Rate-limiting of IPv6 traceroutes is widespread: measurements and mitigations.

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Outline

- Traceroute is an important tool in understanding overall Internet topology
- We have observed worse performance for IPv6 traceroutes compared to IPv4
- What are the underlying reasons for data loss, and the characteristics of this loss?
- Is there something we can do to improve performance within the current state of affairs?
- How can / should we change that state of affairs?

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How much worse are IPv6 traces than IPv4?

- Collect
  - ~20M traceroutes
  - to ~200K IPv4 and ~100K IPv6 targets
  - From ~8K sources
  - Over 1 day (most traces collected within 1st 6 hours)
- Count the number of null hops before the last non-null hop on each trace
- Aggregate % missing hops for each target and for each source separately.

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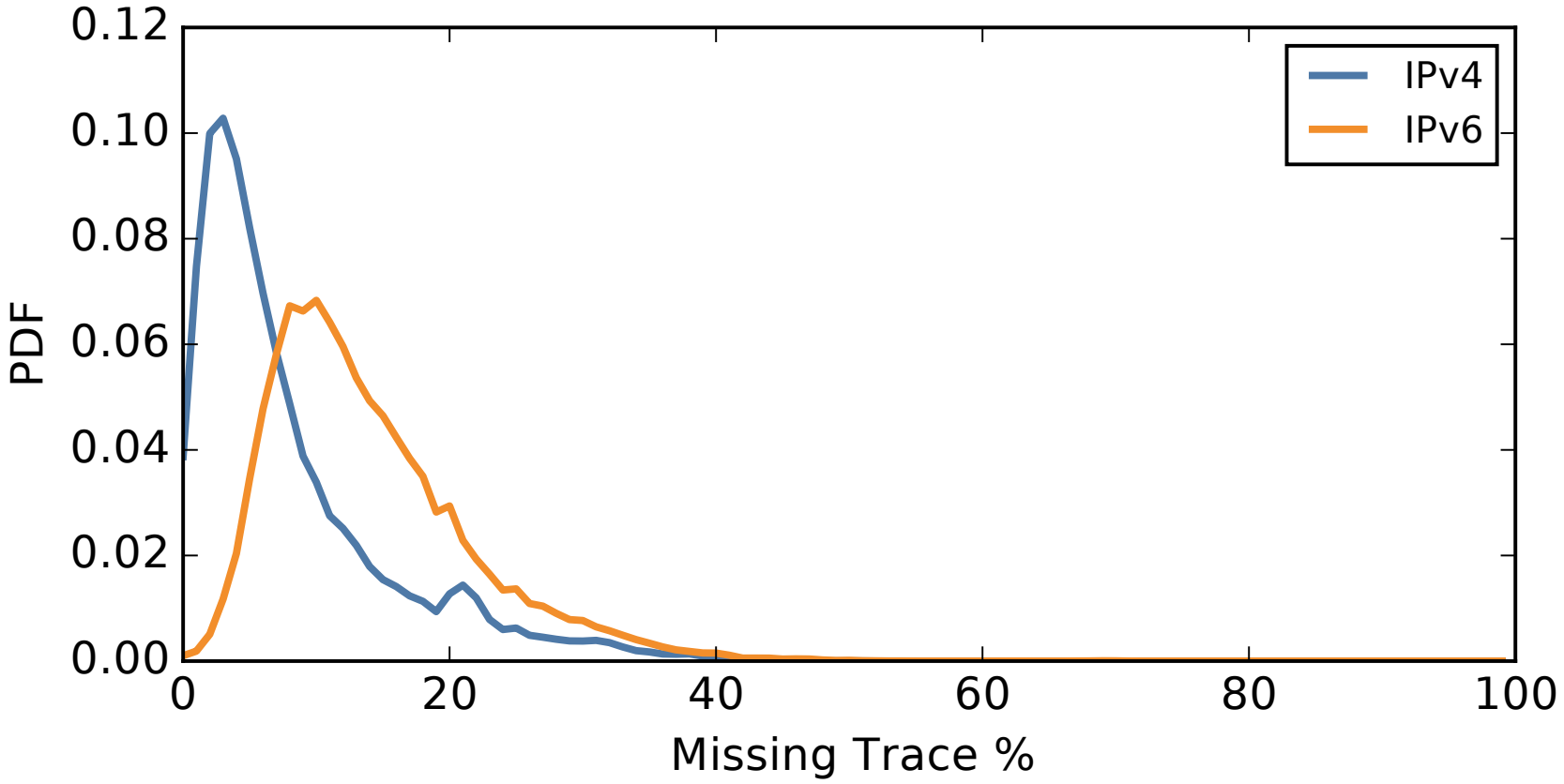
How much worse are IPv6 traces than IPv4?

Missing routers for each target



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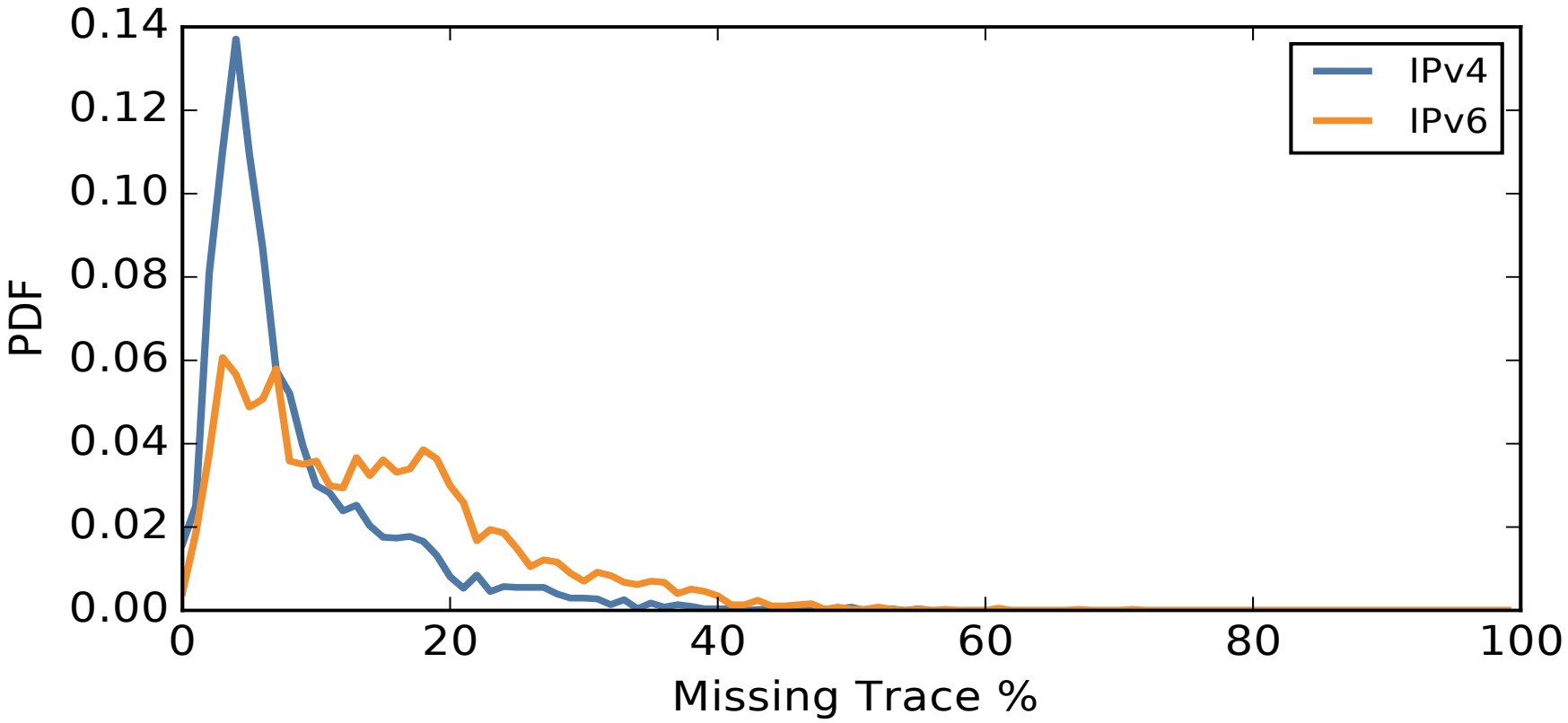
How much worse are IPv6 traces than IPv4?

Missing routers for each source



Many more missing hops in IPv6 traces, whether we aggregate over source or over target.

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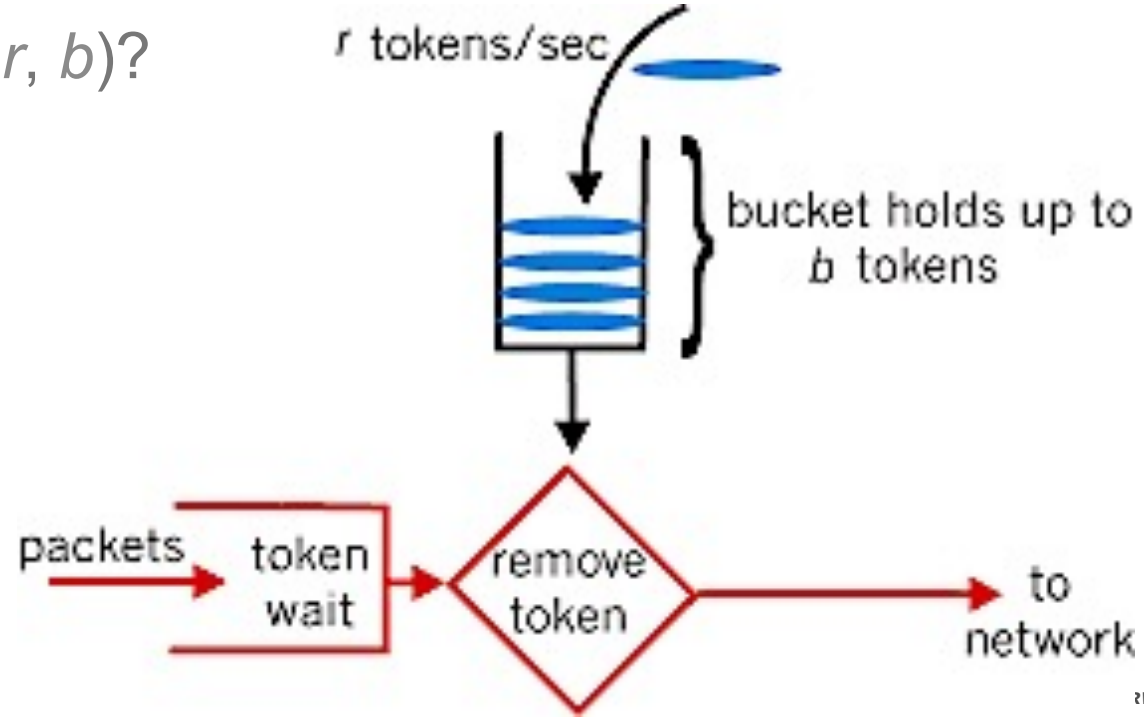
Why routers drop IPv6 error packets

- Analysis shows presence of rate-limiting for v6
- RFC 4443: routers MUST rate-limit v6 error messages
- RFC recommends using token-bucket for rate-limiting
- Token-bucket(*r*, *b*) allows *r* error packets per second, bursts of *b* packets
- Can we estimate (*r*, *b*)?



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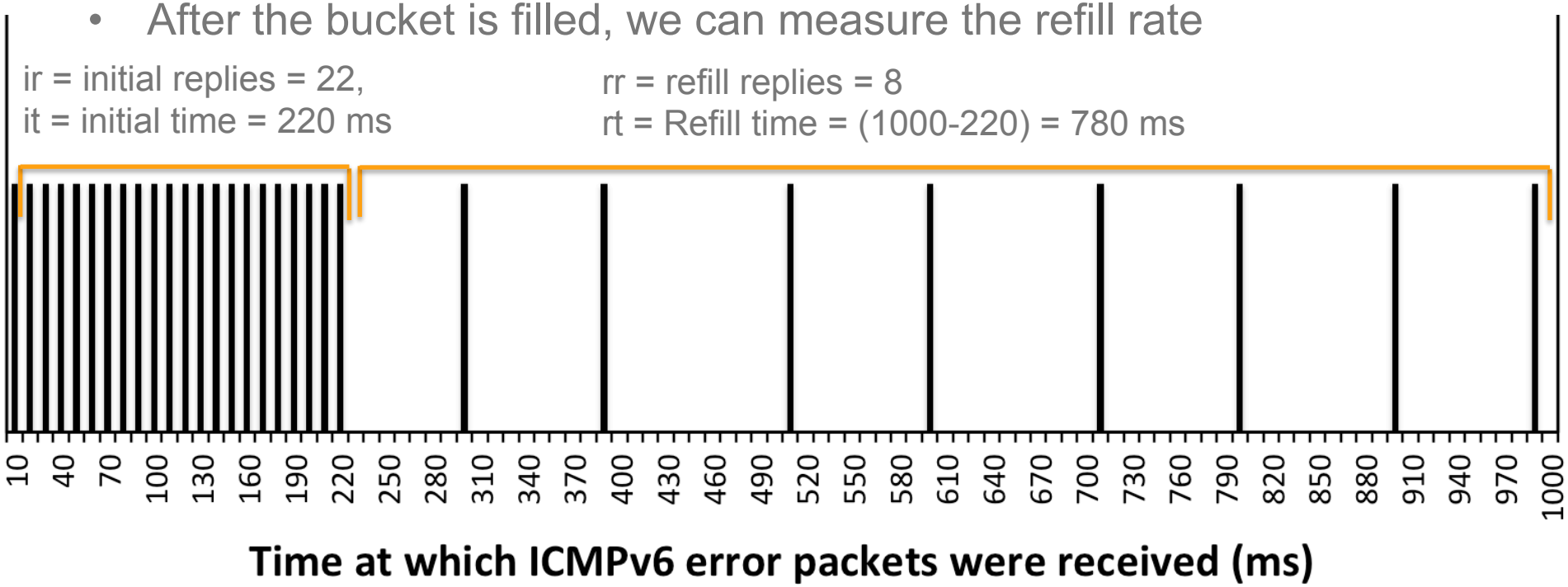
Measuring ICMPv6 error packet rate limiting

- Send a packet with the same TTL to the same target every ~10ms
- See how many come back, and when
- The “clump” at the start is the bucket size
- After the bucket is filled, we can measure the refill rate



- refill rate estimate = rr/rt = 11 Hz
- Bucket size = ir – (it * refill rate) = 20
- Adjusted refill rate = (rr + (ih – bucket size)) / rt = 10 Hz
- If refill rate > 66Hz, ignore bucket size (hard to measure)

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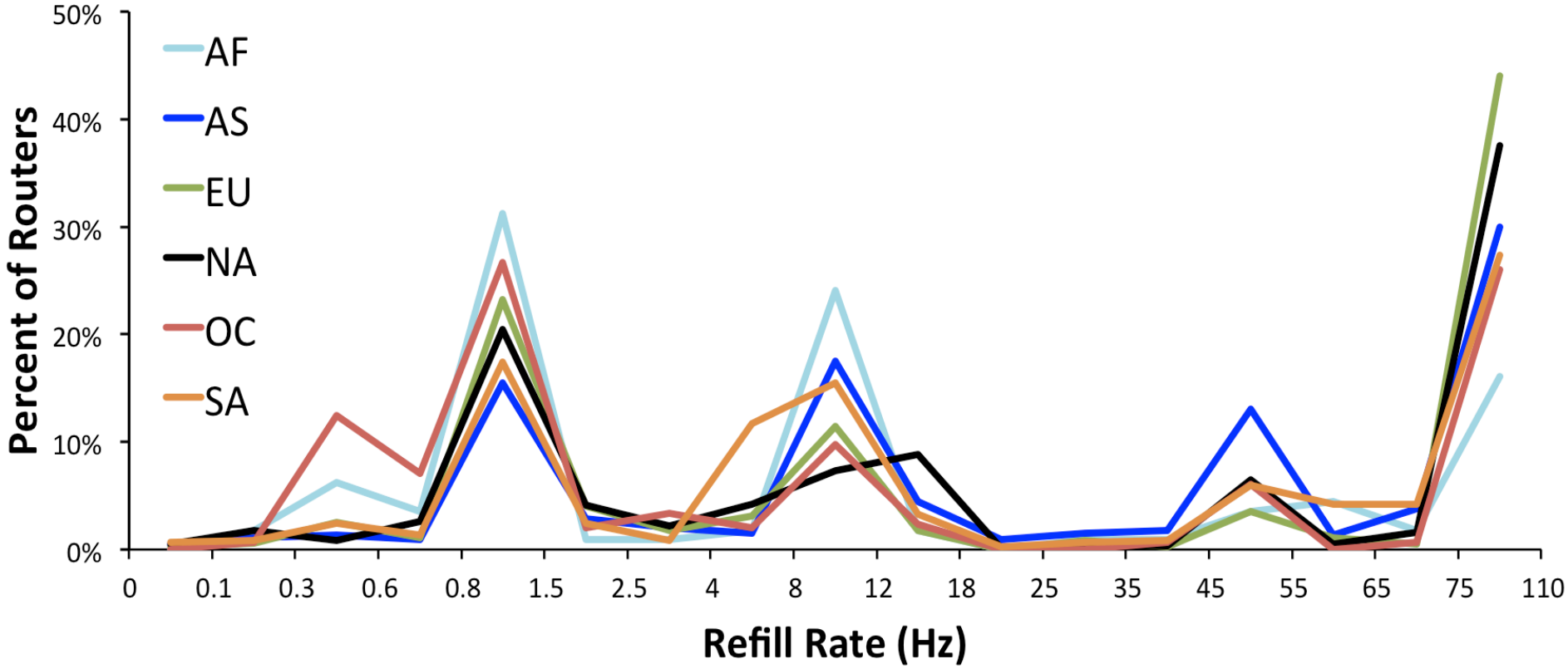
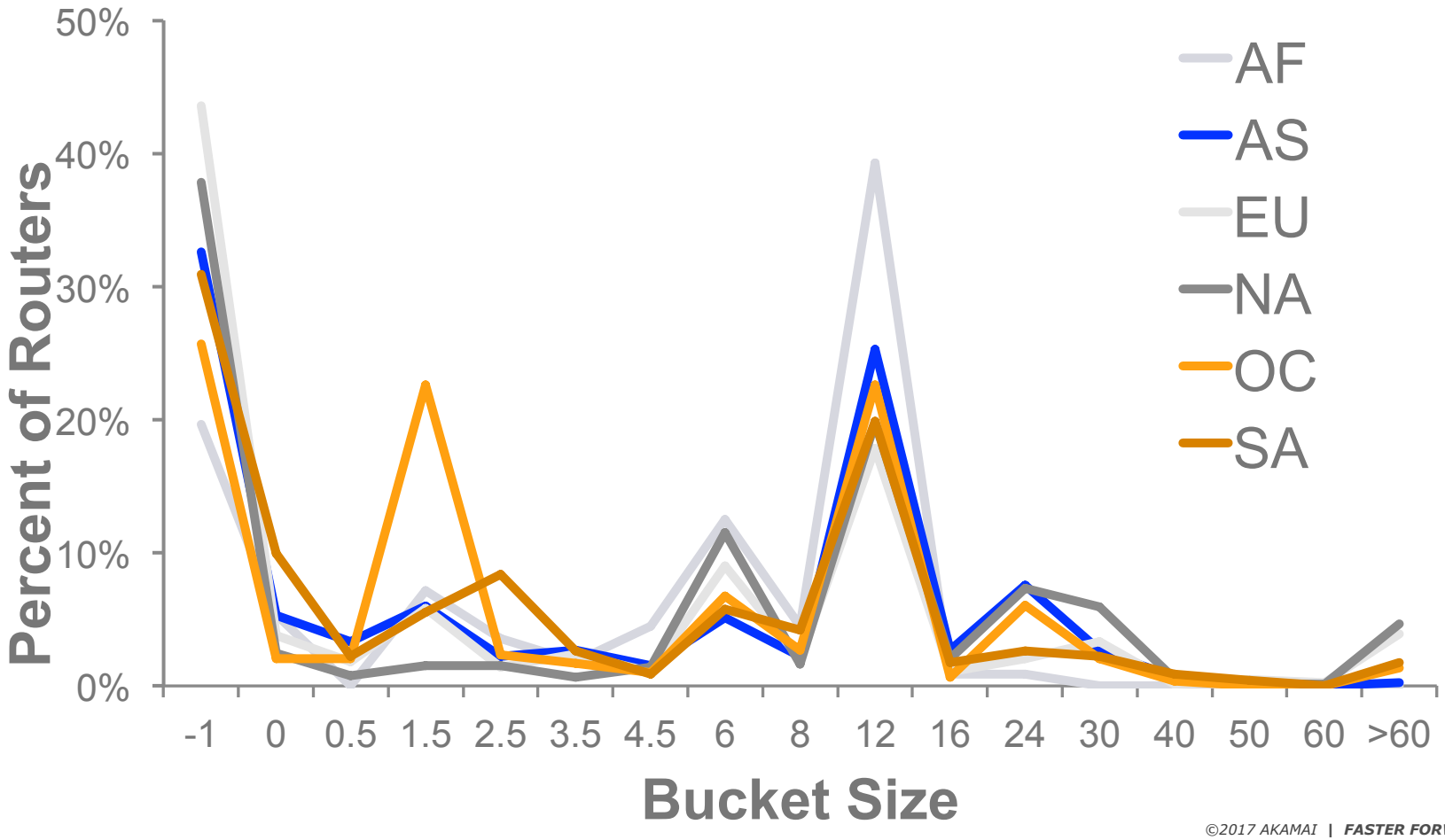
Results: many routers show similar rate limits

- 3078 routers in 6 continents (112 in AF … 906 in NA. NA and SA are separate)
- 18% of hops (8700/48000) had more than one router, not used here.
- ~1/3 of routers do not show rate-limiting at the ~100Hz frequency we tested.
- There are consistent peaks in refill rate across continents, probably reflecting default factory settings on the routers



Routers also show similar bucket sizes

- Again, the data support the idea most routers are set to default configurations
- Size == -1 indicates no bucket size detected (router allows rates close to 100 Hz).



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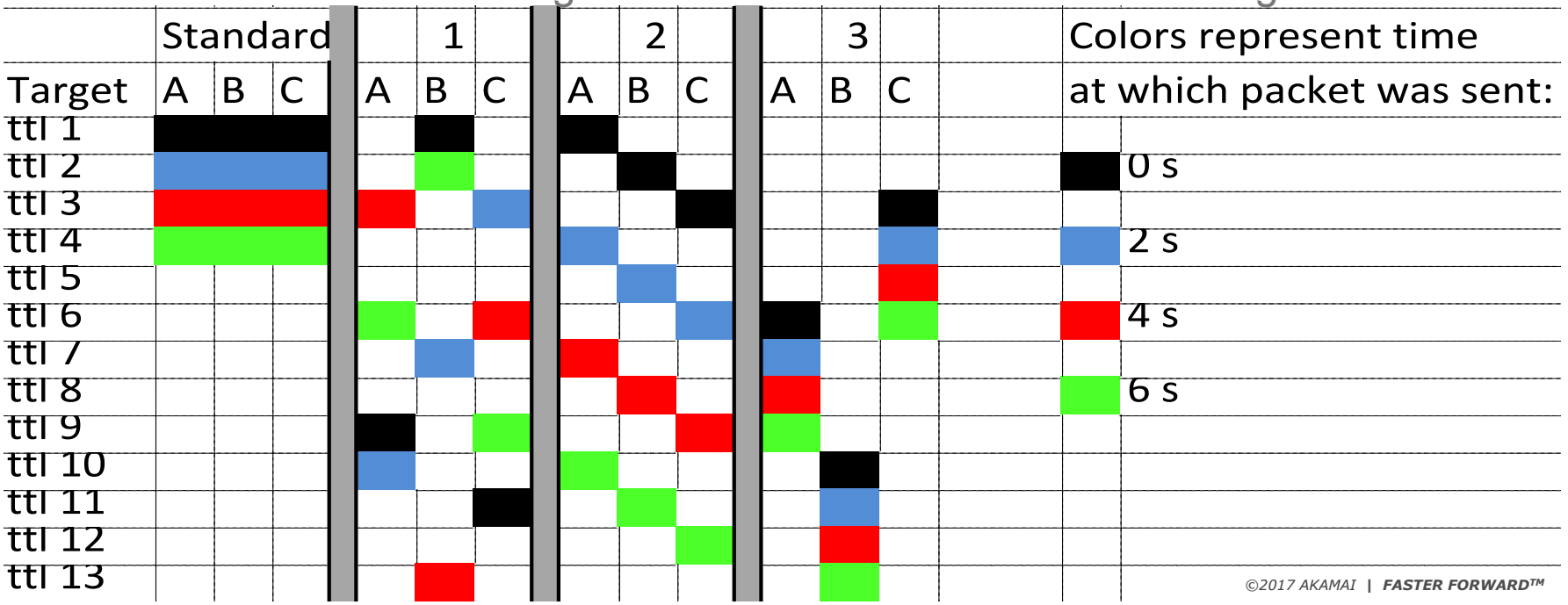
Mitigation 1: Spread out TTLs

- Standard method: send out a packet with TTL 1 for each target, wait for return, send out packet with TTL 2, etc…
- This is the worst possible way to do things for multiple targets: since many traces hit the same routers at the same time, we empty the token bucket as fast as we can and do not allow time for refills.

1. Random TTLs overall

2. TTLs increasing across targets

3. Start trace at random TTL for each target.



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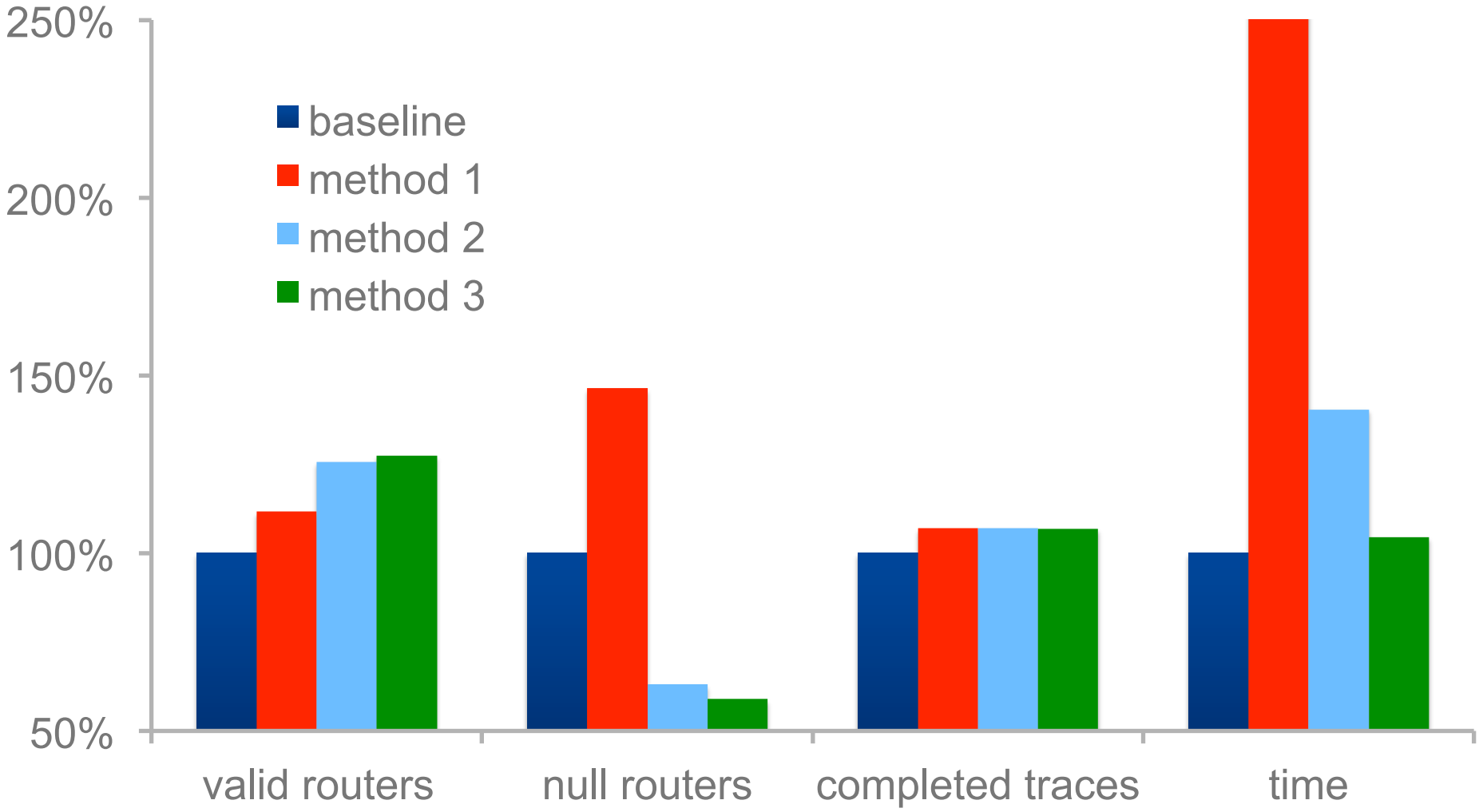
How much does spreading out TTLs help?



Method 3 seems the best choice: pretty fast, and clear improvements

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Mitigation 2: Fill in traces with known data

- If a router's bucket is empty, that means it has previously sent back at least one error packet
- We are likely to have that information, and can use it to fill in subsequent trace efforts

Example:

Trace 1: A->**B**->C->D->E->F->G->H

Trace 2: A->*->C->**T**->U->V->W

Trace 3: A->*->C->*->U->M->N->O->P

Trace 3 filled in: A->**B**->C->**T**->U->M->N->O->P

Caveats:

- Cannot keep old data around too long
- Ignores load balancing routers
- Sometimes we just don't have the data

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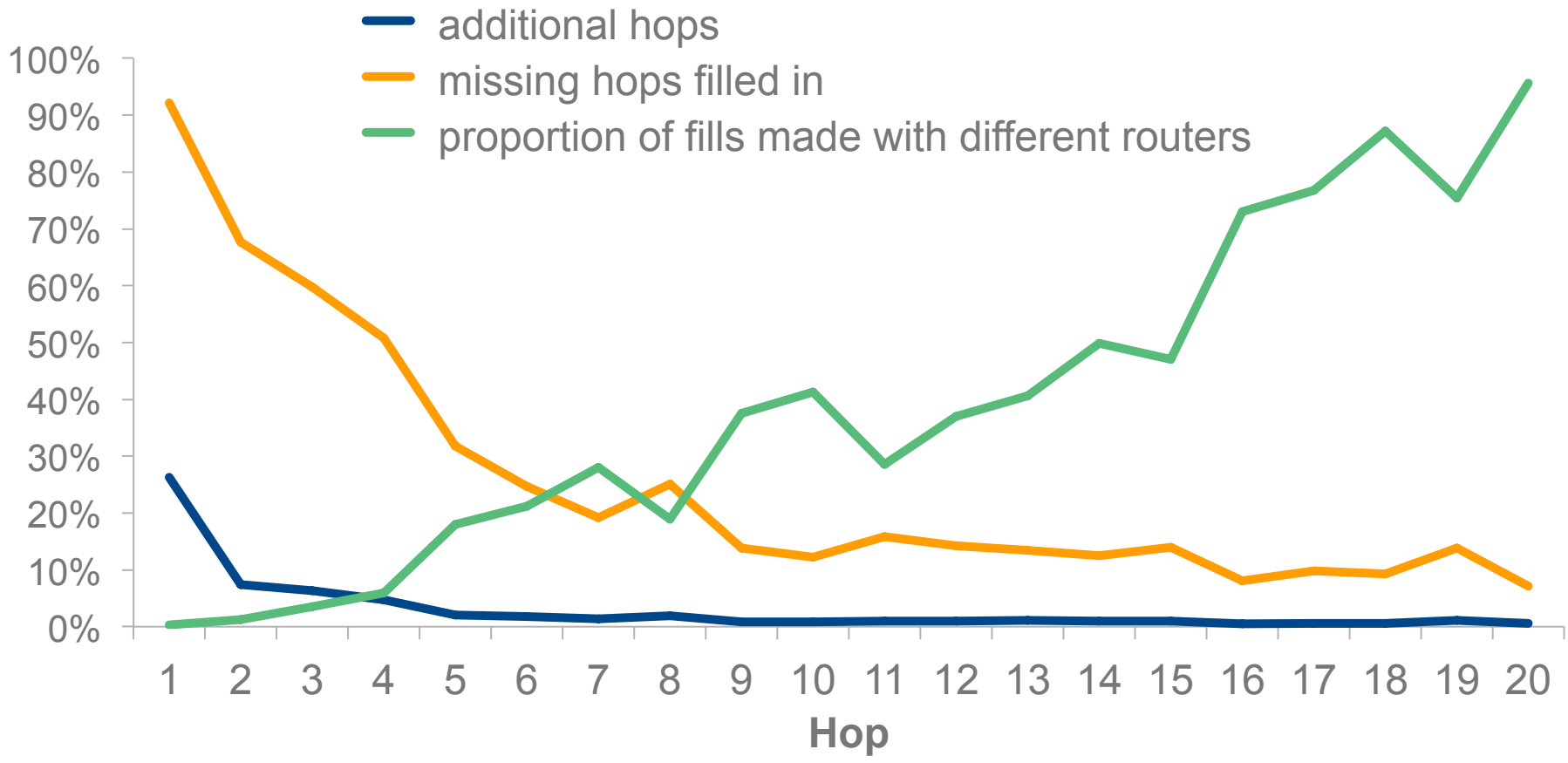
Gains from filling in traces with known data



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Summary

- Starting many IPv6 traces at the same time is problematic: routers will drop many of the return packets due to RFC-imposed rate-limiting.
- Different routers have very different rate-limiting properties
- Rate-limiting properties are little known and appear to remain at factory defaults.

Tested possible mitigations from the tracing side:

- Changing the order of TTLs to avoid having multiple traces hit the same router at nearby times.
- Using recently collected traces to complete other traces
- Moderate improvement: on the order of 10-20% more routers

Requests:

- Much higher limits (e.g. 100 Hz, 50 tokens) can be easily supported by mpst current hardware
- Router manufacturers and/or ISPs can make topology discovery easier by setting higher default limits / configurations.
- IETF recommendations for v6 routers should mention this (current draft in v6ops)

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