When the Dike Breaks: Dissecting DNS Defenses During DDoS

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- Joint research work to appear at:
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- Full text (PDF):
  https://www.isi.edu/~johnh/PAPERS/Moura18b.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) [6] (2017)
  - DDoS as a service: few dollars with booters [8].
- 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


The New York Times

TECHNOLOGY

Hackers Used New Weapons to Disrupt Major Websites Across U.S.

theguardian

DDoS attack that disrupted internet was largest of its kind in history, experts say

Schneier on Security

As more details emerge on last week's massive Dyn DNS DDoS, new analysis indicated as few as 100,000 Mirai IoT botnet nodes were enlisted in the incident and reported attack rates up to 1.2 Tbps.

some users could not reach popular sites [6]

Two large DDoSes, very different outcomes. Why?

DDoS and DNS: two examples

Root DNS DDoS Nov 2015

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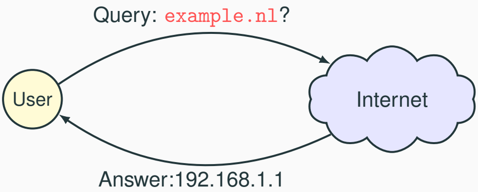
some users could not reach popular sites [6]

Two large DDoSes, very different outcomes. Why?

DNS Basics



- That’s what most users (need to) know about DNS
- Let’s see what really happens

Background: the many parts of DNS

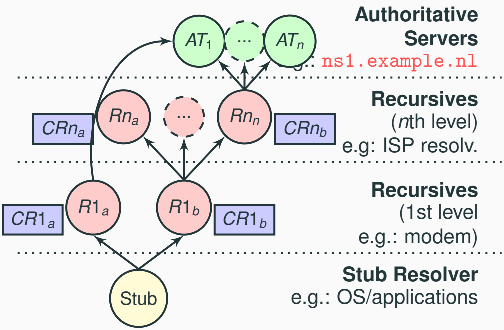
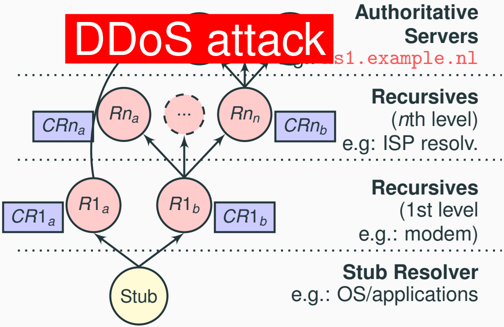


Figure 1: Relationship between resolvers,caches, and authoritatives

- DNS query: where's `example.nl` (`$ dig A example.nl`)
- Answer: `example.nl.  3600 IN A 94.198.159.35`
- **DNS TTL**: max time to cache a record

Background: the many parts of DNS



- How much will resolver's built-in defenses help users during DDoS?

OPS expectation during DDoS

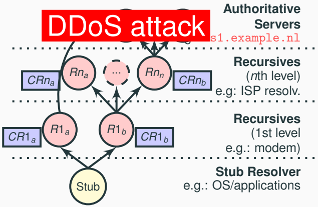


Figure 2: TTL= how long your star powers will last – answer from cache

Evaluating DNS Resiliency

- **Part 1**: evaluate user experience under “normal” operations
- **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

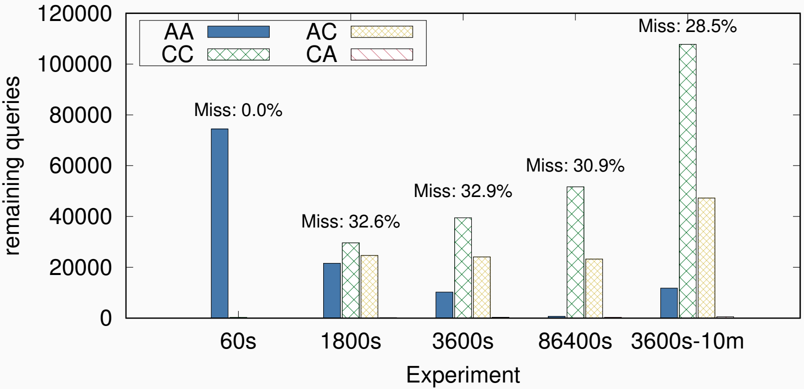
Setup

1. register our new domain (`cachetest.nl`)
2. run two unicast IPv4 authoritatives on EC2 Frankfurt
3. User Ripe Atlas and their resolvers as vantage points ($\sim$ 15k)
4. Each VP sends a unique AAAA query, so no interference
   - e.g.,: `500.cachetest.nl` for probeID=500
5. Each AAAA DNS answer encodes a counter that allow us to tell if it was cache hit or miss
   - `$PREFIX:$SERIAL:$PROBEID:$TTL`
6. Probe every 20min, and run scenarios with different TTLs, for 2 to 3 hours (to match various TTLs in the wild)
   - 60, 1800,3600, and 86400 seconds TTL

Part 1: measuring caching in the wild

- We control auth servers and clients (stub resolver)
- We do not control recursives
- How efficient is caching in the wild?
    - Remember: TTL sets upper limit for HOW LONG it should be cached by recursives

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)

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 [9])

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

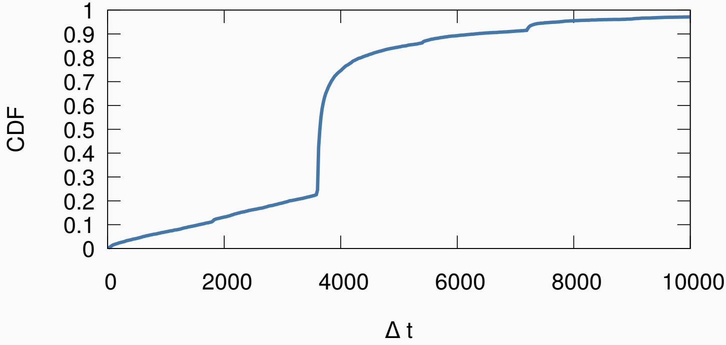
Table 1: AC answers (cache miss) public resolver classification

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` production 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)
- 28% do not respect the 1h TTL
- **Yes, experiments are like real zone**
- (we also look into the Roots , see paper [4])



OK, so what do you we have so far?

- We know how caching works in the wild (both Ripe and `.nl`)
- Time to move Part 3: emulate DDoS
- 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?
- We show only few experiments, many more in the paper

Scenario A: all servers DOWN

- Worst **nightmare** for a DNS operator
- Only resolver's cache can save clients
- TTL=3600s (1 hour)
- We probe every 10 minutes
- At $t = 10 min$, we drop all packets

Complete DDoS: TTL: 60min, 100% failure

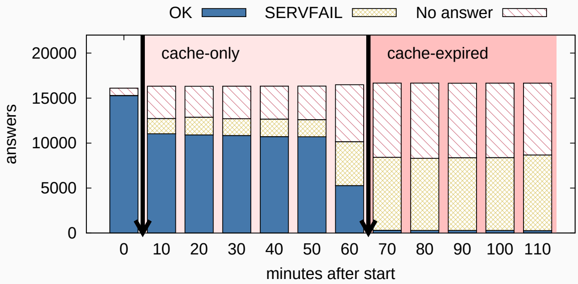


Figure 3: Scenario A: 100% failure after 10min, TTL: 60min

- 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`

Complete DDoS: changing cache freshness

- Scenario B: Cache freshness: about to expire
- How clients will experience DDoS?

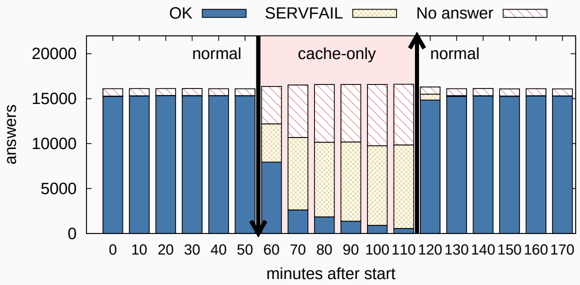


Figure 4: Scenario B: 100% failure after 60min, TTL: 60min

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

Complete DDoS: changing cache freshness

- Scenario B: Cache freshness: about to expire
- How clients will experience DDoS?

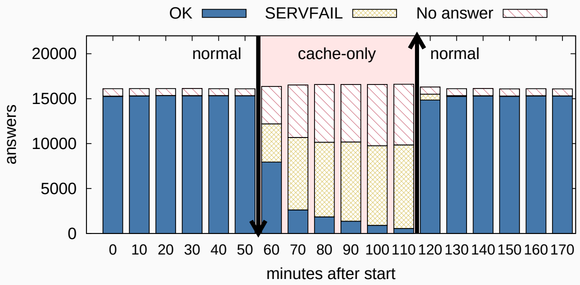


Figure 4: Scenario B: 100% failure after 60min, TTL: 60min

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

Complete DDoS: TTL record influence

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

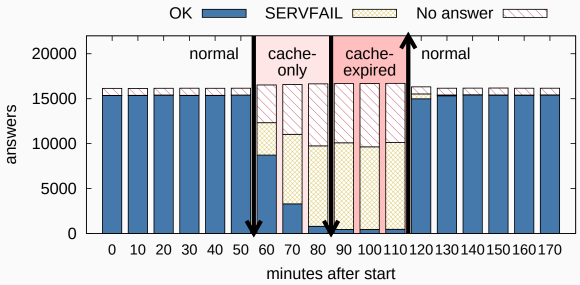


Figure 5: Scenario C: 100% failure after 60min, TTL: 30min

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

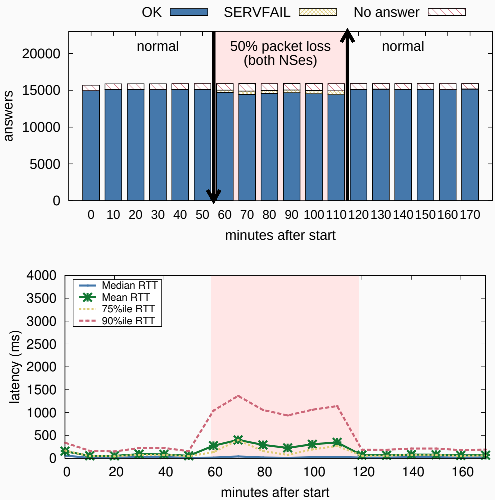
Discussion complete DDoS

- Caching is *partially* successful during complete DDoS
- OPs: don't expect protection for clients as long as your TTL; depends on their cache state
- Serving stale content 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

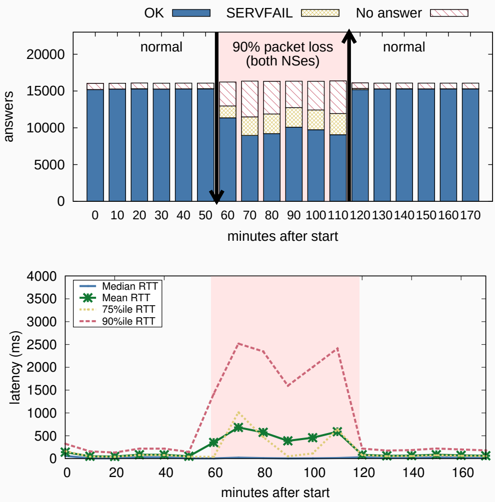
- Not all DDoS are strong enough to bring all servers down
- Some lead to partial failure (Root DNS Nov 2015 [3])
  - Partial failure: some of the available authoritative fail to answer all queries, or take longer to answer; then users experience longer latencies
- In this case, how would users experience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

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



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

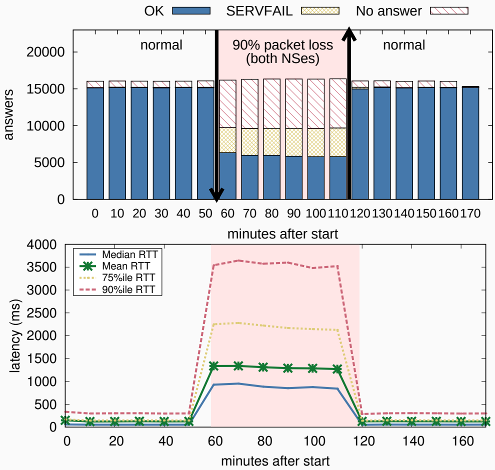
Experiment H: 90% success DDoS, TTL: 30min



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

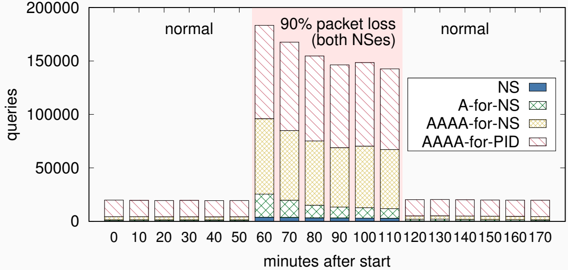


Figure 6: Queries received at Auth Servers .Experiment I: 90% success DDoS, TTL: 1min

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 [5])
- 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 [7])

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
  - Serving stale content is controversial, some deploy it

Questions?

- Paper: https://www.isi.edu/~johnh/PAPERS/Moura18b.pdf
- Contact: giovane.moura@sidn.nl
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