When the Dike Breaks: Dissecting DNS Defenses During DDoS

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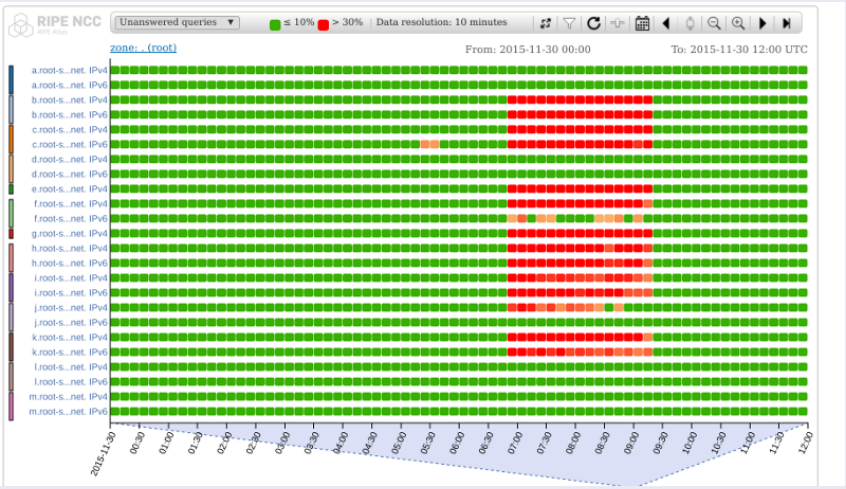
paper: https://www.isi.edu/~johnh/PAPERS/Moura18a.pdf

DDoS Attacks

- DDoS attacks are on the rise
- Getting bigger, more frequent, cheaper, and easier
  - Arbor: 1.7 Tb/s [2] (2018)
  - Github DDoS: 1.35 Tb/s [1] (2018)
  - Dyn DDoS: 1.2 Tb/s (Mirai IoT) [5] (2017)
  - DDoS as a service: few dollars with booters [7].
- Many DNS services have been victim of DDOS attacks

DDoS and DNS: two examples

Root DNS DDoS Nov 2015



no known reports of errors seen by users [3]

Dyn Oct 2016

some users could not reach popular sites [5]

Two large DDoSes, very different outcomes. Why?

DDoS and DNS: two examples

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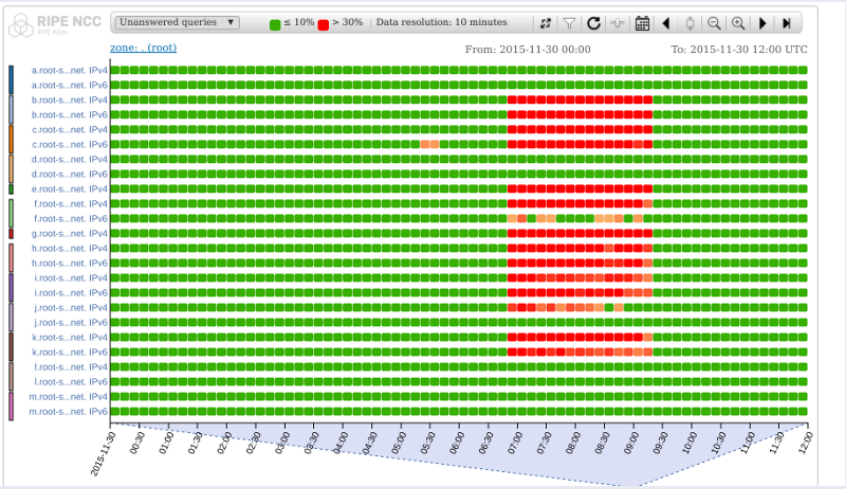

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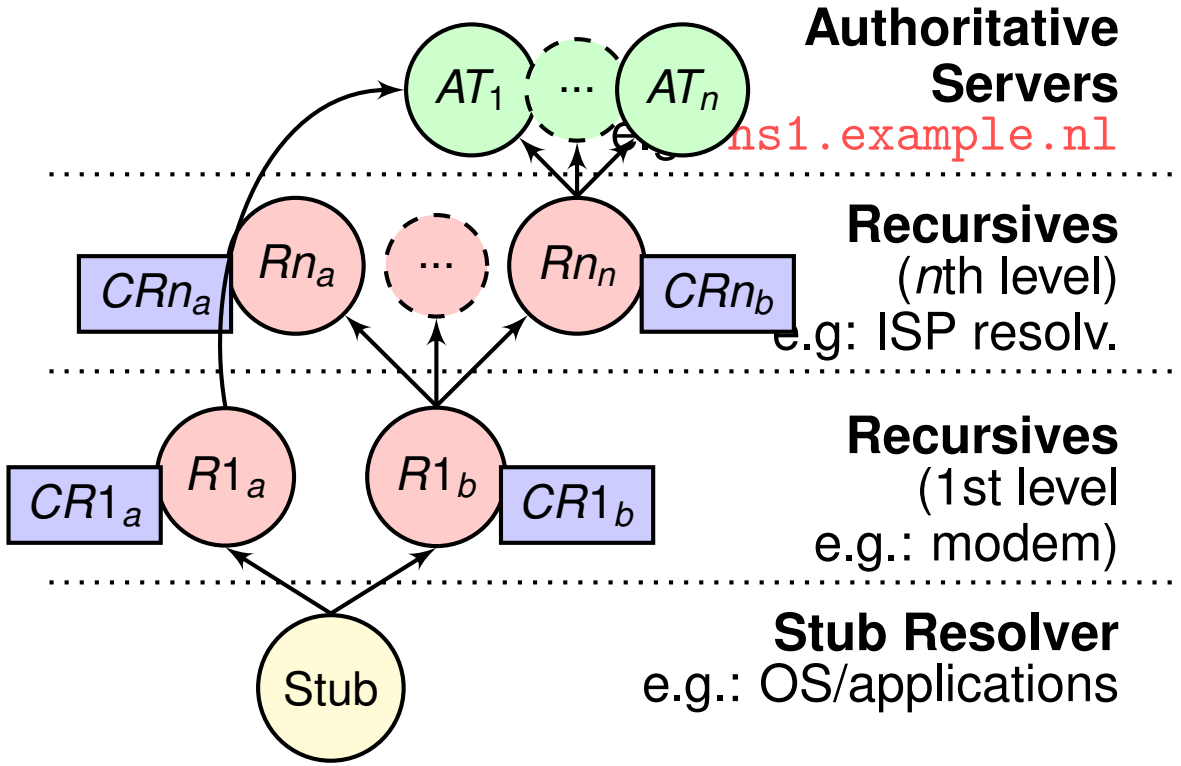
Two large DDoSes, very different outcomes. Why?

What Accounts for Different Outcomes?

- What factors affect the DNS **user experience**?
- When does DDoS cause “no change” vs. “sporadic problems”?
- Common knowledge: recursives **caching** and **retries** help?
- Can DNS operators and purchasers of their services improve?

Background: the many parts of DNS



DNS records TTL: max value for recursives keep a record in cache, by Auth servers

So, can we evaluate DNS built-in resilience?

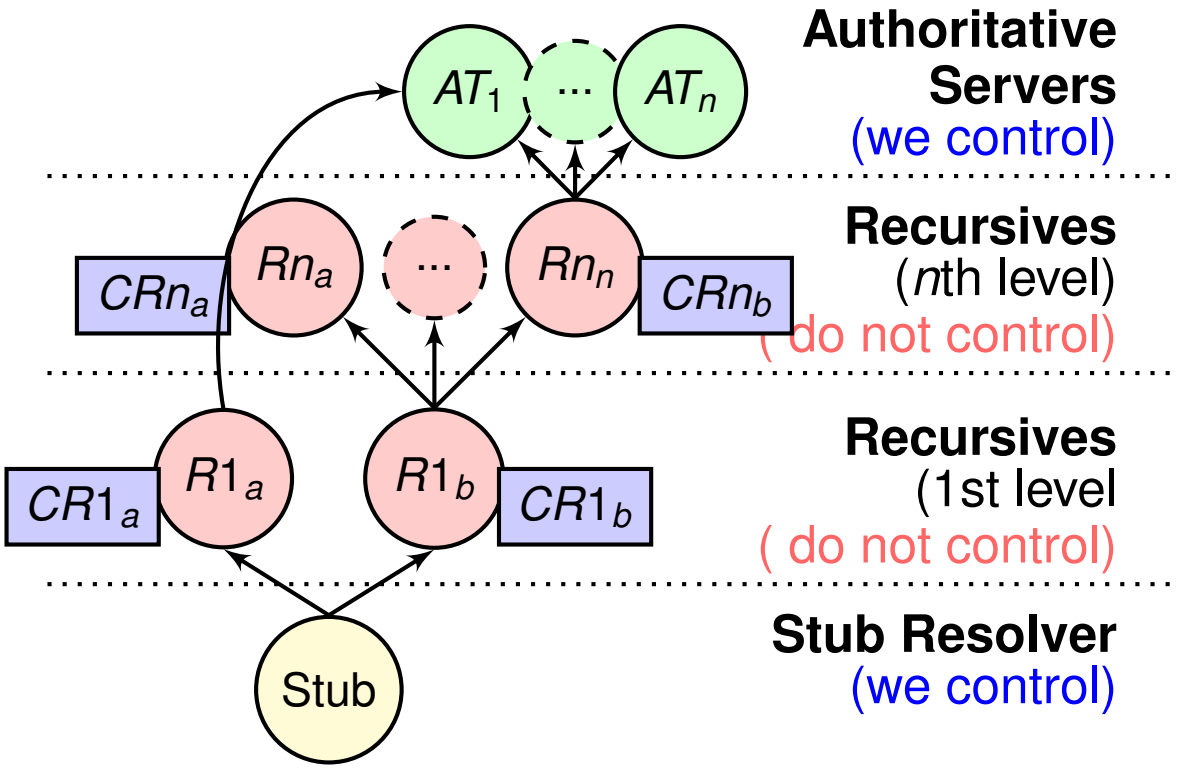
- **Part 1**: evaluate user experience under “normal” operations
  - learn how much is cached/retried in a controlled env.
- **Part 2**: Verify results of part 1 in production zones (`.nl`)
- **Part 3**: Emulate DDoSes in the wild to evaluate caching/retrials under stress, **to observe user experience**

Part 1: measuring caching in the wild

Setup

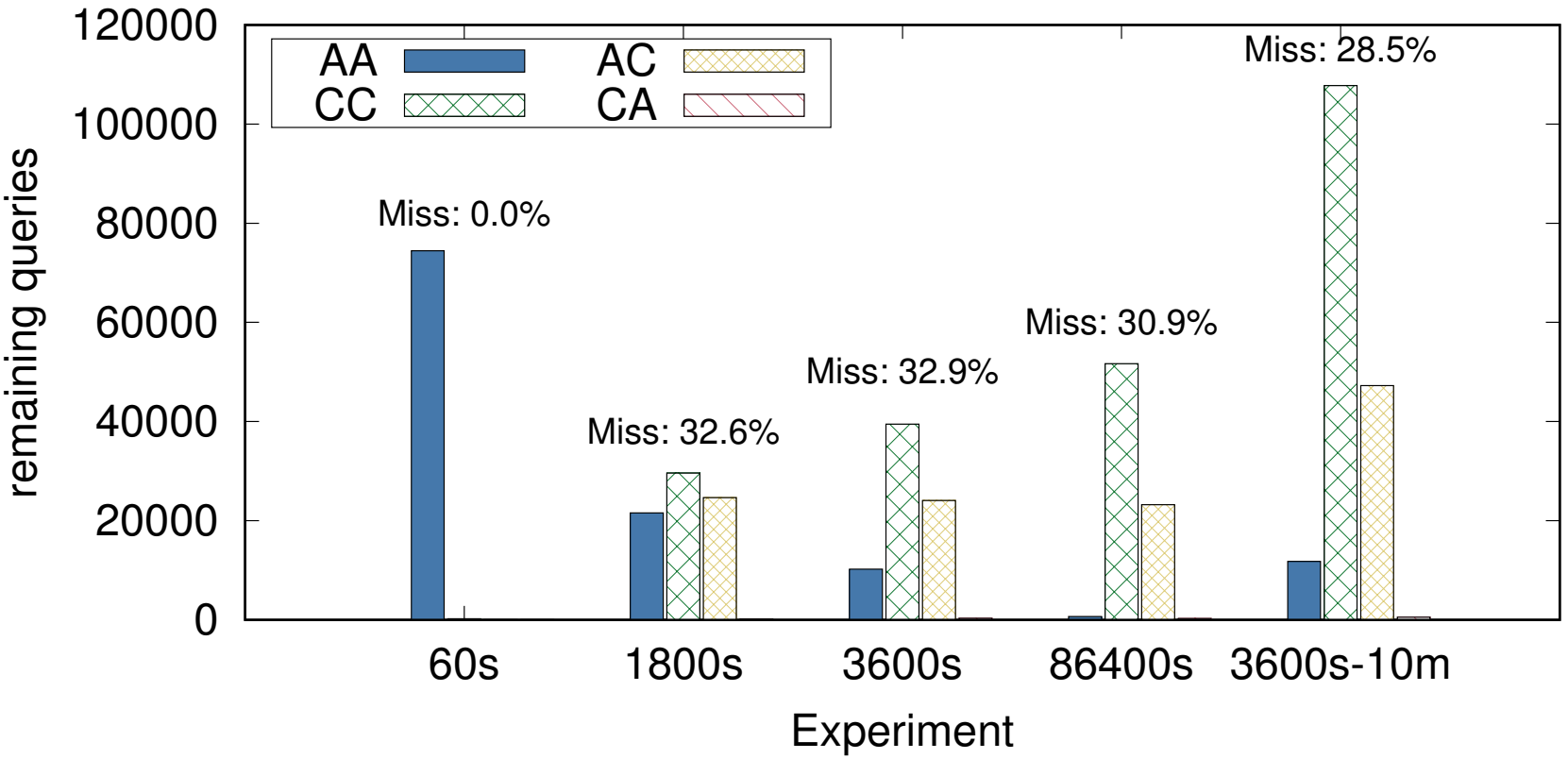
1. register our new domain (`cachetest.nl`)
2. run two unicast IPv4 authoritatives on EC2 Frankfurt
   - we do not analyze anycast auth in this work
3. User Ripe Atlas and their resolvers as vantage points ($\sim$ 15k)
4. Each VP sends a unique query, so no interference
   - e.g.,: `500.cachetest.nl` for probeID=500
5. Each DNS answer encodes a counter that allow us to tell if it was cache hit or miss (see paper)
6. Probe every 20min, and run scenarios with different TTLs, for 2 to 3 hours
   - 60, 1800,3600, and 86400 seconds TTL

Part 1: measuring caching in the wild



- We control auth severs and clients (stub resolver)
- How efficient is caching in the wild?

Results: how good caching is in the wild?



1. Good news: caching works fine for 70% of all 15,000 VPs
   - With our not popular domain
2. Not so good news: $\sim$ 30% of cache misses (AC)

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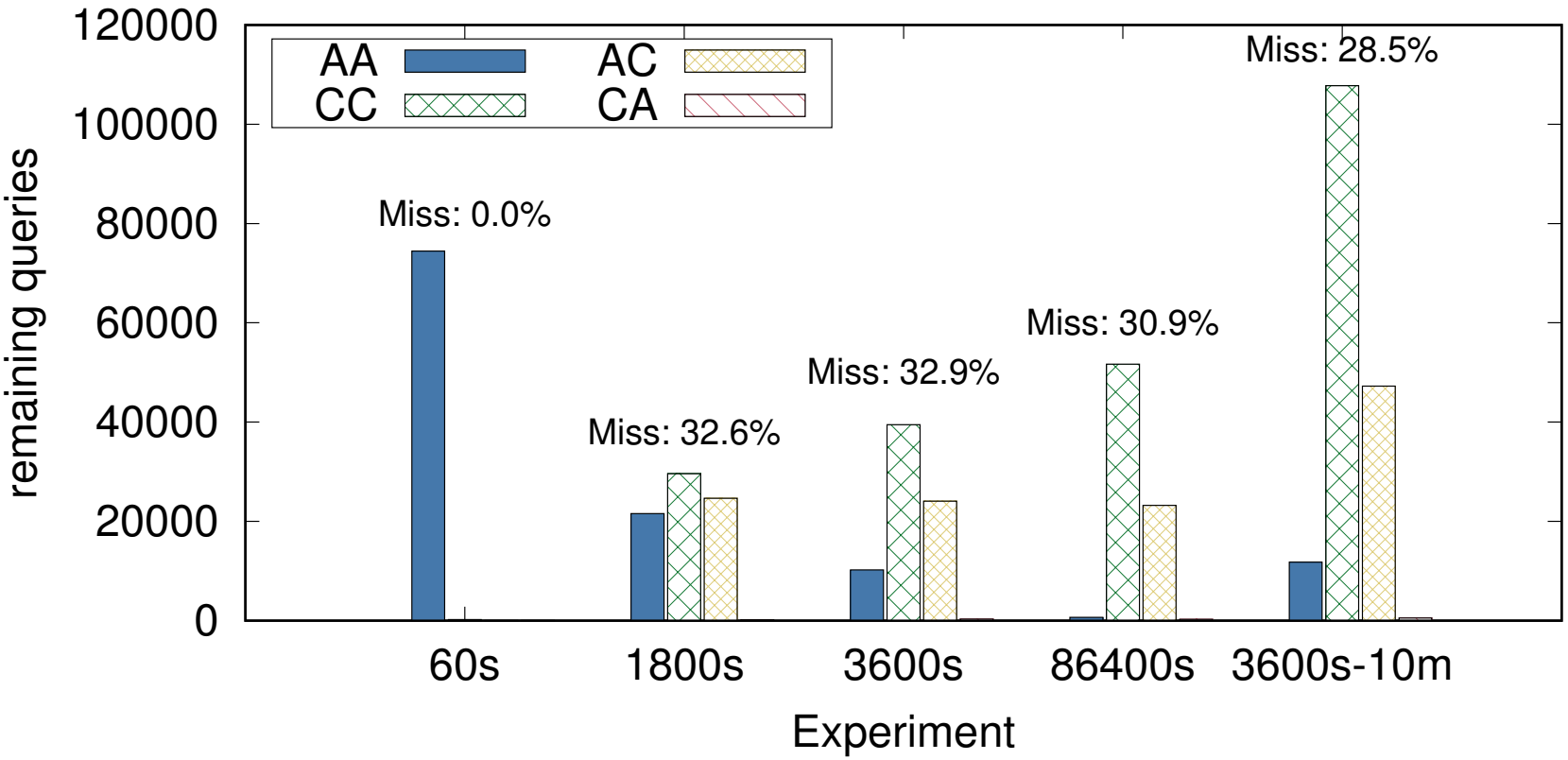

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Why cache misses (Why AC?)

Possible: capacity limits, cache flushes, complex caches
Mostly: complex caches

- cache fragmentation with multiple servers
- (previous work on Google DNS [8])

TTL	60	1800	3600	86400	3600-10m
AC Answers	37	24645	24091	23202	47,262
Public R_1	0	12000	11359	10869	21955
Google Public R_1	0	9693	9026	8585	17325
other Public R_1	0	2307	2333	2284	4630
Non-Public R_1	37	12645	12732	12333	25307
Google Public R_n	0	1196	1091	248	1708
other R_n	37	11449	11641	12085	23599

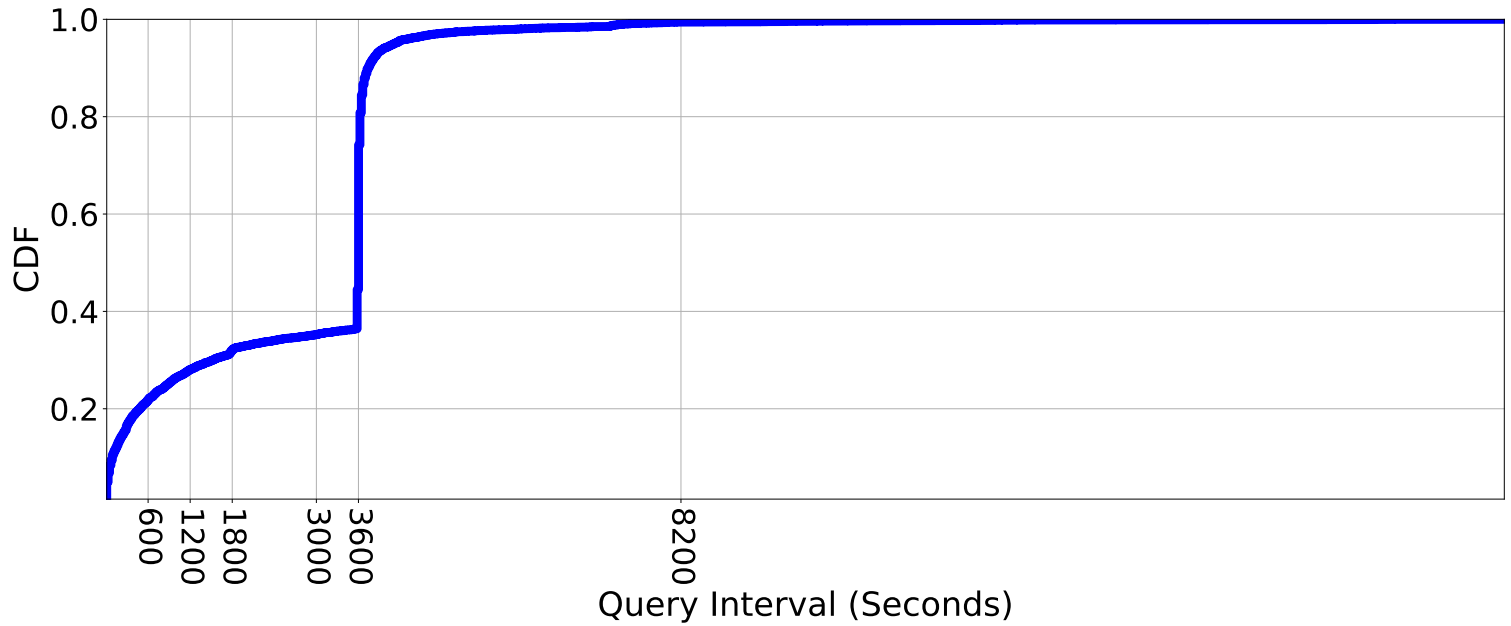
Table: AC answers public resolver classification.

Part 2: caching in production zones

- OK, in our controlled environment, we show that caching works 70% as expected
- Are these experiments representative?
- We look at `.nl` data
  - we compute Δt (time since last query)
  - Compare to TTL of 3600s
  - 485k queries from 7,779 recursives

Part 2: caching in production zones

- Most resolvers send queries usually ∼3600s (`.nl` TTL)
- **Yes, experiments are like real zone**
- (we also look into the roots , see paper)

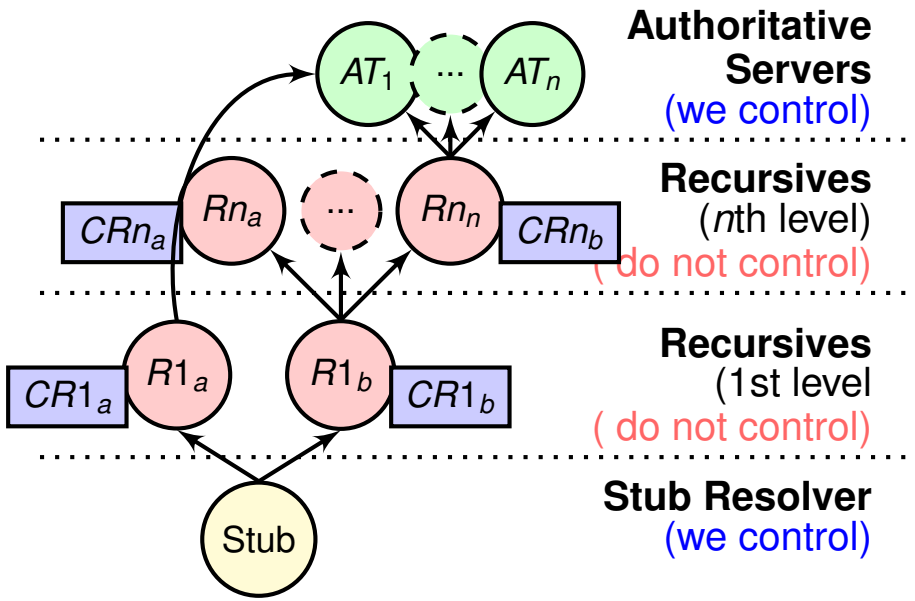


OK , so far, what do we have?

- **We know how caching works in the wild**
- Time to move Part 3: emulate DDoS to evaluate DNS built-in resilience
- Goal: understand client experience under DDoS

Part 3: Emulating DDoS

- Similar setup as other experiments:
  - Emulate DDoS: drop incoming queries at certain rates at Authoritative servers, with `iptables`
- Question: (when) do caches protect clients?
- Or why some DDoS attacks seem to have more impact?



Complete DDoS: TTL: 60min, 100% failure

- This is **doomsday** for DNS ops: all auth DNS down
- How much cache can protect? For how long?

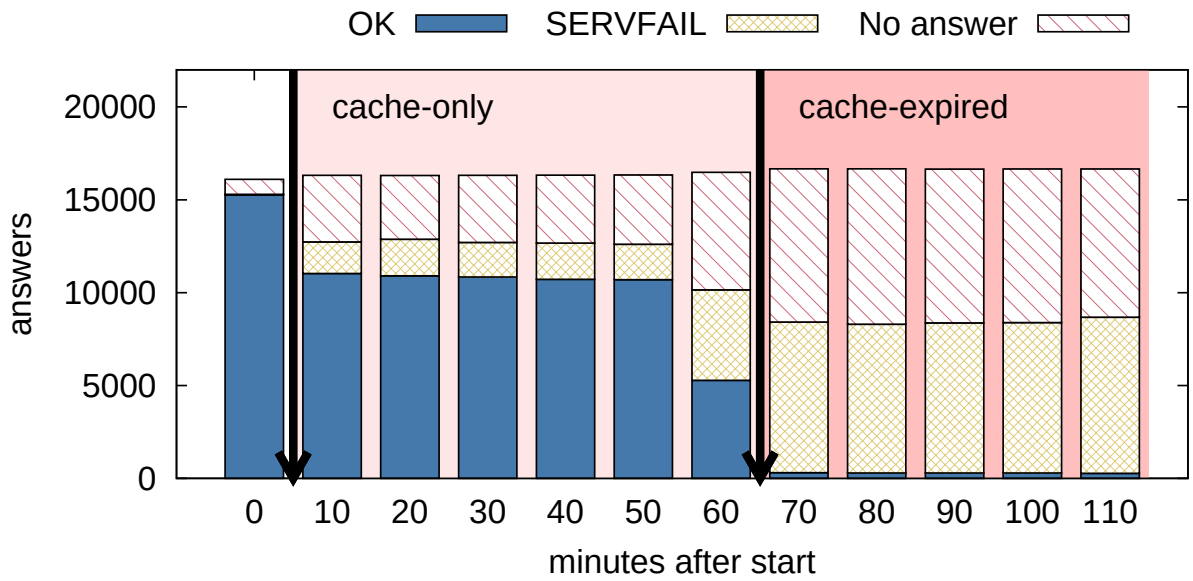


Figure: Scenario A: 100% failure after 10min, TTL: 60min

- DDoS starts after 1st query (fresh cache)
- During DDoS: **35%-70% of clients are served** (cache)
- After cache expires: only 0.2% clients (serve state)
  - `draft-ietf-dnsop-serve-stale-00`

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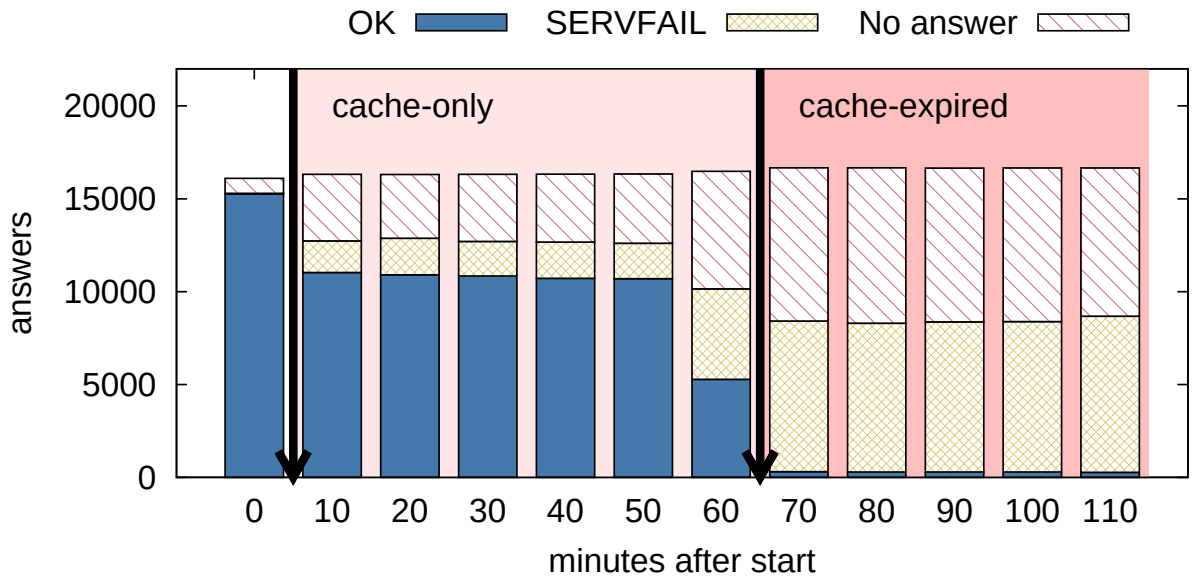

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Complete DDoS: changing cache freshness

- Carrying on with more doomsday
- Scenario B: Cache freshness: about to expire
- How clients will experience DDoS?

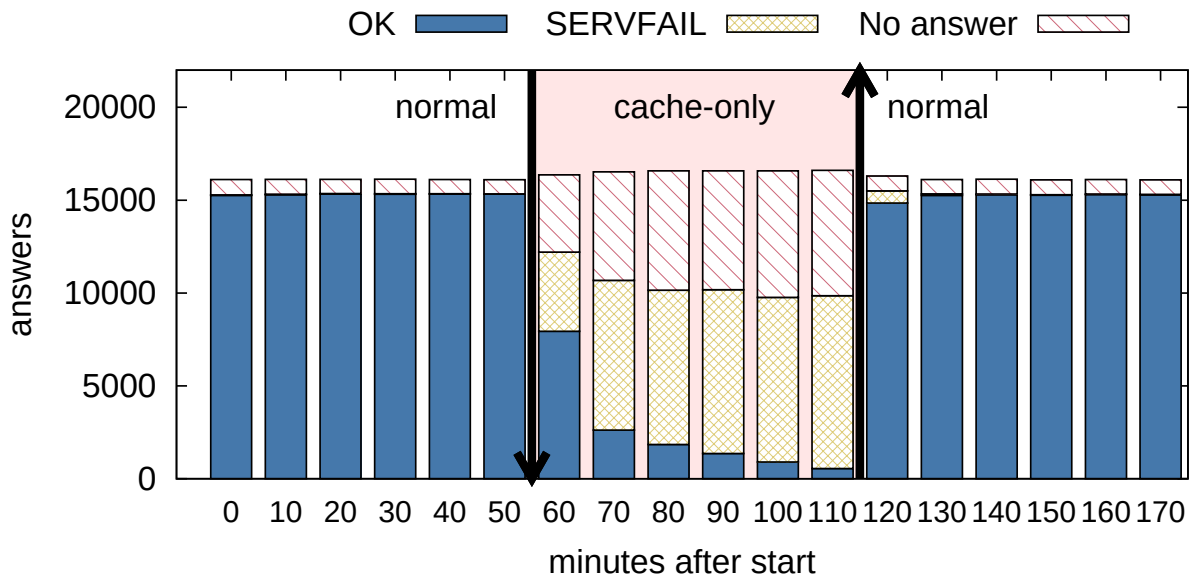

Figure: Scenario B: 100% failure after 60min, TTL: 60min

- Cache much less effective (as time out near attack)
- Fragmented cached helps some (by filling later)

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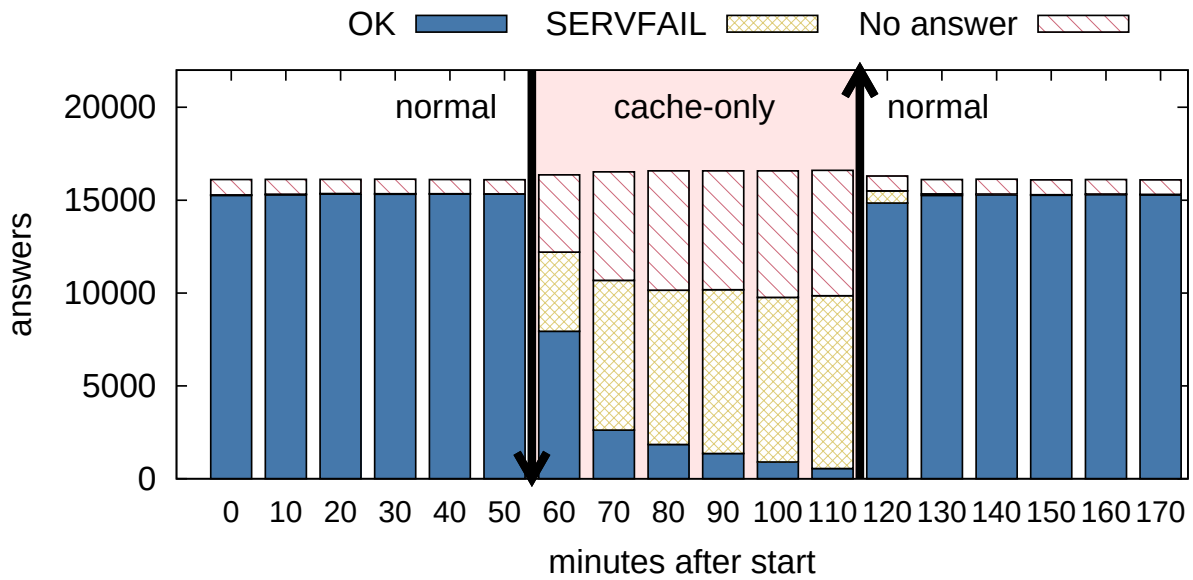

Figure: Scenario B: 100% failure after 60min, TTL: 60min

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Complete DDoS: TTL record influence

- Influence of TTL: reducing from 60min to 30min
- How clients will experience DDoS?

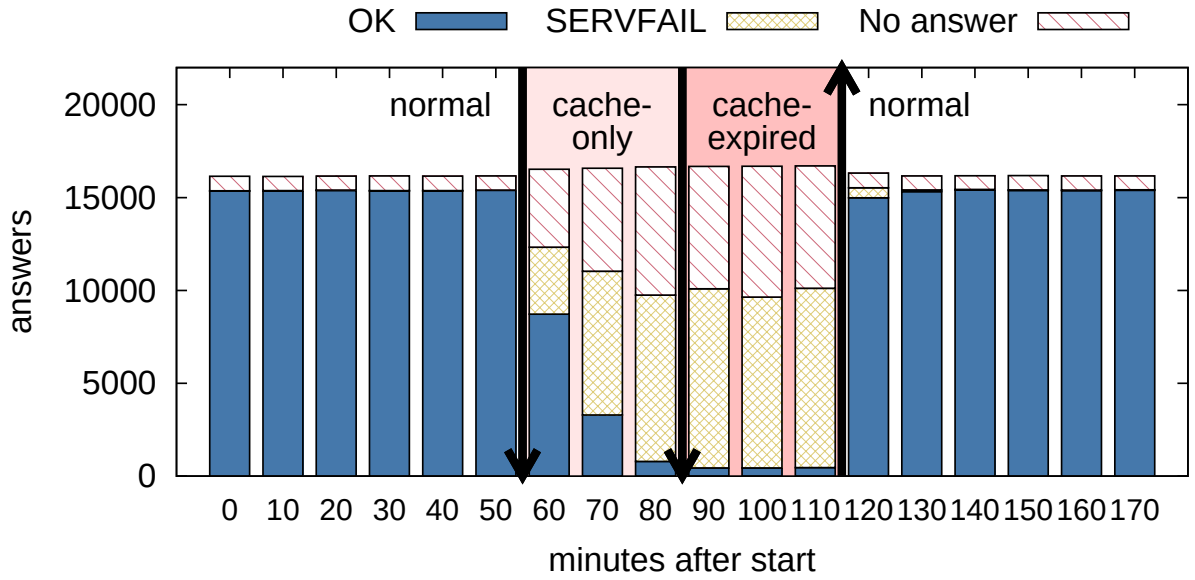


Figure: Scenario C: 100% failure after 60min, TTL: 30min

- Users experience worsens a lot with shorter TTL
- OPs: choose wisely the TTL of your records when engineering for DDoS

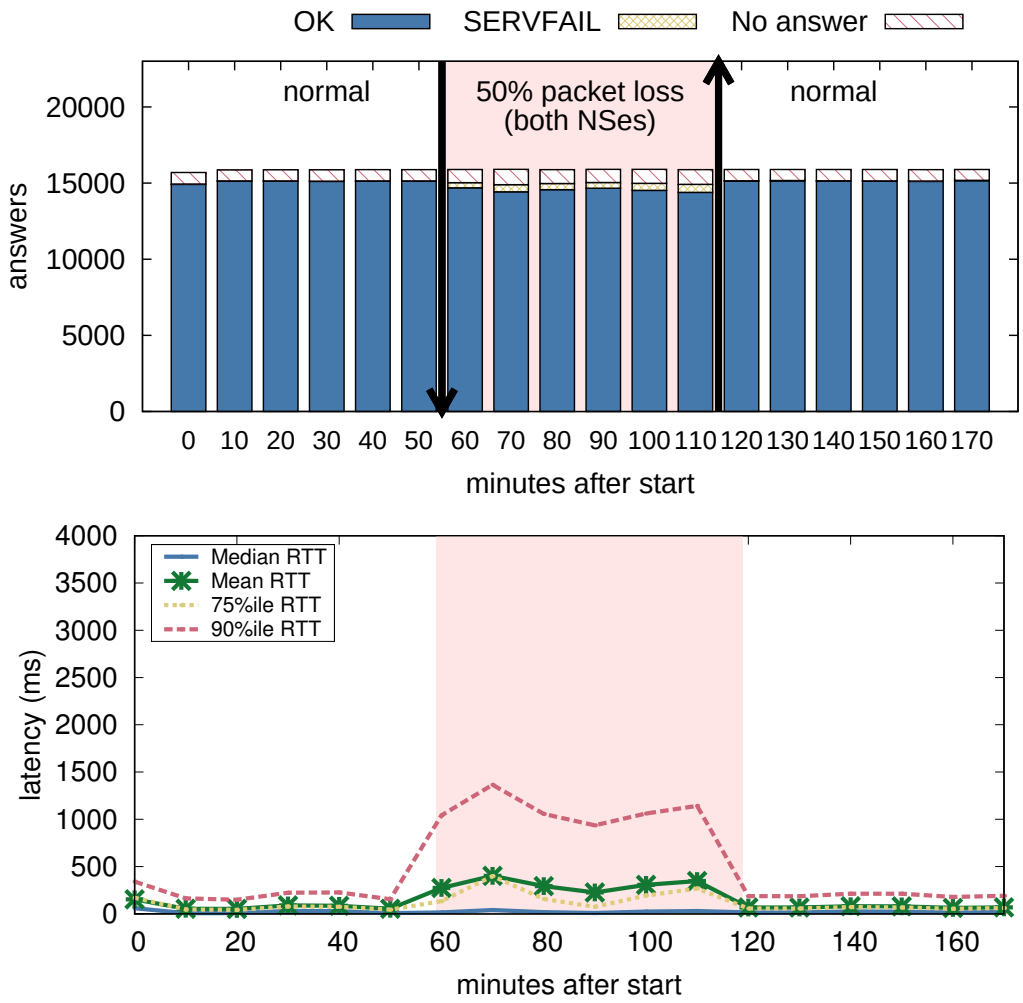
Discussion complete DDoS

- Caching is partially successful during complete DDoS
- OPs: don't expect protection for clients as long as your TTL; depends on their cache state (even pop domains)
- Serve stale provides the last resort for Doomsday scenario
  - some ops (Google, OpenDNS) seem to do it, but it is not widespread yet
- TTL of records: the shorter you set them, the less you protect users during a complete DDoS

Partial DDoS

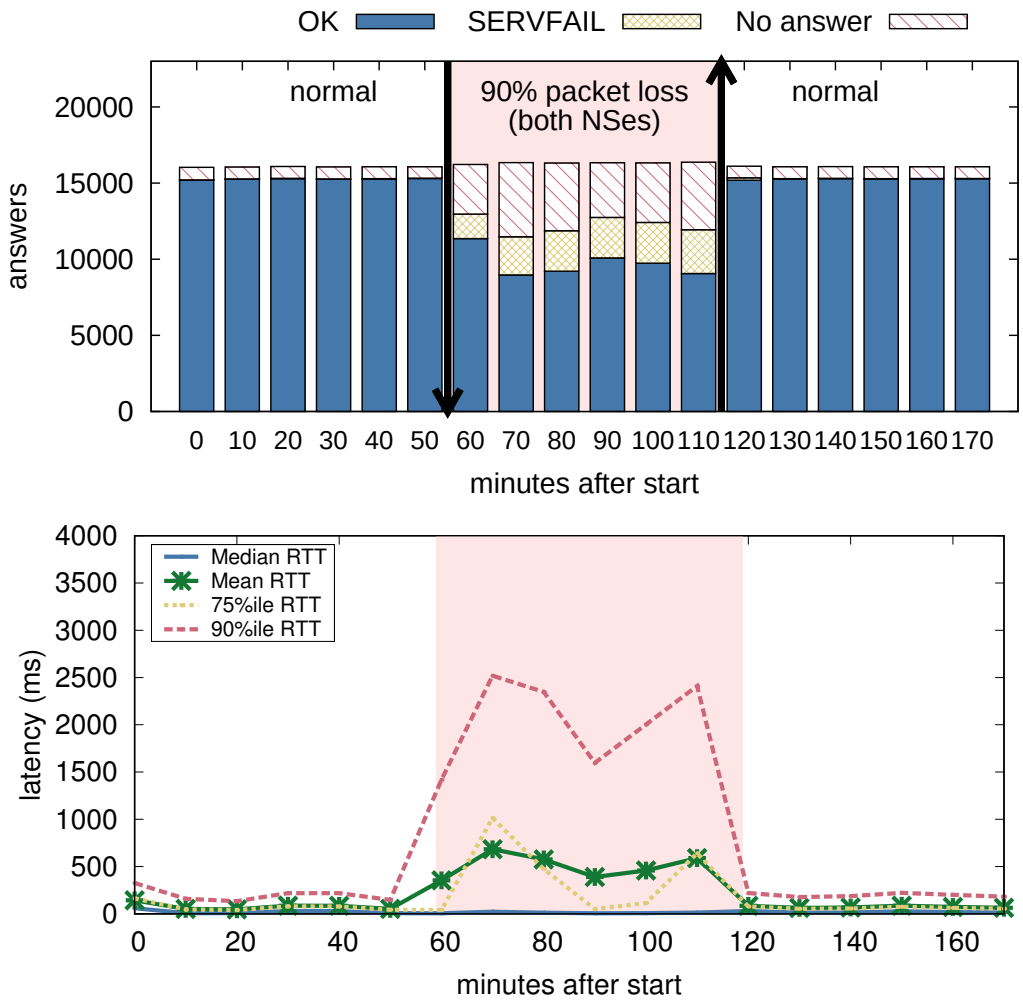
- Not all DDoS are a complete success;
- Some lead to partial failure (Root DNS Nov 2015 [3])
  - Partial failure: some of the available authoritative fail to answer all queries, or take longer to answer; then users experience longer latencies
- In this case, how would users experience the attack?

Experiment E: 50% success DDoS, TTL: 30min



Good! Most clients are happy, as they retry (but takes longer)

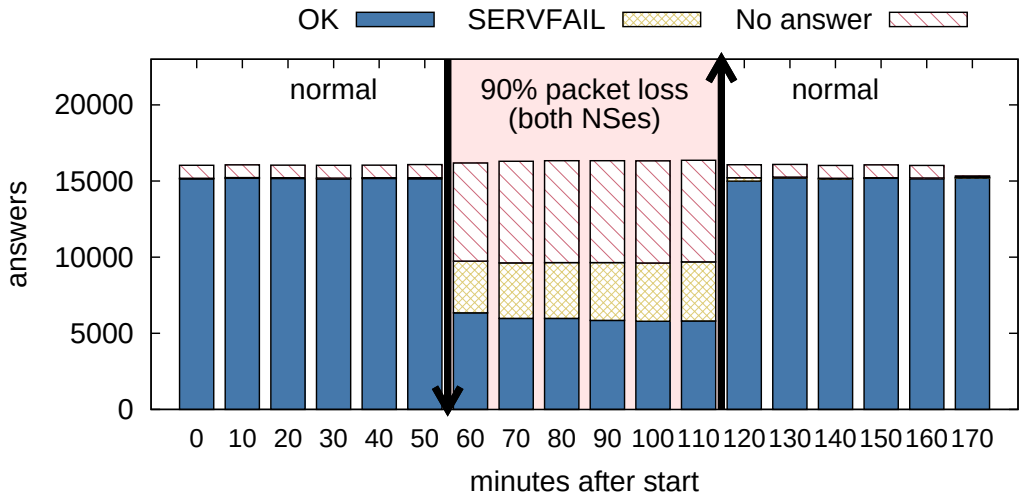
Experiment H: 90% success DDoS, TTL: 30min

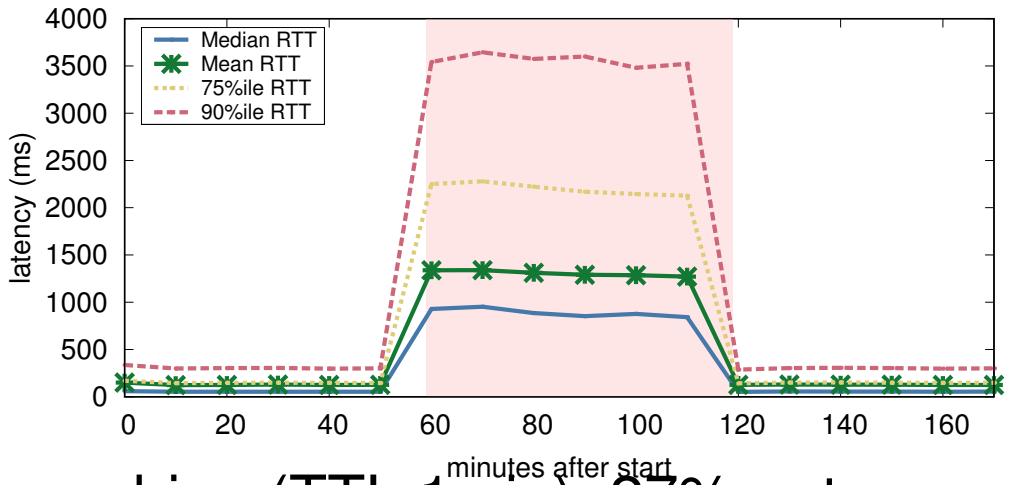


Good! Even at 90% packet loss with TTL 30min, most clients (60%) get an answer!! **Good Engineering!**

Experiment I: 90% success DDoS, TTL: 1min

- What's TTL influence in partial DDoS?





Even with no caching (TTL 1min), 27% get an answer: stale + retries

Retries cost: hammering Auth servers

- Part of DNS resilience is that recursives keep on retrying
- There's a cost to it however: 8.1x in case of no caching!
- Implications: OPS: be ready for friendly fire
  - usually not noticed during DDoS
  - If you overprovision level is 10x, know that 8.1x is friendly fire

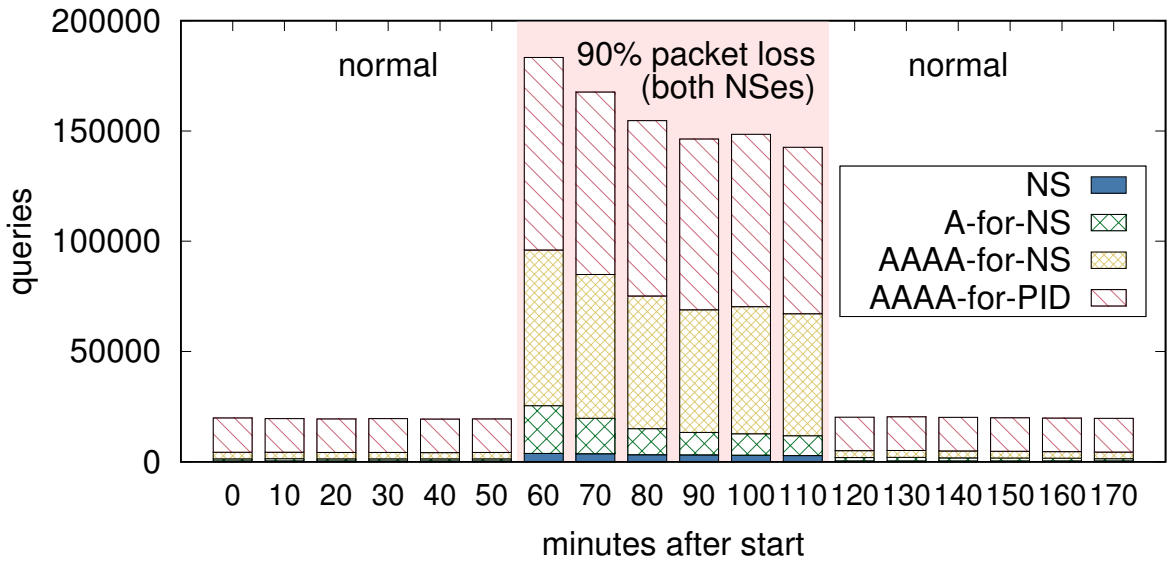


Figure: Queries received at Auth Servers .Experiment I: 90% success DDoS, TTL: 1min

Implications

- Caching and retries work *really well*
  - provided some authoritative stays partially up
  - and caches last longer than DDoS (as in TLDs, not in CDNs)
  - For DNS OPs: make one auth very strong? (careful with load distrubtion, see [4])
- Explains prior root DDoS outcomes

Implications

- There is a clear **trade-off** between TTL and DNS resilience
  - provided caches are filled and not about to expire
- Many commercial websites have short TTLs
  - explains the pain of Dyn's customers and users perception
  - shorter TTLs given them quicker management options (Amazon EC2 resolvers cap all answer TTl to 60s [6])

Conclusions

- First study to evaluate DNS resilience to DDoS from user's perspective
- Evaluate design choices of various vendors using measurements
- **Caching and retries**: important part of DNS resilience
  - Good engineering: thanks for all IETFers/devs who have built this
- Experiments show when they help and when they won't
- Consistent with recent outcomes
- DNS community:
  - There's a clear trade-off between TTL and DDoS robustness, choose wisely
  - Shall we advocate for serve-state deployment ?
  - `draft-ietf-dnsop-serve-stale-00`

Questions?

- Tech report:
  https://www.isi.edu/~johnh/PAPERS/Moura18a.pdf
- Contact: giovane.moura@sidn.nl
- Thanks RIPE NCC and reviewers of various drafts:
  - Wes Hardaker, Duanne Wessels, Warren Kumari, Stephane Bortzmeyer, and Maarten Aertsen

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