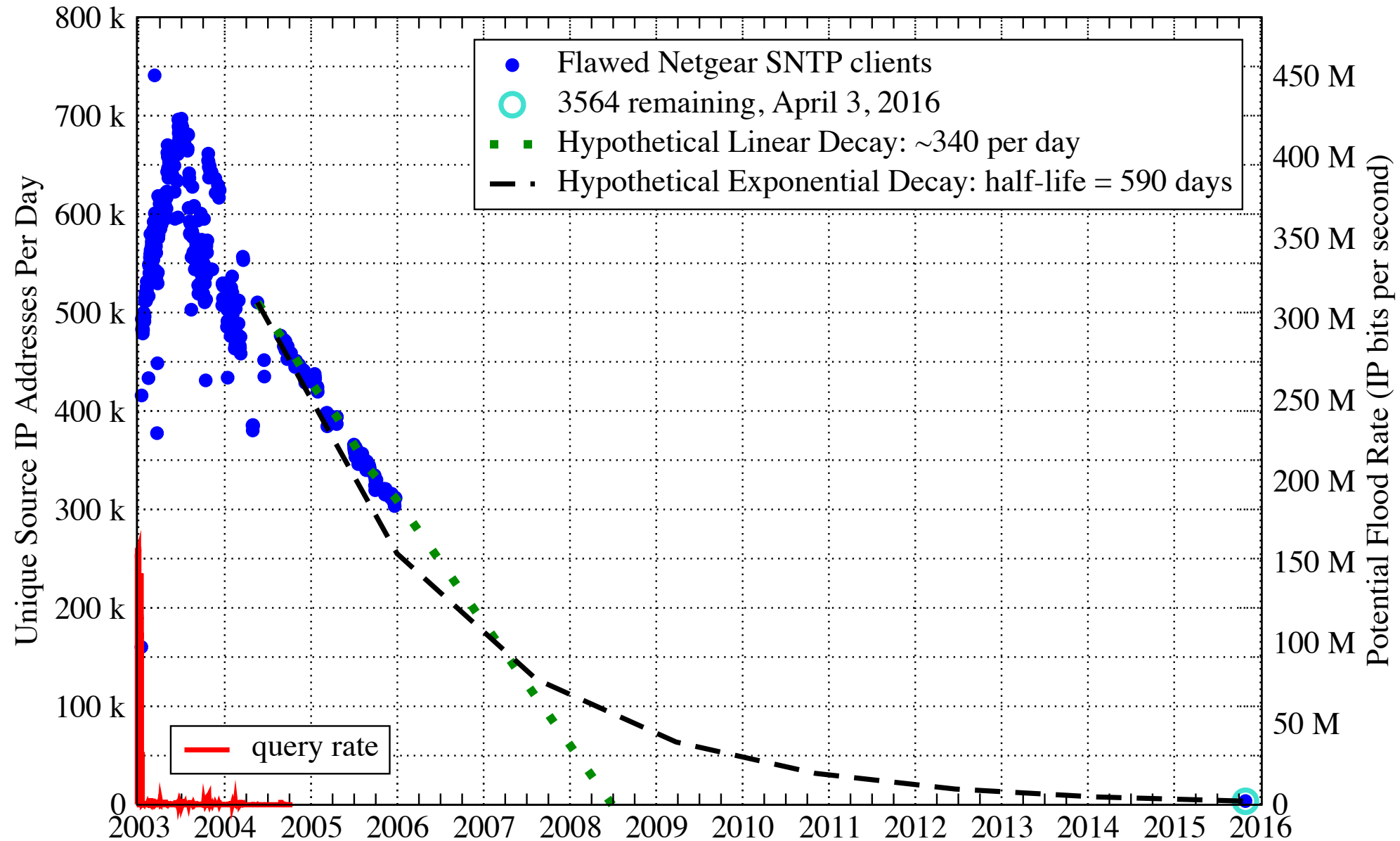


NTP client unique IP addrs by src port (2016)





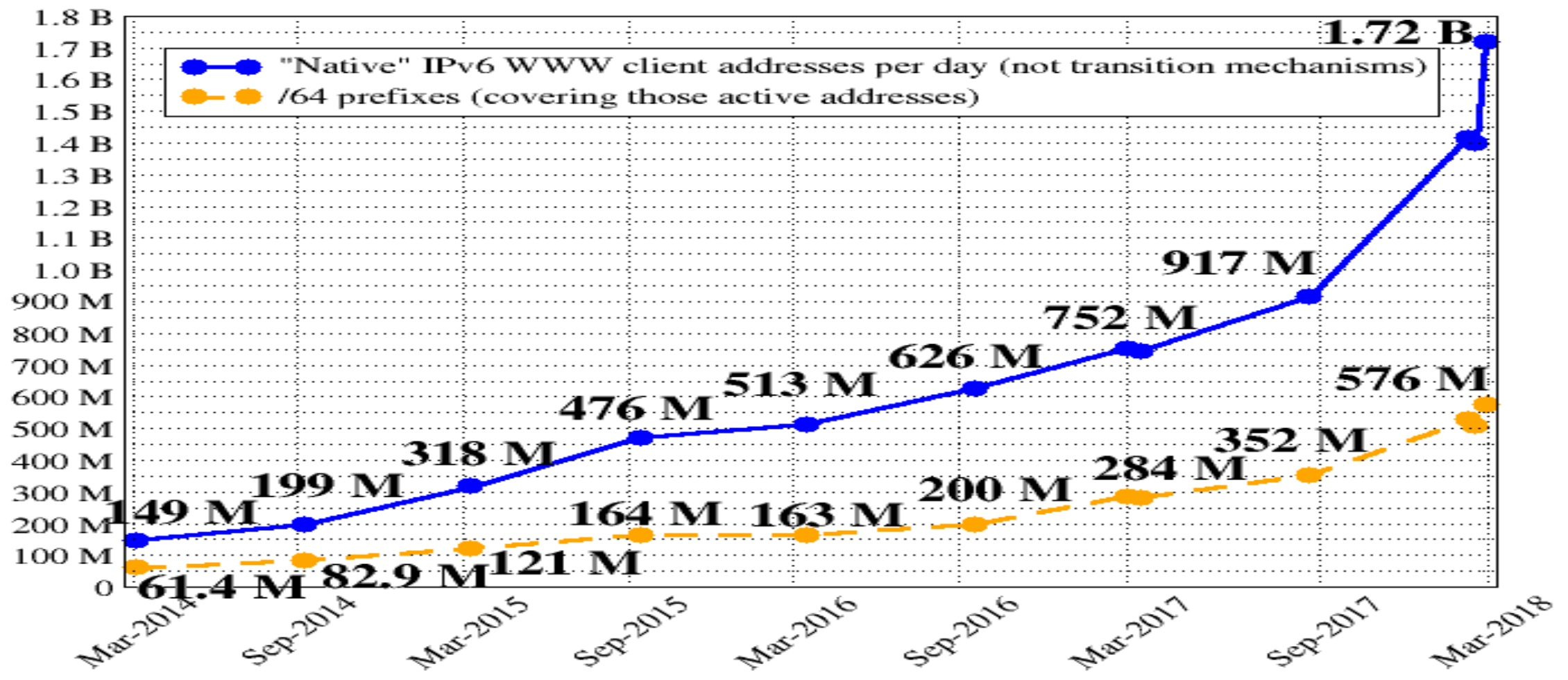
Active “thing” count, through June 2016



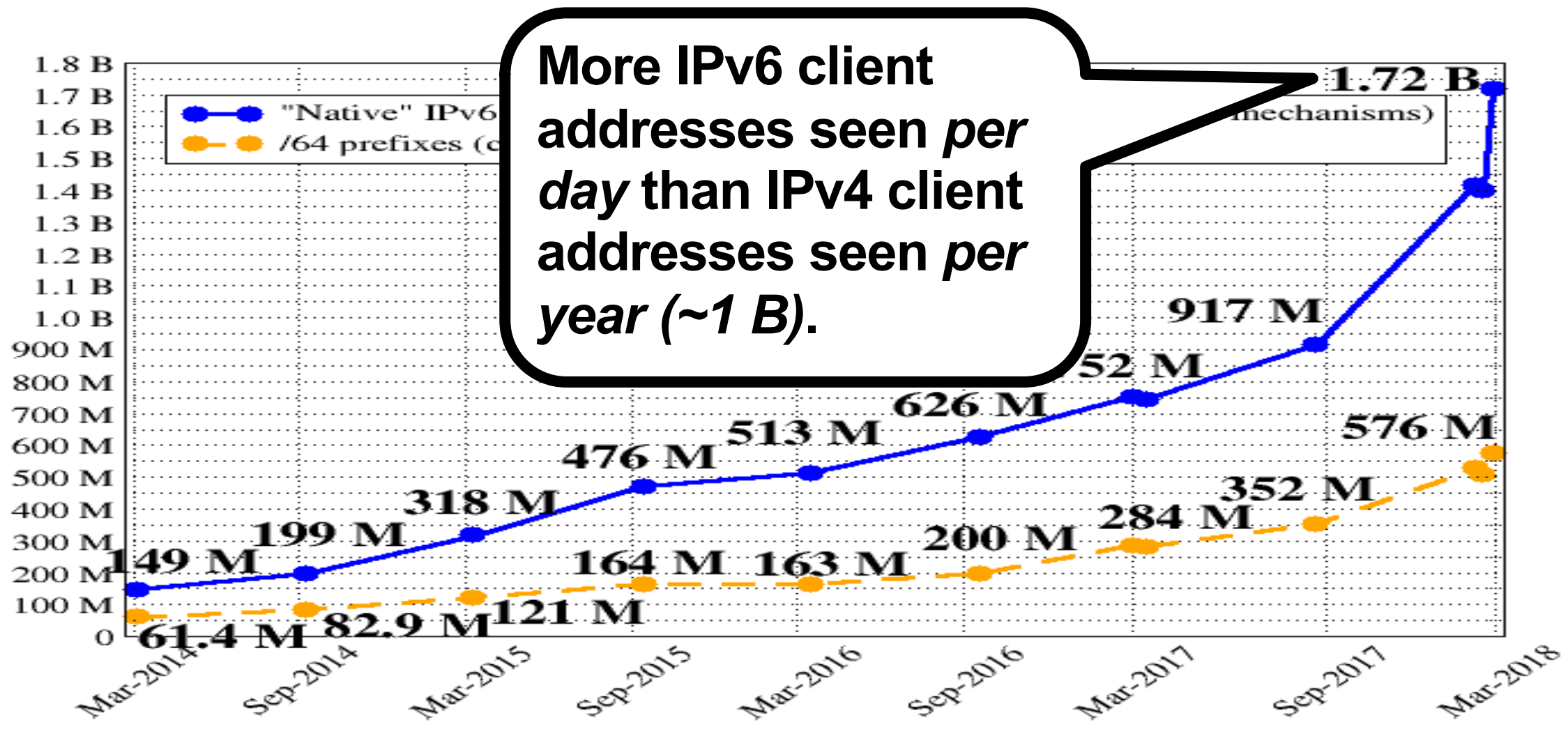
Measuring IPv6: the Active WWW Client Space

Rendezvous: How many hosts have multiple IP identities? Which do they use?

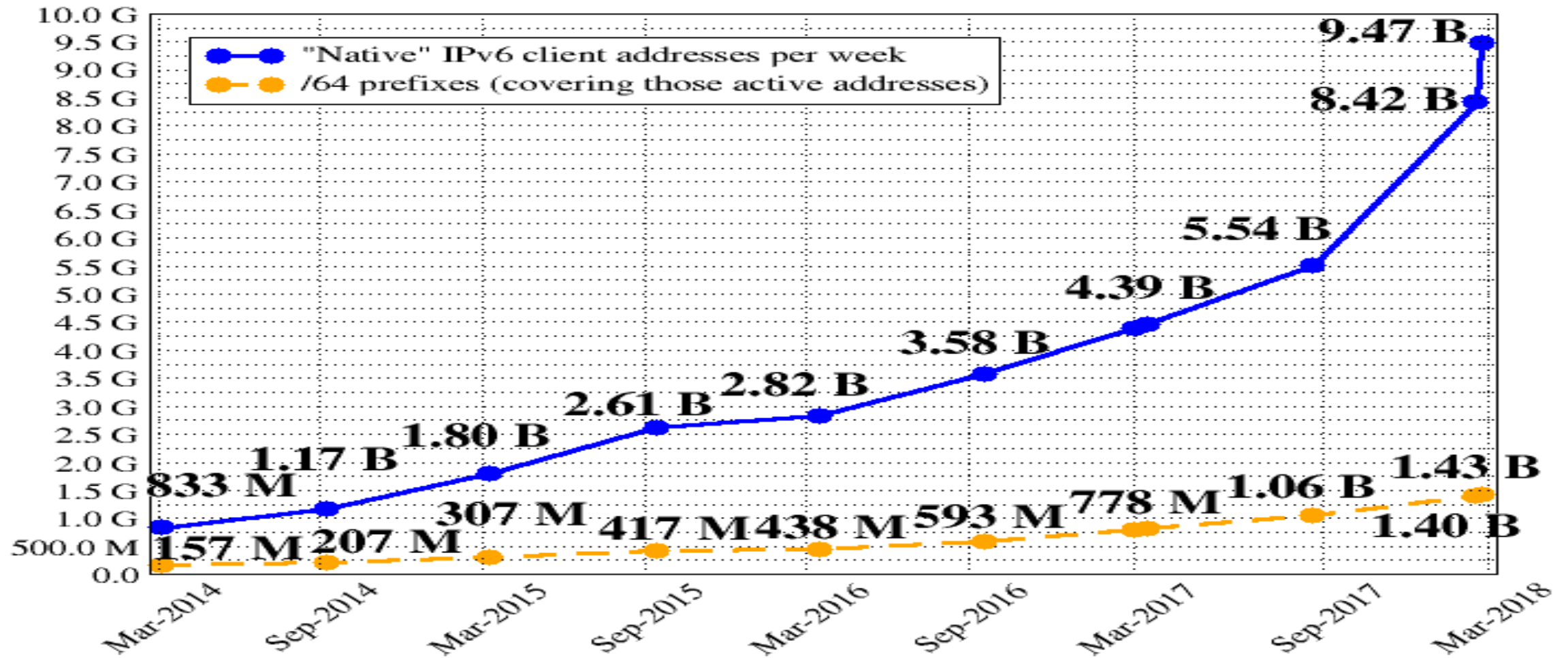
Active IPv6 WWW Client Addresses per day



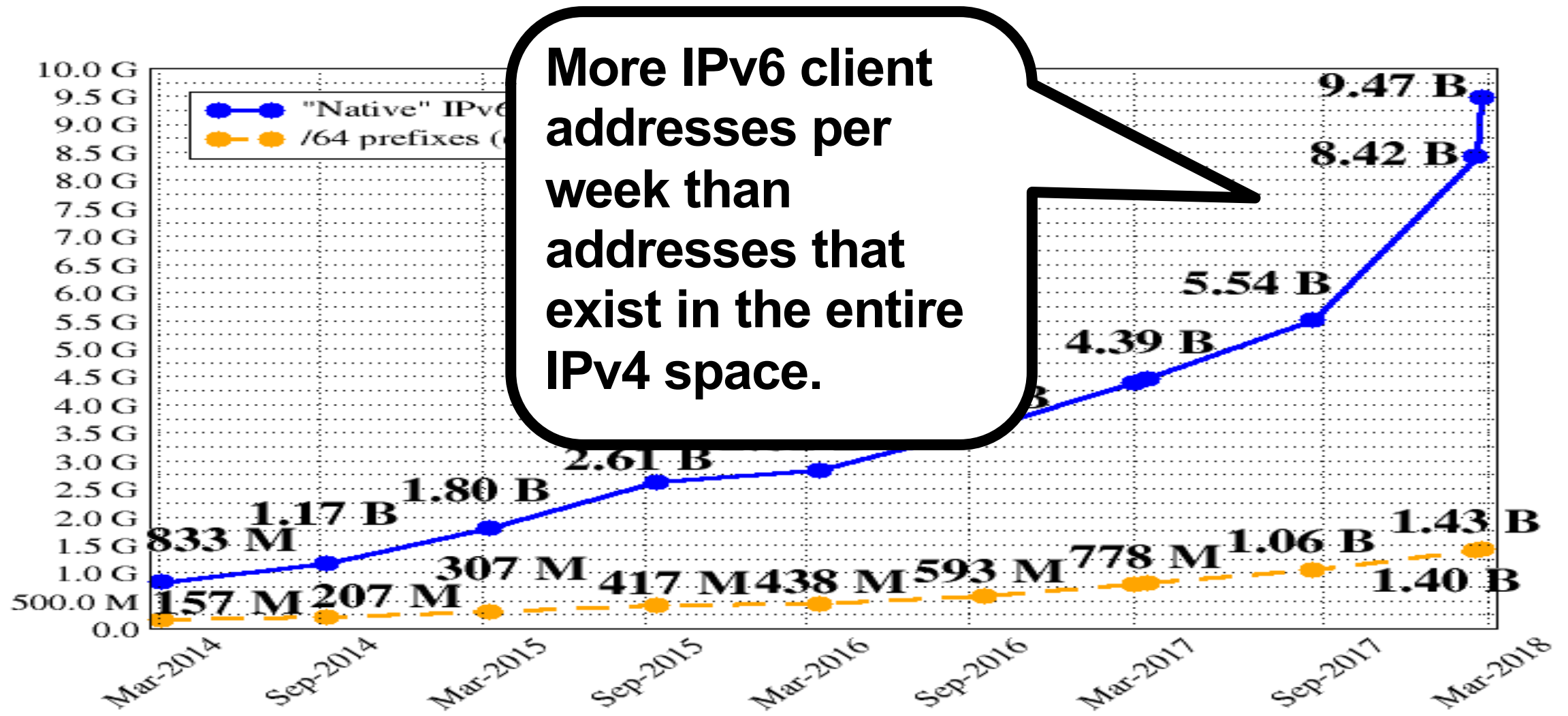
Active IPv6 WWW Client Addresses per day



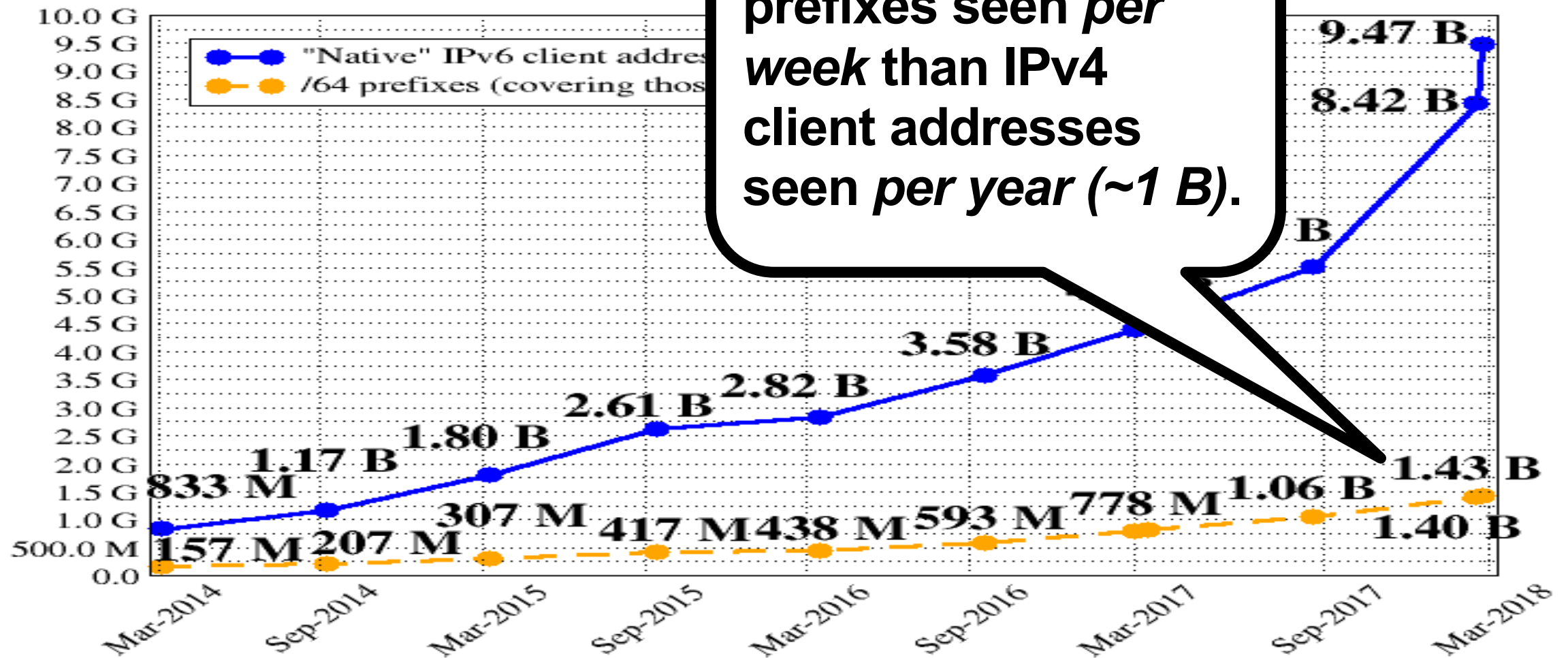
Active IPv6 WWW Client Addresses per week



Active IPv6 WWW Client Addresses per week

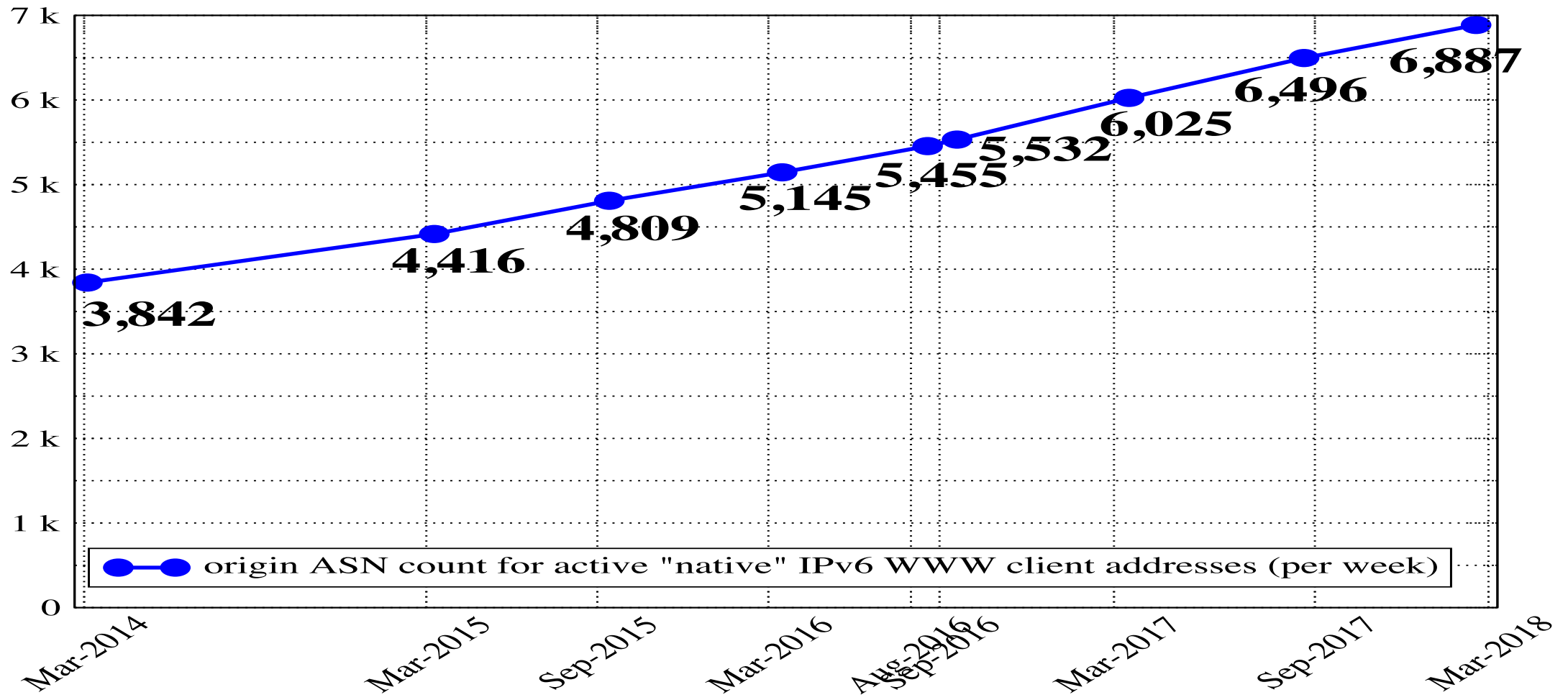


Active IPv6 WWW Client Addresses per week

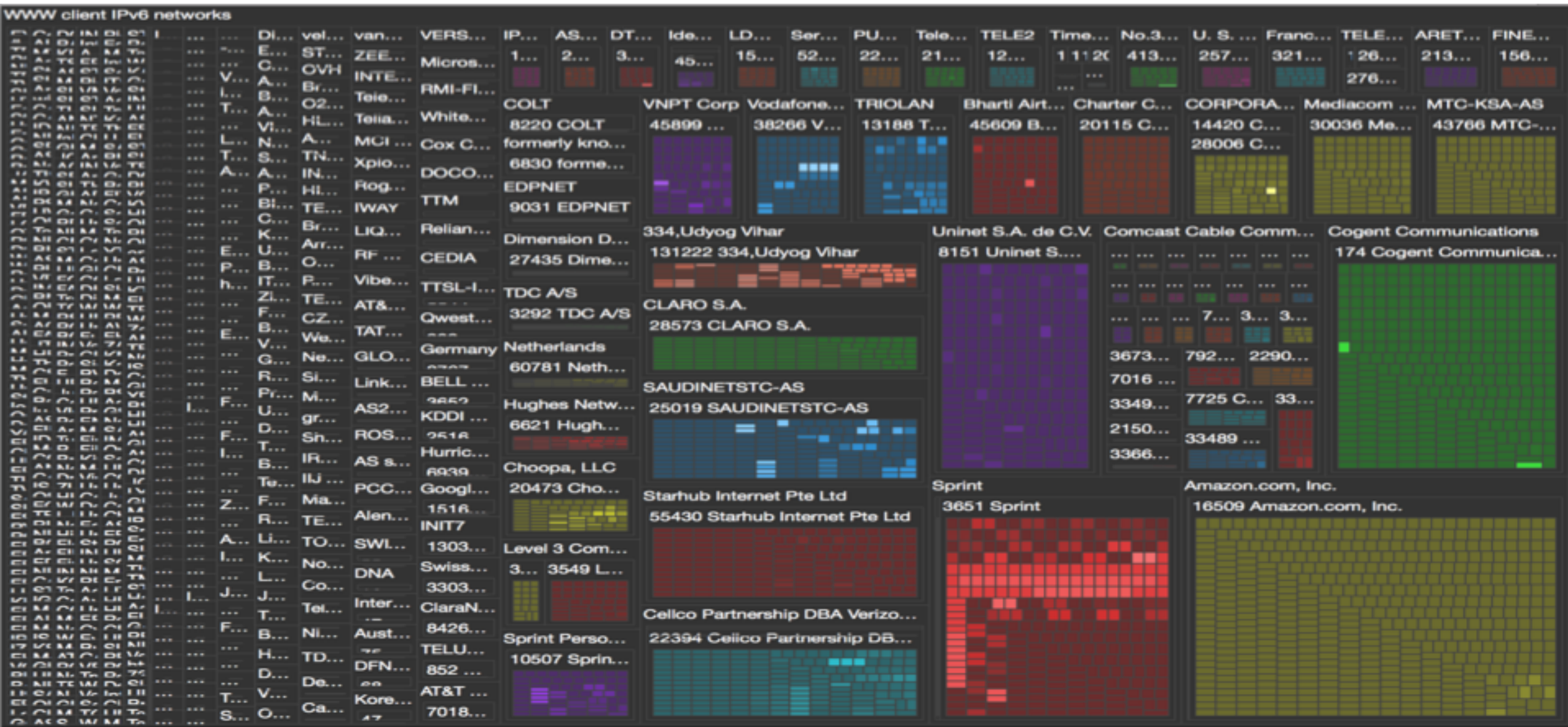


More IPv6 /64 client prefixes seen *per week* than IPv4 client addresses seen *per year* (~1 B).

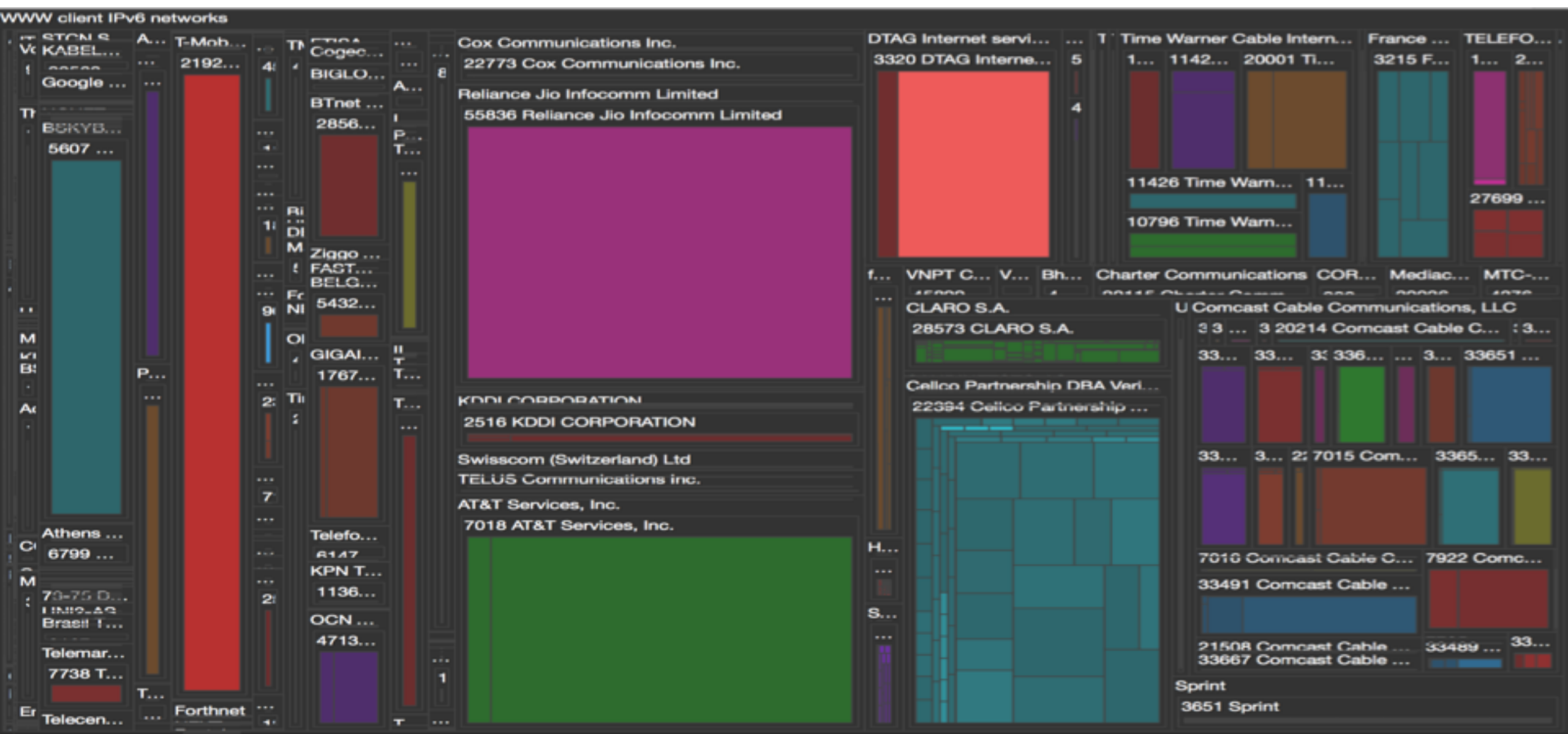
IPv6 WWW Clients' Origin ASNs: weekly counts



IPv6 Networks sized by Advertised Prefixes



IPv6 Networks sized by Client Addresses per day



Some Take-Aways

- Despite steady growth in number of IPv6-capable, **many ASNs seem not to have IPv6-connected hosts.**
- Still, there are clearly **hundreds of millions** of hosts using IPv6 every day and growing.
- IPv6 has **performance, reliability, scalability, security, and privacy ramifications.**
Thus, so does ignoring it, *e.g.*, in your work.

If you happen to disagree (explicitly *or implicitly*), consider the question:
Which hundreds of millions would you ignore in your work?

Measuring Privacy: IPv6 Address Anonymization with *kIP*

Anonymization: Discarding [Personally Identifiable] Information

```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000fdd4f4f54264cc52 75 0d
20010db8000e0000fdf73310ae0043da 75 2d
20010db8000e0000feedfacedeadebabe 71 3d
```

/64 prefix

Anonymization: Discarding [Personally Identifiable] Information

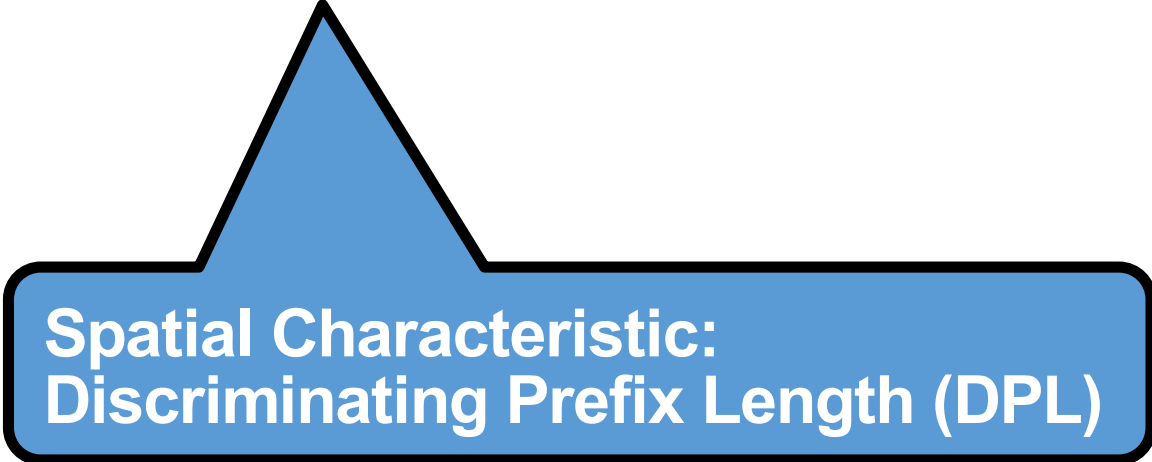
```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000fdd4f4f54264cc52 75 0d
20010db8000e0000fdf73310ae0043da 75 2d
20010db8000e0000feedfacedeadebabe 71 3d
```

/64 prefix

IID

Anonymization: Discarding [Personally Identifiable] Information

```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000 added 4f4f54264cc52 75 0d
20010db8000e0000 added fdf73310ae0043da 75 2d
20010db8000e0000 added feedfacedeadbabe 71 3d
```



**Spatial Characteristic:
Discriminating Prefix Length (DPL)**

Anonymization: Discarding [Personally Identifiable] Information

```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000 added 4f4f54264cc52 75 0d
20010db8000e0000 added fdf73310ae0043da 75 2d
20010db8000e0000 added feedfacedeadbabe 71 3d
```

Temporal Characteristic:
Stable Days (SD)

Spatial Characteristic:
Discriminating Prefix Length (DPL)

Anonymization: Discarding [Personally Identifiable] Information

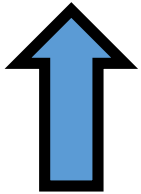
```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000 added 4f4f54264cc52 75 0d
20010db8000e0000 added fd73310ae0043da 75 2d
20010db8000e0000 added feedfacedeadbabe 71 3d
```

Stateless Classification:
(from F. Gont's IPv6 Toolkit)

```
$ addr6 -a 20010db8000e0000feedfacedeadbabe
unicast=global=global=randomized=unspecified
```

Anonymization: Discarding [Personally Identifiable] Information

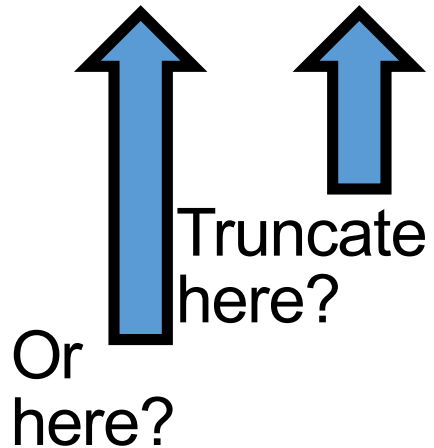
```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000fdd4f4f54264cc52 75 0d
20010db8000e0000fdf73310ae0043da 75 2d
20010db8000e0000feedfacedeadebabe 71 3d
```



Truncate
here?

Anonymization: Discarding [Personally Identifiable] Information

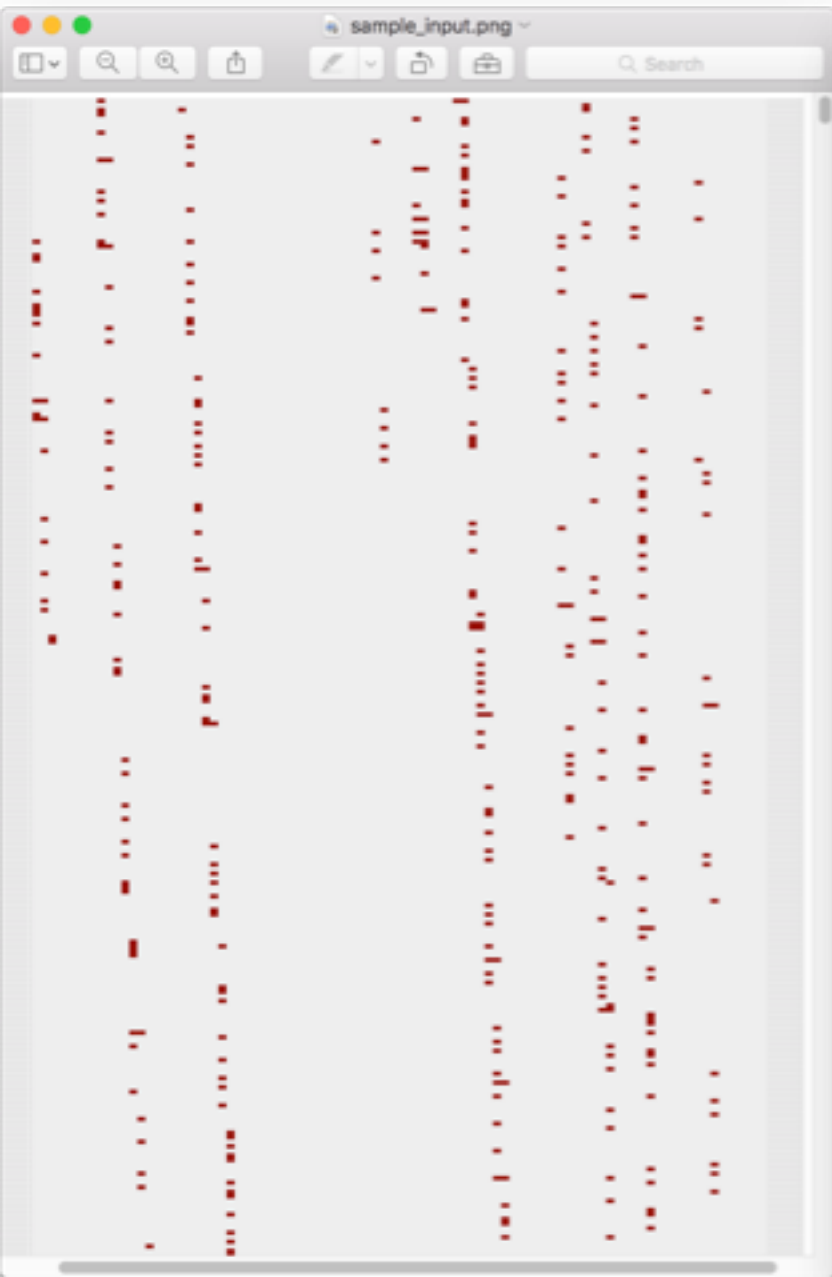
```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000fdd4f4f54264cc52 75 0d
20010db8000e0000fdf73310ae0043da 75 2d
20010db8000e0000feedfacedeadebabe 71 3d
```



Step 2. Address Activity Matrix Analysis



IPv6 Address Activity Matrix



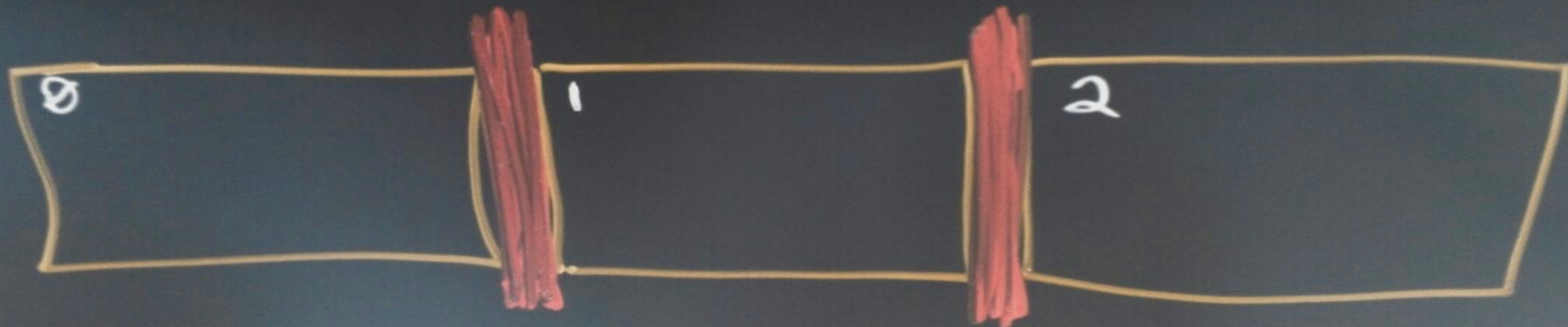
3. “Fencepost” Counting



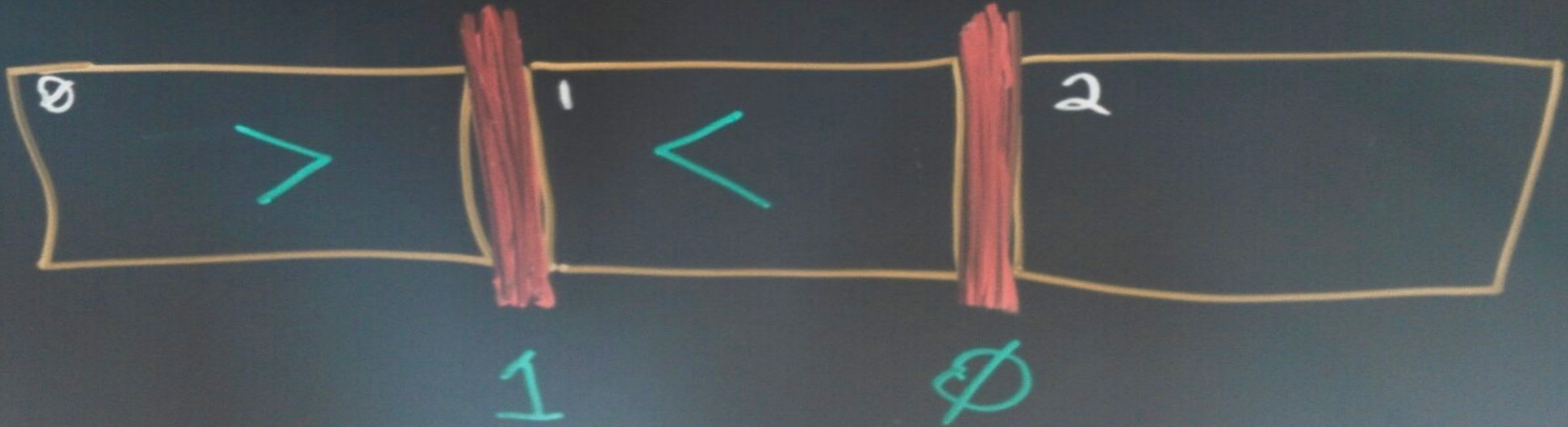
$$i = 1$$

$$w = 3$$

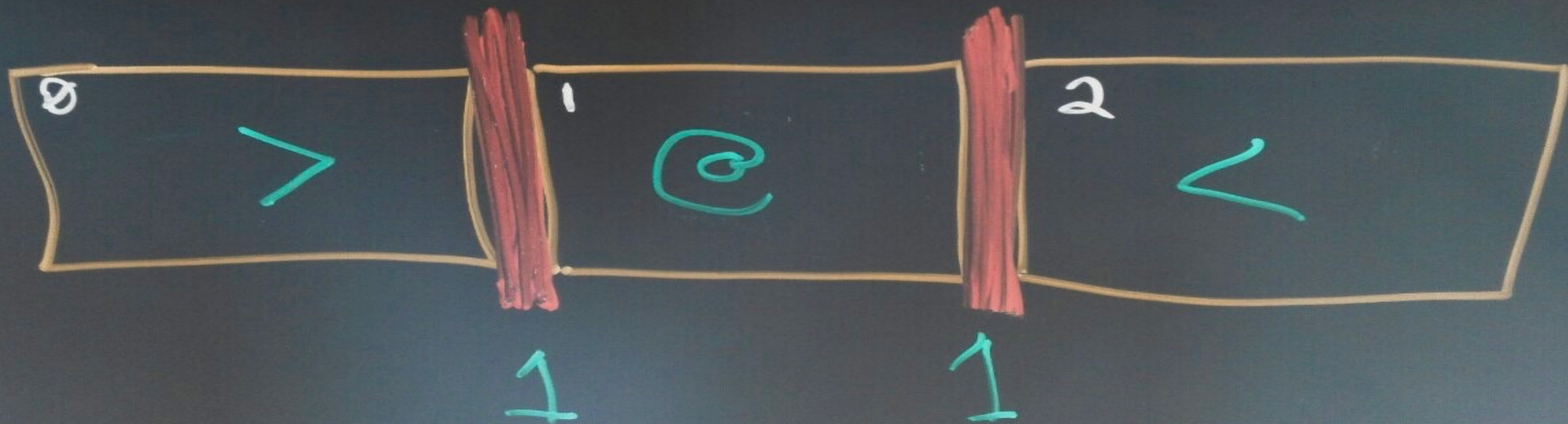
$$f = 2$$



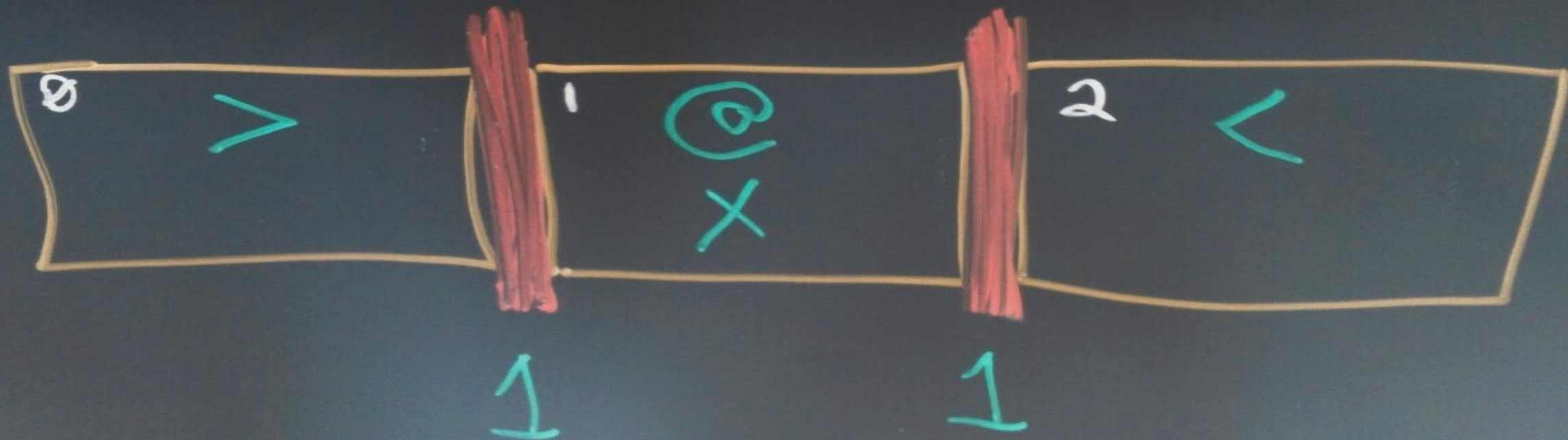
$$i = 1$$
$$w = 3$$
$$f = 2$$



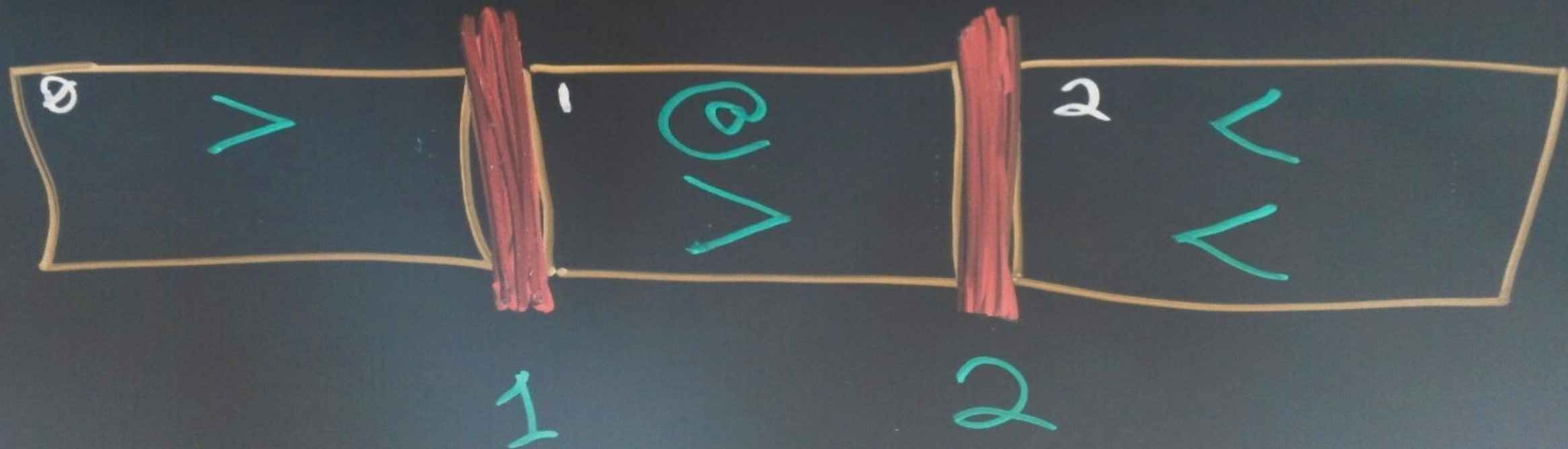
$$\begin{aligned}i &= 1 \\ w &= 3 \\ f &= 2\end{aligned}$$



$$i = 1$$
$$w = 3$$
$$f = 2$$



$i = 1$
 $w = 3$
 $f = 2$



IPv6 Address Activity Matrix

```

012345678901234567890123
20010db823000a00117ae091b2bdca65 67 0d |-----+-----+--##---
20010db823000a0021ad6d24641a1314 68 0d |--#-----+-----+-----
20010db823000a003454ae0d20a0df4d 68 0d |-----+--#-----+-----
20010db823000a004974fa8b465d4c2a 68 0d |-----+-----+##---#--
20010db823000a00503ca91dbe009a63 68 0d |-----##-###-+-----
20010db823000a0068678a645417e731 70 0d |-----+--##-+-----
20010db823000a006d35ee11ec45f658 70 0d |-----+-----+##-----
20010db823000a007070a7fc47d502ba 70 0d |-----#+-----+-----
20010db823000a007554b66aa9839665 70 0d |-----+--#-----+-----
20010db823000a0079391bd6fec285bb 70 0d |-----+-----#-----+
20010db823000a007ccc39777c76bdef 70 0d |-----+-----+--#-----
20010db823000a00890b1f0d14e20ccb 67 0d |-----+-----#-----+
20010db823000a00a0fc1e1848aaeb2e 67 0d |-----+--#-----#-----
20010db823000a00f9309833f8c53926 74 0d |-----+-----#-----#-----
20010db823000a00f94dfcec6b8ed61f 74 0d |-----#-----+-----
20010db823000a00fd2850fe844583e7 70 0d |--#-----+-----+-----
20010db823000a00 16 Temporary SLAAC: 100.00% stable: 0.00%

```

/64 prefix

ounted during the given hour

IPv6 Address Activity Matrix

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20010db823000a00 16 Temporary SLAAC: 100.00% stable: 0.00%

/64 prefix

IID

counted during the given hour

IPv6 Address Activity Matrix

			0												1												2																					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3		
20010db823000a00117ae091b2bdca65	67	0d		-----	+	-----	+	---	##	---																																						
20010db823000a0021ad6d24641a1314	68	0d		--#	----	+	-----	+	-----																																							
20010db823000a003454ae0d20a0df4d	68	0d		-----	+	---	#	----	+	-----																																						
20010db823000a004974fa8b465d4c2a	68	0d		-----	+																																											
20010db823000a00503ca91dbe009a63	68	0d		-----																																												
20010db823000a0068678a645417e731	70	0d		-----																																												
20010db823000a006d35ee11ec45f658	70	0d		-----																																												
20010db823000a007070a7fc47d502ba	70	0d		-----																																												
20010db823000a007554b66aa9839665	70	0d		-----																																												
20010db823000a0079391bd6fec285bb	70	0d		-----																																												
20010db823000a007ccc39777c76bdef	70	0d		-----																																												
20010db823000a00890b1f0d14e20ccb	67	0d		-----																																												
20010db823000a00a0fc1e1848aaeb2e	67	0d		----																																												
20010db823000a00f9309833f8c53926	74	0d		--																																												
20010db823000a00f94dfcec6b8ed61f	74	0d		-----																																												
20010db823000a00fd2850fe844583e7	70	0d		--#	----	+	-----	+	-----																																							

There is an expected
Prefix Length (D)
addresses with 1

At probability of
addresses have

Here, where $n=1$
74 (bits); thus, th

There is an expected maximum Discriminating Prefix Length (DPL) for a set, size n , of IPv6 addresses with random IIDs.

At probability of 0.99 (99%), e.g., $n=16$ such addresses have expected max. DPL ≤ 79 (bits).

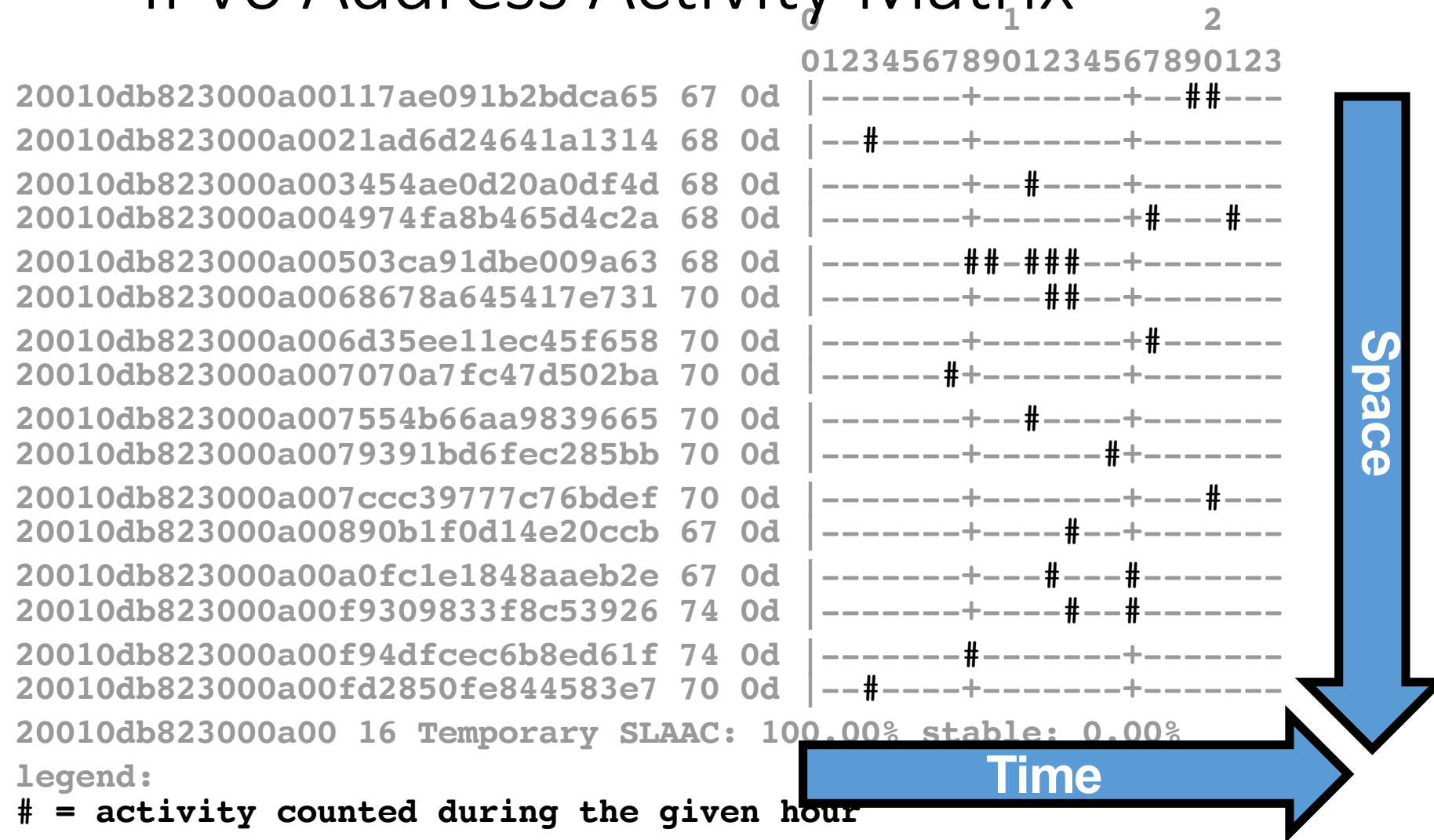
Here, where $n=16$, the observed max. DPL was 74 (bits); thus, they have plausibly random IIDs.

2001:db8::/64 16; Temporary SLAAC: 100% stable: 0.00%

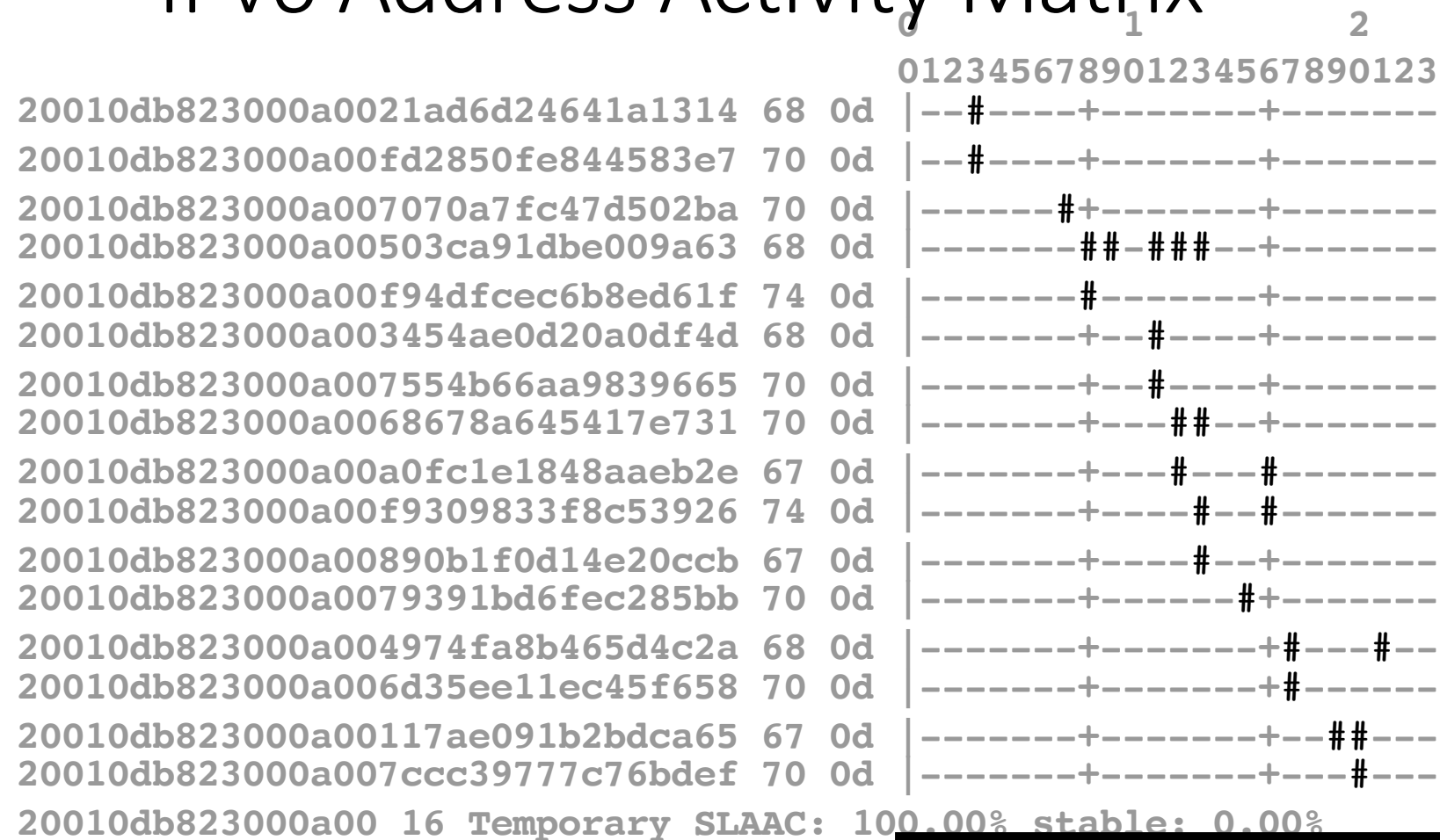
legend:

= activity counted during the given hour

IPv6 Address Activity Matrix



IPv6 Address Activity Matrix



legend:

= activity counted during the given hour

Time

IPv6 Address Activity Matrix

			0													1													2																				
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3			
20010db823000a0021ad6d24641a1314	68	0d		--	#	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00fd2850fe844583e7	70	0d		--	#	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a007070a7fc47d502ba	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00503ca91dbe009a63	68	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00f94dfcec6b8ed61f	74	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a003454ae0d20a0df4d	68	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a007554b66aa9839665	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a0068678a645417e731	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00a0fc1e1848aaeb2e	67	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00f9309833f8c53926	74	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00890b1f0d14e20ccb	67	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a0079391bd6fec285bb	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a004974fa8b465d4c2a	68	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a006d35ee11ec45f658	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00117ae091b2bdca65	67	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a007ccc39777c76bdef	70	0d		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00 16 Temporary SLAAC: 100.00% stable: 0.00%																																																	

legend:

= activity counted during the given hour

@ = assignment of address inferred throughout the given hour

IPv6 Address Activity Matrix

			0												1												2																							
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3				
20010db823000a0021ad6d24641a1314	68	0d		--	#	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00fd2850fe844583e7	70	0d		--	#	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007070a7fc47d502ba	70	0d		---	---	---	---	---	#	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00503ca91dbe009a63	68	0d		---	---	---	---	---	#	@	@	@	@	#	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00f94dfcec6b8ed61f	74	0d		---	---	---	---	---	#	---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a003454ae0d20a0df4d	68	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007554b66aa9839665	70	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a0068678a645417e731	70	0d		---	---	---	---	---	+	---	#	#	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
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20010db823000a0079391bd6fec285bb	70	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a004974fa8b465d4c2a	68	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	#	@	@	@	#	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a006d35ee11ec45f658	70	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	#	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00117ae091b2bdca65	67	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	#	#	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007ccc39777c76bdef	70	0d		---	---	---	---	---	+	---	#	---	---	---	---	+	#	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00 16 Temporary SLAAC: 100.00% stable: 0.00%																																																		

20010db823000a00 16 Temporary SLAAC: 100.00% stable: 0.00%

legend:

= activity counted during the given hour

@ = assignment of address inferred throughout the given hour

IPv6 Address Activity Matrix

			0													1													2																								
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3																	
20010db823000a0021ad6d24641a1314	68	0d		--	X	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a00fd2850fe844583e7	70	0d		--	X	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a007070a7fc47d502ba	70	0d		---	---	---	---	X	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a00503ca91dbe009a63	68	0d		---	---	---	---	---	---	>	@	@	@	<	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
20010db823000a00f94dfcec6b8ed61f	74	0d		---	---	---	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a003454ae0d20a0df4d	68	0d		---	---	---	---	---	---	+	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a007554b66aa9839665	70	0d		---	---	---	---	---	---	+	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
20010db823000a0068678a645417e731	70	0d		---	---	---	---	---	---	+	---	>	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
20010db823000a00a0fc1e1848aaeb2e	67	0d		---	---	---	---	---	---	+	---	>	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
20010db823000a00f9309833f8c53926	74	0d		---	---	---	---	---	---	+	---	>	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00890b1f0d14e20ccb	67	0d		---	---	---	---	---	---	+	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a0079391bd6fec285bb	70	0d		---	---	---	---	---	---	+	---	---	---	X	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
20010db823000a004974fa8b465d4c2a	68	0d		---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a006d35ee11ec45f658	70	0d		---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00117ae091b2bdca65	67	0d		---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a007ccc39777c76bdef	70	0d		---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

legend:
= activity counted during the given hour
@ = assignment of address inferred throughout the given hour
X = activity started and ended during the given hour (within this whole window, e.g., 1 day)
> = starting activity during the given hour (within this whole window, e.g., 1 day)
< = ending activity during the given hour (within this whole window, e.g., 1 day)

IPv6 Address Activity Matrix

			0												1												2											
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3		
20010db823000a0021ad6d24641a1314	68	0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00fd2850fe844583e7	70	0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a007070a7fc47d502ba	70	0d		---	---	---	---	x	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00503ca91dbe009a63	68	0d		---	---	---	---	---	---	>	@	@	@	<	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00f94dfcec6b8ed61f	74	0d		---	---	---	---	x	---	---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a003454ae0d20a0df4d	68	0d		---	---	---	---	+	---	x	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a007554b66aa9839665	70	0d		---	---	---	---	+	---	x	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a0068678a645417e731	70	0d		---	---	---	---	+	---	>	<	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00a0fc1e1848aaeb2e	67	0d		---	---	---	---	+	---	>	@	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00f9309833f8c53926	74	0d		---	---	---	---	+	---	>	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00890b1f0d14e20ccb	67	0d		---	---	---	---	+	---	x	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a0079391bd6fec285bb	70	0d		---	---	---	---	+	---	---	---	---	x	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a004974fa8b465d4c2a	68	0d		---	---	---	---	+	---	---	---	---	---	---	---	+	>	@	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a006d35ee11ec45f658	70	0d		---	---	---	---	+	---	---	---	---	---	---	---	+	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a00117ae091b2bdca65	67	0d		---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
20010db823000a007ccc39777c76bdef	70	0d		---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	x	---	---	---		

legend:
= activity counted during the given hour
@ = assignment of address inferred throughout the given hour
X = activity started and ended during the given hour (within this whole window, e.g., 1 day)
> = starting activity during the given hour (within this whole window, e.g., 1 day)
< = ending activity during the given hour (within this whole window, e.g., 1 day)

Counting Simultaneous SLAAC IIDs

[illegible]

legend:

= activity counted during the given hour

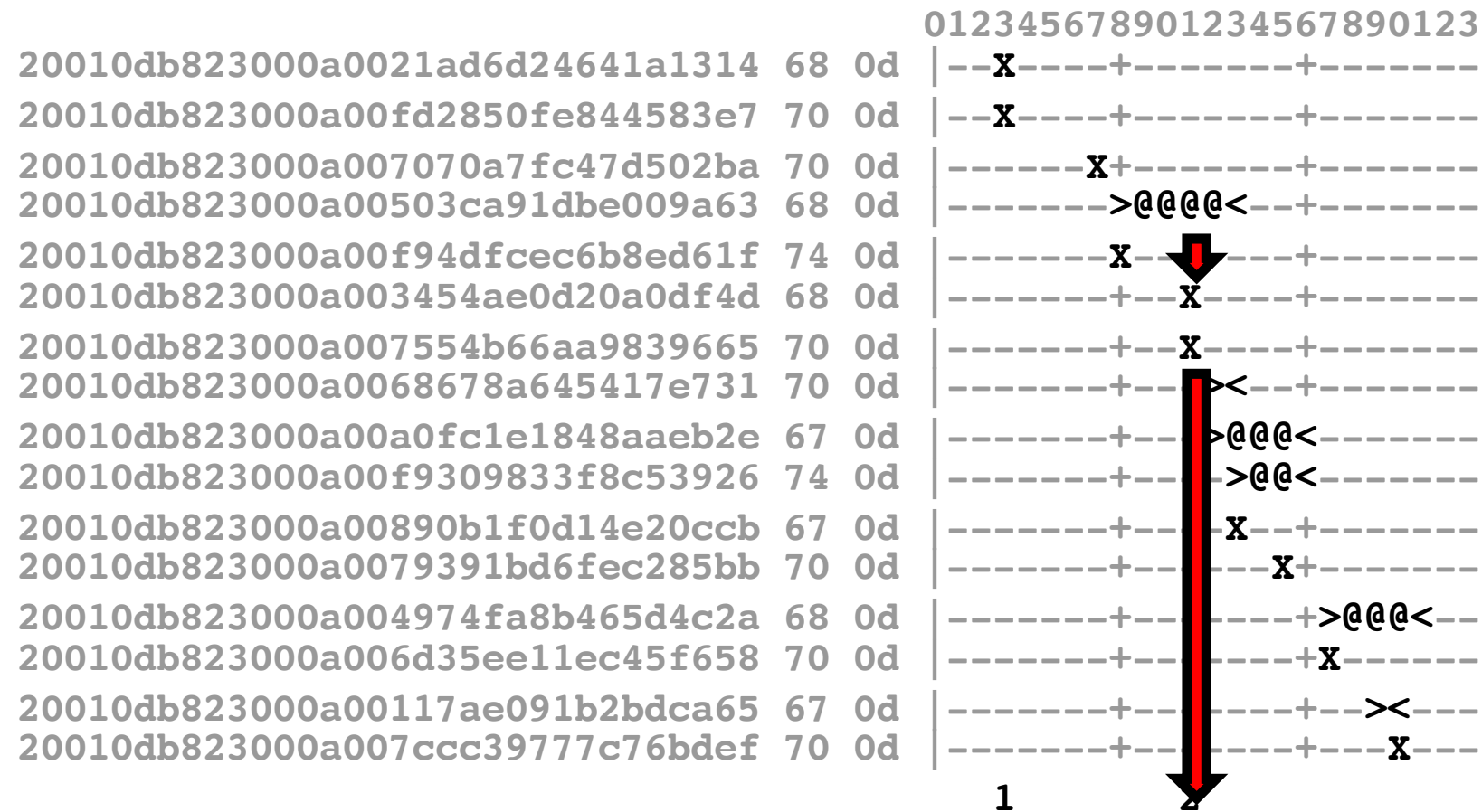
X = activity started and ended during the given hour (within this whole window, e.g., 1 day)

> = starting activity during the given hour (within this whole window, e.g., 1 day)

< = ending activity during the given hour (within this whole window, e.g., 1 day)

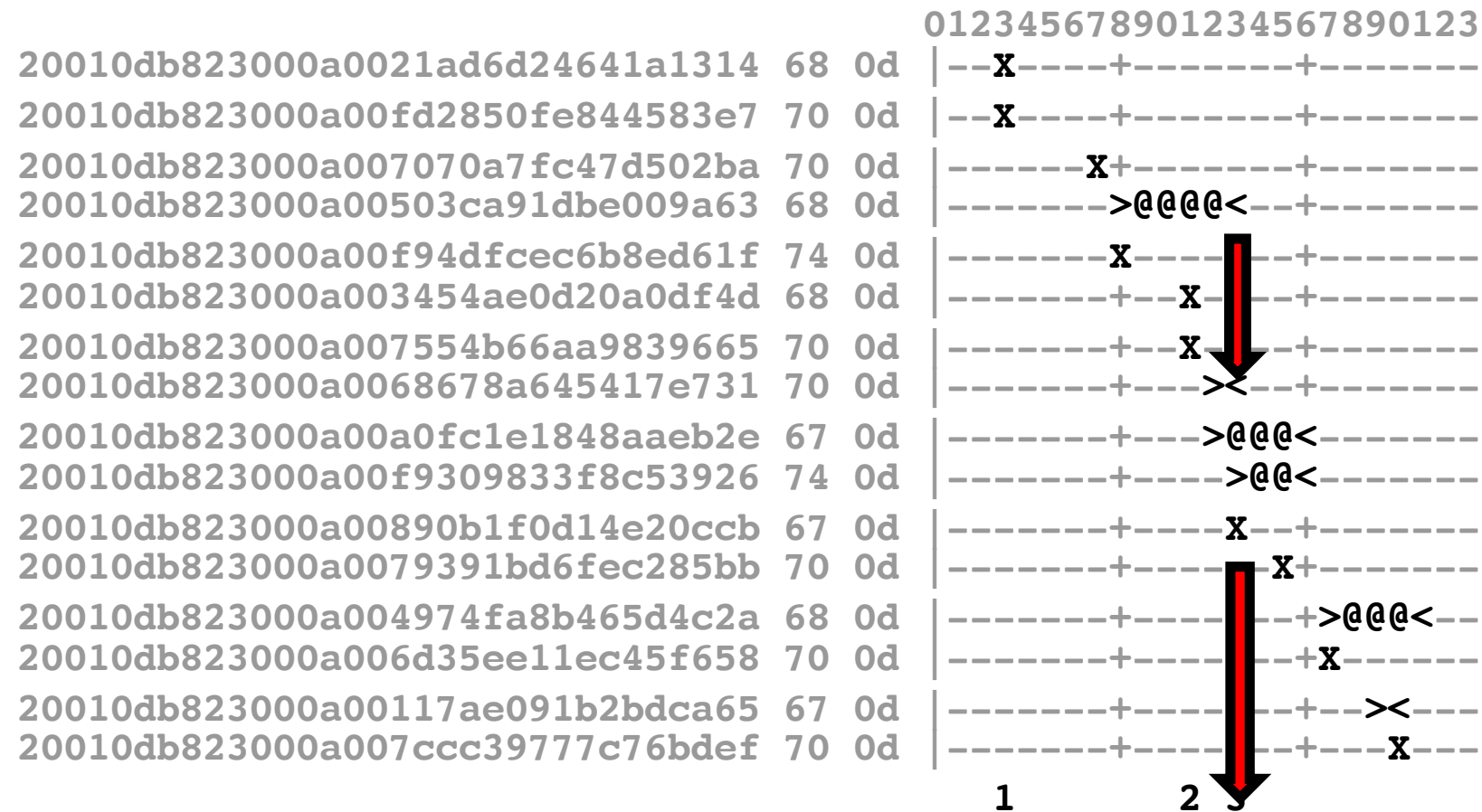
@ = assignment of address inferred throughout the given hour

Counting Simultaneous SLAAC IIDs



legend:
= activity counted during the given hour
X = activity started and ended during the given hour (within this whole window, e.g., 1 day)
> = starting activity during the given hour (within this whole window, e.g., 1 day)
< = ending activity during the given hour (within this whole window, e.g., 1 day)
@ = assignment of address inferred throughout the given hour

Counting Simultaneous SLAAC IIDs



legend:

= activity counted during the given hour

X = activity started and ended during the given hour (within this whole window, e.g., 1 day)

> = starting activity during the given hour (within this whole window, e.g., 1 day)

< = ending activity during the given hour (within this whole window, e.g., 1 day)

@ = assignment of address inferred throughout the given hour

Counting Simultaneous SLAAC IIDs

			012345678901234567890123
20010db823000a0021ad6d24641a1314	68	0d	-- x ----+-----+-----
20010db823000a00fd2850fe844583e7	70	0d	-- x ----+-----+-----
20010db823000a007070a7fc47d502ba	70	0d	----- x +-----+-----
20010db823000a00503ca91dbe009a63	68	0d	----->@@@<--+-----
20010db823000a00f94dfcec6b8ed61f	74	0d	----- x -----+-----
20010db823000a003454ae0d20a0df4d	68	0d	-----+-- x ----+-----
20010db823000a007554b66aa9839665	70	0d	-----+-- x ----+-----
20010db823000a0068678a645417e731	70	0d	-----+--><--+-----
20010db823000a00a0fc1e1848aaeb2e	67	0d	-----+--->@@@<-----
20010db823000a00f9309833f8c53926	74	0d	-----+----->@@<-----
20010db823000a00890b1f0d14e20ccb	67	0d	-----+----- x --+-----
20010db823000a0079391bd6fec285bb	70	0d	-----+----- x +-----
20010db823000a004974fa8b465d4c2a	68	0d	-----+-----+>@@@<--+
20010db823000a006d35ee11ec45f658	70	0d	-----+-----+ x -----
20010db823000a00117ae091b2bdca65	67	0d	-----+-----+--><--+
20010db823000a007ccc39777c76bdef	70	0d	-----+-----+-- x ----
			000100011112332321122100

legend:

= activity counted during the given hour

X = activity started and ended during the given hour (within this whole window, e.g., 1 day)

> = starting activity during the given hour (within this whole window, e.g., 1 day)

< = ending activity during the given hour (within this whole window, e.g., 1 day)

@ = assignment of address inferred throughout the given hour

Counting Simultaneous SLAAC IIDs

				0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3
20010db823000a0021ad6d24641a1314	68	0d		--	x	---	+	-----	+	-----																	
20010db823000a00fd2850fe844583e7	70	0d		--	x	---	+	-----	+	-----																	
20010db823000a007070a7fc47d502ba	70	0d		-----				x	+	-----	+	-----															
20010db823000a00503ca91dbe009a63	68	0d		-----				>	@@@@	<	---	+	-----														
20010db823000a00f94dfcec6b8ed61f	74	0d		-----				x	---			+	-----														
20010db823000a003454ae0d20a0df4d	68	0d		-----				+	---	x	---		+	-----													
20010db823000a007554b66aa9839665	70	0d		-----				+	---	x	---		+	-----													
20010db823000a0068678a645417e731	70	0d		-----				+	---			><	---	+	-----												
20010db823000a00a0fc1e1848aaeb2e	67	0d		-----				+	---			>	@@@	<	-----												
20010db823000a00f9309833f8c53926	74	0d		-----				+	---			>	@@	<	-----												
20010db823000a00890b1f0d14e20ccb	67	0d		-----				+	---			x	---	+	-----												
20010db823000a0079391bd6fec285bb	70	0d		-----				+	---				x	+	-----												
20010db823000a004974fa8b465d4c2a	68	0d		-----				+	---						>	@@@	<	---									
20010db823000a006d35ee11ec45f658	70	0d		-----				+	---						+	x	---										
20010db823000a00117ae091b2bdca65	67	0d		-----				+	---						+		><	---									
20010db823000a007ccc39777c76bdef	70	0d		-----				+	---						+		x	---									

000100011112332321122100 => 3 simultaneous IIDs, maximum

legend:

= activity counted during the given hour

X = activity started and ended during the given hour (within this whole window, e.g., 1 day)

> = starting activity during the given hour (within this whole window, e.g., 1 day)

< = ending activity during the given hour (within this whole window, e.g., 1 day)

@ = assignment of address inferred throughout the given hour

IPv6 Address Activity Matrix: Identity Assignment

			012345678901234567890123
20010db823000a0021ad6d24641a1314	68	0d	-- x ----+-----+-----
20010db823000a00fd2850fe844583e7	70	0d	-- x ----+-----+-----
20010db823000a007070a7fc47d502ba	70	0d	----- x +-----+-----
20010db823000a00503ca91dbe009a63	68	0d	----->@@@@<--+-----
20010db823000a00f94dfcec6b8ed61f	74	0d	----- x -----+-----
20010db823000a003454ae0d20a0df4d	68	0d	-----+-- x ----+-----
20010db823000a007554b66aa9839665	70	0d	-----+-- x ----+-----
20010db823000a0068678a645417e731	70	0d	-----+--><--+-----
20010db823000a00a0fc1e1848aaeb2e	67	0d	-----+--->@@@@<-----
20010db823000a00f9309833f8c53926	74	0d	-----+--->@@@<-----
20010db823000a00890b1f0d14e20ccb	67	0d	-----+--- x --+-----
20010db823000a0079391bd6fec285bb	70	0d	-----+----- x +-----
20010db823000a004974fa8b465d4c2a	68	0d	-----+-----+>@@@@<--
20010db823000a006d35ee11ec45f658	70	0d	-----+-----+ x -----
20010db823000a00117ae091b2bdca65	67	0d	-----+-----+--><----
20010db823000a007ccc39777c76bdef	70	0d	-----+-----+-- x ----

000100011112332321122100 => 3 simultaneous IIDs, maximum

2001:db8::/64 16; Temporary SLAAC: 100%-----!!!!!!!-!!!!--?

0000000011111110111100? => /64 assignment @ fenceposts

legend:

```
! = infer /64 prefix assigned at the "fencepost" moments between intervals
```

IPv6 Address Activity Matrix: Identity Assignment

			0													1													2																					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3				
20010db823000a0021ad6d24641a1314	68	0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00fd2850fe844583e7	70	0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007070a7fc47d502ba	70	0d		---	---	---	---	x	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00503ca91dbe009a63	68	0d		---	---	---	---	---	---	>	@	@	@	<	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00f94dfcec6b8ed61f	74	0d		---	---	---	---	x	---	---	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a003454ae0d20a0df4d	68	0d		---	---	---	---	+	---	x	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007554b66aa9839665	70	0d		---	---	---	---	+	---	x	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a0068678a645417e731	70	0d		---	---	---	---	+	---	>	<	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20010db823000a00a0fc1e1848aaeb2e	67	0d		---	---	---	---	+	---	>	@	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00f9309833f8c53926	74	0d		---	---	---	---	+	---	>	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00890b1f0d14e20ccb	67	0d		---	---	---	---	+	---	x	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a0079391bd6fec285bb	70	0d		---	---	---	---	+	---	---	x	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a004974fa8b465d4c2a	68	0d		---	---	---	---	+	---	---	---	---	+	>	@	@	@	<	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a006d35ee11ec45f658	70	0d		---	---	---	---	+	---	---	---	---	+	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a00117ae091b2bdca65	67	0d		---	---	---	---	+	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
20010db823000a007ccc39777c76bdef	70	0d		---	---	---	---	+	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	

000100011112332321122100 => 3 simultaneous IIDs, maximum

2001:db8::/64 16; Temporary SLAAC: 100%-----! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ?

000000001111111101111100? => /64 assignment @ fenceposts

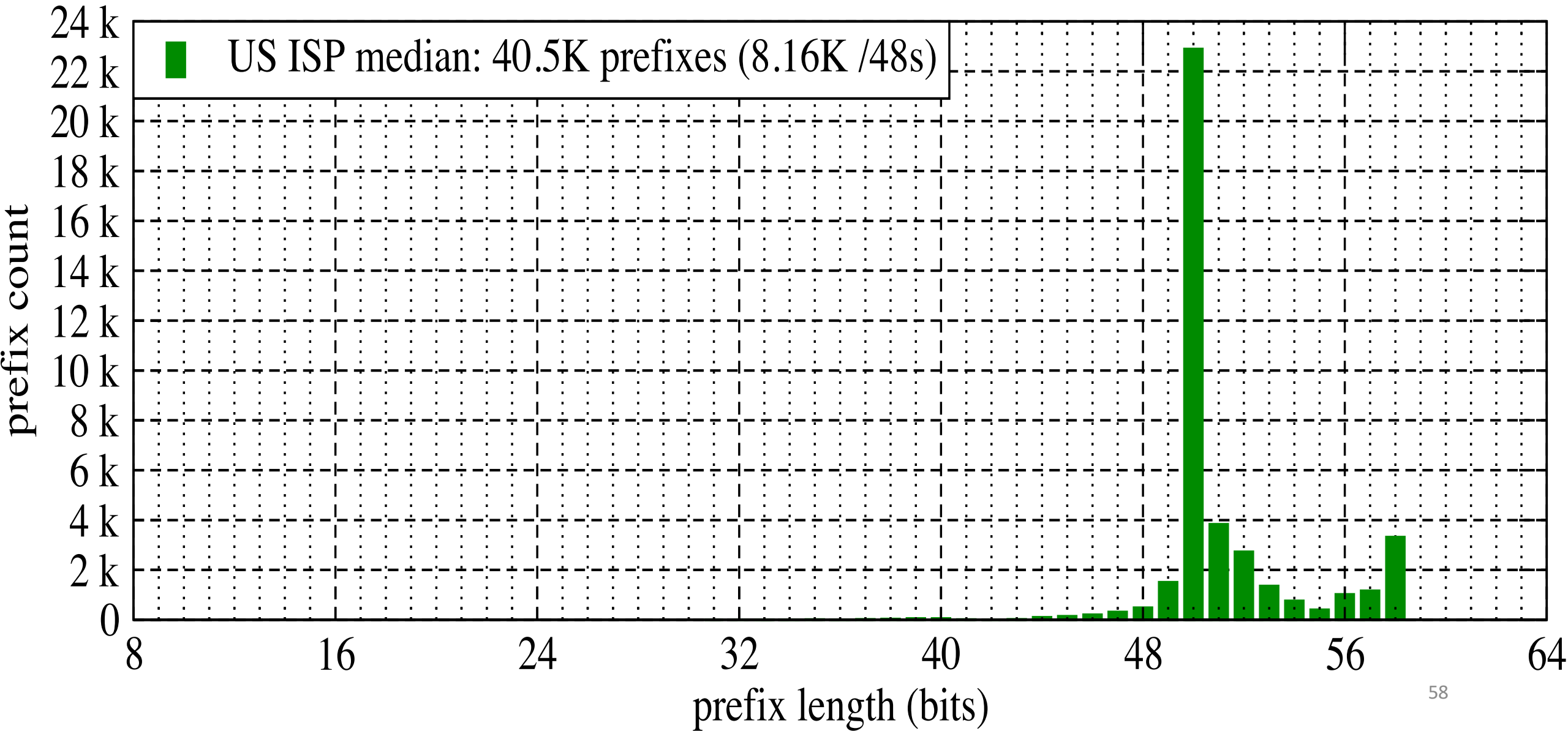
legend:

! = infer /64 prefix assigned at the "fencepost" moments between intervals

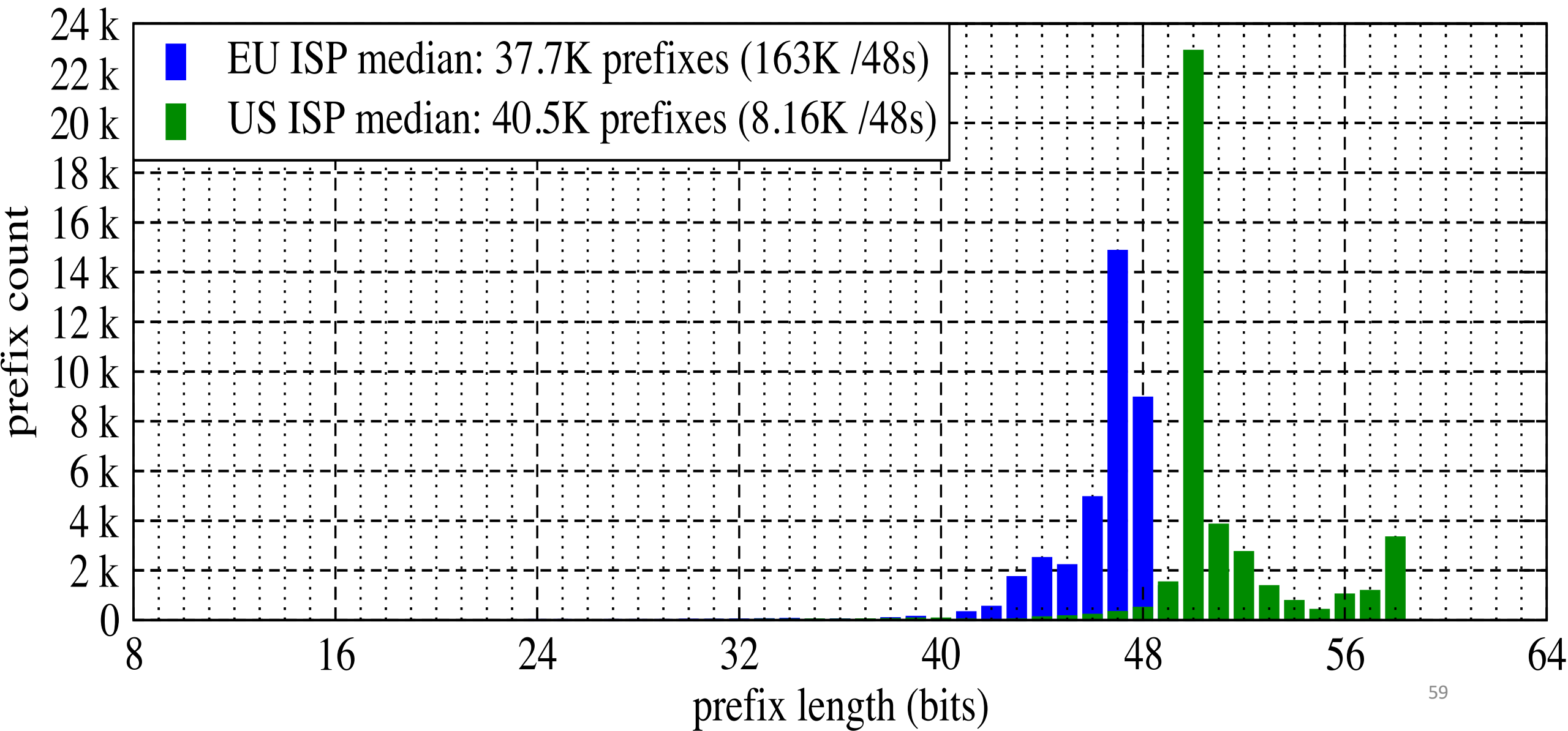
Results: simultaneously-assigned addresses and prefixes

Data set	Active /48 prefixes (7 days)	Active /64 prefixes (7 days)	Simultaneously-assigned /64 prefixes max. (median)	Simultaneously-assigned addresses max. (median)	Active addresses (7 days)
Meeting Network	1	3	3 (2)	309 (84)	15.4K
EU ISP	163K	21.4M	2.02M (1.52M)	3.80M (2.63M)	125M
JP ISP	2.46M	2.46M	1.21M (897K)	2.26M (1.54M)	72.2M
US ISP	8.16K	2.42M	1.81M (1.66M)	4.71M (3.82M)	84.5M

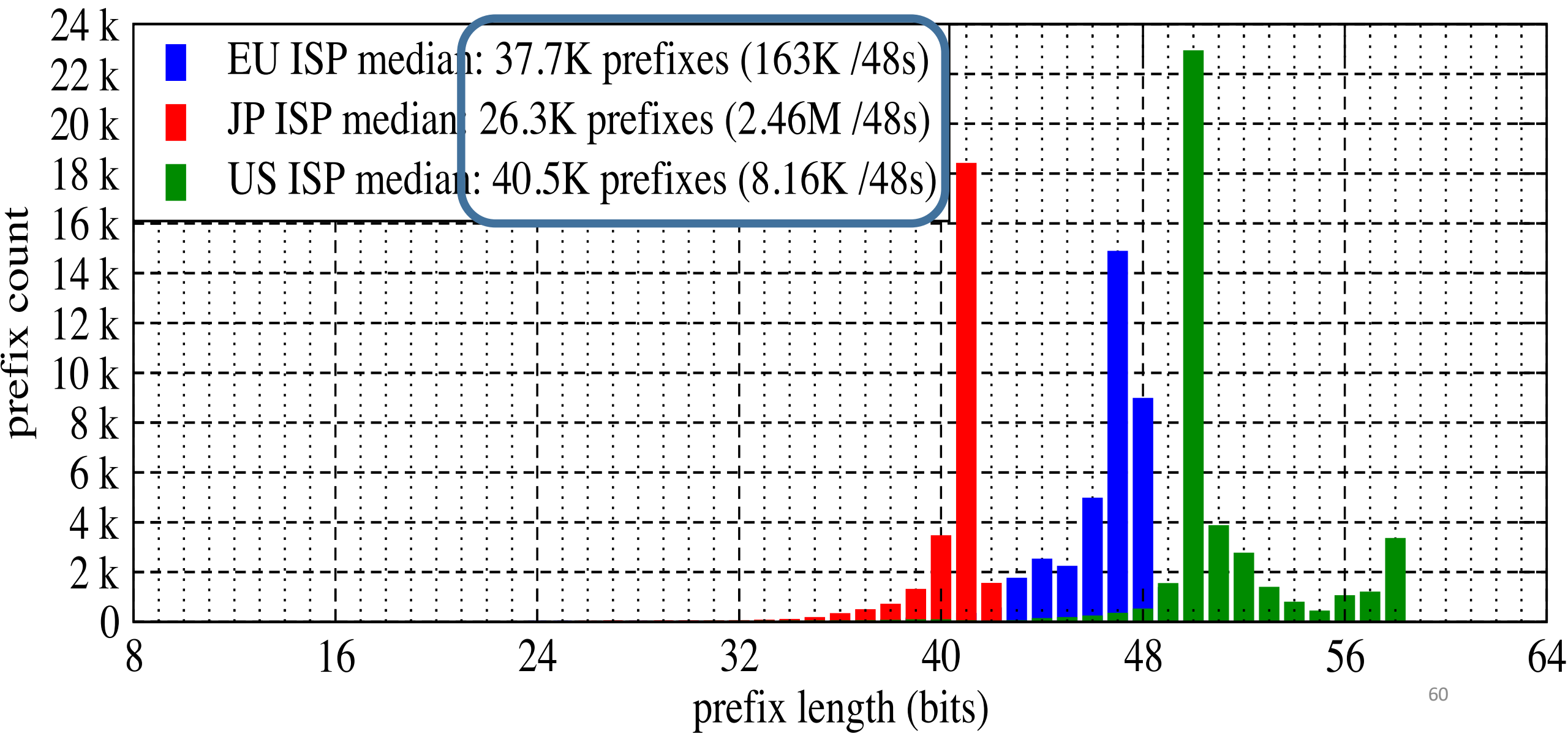
Histogram **k=32** anonymous aggregate prefix lengths (w=7d, i=1h)



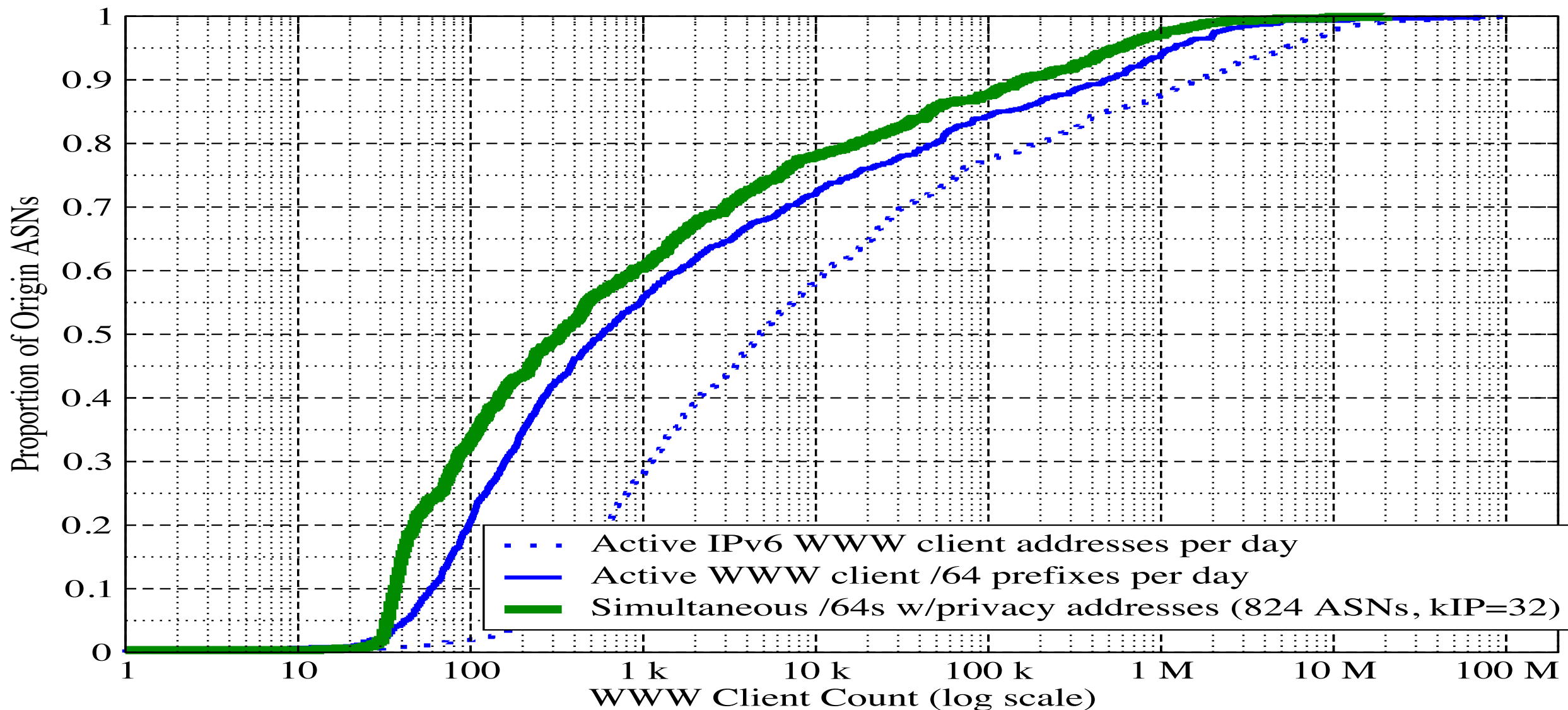
Histogram k=32 anonymous aggregate prefix lengths (w=7d, i=1h)



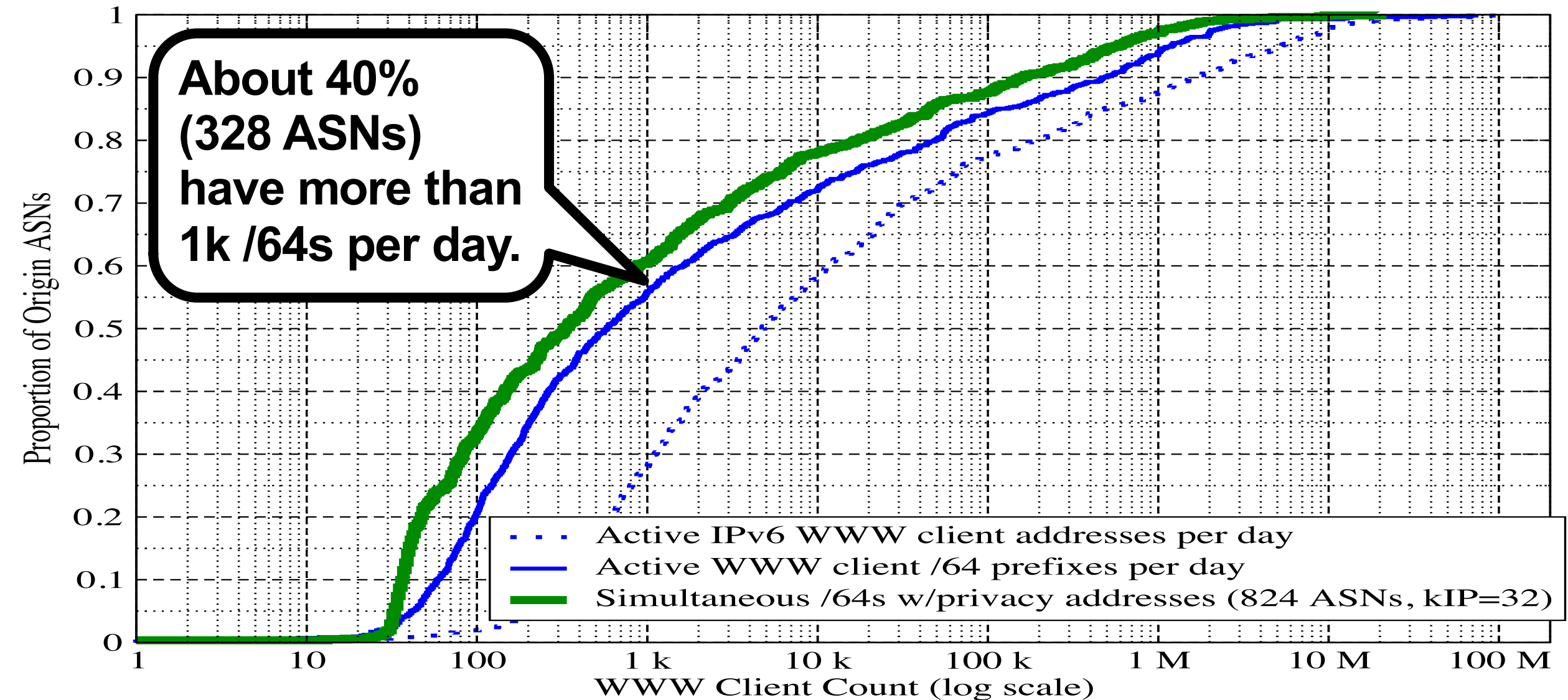
Histogram: k=32 anonymous aggregate prefix lengths (w=7d, i=1h)



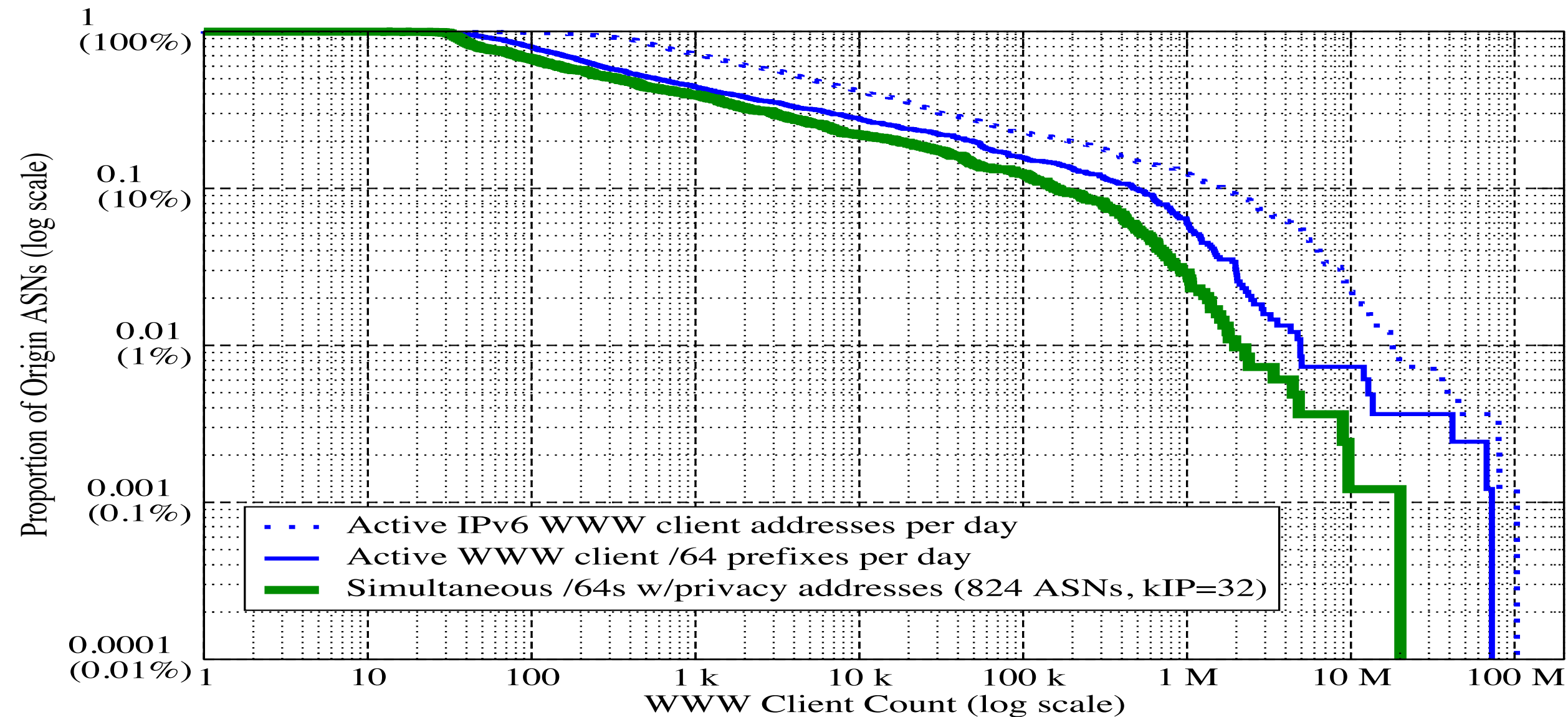
IPv6 Networks sized by Client Addresses (CDF)



IPv6 Networks sized by Client Addresses (CDF)

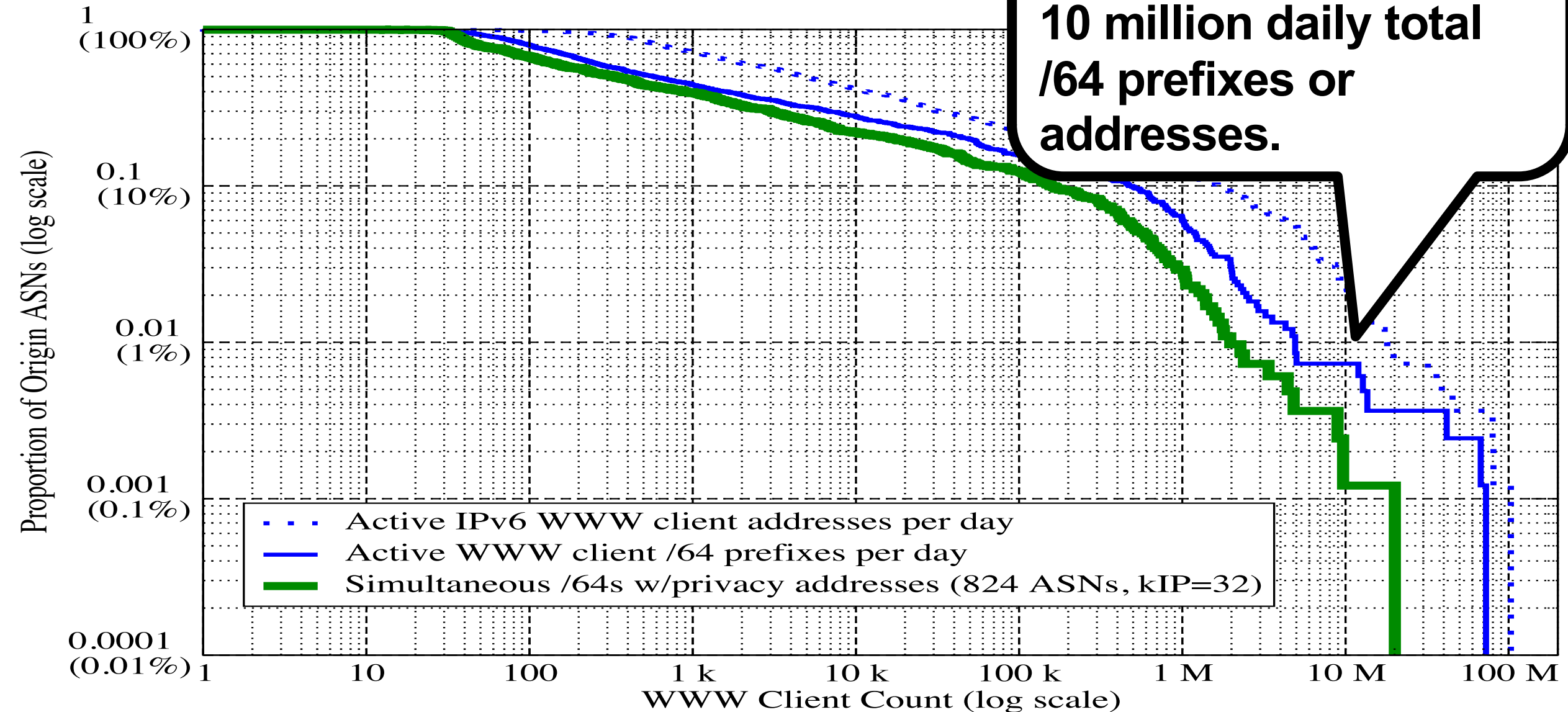


IPv6 Networks sized by Client Addresses (CCDF)



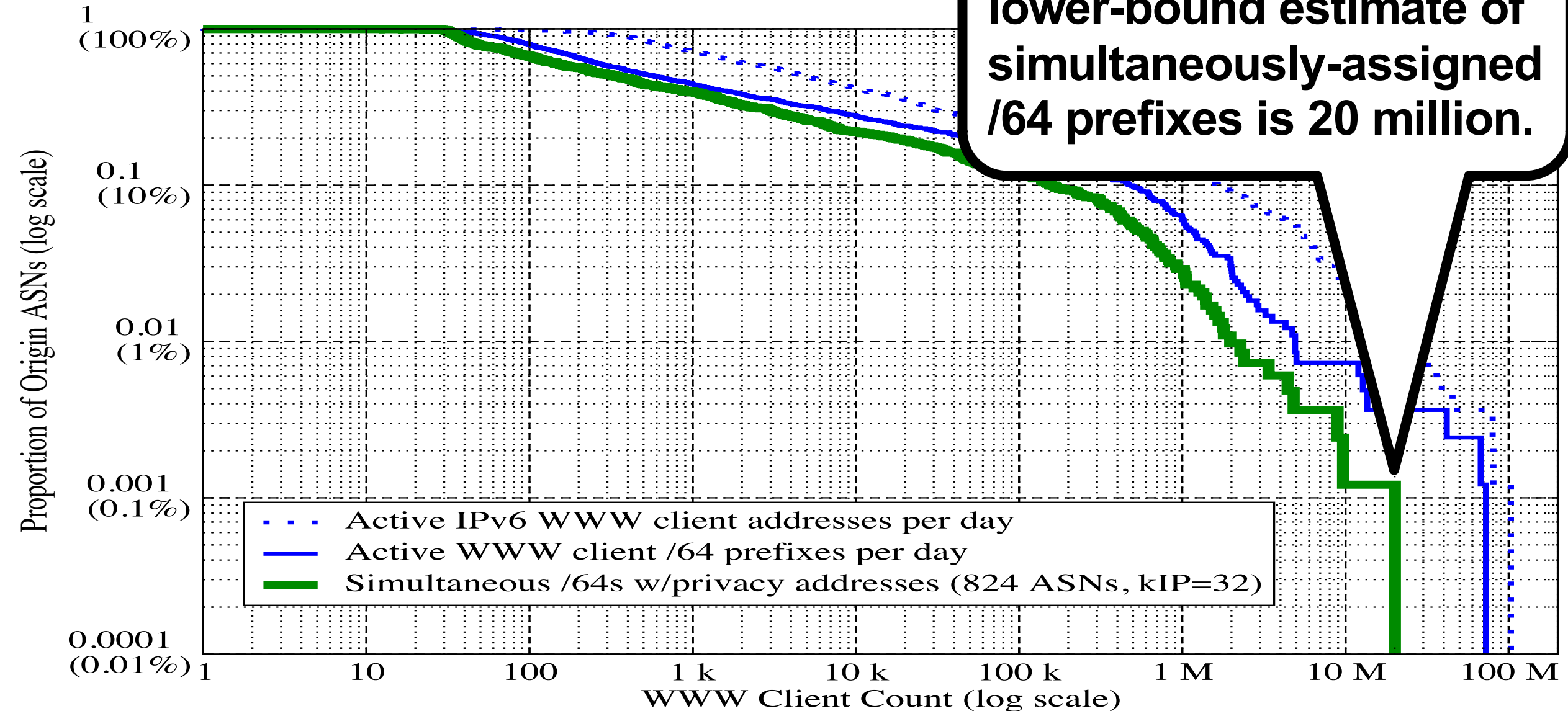
IPv6 Networks sized by Client A

**About 1% (10 ASNs)
have more than
10 million daily total
/64 prefixes or
addresses.**

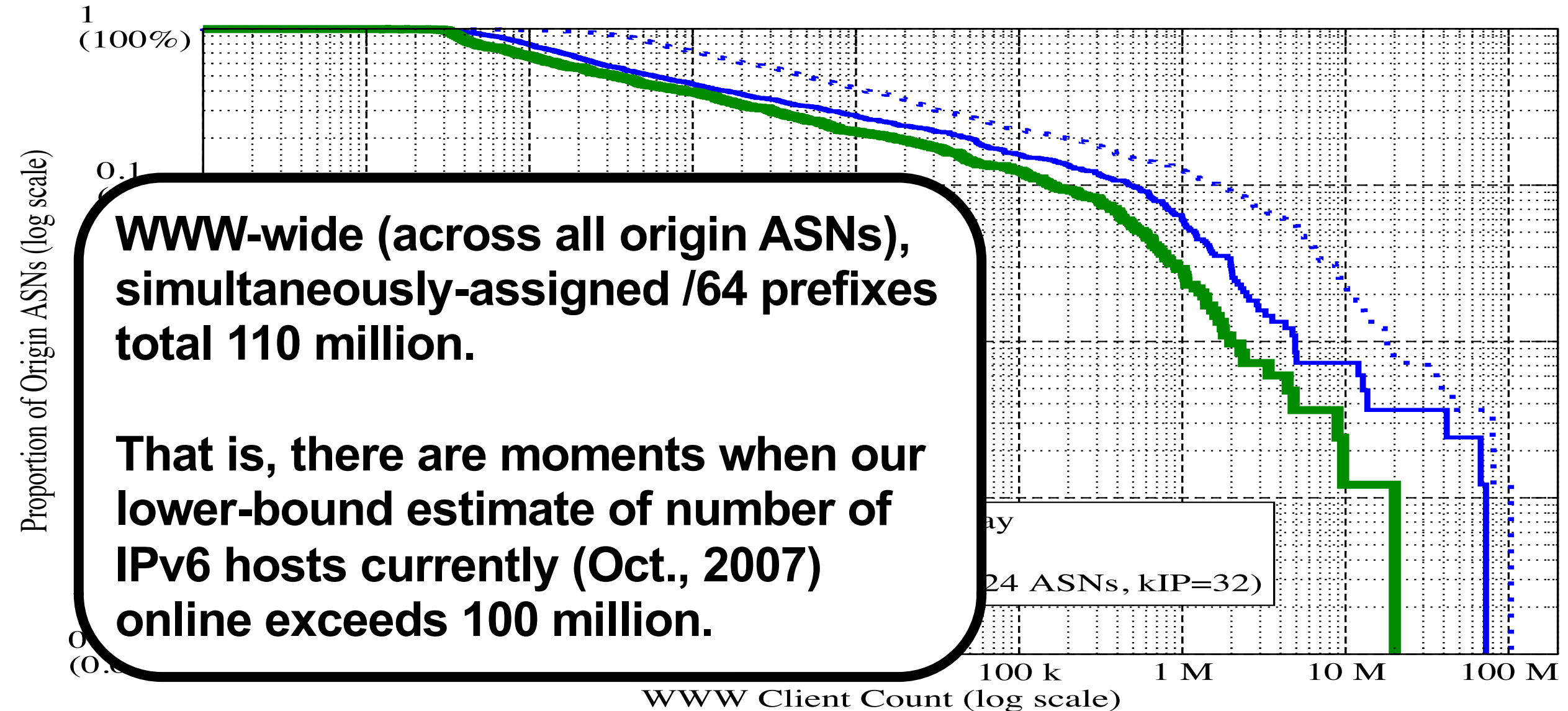


IPv6 Networks sized by Client

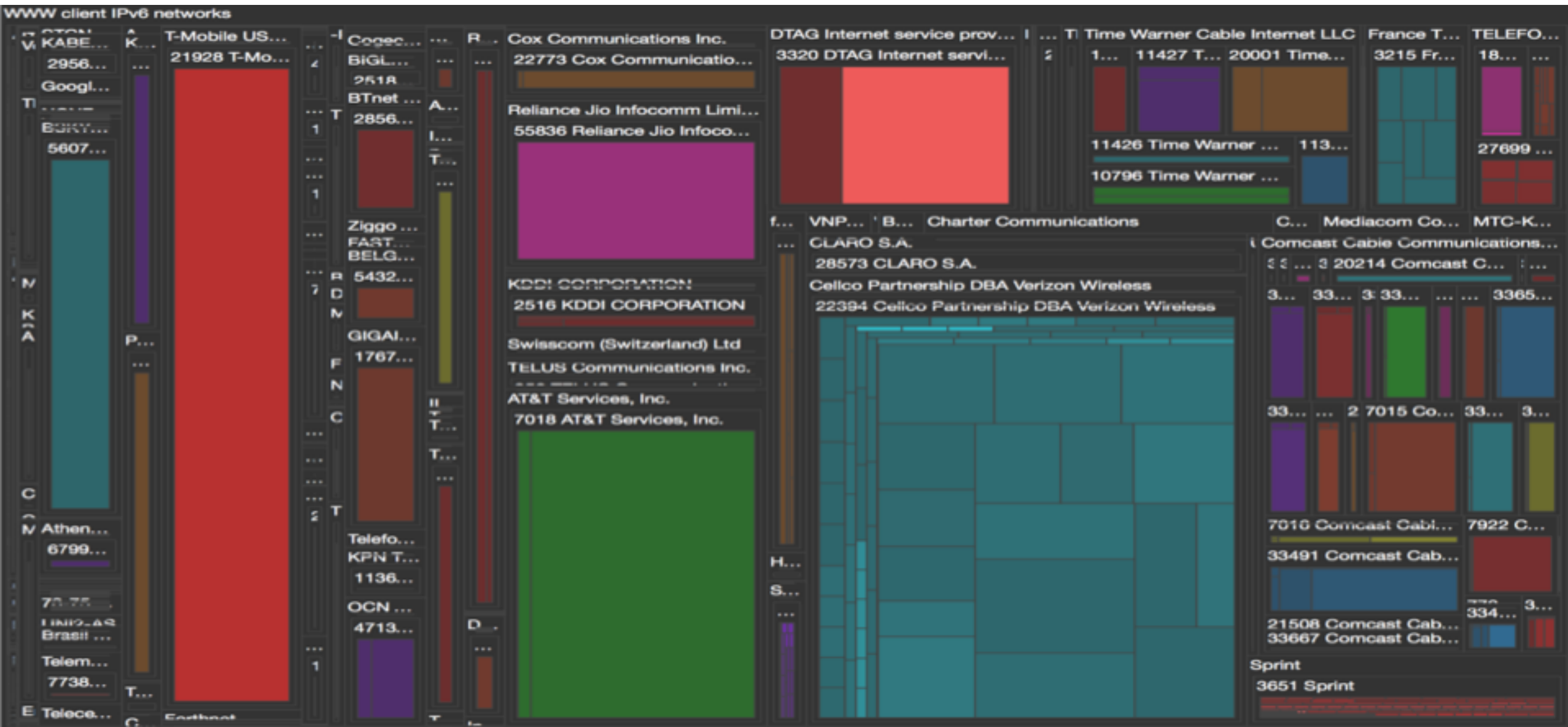
Per ASN, the maximum lower-bound estimate of simultaneously-assigned /64 prefixes is 20 million.



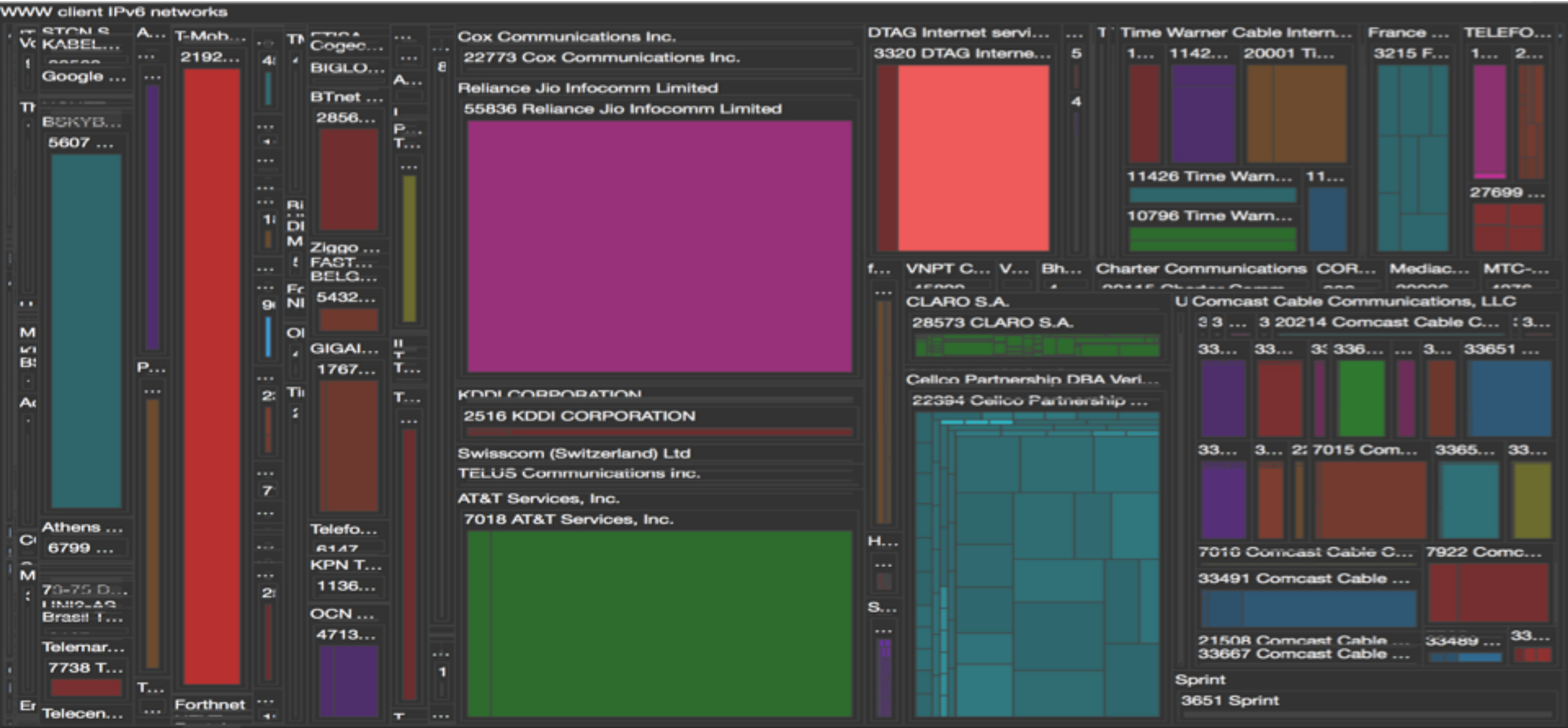
IPv6 Networks sized by Client Addresses (CCDF)



IPv6 Networks by Simultaneous /64 Client count



IPv6 Networks sized by Client Addresses per day



Some Take-Aways

- While most IPv6 clients use temporary privacy addresses, **there are millions of IPv6 clients in some networks that are *not* using privacy addresses!**
- With IPv6 in the dual-stack era, Internet users have **multiple identities** and, with respect to privacy, we must attend to all of them.
- Perhaps surprisingly, **privacy addresses can enable counting of clients** – something we can't do in IPv4 largely due to NA[P]T.

IPv6 & Privacy & IoT: Strategies for Active Topology Discovery

I know traceroute.

What is Yarrp?

“Yelling at Random Routers Progressively”

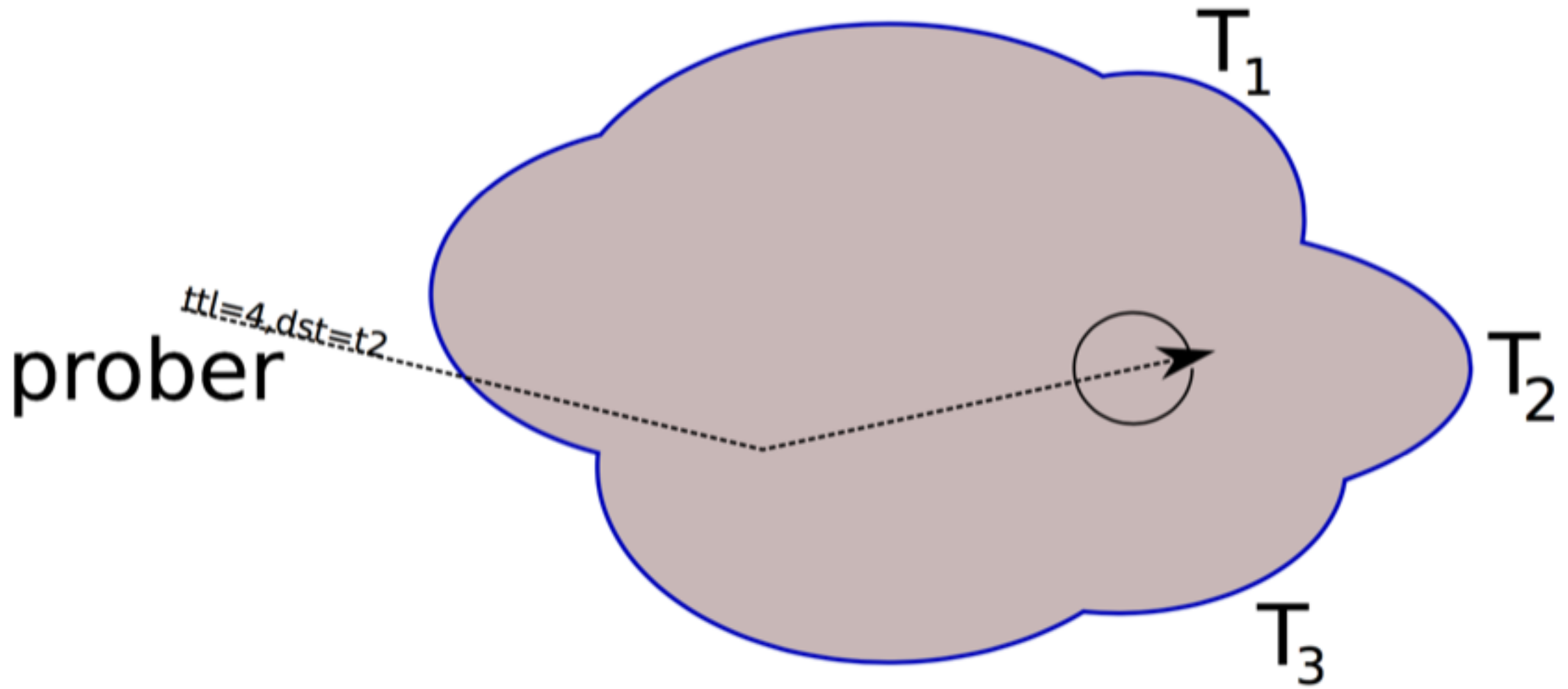


Image credit: R. Beverly, 2016.

In contrast, Yarrp iterates through randomly permuted $\langle Target, TTL \rangle$ pairs

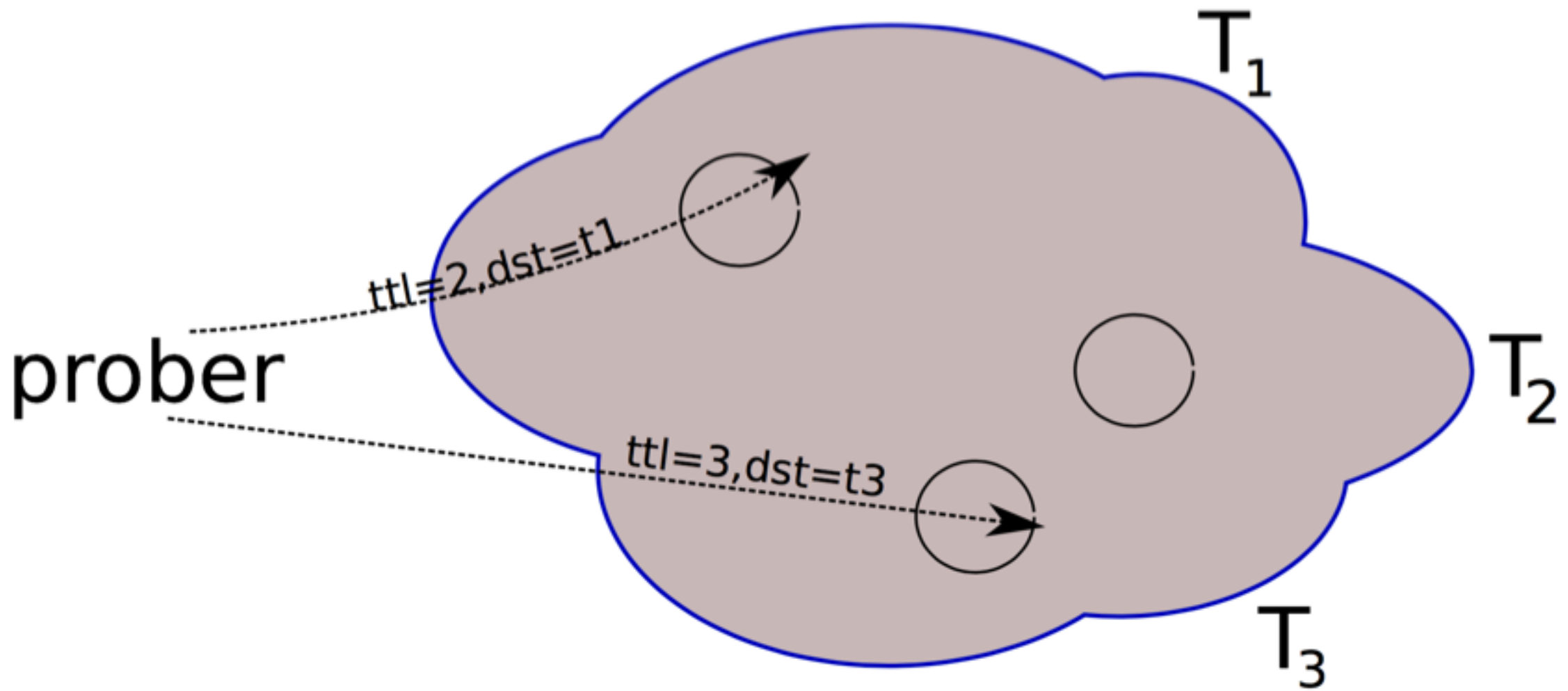


Image credit: R. Beverly, 2016.

In contrast, Yarrp iterates through randomly permuted $\langle Target, TTL \rangle$ pairs

prober

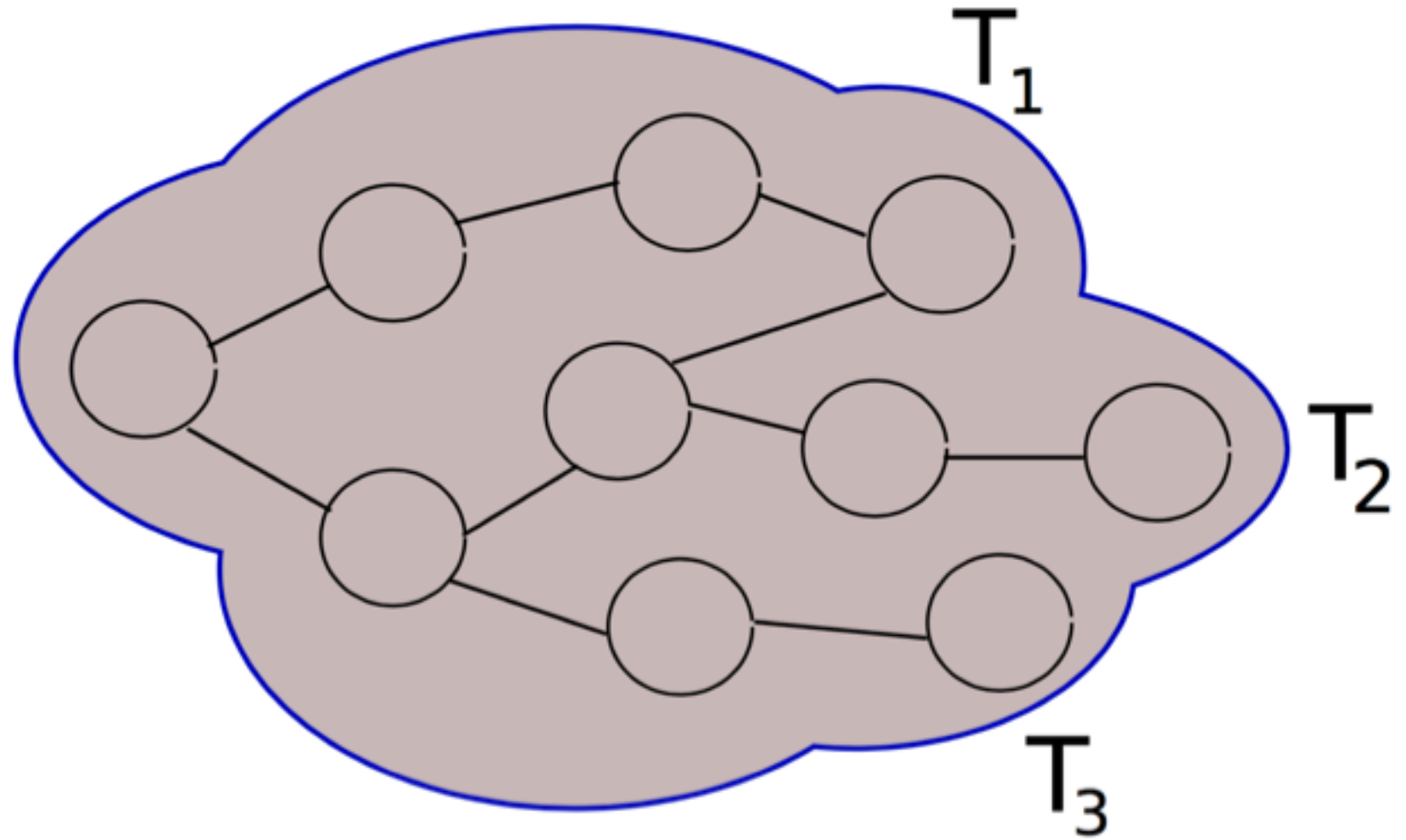


Image credit: R. Beverly, 2016.

Finally, stitch together topology. Requires state and computation, but decoupled (off-line after probing completes).

Rendezvous: How do we [best] choose
targets for probes?

Seed address set (a.k.a. “hit list”) Characterization:

Finding where the IPv6 action is

Name	Method	Date yyyy-mm-dd	# Addrs
CAIDA [7]	BGP-derived	2018-05-09	105.2k
DNSDB [41]	Passive DNS	2018-04-28	5.4M
Fiebig [16]	Reverse DNS	2018-03-27	11.7M
FDNS [38]	Fwd. DNS	2018-04-27	24.8M
CDN Clients [36]	<i>k</i> 256 Agg.	2018-03-03	N/A
	<i>k</i> 32 Agg.	2018-03-03	N/A
6gen [34]	Generative	2018-02-13	4.9M
Combined	Join Sets	Varies	50.8M
TUM [18]	Collection	Varies	5.6M
Random	Random	2018-05-23	26.5M

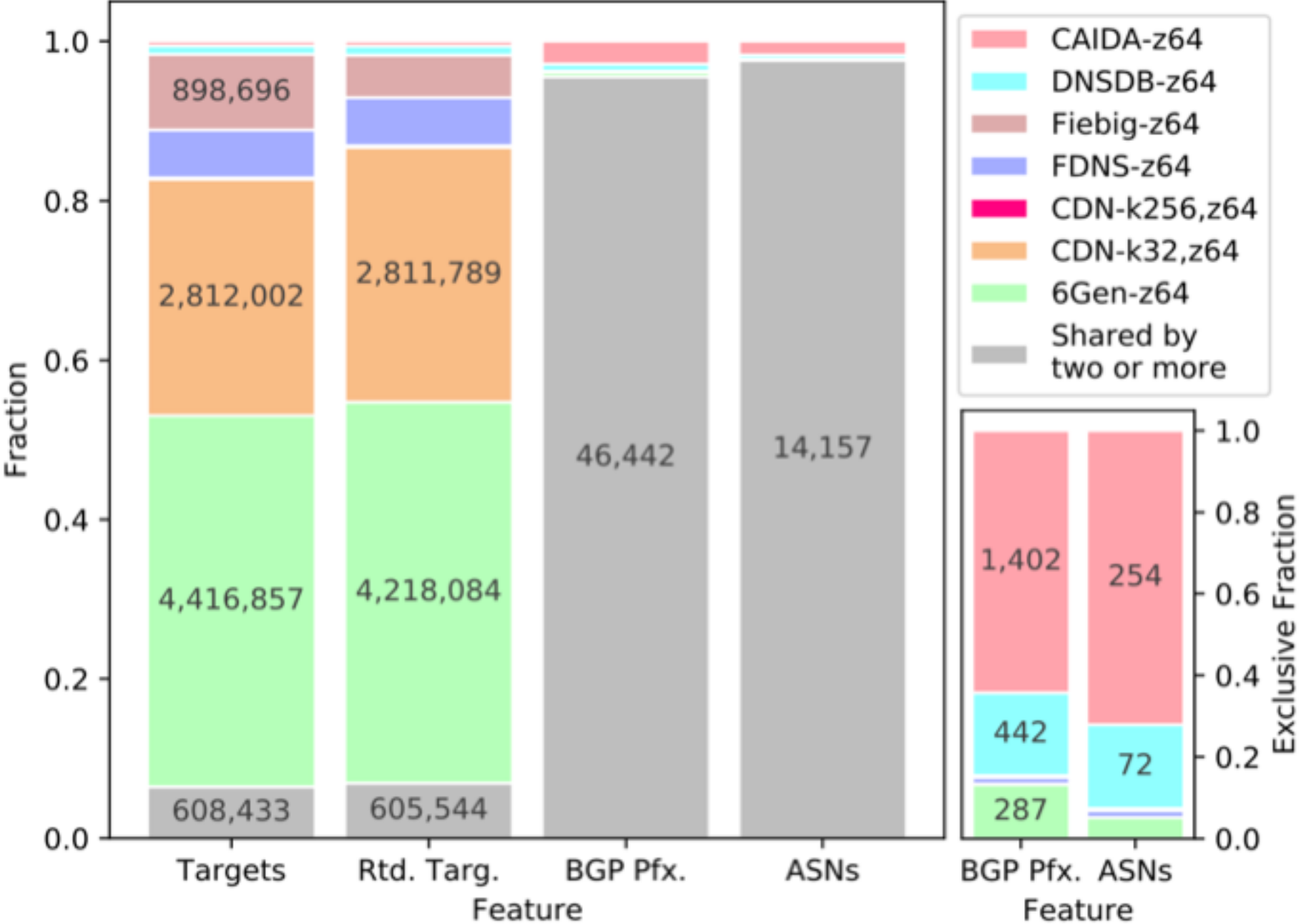
Seed address set (a.k.a. “hit list”) Characterization:

Finding where the IPv6 action is

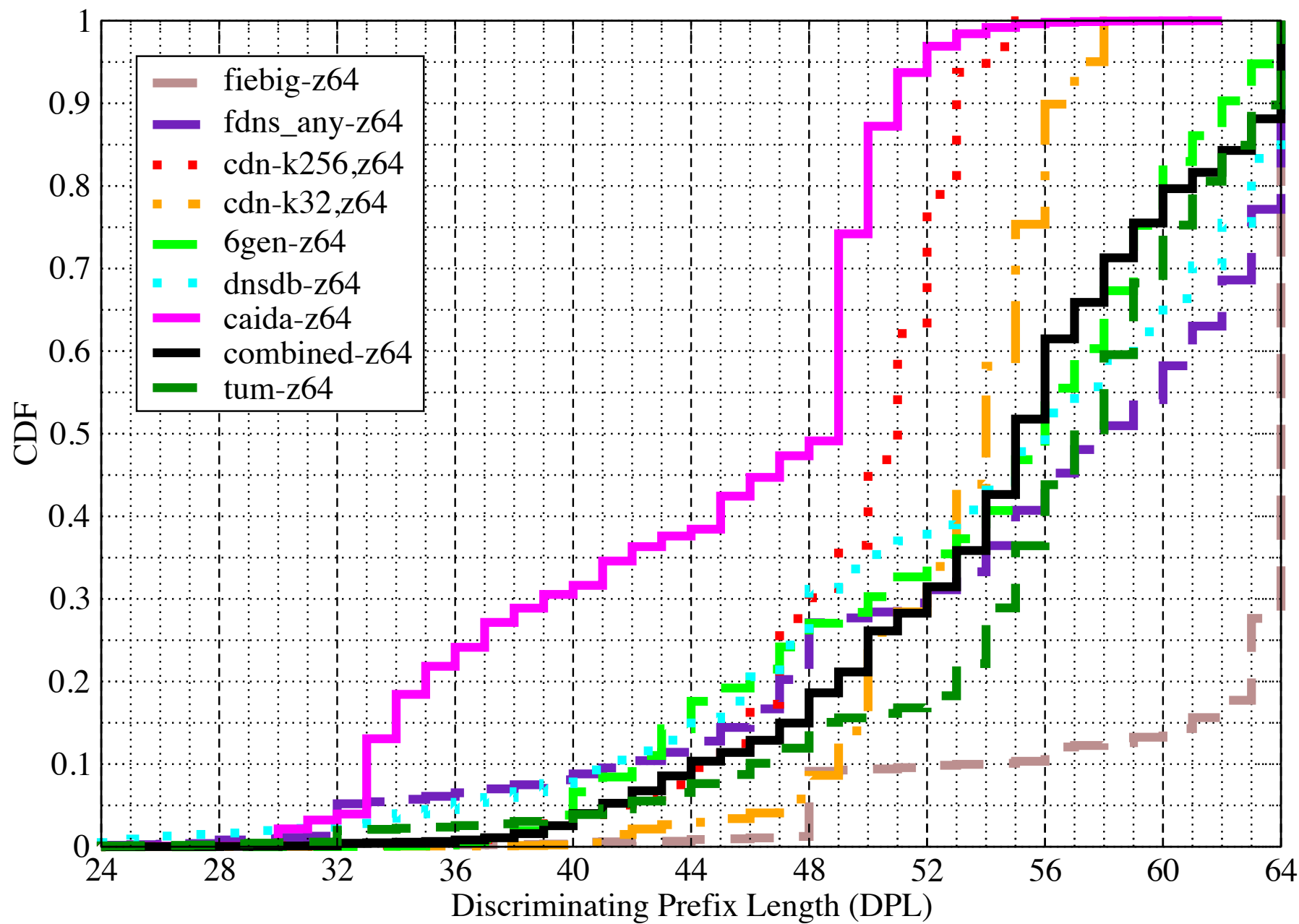
Name	Method	Date yyyy-mm-dd	# Addrs
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Random	Random	2018-05-23	26.5M



Seed Characterization: Finding where the IPv6 action is



Predicting Target Set Power



Yield in yarrp campaigns

Table 7: Results of aggregate yarrp campaigns run from three vantages, reverse sorted by yield. Rtr Hop Addrs are sources of ICMPv6 Time-Exceeded messages.

Yarrp6 Campaign	Agg	Traces	Target Addrs	Rtr Hop Addrs	Excl Hop Addrs	Rtr BGP Pfxs	Excl Rtr BGP	Rtr ASNs	Excl Rtr ASNs	EUI-64 Hop Addrs
ALL	both	45.8M	12.6M	1.4M	0	9.9k	0	7.1k	0	651.4k
EU-NET	both	15.0M	12.2M	1.3M	136.0k	9.5k	236	6.9k	110	613.0k
US-EDU-1	both	15.4M	12.6M	1.3M	84.9k	9.4k	75	6.8k	31	602.7k
US-EDU-2	both	15.4M	12.6M	881.4k	20.7k	7.4k	148	5.5k	76	540.6k
cdn k32	z64	9.6M	3.2M	756.6k	91.6k	2.0k	31	1.2k	7	297.2k
tum	z64	6.2M	2.1M	582.4k	113.7k	7.9k	234	6.0k	131	311.2k
cdn k32	z48	1.6M	524.2k	203.7k	16.5k	1.8k	21	1.2k	7	79.8k
fdns	z64	2.2M	746.9k	185.2k	33.8k	6.2k	147	5.0k	80	15.4k
dnsdb	z64	698.6k	233.0k	154.0k	26.8k	7.8k	223	6.0k	132	10.1k
6gen	z64	13.4M	4.5M	126.4k	21.5k	7.1k	242	5.2k	115	24.8k

Yield in yarrp campaigns

Table 7: Results of aggregate yarrp campaigns run from Rtr Hop Addrs are sources of ICMPv6 Time-Exceeded

Yarrp6 Campaign	Agg	Traces	Target Addrs	Rtr Hop Addrs	Ex H
ALL	both	45.8M	12.6M	1.4M	
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dnsdb	z64	698.6k	233.0k	154.0k	26.8k
6gen	z64	13.4M	4.5M	126.4k	21.5k

45.8 M traceroutes, from 3 vantages, to 12.6 M target addresses yields 1.4 M IPv6 router addresses.

15.0 M traceroutes, from 1 vantage to 12.2 M target addresses yields 1.3 M router addresses.

Yield in yarrp campaigns

Very many EUI-64 router hop addresses, *i.e.*, having embedded MAC addresses!

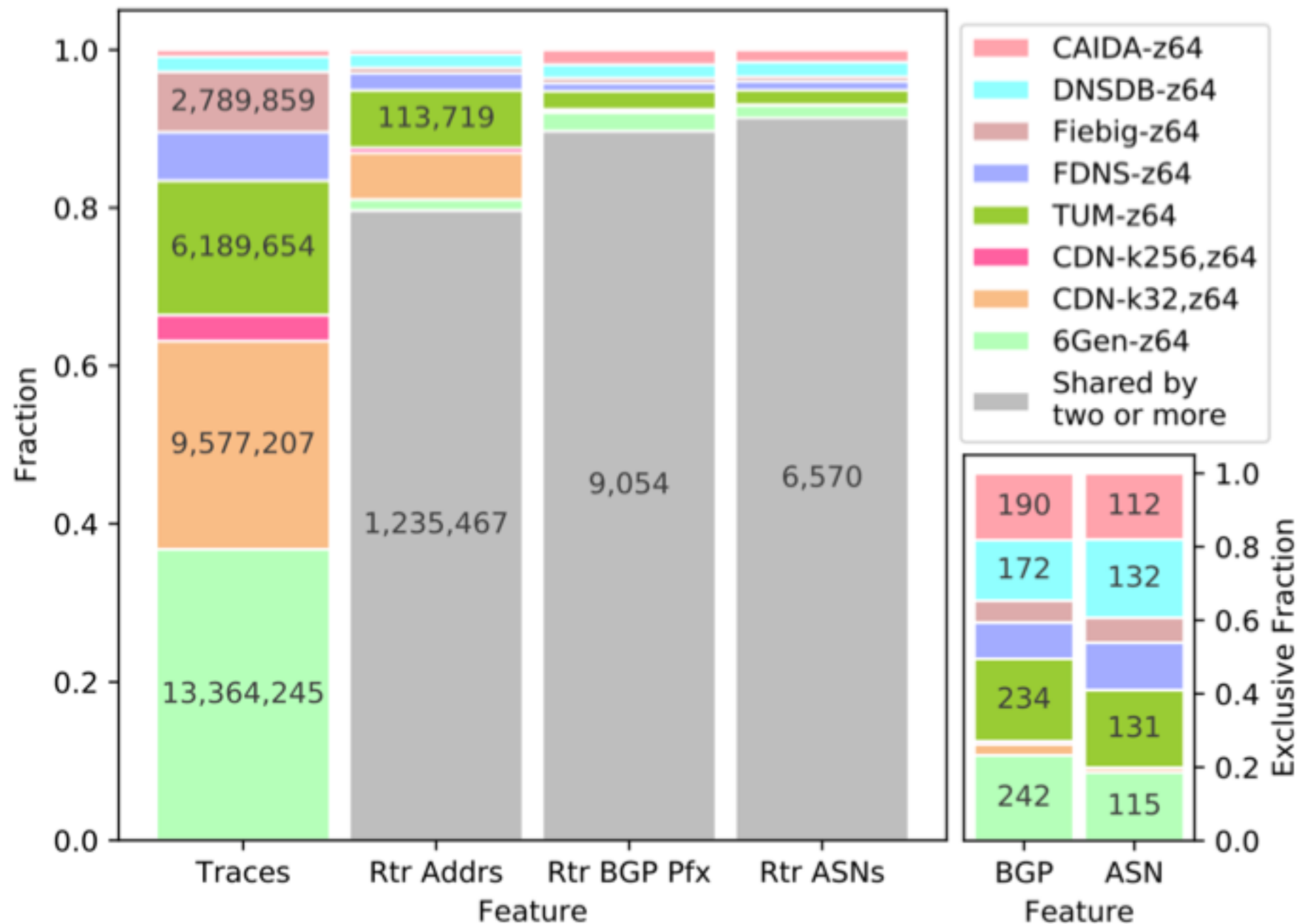
59% of these MAC addresses were just two manufacturers: 99.9% of each of these are in just two ISP networks, *i.e.*, large sets of homogenous, IPv6-connected things: ostensibly CPE routers.

Table 7: Results of a
Rtr Hop Adrs are s

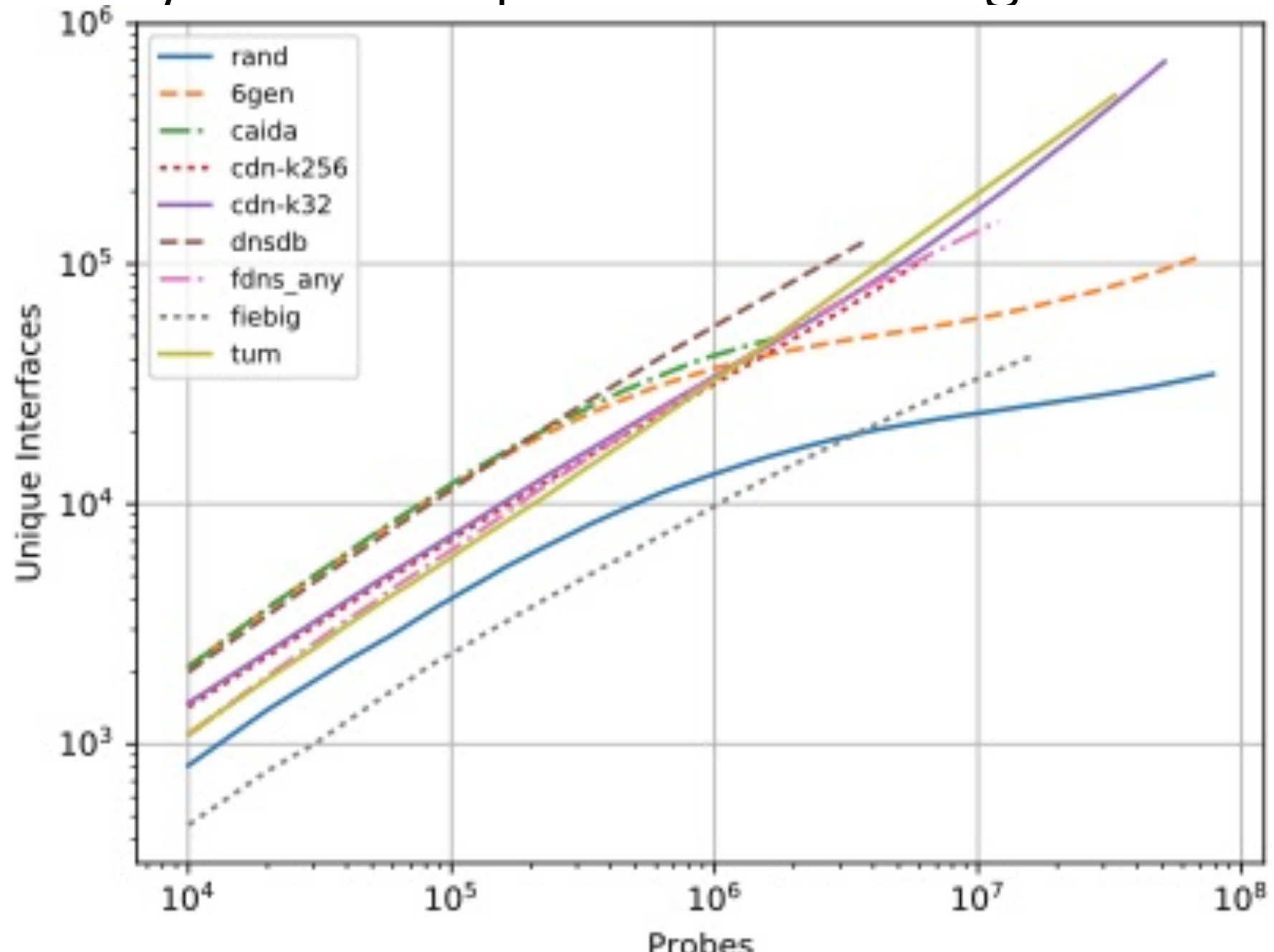
Yarrp6 Campaign	Agg										
ALL	both										
EU-NET	both										
US-EDU-1	both										
US-EDU-2	both										
cdn k32	z64										
tum	z64										
cdn k32	z48										
fdns	z64										
dnsdb	z64	698.6k	233.0k	154.0k	26.8k	7.8k	223	6.0k	132	10.1k	
6gen	z64	13.4M	4.5M	126.4k	21.5k	7.1k	242	5.2k	115	24.8k	

Rtr Ns	Excl Rtr ASNs	EUI-64 Hop Adrs
1.1k	0	651.4k
1.1k	110	613.0k
1.1k	31	602.7k
1.1k	76	540.6k
1.1k		297.2k
1.1k	131	311.2k
1.2k	7	79.8k
5.0k	80	15.4k
6.0k	132	10.1k
5.2k	115	24.8k

Yield in yarrp campaigns

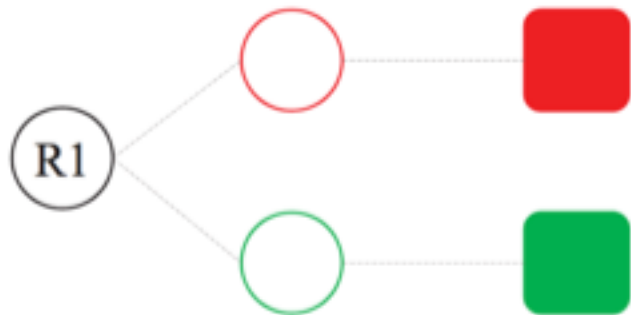


Yield by router hop addresses: Target Set Power



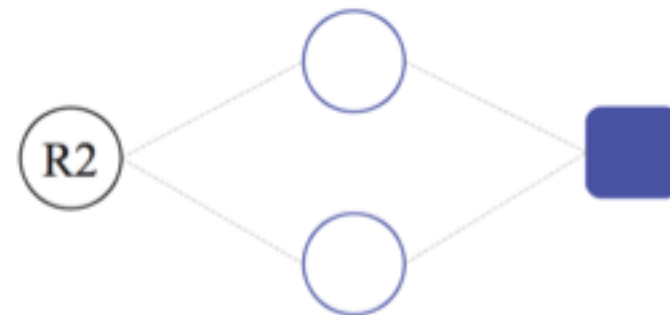
Path Divergence Analysis

```
router R1> show ip route
[ ... ]
A.A.A.0/25      via X.X.X.1
A.A.A.128/25    via Y.Y.Y.1
[ ... ]
```



Heterogeneous

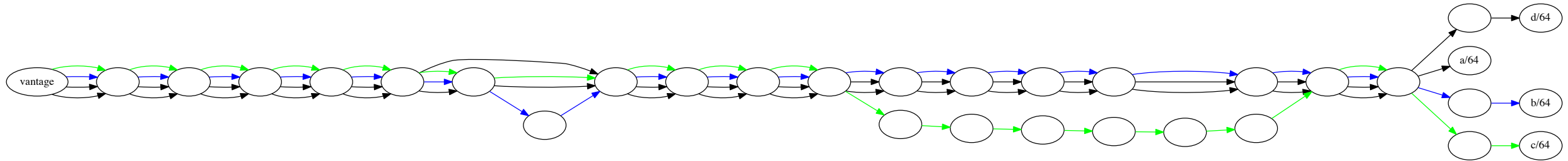
```
router R2> show ip route
[ ... ]
C.C.C.0/24      via X.X.X.2
                via Y.Y.Y.2
[ ... ]
```



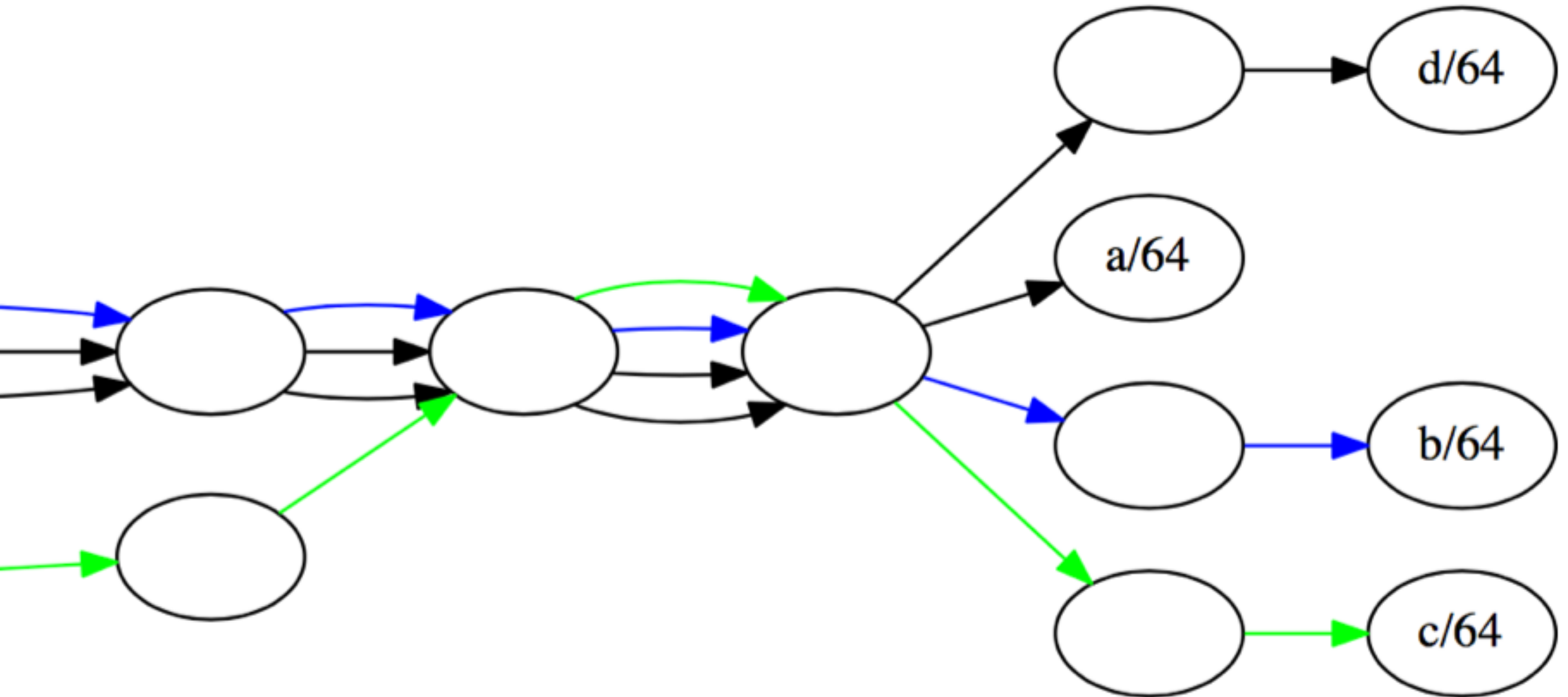
Homogeneous

Figure 1: Different last-hop routers due to distinct route entries (left) and per-destination load-balancing (right).

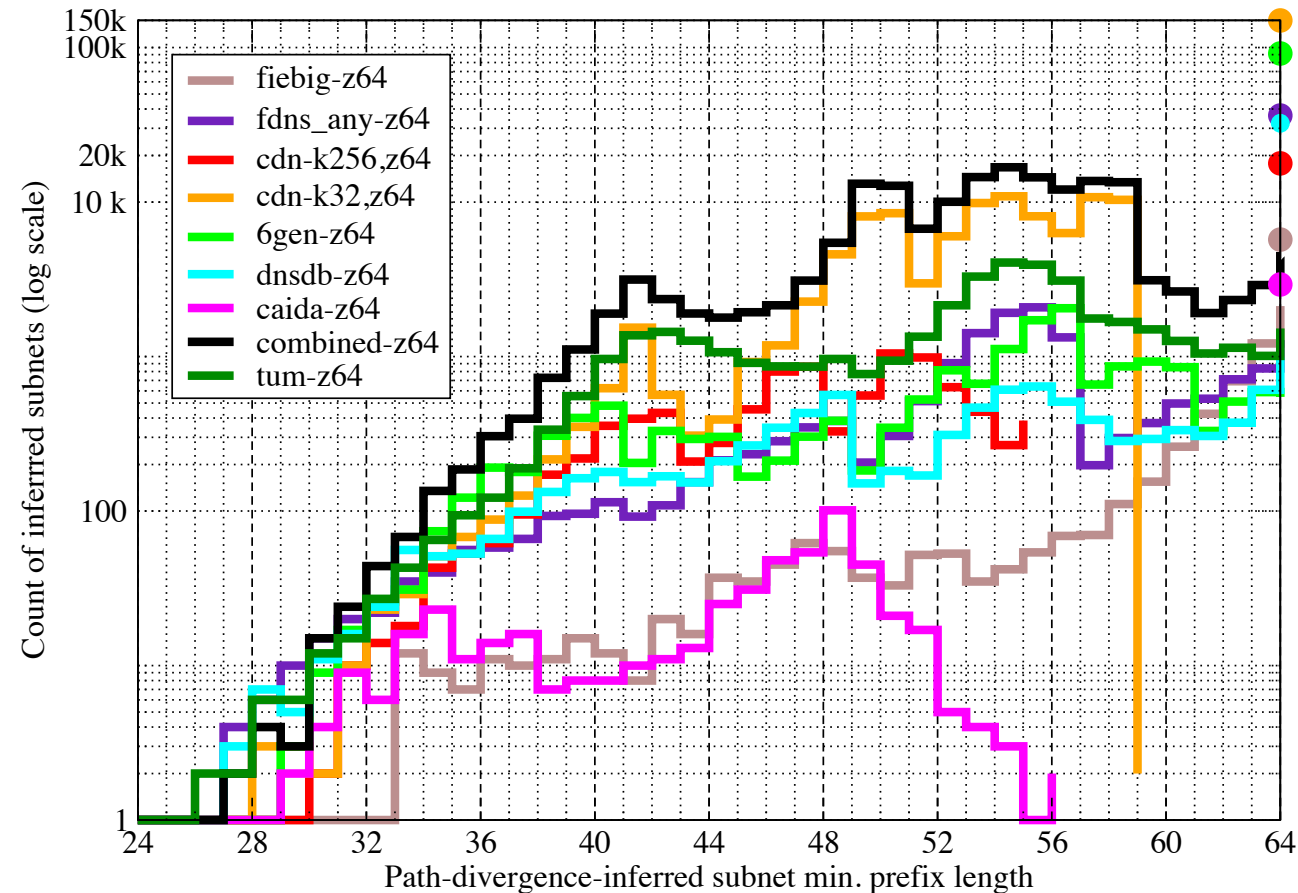
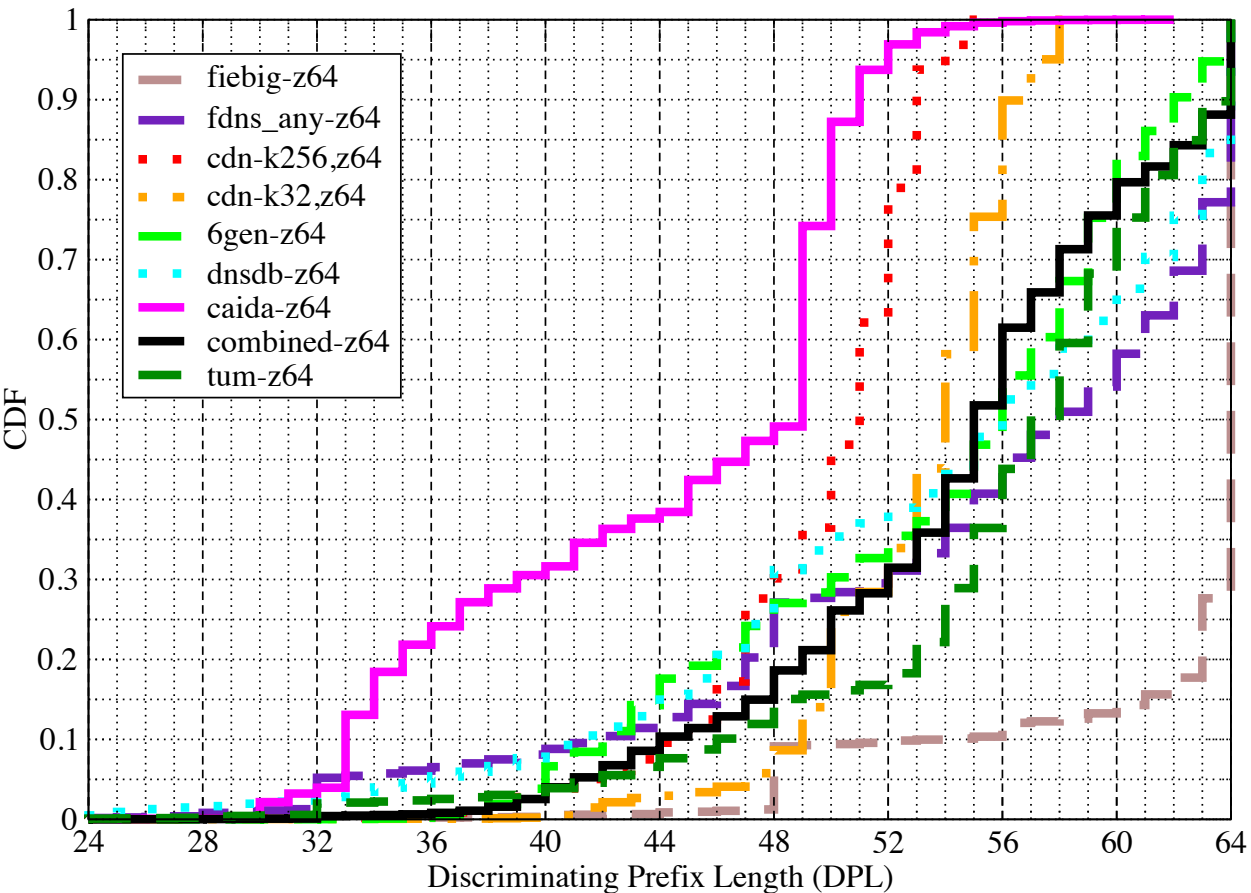
Path Divergence Analysis



Path Divergence Analysis



From targets to topology discovered



Some Final Take-Aways

- Don't [let others] believe that IPv4 techniques work [well] with IPv6 or when both protocol versions are use simultaneously.
There are lots of open problems to solve in our current Internet.
- Most Internet measurement work has an interesting *rendezvous* aspect. How do hosts find each other and what do they know of each other?
- Lets not leave IoT and privacy to only *accidental* measurements. How can we make it *explicit*: **both measurable and measured?**
- ***Socialize or redirect your*** unpublished (whether rejected or yet-to-be-accepted) **works** to other forums, *e.g.*, IETF and IRTF.

Thanks! Questions?

David Plonka <plonka@akamai.com | dave@plonka.us>

Measurement and Analysis for Protocols Research Group (MAPRG)

For details, search for “maprg” in Google 😊

<https://irtf.org/maprg>

<https://trac.ietf.org/trac/irtf/wiki/map>