

*k*IP: a Measured Approach to IPv6 Address Anonymization

MAPRG Meeting – Prague, July 20, 2017

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“*k*IP: a Measured Approach to IPv6 Address Anonymization” (pre-print)

<https://arxiv.org/abs/1707.03900/>

IP Address Anonymization

- **Methods of IP address anonymization include:**
- **Pseudorandom Permutation**, “prefix-[length-]preserving” pseudonymization
e.g., Skipjack, Crypto-PAn
- **Reverse Truncation**
e.g., 2001:db8::
- **Truncation and/or Aggregation**

Background: IPv4 Address Anonymization

10.0.42.24	1	10.0.42.31	1
10.0.42.30	1	10.0.42.10	1
10.0.42.25	1	10.0.42.22	1
10.0.42.6	1	10.0.42.16	1
10.0.42.17	1	10.0.42.4	1
10.0.42.17	1	10.0.42.21	1
10.0.42.9	1	10.0.42.8	1
10.0.42.19	1	10.0.42.20	1
10.0.42.29	1	10.0.42.3	1
10.0.42.26	1	10.0.42.14	1
10.0.42.11	1	10.0.42.1	1
10.0.42.27	1	10.0.42.15	1
10.0.42.13	1		
10.0.42.7	1		
10.0.42.0	1		
10.0.42.12	1		
10.0.42.28	1		
10.0.42.2	1		
10.0.42.23	1		
10.0.42.5	1		

Background: IPv4 Address Anonymization by Aggregation

10.0.42.24	1	10.0.42.31	1
10.0.42.30	1	10.0.42.10	1
10.0.42.25	1	10.0.42.22	1
10.0.42.6	1	10.0.42.16	1
10.0.42.17	1	10.0.42.4	1
10.0.42.17	1	10.0.42.21	1
10.0.42.9	1	10.0.42.8	1
10.0.42.19	1	10.0.42.20	1
10.0.42.29	1	10.0.42.3	1
10.0.42.26	1	10.0.42.14	1
10.0.42.11	1	10.0.42.1	1
10.0.42.27	1	10.0.42.15	1
10.0.42.13	1		
10.0.42.7	1		
10.0.42.0	1		
10.0.42.12	1		
10.0.42.28	1		
10.0.42.2	1		
10.0.42.23	1		
10.0.42.5	1		



10.0.42.0/27 32

IP Address Anonymization

- **Truncation and/or Aggregation**

Application: Privacy of client/subscriber/PII when characterizing activity in the whole IP address space, *e.g.*, for correlating web analytics with network topology, routing, service providers, and geographic locations.

Truncation-based anonymization is ideal if, and only if, it can be guaranteed to improve privacy.

Thus we propose k IP anonymization:

make an individual appear indistinguishable amongst a set of $[k]$ individuals

[<https://en.wikipedia.org/wiki/K-anonymity>,

RFC 6973: “Privacy Considerations for Internet Protocols”]

Characteristics of the data sets

Data set	Active /48 prefixes (7 days)	Active /64 prefixes (7 days)	Active addresses (7 days)
Meeting Network	1	3	15.4K
EU ISP	163K	21.4M	125M
JP ISP	2.46M	2.46M	72.2M
US ISP	8.16K	2.42M	84.5M

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*k*IP: a measurement-based approach...

- 1. Temporal & Spatial Address *Classification*:**
“address dendrachonology”
- 2. Address *Activity Matrix* Analysis:**
estimating simultaneously assigned addresses
- 3. Anonymous Aggregate (Prefix) Synthesis:**
longest-prefix match to get results

Step 1. Classification: address dendrachronology
introduced in "IPv6 Prefix Intelligence," MAPRG Meeting, April 2016



Classification: 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
20010db8000e0000feedfacedeadbabe 71 3d



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

Classification: 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
20010db8000e0000feedfacedeadbabe 71 3d

**Temporal Characteristic:
Stable Days (SD)**

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

Classification: Discarding [Personally Identifiable] Information

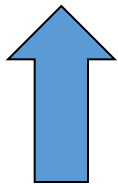
```
20010db8000e000000172cd5fa4bd6b1 75 0d
20010db8000e0000002ae748ea083efb 75 0d
20010db8000e0000005d58e18441347a 79 1d
20010db8000e0000005f1dd3864f2d03 79 0d
20010db8000e000000872ce4d7e0d16c 76 0d
... (1594 more addresses) ...
20010db8000e0000fdbefa6dce8d096c 80 1d
20010db8000e0000fdbf6e62e74a33a4 80 1d
20010db8000e0000fdd4f4f54264cc52 75 0d
20010db8000e0000fdf73310ae0043da 75 2d
20010db8000e0000feedfacedeadbabe 71 3d
```

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

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

Classification: 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
```

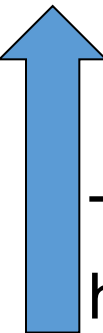


Truncate
here?


Classification: 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 df73310ae0043da 75 2d
20010db8000e0000 added feedfacedeadbabe 71 3d
```

Or
here?



Truncate
here?

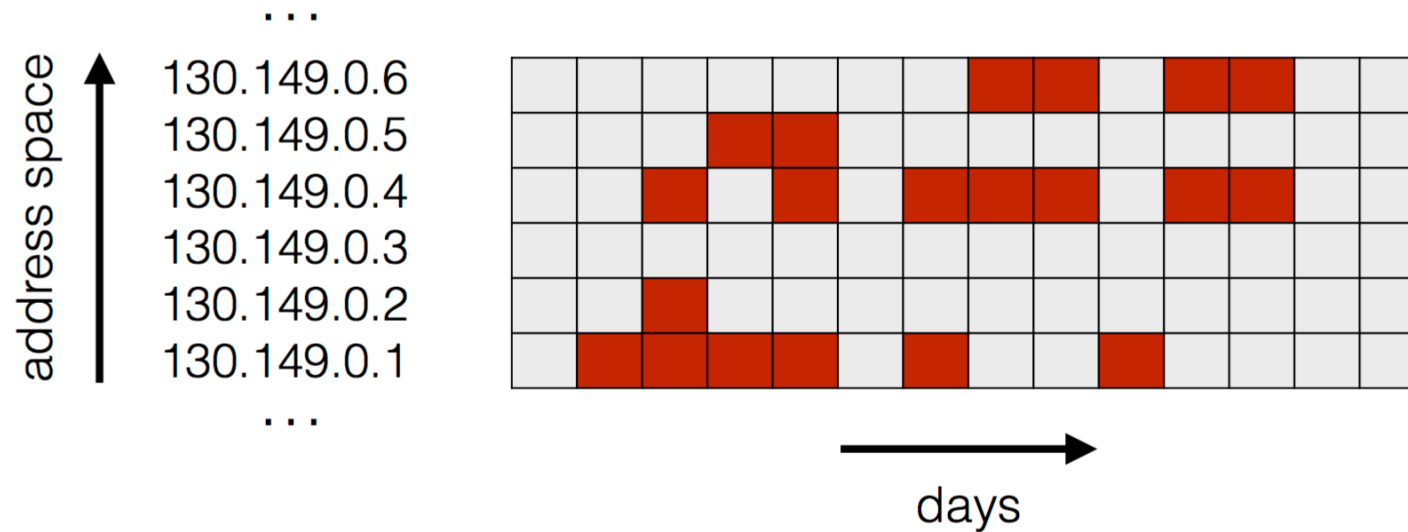


Step 2. Address Activity Matrix Analysis



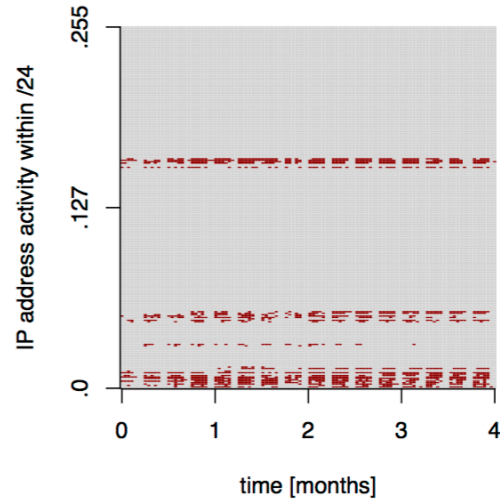
Related Work: IPv4 Address Activity Matrix

introduced in “Beyond Counting ...”, MAPRG Meeting July 2016

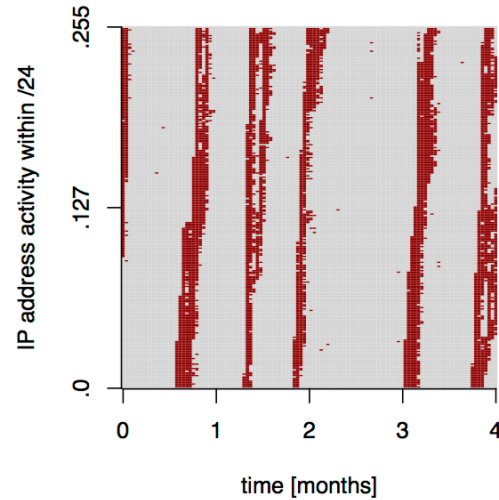


for each day on which an IP address was active (requested content), we draw a red dot.

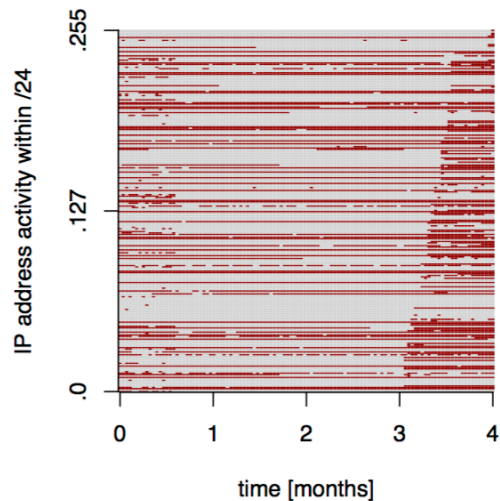
Related Work: IPv4 Address Activity Matrix



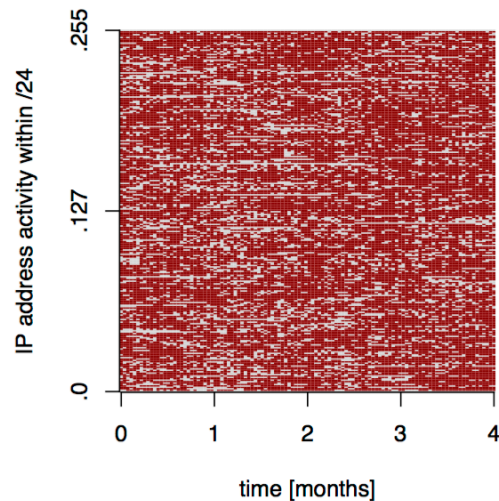
static block DE University



DHCP pool US University



residential users US ISP



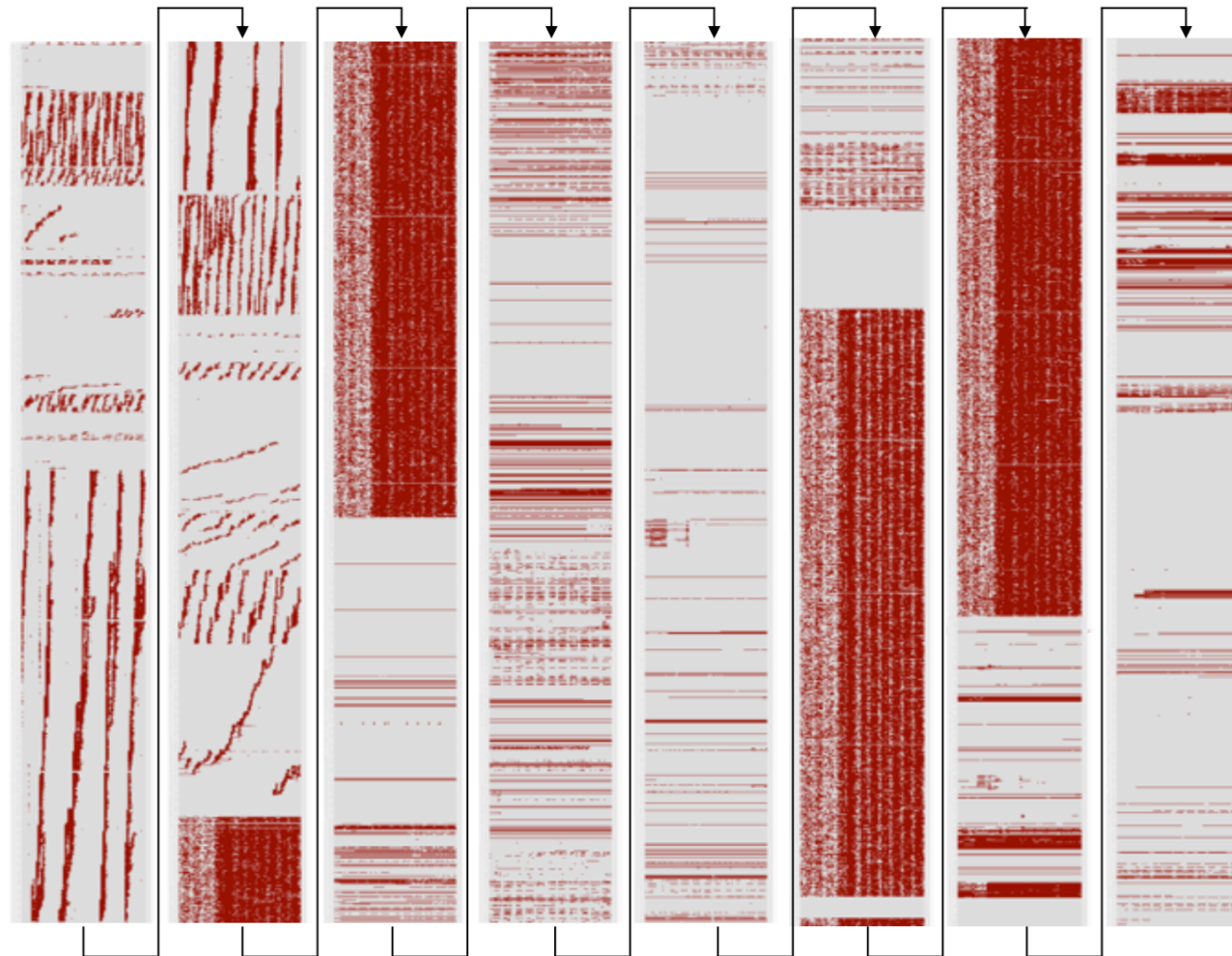
residential users DE ISP

**“in situ” activity:
address assignment practice
+
user behavior**

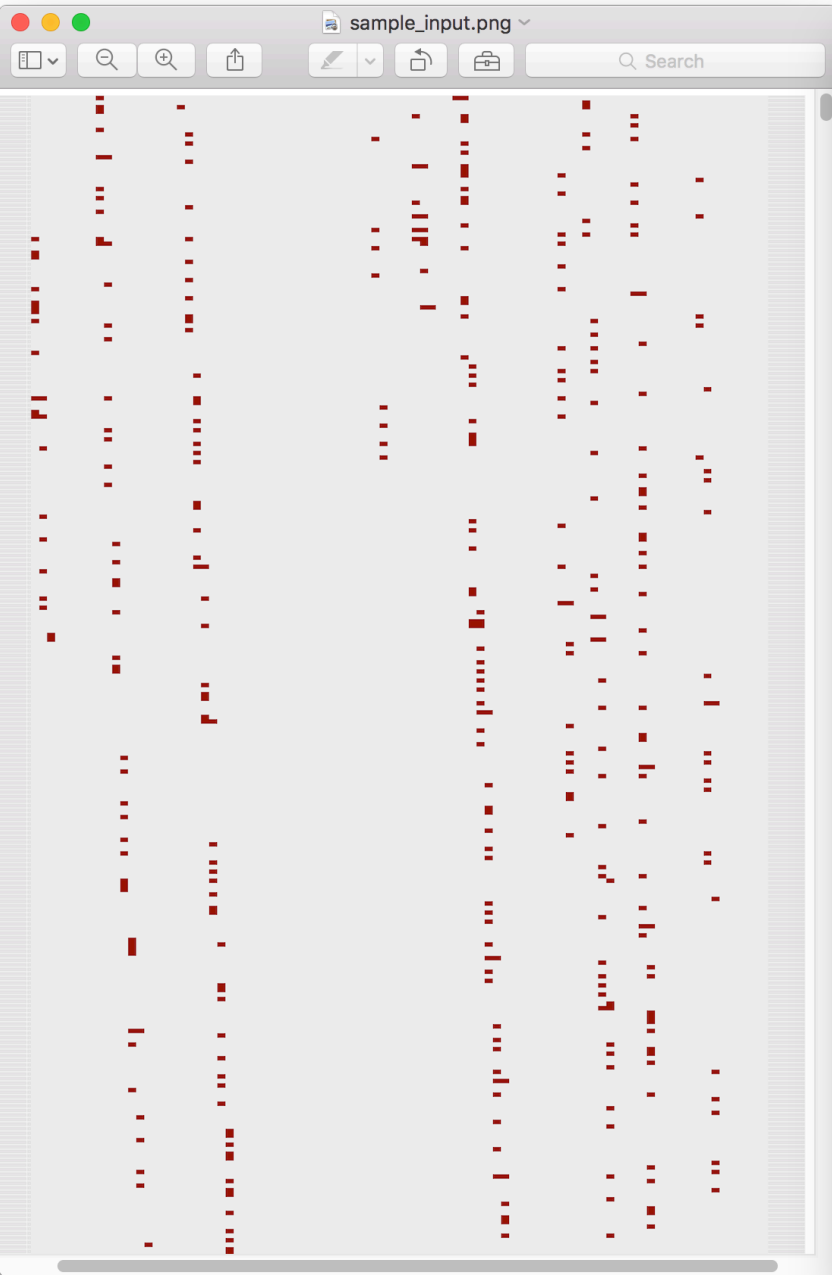
**(no visible modification of
address assignment practice)**

Related Work: IPv4 Address Activity Matrix

20k adjacent IP addresses (in active /24s), University Network



IPv6 Address Activity Matrix



Counting Simultaneous SLAAC IIDs: IPv6 Address Activity Matrix

```

0           1           2
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 |-----+-----#--+-----
20010db823000a00a0fc1e1848aeb2e 67 0d |-----+-----#--#-----
20010db823000a00f9309833f8c53926 74 0d |-----+-----#--#-----
20010db823000a00f94dfcec6b8ed61f 74 0d |-----#-----+-----
20010db823000a00fd2850fe844583e7 70 0d |--#-----+-----+-----

```

```

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

```

/64 prefix

counted during the given hour

Counting Simultaneous SLAAC IIDs: IPv6 Address Activity Matrix

0 1 2
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

IID

counted during the given hour

Counting Simultaneous SLAAC IIDs: IPv6 Address Activity Matrix

0 1 2
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		--#-----+-----+-----

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

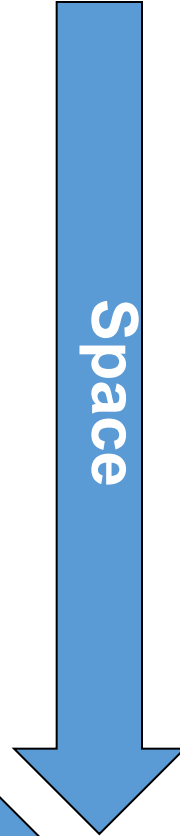
0 1 2
012345678901234567890123

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%

legend:

= activity counted during the given hour



IPv6 Address Activity Matrix

			0	1	2
			0	1	2
			0	1	2
			0	1	2
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



IPv6 Address Activity Matrix

			0	1	2
			012345678901234567890123		
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												
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
			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 ---		

- 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												
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)

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						
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	---							

1


- 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

			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						
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
 - 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

			0	1	2
			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 ---		
				1	2 3

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

			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						
20010db823000a0021ad6d24641a1314	68	0d		--	x	---	+	-----	+	-----	---																					
20010db823000a00fd2850fe844583e7	70	0d		--	x	---	+	-----	+	-----	---																					
20010db823000a007070a7fc47d502ba	70	0d		-----			x	+	-----	+	-----	---																				
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		-----																												
				000	1000	111	123	323	211	22	100																					

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

			0	1	2
			0	1	2
			0	1	2
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

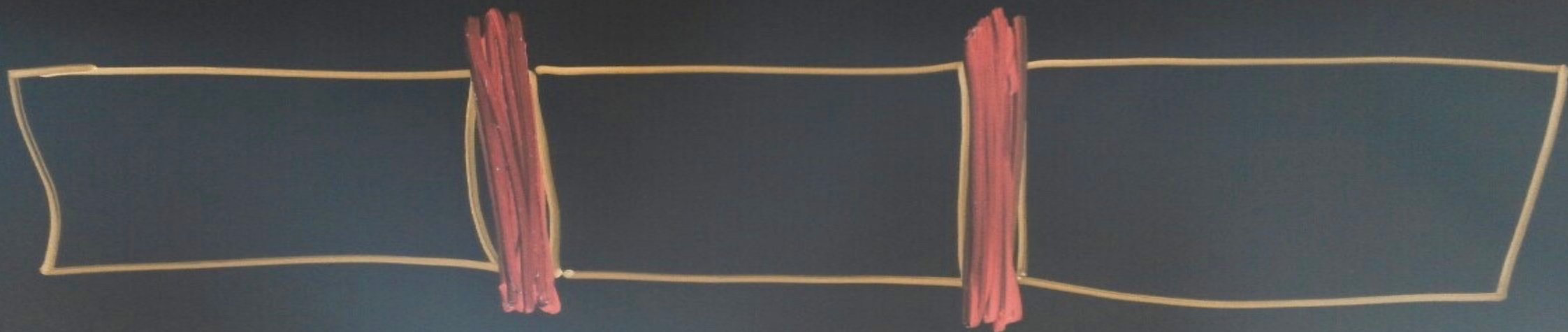
IPv6 Address Activity Matrix

		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												
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		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---													
			000100011112332321122100	=> 3 simultaneous IIDs, maximum																																	
2001:db8::/64 16; Temporary SLAAC: 100%			-----!!!!!!!-!!!!--?																																		
			00000000111111110111100?	=> fencepost simultaneous /64s																																	

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

3. Synthesizing Anonymous Aggregates

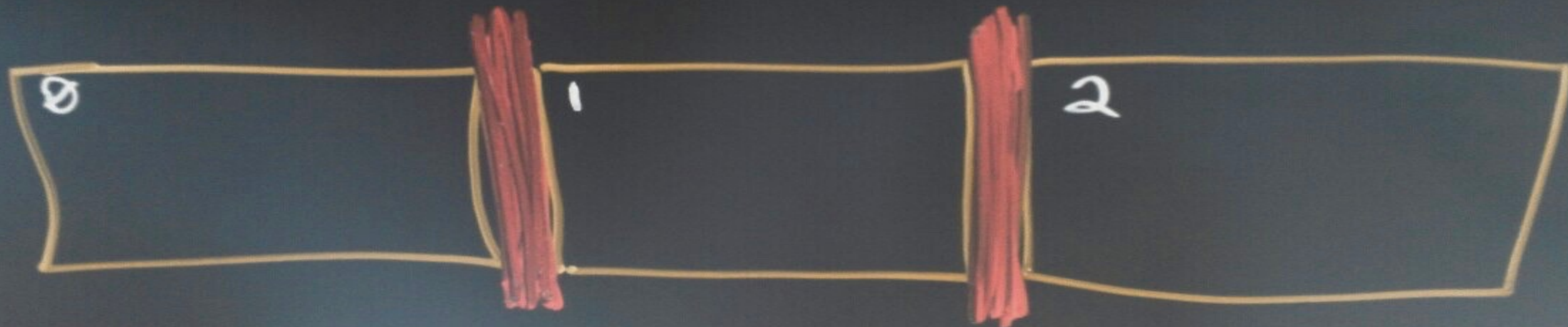




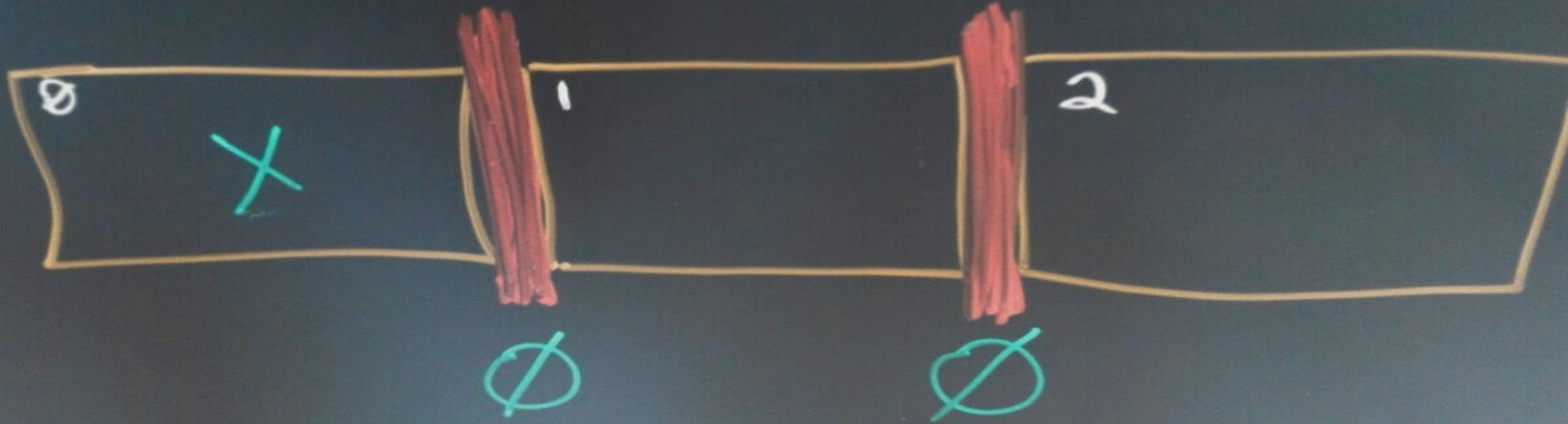
$$i = 1$$

$$w = 3$$

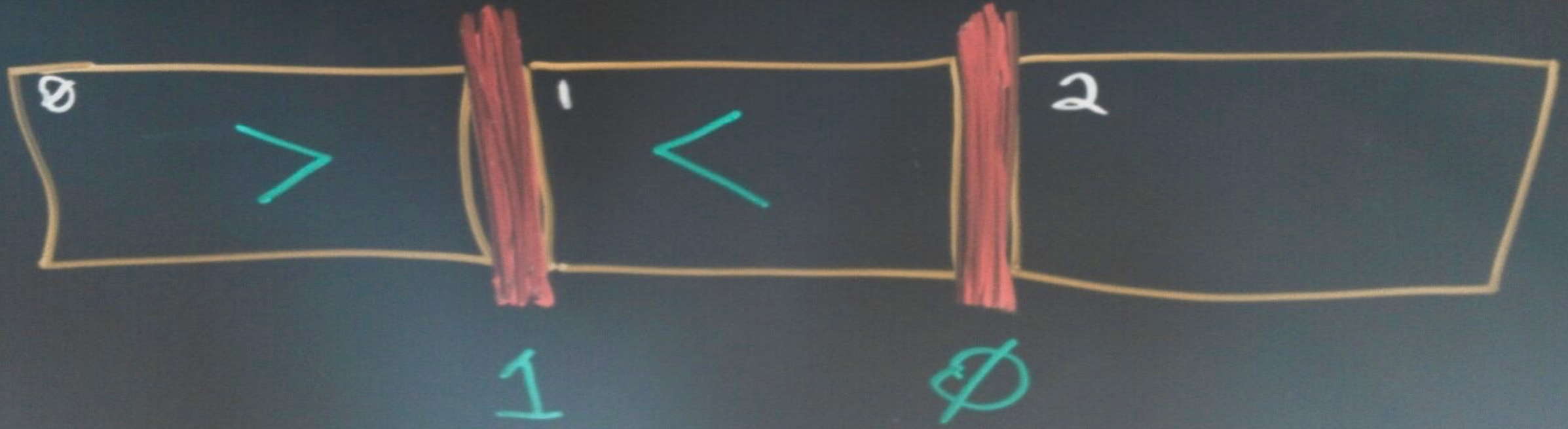
$$f = 2$$



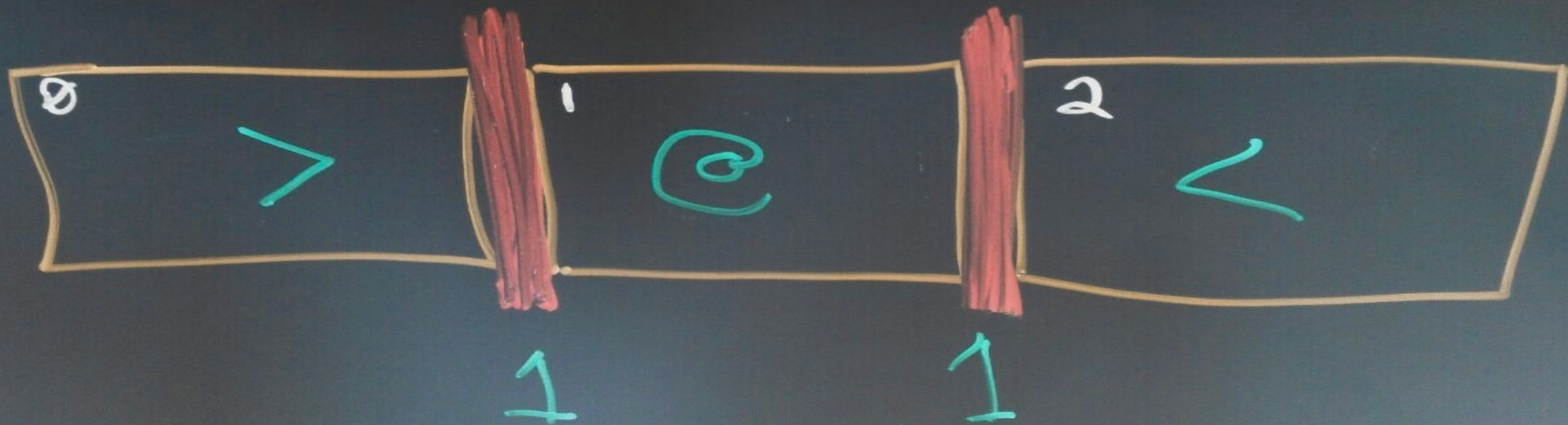
$i = 1$
 $w = 3$
 $f = 2$



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



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

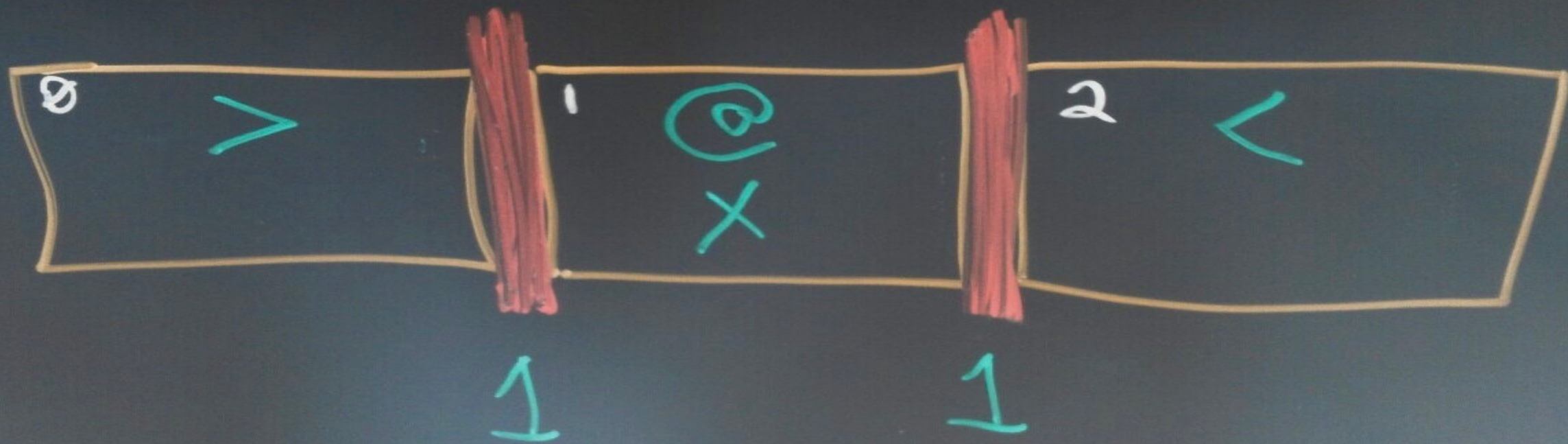


IPv6 Address Activity Matrix

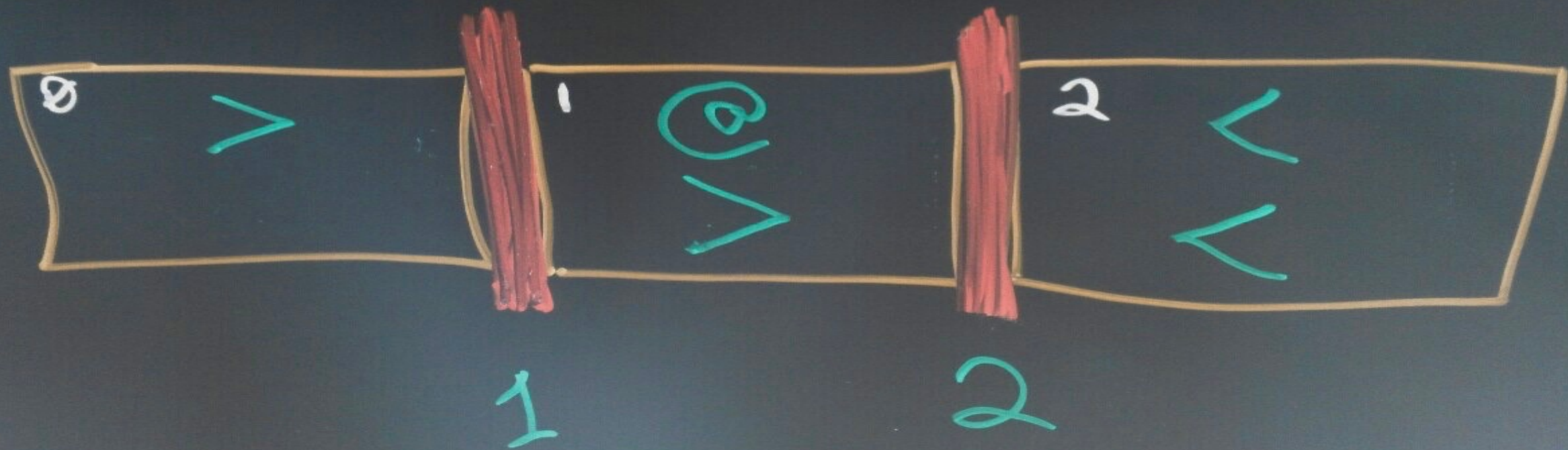
		0												1												2											
		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3												
20010db823000a0021ad6d24641a1314	68 0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---													
20010db823000a00fd2850fe844583e7	70 0d		--	x	---	+	---	---	---	---	---	+	---	---	---	---	---	---	---	---	---	---	---	---													
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	---	---	---	---	---	---	---	---	---	---	---													
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			000000001111111101111100?	=> fencepost simultaneous /64s																																	

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

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



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

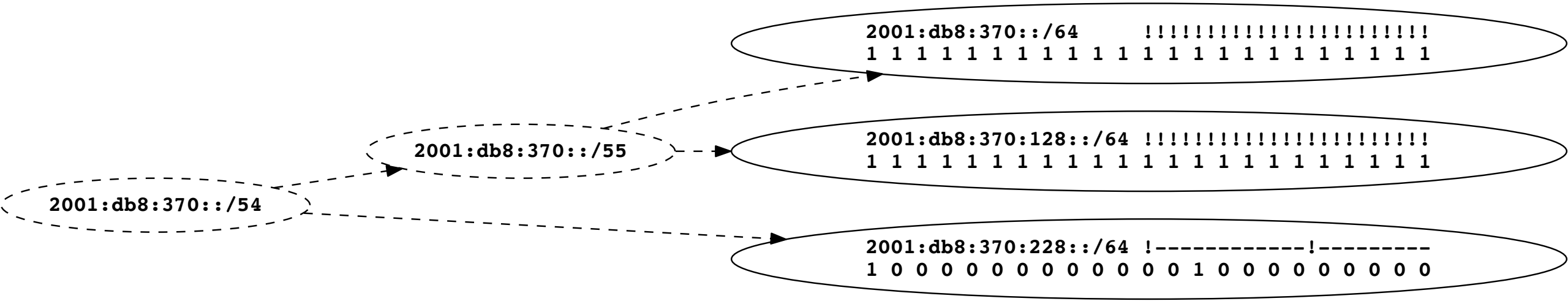


Characteristics of the data sets

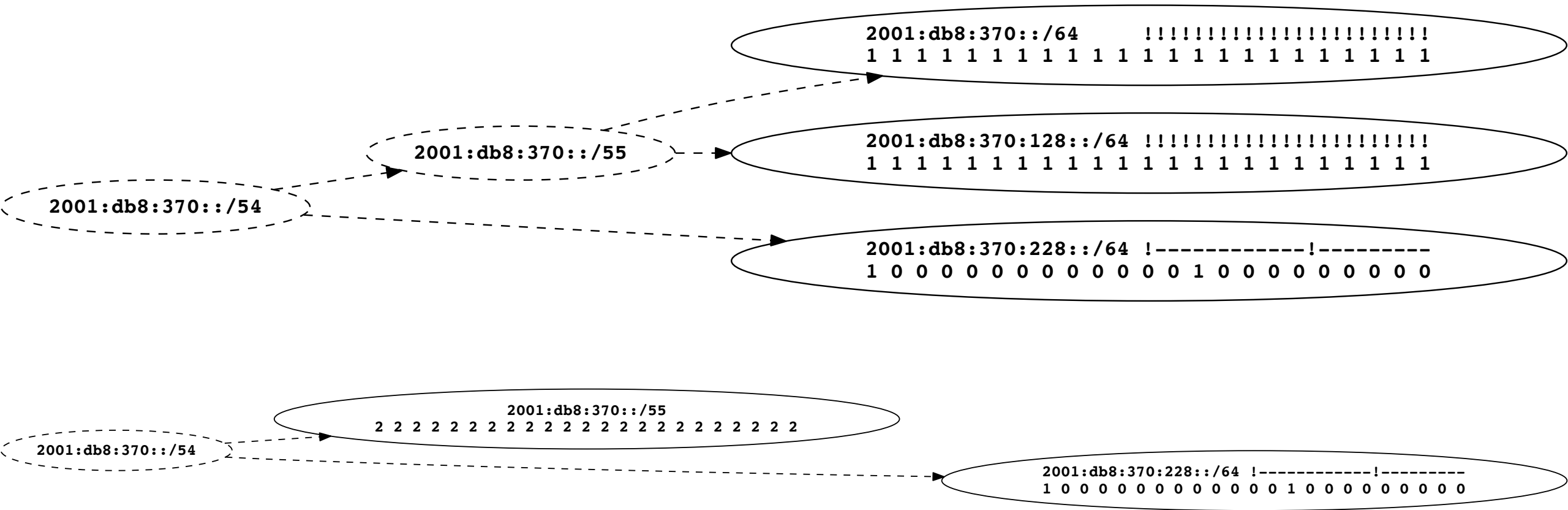
Data set	Active /48 prefixes (7 days)	Active /64 prefixes (7 days)	Active addresses (7 days)
Meeting Network	1	3	15.4K
EU ISP	163K	21.4M	125M
JP ISP	2.46M	2.46M	72.2M
US ISP	8.16K	2.42M	84.5M

Step 3. Synthesizing Anonymous Aggregates

Example: $k=2$ aggregates ($w=1d, i=1h$)



Example: Synthesizing anonymous $k=2$ aggregates ($w=1d$, $i=1h$)



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

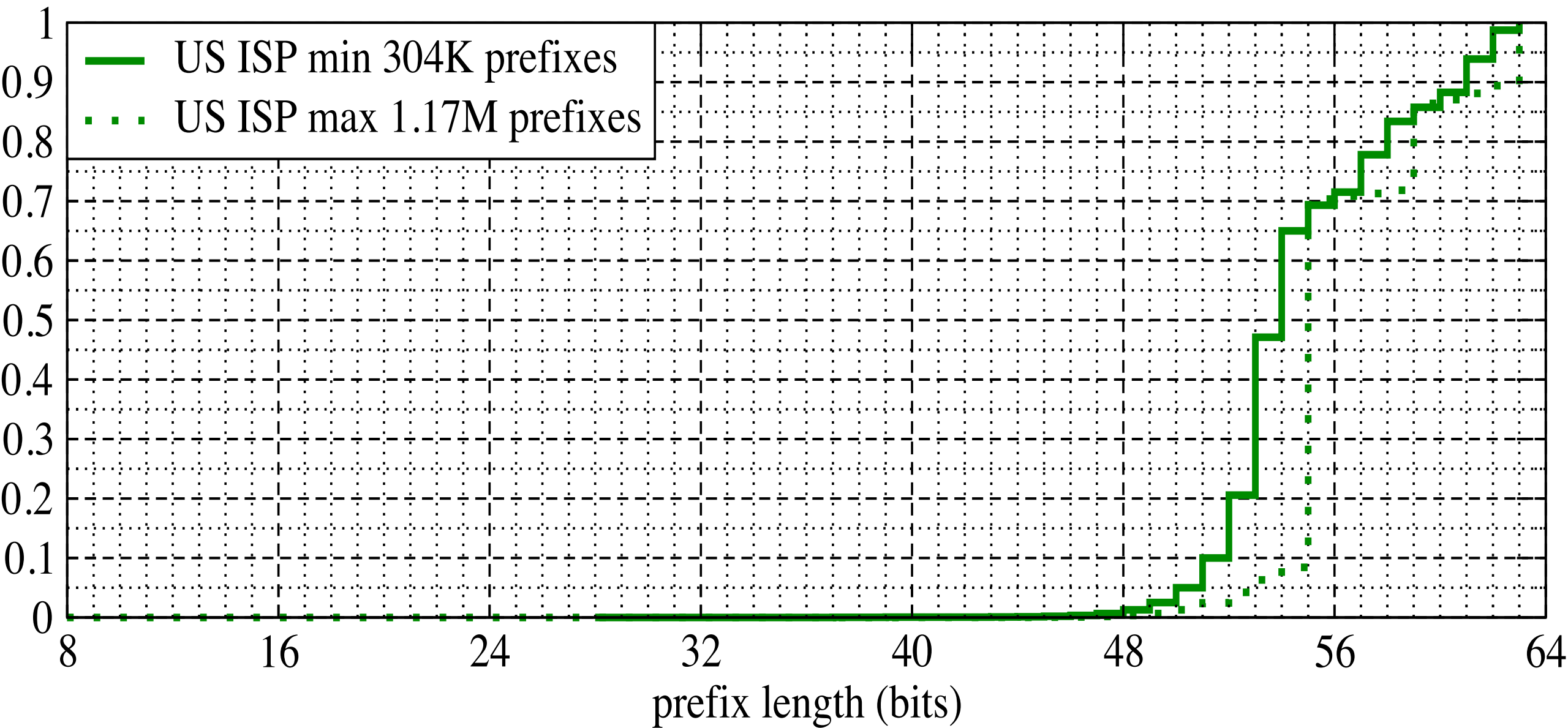
Results: simultaneously-assigned addresses and prefixes

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)
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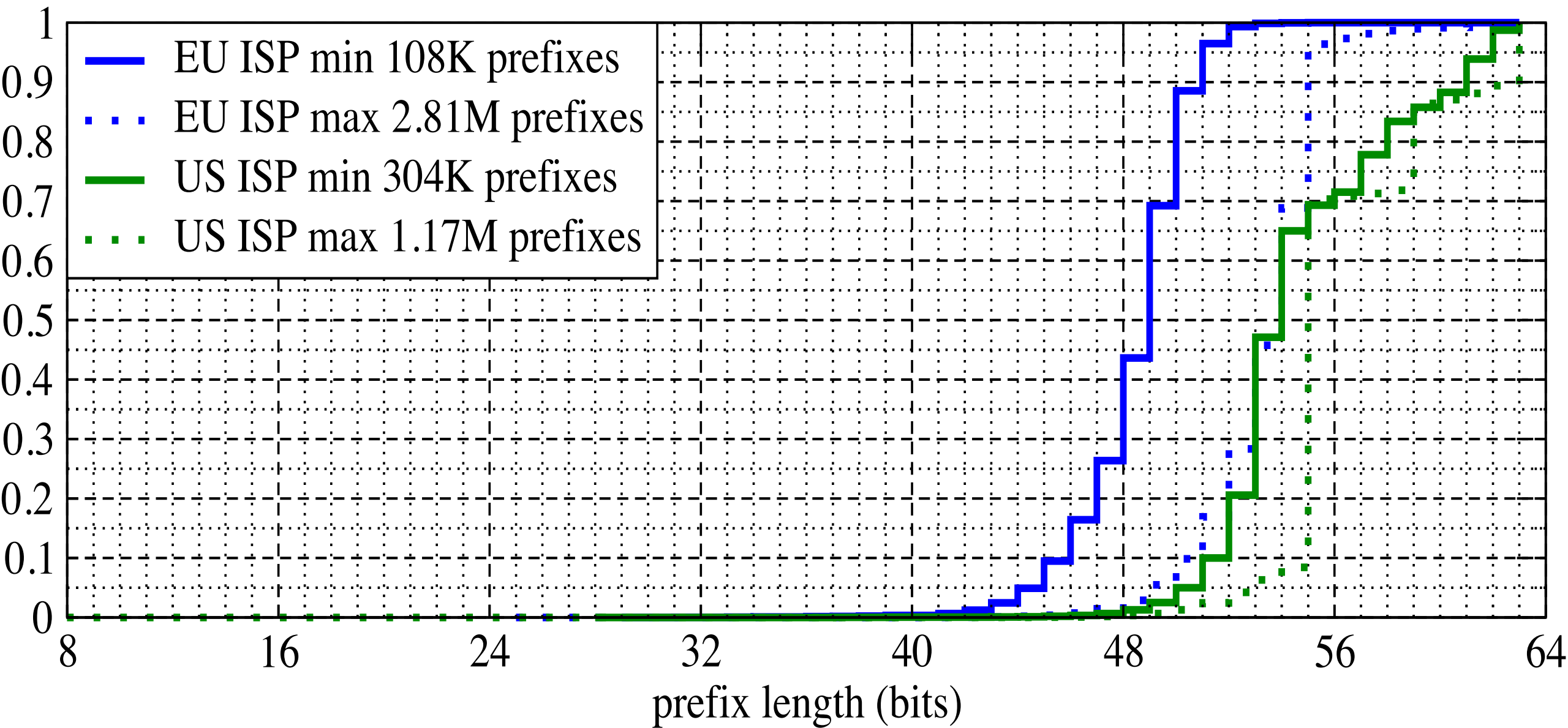
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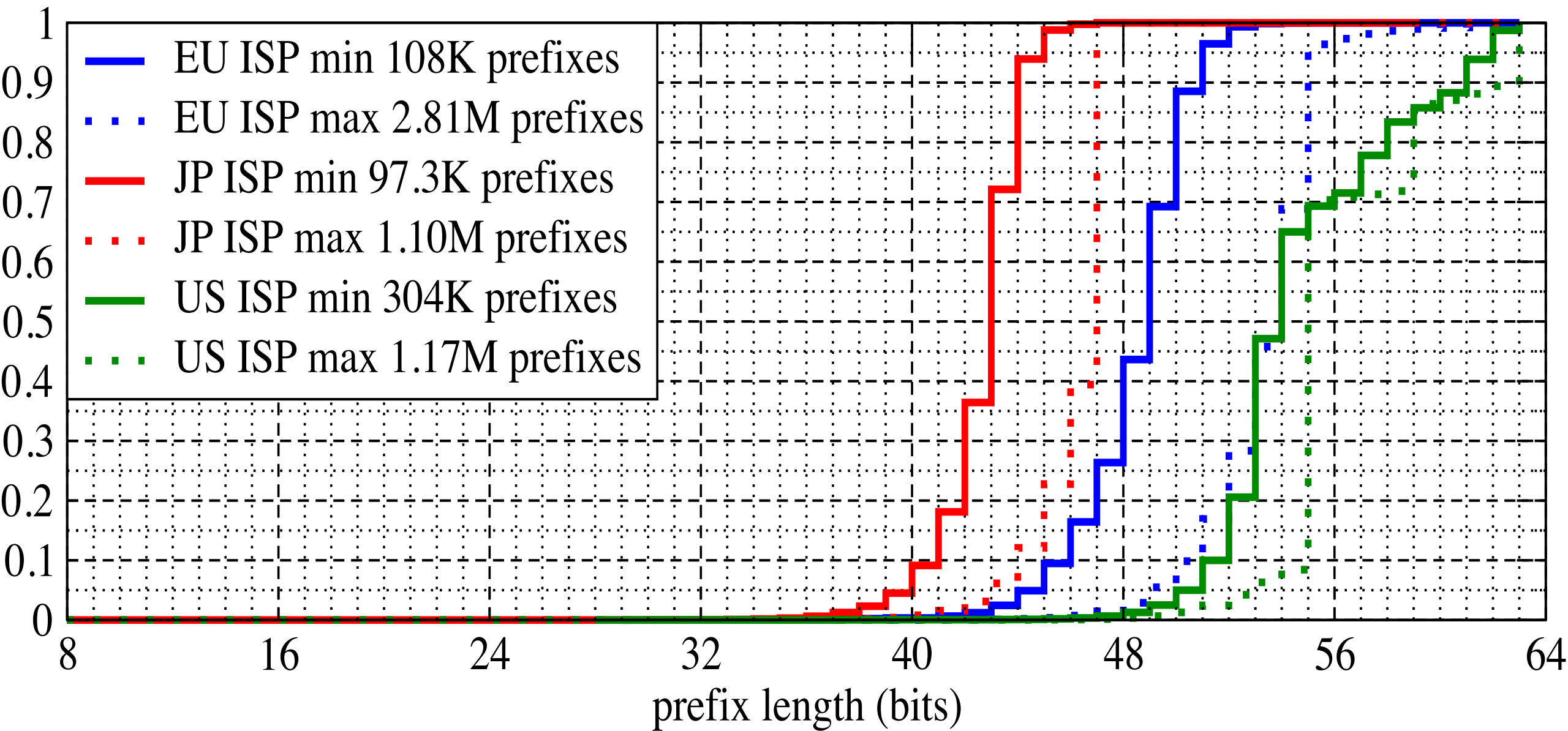
CDF **k=2** anonymous aggregate prefix lengths (w=7d, i=1h)



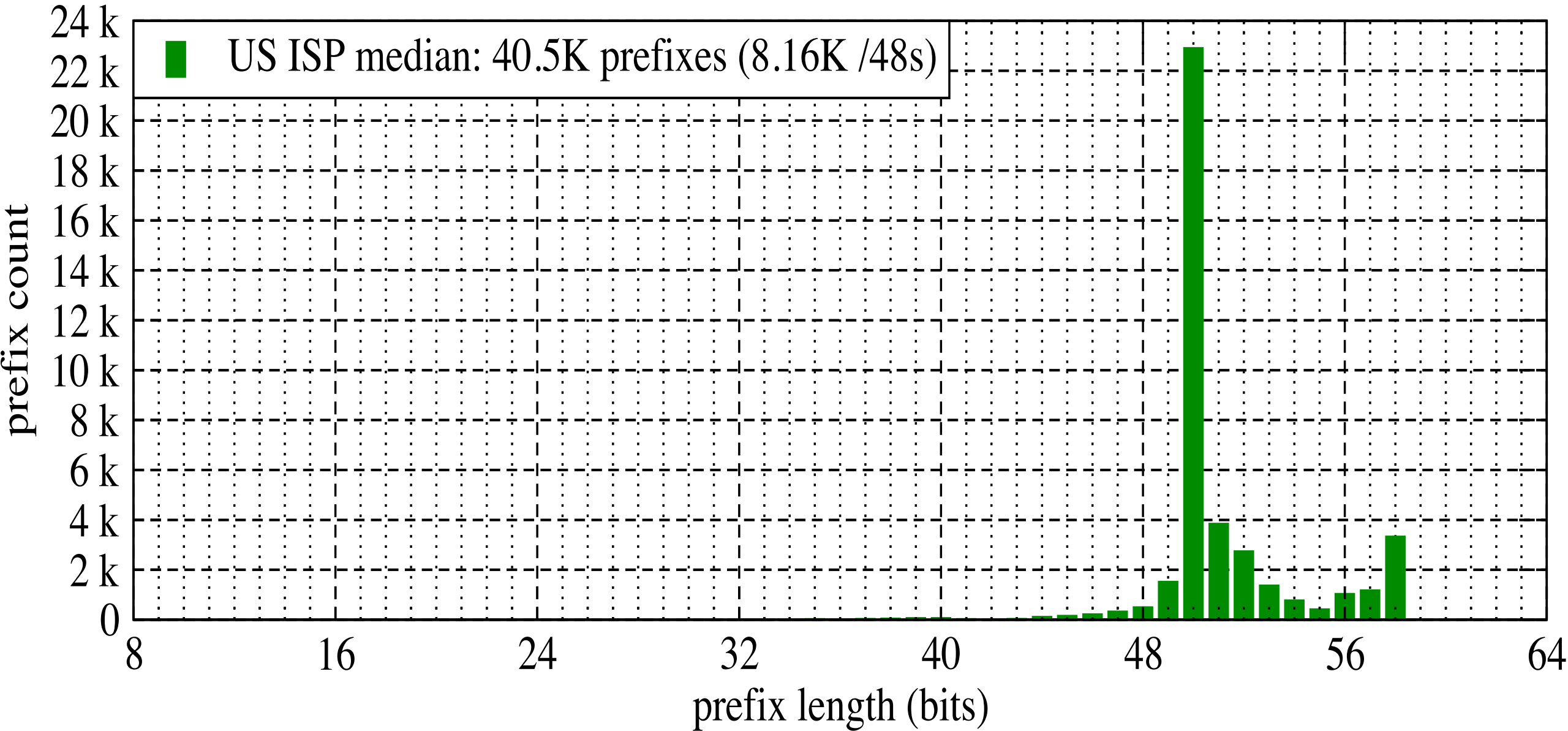
CDF: k=2 anonymous aggregate prefix lengths (w=7d, i=1h)



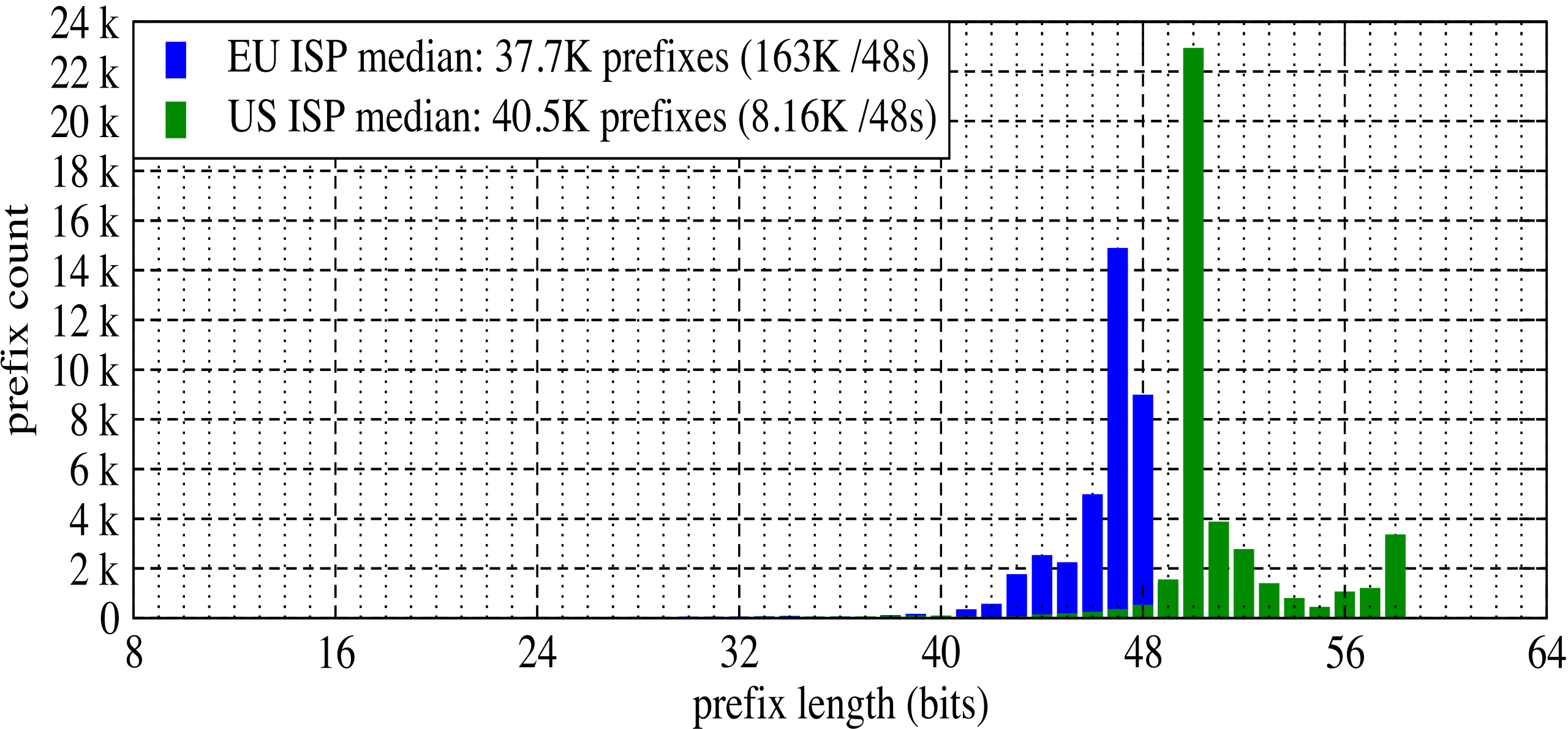
CDF: k=2 anonymous aggregate prefix lengths (w=7d, i=1h)



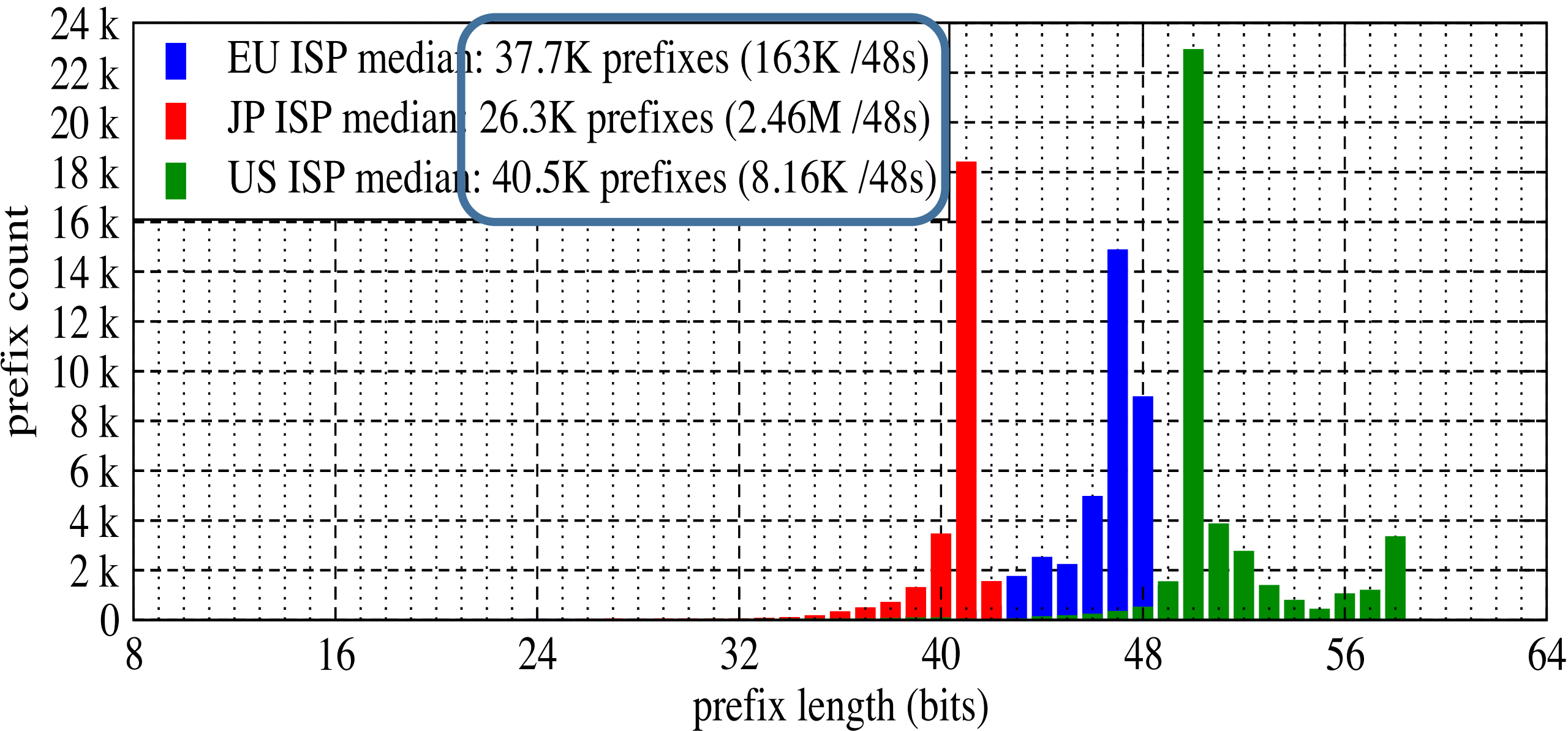
Histogram **k=32** anonymous aggregate prefix lengths (w=7d, i=1h)



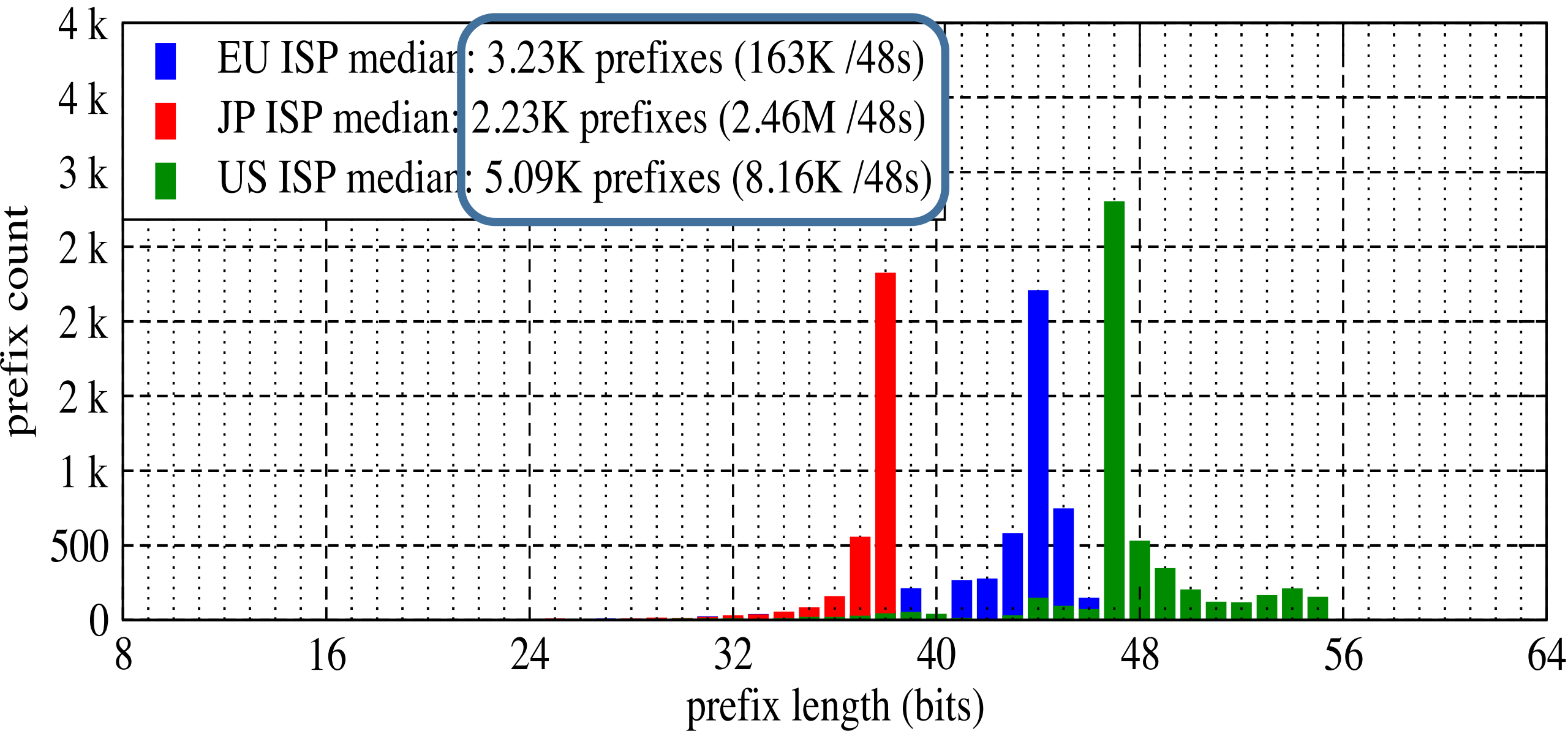
Histogram: k=32 anonymous aggregate prefix lengths (w=7d, i=1h)



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



Histogram **k=256** anonymous aggregate prefix lengths (w=7d, i=1h)



*k*IP: a Measured Approach to IPv6 Address Anonymization

MAPRG Meeting – Prague, July 20, 2017

David Plonka <plonka@akamai.com>

“*k*IP: a Measured Approach to IPv6 Address Anonymization” (pre-print)

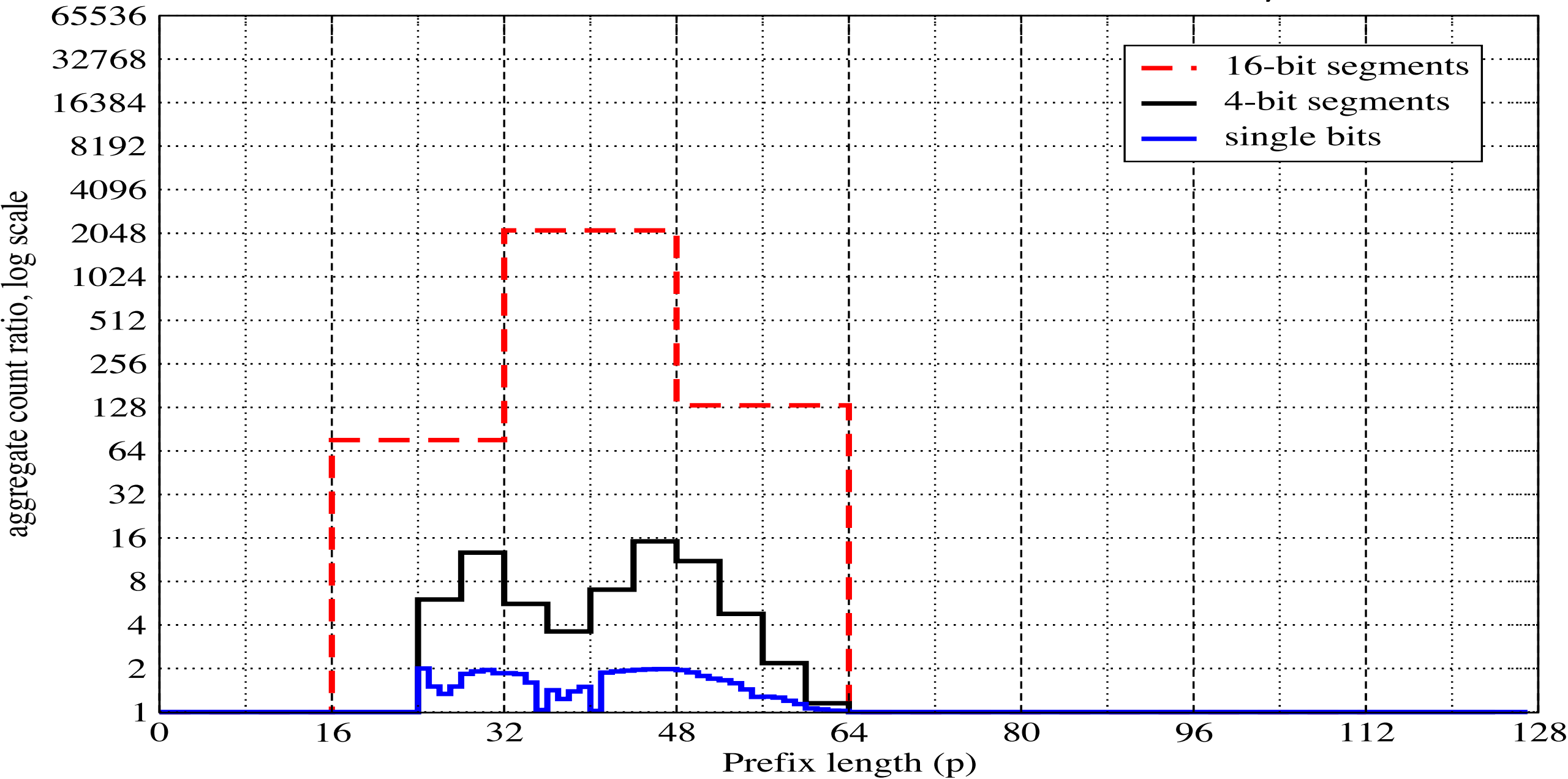
<https://arxiv.org/abs/1707.03900/>

The following are supplementary slides

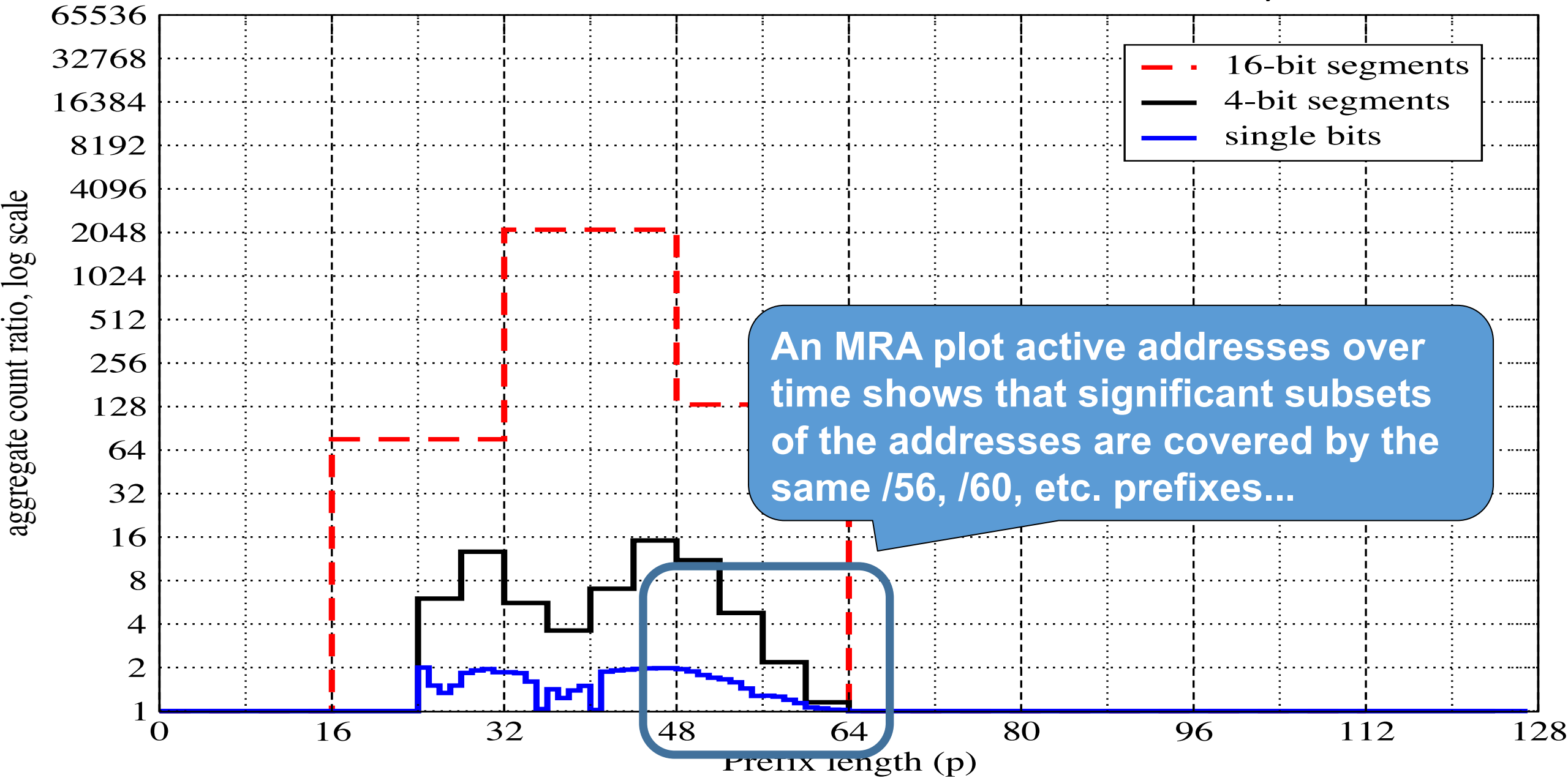
What are other applications of address activity matrix analysis and identifying simultaneously-assigned addresses?

Can we find the prefix length of an ISP's Identity Assignments (e.g., from DHCPv6 IA requests)?

MRA Plot: EU ISP, 21.5M active addrs, 7 days



MRA Plot: EU ISP, 21.5M active addrs, 7 days



MRA Plot: EU ISP, 2.02M simultaneously assigned addrs, max.

