DynamIPs: Analyzing address assignment practices in IPv4 and IPv6

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Can dynamic IP addresses be subscriber identifiers?

Residential
Subscriber

Dynamic IP

Analyze address assignment dynamics of residential IPv6 subscribers

IPv6's 128-bit address space offers enormous flexibility to ISPs to assign addresses

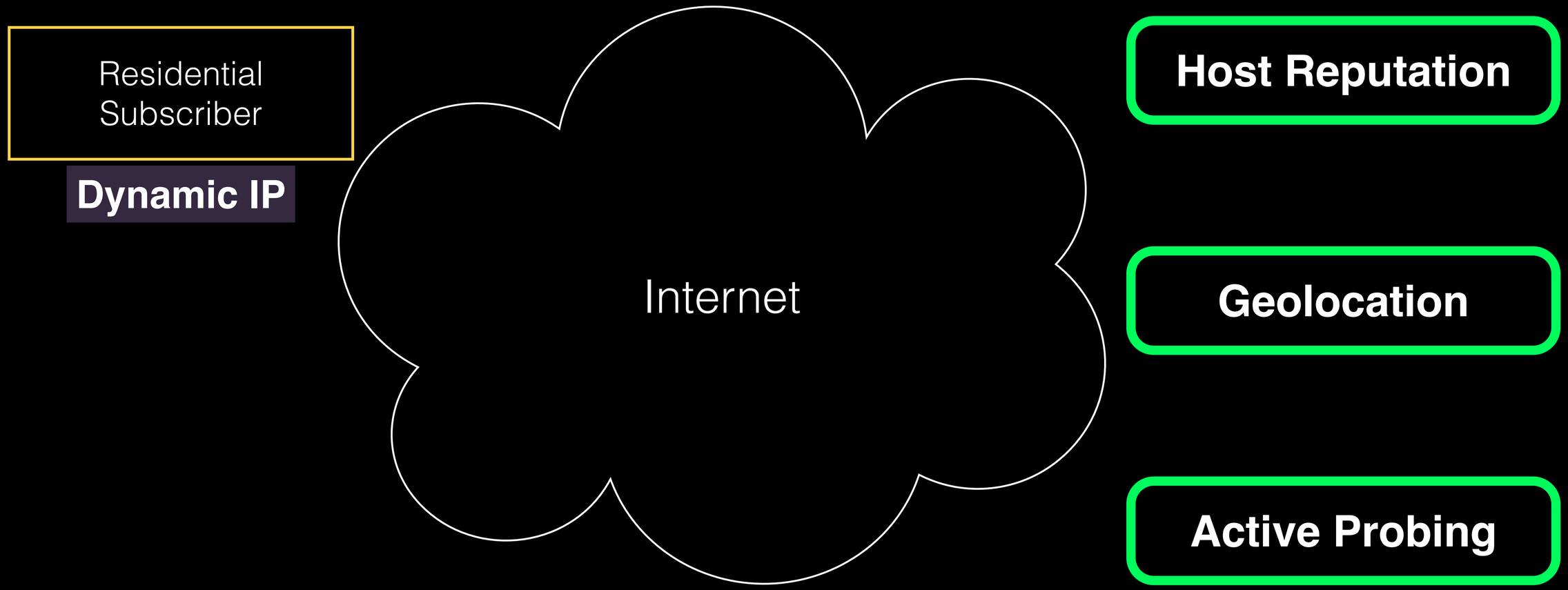
Residential Subscriber

Dynamic IP

Temporal Dynamics

Spatial Dynamics

Many applications would benefit from knowing if addresses can be subscriber identifiers



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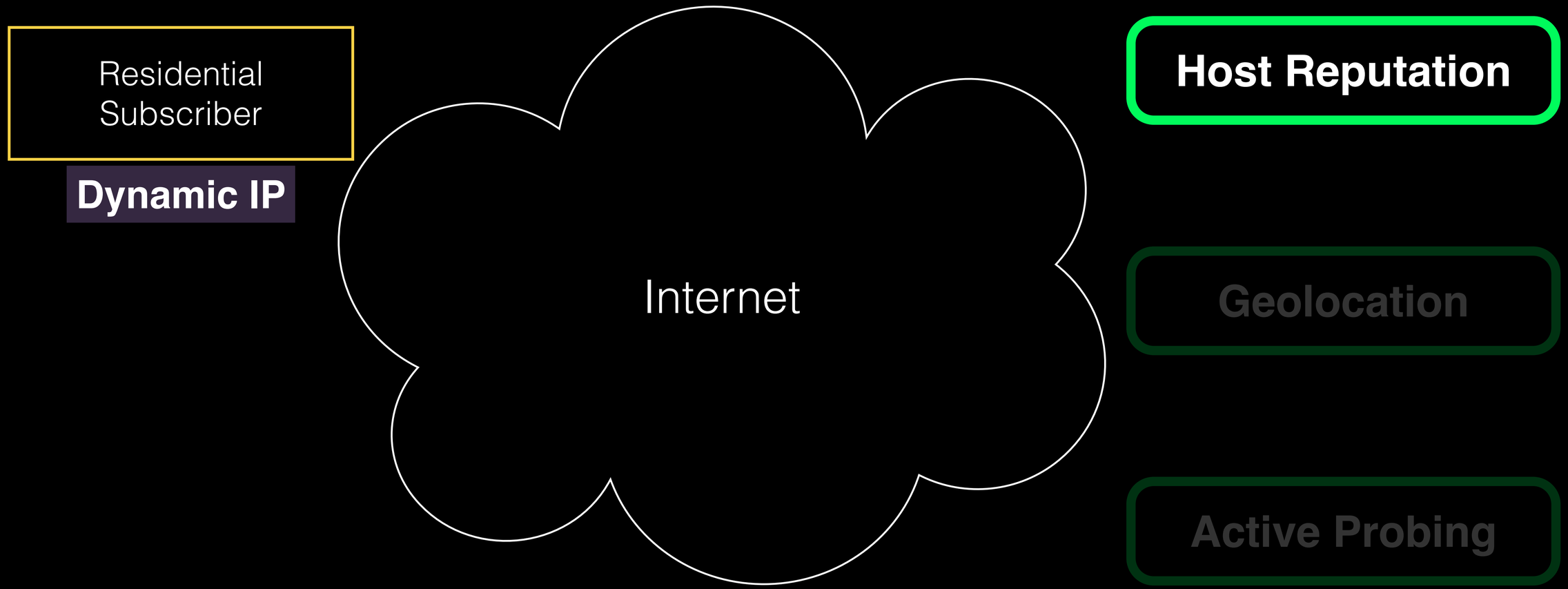

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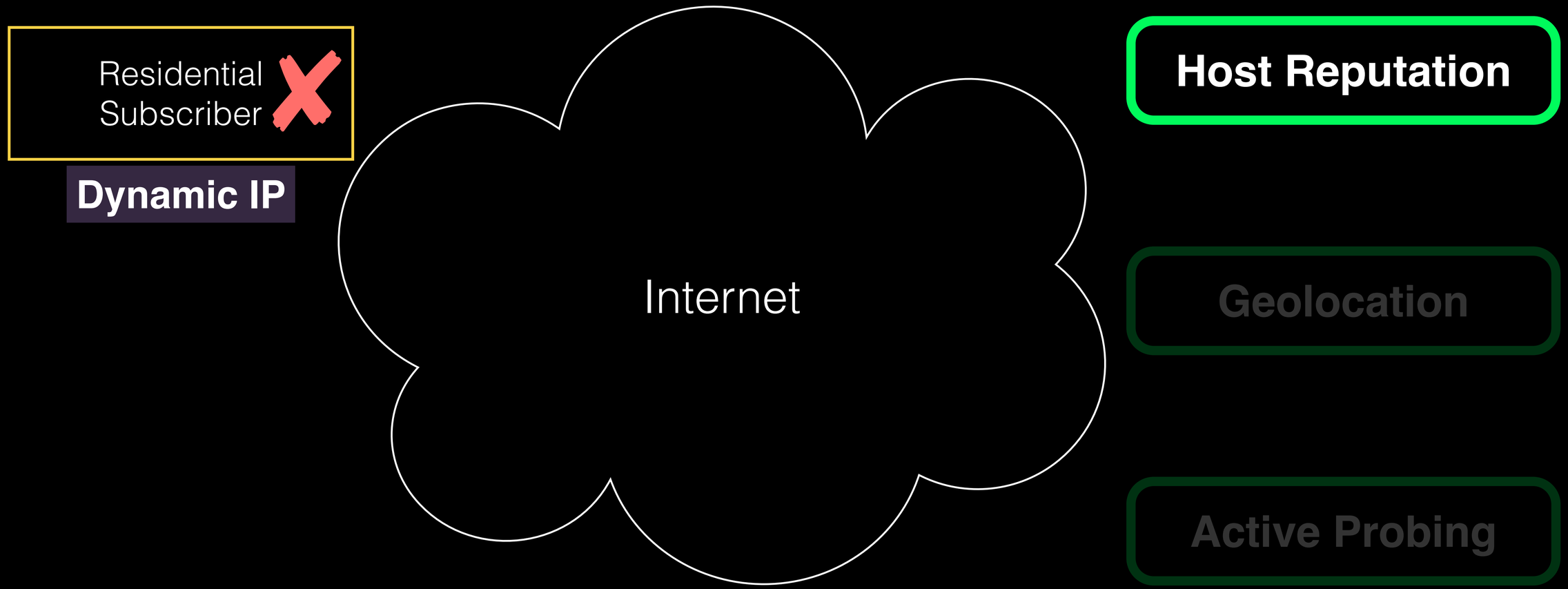

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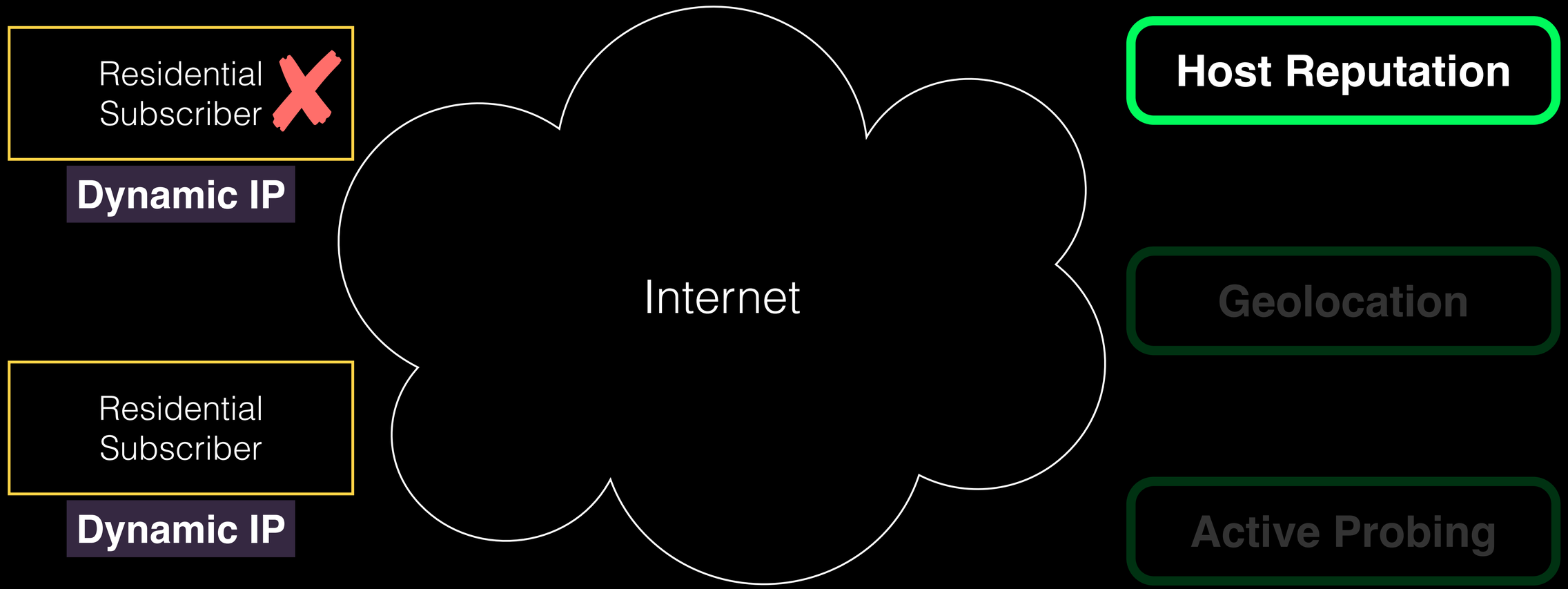

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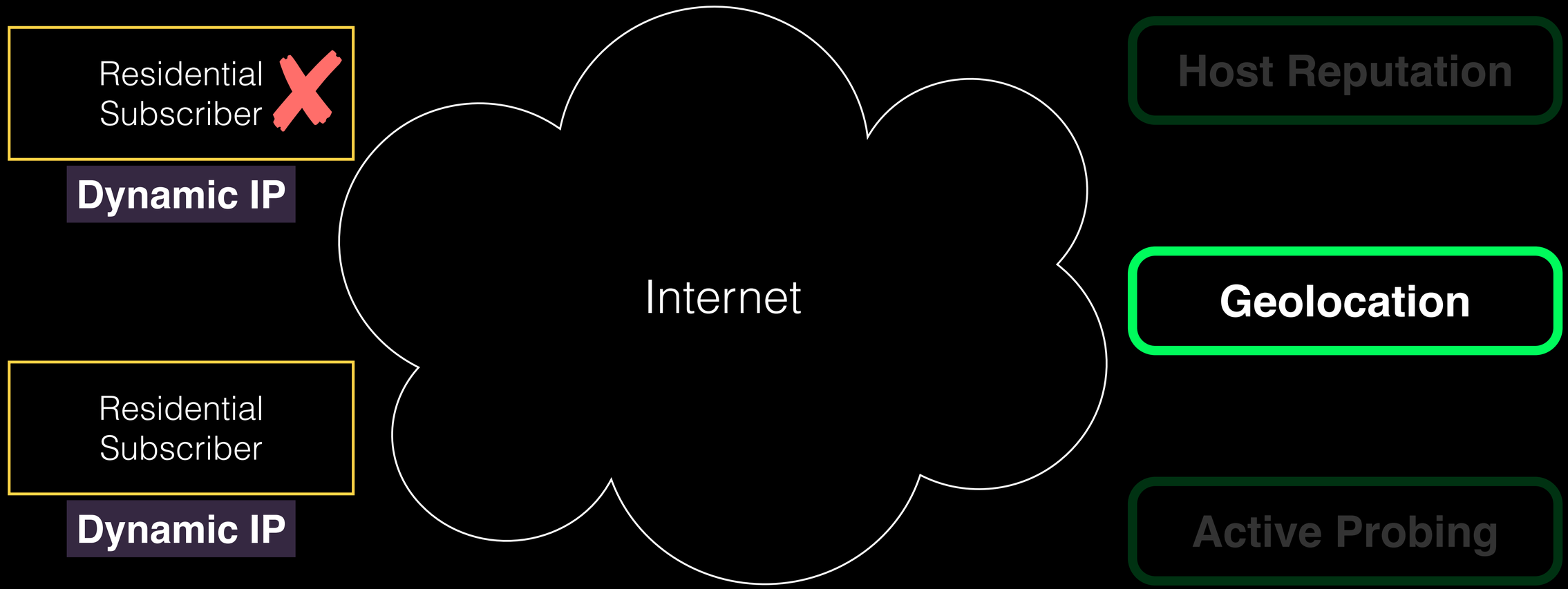

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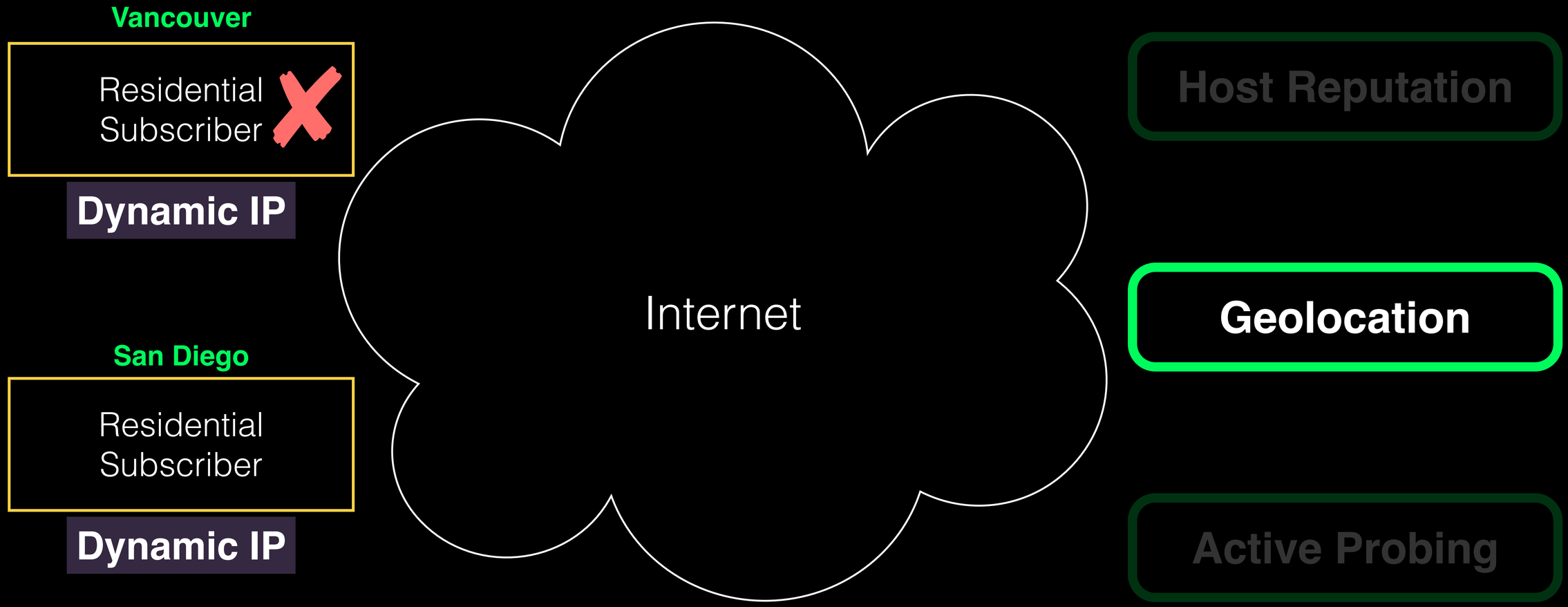

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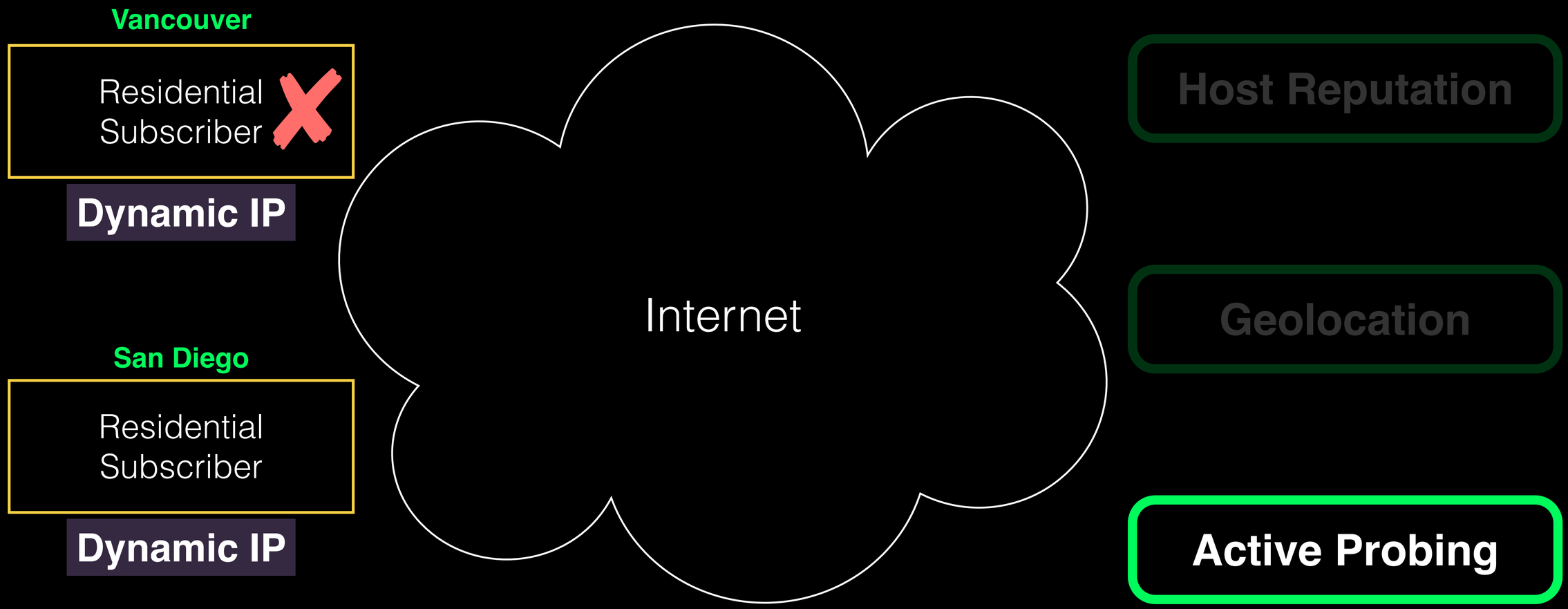

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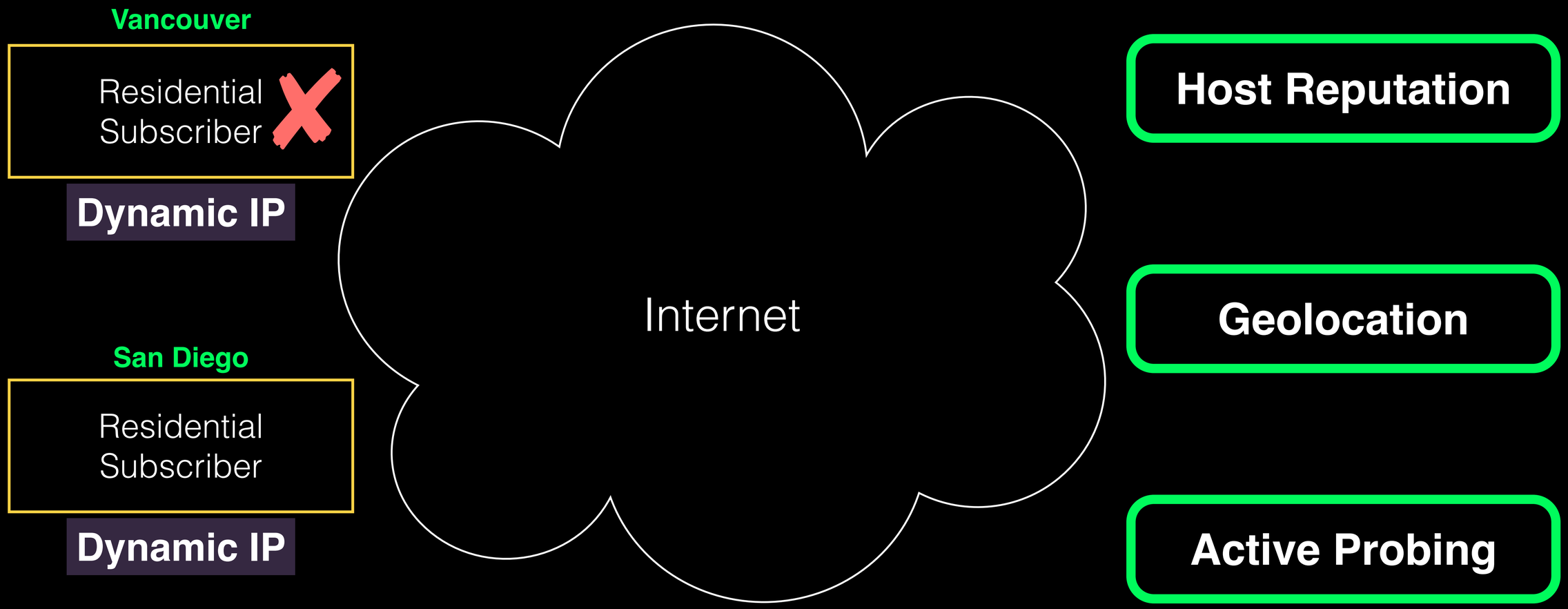
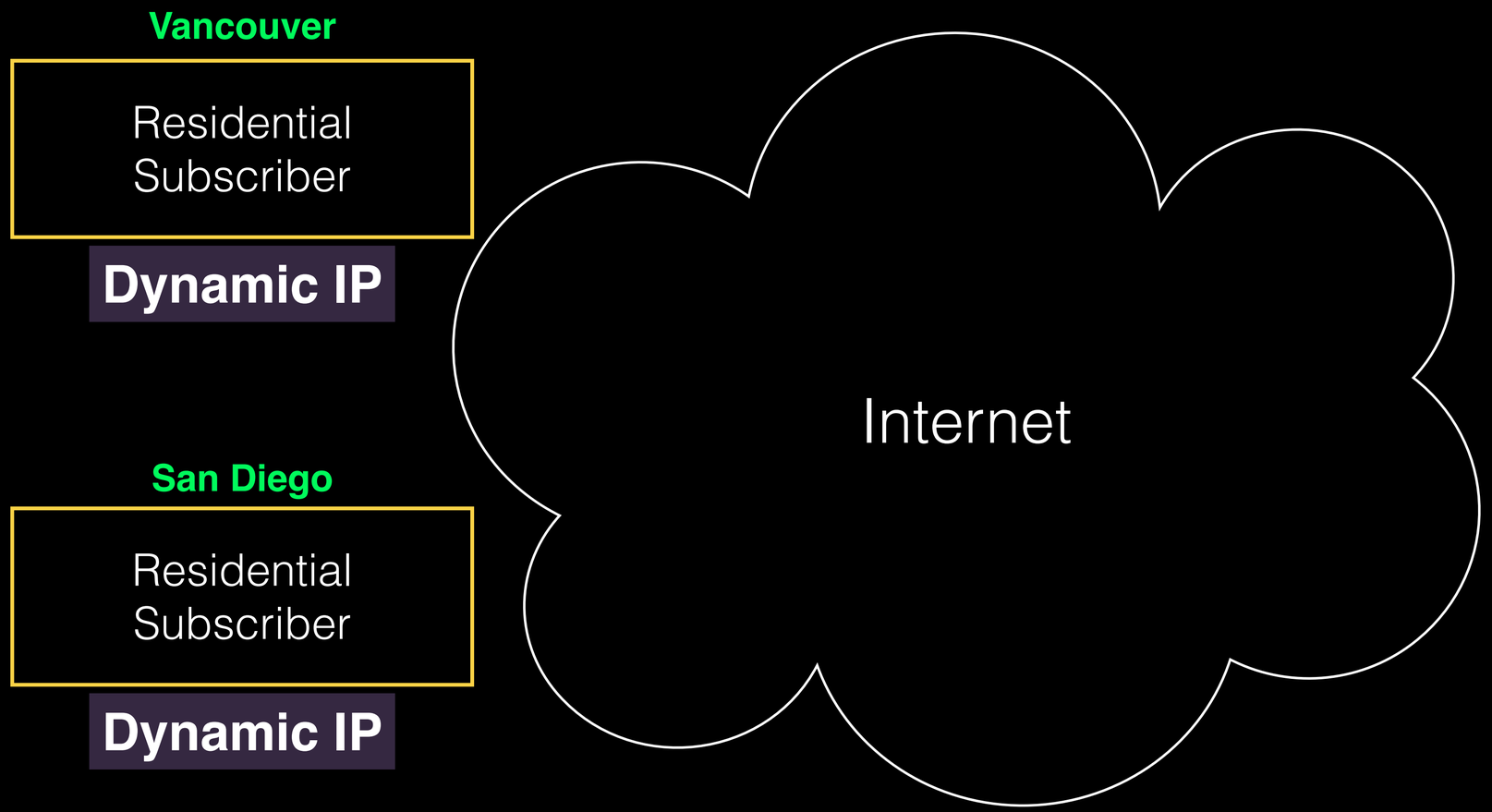


There are important privacy implications if IP addresses can identify subscribers



IPv4 address assignment primer

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ISP DHCP Server

Address Pool

68.80.0.0/16

Home Router

Dynamic IP

RFC 1918

10.0.0.123

RFC 1918

IPv4 address assignment primer

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IPv6 address assignment primer

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2601:47::/32

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2601:47:4500:5c40::/64

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Network part (64 bits)

2601:47:4500:5c40

2601:47:4500:5c40

IPv6 address assignment primer

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Network part (64 bits) **Host part (64 bits)**

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We focus upon the dynamics of the 64-bit network part of IPv6 addresses

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IPv6 subscribers can be delegated prefixes that are shorter than a /64

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Home Router

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2601:47:4500:5c00:385d:49a9:b9da:c212

2601:47:4500:5c00:random

Subscribers with dual-stack connections have IPv4 and IPv6 addresses

ISP DHCP Server

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2601:47:4500:5c00::/56

2601:47:4500:5c00:random

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RFC 1918
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RFC 1918
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RFC 1918
2601:47:4500:5c00:random

Analyze address assignment dynamics using two complementary datasets

Temporal Dynamics

How long can IPv4 addresses and IPv6 prefixes identify residential subscribers?

Spatial Dynamics

Which IPv6 prefixes can identify residential subscribers?

Where do addresses move upon reassignment?

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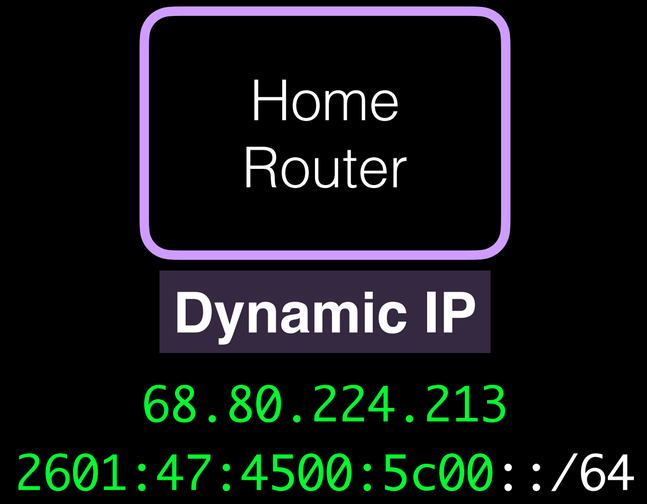

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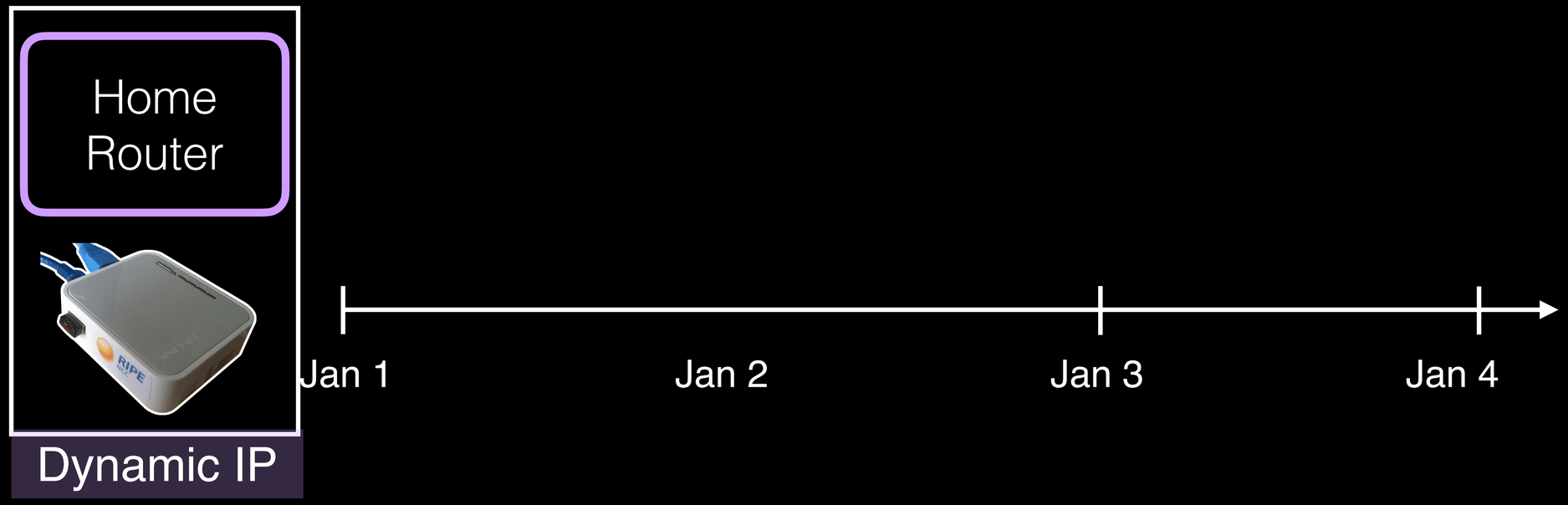
We study IPv4 addresses and IPv6 /64 prefixes using RIPE Atlas's IP Echo dataset

RIPE Atlas platform consists of ~10K active probes

Probes conduct measurements (pings, traceroutes, DNS)

We use the "IP Echo" dataset (2014 to 2020)

Finding assignment changes using the RIPE Atlas IP echo dataset



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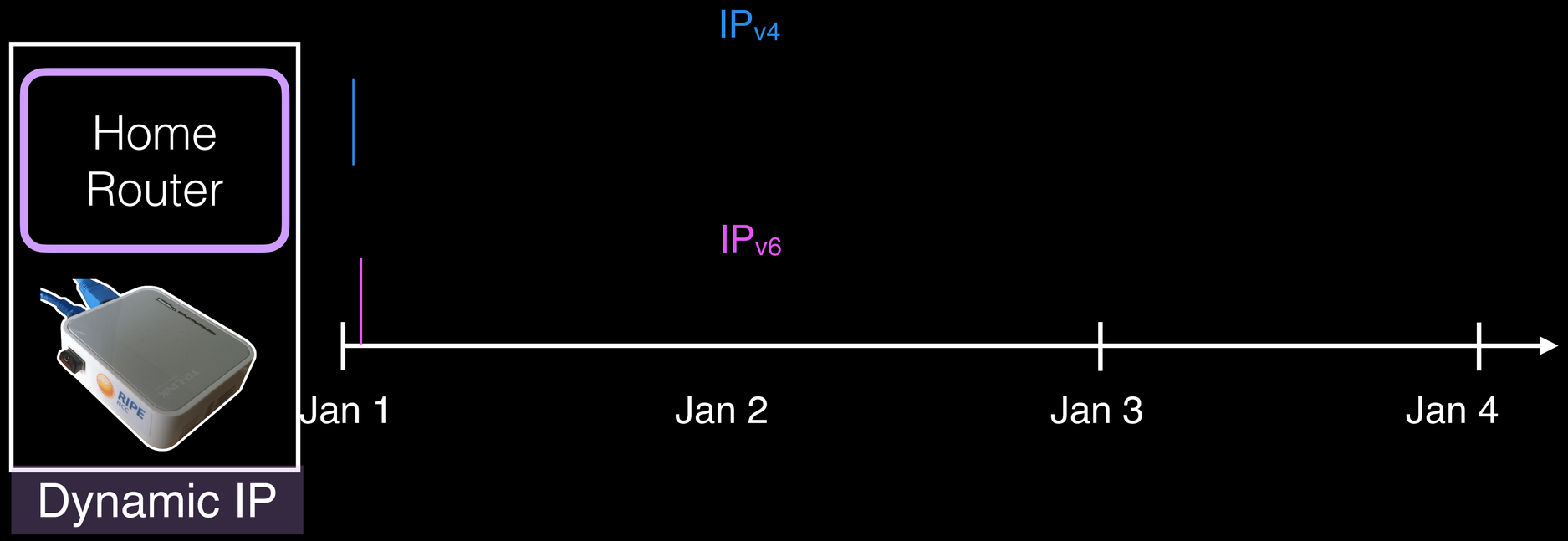

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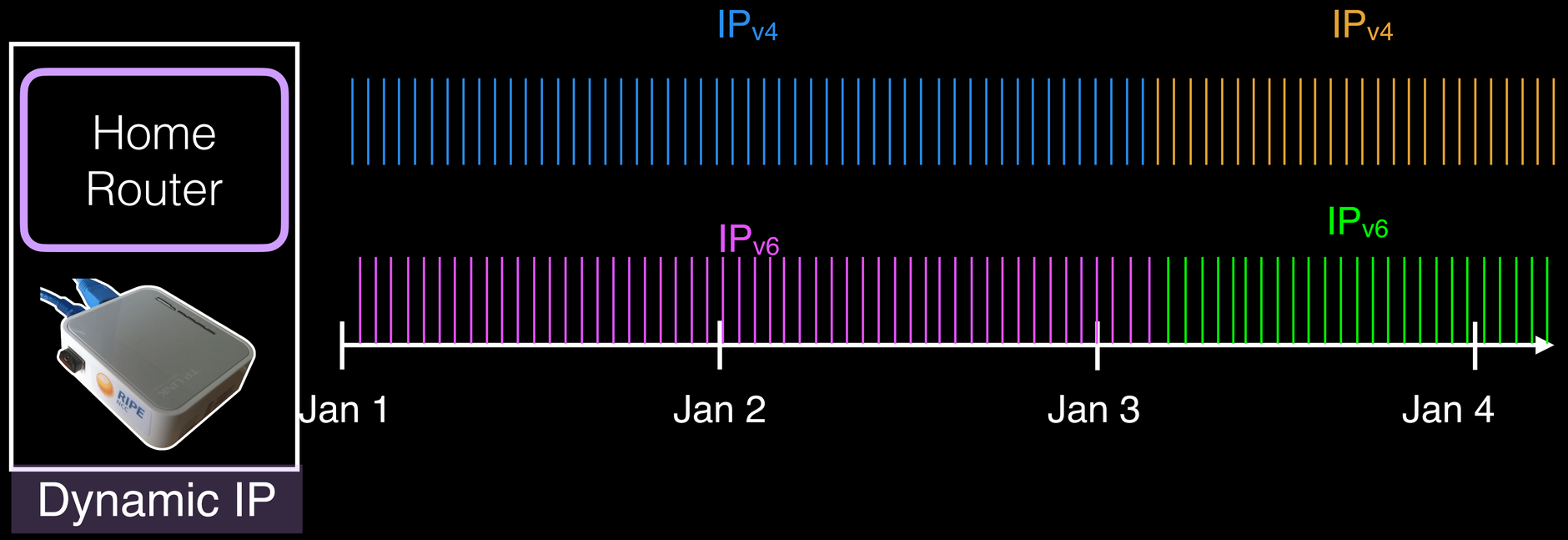

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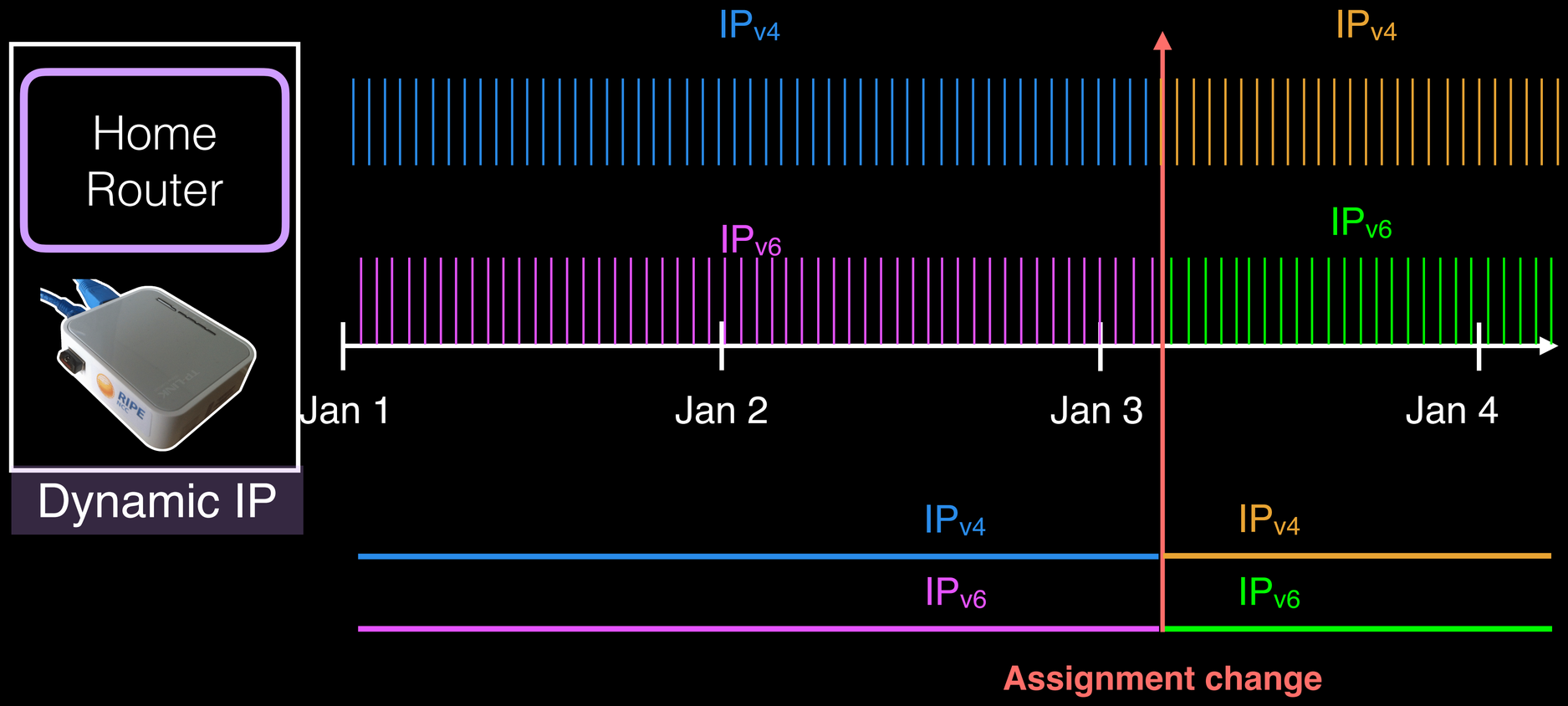

CDN dataset consists of associations between IPv4 and IPv6 addresses

CDN RUM Server

CDN Content Server

Home Router

Dynamic IP

68.80.224.213

2601:47:4500:5c40::/64

RFC 1918

2601:47:4500:5c40:random

RFC 1918

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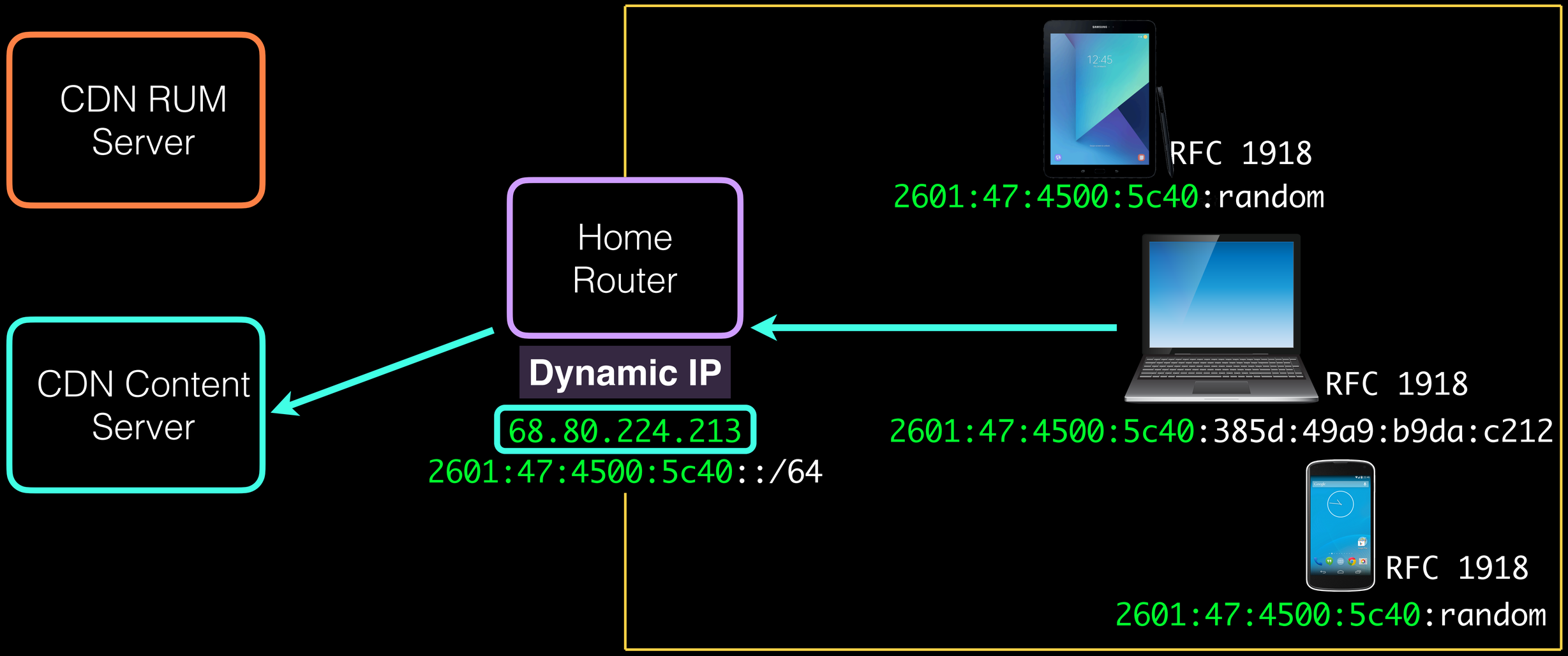

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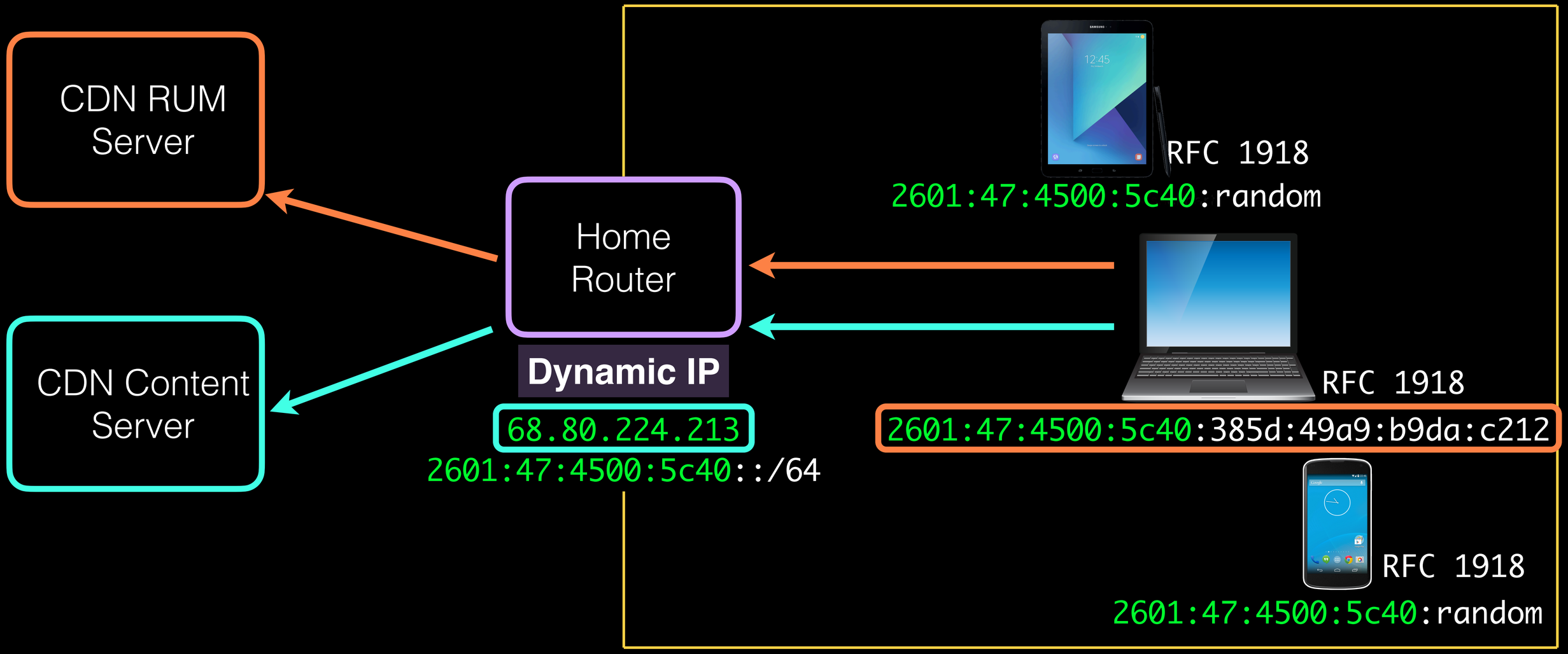

The CDN dataset offers a broader but less detailed perspective

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CDN Content Server

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68.80.224.0/24

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RFC 1918

2601:47:4500:5c40:385d:49a9:b9da:c212

T1

68.80.224.0/24

2601:47:4500:5c40::/64

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RFC 1918

2601:47:4500:5c40:385d:49a9:b9da:c212

T1	68.80.224.0/24	⟷	2601:47:4500:5c40::/64
T2	68.80.224.0/24	⟷	2601:47:4500:5c40::/64

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RFC 1918

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T2	68.80.224.0/24	2601:47:4500:5c40::/64
T_n	68.80.224.0/24	2601:47:4500:5c40::/64

Repeated associations over time allow us to estimate the duration of each association

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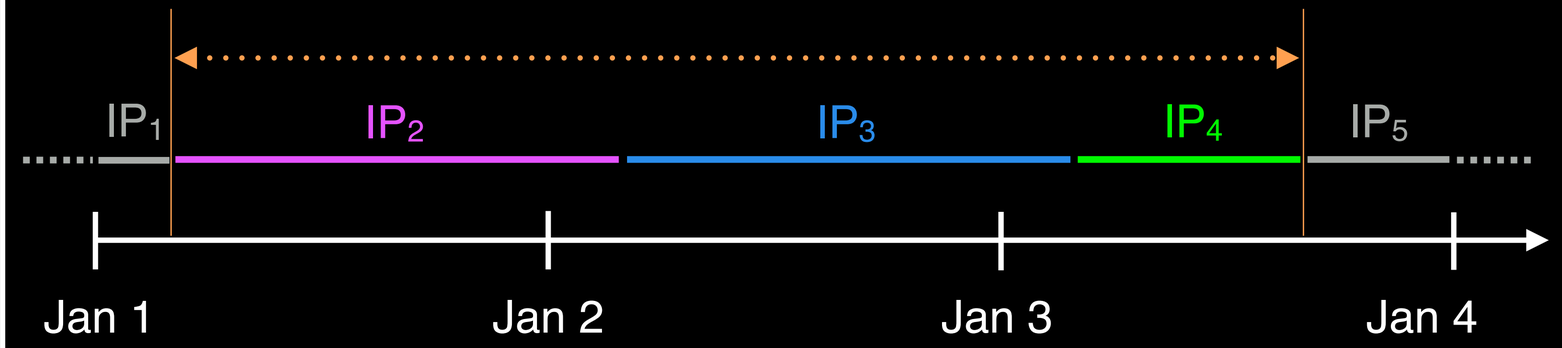
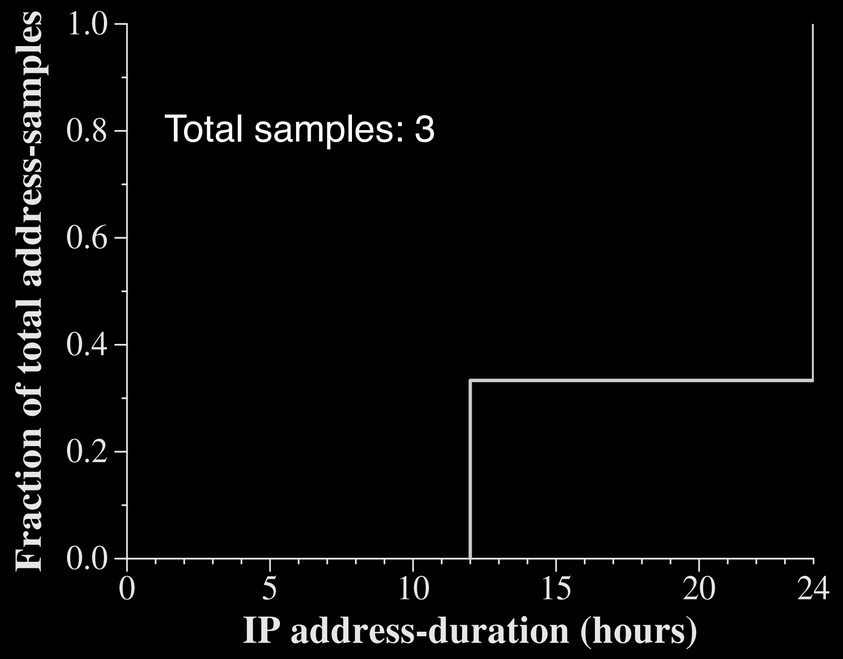
Analyzing address durations



	Duration (hours)
IP_1	NA
IP_2	24
IP_3	24
IP_4	12
IP_5	NA

Can plot CDF…



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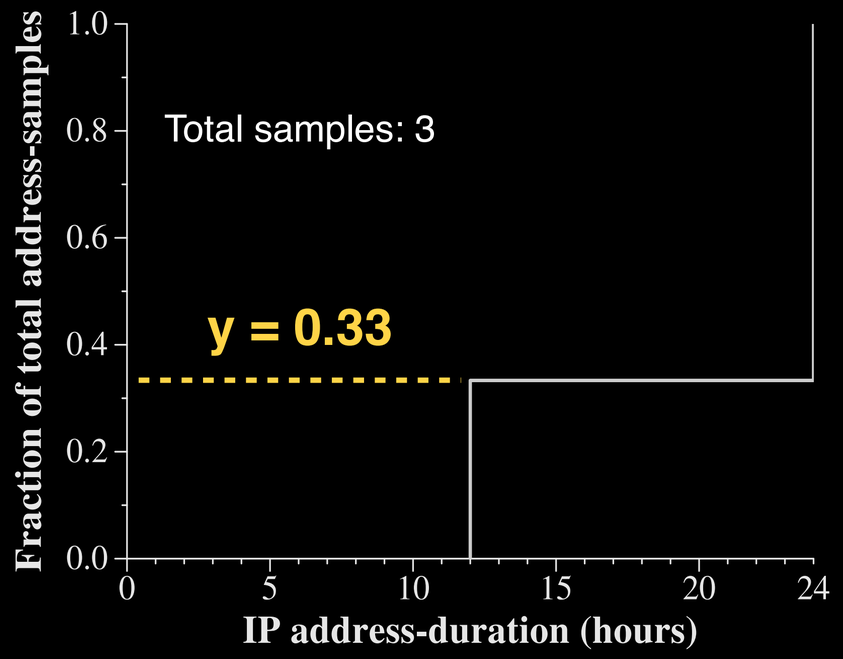

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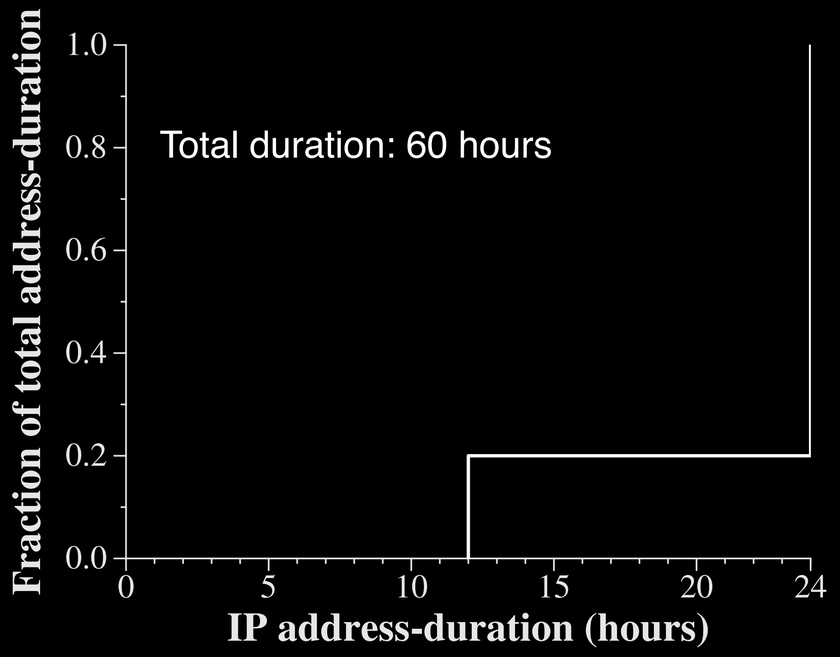
Weight by duration and plot distribution



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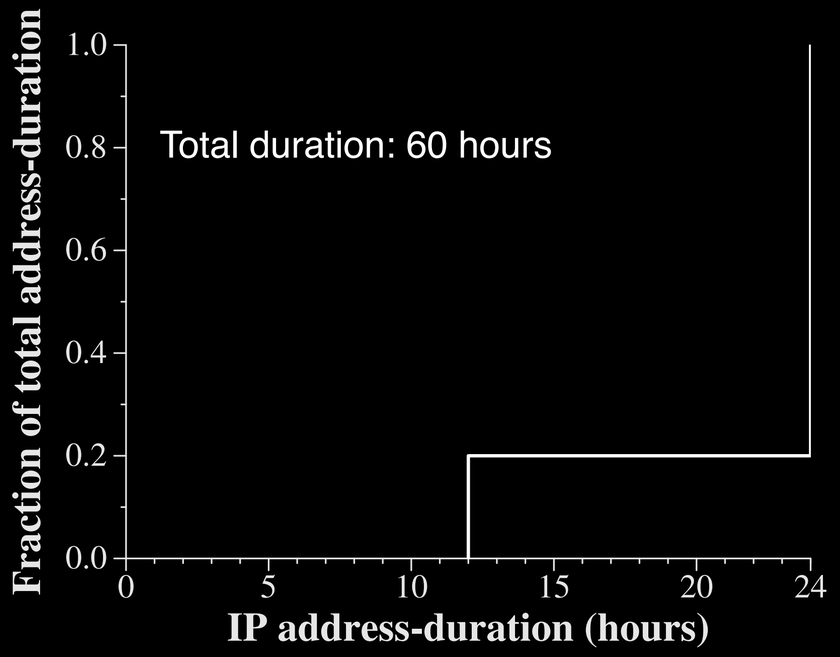
Weighted distribution shows fraction of total time spent in each duration

Weight by duration and plot distribution



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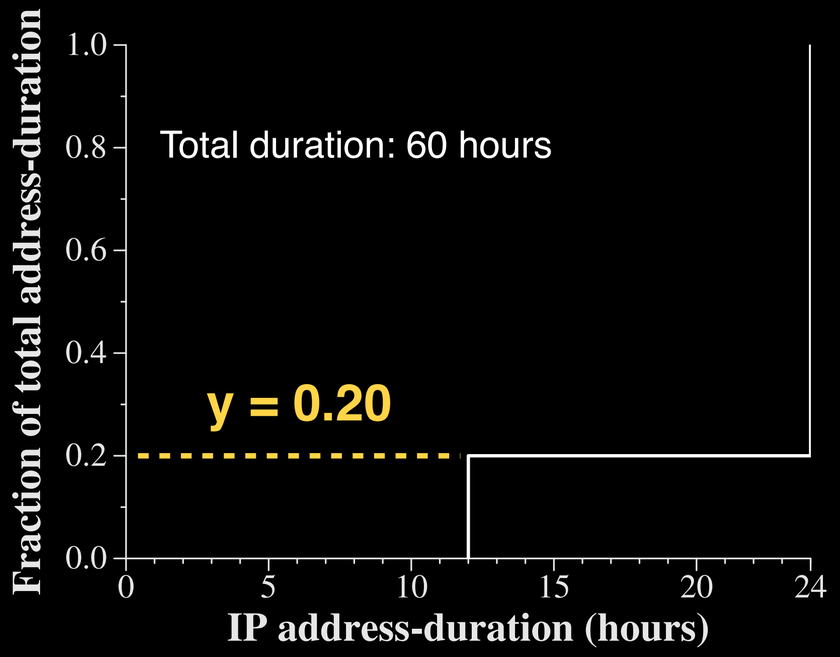
Σ time: 60

Weighted distribution shows fraction of total time spent in each duration

Weight by duration and plot distribution



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IP_1	NA
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Σ time: 60

Weighted distribution shows fraction of total time spent in each duration

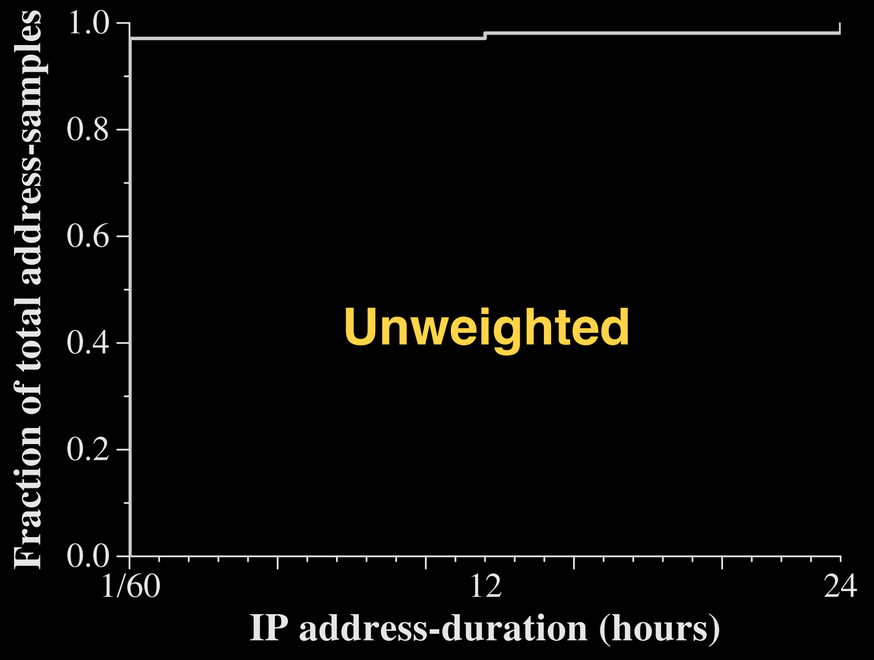
Suppose we add 100 new durations of 1 minute each

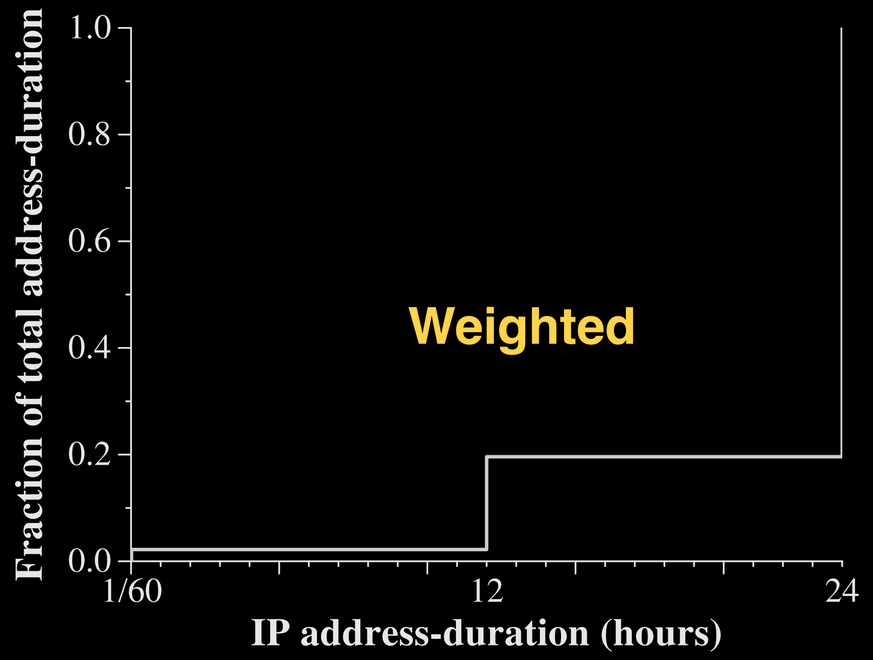
	Duration (hours)
IP_1	NA
IP_2	24
IP_3	24
IP_4	12
IP_5	NA

Suppose we add 100 new durations of 1 minute each

	Duration (hours)
IP_1	NA
IP_2	24
IP_3	24
IP_4	12
IP_5	NA
IP_6	1/60
IP_7	1/60
…	1/60
IP_{104}	1/60
IP_{105}	1/60

Weighted distribution shows probability that an address lasted X hours





If we blacklist an IP address, how long to keep it in the blacklist?

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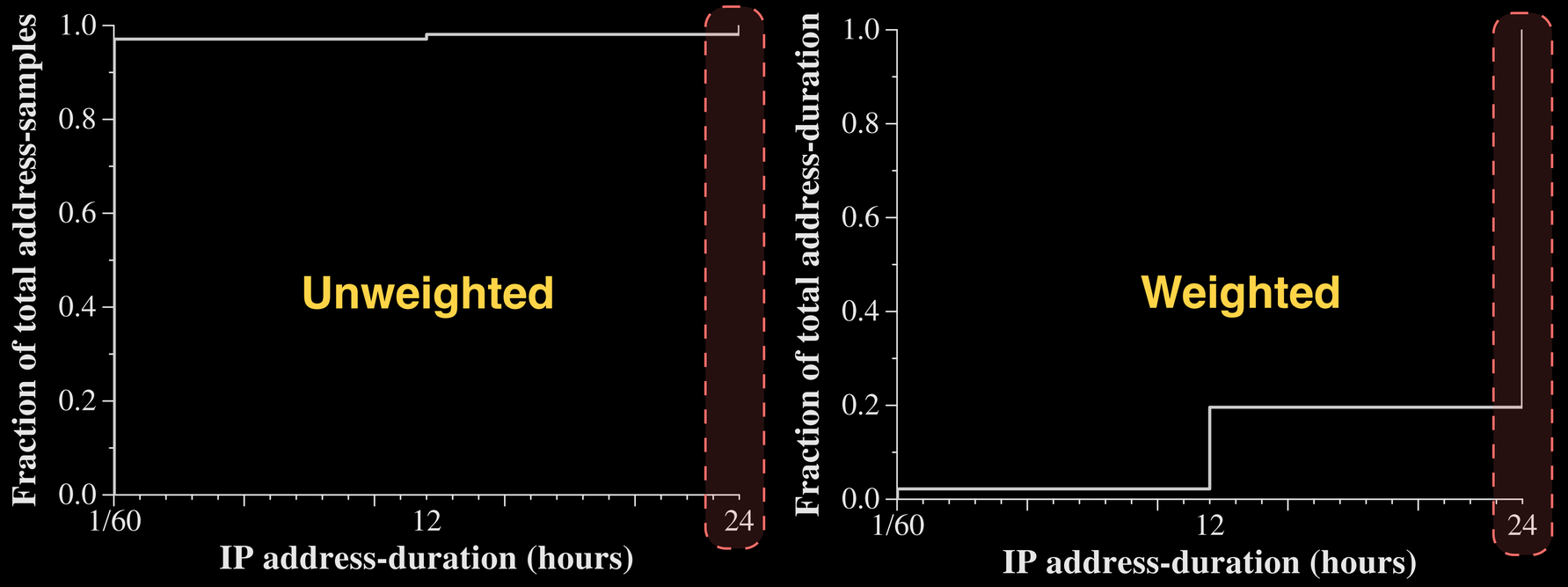

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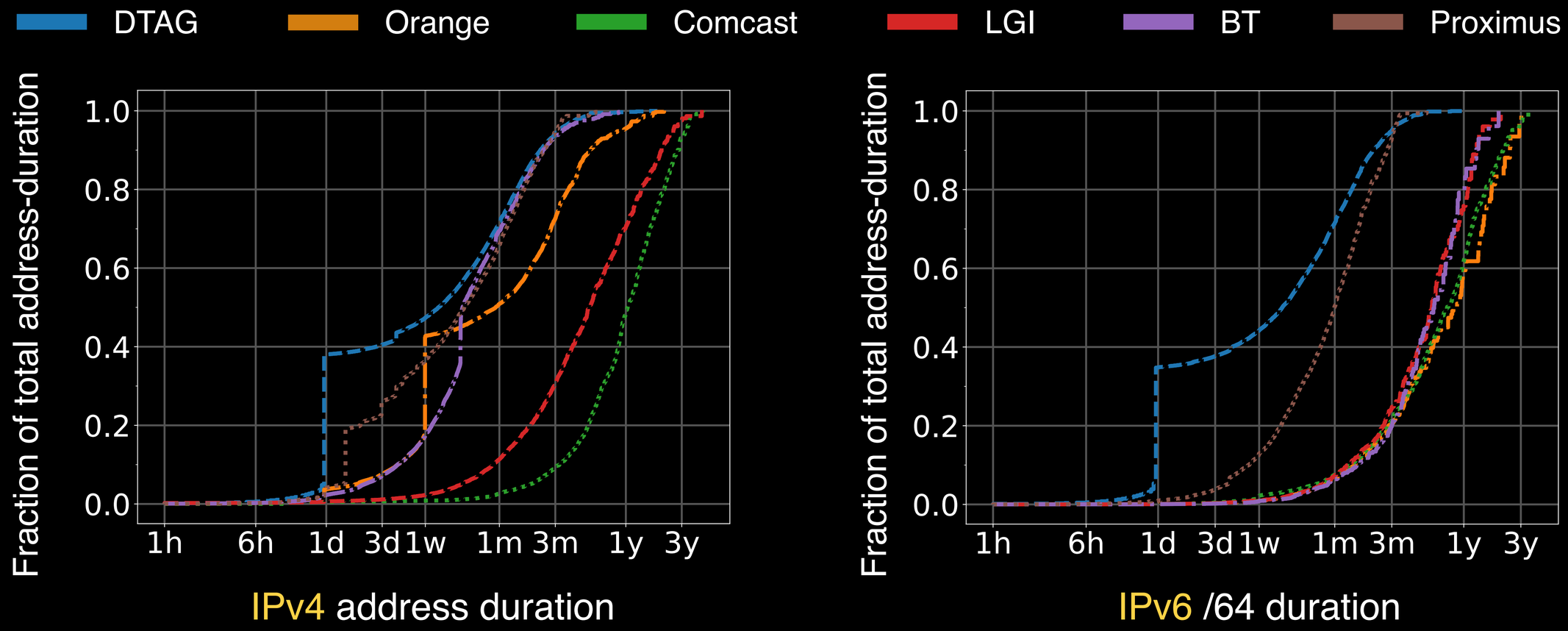
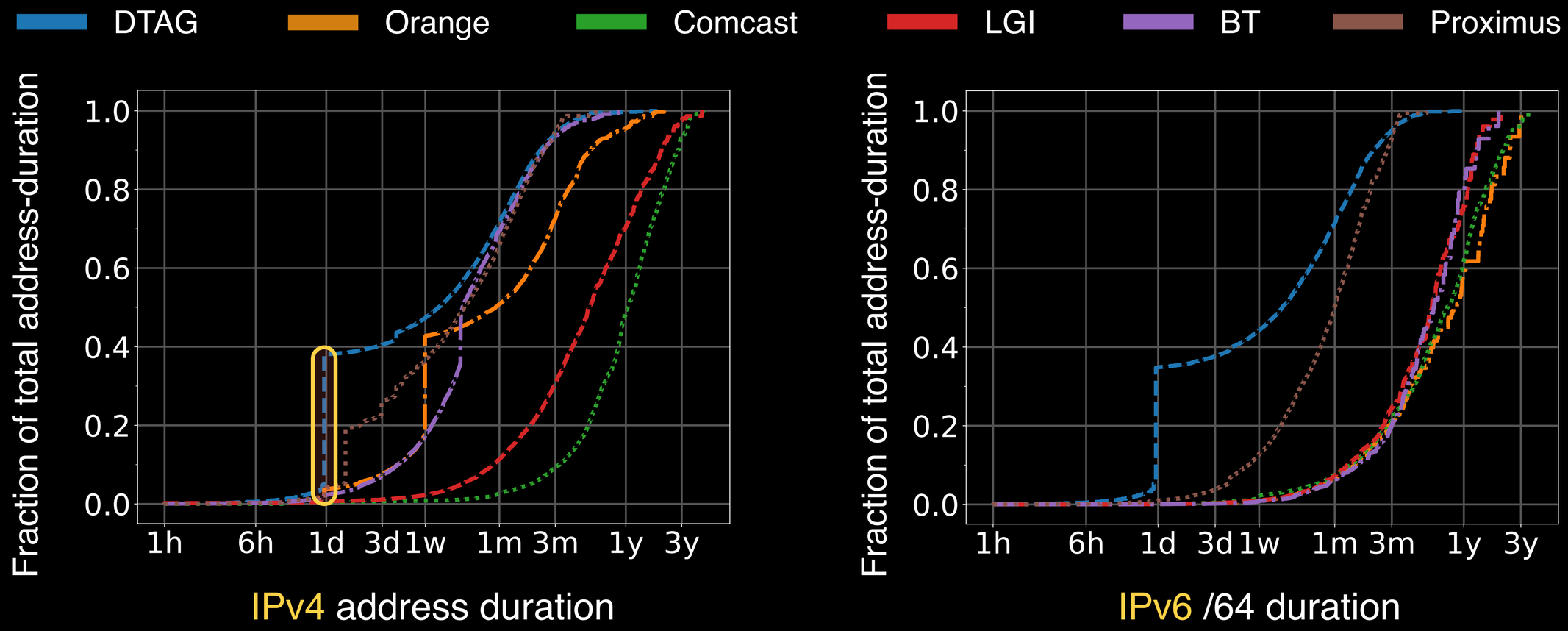
IPv6 assignments have longer durations than IPv4 assignments



The CDN dataset corroborates our observations of long assignment durations

IPv6 assignments have longer durations than IPv4 assignments



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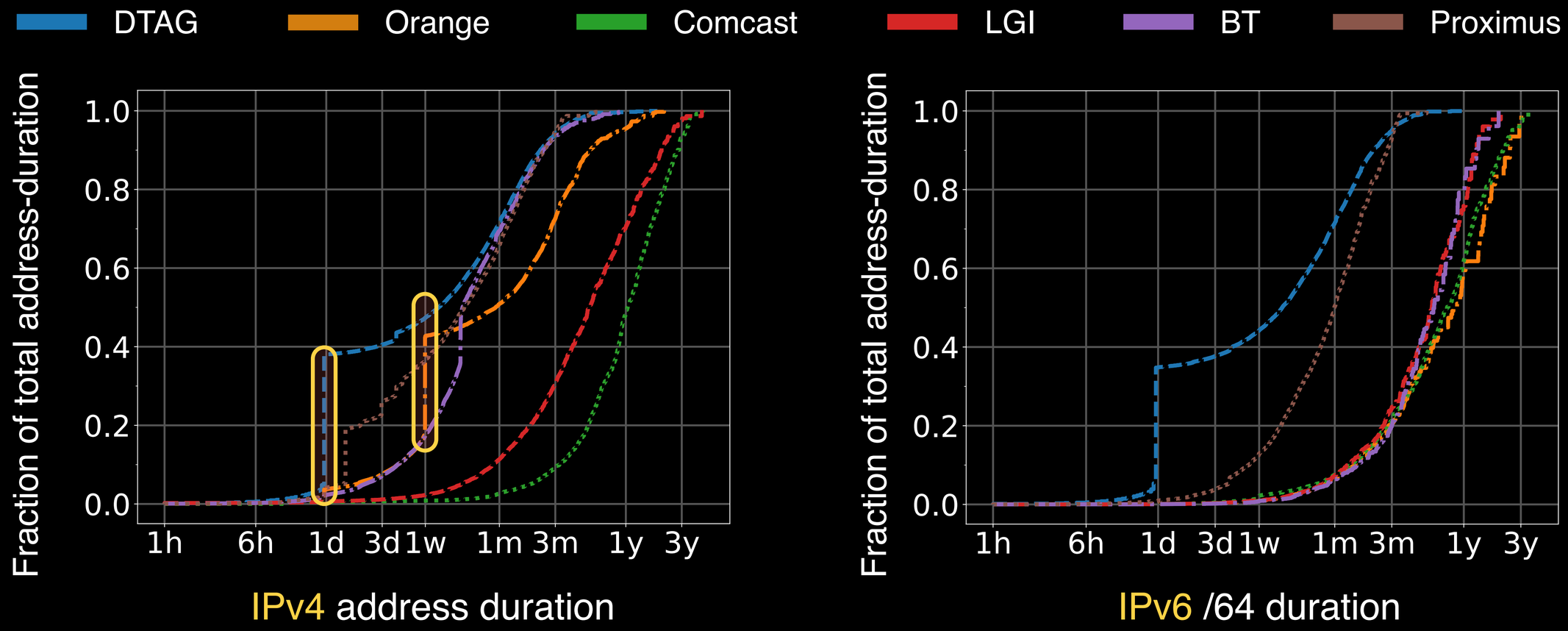

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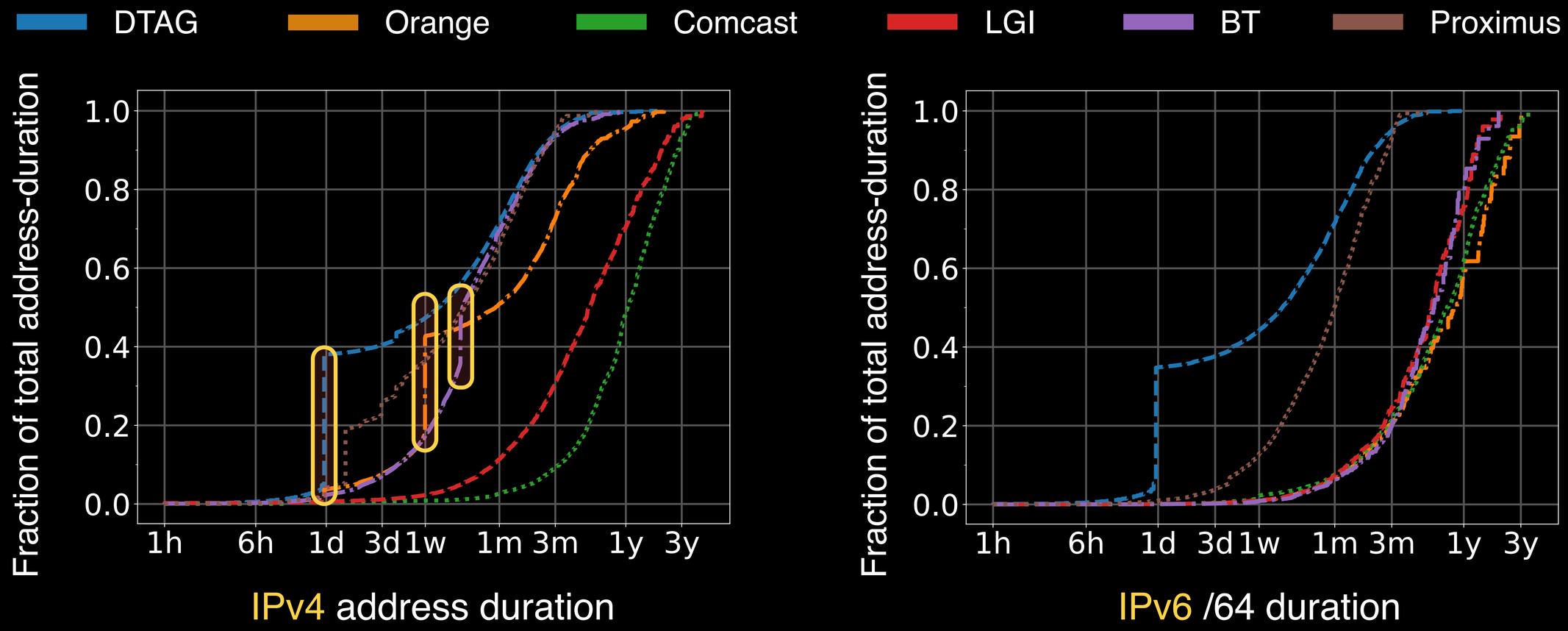

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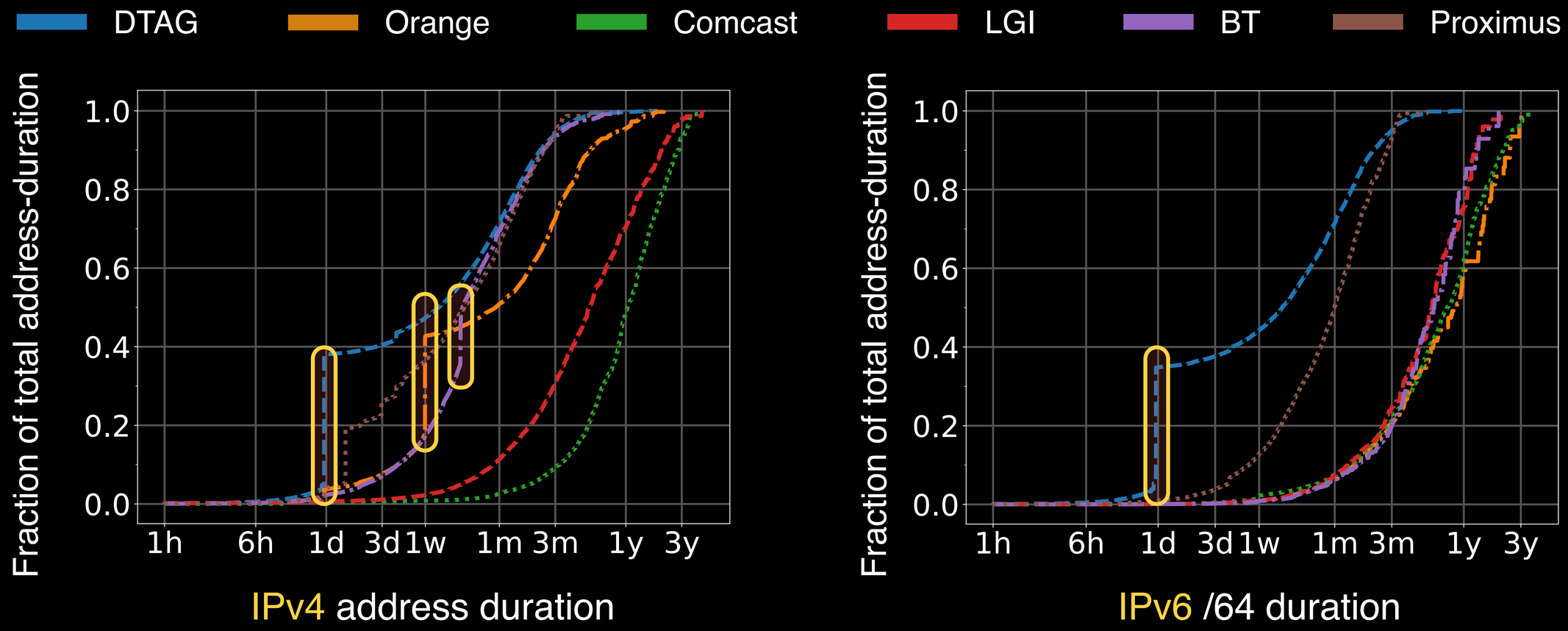

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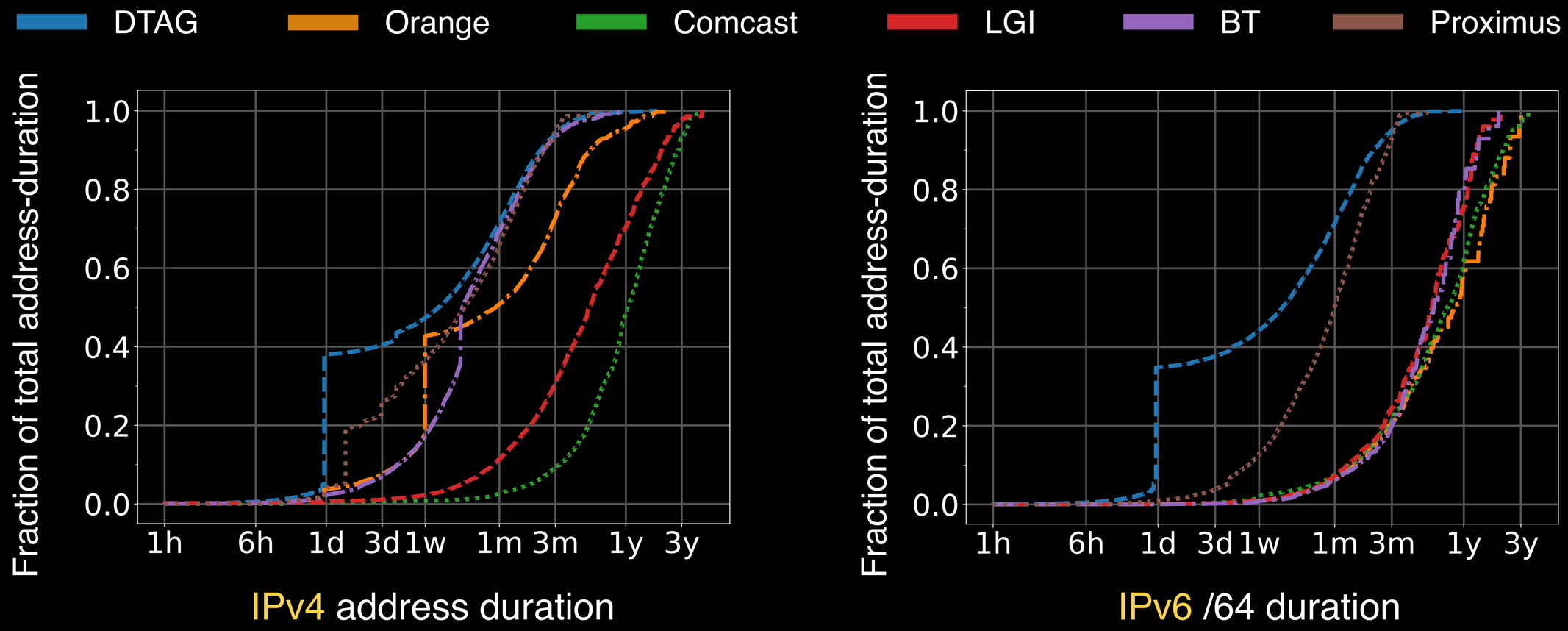
Long assignment durations suggest that IPv6 addresses can be long-term subscriber identifiers



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Temporal Dynamics

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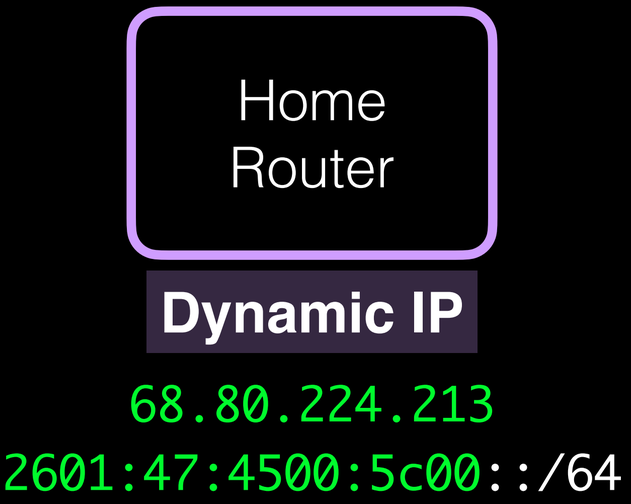

Spatial Dynamics

Which IPv6 prefixes can identify residential subscribers?

Where do addresses move upon reassignment?

Analyze address assignment dynamics using two complementary datasets

Temporal Dynamics

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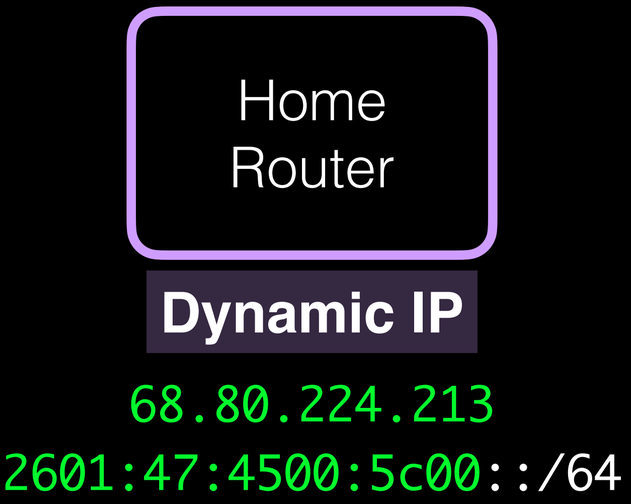

Spatial Dynamics

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Where do addresses move upon reassignment?

IPv6 subscribers can be delegated prefixes that are shorter than a /64

ISP DHCP Server

Address Pool

2601:47::/32

Home Router

Dynamic IP

2601:47:4500:5c00::/56

2601:47:4500:5c00:random

2601:47:4500:5c00:385d:49a9:b9da:c212

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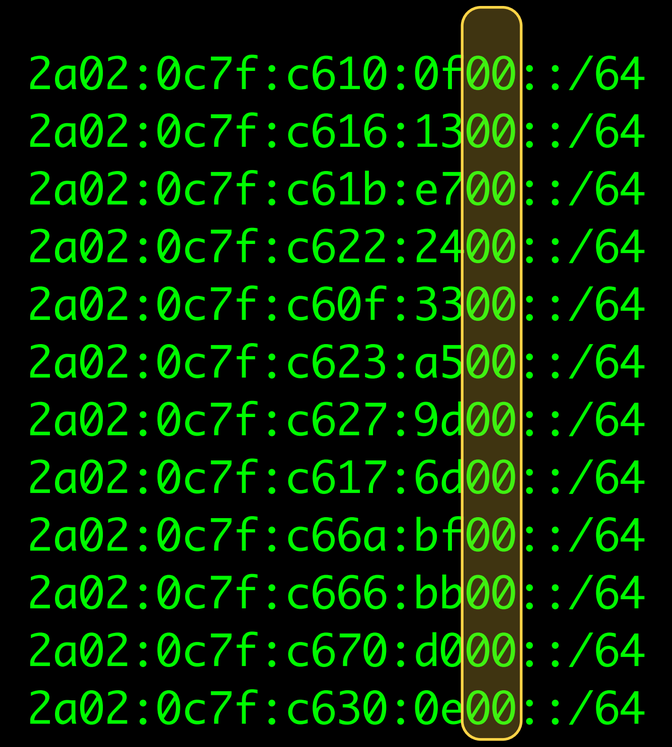
Finding a subscriber's delegated prefix by observing multiple /64 assignments over time

IPv6 /64s assigned over time to probe 17511 in Sky U.K. (AS 5607)



Inferred delegated prefix: /56

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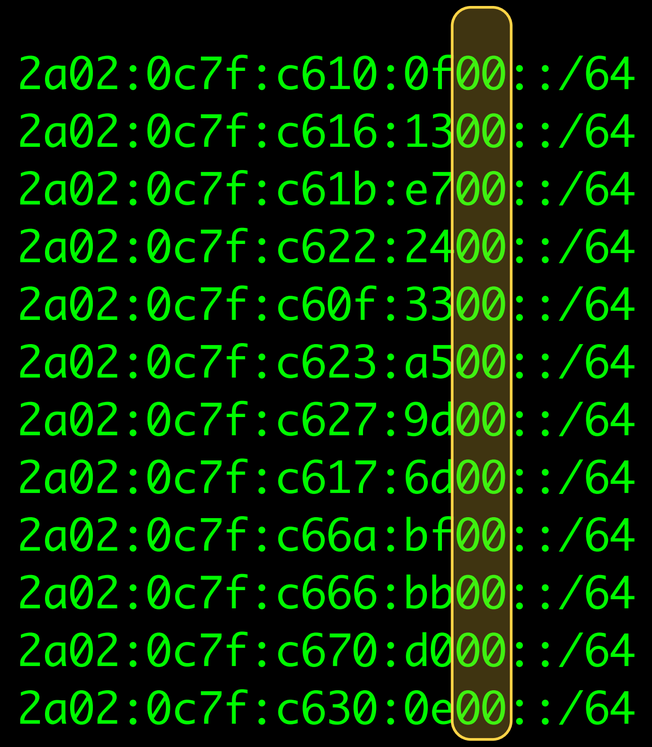
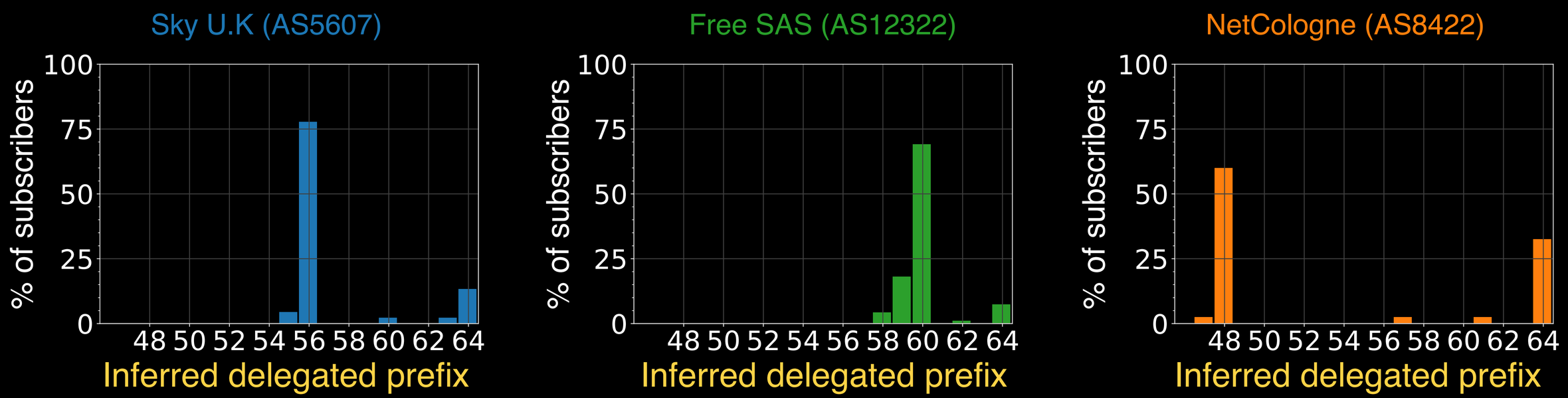


Rightmost 8 bits in the network part are always set to 0

Inferred delegated prefix: /56

Prefixes delegated to subscribers vary widely across ISPs

In NetCologne, a /48 prefix can identify a residential subscriber!



We validated our findings and also provide additional corroboration using the CDN dataset

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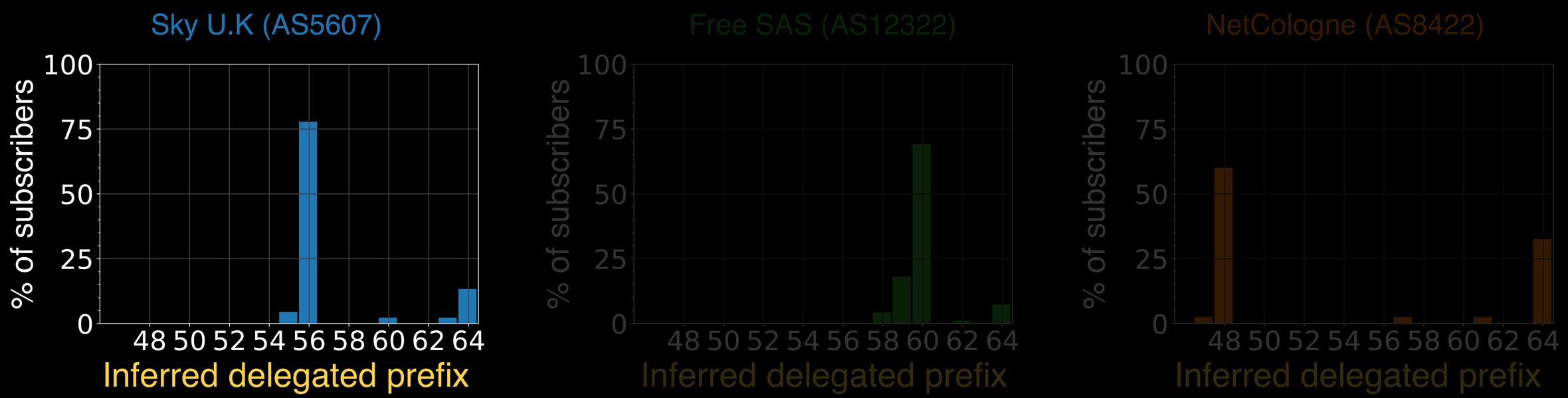

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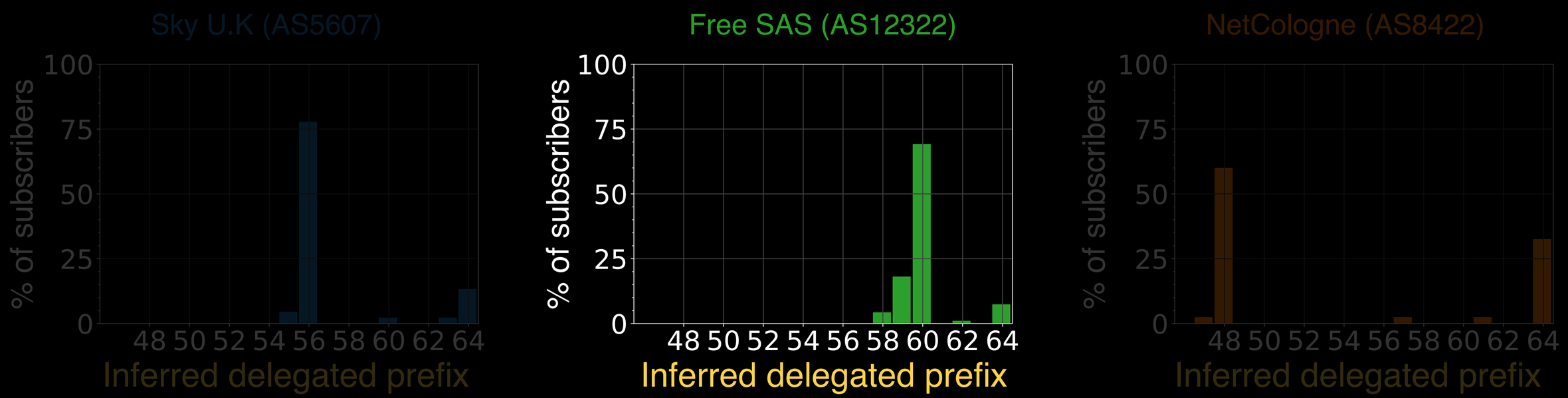

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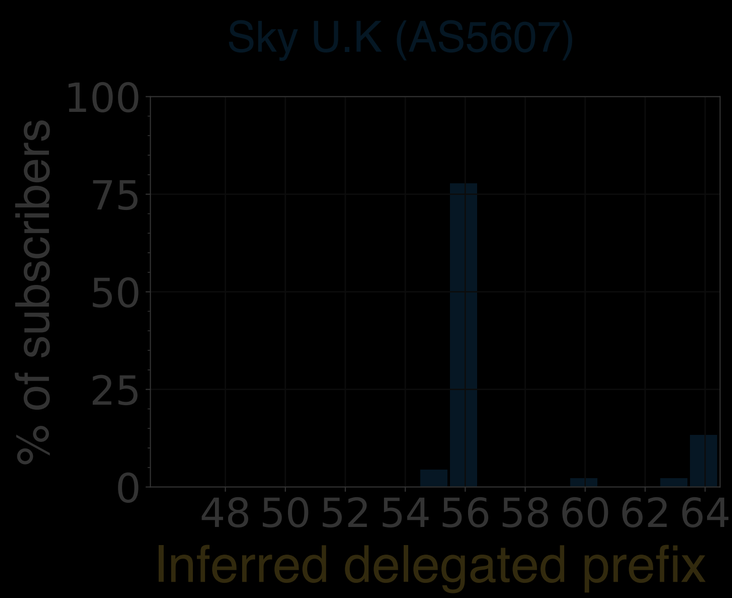

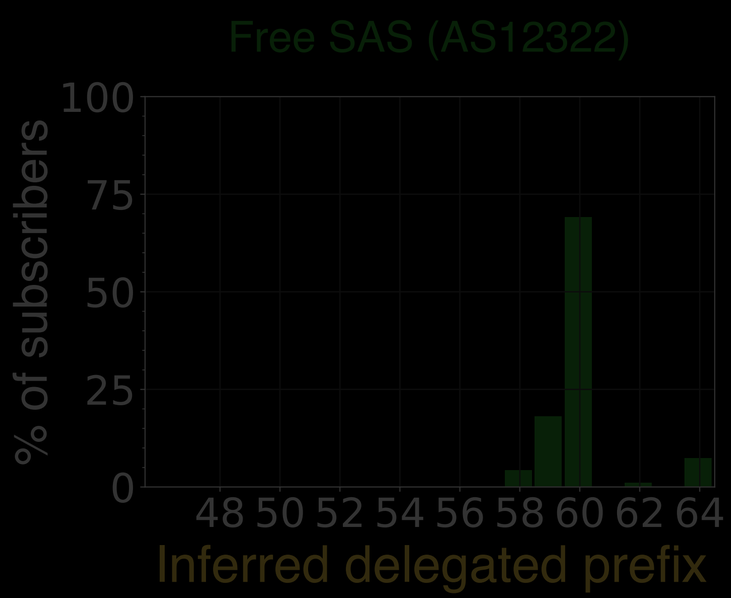

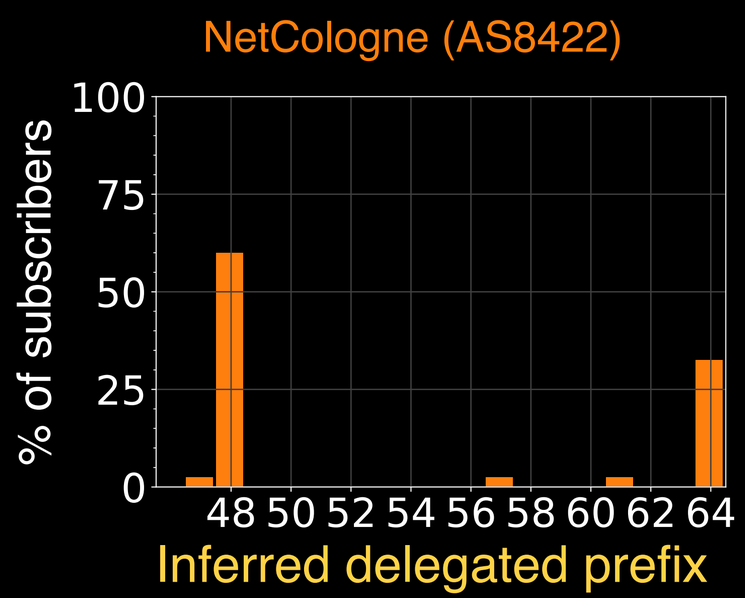

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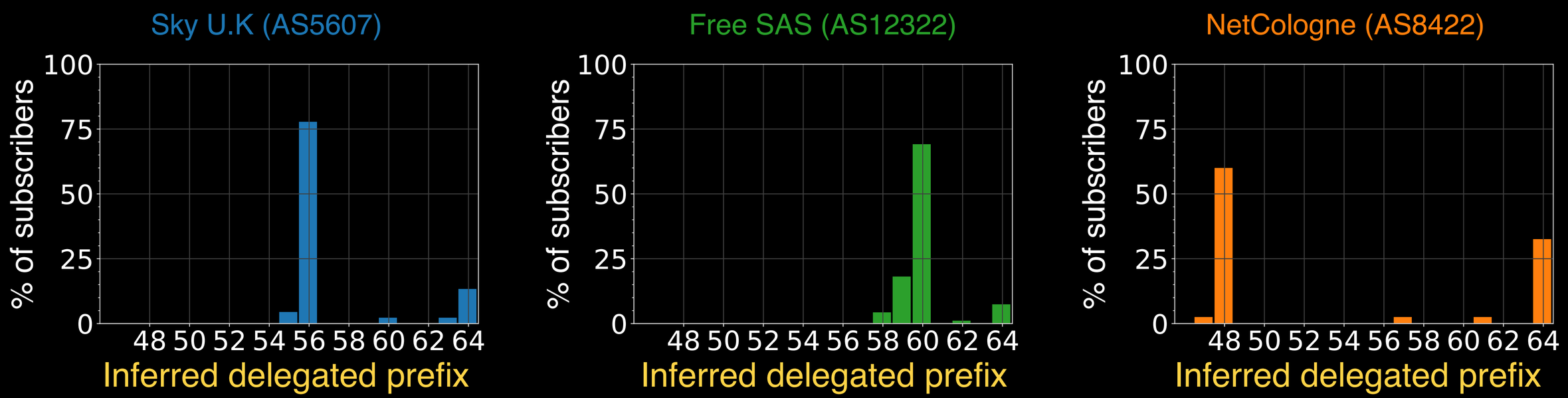

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We analyzed address assignment dynamics using two complementary datasets

Temporal Dynamics

IPv6 /64 assignments to residential subscribers may remain unchanged for months

Spatial Dynamics

IPv6 prefix lengths delegated to subscribers vary widely across ISPs

Subsequent addresses assigned to the same subscriber are often from the same /40

Host Reputation

Geolocation

Active Probing