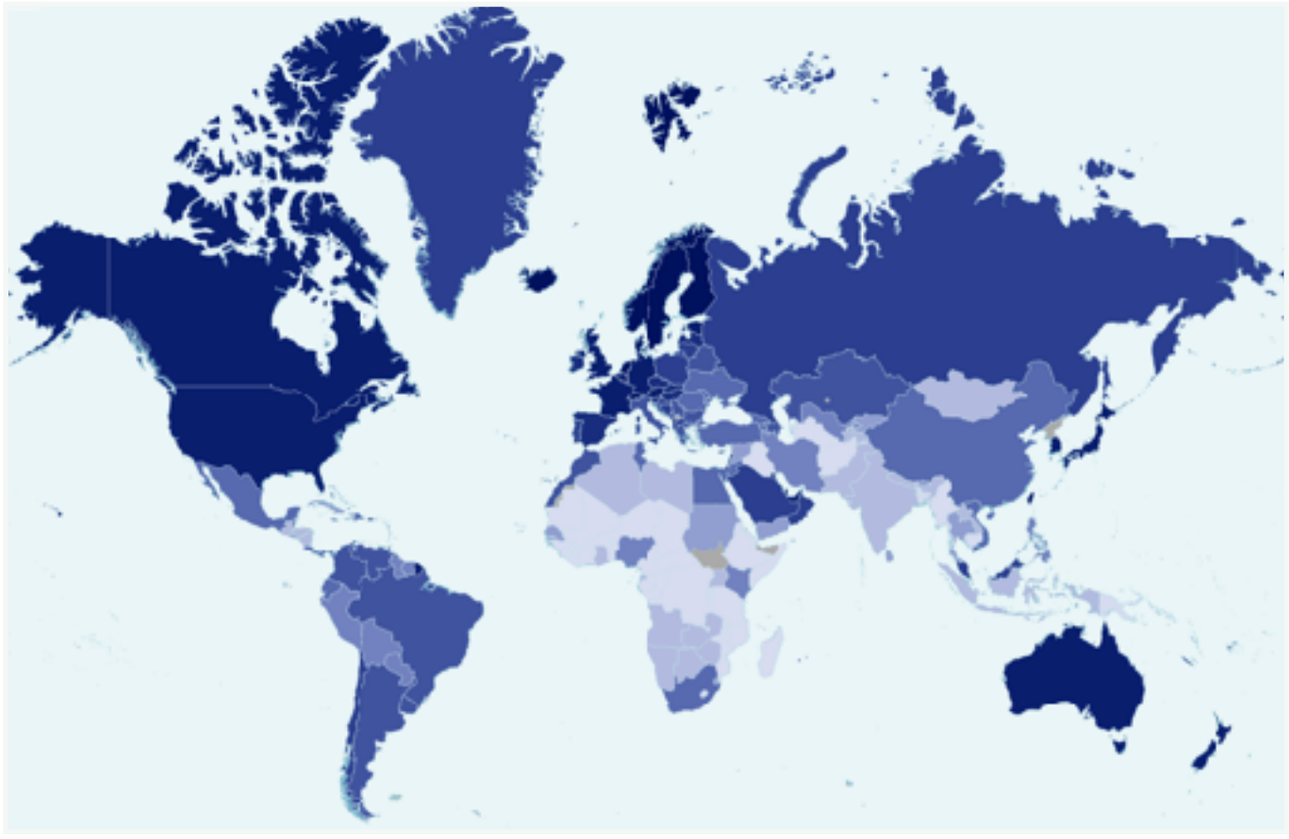
Empirical Analysis of the Effects and the Mitigation of IPv4 Address Exhaustion

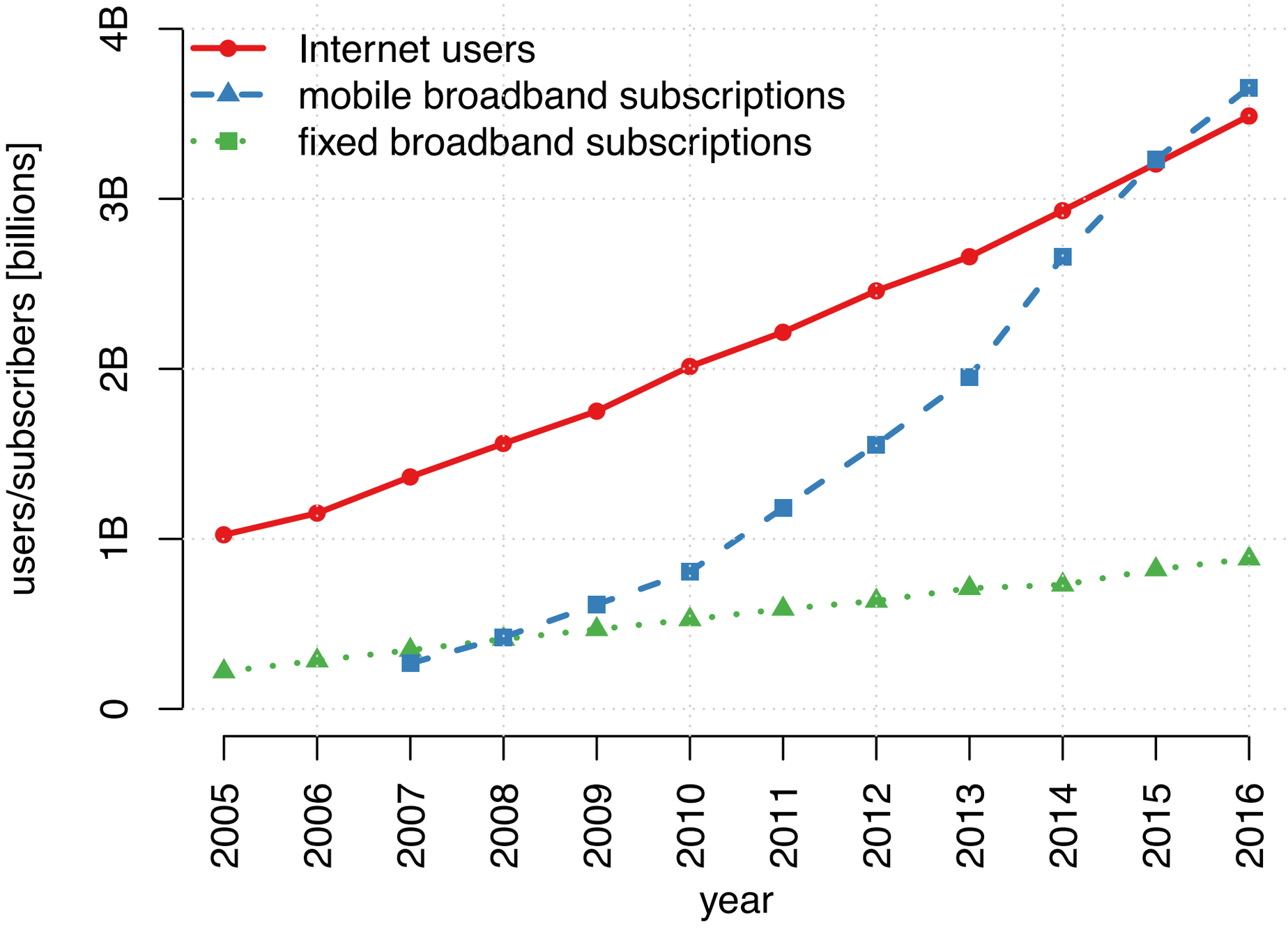
wissenschaftliche Aussprache
2. August 2017

Philipp Richter

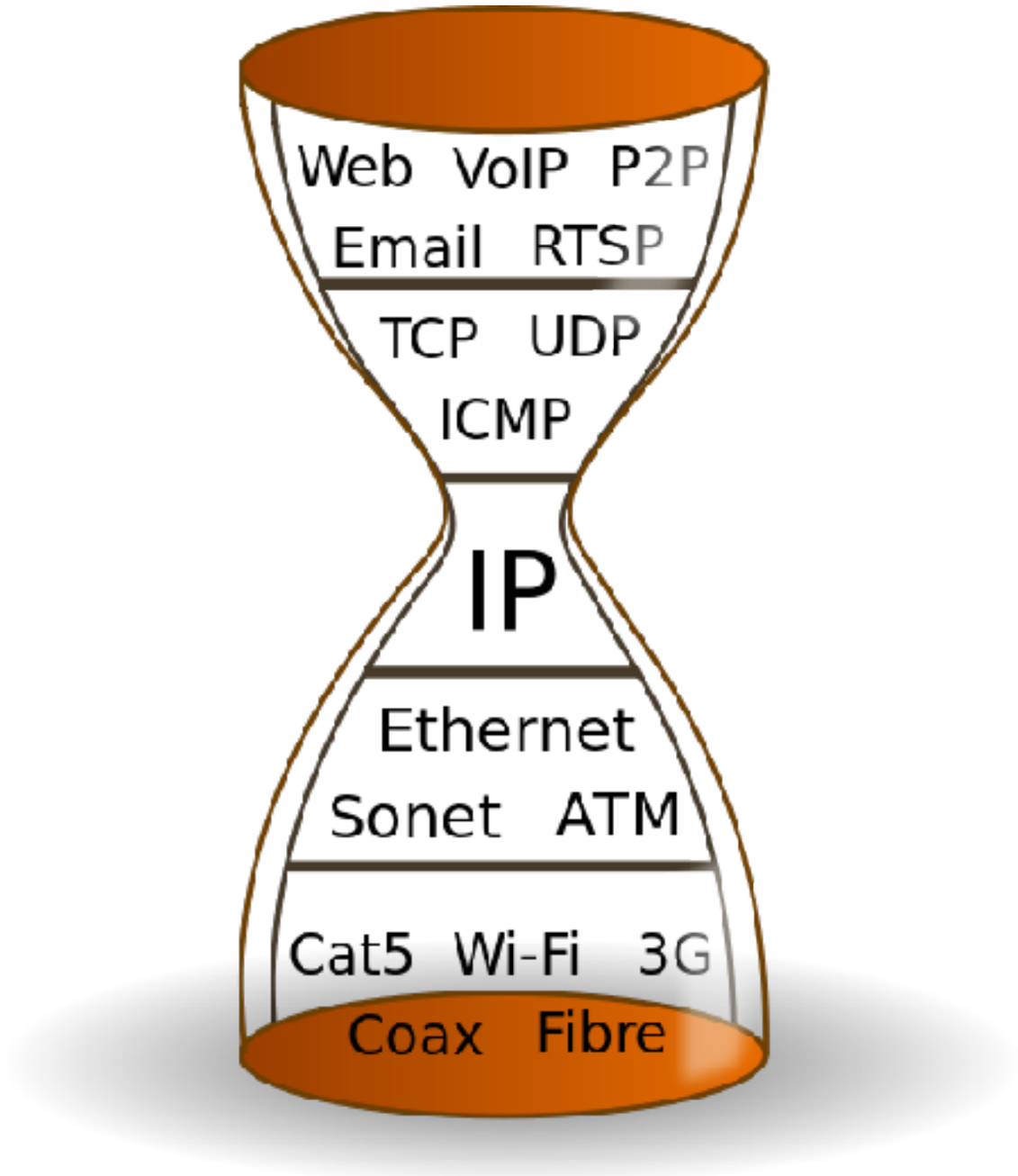


Internet Penetration, 2017, ISOC.

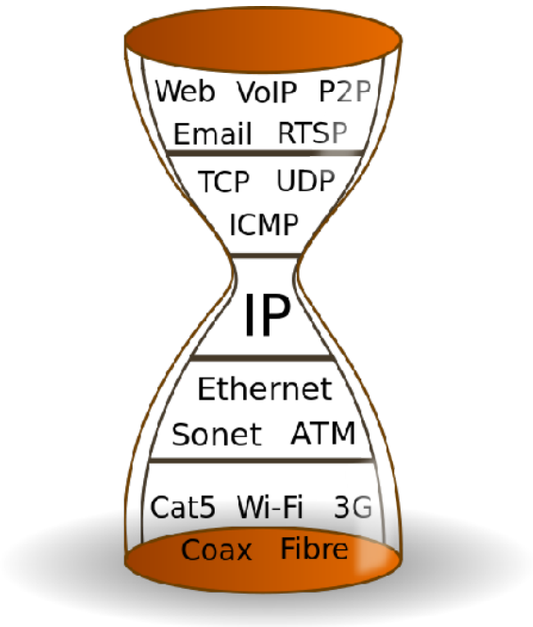
The Internet connects 3.5 billion people as of 2016. (48% of world population)


Internet users
mobile broadband subscriptions
fixed broadband subscriptions
users/subscribers [billions]
0
1B
2B
3B
4B
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
year

The Internet Protocol Suite



The Narrow Waist of the Protocol Stack



- Original design: One IP address per host
- **IPv4:** 32-bit addresses, est. 1981
  - ~ 4B unique IPv4 addresses
- Today: 3.5B users, ~7B connected devices.

IPv4 Address Exhaustion

IPv4 Exhaustion received a lot of attention.
But little in terms systematic empirical assessment.

Systematic Framing of IPv4 Address Exhaustion

ACM CCR '15 (Best of CCR)

Systematic Framing of IPv4 Address Exhaustion

ACM CCR '15 (Best of CCR)

- IPv4 addresses need to be globally unique
- We need a management body that distributes them

A History of IPv4 Address Block Management

1981	~1995	~2011
Early Registration	**Needs-Based Provision**	**Depletion & Exhaustion**
• Informal Distribution • Scarcity minor issue • Non-commercial Internet	• Distribution process • Justification of need • ISPs don't pay for IPs	• 4 out of 5 RIRs depleted • Address Markets • Transfer Policies

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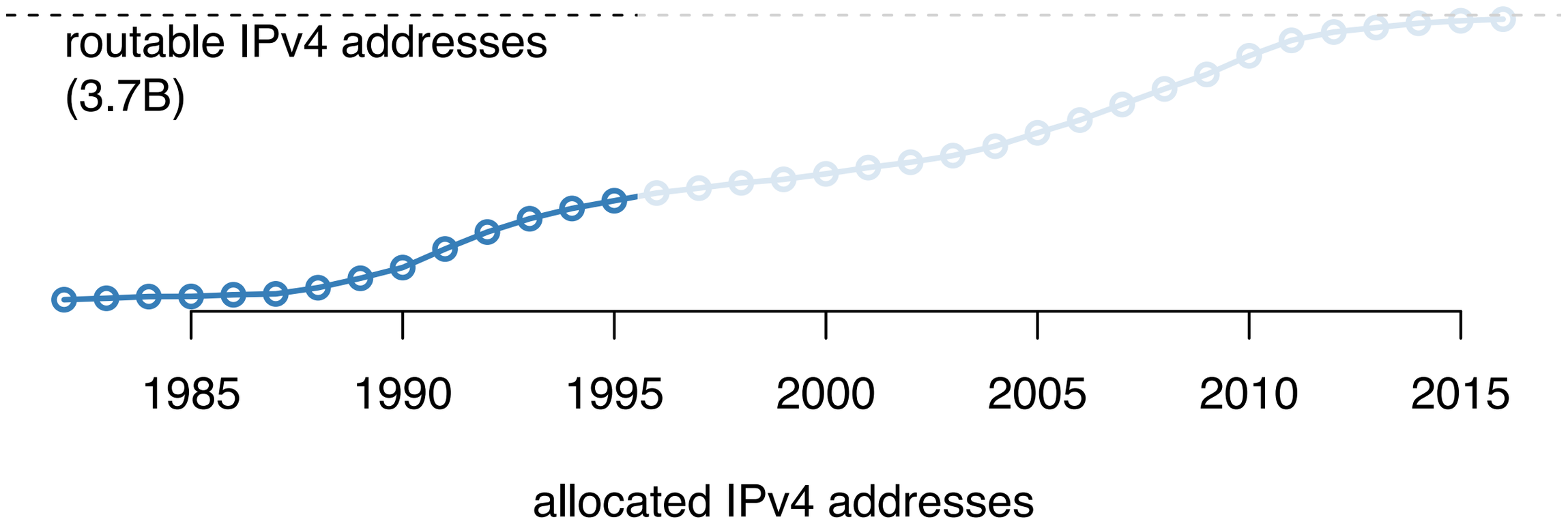

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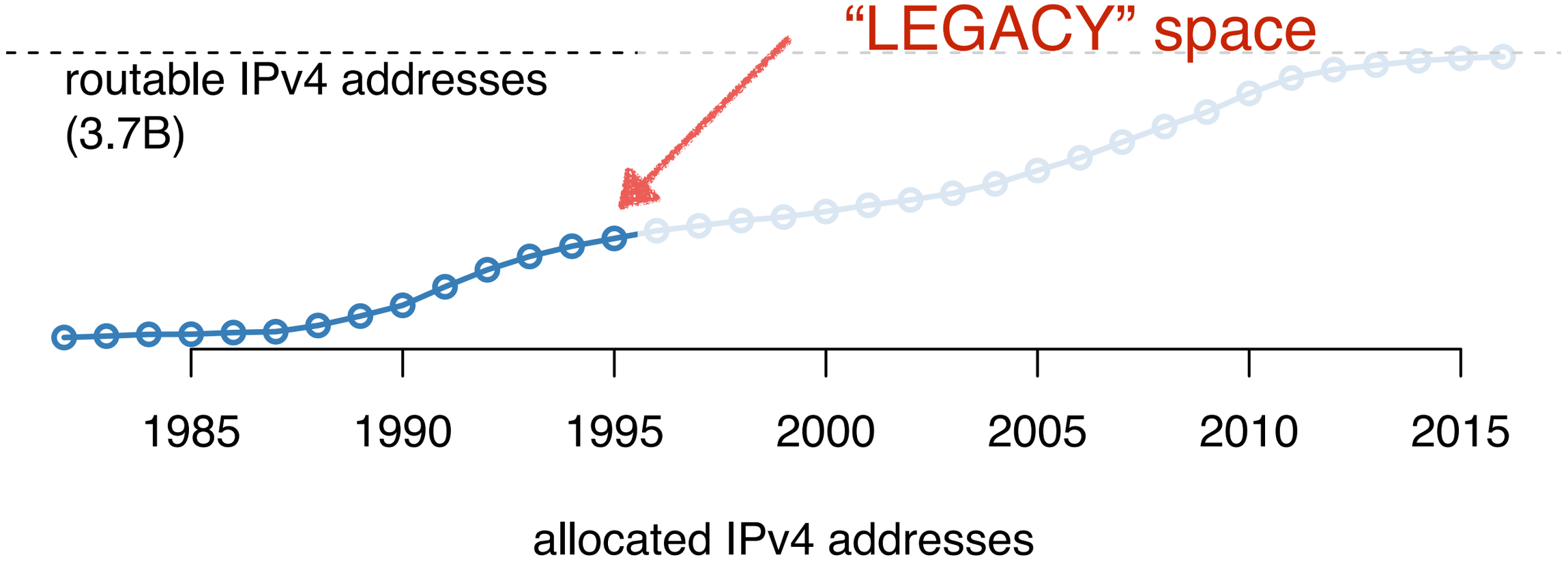
40% of the space given out by ~1995



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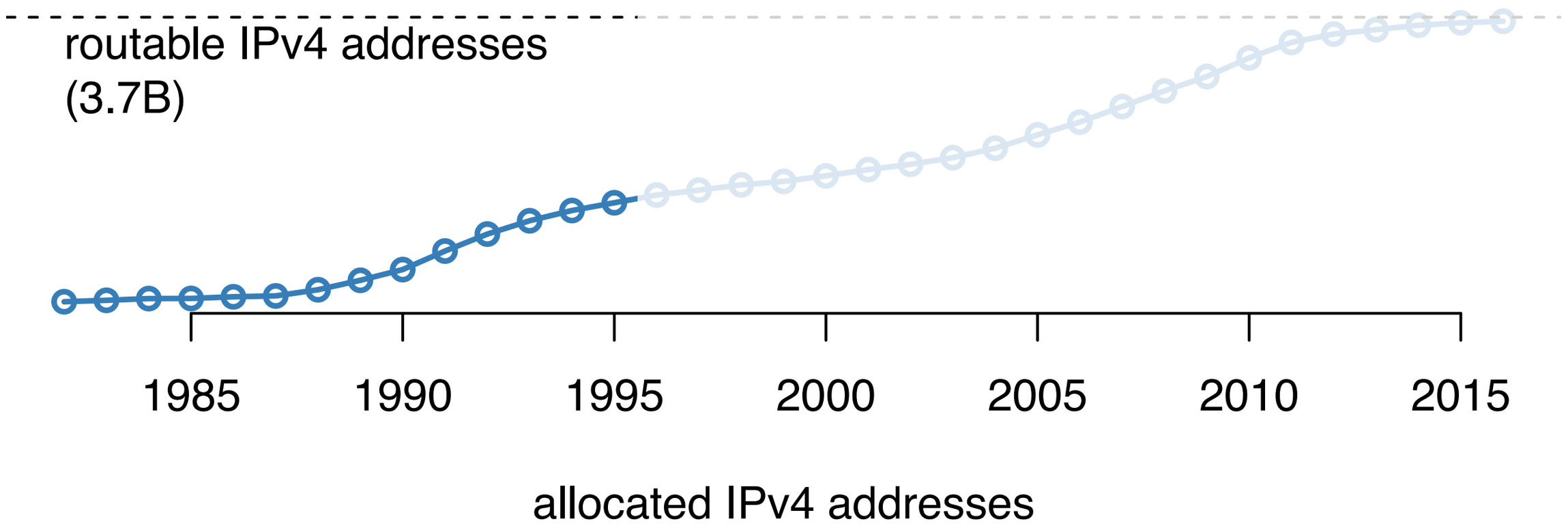

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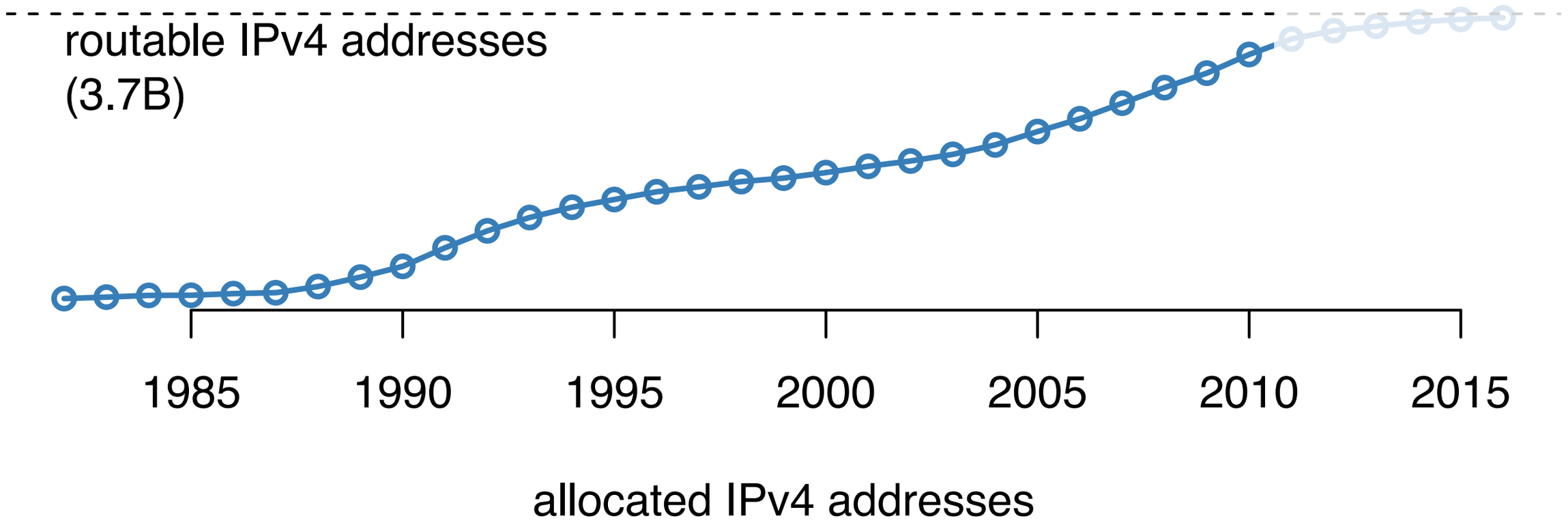

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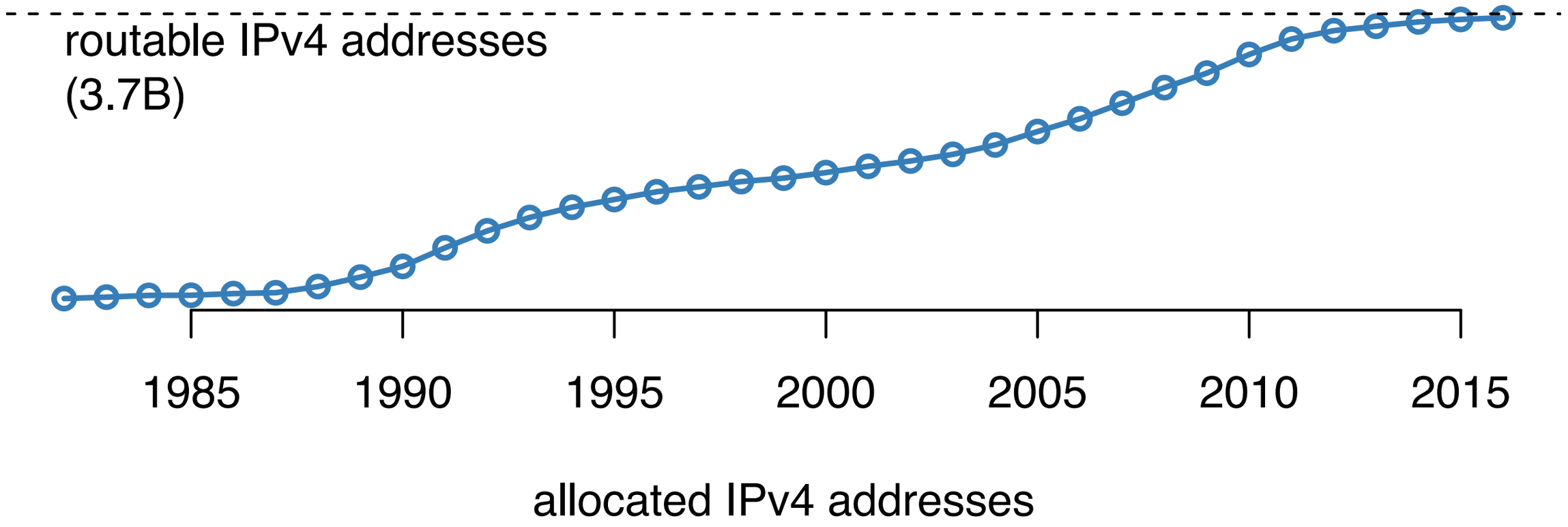

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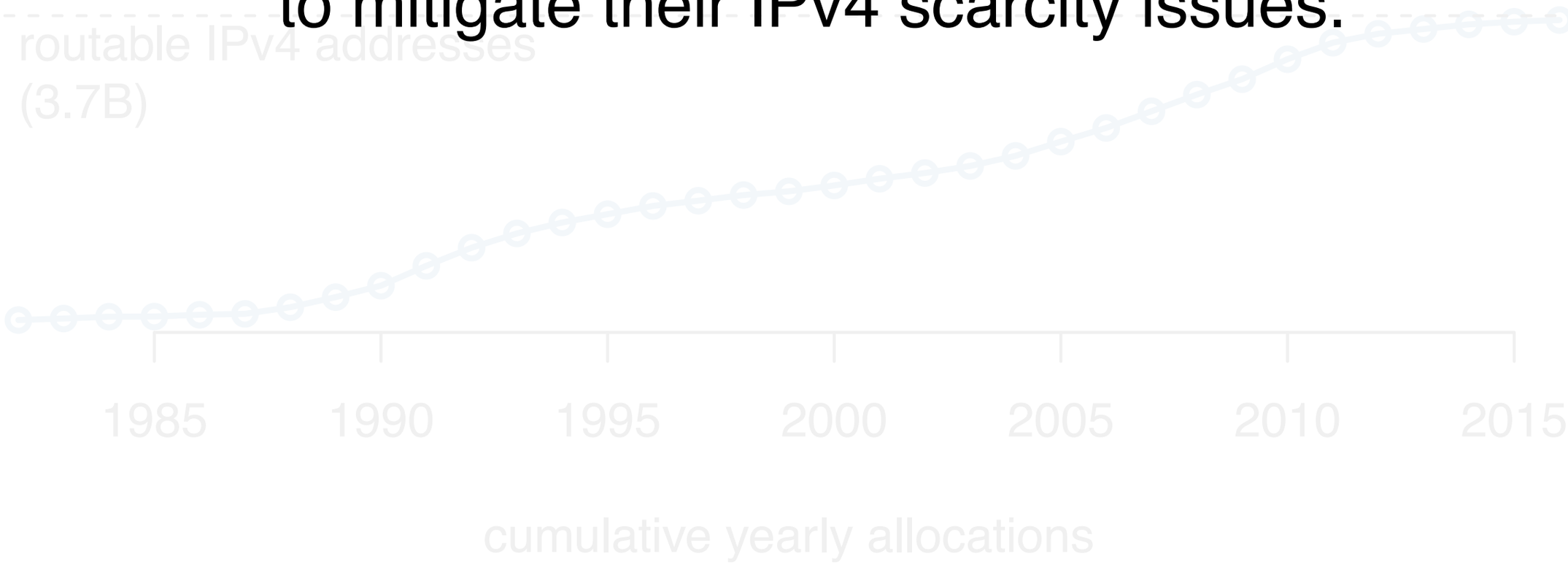
Network operators around the world need to find ways to mitigate their IPv4 scarcity issues.



Systematic Framing of IPv4 Exhaustion

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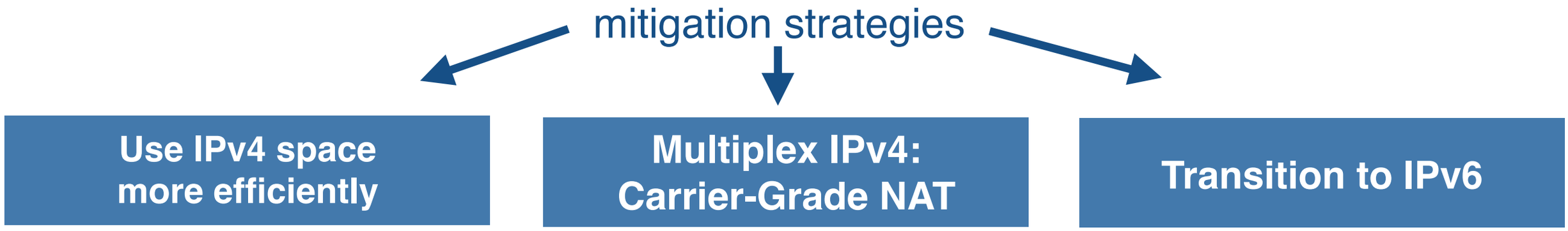

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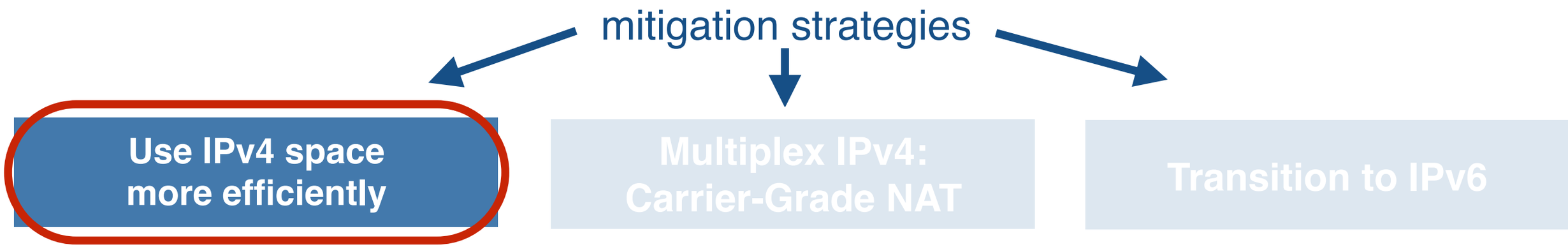

Strategy (i): Use IPv4 space more efficiently

Hypothesis

- IPv4 space not fully utilized
- Underutilized space could be freed up and used/transferred

Research Questions

- What is the potential for utilization increase?
- Which knobs could be adjusted here?

Degrees of Address Use

Allocation

registered to a network?

~99%

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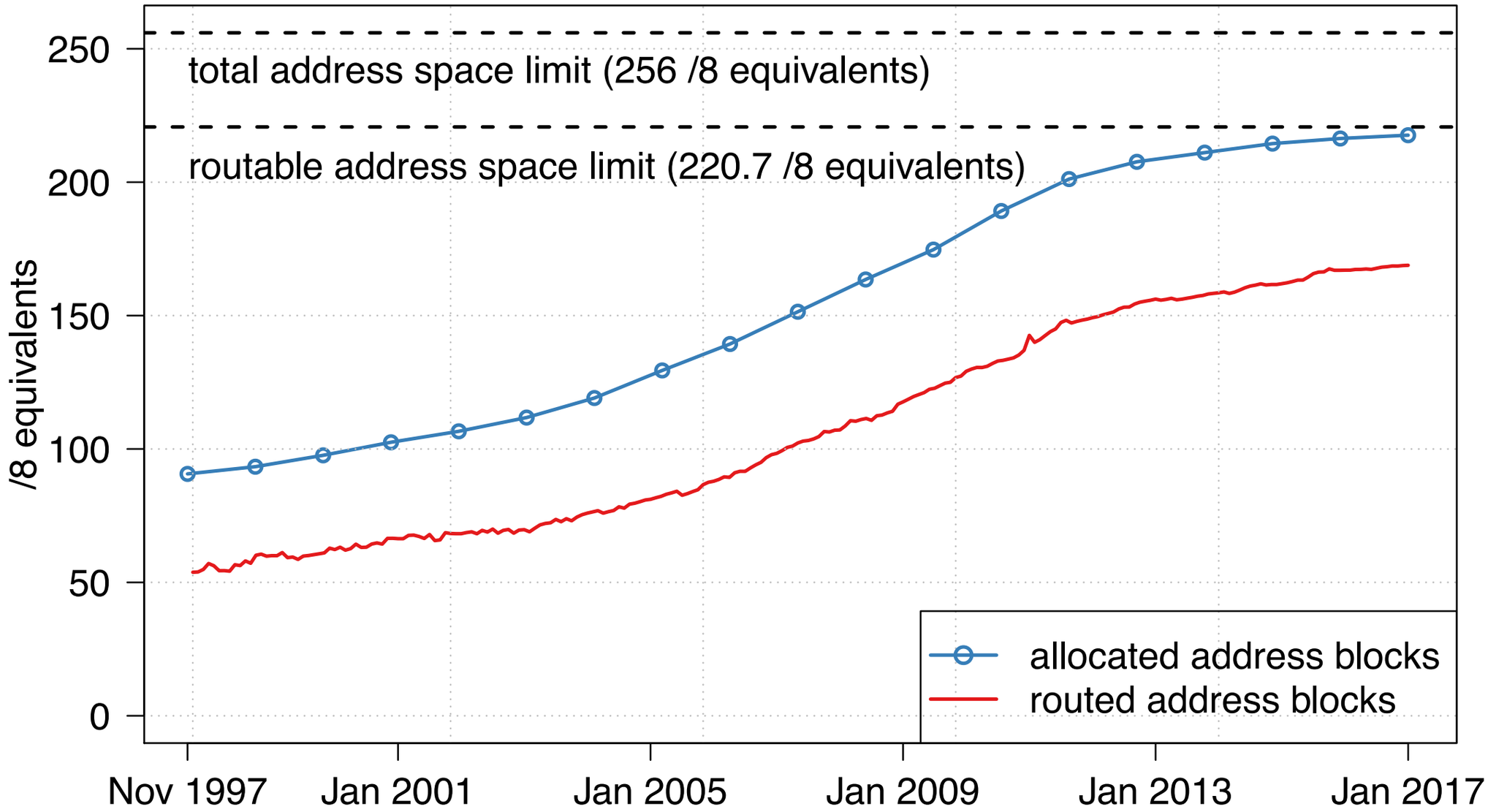
Routing

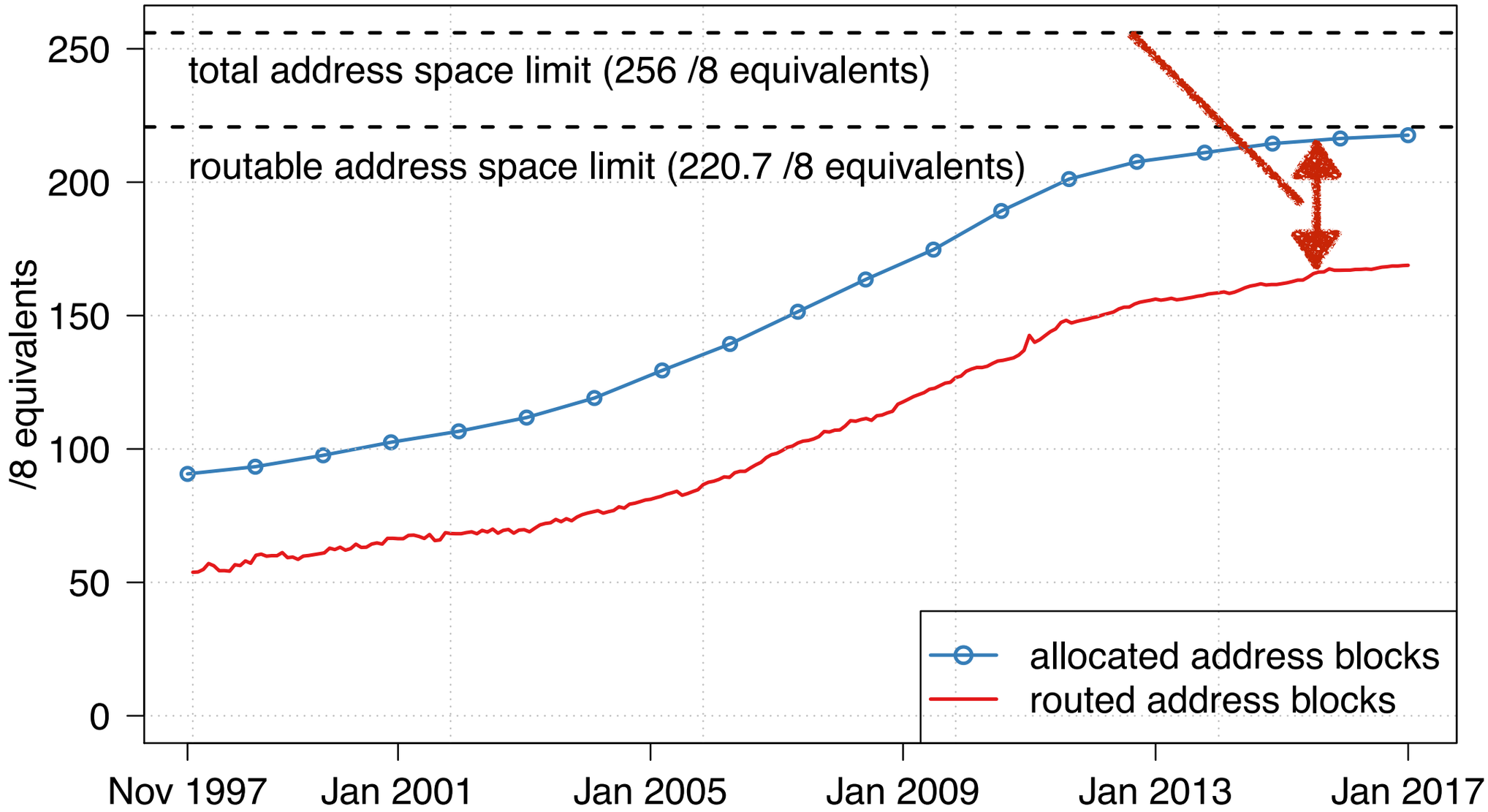
advertised in the global routing table?

IPv4 Address Activity: Global Routing Table



IPv4 Address Activity: Global Routing Table

Mostly LEGACY (pre-1995) allocations



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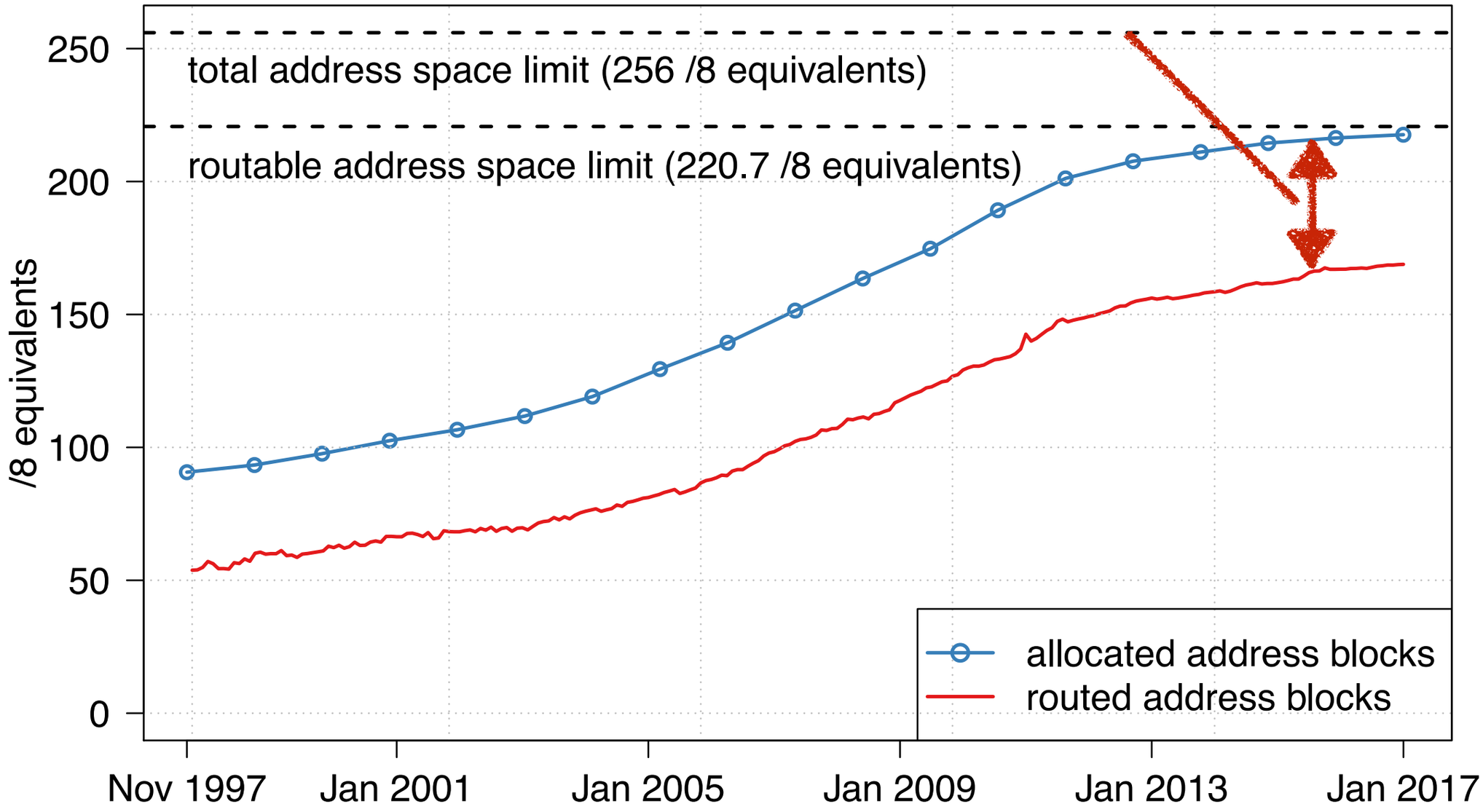

Impact of Internet Governance!

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~75%

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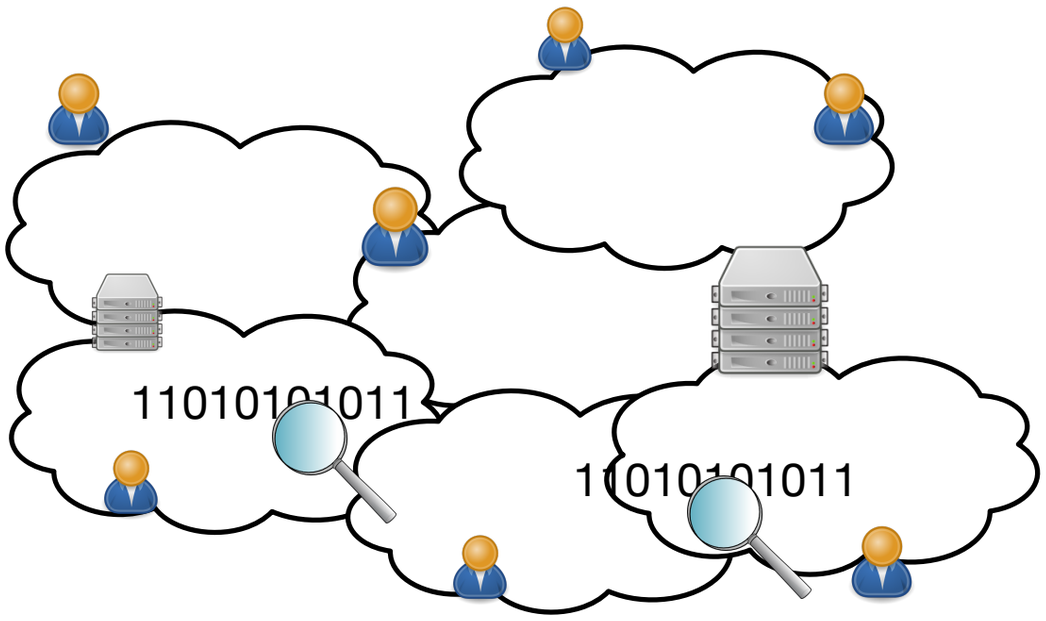
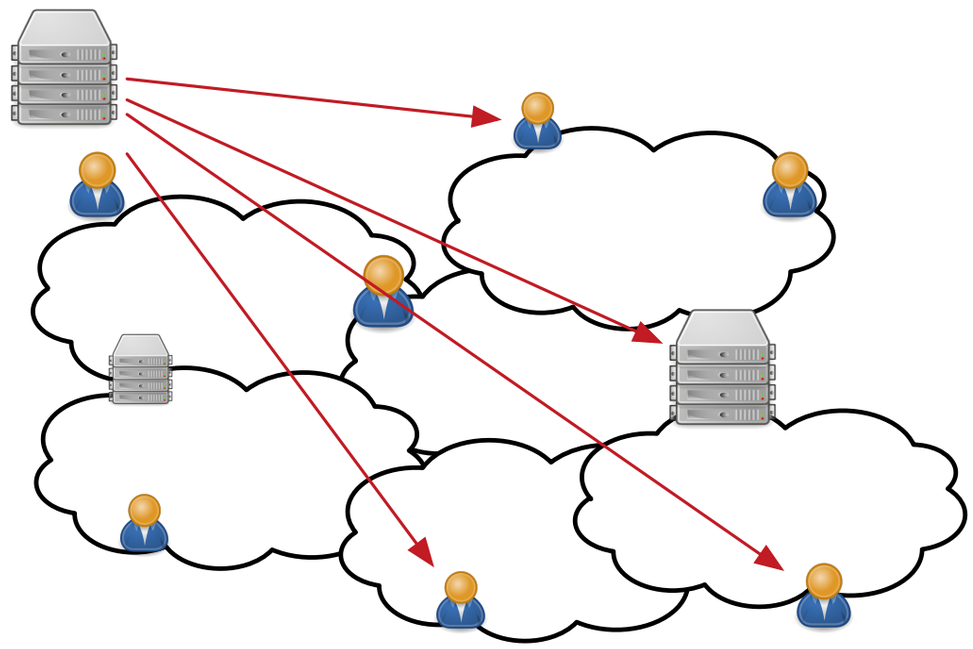
Activity
actively used?

Measuring IPv4 Activity

Passive Measurements



Active Measurements



"How many IPv4 address blocks show activity?"

IPv4 Activity - Counting Active Addresses

Our preliminary study

- 4 passive vantage points **33%** (4.8M /24s)
- 3 active scanning campaigns **31%** (4.5M /24s)

total active: **36%** (5.3M /24s)

Overlap, but each vantage point has unique contribution

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Related Work (Zander et al.)

- 7 passive vantage points & 2 active campaigns

total active: **41%** (5.9M /24s)

Degrees of Address Use

Allocation
registered to a network?

~99%

Routing
advertised in the global routing table?

~75%

Activity
actively used?

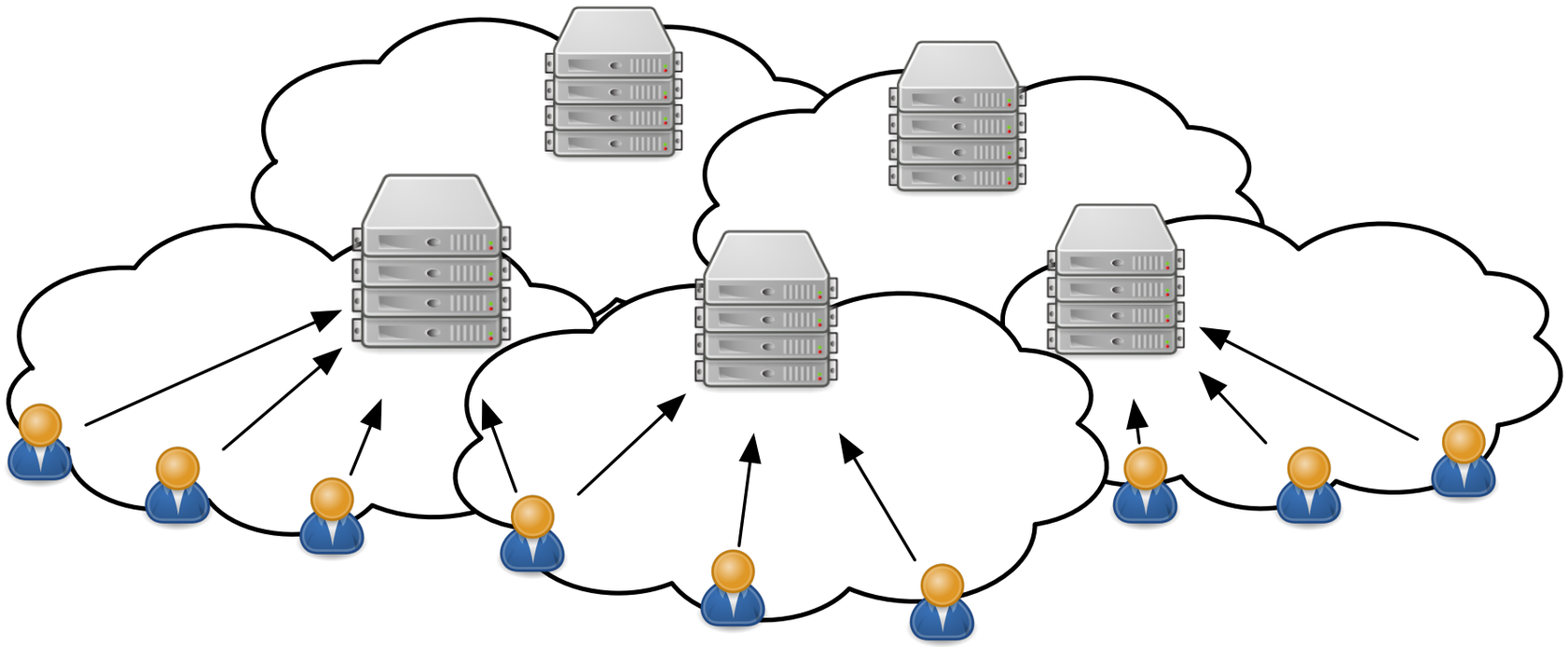
lower bound:
~36-41% (/24s)

Degrees of Address Use

Allocation registered to a network?	**~99%**
Routing advertised in the global routing table?	**~75%**
Activity actively used?	**lower bound:** **~36-41% (/24s)**

Significant potential for increasing the utilization of the IPv4 address space

IPv4 Address Activity from a CDN



The CDN Vantage Point

- 200,000+ servers in 1500+ ASes in 120+ countries
- Web content, mobile content, software updates, etc.
- **3 trillion requests on a daily basis**

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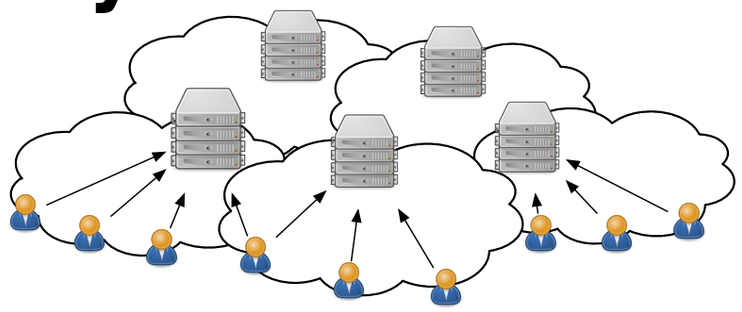

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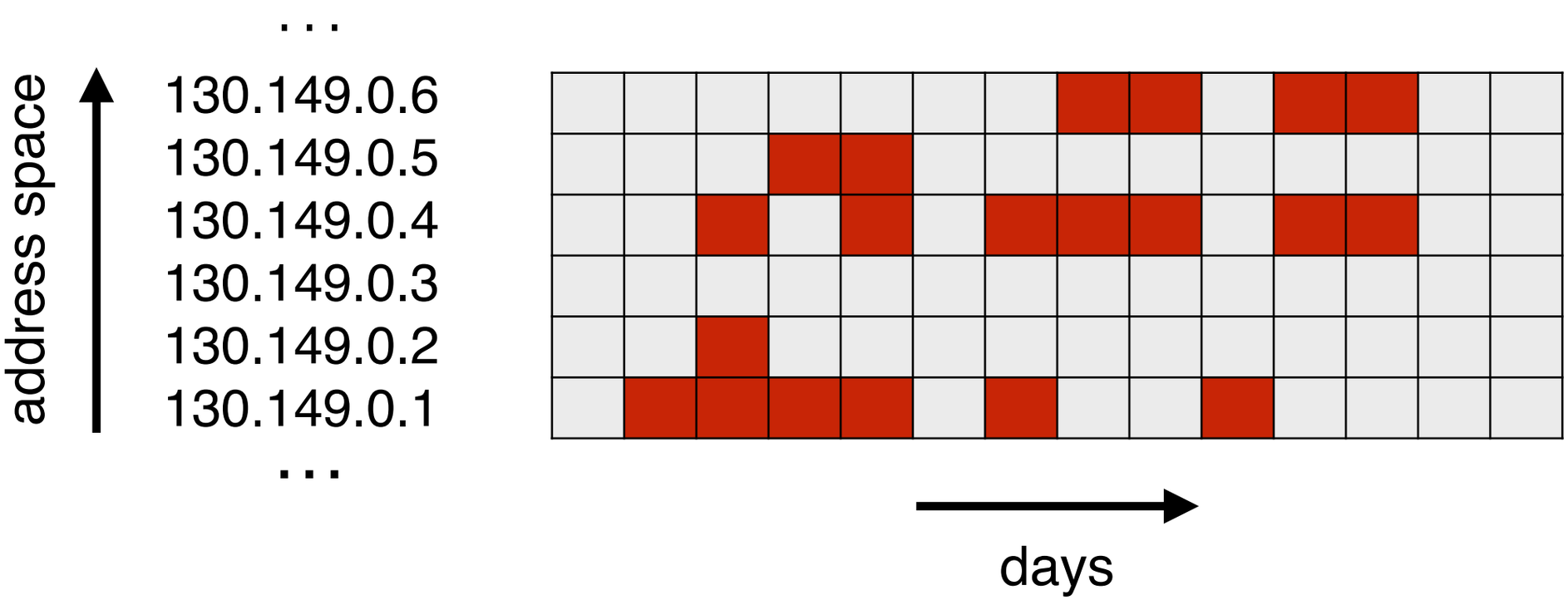
CDN Vantage Point: Active IPv4 Addresses

- 44% active /24 address blocks (6.5M, lower bound raised)
- 32% active IPv4 addresses (1.2B)

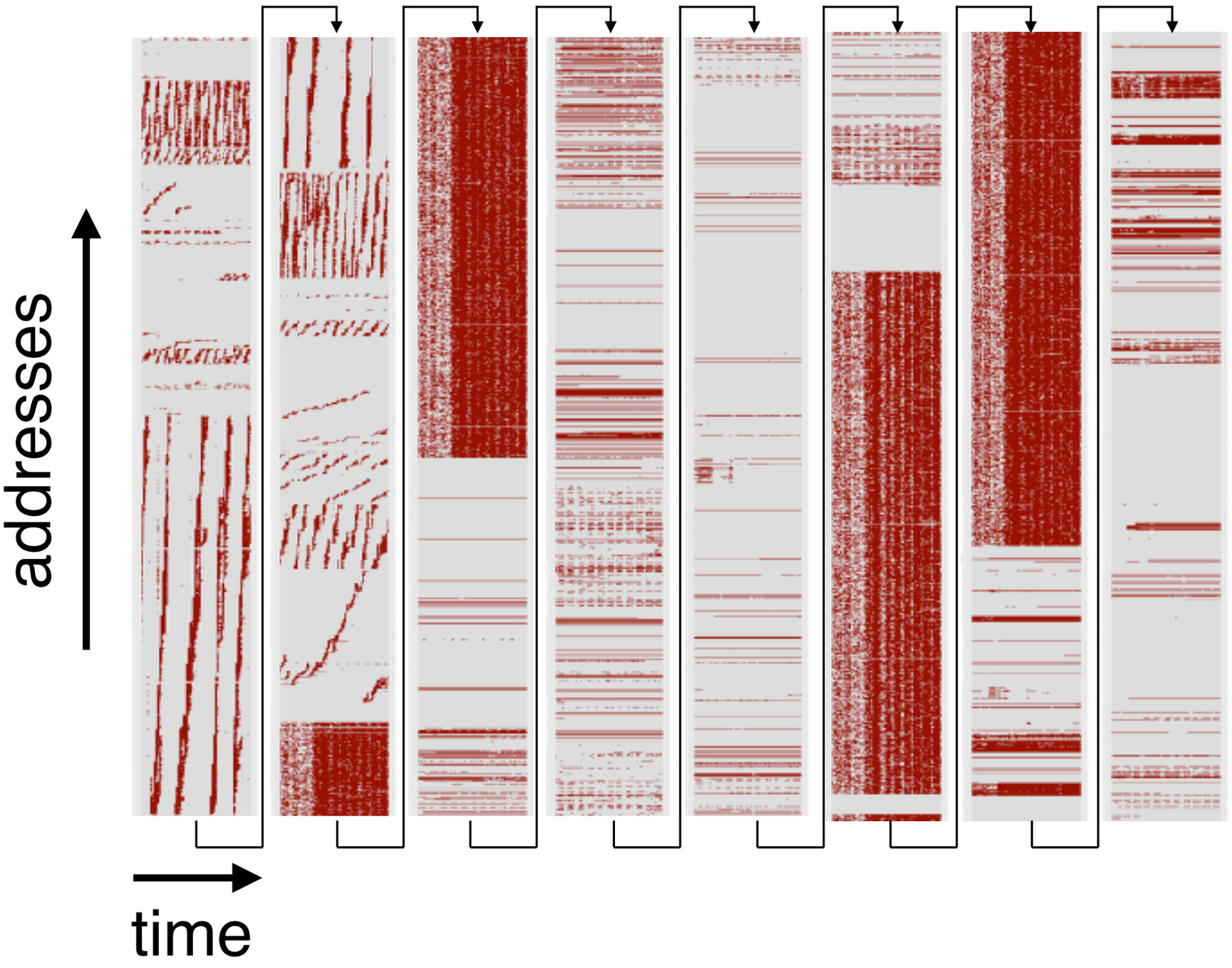
IPv4 Address Activity Matrix



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

Address Activity Matrix at Scale (“Bacon Strips”)

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



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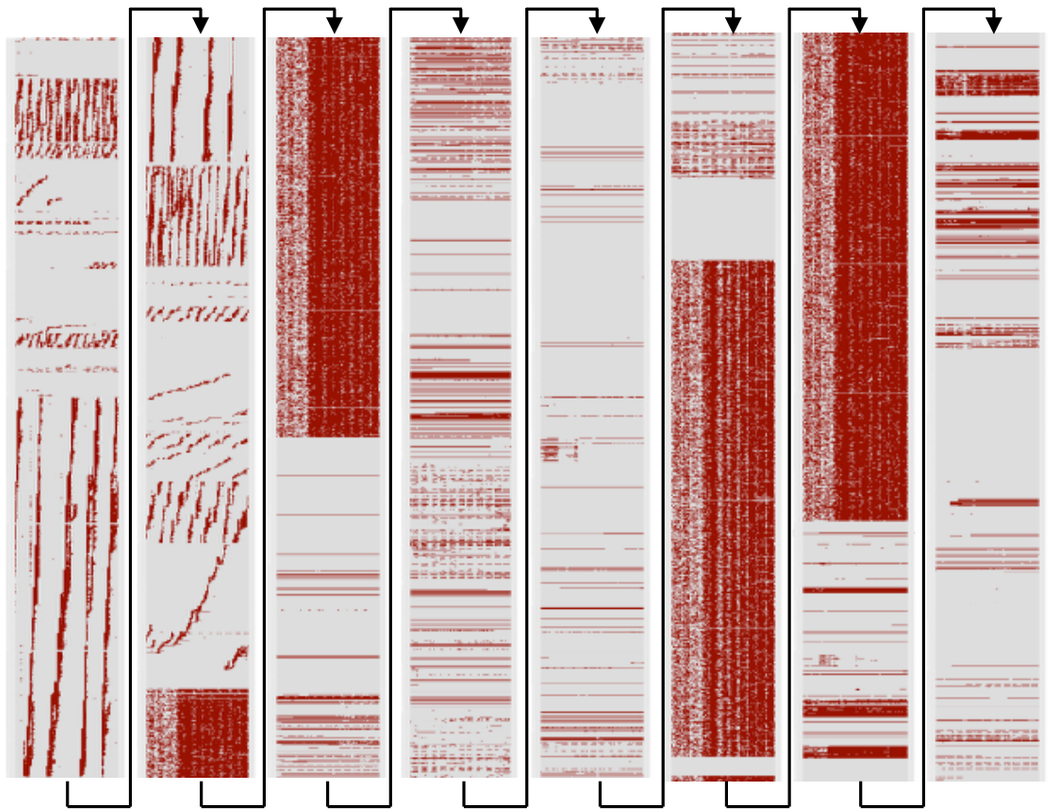
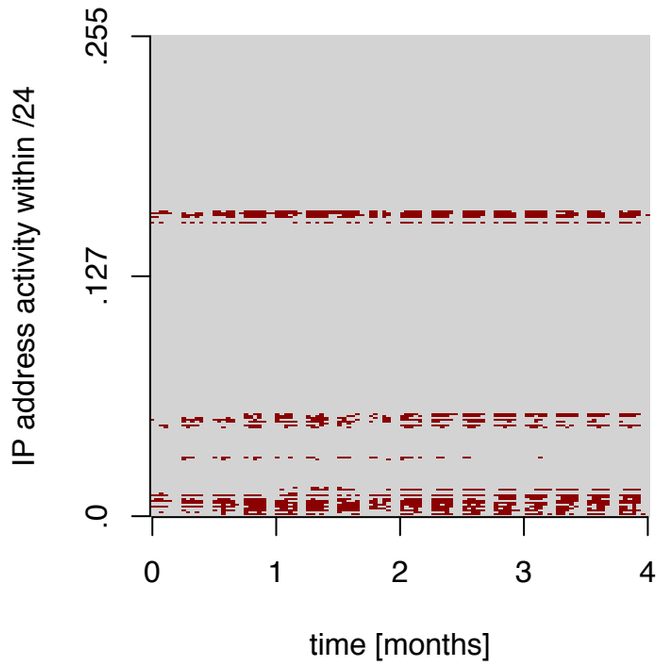
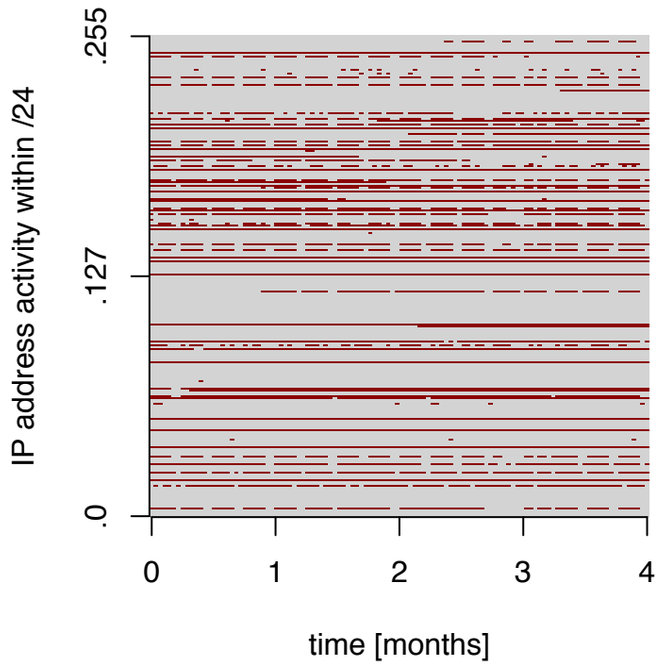


- Metrics that can capture address activity in space and time
- Study the effect of addressing mechanisms on
  - Address activity patterns
  - Utilization (seen from the CDN)

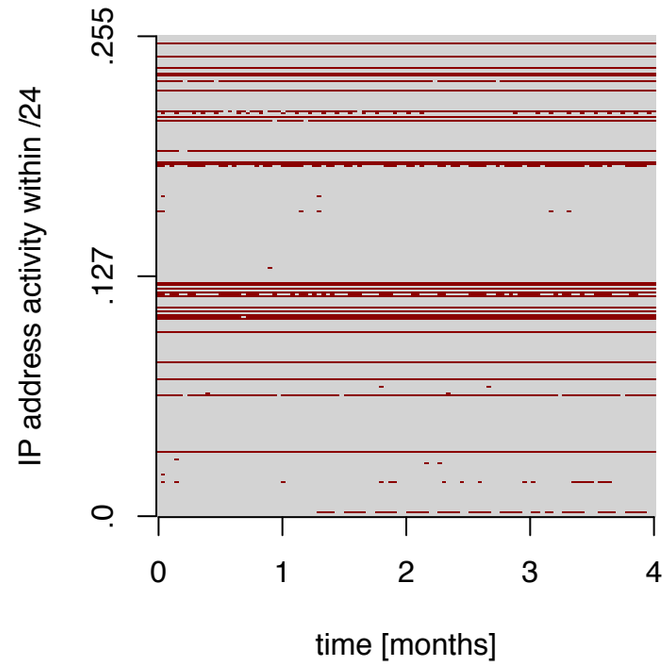
Patterns: Static Address Blocks



University



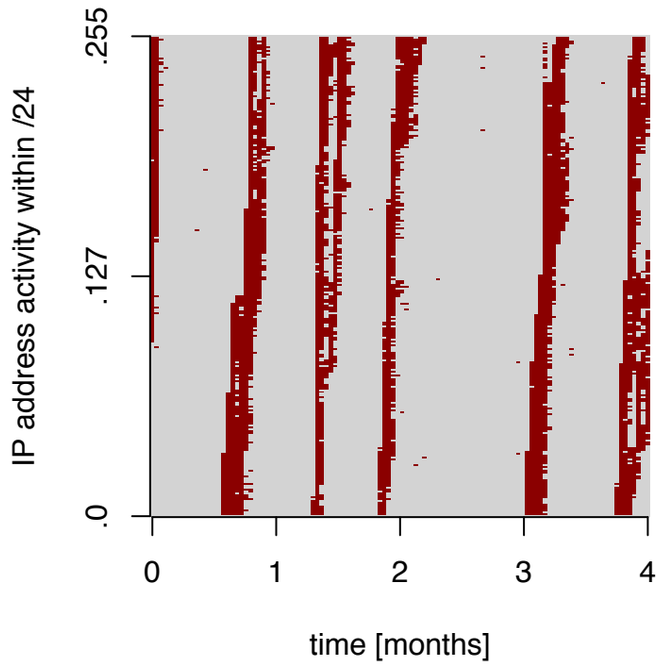
Enterprise ISP



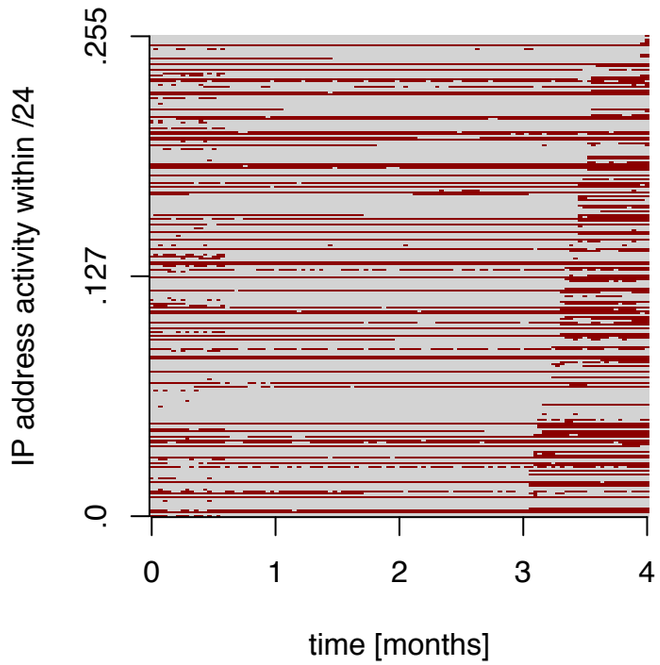
Residential ISP

Most static address blocks show “activity gaps”

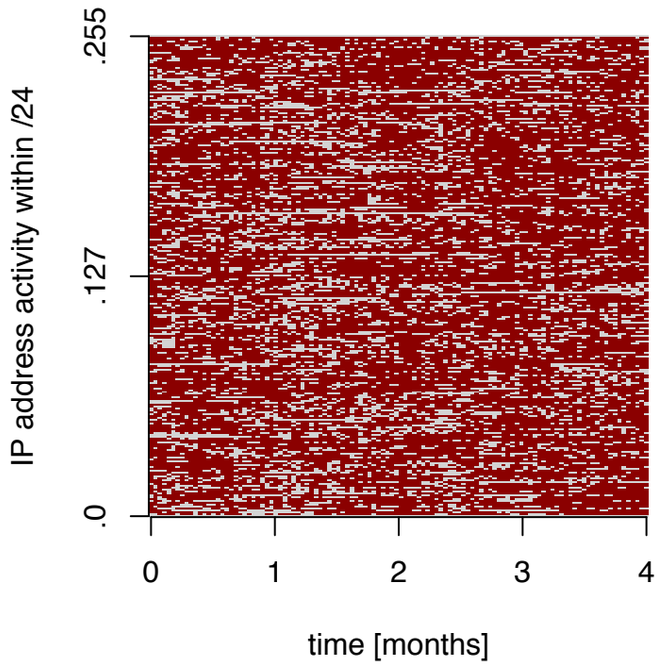
Patterns: Dynamic Address Blocks



DHCP pool US University



residential users US ISP



residential users DE ISP

Activity/utilization depends on pool size and lease time

Which Knobs could be adjusted to increase Utilization?

- Addressing mechanisms impact address activity
- Utilization seen from the CDN:
  - Static address blocks harbor large supply of potentially unused addresses
  - Dynamic address blocks could be adjusted to free up underutilized space

Systematic Framing of IPv4 Exhaustion

ACM CCR '15 (Best of CCR)

mitigation strategies

Use IPv4 space more efficiently

Contribution

Multi-perspective analysis of address activity, churn, addressing, and utilization.

Findings

- Strong potential for utilization increase.
- Knobs to adjust: Governance & Addressing mechanisms.
- Exhaustion effects, stagnation of routed & active addresses.

ACM IMC '16 (Best Paper Award)
IEEE JSAC '16

Multiplex IPv4: Carrier-Grade NAT

Transition to IPv6

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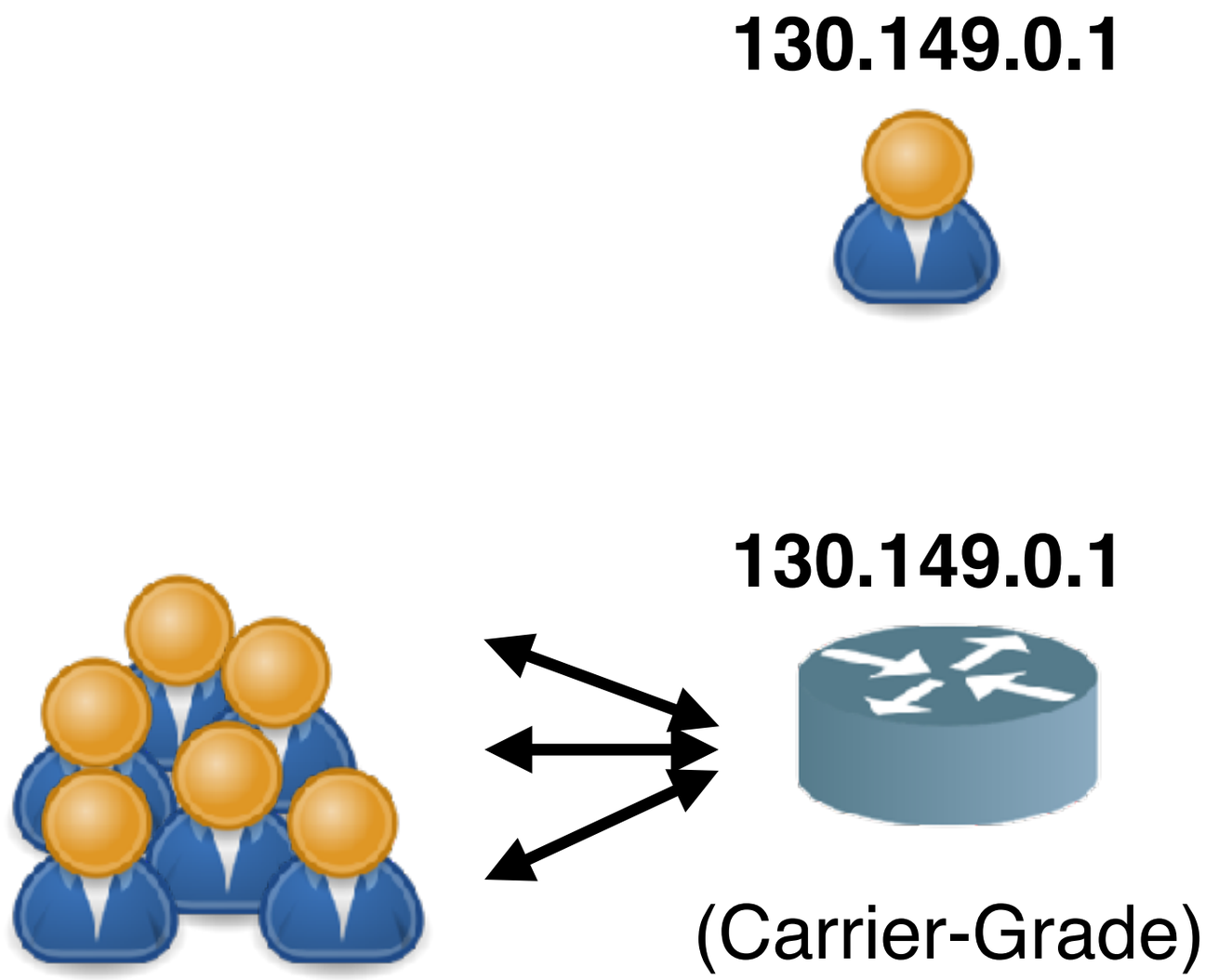
Multiplex IPv4 space with Carrier-Grade NAT



Carrier-Grade NAT

- CGN allows end-user ISPs to ease scarcity issues
- At the cost of breaking the end-to-end Internet

- “Nobody really talks about it”
- Uncertainty in the community

- **No systematic studies!**

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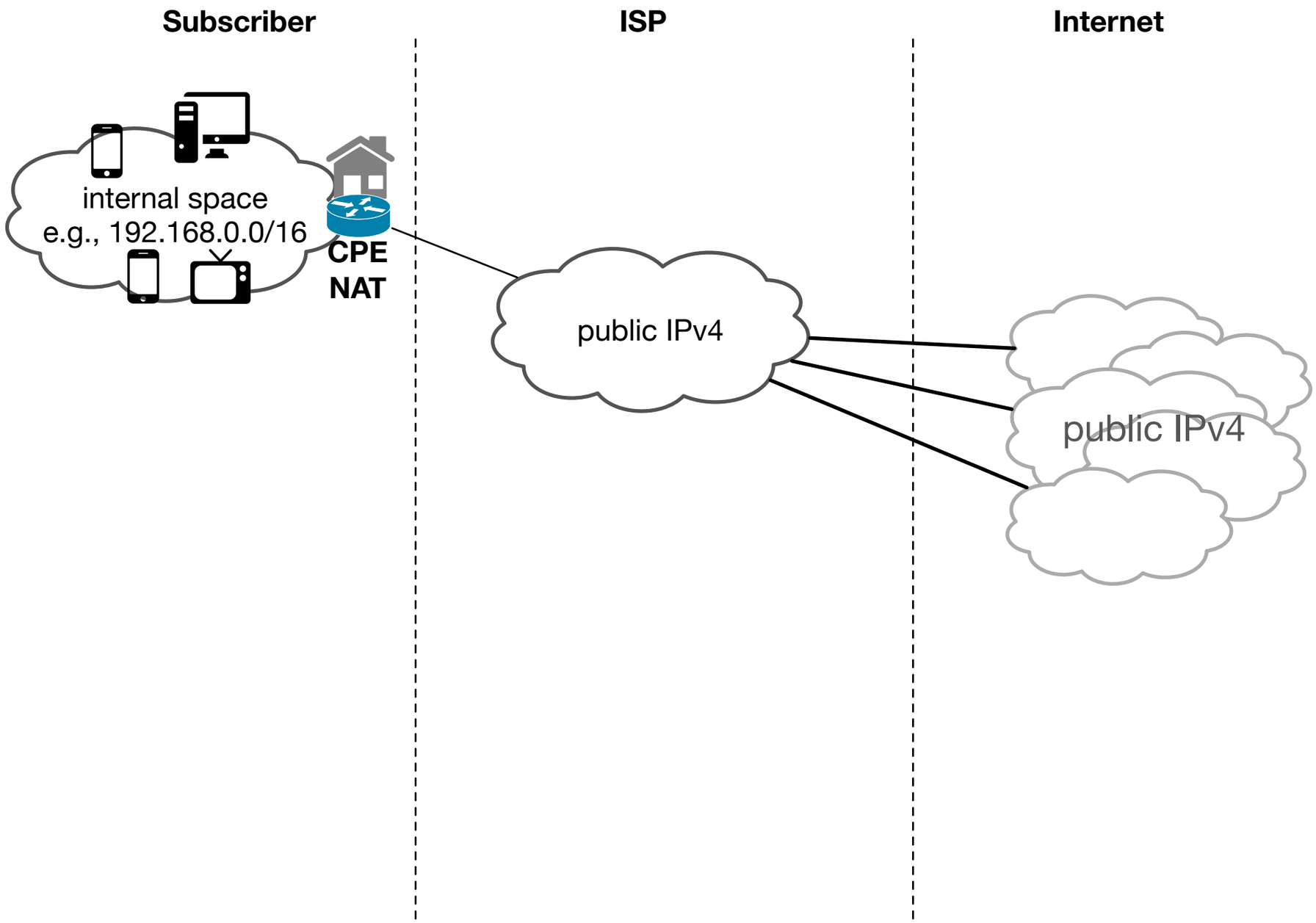
Research Questions

- How can we detect Carrier-Grade NAT?
- How widespread is Carrier-Grade NAT?
- What’s the effect on the Internet and its users?

NATs between Subscribers and the Internet

NAT44
(subscriber-side)



NATs between Subscribers and the Internet

NAT44
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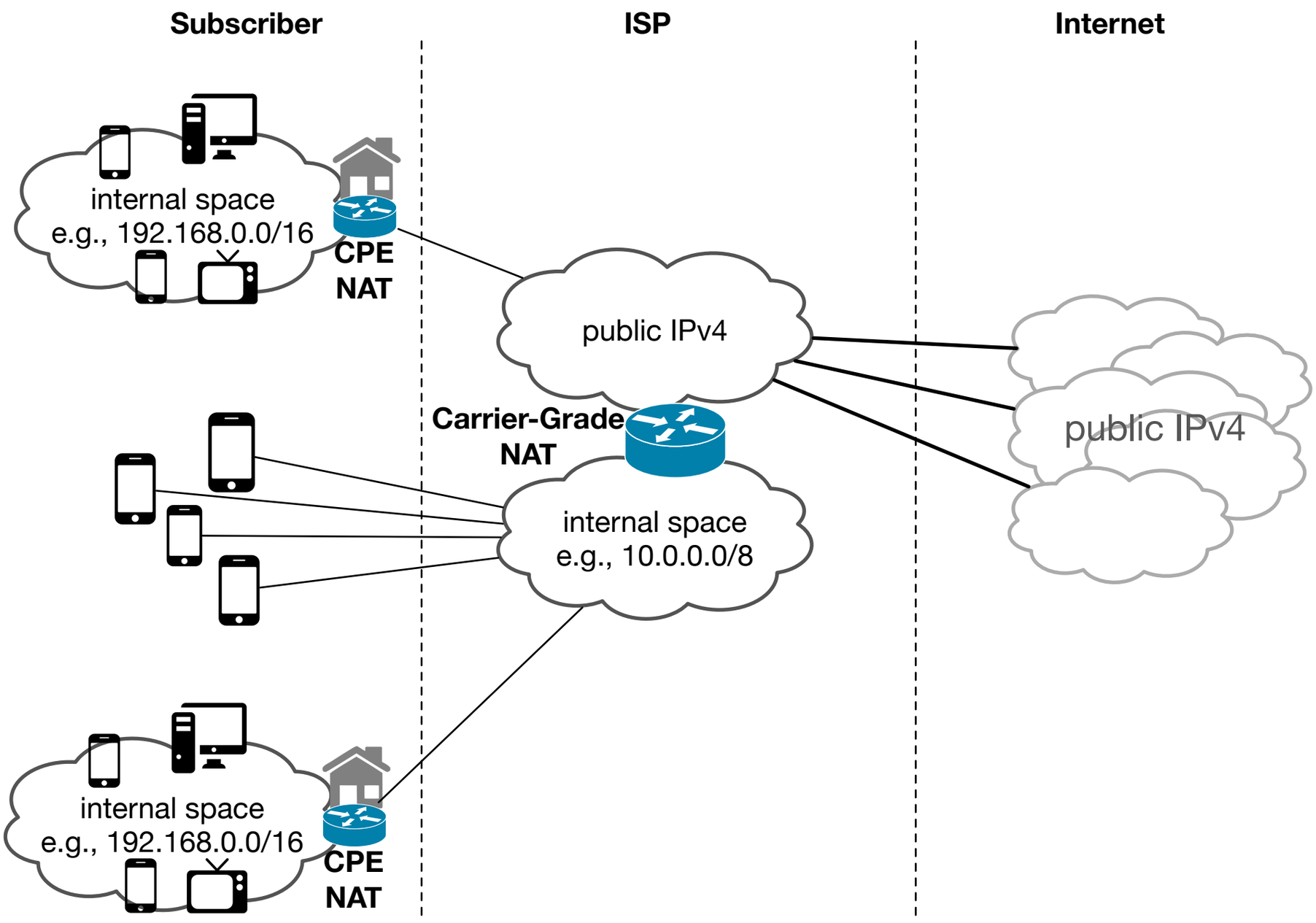
NAT44
(carrier-side)

NAT444
(subscriber-side
and
carrier-side)



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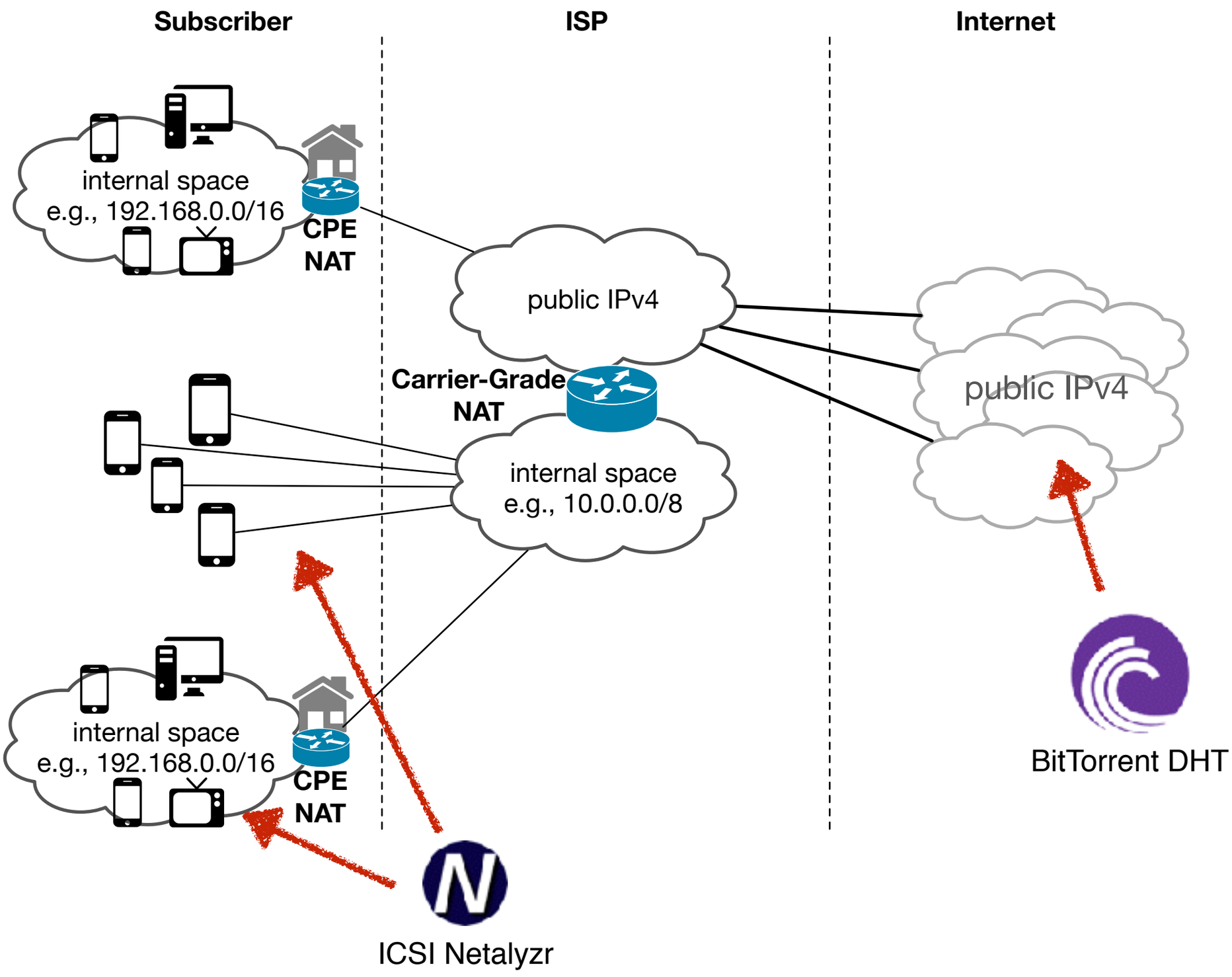
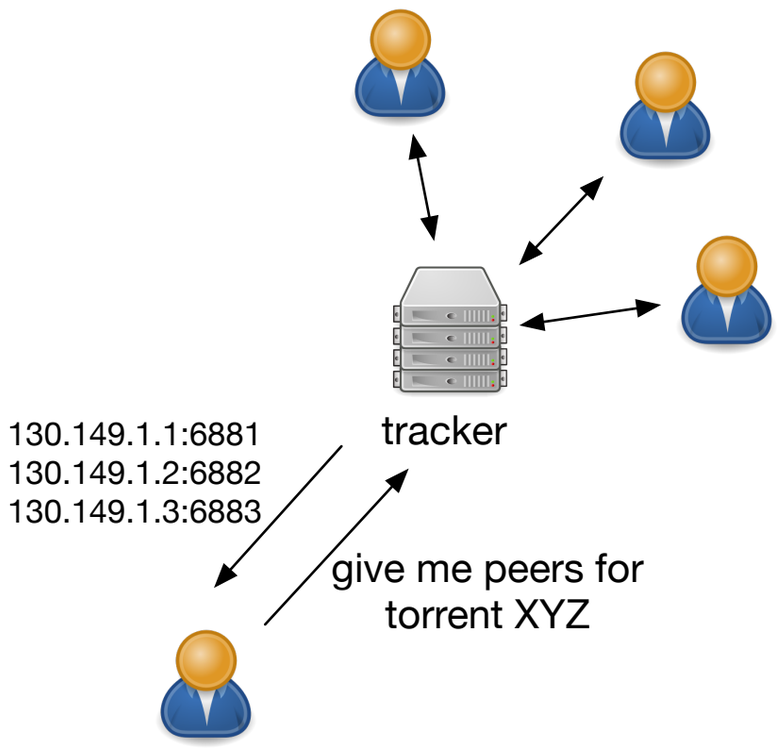
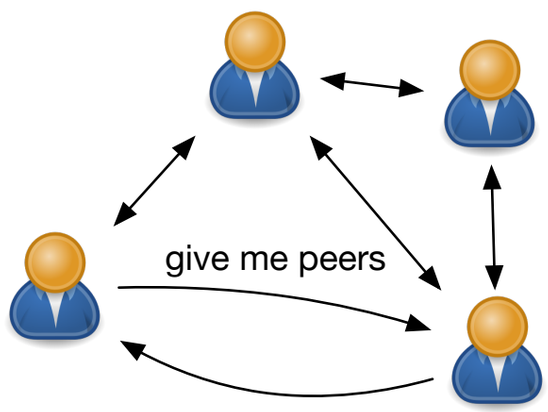


The BitTorrent DHT





Classic BitTorrent

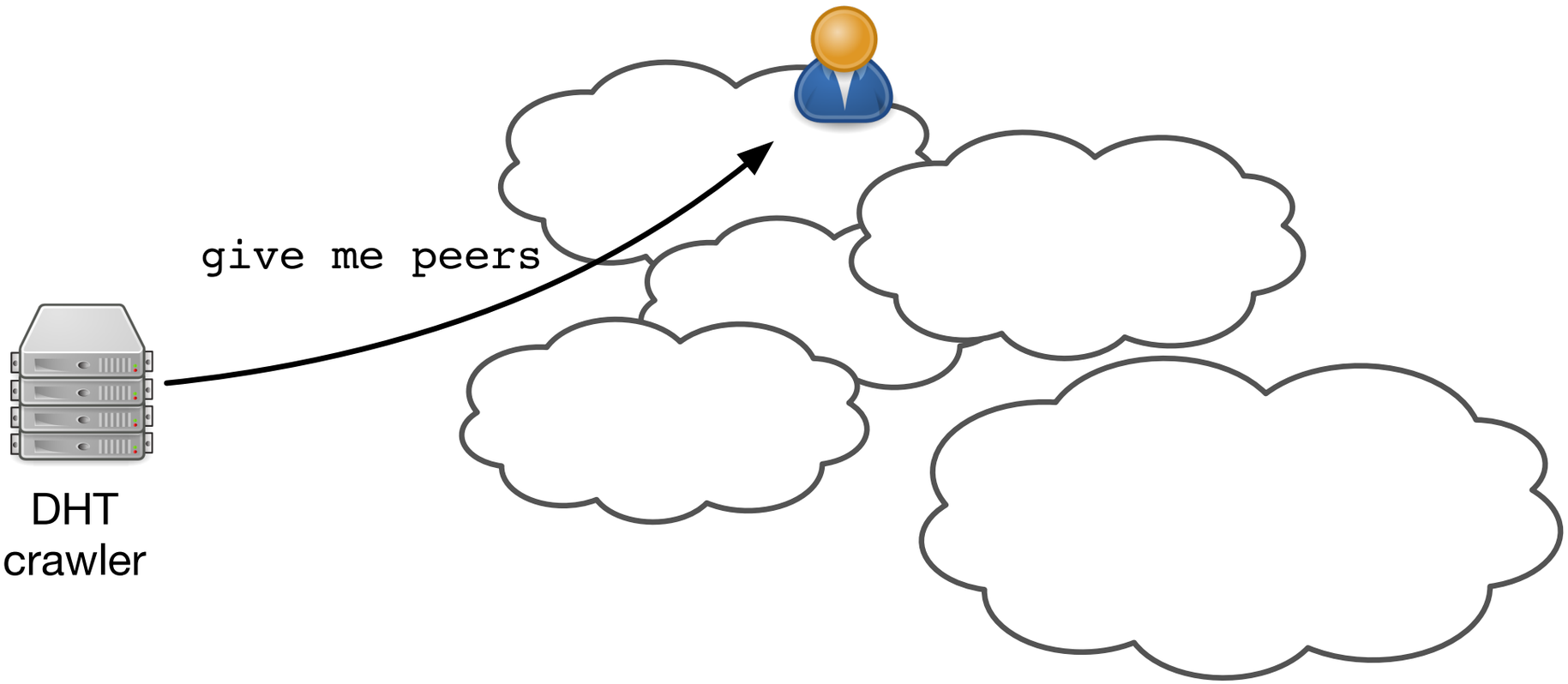
Tracker stores peer contact information

BitTorrent DHT

Peers store each others' contact information

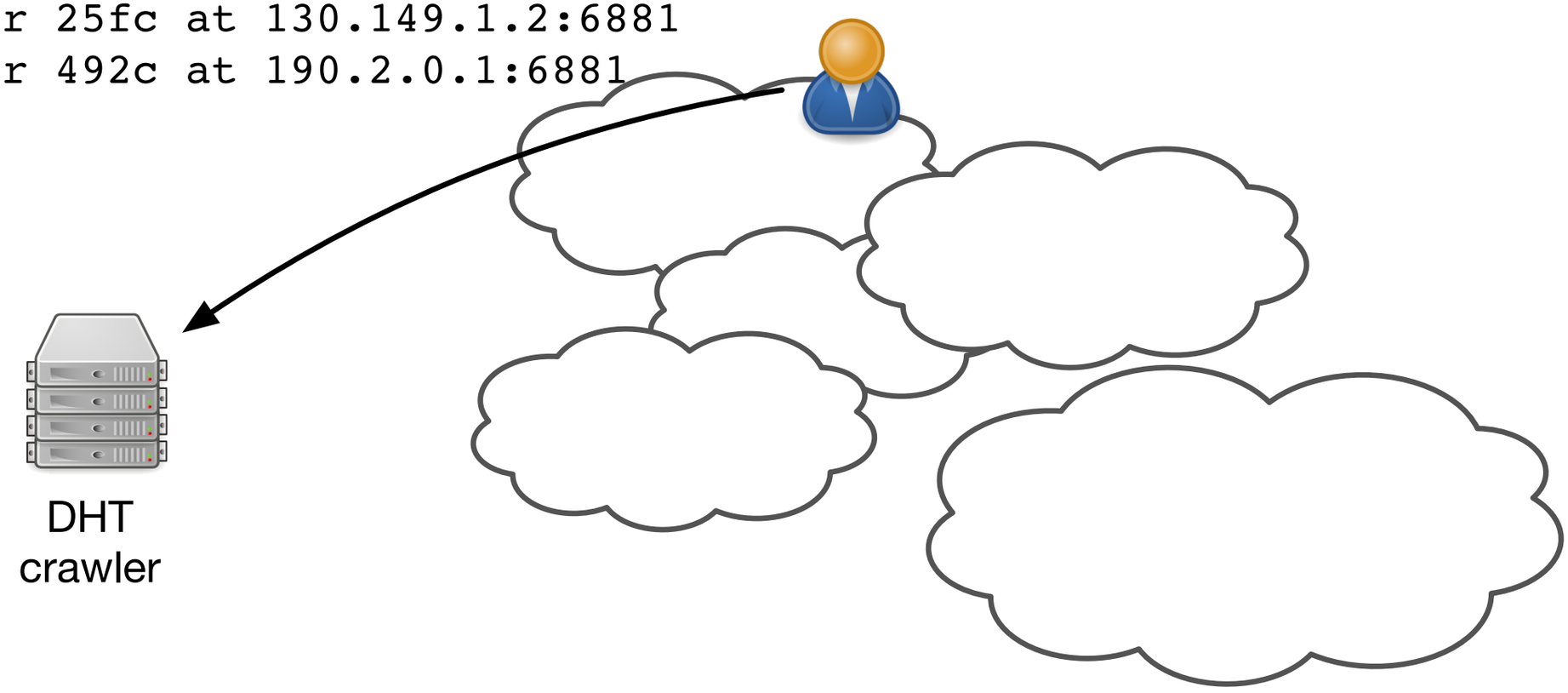
We can use DHT peers as vantage points

Crawling the BitTorrent DHT



Crawling the BitTorrent DHT

```
i can reach
peer 25fc at 130.149.1.2:6881
peer 492c at 190.2.0.1:6881
…
```



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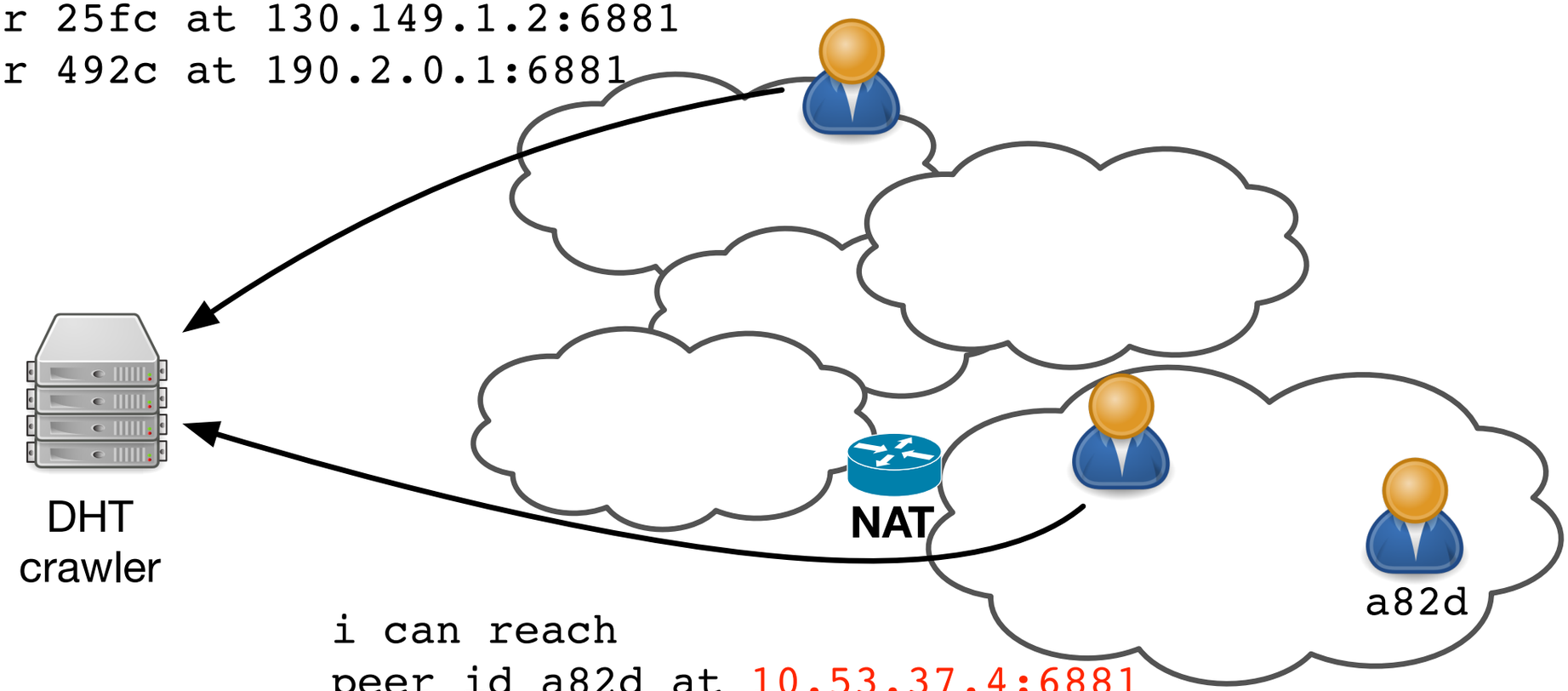


```
i can reach
peer id a82d at 10.53.37.4:6881
…
```

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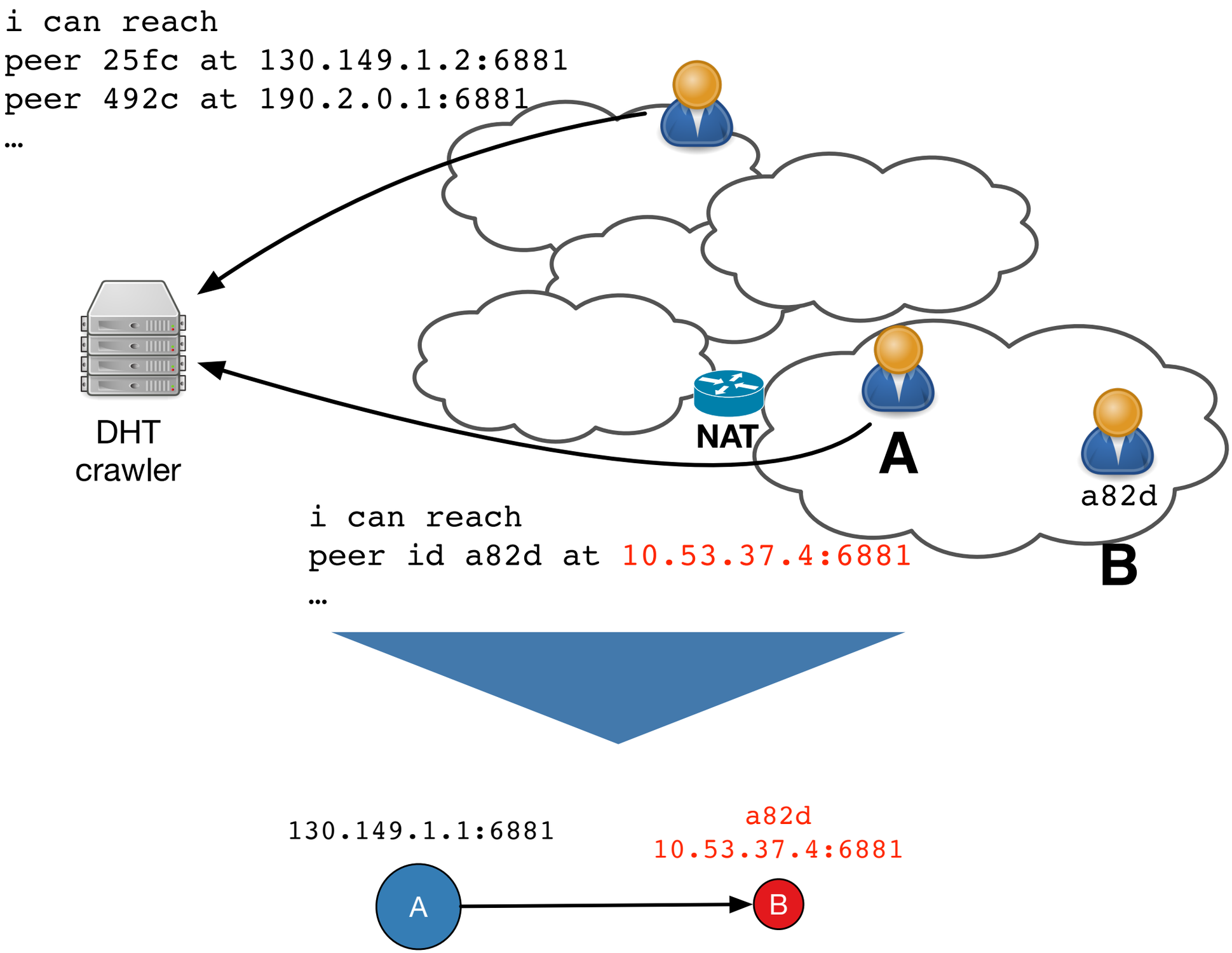
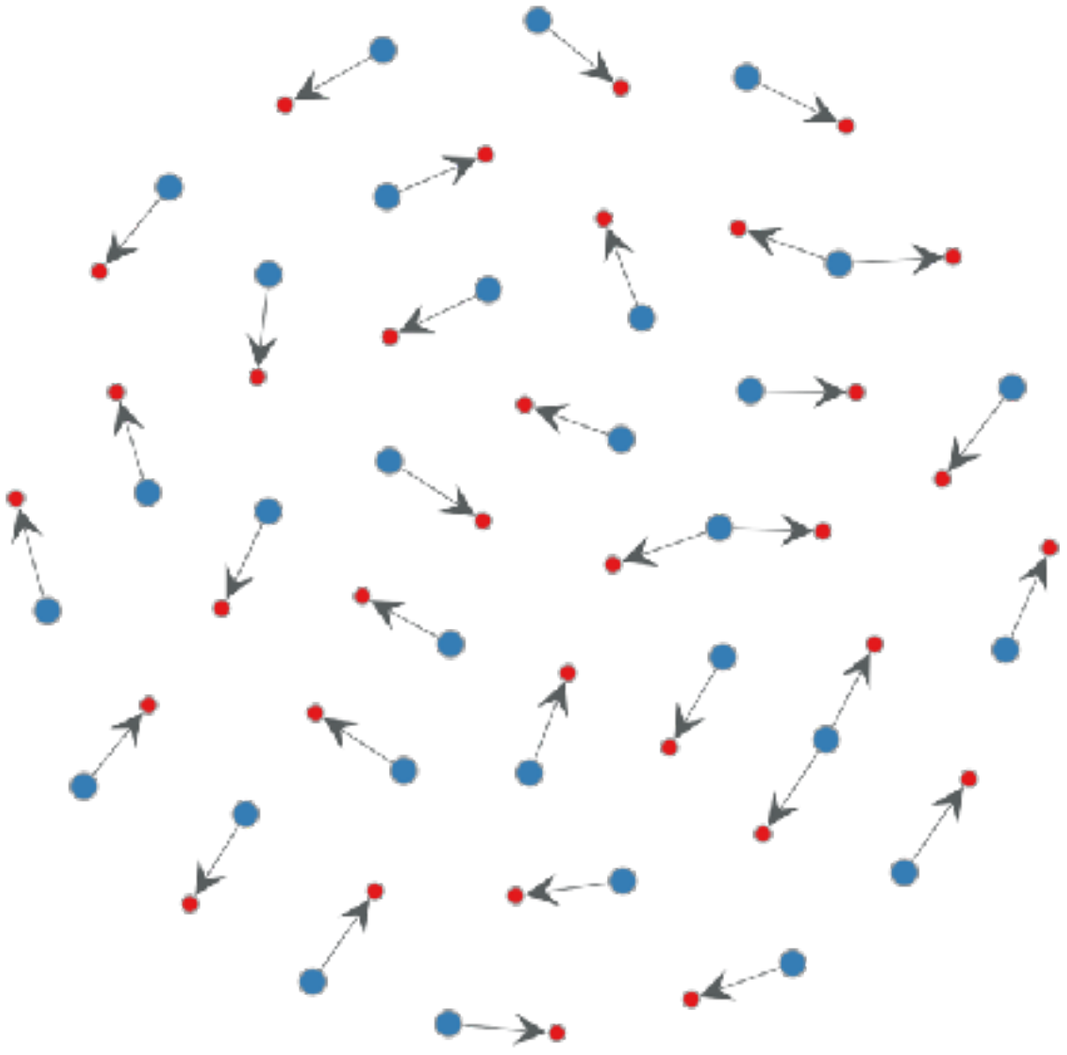
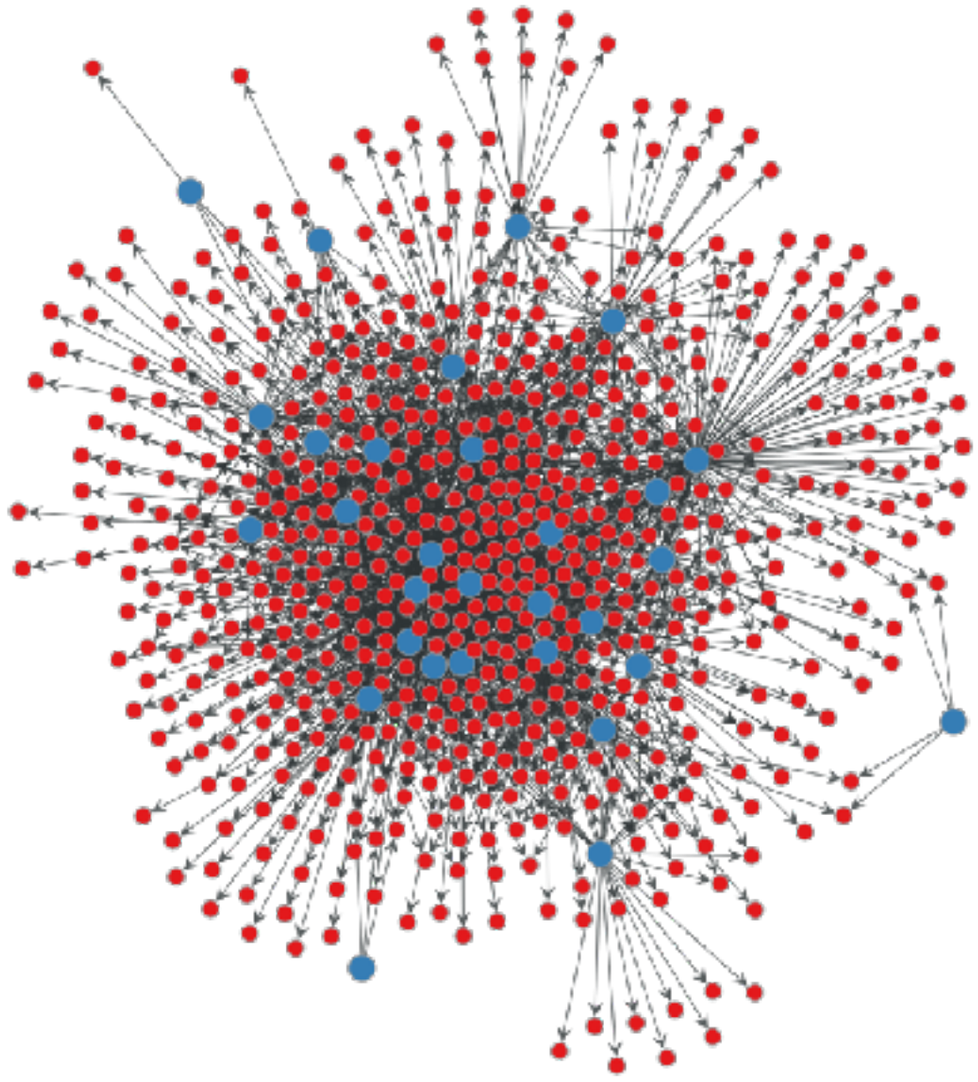


BitTorrent Peer Leakage Graph



In this AS:
no CGN detected



In this AS:
CGN detected

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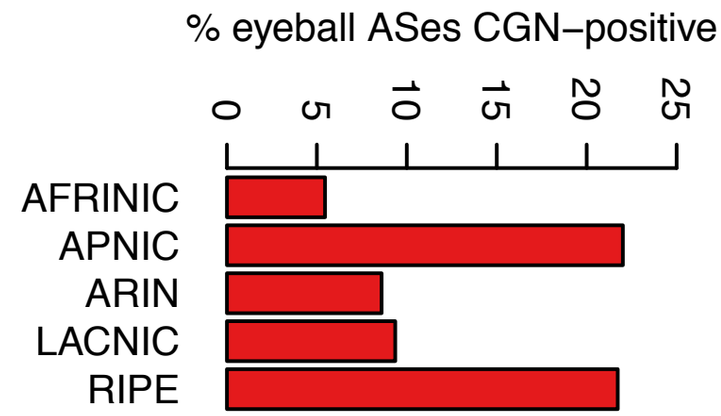

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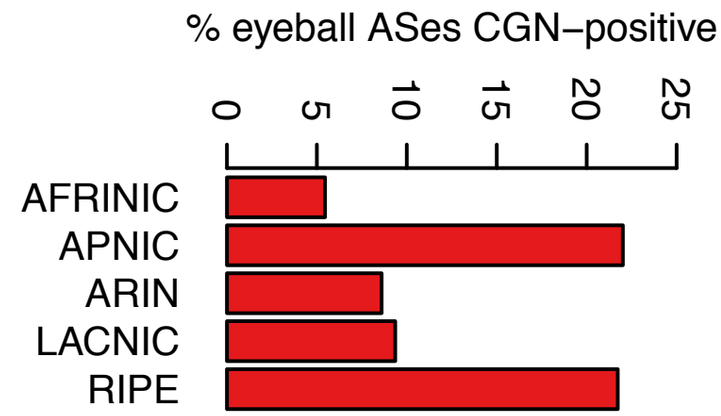
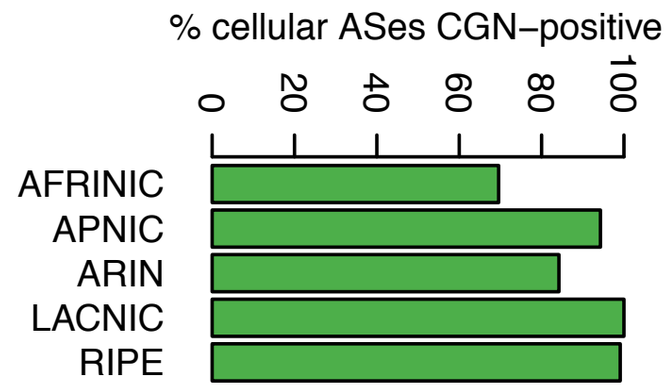


Cellular Networks

- CGN-positive: **94%**
  - CGN is the norm for cellular



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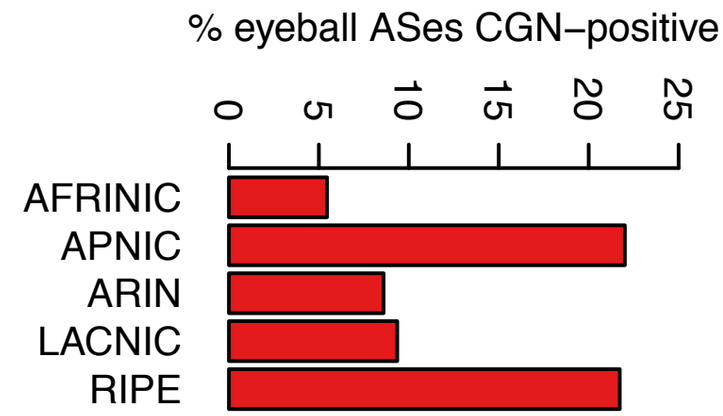

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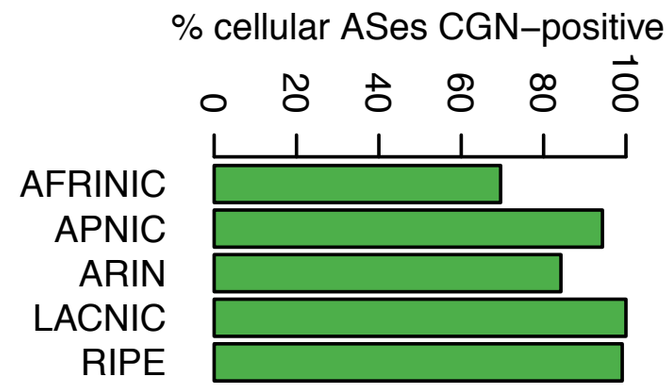
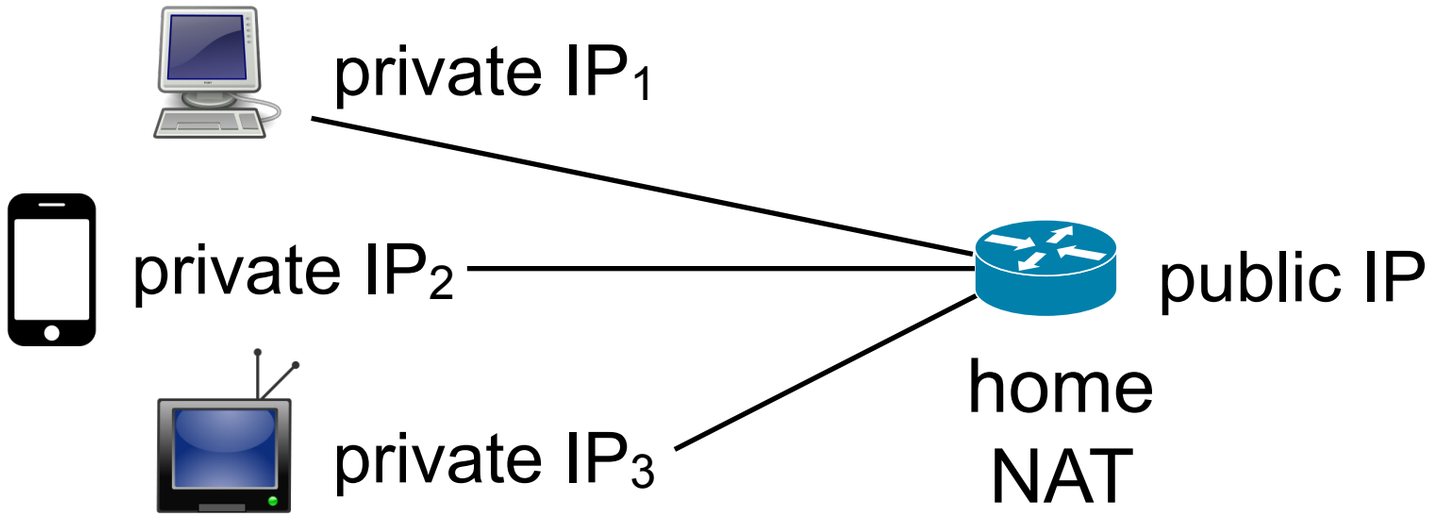
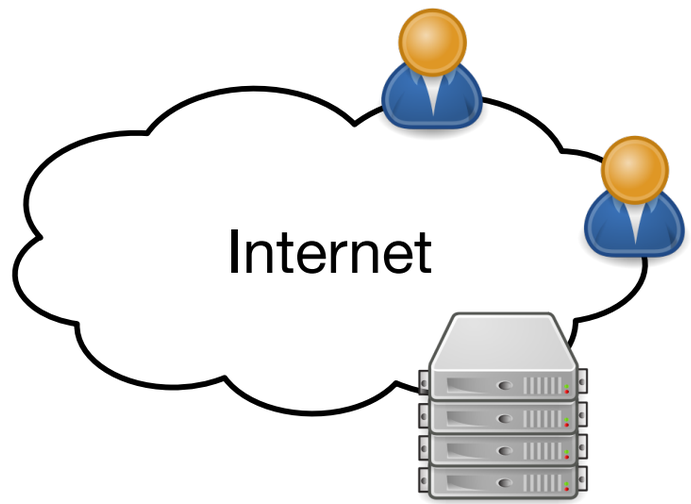


CGN is reality for the majority of Internet Users

What's the Impact of Carrier-Grade NATs?





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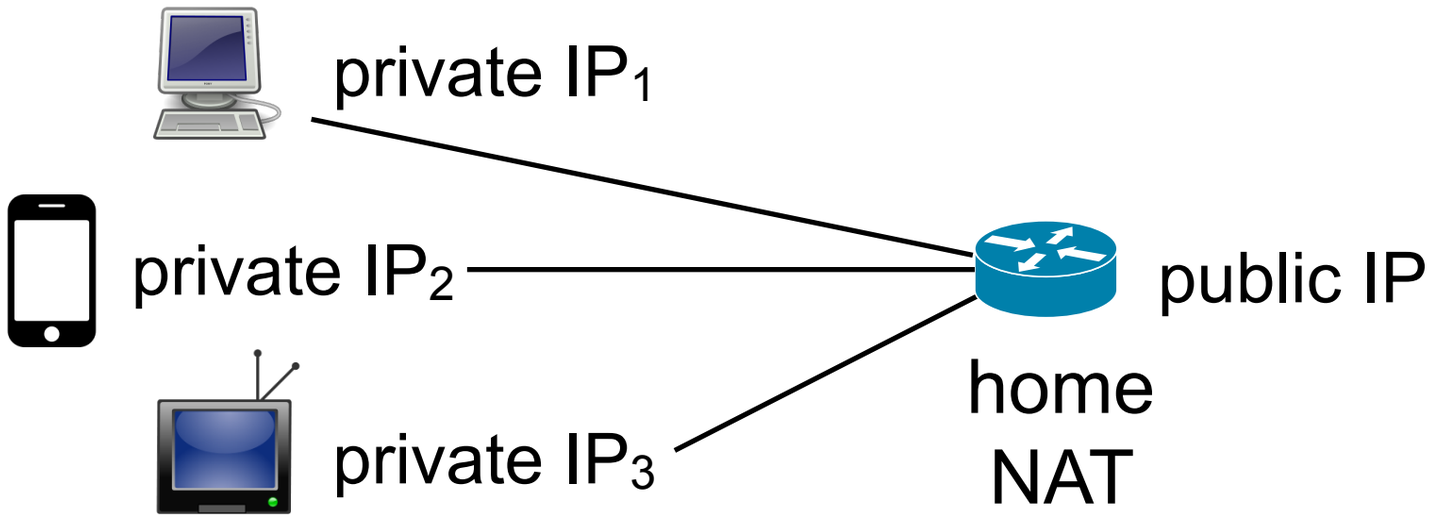

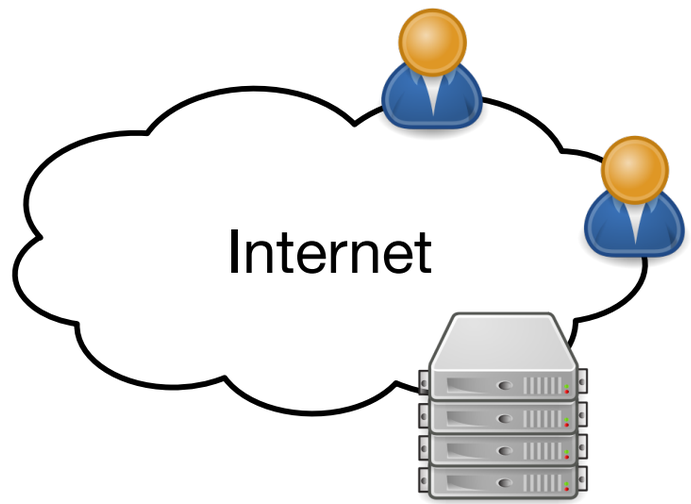

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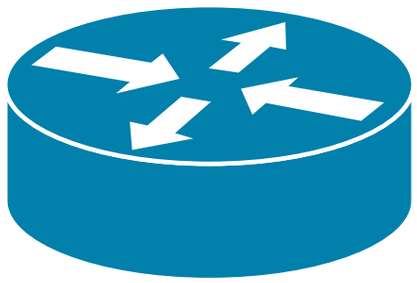
IP ranges



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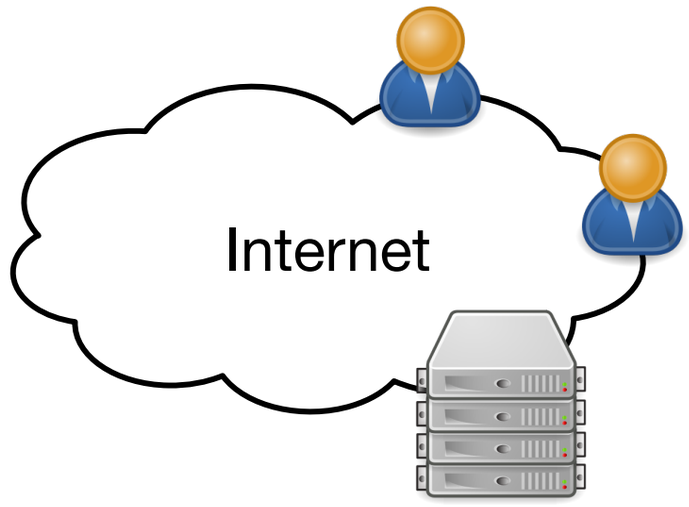

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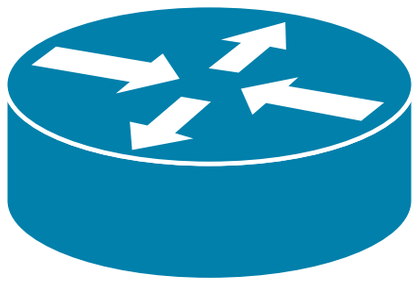

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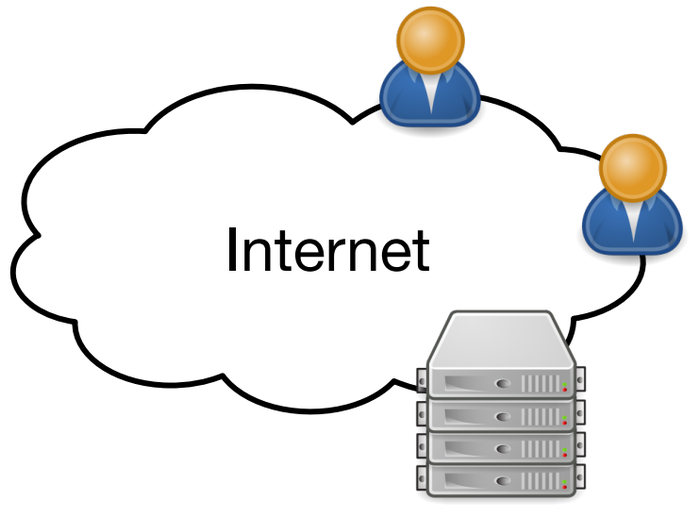

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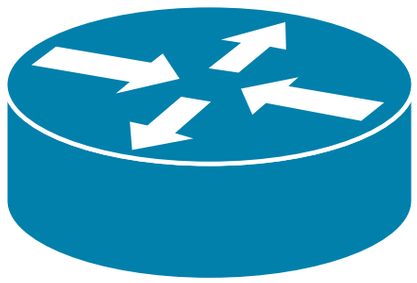

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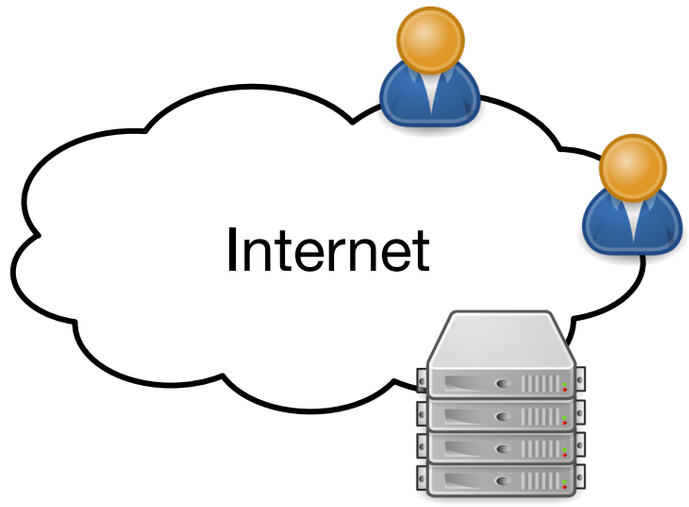

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1) Directionality
2) Limits/Quotas on flows per subscriber
3) Restrictiveness of NAT mappings, timeouts

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Deployment Issues

- Exhaustion of internal IPv4 address space
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CGNs limit "how much Internet" subscribers receive

CGN means very different things for different ISPs

Systematic Framing of IPv4 Exhaustion

ACM CCR '15 (Best of CCR)

mitigation strategies

Use IPv4 space more efficiently

Contribution

Multi-perspective analysis of address activity, churn, addressing, and utilization.

Findings

- Strong potential for utilization increase.
- Knobs to adjust: Governance & Addressing mechanisms.
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ACM IMC '16 (Best Paper Award)
IEEE JSAC '16

Multiplex IPv4: Carrier-Grade NAT

Contribution

First broad and systematic study of CGN deployment in the Internet and properties.

Findings

- CGNs are very broadly deployed (majority of users).
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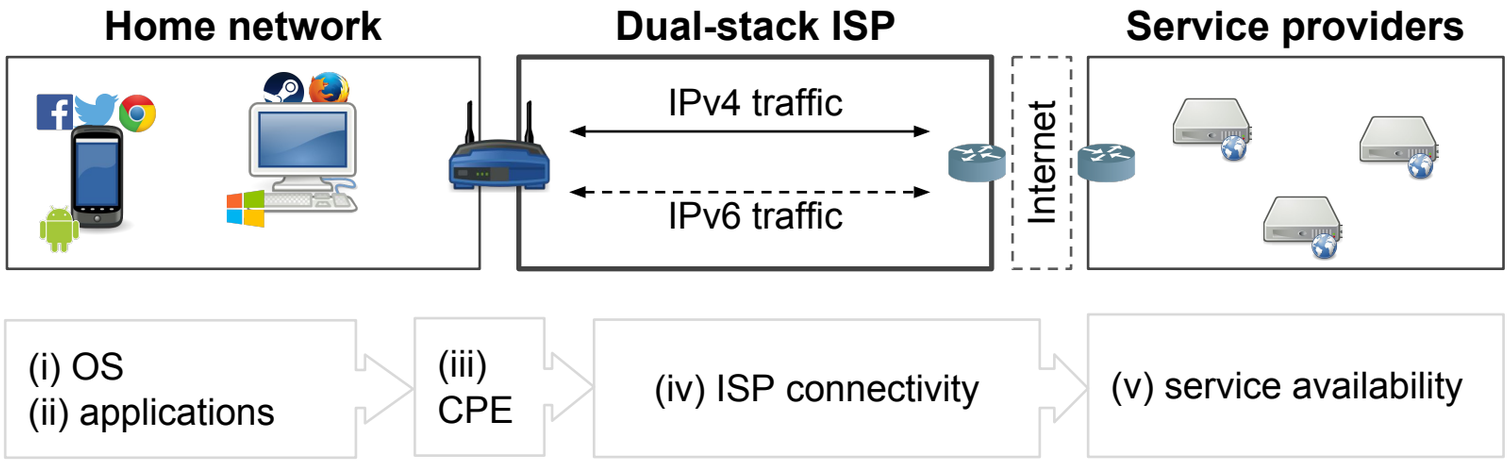
- Long-term solution to the IPv4 scarcity problem
- **Enormous Task: Replacing the central Internet Protocol**



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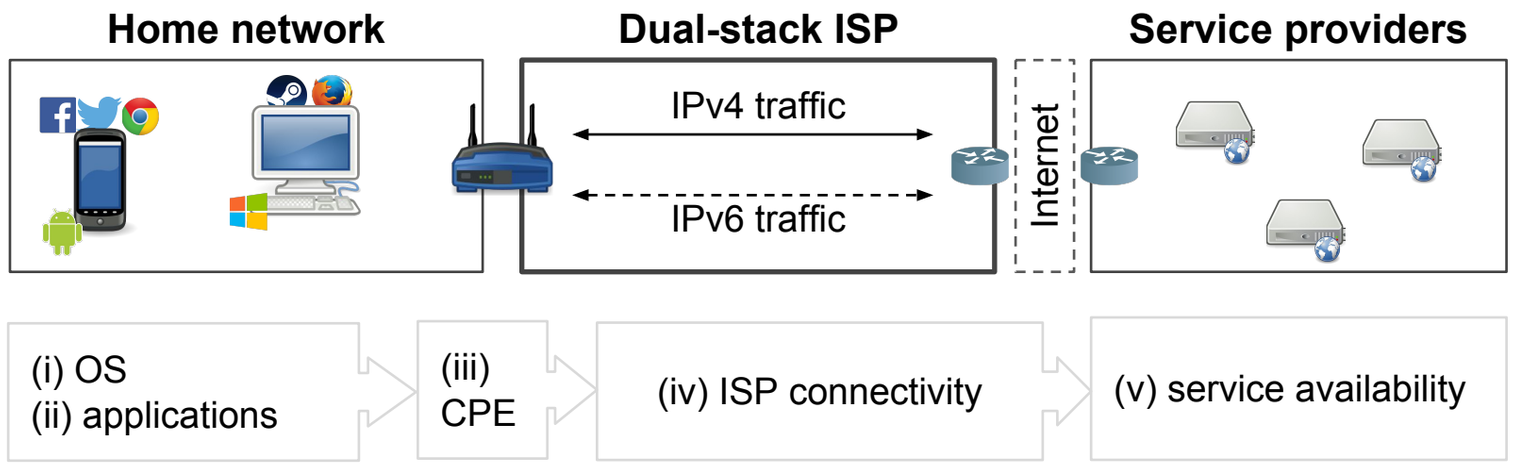

- As of 2017:
  - A minority of Internet hosts speak IPv6
  - Majority of Internet traffic carried over IPv4

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- Traffic over IPv6 lags behind connectivity.
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ACM IMC '14, PAM '15, PAM '17

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- Today: Economic pressure due to IPv4 scarcity!
  - Growing IPv4 address markets
  - Widespread Carrier-Grade NAT deployment
  - Increasing Dual-Stack IPv4/IPv6 deployment

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