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BRIEFINGS

IPvSeeYou: Exploiting Leaked Identifiers in IPv6 for Street-Level Geolocation

Erik Rye (@gigaryte, CMAND)

Rob Beverly (@badcksum, CMAND)

6::int

https://sixint.io

Outline

- Overview
- Background
- IPvSeeYou
- Tool and Demo
- Conclusions
- Questions

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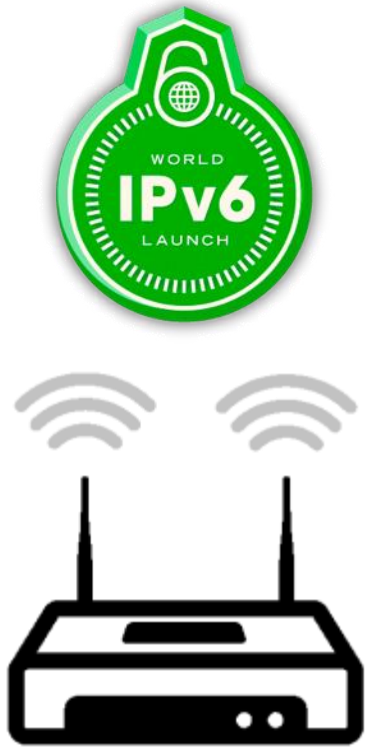
IPvSeeYou: Home Routers

- Got IPv6 at home? (I think…)
- Know how your router is configured? (we didn't…)
- What does your router reveal about you? (you might be surprised…)



IPvSeeYou: In a Nutshell

- Routers deployed in the wild use legacy EUI-64 IPv6 addressing
- Anyone (able to `ping6` / `traceroute6`) can find router's physical geolocation
  - …. with *street-level* precision
  - E.g., a subscriber's home

IPvSeeYou: Our Contributions

- Developed a technique to find residential routers (needle in a haystack in IPv6)
- Discovered >60M routers in the wild that reveal their hardware (MAC) address
- Gathered 450M BSSID -> Geolocations
- Developed a technique to infer the WAN MAC -> WiFi BSSID mapping
- Data fusion to geolocate IPv6 prefixes of home routers

Active Measurement
EUI-64 IPv6 Address Discovery

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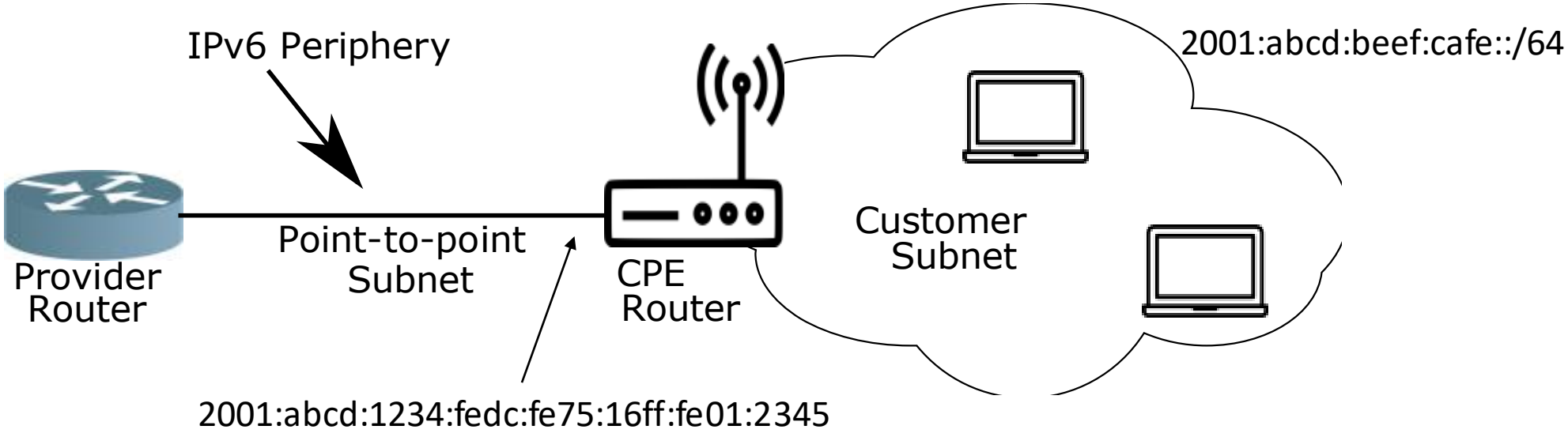
IPv6 Primer

- IPv6:
  - IPv6 addresses are 128 bits
    - E.g., `2001:abcd:1234:fedc:fe75:16ff:fe01:2345`
  - Huge address space + sparsity
    - No way to actively probe entire IPv6 Internet, ala zmap
  - Even residential customers allocated a /64 (=2^{64} addresses)
    - No NAT
- Implication:
  - IPv6 is deployed <u>differently</u> than IPv4!

IPv6 “Periphery”

- Device at customer premises (CPE) is a routed hop!
- One subnet allocated to link between provider’s router and CPE
- Different subnet allocated to customer, on other side of CPE



Background (or, IPv6 gore)

- Smallest allocation, e.g., to a residential customer, is a /64
- What's a home to do with 2^{64} addresses?
  - Every device needs a unique IPv6 address
- How do devices choose an address within this /64?
  - Today (RFC3041/4941): "privacy extensions", i.e., random and short-lived
  - Legacy (RFC1971/2462): "EUI-64", encode hardware MAC address into lower 64 bits

Background: EUI-64 Addresses

- Recall, IEEE MAC addresses are 6 bytes, in hex:

  `00:11:22:33:44:55`

  Organizational Unique Identifier (OUI) = hardware manufacturer that owns block

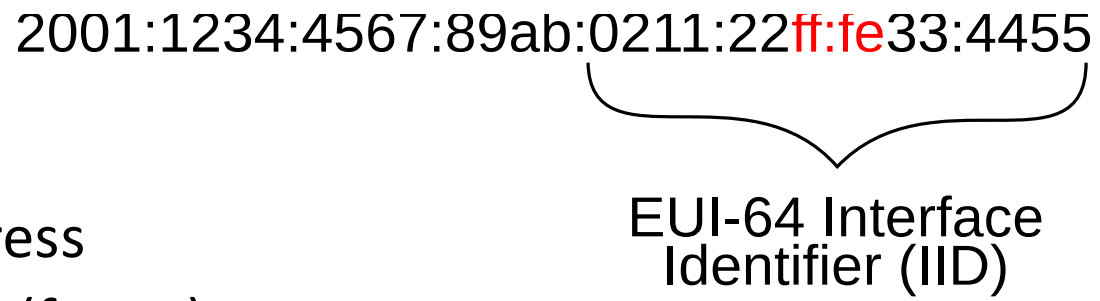
- IPv6 EUI-64 address:
  - Insert `ff:fe` between upper and lower 3B of MAC
  - Invert 7th most significant bit

  2001:1234:4567:89ab:0211:22ff:fe33:4455

  EUI-64 Interface Identifier (IID)

Background: EUI-64 Addresses

- Advantages:
  - Simple to implement
  - Guarantees (in theory) unique IPv6 address
  - No need for duplicate address detection (faster)
- Disadvantages:
  - Exposes layer 2 (Ethernet address) in layer 3 (IP)
    - Reveals device details (hardware, vendor, etc)
  - Static address doesn't change, even if device connects to new network
    - Globally unique -- permits tracking!



Background: Privacy Extensions

- RFC3041, January 2001
  - Generate short-lived random interface identifier
  - Perform duplicate address detection
  - Regenerate address often
  - For example: `2001:558:6045:1c:8c9c:5f05:ecc0:1f49`
- Privacy implications of SLAAC / EUI-64 known for 20+ years
  - So, all devices use privacy extensions, right?

IPvSeeYou: Impact

1. A remote, unprivileged attack on privacy, even when end-hosts utilize IETF standardized IPv6 “privacy extensions”
2. Tool that maps IPv6 router address to geolocation
3. Precision geolocation of ~12M residential IPv6 routers and allocated IPv6 prefixes
4. Geolocation of provider last-hop infrastructure, thereby geolocating IPv6 routers that use privacy extensions
5. Responsible disclosure and vendor remediation

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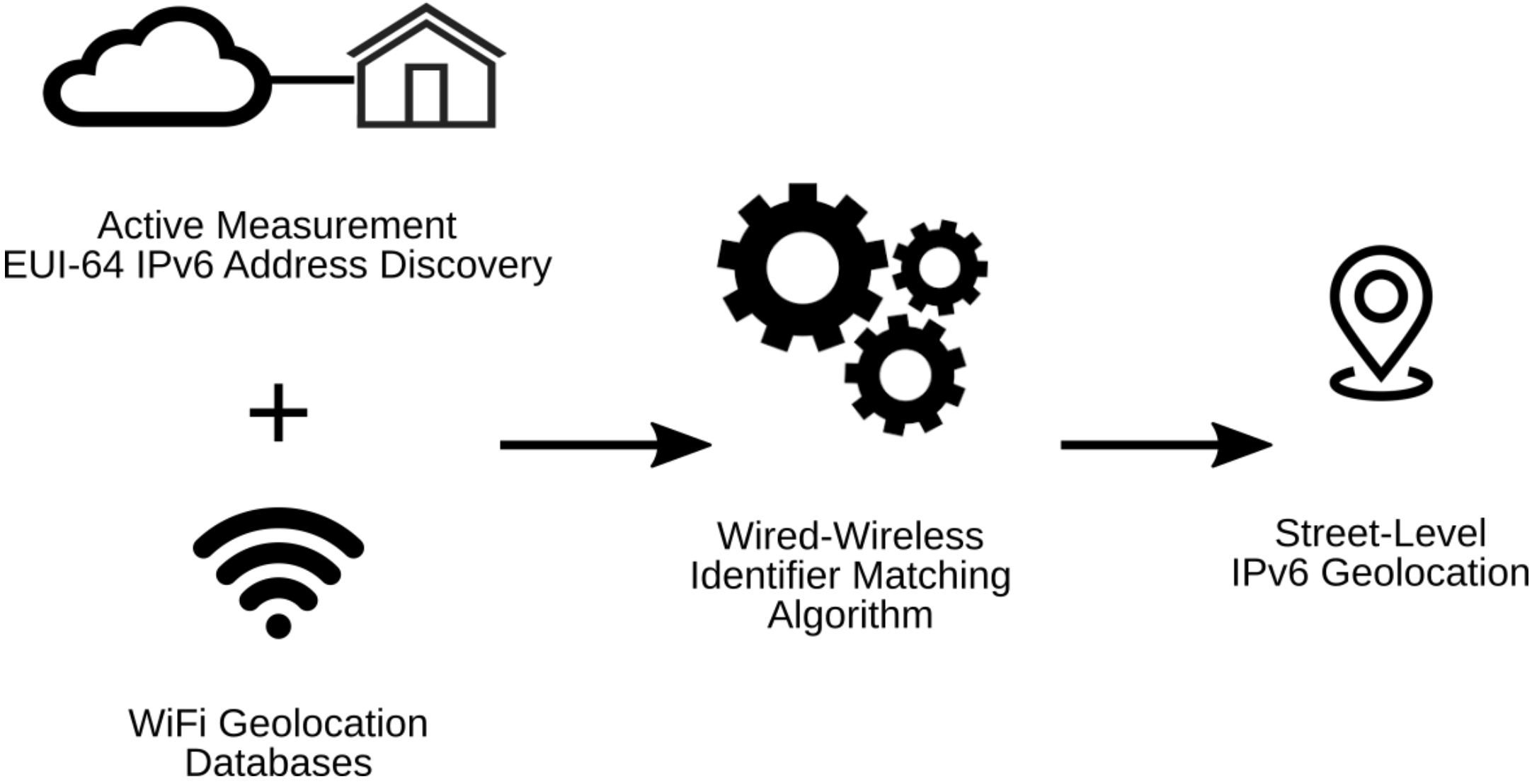

Active Measurement
EUI-64 IPv6 Address Discovery
+
WiFi Geolocation
Databases
Wired-Wireless
Identifier Matching
Algorithm
Street-Level
IPv6 Geolocation

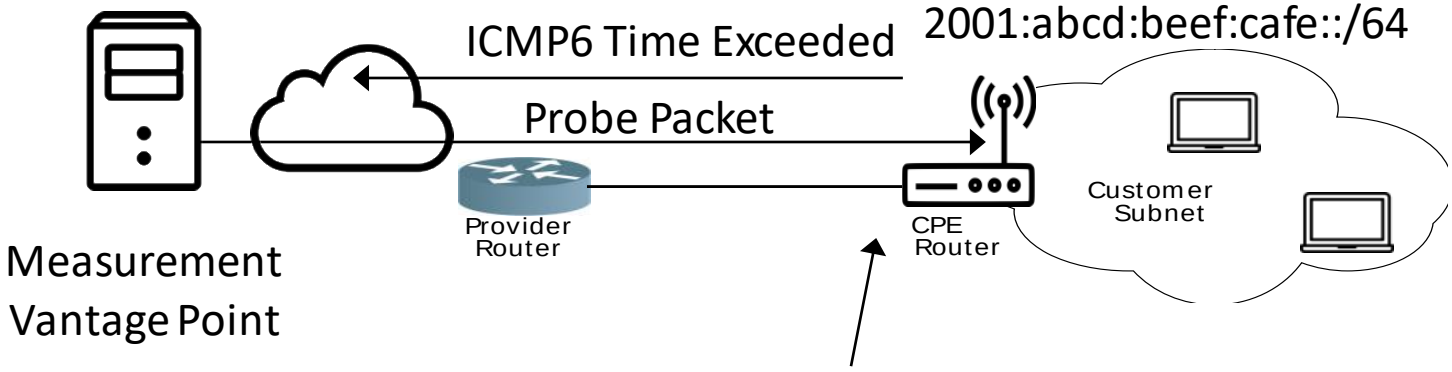
IRB & Ethical Considerations

- This work combines
  - IPv6 addresses w/embedded MAC addresses
  - BSSIDs w/fine-grained geolocation data
  - To geolocate IPv6 addresses
- Consulted with IRB
  - Follow all best practices to minimize any potential for harm
- Publish aggregate data analysis only
- Goal: ultimately *improve* privacy protections by highlighting this vulnerability

EUI-64 Address Discovery at Scale

- IPv6: no NAT, in-home devices publicly addressed
- *Smallest* IPv6 allocation a /64:
  - Traceroute to a *random* target in each /64 in a provider's network
  - (Target unlikely to exist)
  - But, typically elicits an *ICMPv6 Time Exceeded* from CPE, if /64 is allocated to a customer
- Traceroute is slow! use *yarrp*[*]
- Found >60M EUI-64-derived MAC addresses

Active Measurement
EUI-64 IPv6 Address Discovery



[*] https://www.cmand.org/yarrp

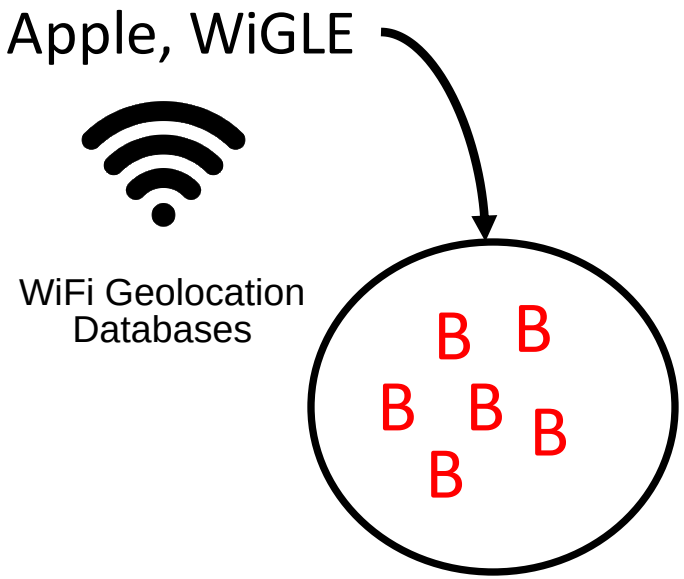
WiFi Geolocation Databases

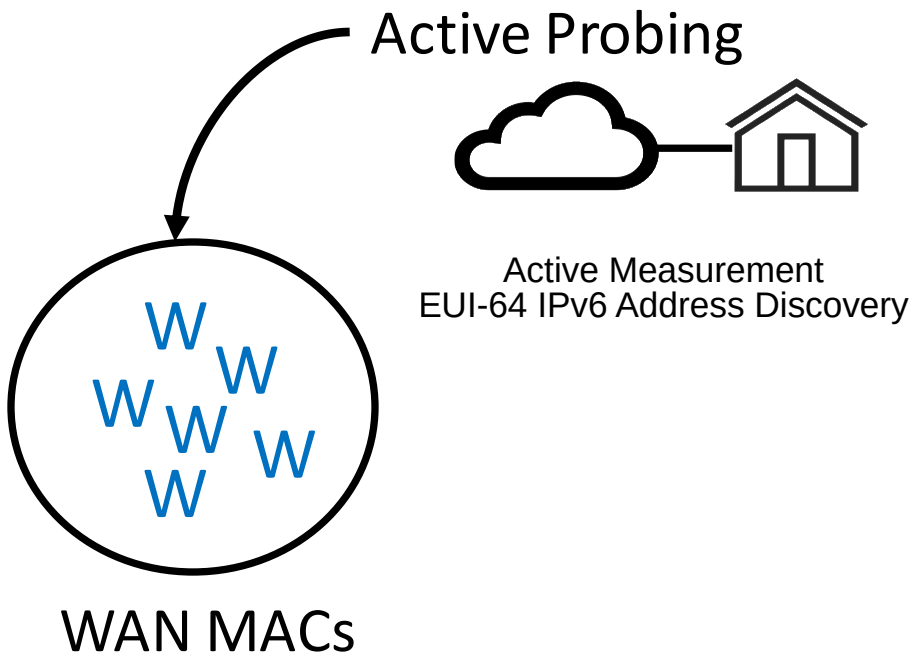
WiFi Geolocation Databases

- BSSID = WiFi interface MAC address
- BSSID geolocations reported by
  - War-drivers
    - wigle.net, mylnikov.net
  - Crowd-sourced network of millions of devices
    - Provides non-GPS geolocation data for other devices in ecosystem
    - Apple Location Services*
    - Google Geolocation API
- Query databases and APIs for BSSIDs in same OUI as EUI-64-derived MAC addresses
- Amass corpus of 450M BSSID geolocations
  - Union of mylnikov.net, openBMap, and openWifi.su databases combined with querying Apple Location Services and WiGLE.net APIs

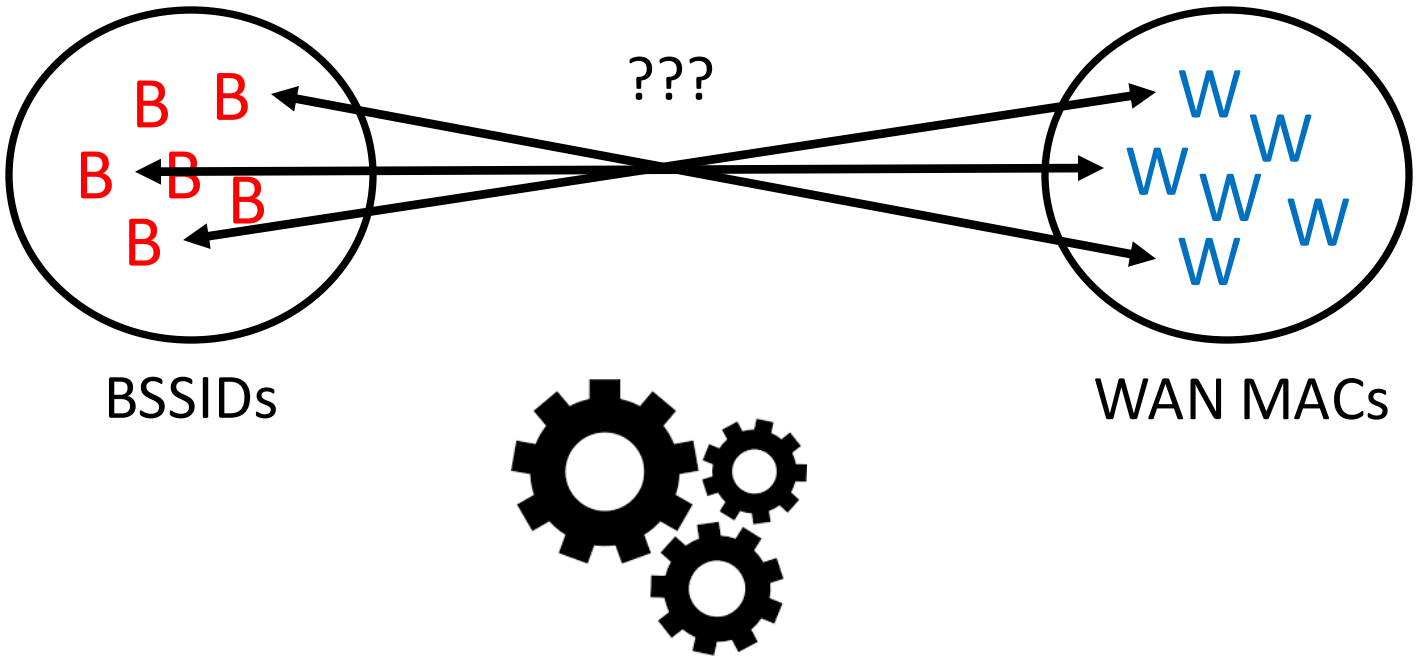
*iSniff-GPS by Hubert Seiwert (BH 2012): https://github.com/hubert3/iSniff-GPS

Mapping WAN MAC to WiFi BSSID



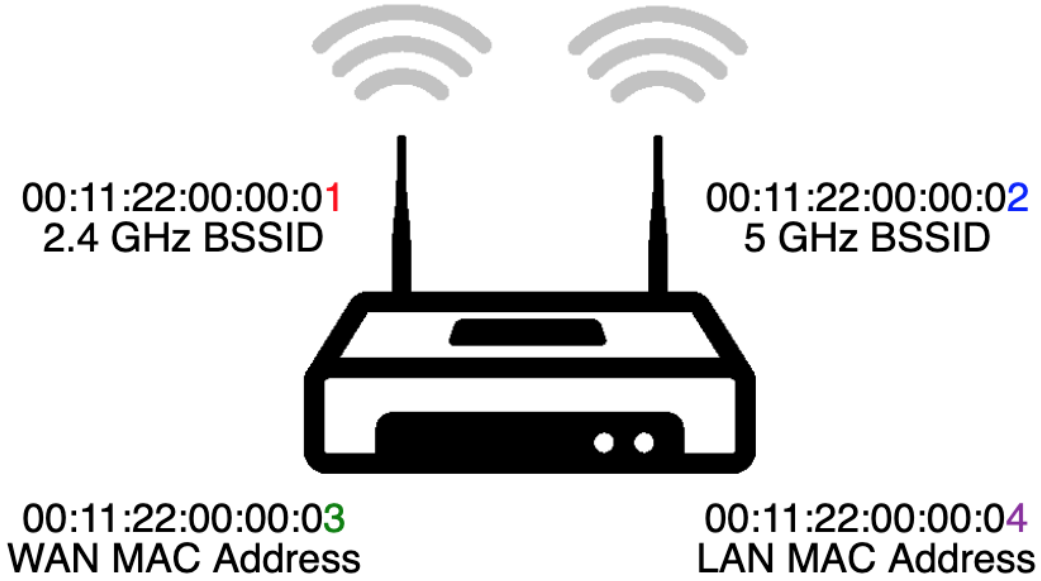


Mapping WAN MAC to WiFi BSSID



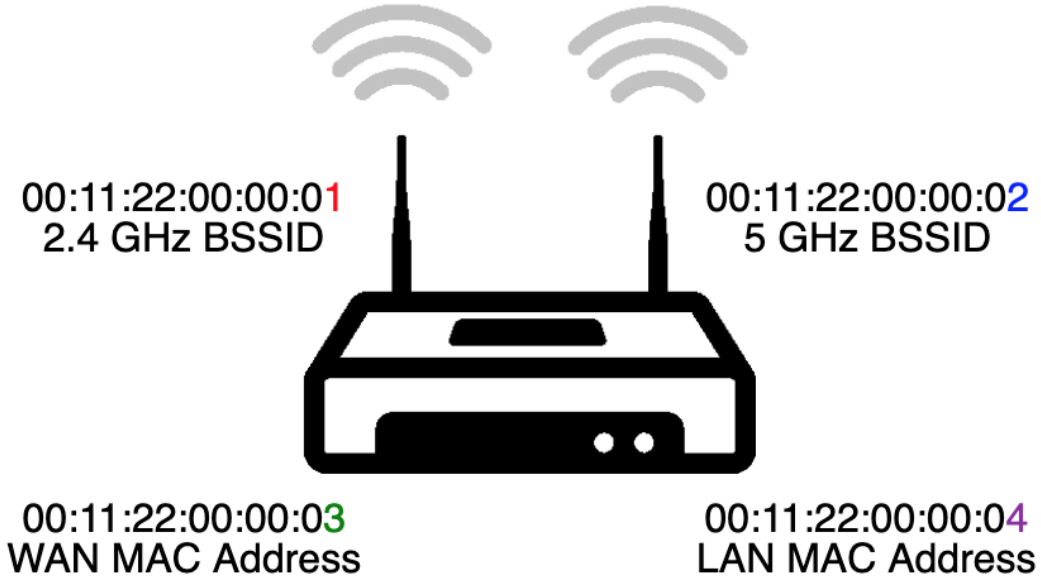
Mapping WAN MAC to WiFi BSSID

- Mental model:
  - Many all-in-one CPE devices, e.g. cable modem with built-in WiFi
  - Many System-on-a-Chip (SoC) designs where all radios made by one company
    - E.g., Broadcom BCM3349
  - Each interface gets its own MAC address
  - These MAC addresses are *related*
    - For example, +/- 1

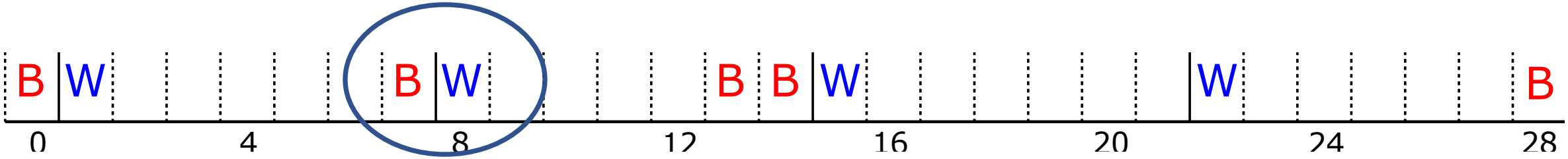


Mapping WAN MAC to WiFi BSSID

- Complications
  - Some devices have many interfaces (WAN, LAN, 2.4GHz, 5GHz, Guest WiFi, Bluetooth, etc)
  - Different devices have different offsets
  - Naïve “nearest” match does not work
- But, in the best case
  - WAN MAC embedded in an EUI-64 IPv6 address: 2001:c001:d00d:0211:22ff:fe00:0003
  - BSSID 00:11:22:00:00:01/2 captured in WiFi geolocation database



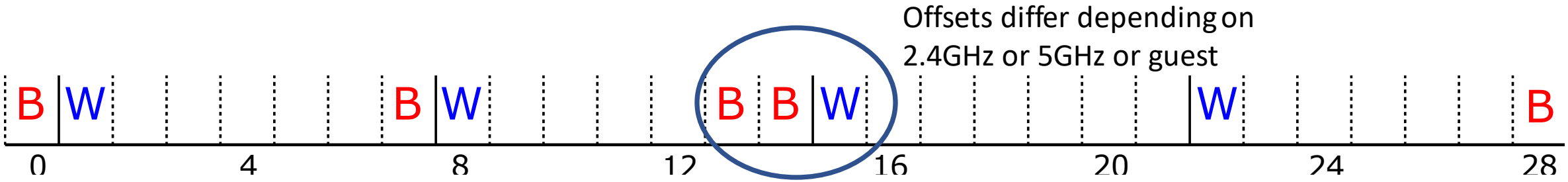
Mapping WAN MAC to WiFi BSSID



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

End result: produce WAN-BSSID offset inference on a per-OUI basis

Mapping WAN MAC to WiFi BSSID



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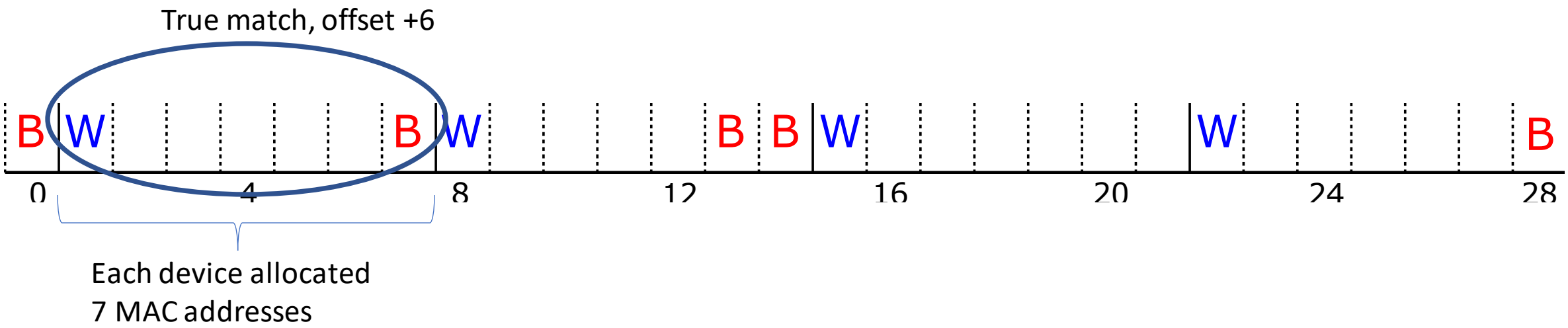


End result: produce WAN-BSSID offset inference on a per-OUI basis

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
    - IoT devices
  - Devices with BSSIDs may not be in wardriving/geolocation databases
    - Restrictions/laws regarding wardriving
- Correlation Limitations
  - MAC addresses assigned to wired and wireless interfaces non-sequential or in different OUI
  - Multiple offsets per OUI
  - 2.4/5 GHz BSSIDs complicate offset inference

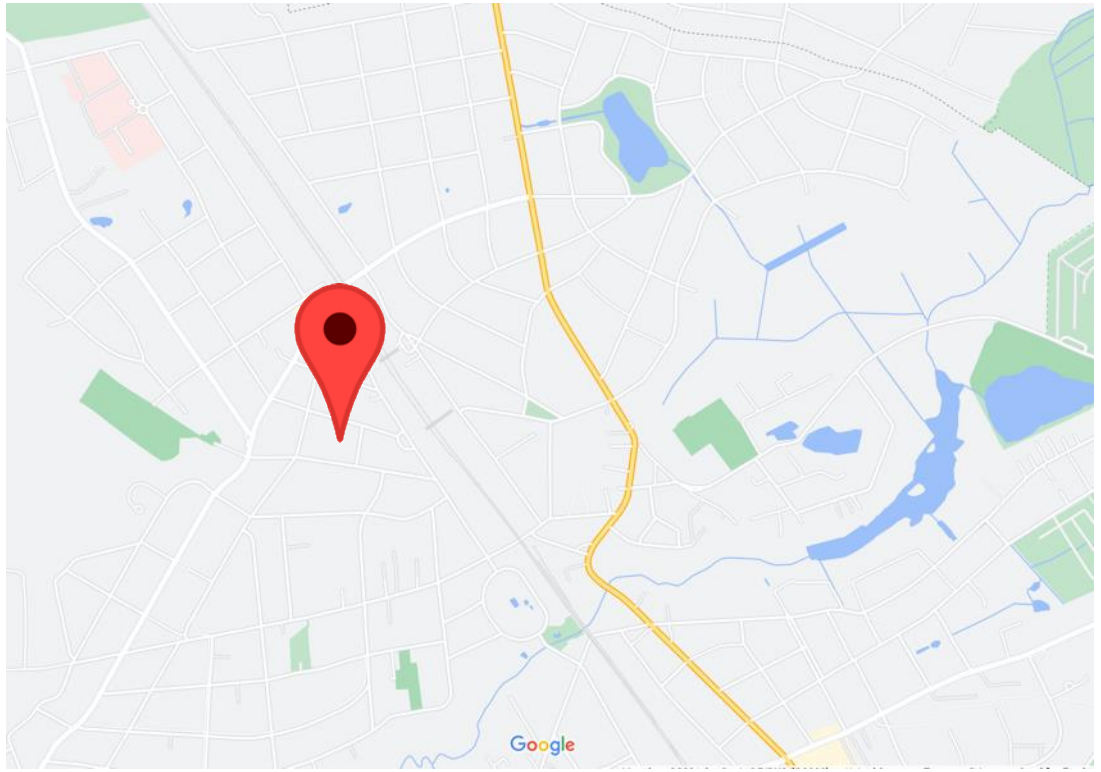
Results

- 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
  - CPE routers typically in homes, businesses
- In this presentation, we examine geolocation results in the aggregate or introduce large error to preserve personal privacy

HARMFUL

Street Level Geo Precision

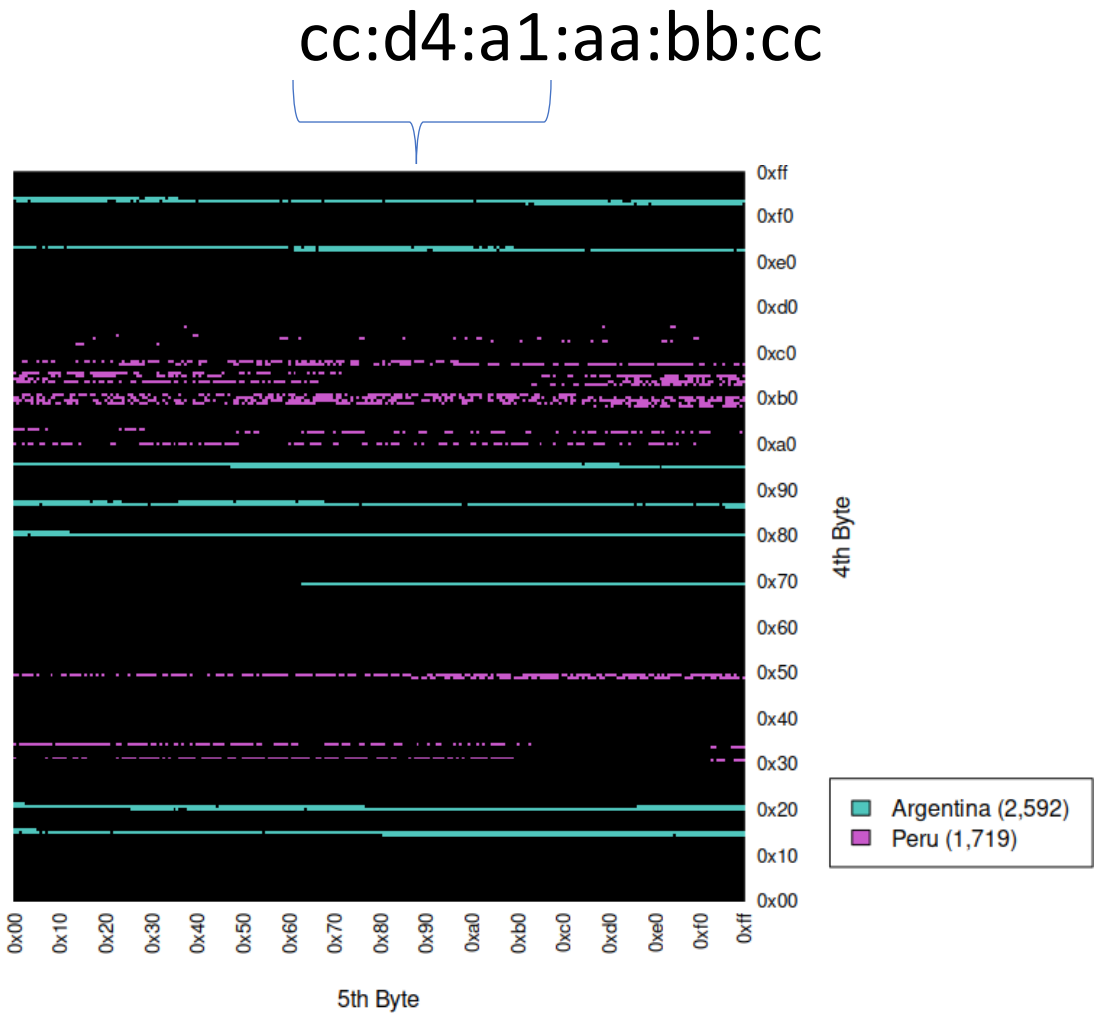
- Solicited volunteers with CPE using EUI-64 IPv6 addresses
  - They divulged internal subnet
    - eg 2003:ab::/56
  - We traceroute to random address in internal network
  - Obtain WAN EUI-64 IPv6 address
  - Use IPvSeeYou to infer BSSID and geolocate IP address
- 4 of 5 volunteer devices geolocated
  - < 50m geolocation accuracy
  - 5th device used EUI-64 IPv6 addressing but non-sequential WAN/BSSID MACs



Volunteer's geolocated device
(substantial error introduced in figure)

Results – OUI Allocations

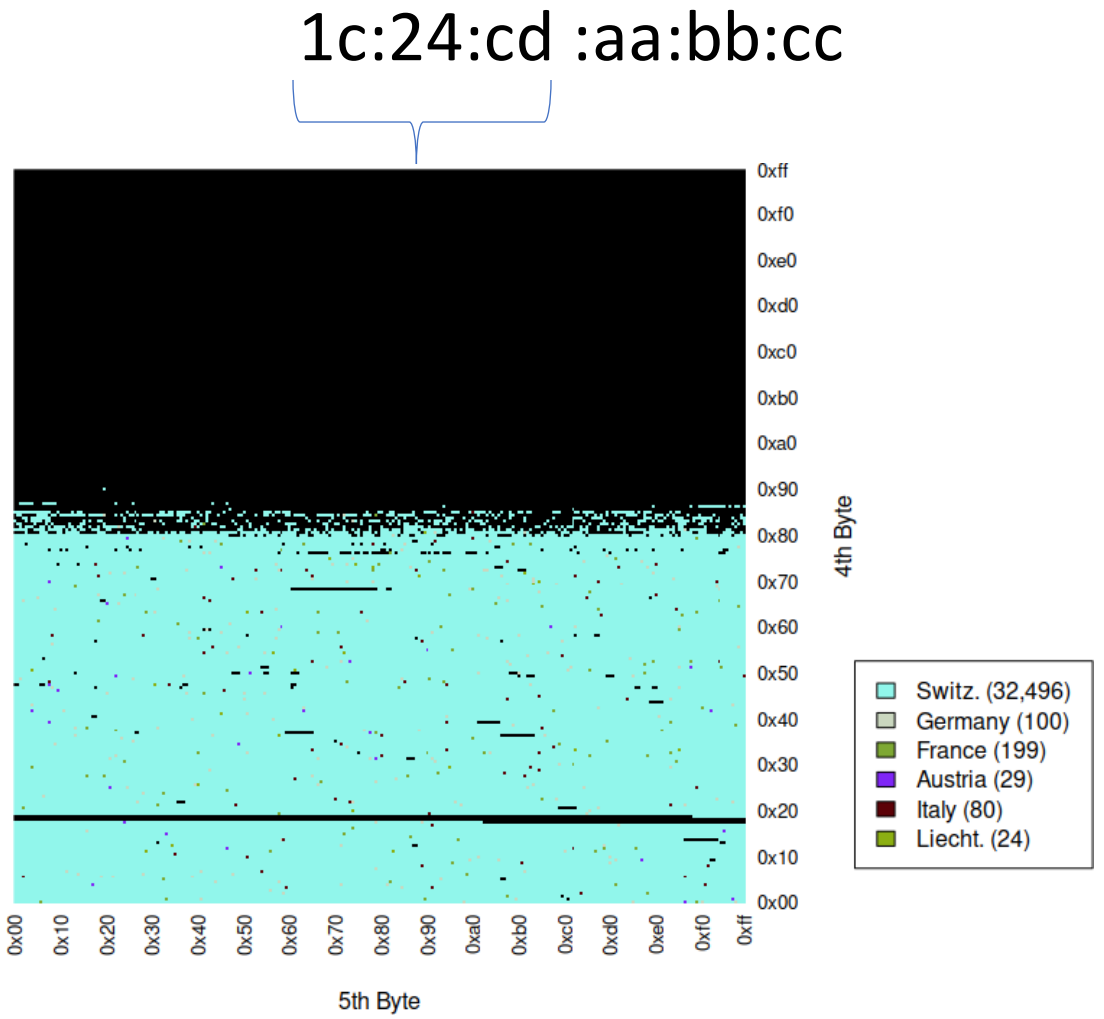
- Manufacturers frequently divide MAC address space by model*
- IPvSeeYou shows this results in geographic divisions, too
- MitraStar OUI shows clear bands of devices geolocated to Argentina and Peru



*Decomposition of MAC Address Structure for Granular Device Inference – Martin, Rye & Beverly, ACSAC 2016

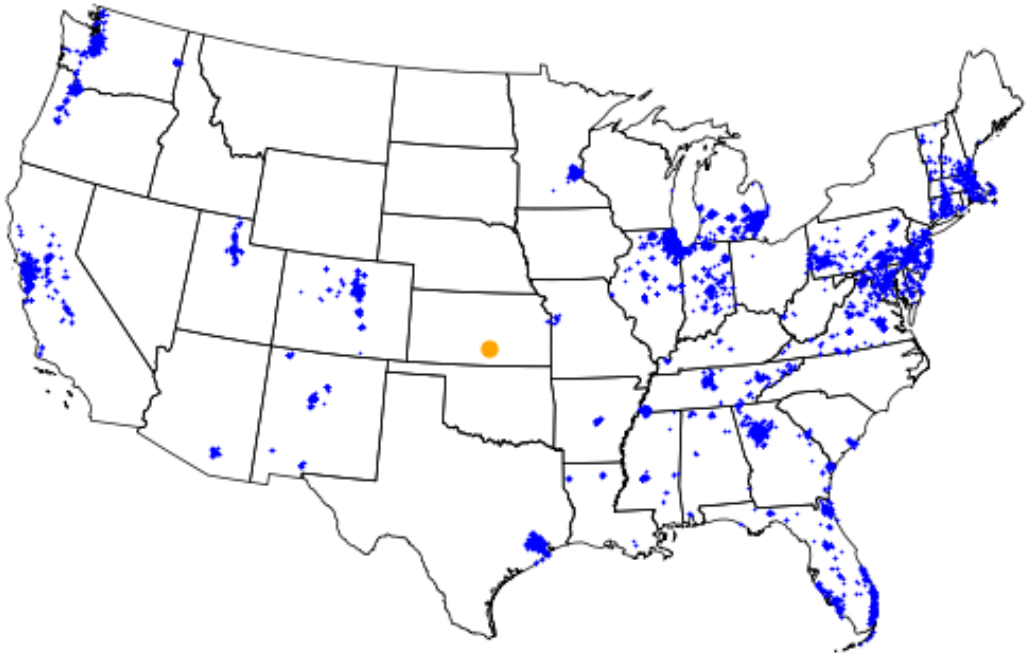
Results – OUI Allocations

- Other OUIs show consistent country geolocations
  - Minor regional variations oftentimes exist
- Askey Corp OUI shows vast majority of geolocations in Switzerland
- Swisscom, a major Swiss ISP, provides Askey routers as its standard home WLAN device



Results – Comparison vs IP Geo DBs

- Can infer an ISP's coverage area
- Blue
  - >1M geolocated Xfinity routers
- Orange
  - Maxmind's GeoLite database geolocation for ***all*** 1M IP addresses
- Far surpasses IP geolocation database performance
- IPvSeeYou geolocation matches FCC coverage map, validating methodology



Inferred Comcast Xfinity service map in contiguous US

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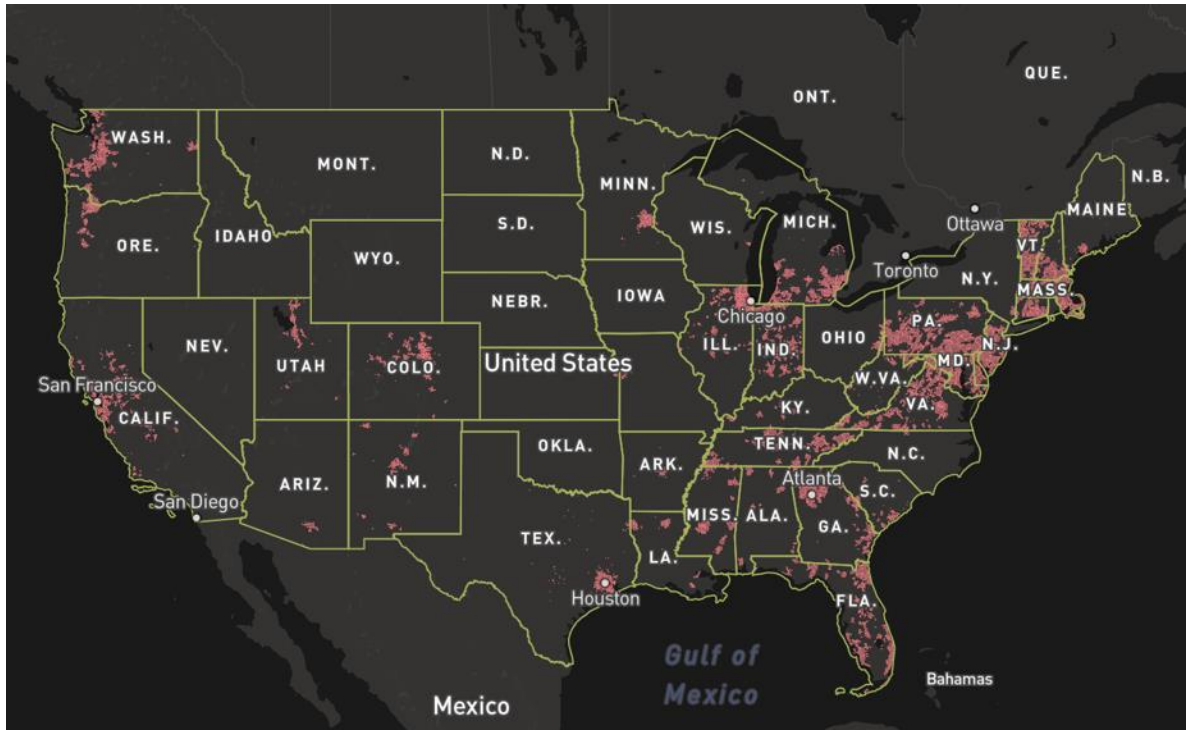
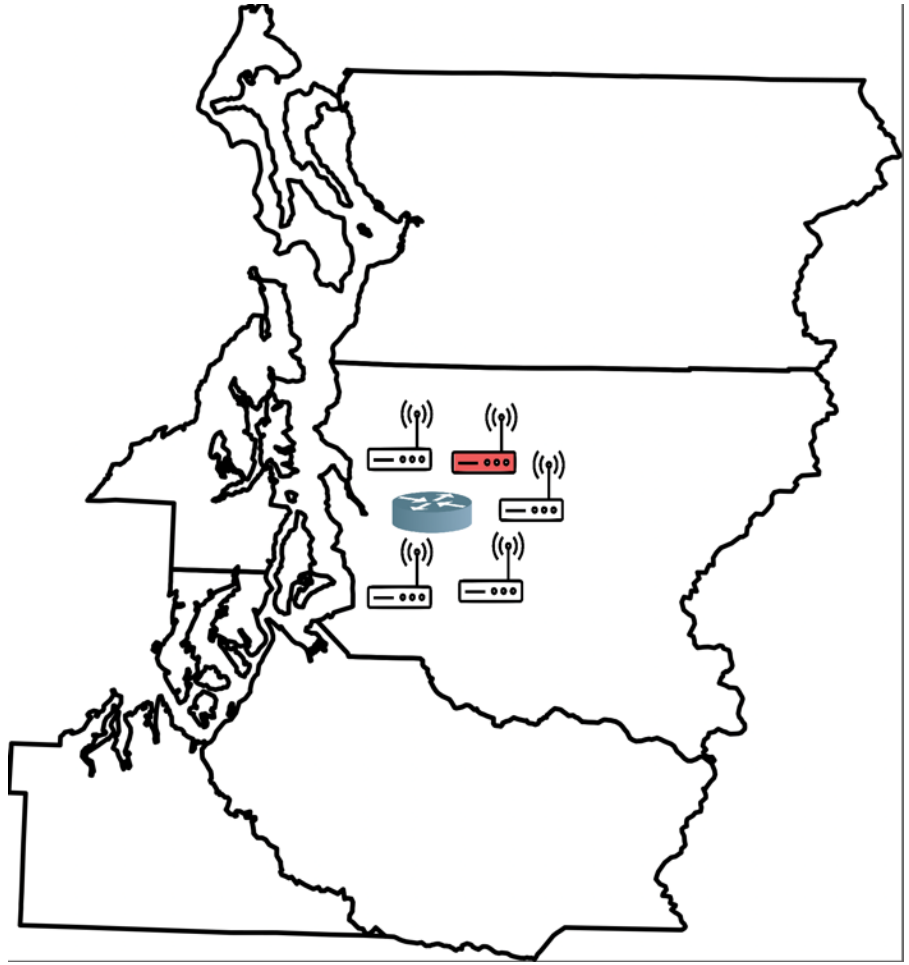


FCC 2020 Comcast Coverage Map
https://broadbandmap.fcc.gov/#/provider-detail

Results – Geolocation by Association

- Assume IPv6 periphery (link from provider to customer router) has physical distance constraint
- If we can geolocate EUI-64 CPE attached to provider router
  - We can geolocate that provider router
  - We can geolocate *non-EUI-64* CPE attached to that same router!



Results – Geolocation by Association

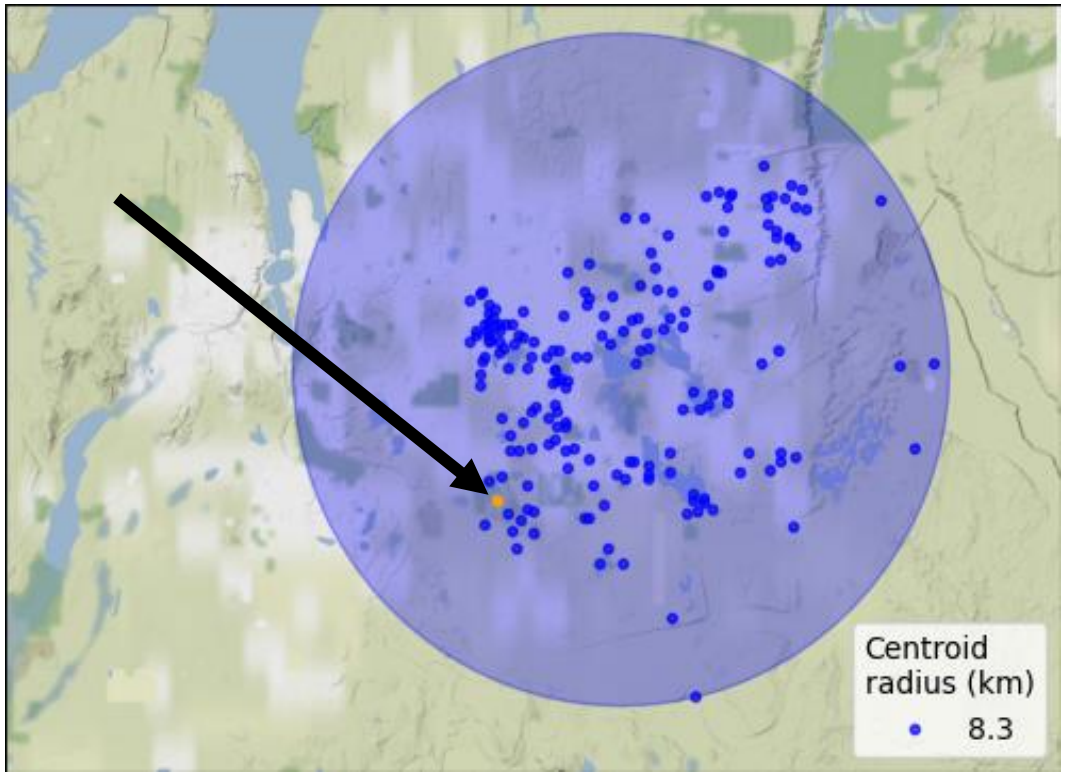
- Recall, using yarrp high-speed IPv6 traceroute
- Penultimate hop is the provider's infrastructure, e.g., cable head-end
- Group geolocated EUI-64 IPv6 addresses by penultimate hop

```
…
18 2001:558:3:25c::2   74.284 ms
19 2001:558:80:1b1::2   71.886 ms
20 2001:558:82:380d::2   72.287 ms
21 2001:558:6045:6:98cf:88bc:79ca:c366   90.986
22 2601:642:c300:963:0211:22ff:fe33:4455  82.029
```

Intuition: last-mile connection between provider and customer (e.g., cable head-end) is relatively short. Geolocation of CPE thus can reveal geolocation of provider infrastructure and non-EUI-64 CPE!

Results – Geolocation by Association

- First, geolocate all EUI-64 CPE(blue dots) connected to same last hop as a target *non-EUI-64 CPE* (unknown location)
- Next, find centroid & EUI-64-encompassing centroid radius (large blue circle)
- Non-EUI-64 CPE inferred to within encompassing circle (orange dot known ground truth)
- Simply living near EUI-64 CPE routers is a location privacy threat



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IPvSeeYou Tool

1. Input WAN MAC or EUI-64 IPv6 address
2. Calculates predicted BSSID value using our inferred WAN MAC – BSSID offsets
3. Queries Apple, wigle.net, or mylnikov.net for predicted BSSID value
4. Optionally outputs KML for geolocated BSSIDs

IPvSeeYou Demo

Disclosure and Remediation

- Ideal remediation: stop using EUI-64 IPv6 addresses
- Disclosed vulnerability to multiple vendors
  - Devices account for millions of geolocated CPE
- Mixed results

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Conclusions

- IPvSeeYou
  - Large scale data fusion attack
  - Combines:
    - EUI-64 IPv6 Addresses
    - Geolocated BSSIDs
  - To geolocate
    - Millions of CPE routers
    - Provider infrastructure
    - Non-EUI-64 CPE devices
- Easy to prevent (don’t use EUI-64 IPv6 addresses), but:
  - Embedded / forgotten infrastructure that doesn’t get updated
    - Often *can’t* be updated
  - Even a single EUI-64 router can compromise privacy of non-EUI-64 devices

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Thanks!

6::int

- IPvSeeYou
  - Large scale data fusion attack
  - To geolocate millions of CPE routers
- Seeking volunteers to test / validate tool; contact us!
- info@sixint.io
- EUI-64 IPv6 Geolocation Tool
  - https://github.com/6int/IPvSeeYou

Questions?