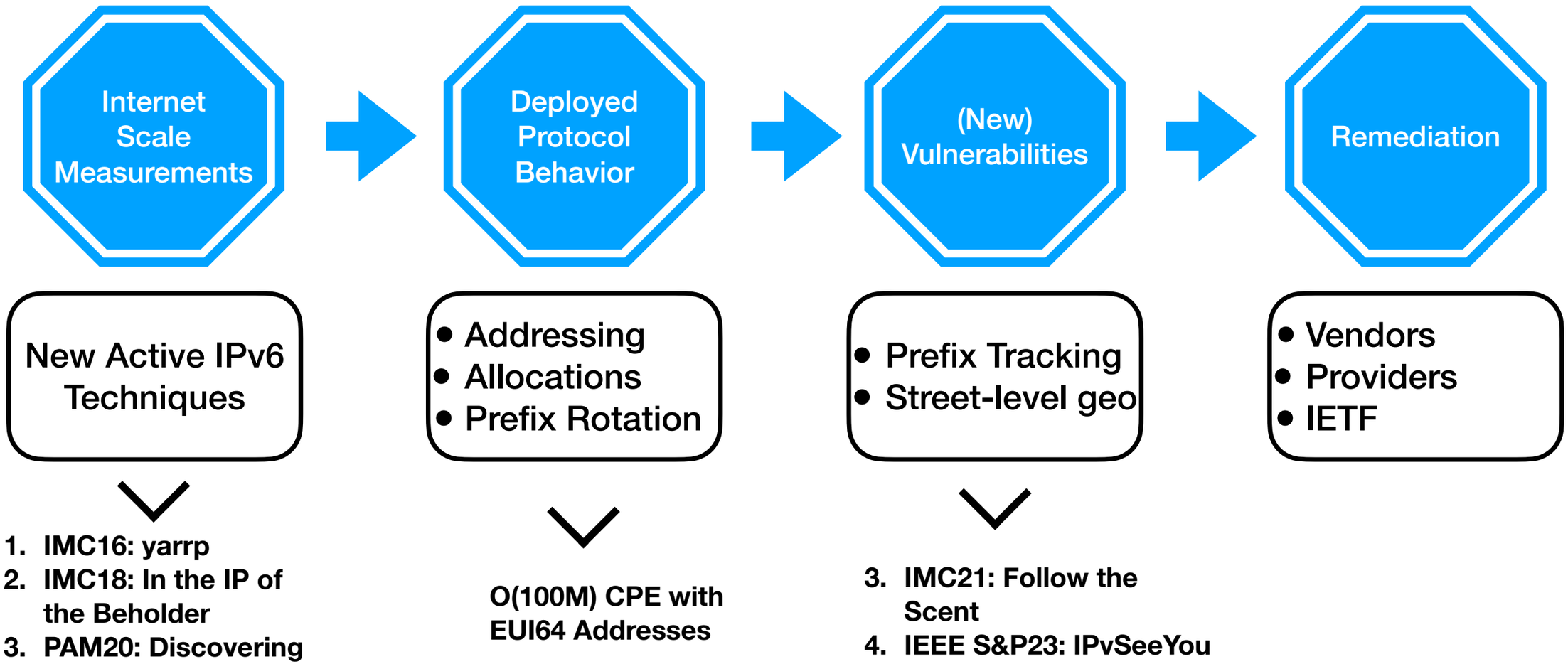
Follow the Scent + IPvSeeYou
(What we did with millions of EUI64 IPv6 CPE Addresses)

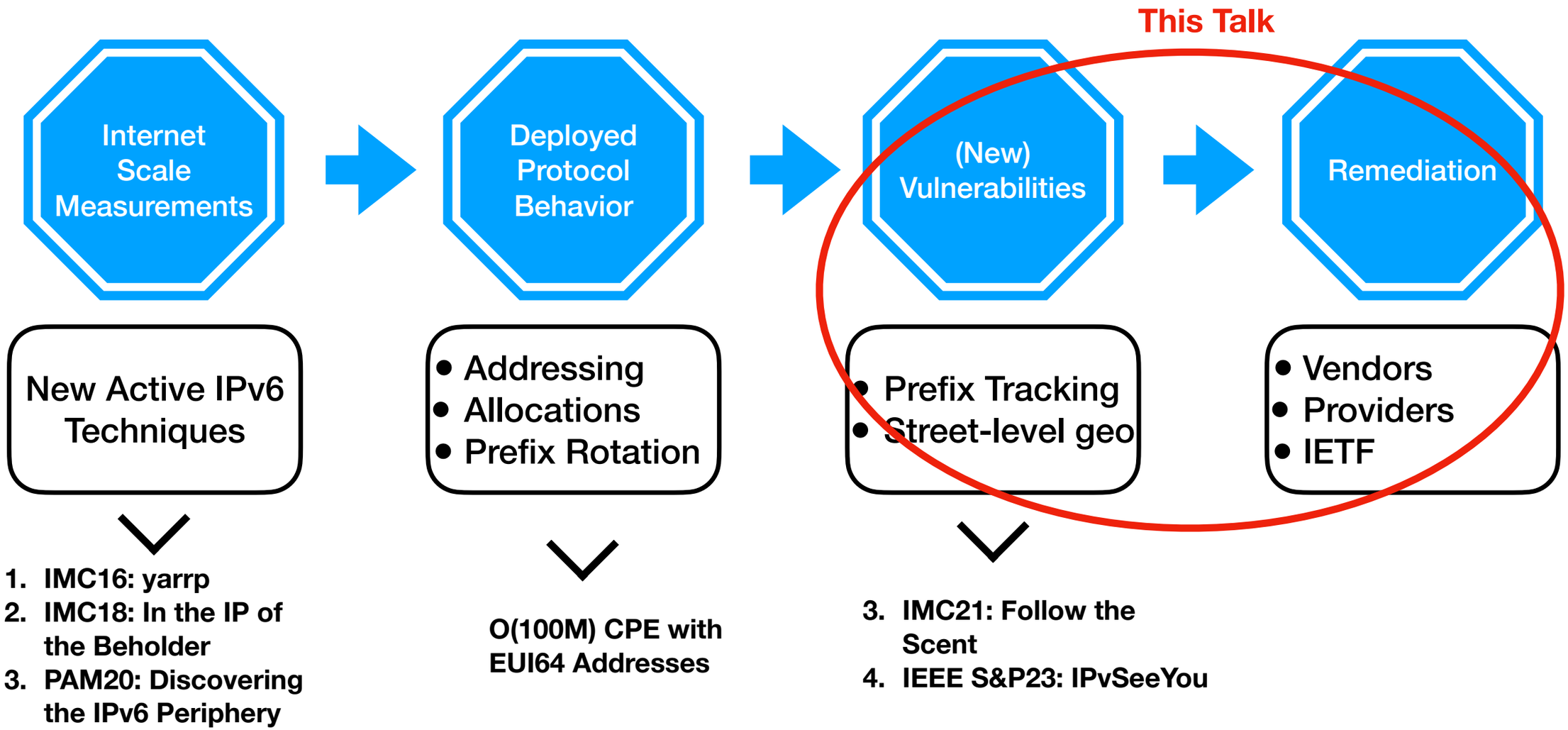
Erik Rye, UMD/CMAND
Robert Beverly, CMAND

IETF 117 maprg
July 28, 2023

maprg outline



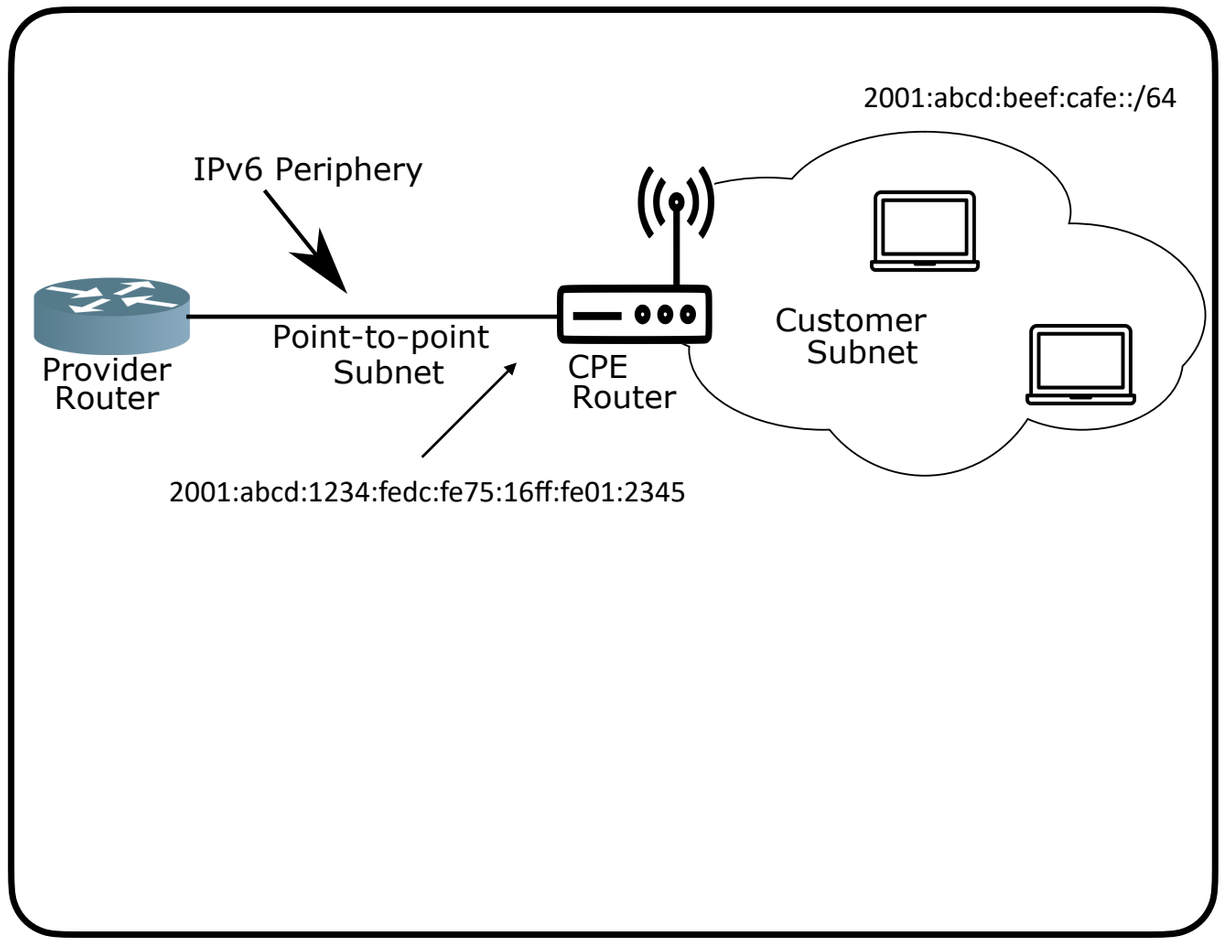
maprg outline



Internet Scale Measurements

Customer IPv6 “Periphery”

No NAT



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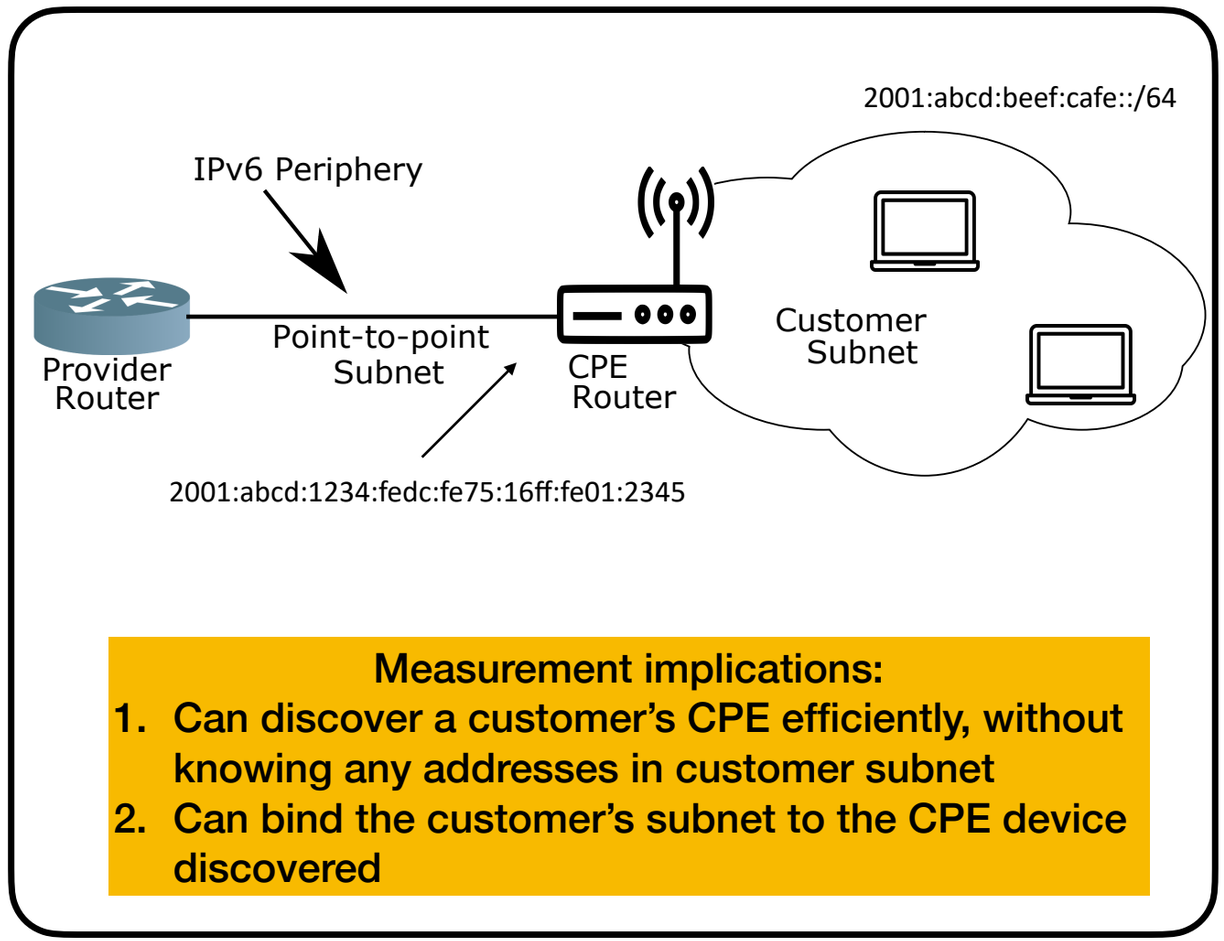

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1. Can discover a customer’s CPE efficiently, without knowing any addresses in customer subnet
2. Can bind the customer’s subnet to the CPE device discovered

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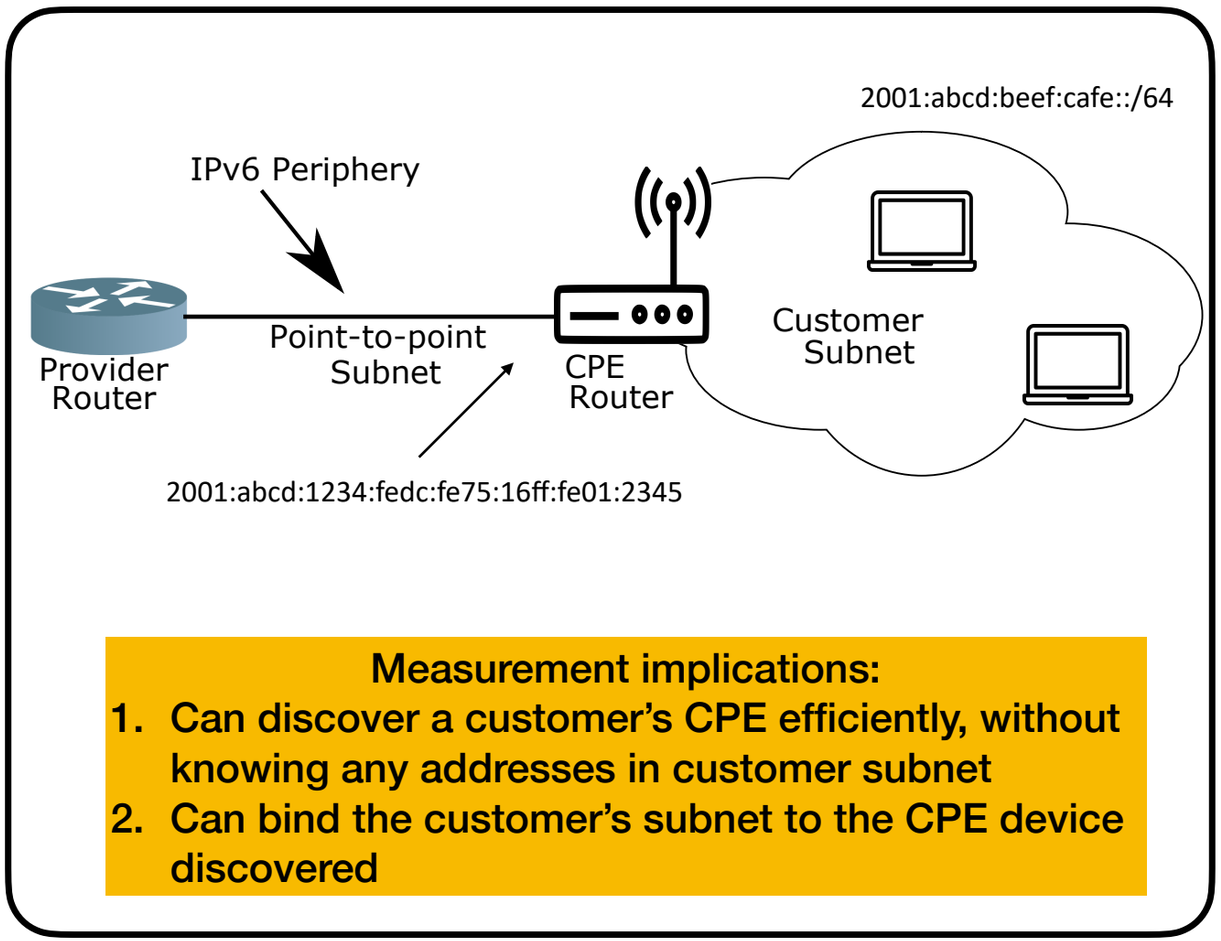

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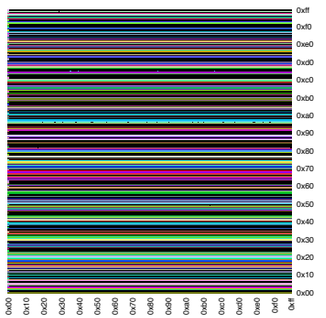
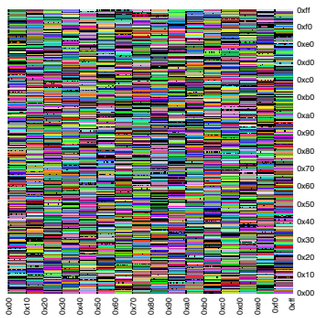
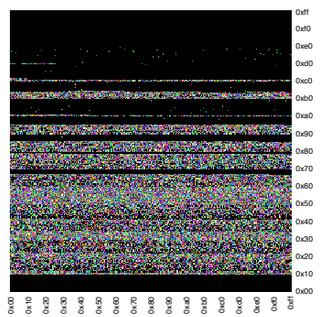
Provider Allocation “Fingerprints”



Entel (Bolivia) /56

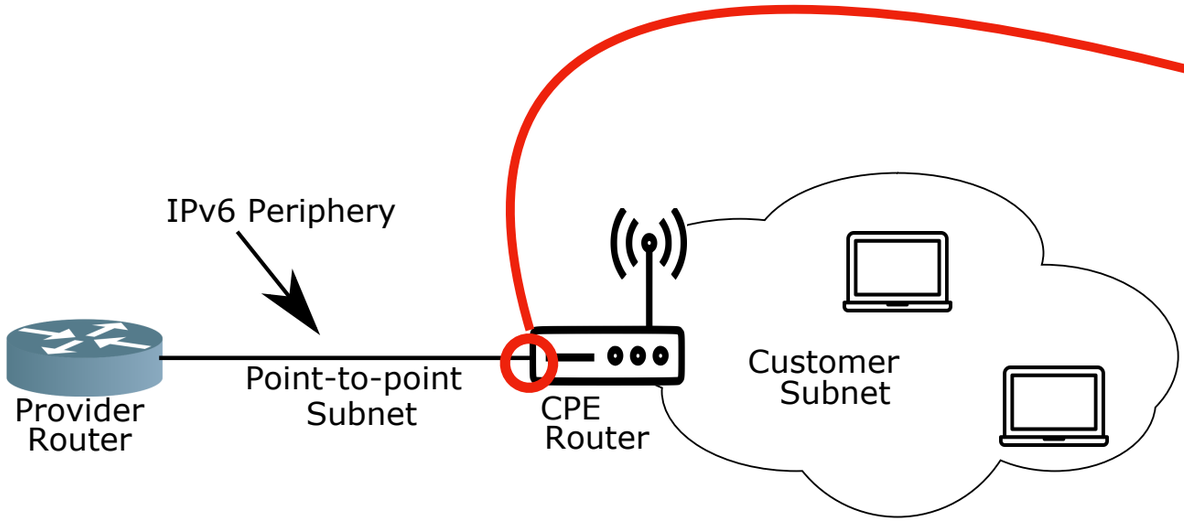


BH Telecom (Bosnia) /60



Starcat (Japan) /64

Old RFCs, Long Lives



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  - Privacy extensions (RFC3041, RFC4941)

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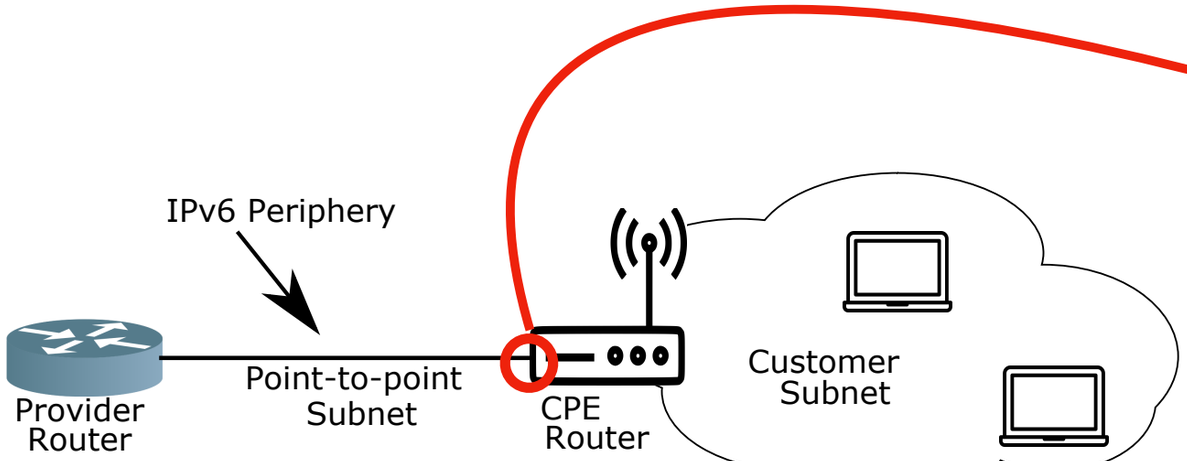
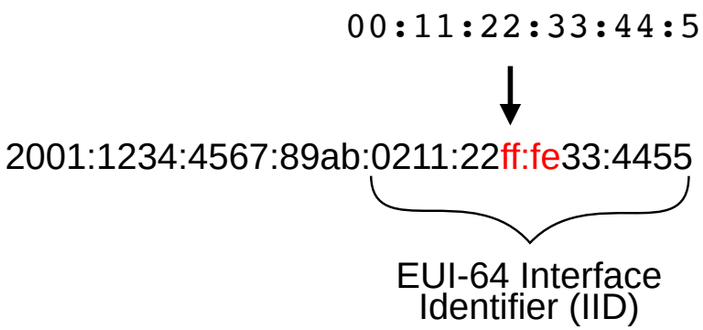




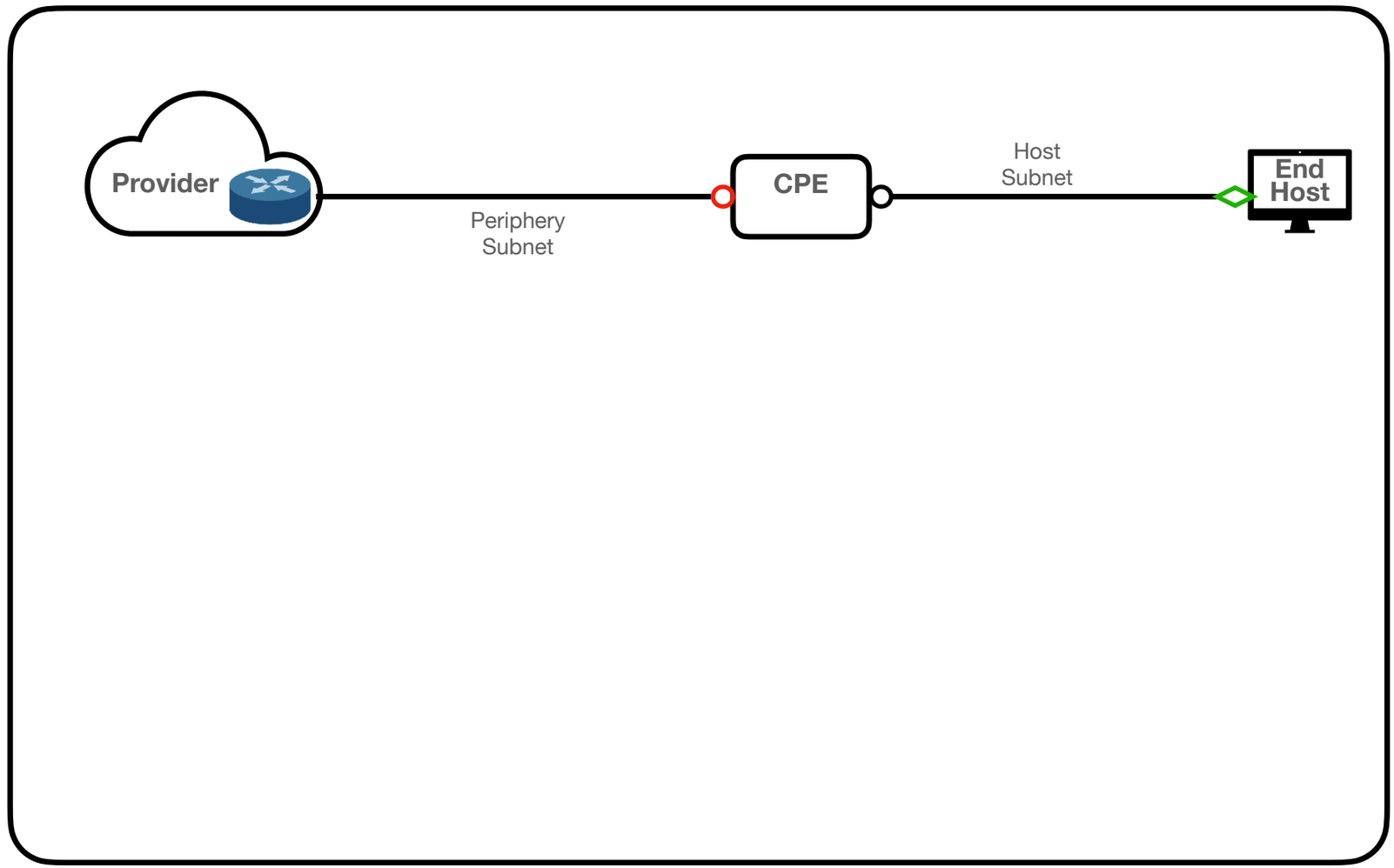
- Interface ID (host's lower 64 bits):
  - static
  - DHCPv6
  - Privacy extensions (RFC3041, RFC4941)
- EUI-64:
  - Form IID from interface MAC (RFC1971, RFC2462)
  - Well-known privacy issues, e.g., RFC7707, RFC9416

How Common is EUI64?

- While modern OS use privacy extensions,
- We find O(100M) unique CPE (home routers) that use EUI64
- How can we leverage these persistent address identifiers?
  - Tracking IPv6 Prefix Rotation [IMC21] 🏆
  - Street Level IPv6 Geolocation [S&P23]

(New)
Vulnerabilities

IPv6 Prefix Rotation



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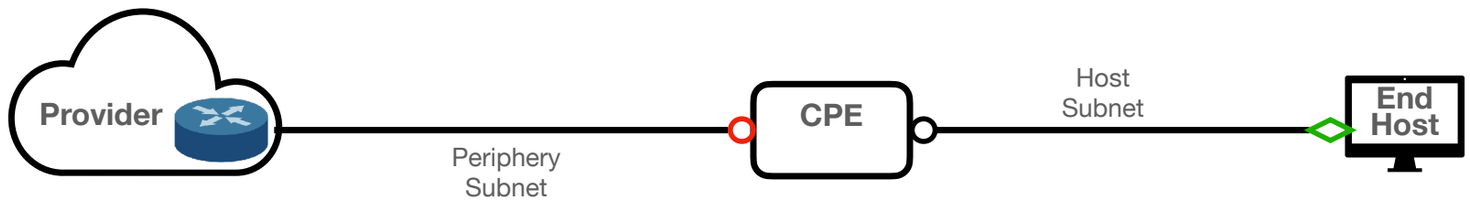

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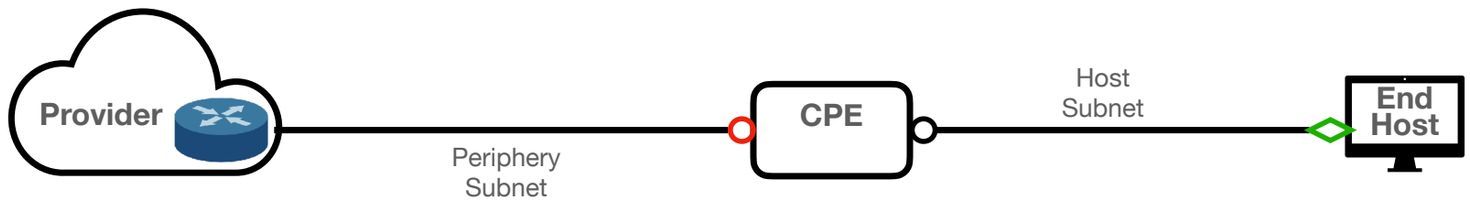

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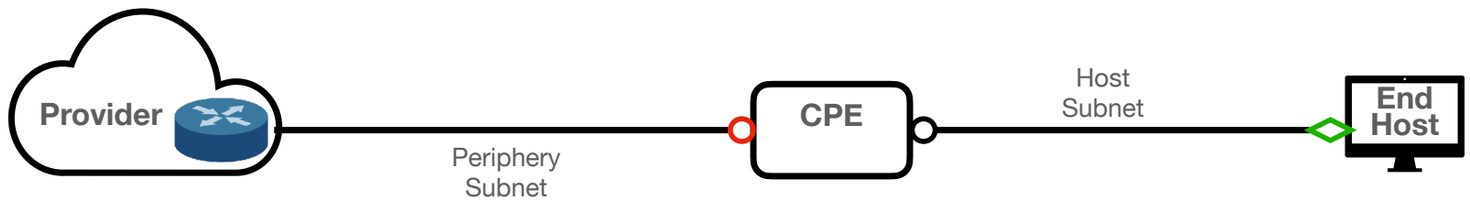

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(New) Vulnerabilities

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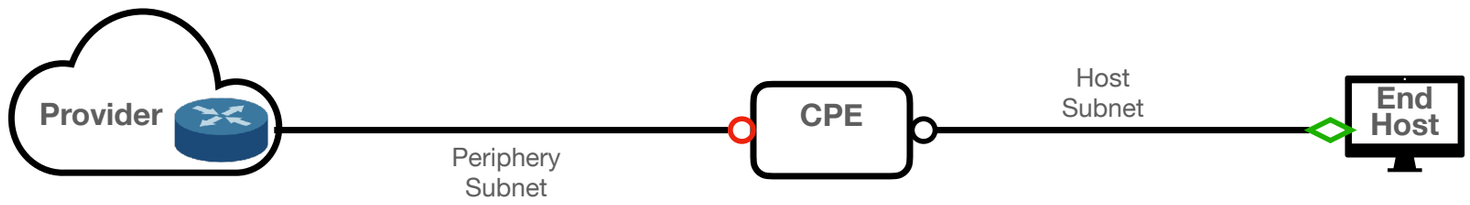

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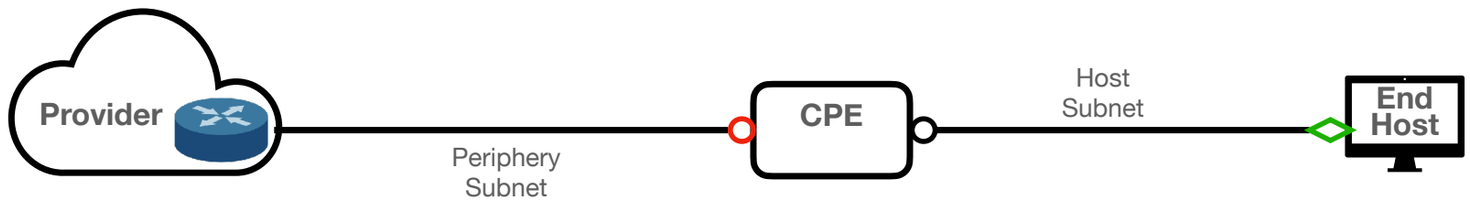
Measurement implications:

1. Both user's prefix and host identifier changing
2. Affords stronger privacy to user

(New) Vulnerabilities

IPv6 Prefix Rotation

In prefix rotating providers, we find >9M CPE devices using EUI-64 addresses!



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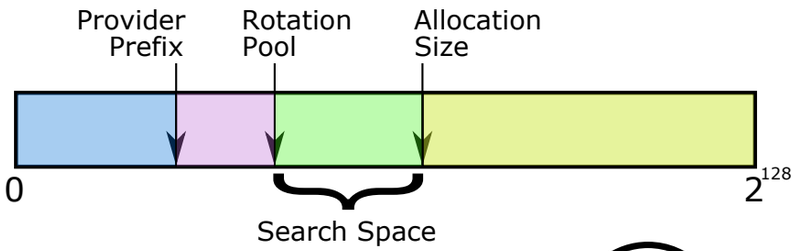

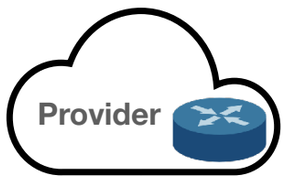

Adversary

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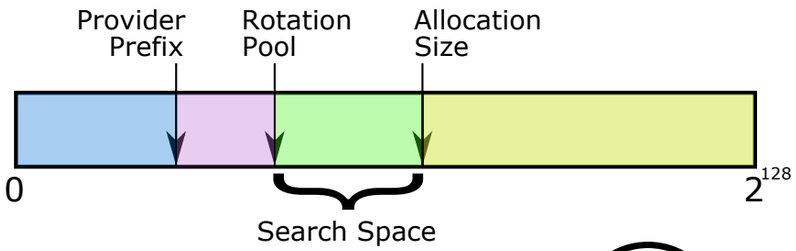

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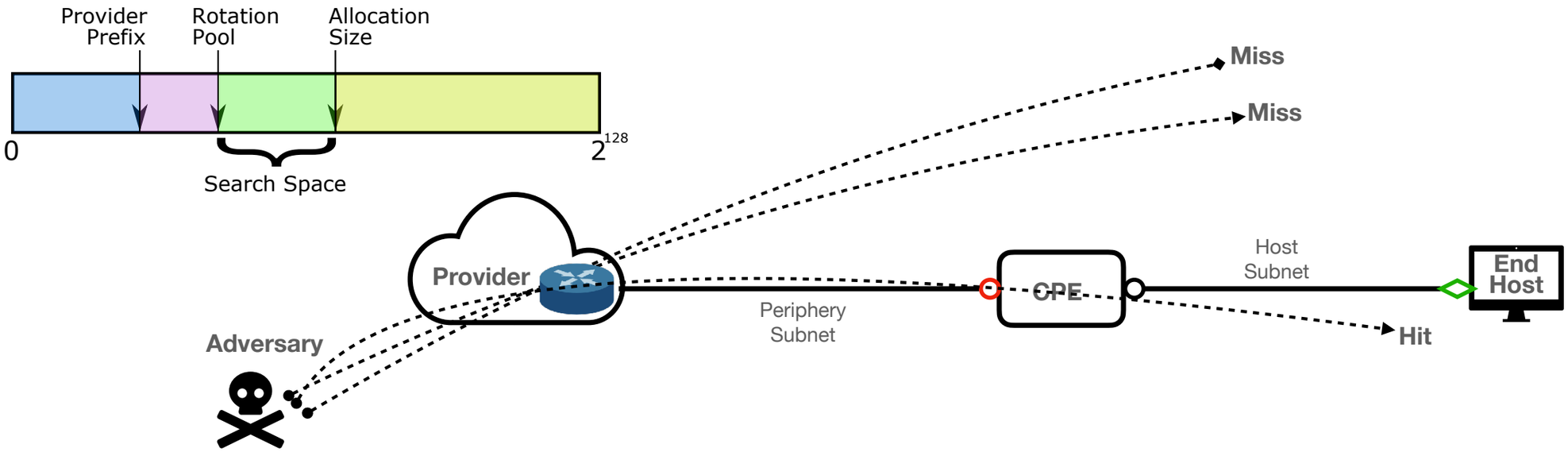

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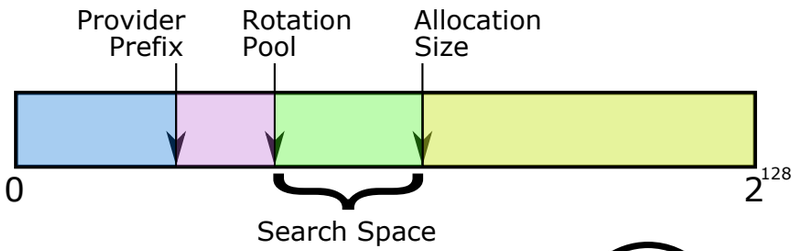

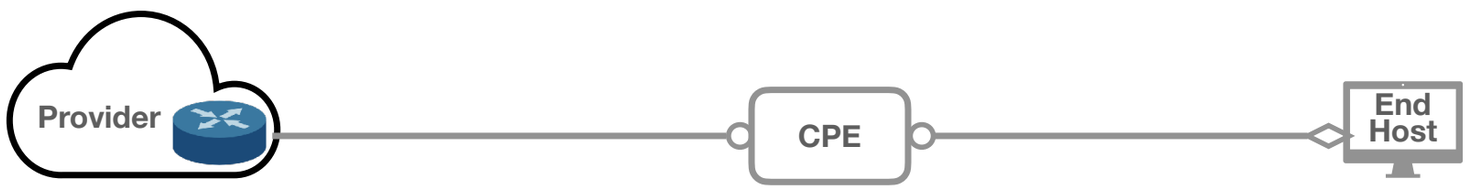

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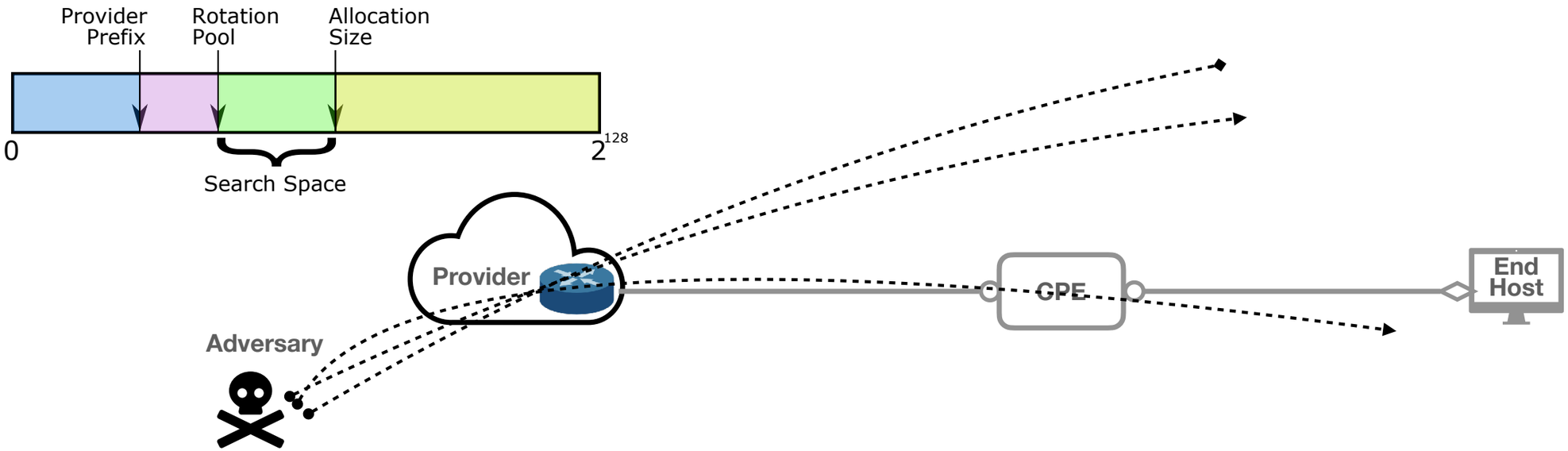

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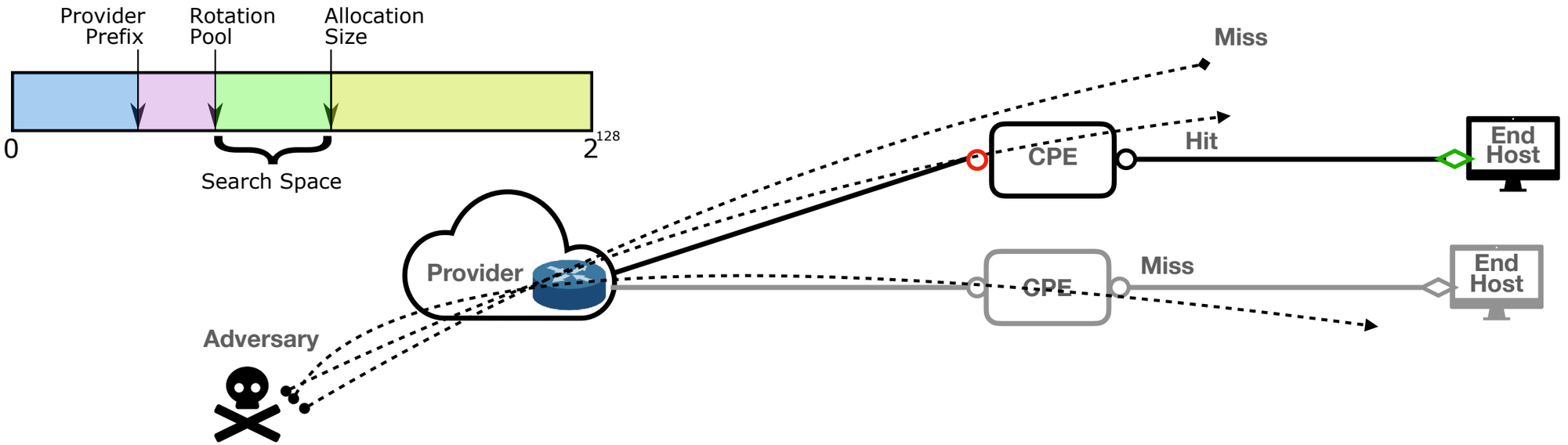

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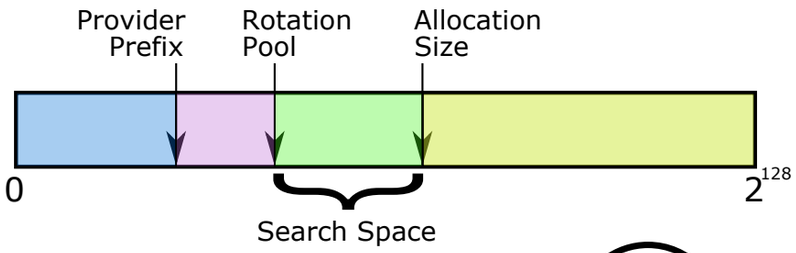

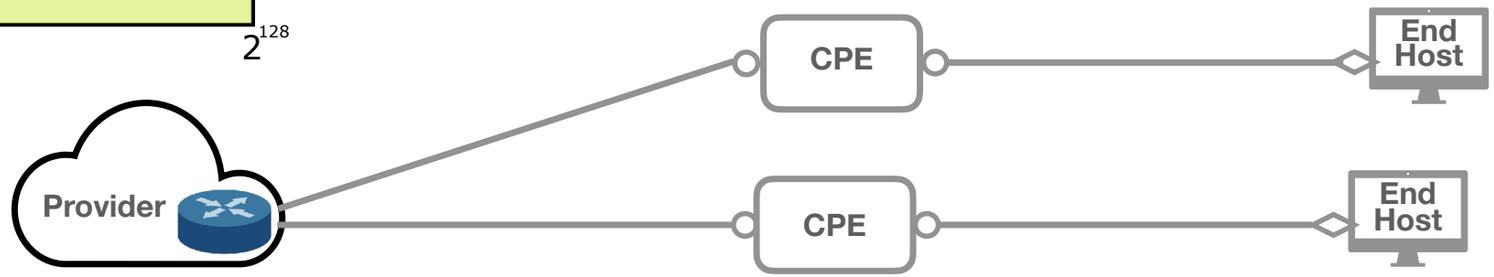

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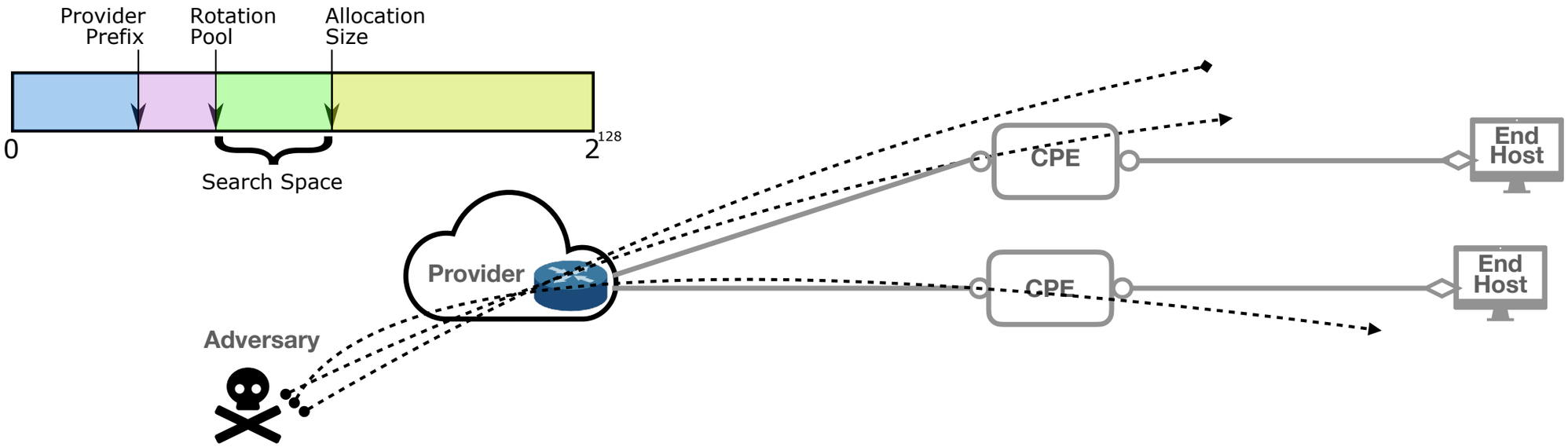

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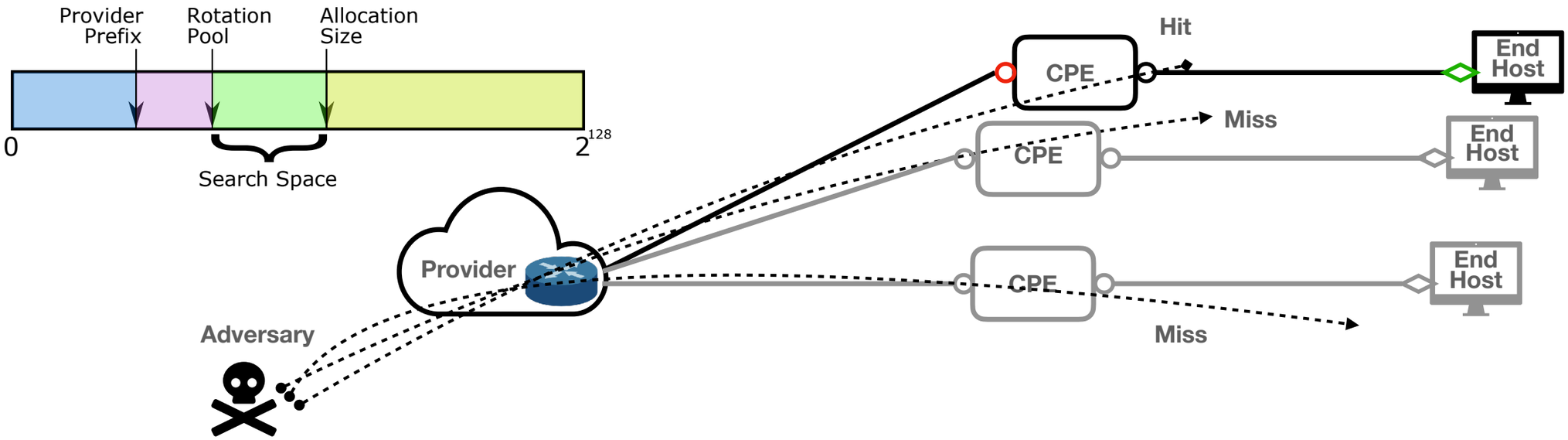

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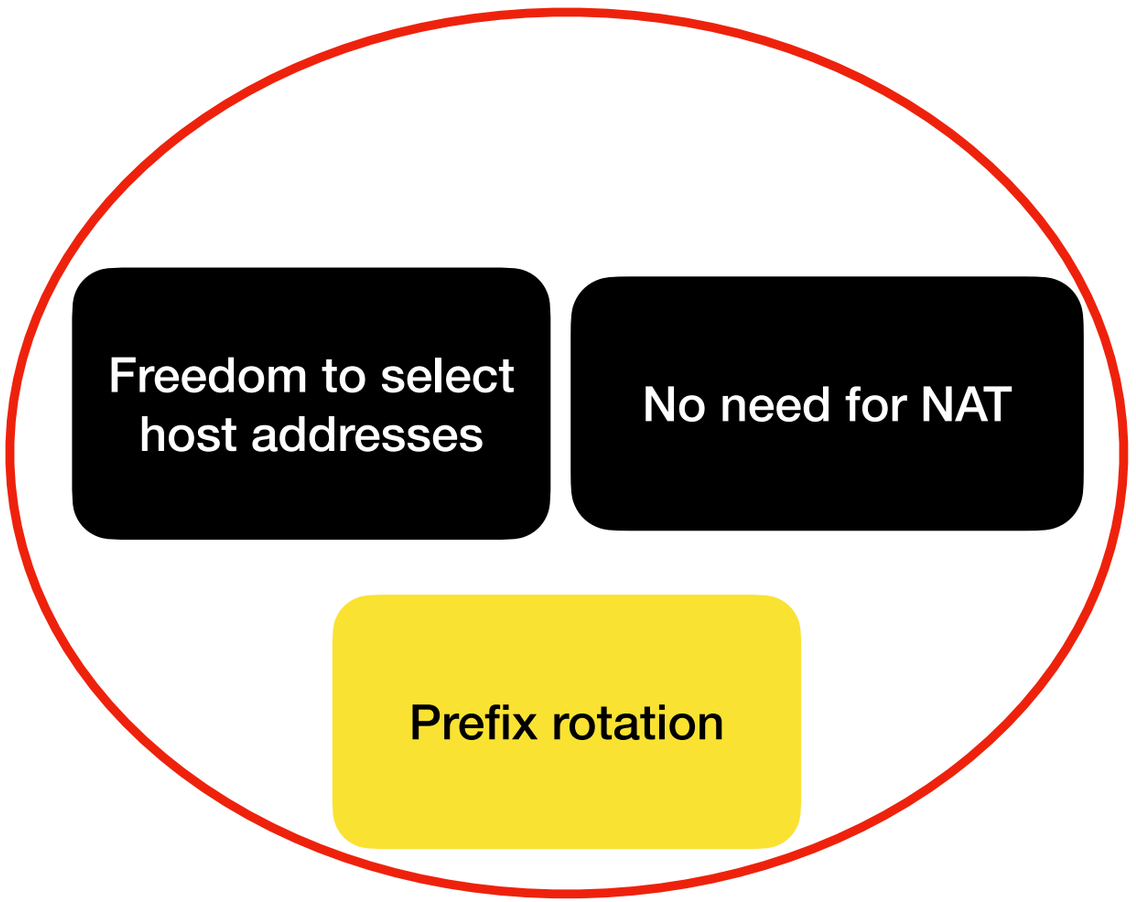
Follow the Scent



1. Technique to discover and characterize IPv6 prefix rotation
2. Internet-wide measurements to understand provider allocations, rotation, and pool sizes
3. Exploit leveraging legacy CPE addressing to track users across prefix and host changes
4. Measurements of >9M IPv6 vulnerable customers across >100 providers
5. Case study demonstrating 60-90% accuracy in tracking IPv6 traffic flows

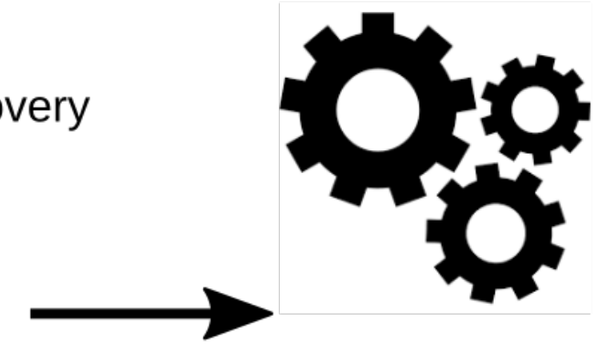
(New)
Vulnerabilities

IPvSeeYou

Active Measurement
EUI-64 IPv6 Address Discovery

+

WiFi Geolocation
Databases



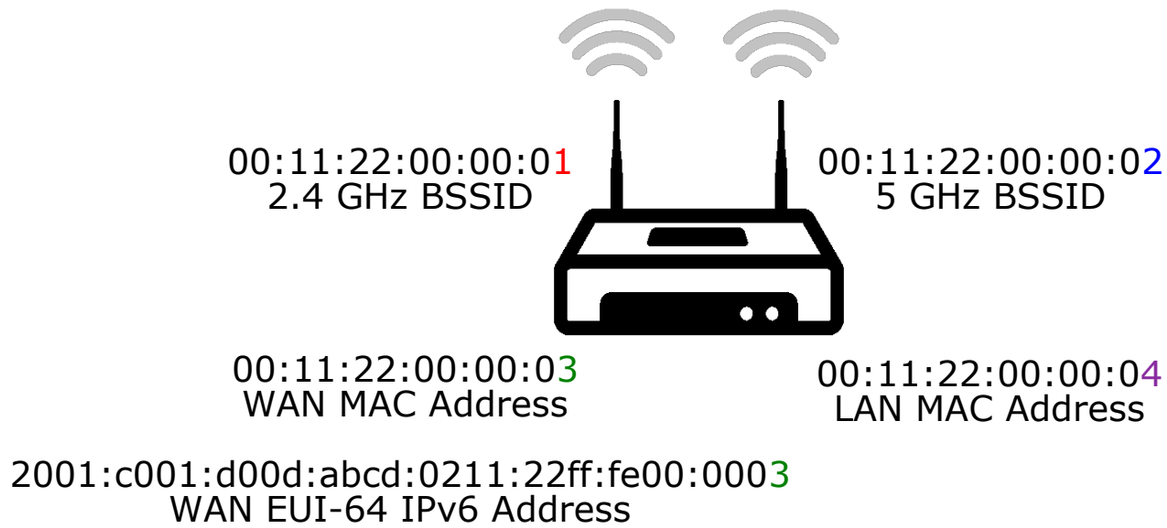
Wired-Wireless
Identifier Matching
Algorithm

Street-Level
IPv6 Geolocation

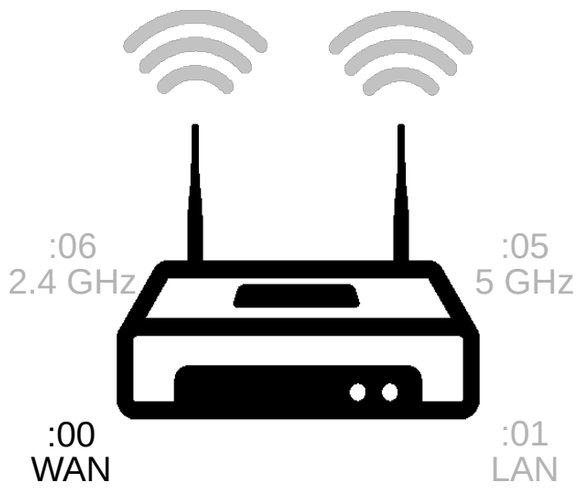
millions of homes exposing their exact physical location (street address) via their IPv6 address

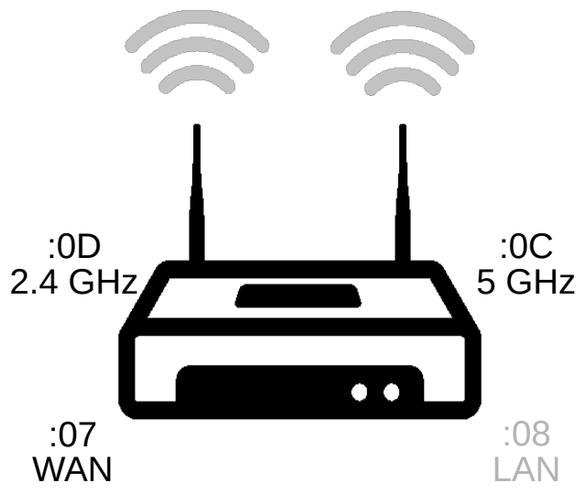
Intuition

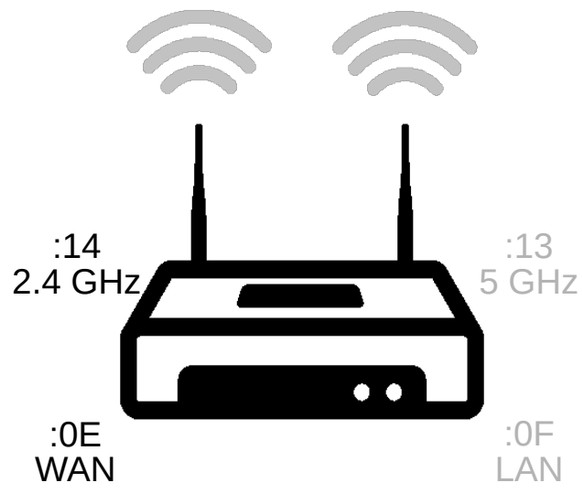
- Can obtain WAN-side MAC address of CPE via EUI64
- (Many) home routers also have WiFi, e.g., all-in-one devices
- IPvSeeYou discovers WAN MACs, then predicts the *offset* between WAN and WLAN MACs
- Can then query war-driving WiFi geolocation databases for the inferred BSSID
- (worked with IRB to ensure ethical research)



Mapping WAN MAC to WiFi BSSID







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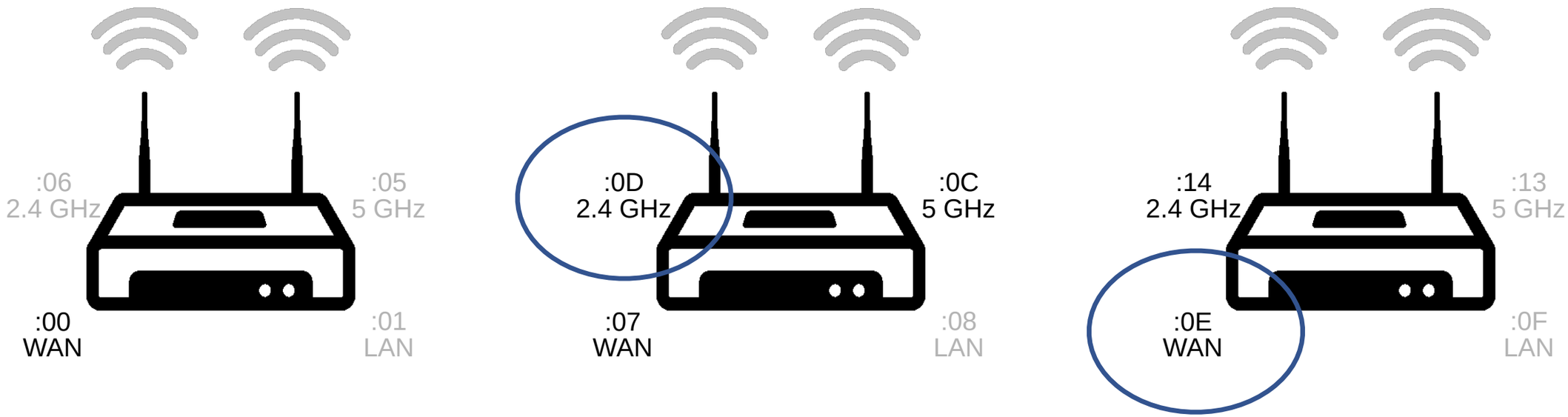
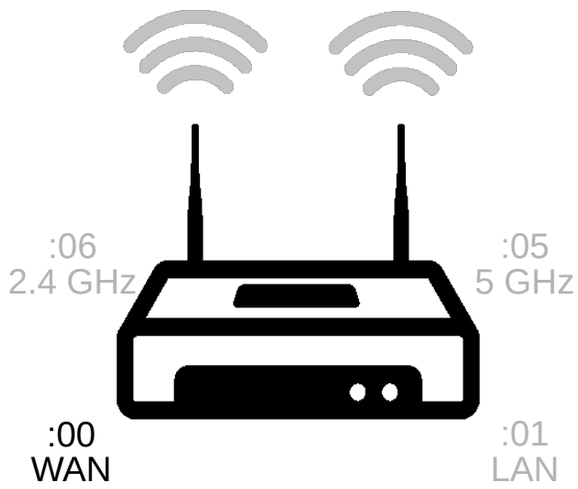
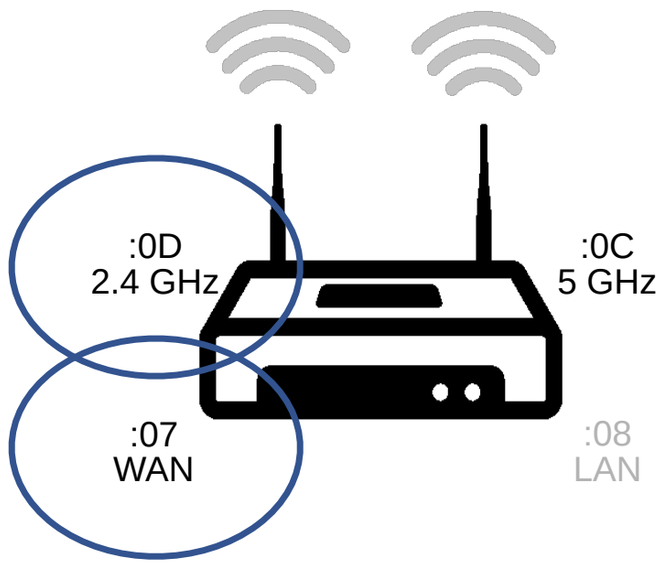
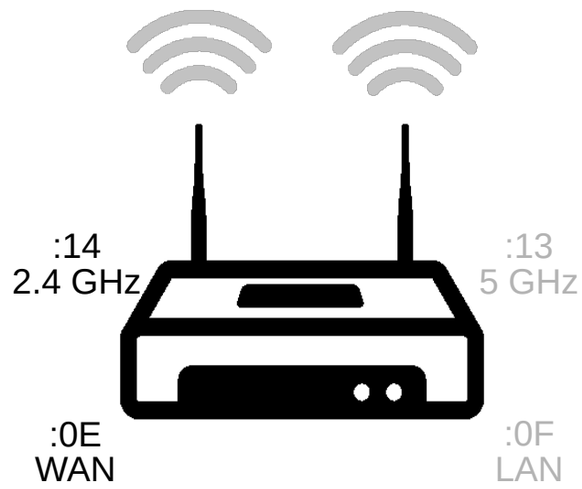


Naively, this BSSID and this WAN MAC are adjacent and belong to same device

Mapping WAN MAC to WiFi BSSID







True offset: +5/+6

Limitations

- IPv6 Collection Limitations
  - Some CPE devices don’t use EUI-64 IPv6 addresses
    - SLAAC w/Privacy Extensions, DHCPv6 addresses
  - Nonresponsive to ICMP6 probes

- WLAN BSSID Collection Limitations
  - Device may not have a BSSID
    - Router w/o built-in WiFi
  - Devices with BSSIDs may not be in wardriving/geolocation databases
    - Restrictions/laws regarding wardriving

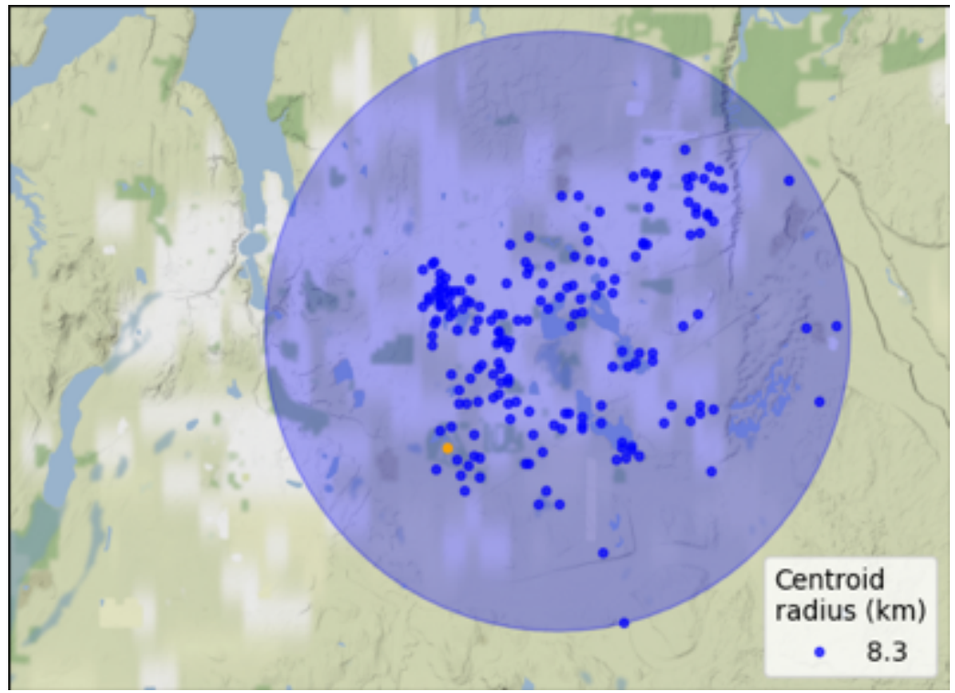
- Correlation Limitations
  - Multiple offsets per OUI
  - 2.4/5 GHz BSSIDs complicate offset inference

Results

- Combining our WAN MAC and BSSID data with our algorithm, we geolocated:
  - At least 12M unique devices of 60M total devices
  - In 147 countries
  - In 1000+ unique OUIs
- Widespread use of EUI-64 IPv6 addresses cause serious location privacy concerns for individuals

Geolocation by Association

- Non-EUI-64 devices are vulnerable to coarse-grained IP geolocation
- First, geolocate all EUI-64 IPv6 addresses *connected to same ISP router*
- Non-EUI-64 IPv6 addresses *attached to same ISP router* necessarily within physical medium constraints



Non-EUI-64 IPv6 address (gold circle) with IPvSeeYou-geolocated EUI-64 IPv6 addresses (blue dots)

Remediation

- Disclosed vulnerability to multiple major CPE vendors
  - FRITZ!OS 7.50
- Worked with a major residential US service provider to change deployed behavior
- Ideal remediation: stop using EUI-64 IPv6 addresses!

Thanks!

6::int

- Follow the Scent
  - Defeating prefix rotation privacy
- IPvSeeYou
  - Large scale data fusion attack
  - Street-level geolocate millions of CPE routers
- info@sixint.io

Questions?