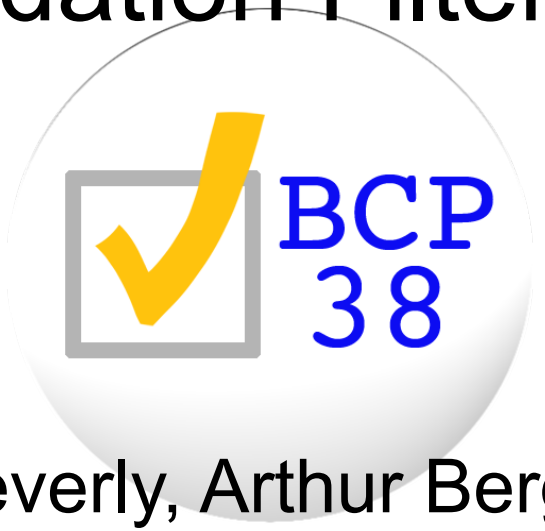
Understanding the Efficacy of Deployed Internet Source Address Validation Filtering



Robert Beverly, Arthur Berger (MIT),
Young Hyun, k claffy (UCSD/CAIDA)

ACM Internet Measurement Conference 2009

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Spoofer Project

- Background
- Recent Relevance
- Project Methodology
- Results
- Parting Thoughts

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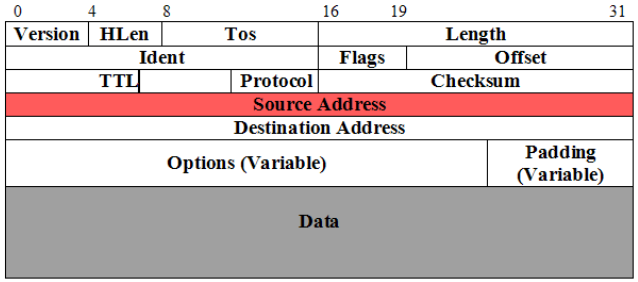
Spoofed-Source IP Packets

- Circumvent host network stack to forge or "spoof" *source address* of an IP packet
- Lack of source address accountability a basic Internet weakness:
  - Anonymity, indirection [VP01], amplification
- Security issue for more than *two-decades* [RTM85, SB89]
- Still an attack vector?



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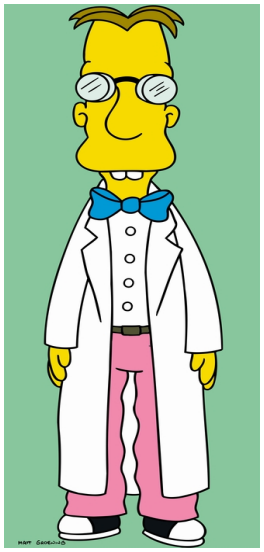
Circa 2004…

IP source spoofing doesn't matter!

a) All providers ***filter***
b) All modern attacks use ***botnets***
c) Compromised hosts are behind ***NATs***



- Strong opinions from many:
  - Academic
  - Operational
  - Regulatory
- …but only anecdotal data

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spoofer.csail.mit.edu

- Internet-wide active measurement effort:
  - Quantify the extent and nature of Internet source address filtering
  - Understand real-world efficacy of available best-practice defenses
  - Validate common assumption of edge filtering
- Began Feb. 2005
  - Understand how filtering has evolved
  - Basis for driving design of more secure architectures

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Prediction: spoofing increasingly a problem in the future

- **Spoofed traffic complicates a defenders job**
- Tracking spoofs is operationally difficult:
  - [Greene, Morrow, Gemberling NANOG 23]
  - Hash-based IP traceback [Snoeren01]
  - ICMP tr[illegible]
- Consider[illegible]
  - Today ([illegible]): [illegible] are widely distributed, a network operator must defend against attack packets from 5% of routeable netblocks.
  - Future: if 25% of zombies capable of spoofing significant volume of the traffic could appear to come any part of the IPv4 address space
- Adaptive programs that make use of all local host capabilities to amplify their attacks

Slide from SRUTI 2005

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The Spoofing Problem (2009)

- DNS Amplifier Attacks
- DNS Cache Poisoning
- In-Window TCP Reset Attacks
- Bots that probe for ability to spoof
- Spam Filter Circumvention
- UW reverse traceroute
- etc, etc…

Can’t anticipate next attack employing IP spoofing

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The Operational Side

- Arbor 2008 Infrastructure Survey:
  - "*Reflective amplification attacks responsible for the largest attacks (40Gbps) exploit IP spoofing*"
  - "*No bots were used in this attack. The attacker had a small number of compromised Linux boxes from which he'd launch the spoofed source DNS query*"
- What's an operator to do?

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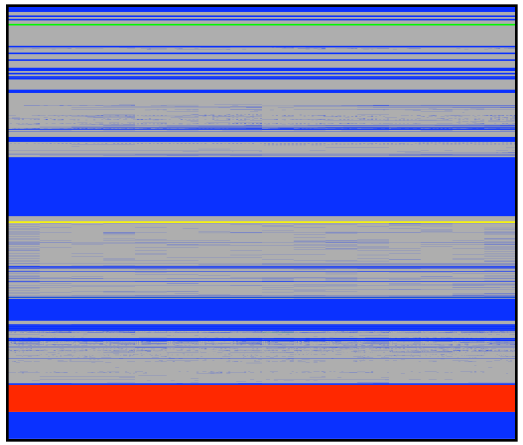
Operational View

- IETF BCP38 best filtering practice
- But, not all sources created equal:

harder

Example Source IP	Description	Possible Defense
192.168.1.1	RFC1918 private	Static ACL
1.2.3.4	Unallocated	Bogon Filters
6.1.2.3	Valid (In BGP table)	uRPF (loose/strict)
Client IP $\oplus$ (2^N)	Neighbor Spoof	Switch, DOCSIS

IPv4 Address Space



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Operational View

- We have defenses, what's the problem?
- BCP38 suffers from:
  - Lack of hardware support (see NANOG)
  - Global participation requirement
  - Management nightmare (edge filters)
  - Multi-homing, asymmetry, etc implies loose uRPF, implies little protection
- This work: understand the real-world efficacy of these best practices

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Spoofer Test

- Willing participants run “spoofer” client to test policy, perform inference, etc.
  - Binaries, source publicly available
  - Useful diagnostic tool for many
  - Runs once, not an agent
- Clients self-selecting
  - Understand population and potential bias

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Spoofer Test

- Testing vulnerability of Internet to source spoofing, not prevalence of source spoofing (e.g. backscatter analysis)
- Uses CAIDA's Ark infrastructure to test many paths
- Aggregate results, tomography, etc to form global picture of best-practices (BCP38) efficacy

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Archipelagio

- Tied into CAIDA's distributed measurement infrastructure (Ark)
- ~40 nodes, globally distributed
- Ark nodes act as IPv4/v6 spoof probe receivers

caida

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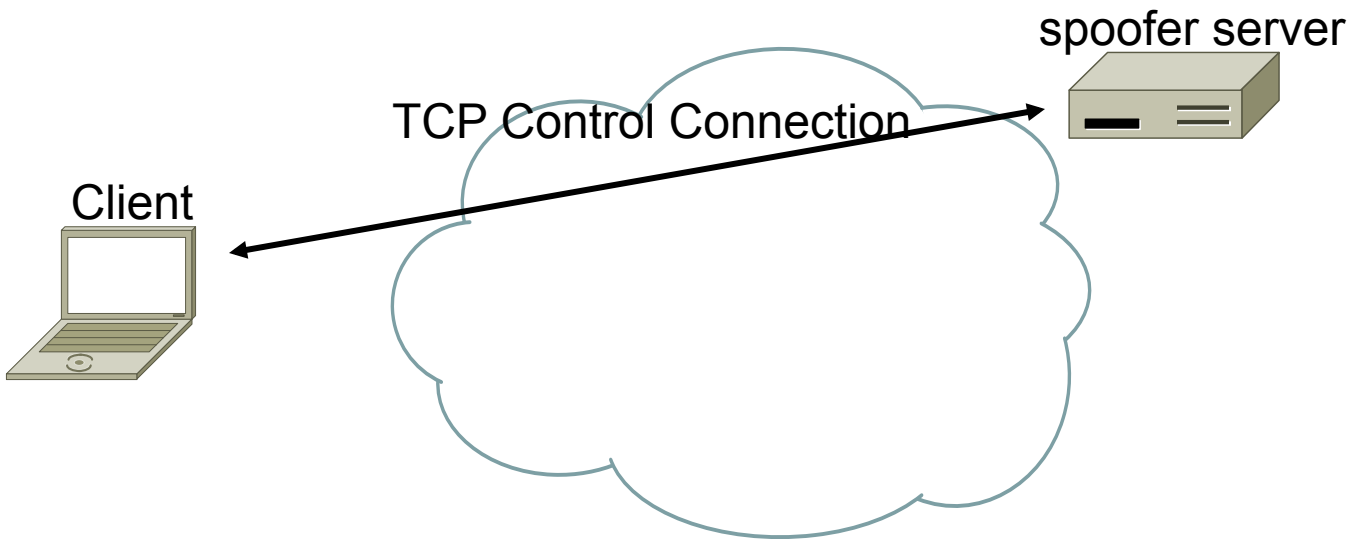
Spoofer Operation



- Client confers with control server, receives test
- (SRC, DST, HMAC, SEQ) probe tuples
- Use TCP destination port 80 to avoid secondary filtering

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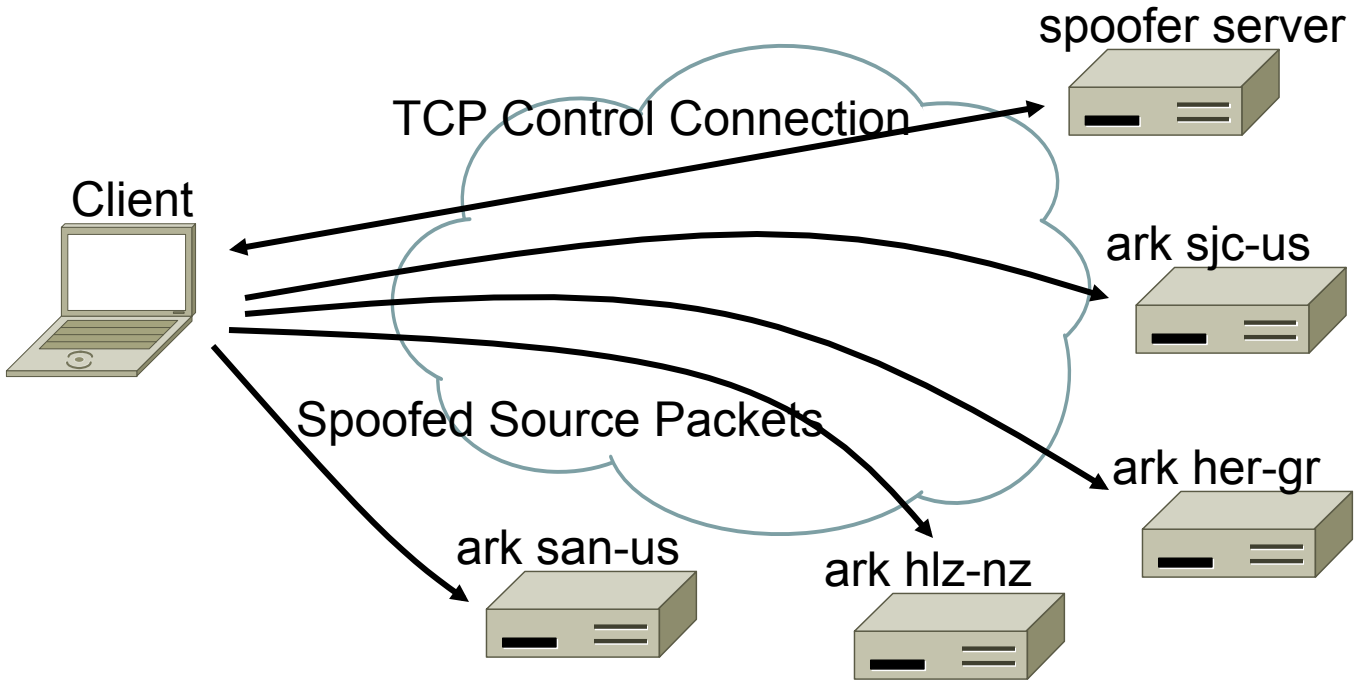
Distributed Probing



- Client sends HMAC keyed spoof probes to ark nodes
- Includes ground-truth validation (non-spoofed) probes
- UDP port 53 + random delay to avoid secondary filtering
- Client runs traceroute to each ark node in parallel

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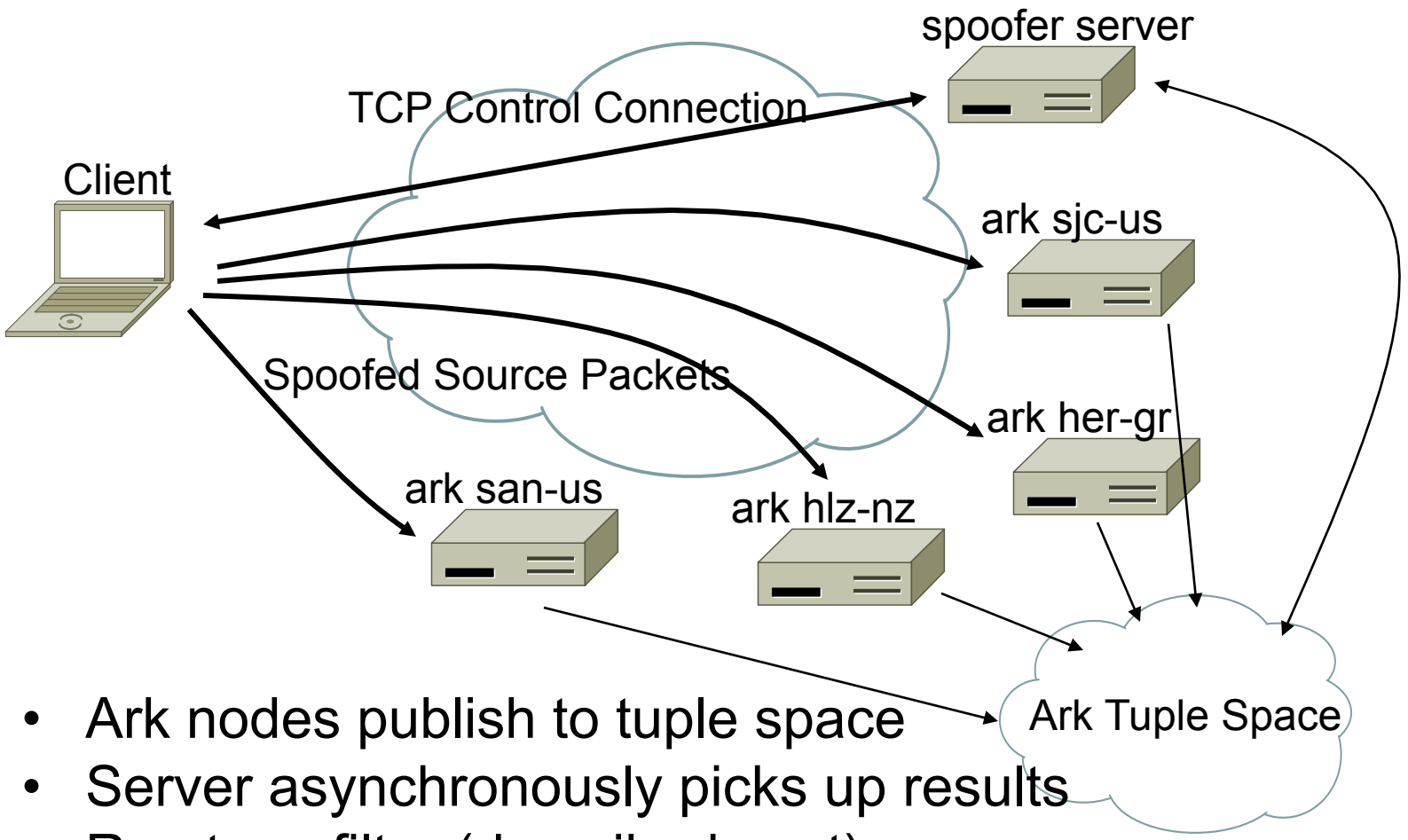
Distributed Probing



- Ark nodes publish to tuple space
- Server asynchronously picks up results
- Run tracefilter (described next)
- Return results to user via web report

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Outcome of a Probe

- Blocked by OS:
  - Detect, revert to raw Ethernet
- Hits a NAT along path:
  - Detect, exclude from results
- Other blocking (proxy, congestion):
  - Detect, exclude from results
- Blocked by source validation filter
- Successfully received at Ark node

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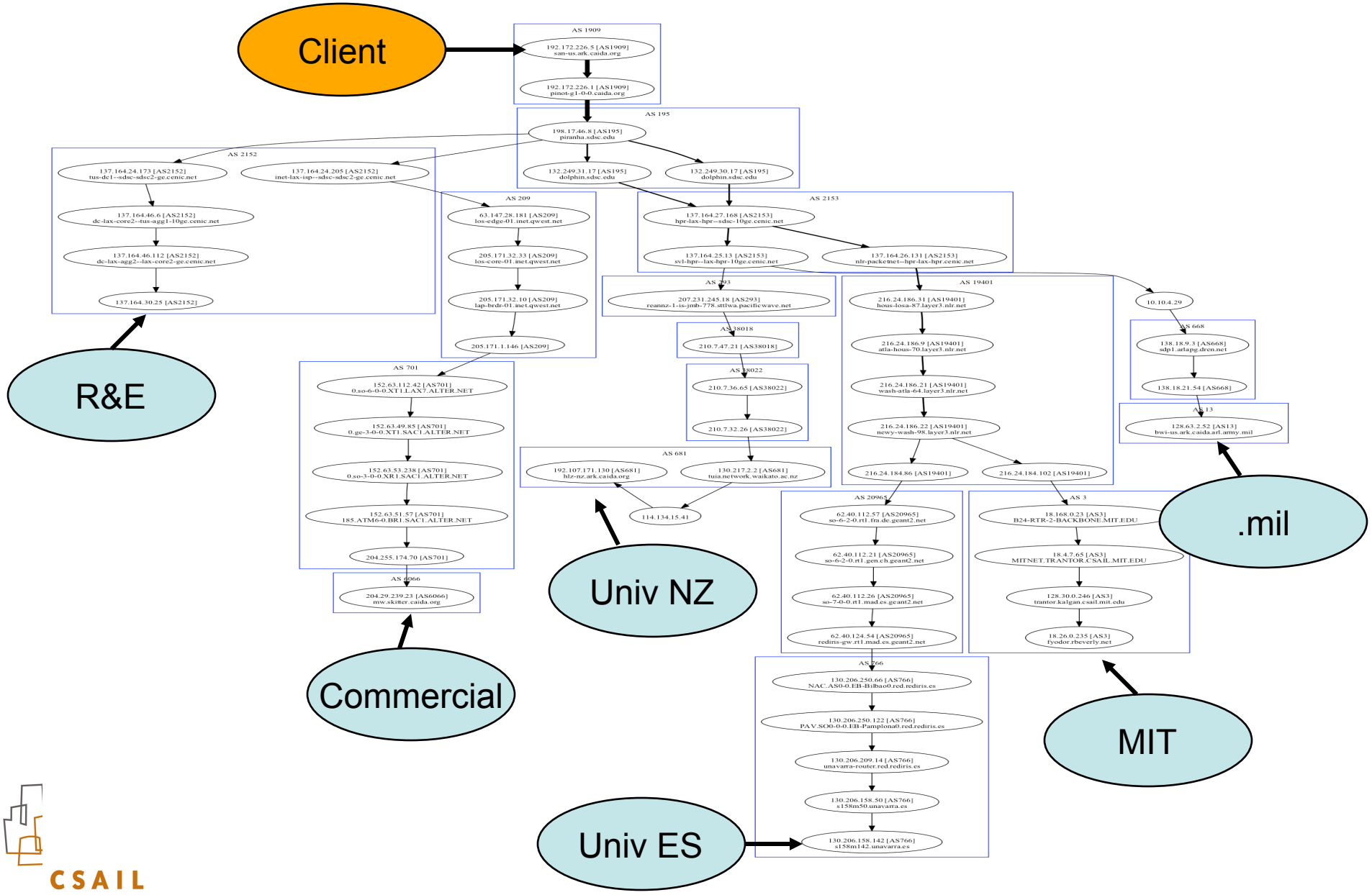
Ark Enables Better Inferences



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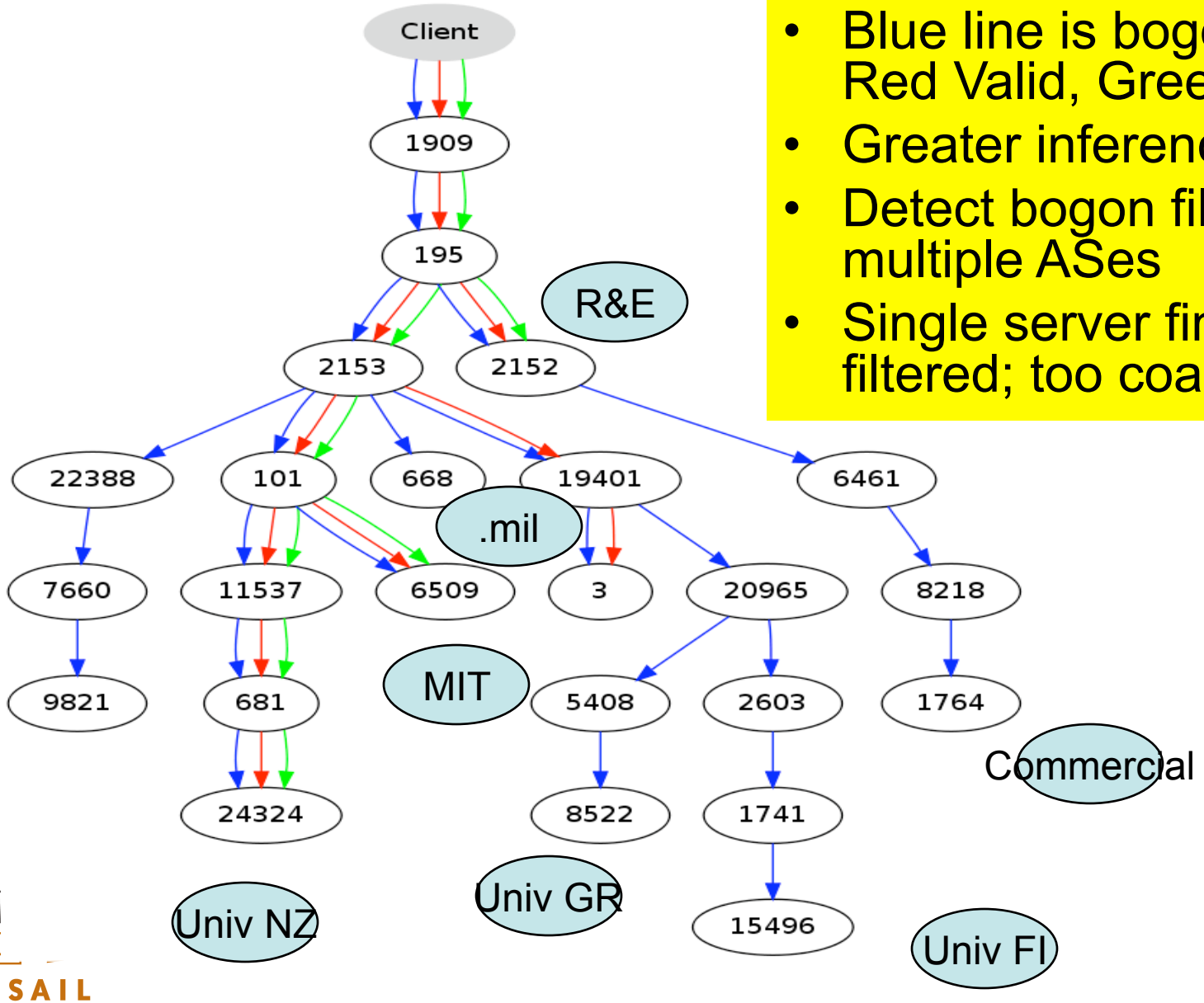
Multiple Destinations



- Blue line is bogon traffic, Red Valid, Green private
- Greater inference power
- Detect bogon filtering at multiple ASes
- Single server finds valid filtered; too coarse!

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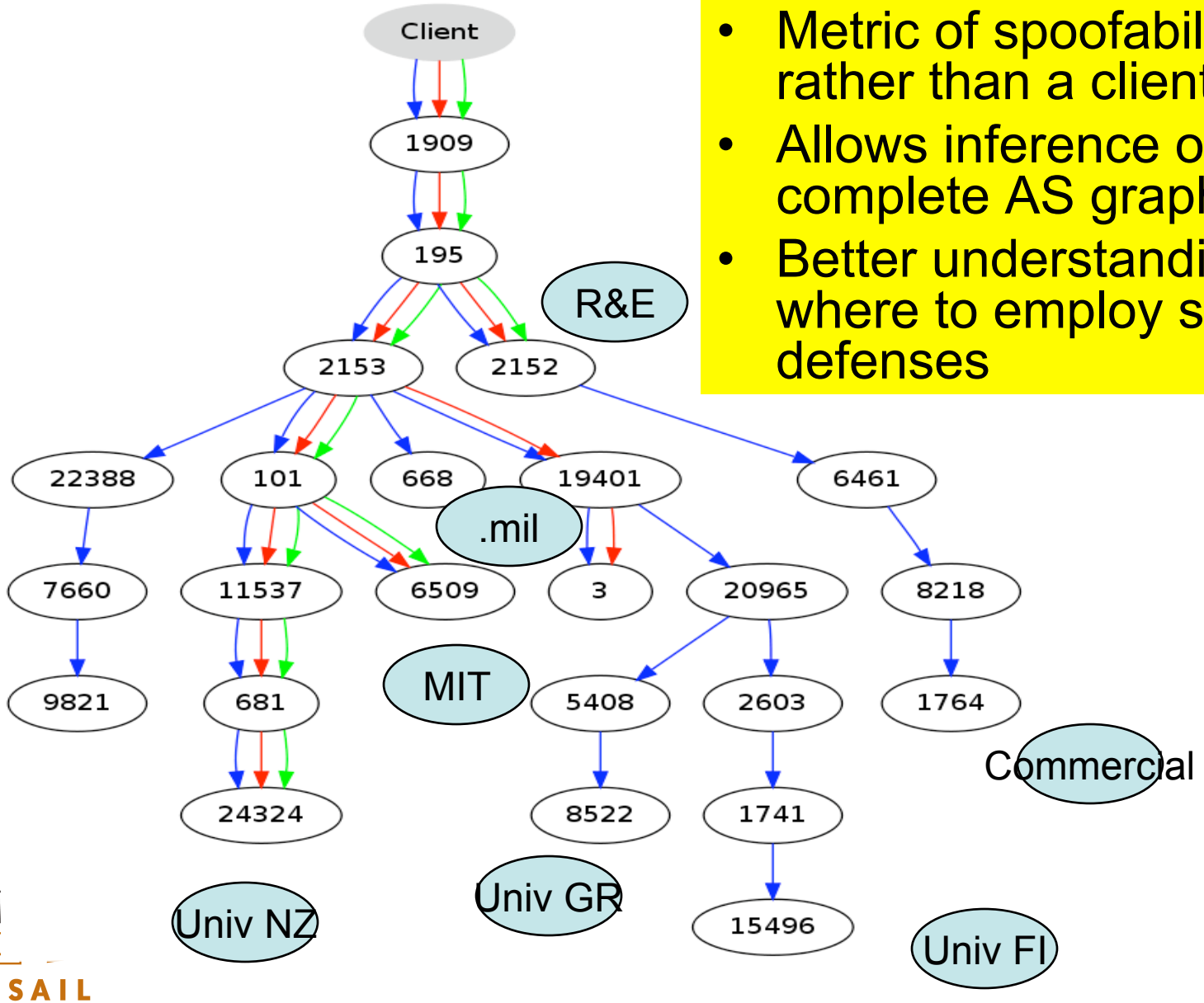
Multiple Destinations



- Metric of spoofability a path rather than a client
- Allows inference on the complete AS graph
- Better understanding of where to employ spoofing defenses

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tracefilter

- A tool for *locating* source address validation (anti-spoofing) filters along path
- “traceroute for BCP38”
- Better understand at finer granularity (router) who is/is not filtering

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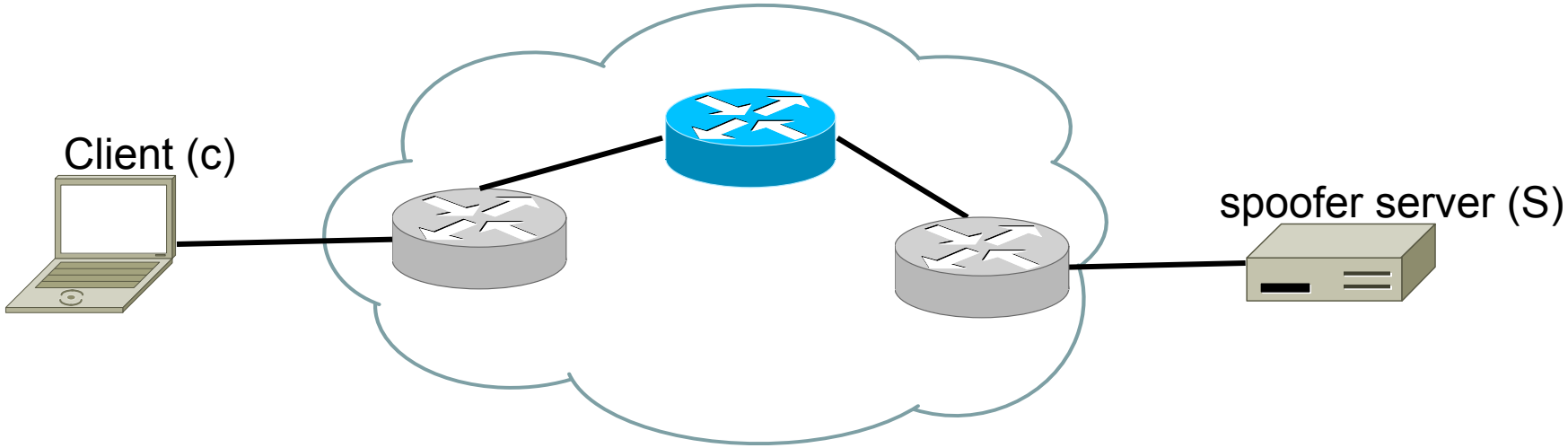
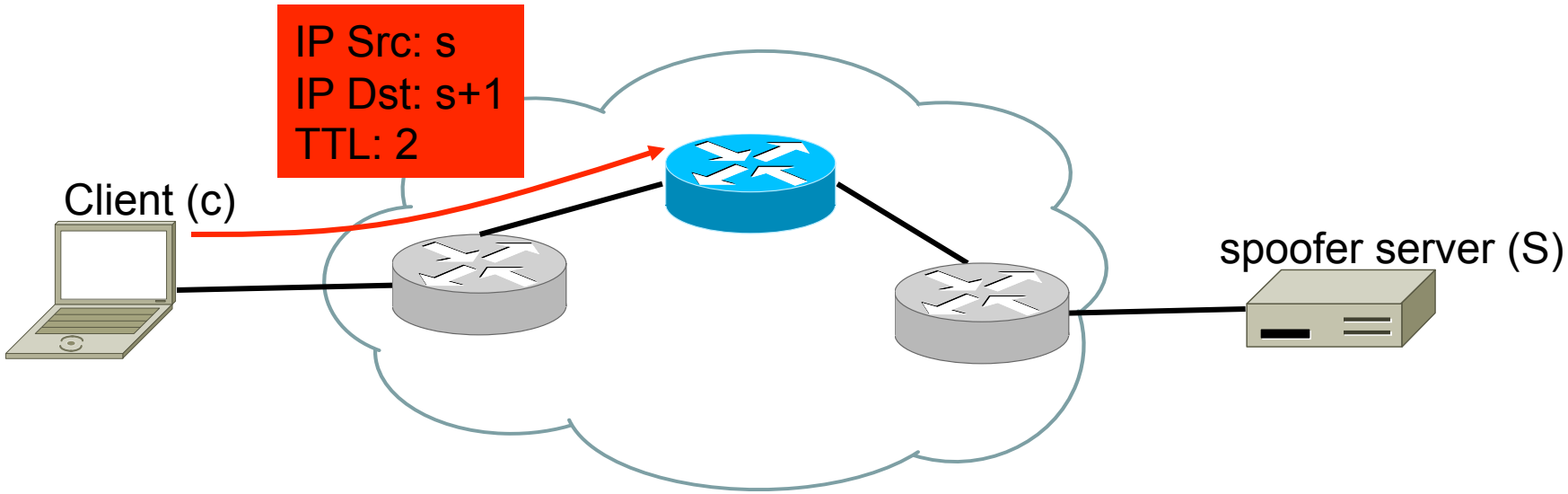
tracefilter



- Client c works in conjunction with our server S

tracefilter



- c sends spoofed packet with:
- ttl=x, src=S, dst=S+1 for 0<x<pathlen

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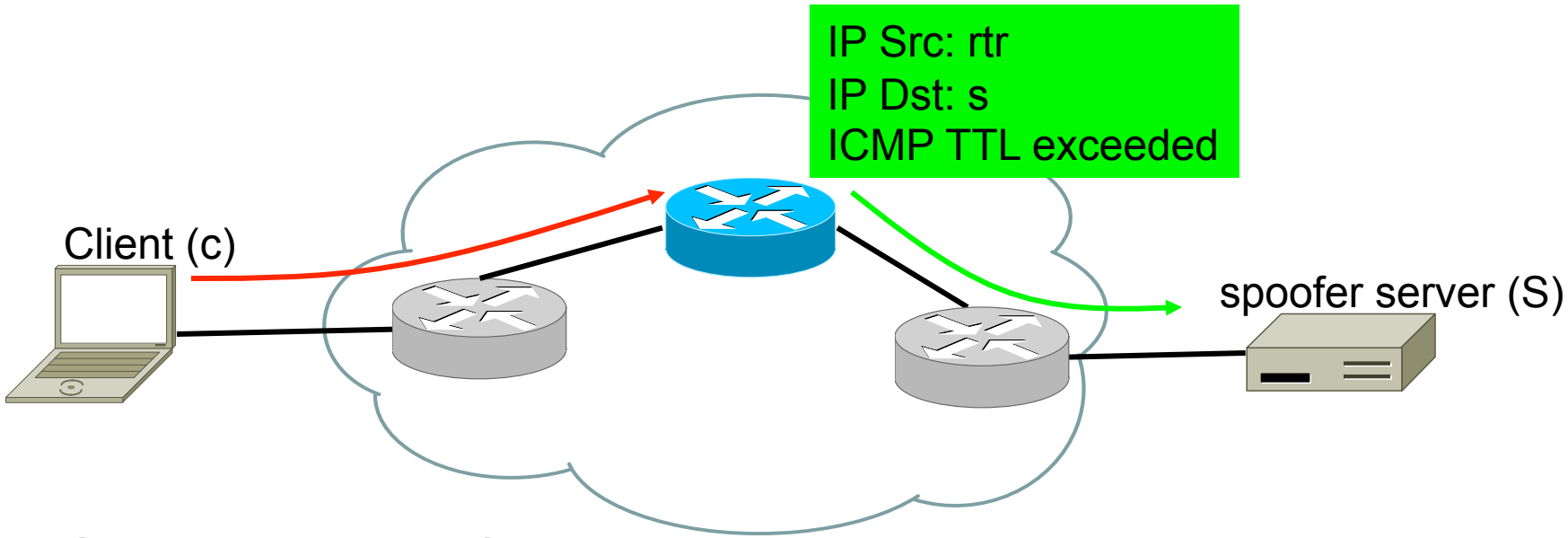
tracefilter



- S receives ICMP expiration messages from routers along path
- For each decoded TTL, S records which spoofed packets are received

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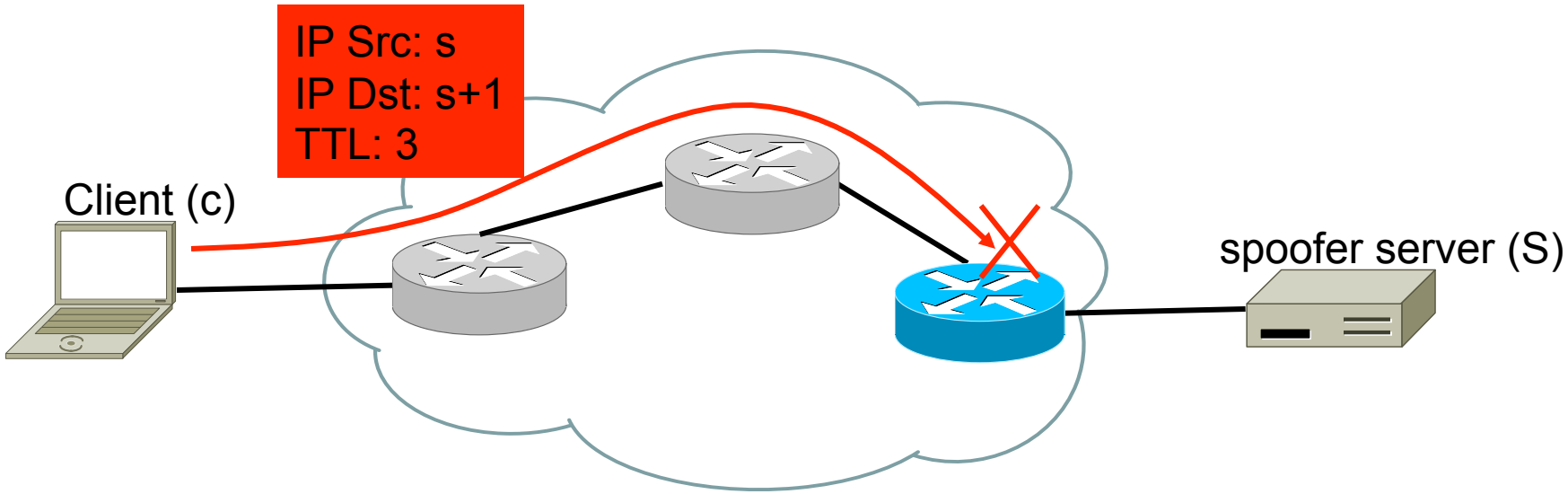
tracefilter



- Increase TTL, repeat
- Largest TTL indicates filtering point

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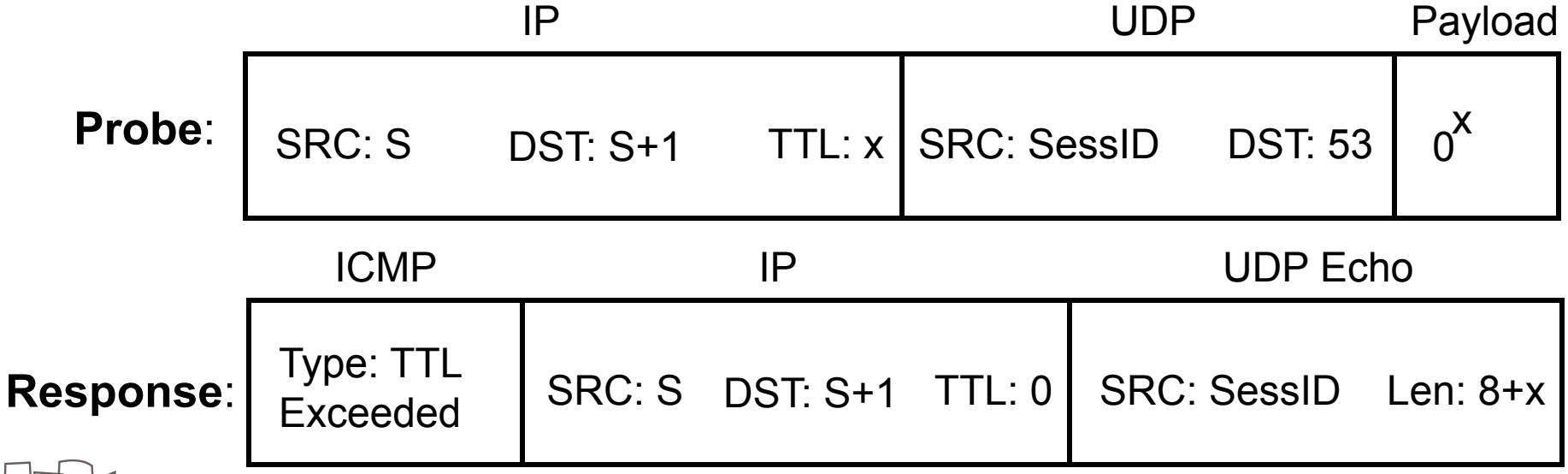
tracefilter

- How can *S* determine *originating* TTL of *c*'s packets?
- ICMP echo includes only 28 bytes of expired packet
- *c* encodes TTL by padding payload with zeros



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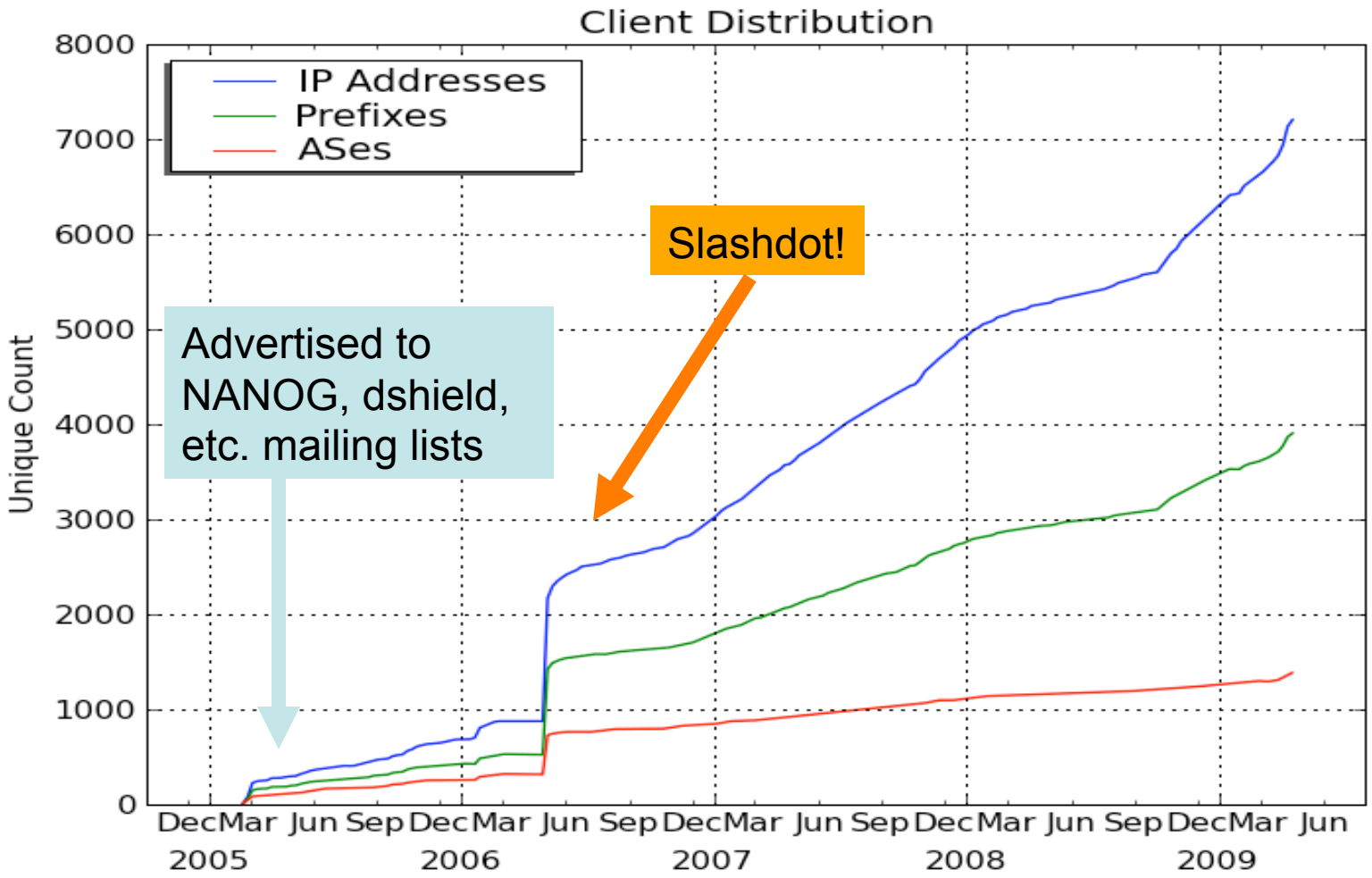
Client Population



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Sample Bias

- Obtain general population using 20.8M unique IPs from random topology traces
- Use NetAcuity for geolocation, descriptive statistics
- Aggregate general population into /24s to eliminate non-homogenous poperties

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Comparing Populations

- Evaluate Bias:
  - Country, speed, organization type, etc.
- Continent Analysis

Continent	Population	Measurement Set
N. America	37%	36%
Europe	29%	33%
Asia	28%	17%
S. America	4%	4%
Oceania	1%	2%
Africa	0.5%	6%

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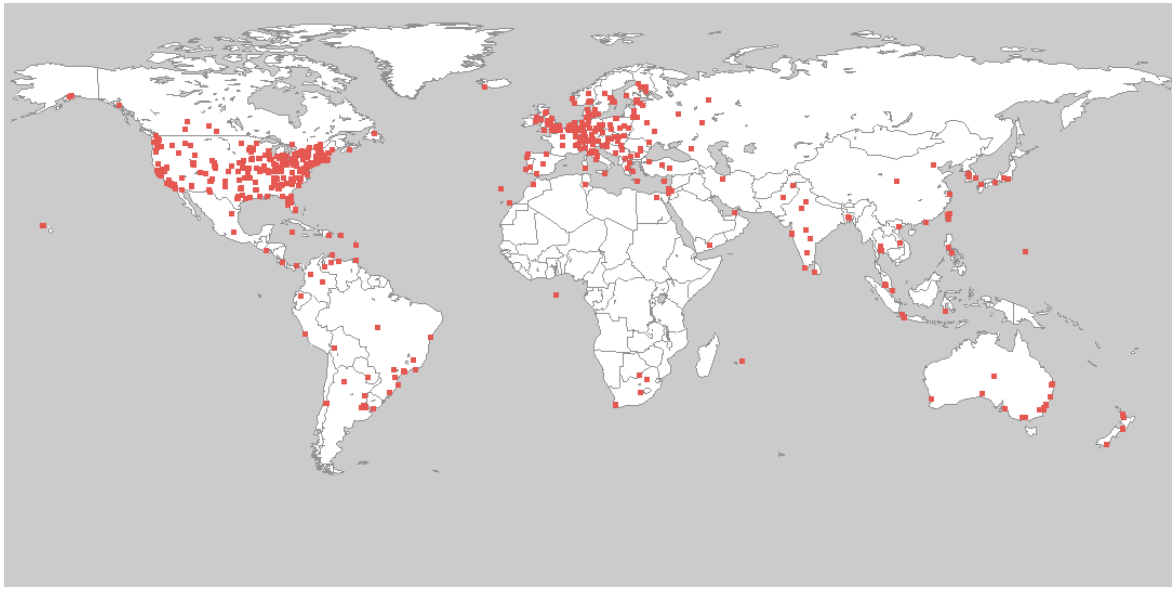
Client Population Distribution

- ~12,000 unique tests
- 132 countries present in data set
- Don’t claim zero bias
- Do claim diverse and representative



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Questions

- Are there filtering variations among paths?
- What filtering methods are used?
- Where in network is source validation?
- Granularity of filtering?
- How vulnerable is the Internet?
- How has filtering evolved over >4 years?

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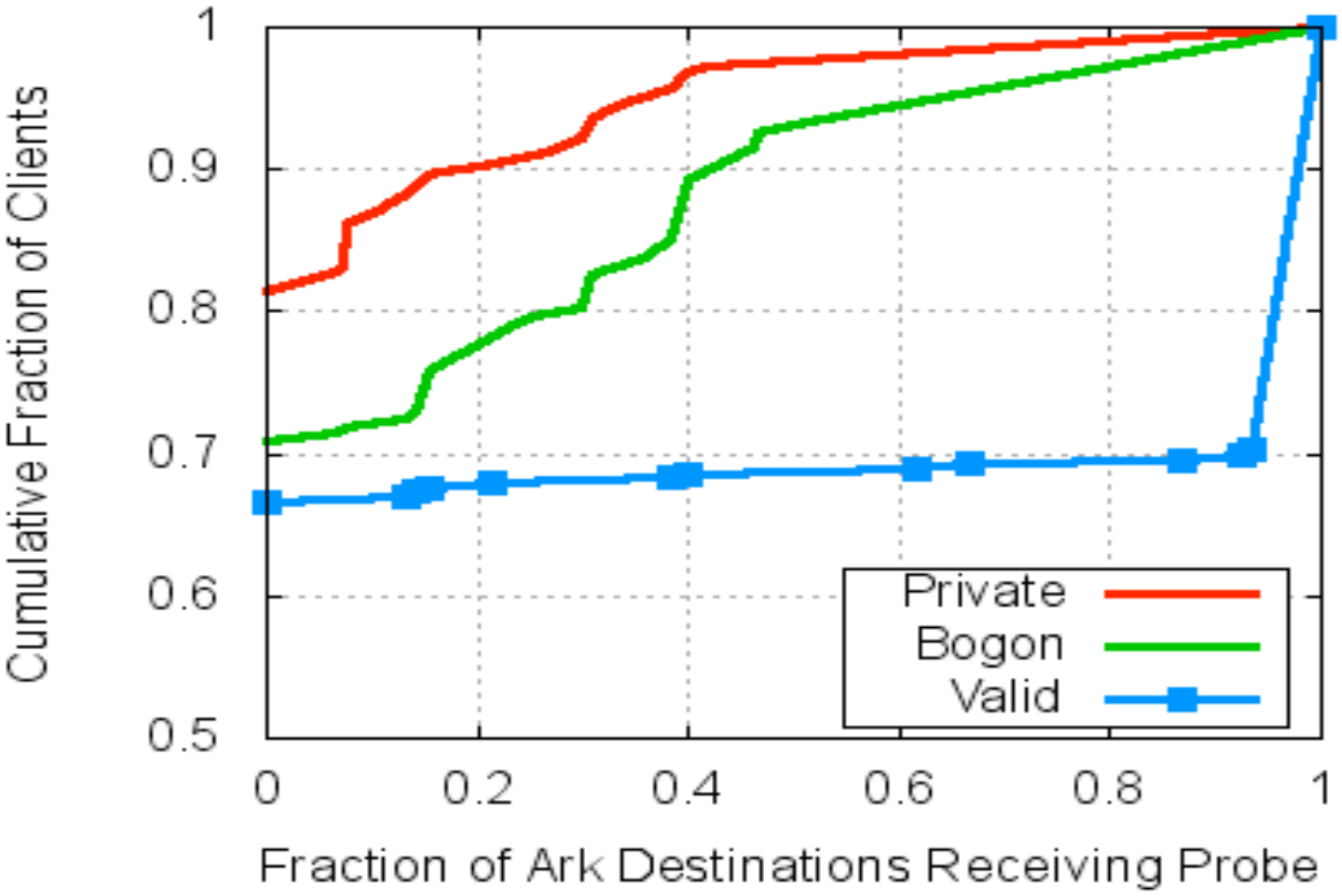
Path-based Filtering Variation?



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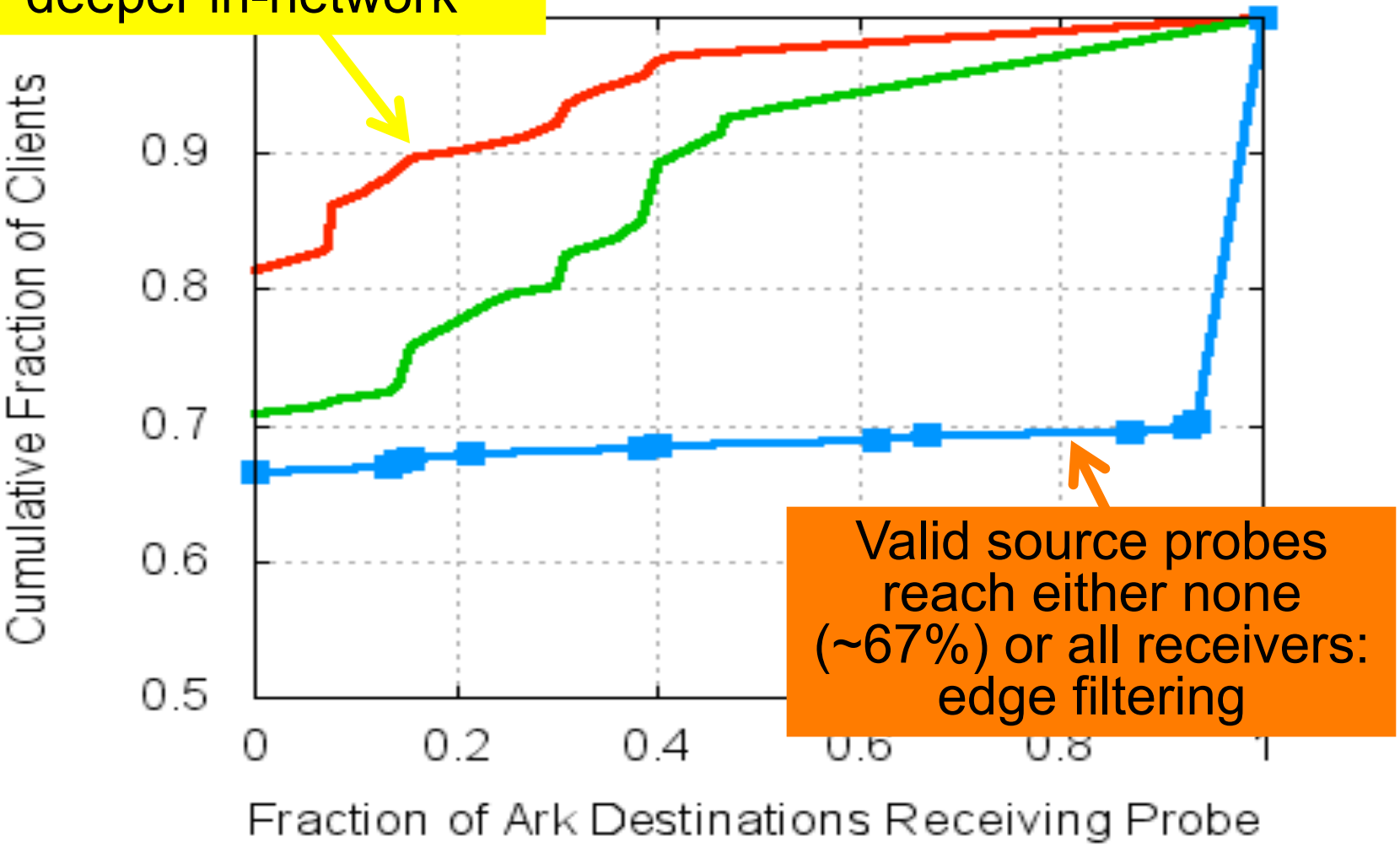
n Variation

Surprising variation among bogon and private sources: filtering deeper in-network



Valid source probes reach either none (~67%) or all receivers: edge filtering

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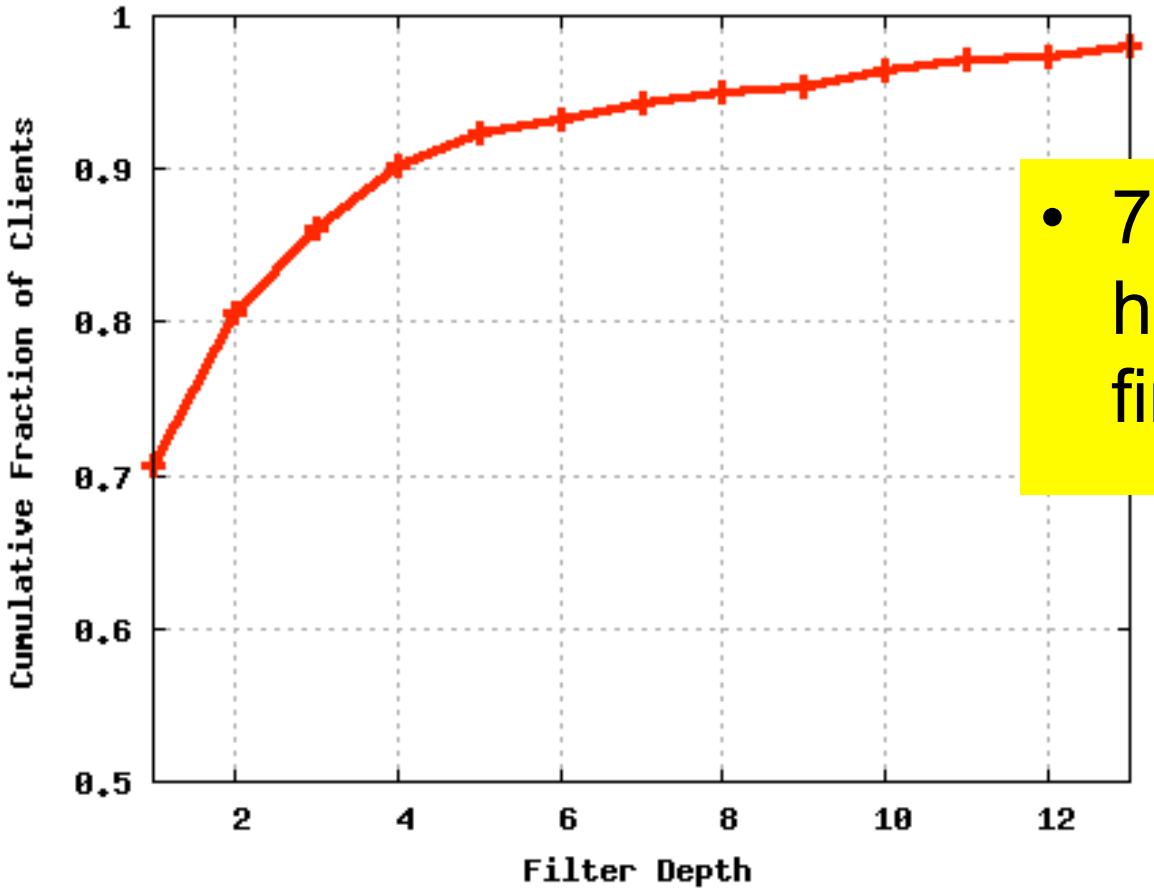
Where is source validation?

- tracefilter results:



- 70% of filters at 1st hop; 81% within first two hops

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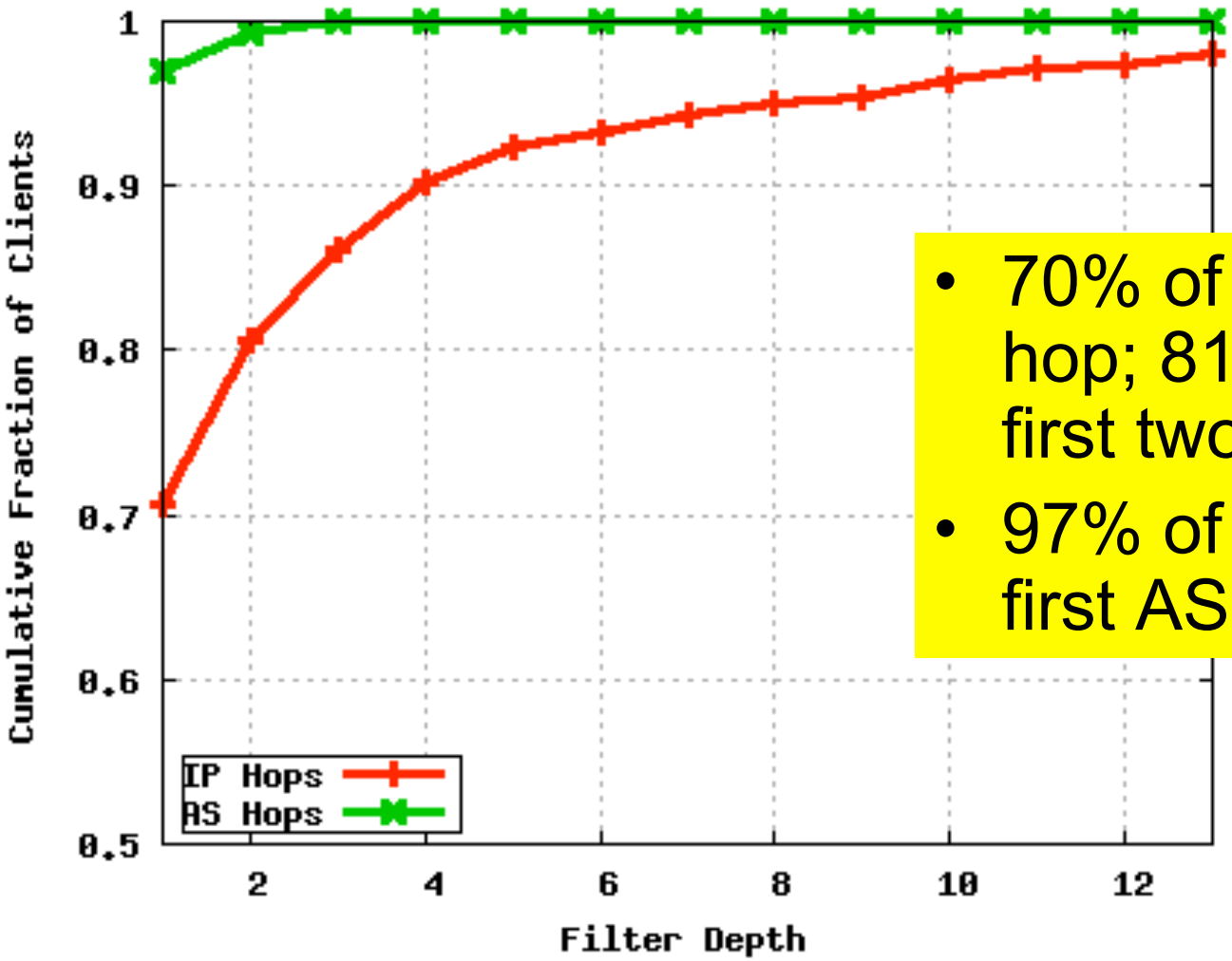
tracefilter Results



- 70% of filters at 1st hop; 81% within first two hops
- 97% of filters within first AS

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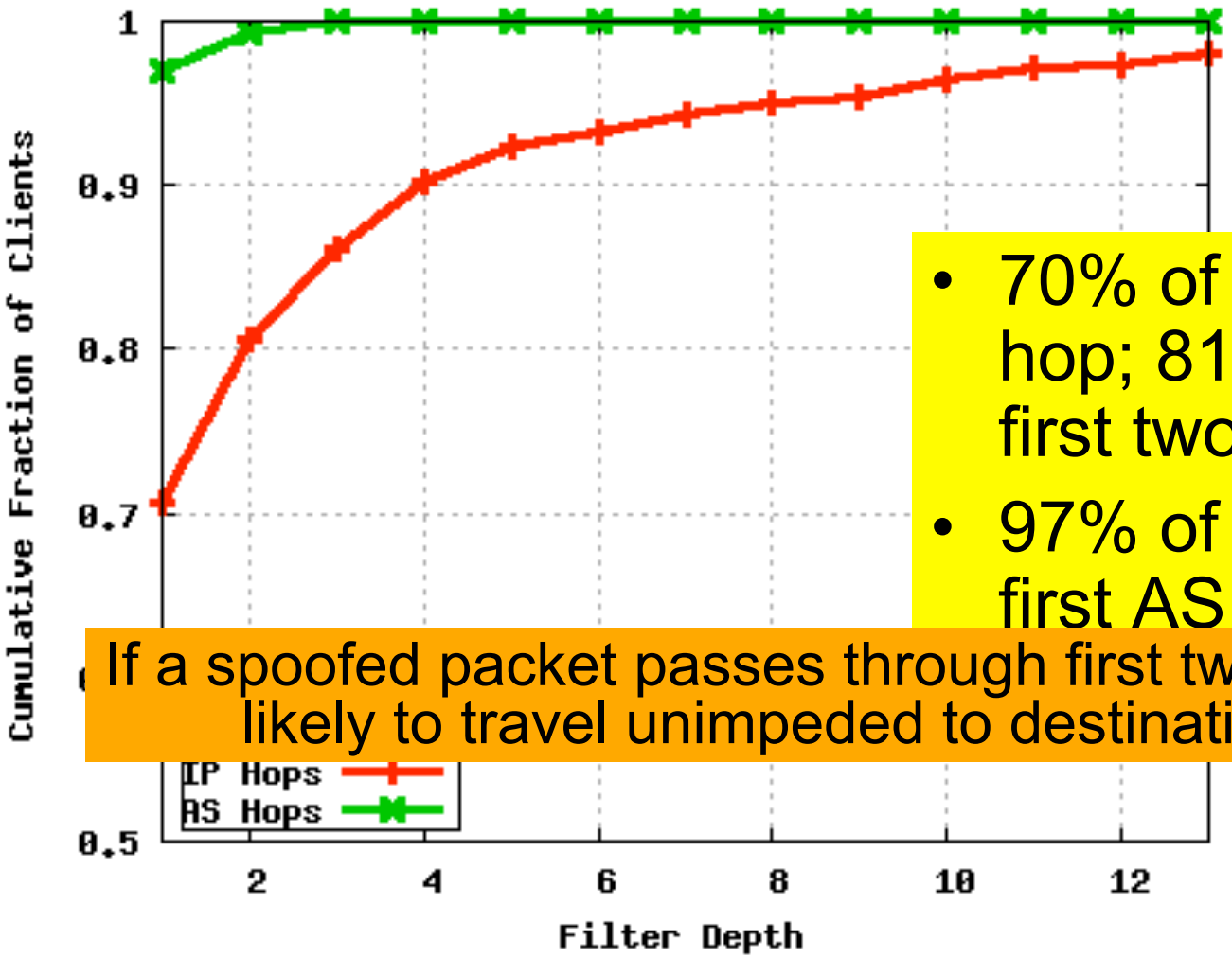
tracefilter Results



- 70% of filters at 1st hop; 81% within first two hops
- 97% of filters within first AS

If a spoofed packet passes through first two hops, likely to travel unimpeded to destination

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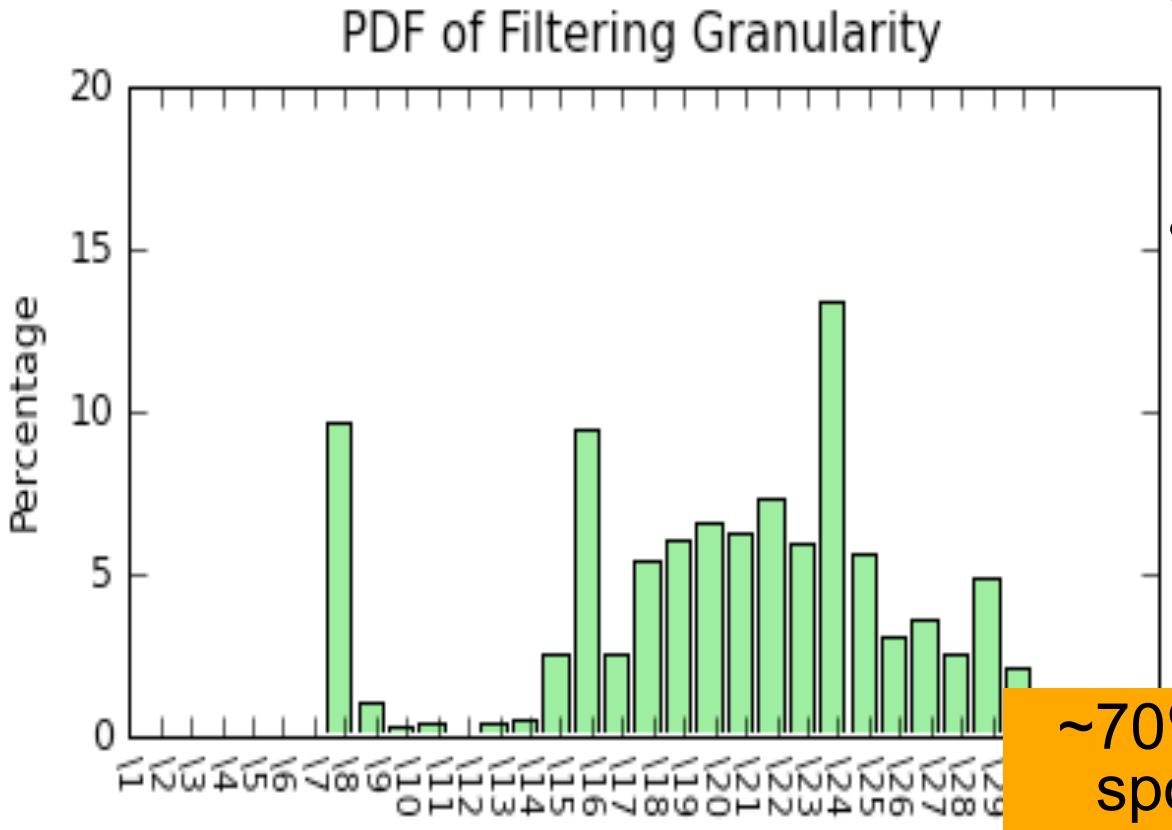
Filtering Granularity



- Clients test own IP ⊕ (2^n) for 0<n<24
- Filtering on a /8 boundary enables a client within that network to spoof ~16M addresses

~70% of clients unable to spoof test sources can spoof neighbors

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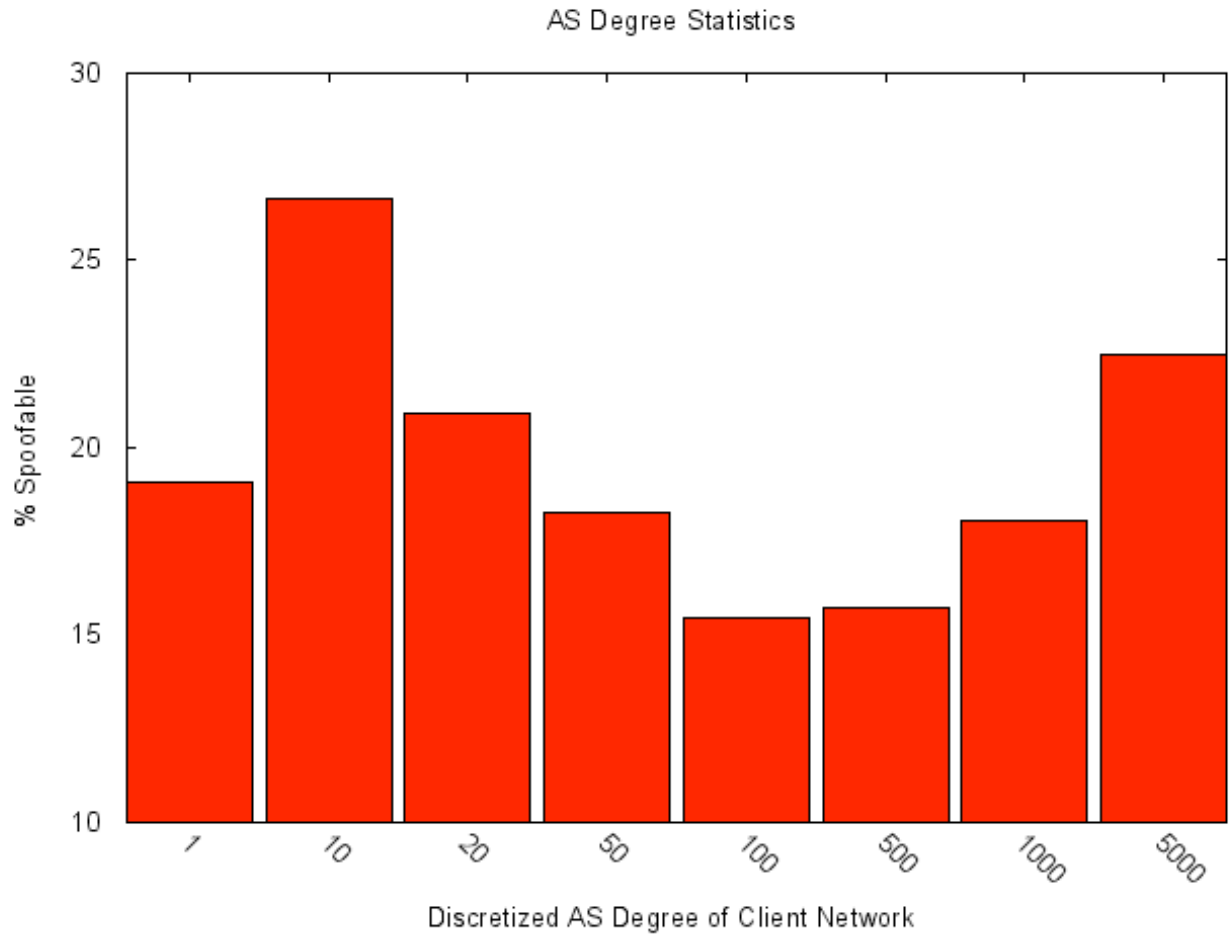
* “Neighbor spoof” excluded from macro results

AS Degree



- Small or large providers filtering?
- Surprisingly, no clear trend
- Work required across the board (or a new solution)

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Evolution of Spoofability

- Find two three-month periods with large and comparable sample sizes

	Proportion Spoofable		
Metric	2005 (single dest)	2009 (single dest)	2009 (all dests)
Sessions	18.8%	29.9%	31.2%
Netblocks	20.0%	30.2%	31.7%
Addresses	5.0%	11.0%	11.1%
ASes	23.4%	31.8%	34.1%

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Less filtering four years later

Change not attributable to increasing number of destinations

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Parting Thoughts

- Even after all these years, source spoofing problem not solved. It's the incentives:
  - Provider can follow BCP38 and still receive anonymous, spoofed traffic
  - Others can spoof a provider's address space
  - Disincentive in form of accidental blocking
- Single unfiltered ingress can compromise entire Internet system
  - Can we plug every hole?
  - Regulatory Response? … but multinational?
  - Spoofer page for public provider flogging?

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Parting Thoughts

- Tracefilter exposes operational tension between filtering incentives and managing edge filters
- If a spoofed packet isn't filtered at edge, will travel unimpeded to destination
- Needed?
  - Filtering in the core
  - Clean slate design
- Think (seriously) about alternate techniques?
  - StackPI [Yaar, Perrig, Song 2006]
  - Passport [Liu, Li, Yang, Wetherall 2008]
  - Others?

Parting Thoughts

- Tracefilter exposes operational tension between filtering incentives and managing edge filters
- If a spoofed packet isn't filtered at edge, will travel unimpeded to destination
- Ne
  - –
  - –
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  - Others?

Thanks!

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