DDoS Defense in Depth for DNS (DDIDD)

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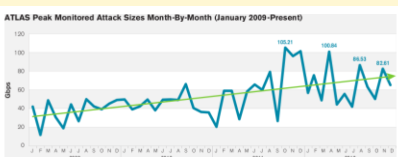
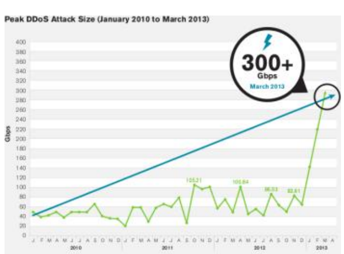
DDoS is Bad… and Getting Worse



[Arbor12a, figure 17]

big
2012 innovation:
automated botnets
for extortion

cheap: booters offer
DDoS-as-a-service
starting at $1/attack
[Santanna et al, 2015]



[Arbor14a, figure 60]

bigger
2013 innovation:
DNS amplification

biggerer (as of Feb. 2018)
2016: 620 Gb/s KrebsOnSecurity.com
800 Gb/s (or more?) OVH
innovation: 145k-node botnet from
hacking IoT devices

biggest (so far)
2018: 1.3Tb/s memcached

Years of Research… the Problem Remains

fixing the problem at the root:
⇒ *but misaligned cost and benefits*

- source address filtering (BCP38)
  - hard to deploy for big ISPs
  - only ~50% after 10 years of work
- attack traceback
  - requires cooperation across ISPs
- better security in end-devices
  - fundamentally hard to be perfect
  - counter to the economics of commodity devices and IoT

mitigating the problem with services
⇒ *loses autonomy and can be expensive*

- traffic scrubbing
  - NTT, etc.
  - re-route traffic, “clean it” (proprietary), forward it to you
- huge infrastructure with automated traffic shifting
  - Akamai, Cloudflare, etc.

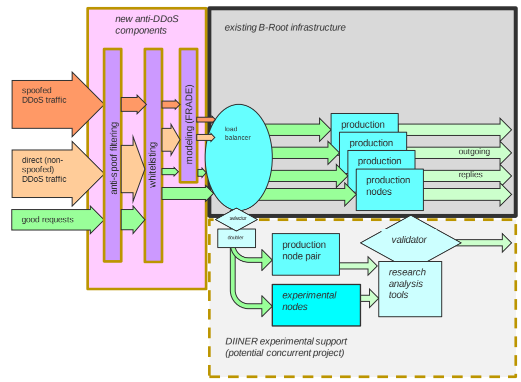
DDoS Fundamental Problem

- any **open service** must accept queries from everywhere
- end-devices will **never be fully secure**
- **millions** of devices exist (more every day)
- each attack is **easy** (DDoS-as-a-Service exists)

=> **huge advantages for attacker**
and **no silver bullet**

Our Approach: Defense In Depth

- no *one* silver bullet
- **Deep Layers:** a *collection* of countermeasures to mitigate attacks
  - chip away at *each part* of problem
- components
  - 1. hop-count filtering: anti-spoofing
  - 2. existing-name query whitelisting
  - 3. known client whitelisting
  - 4. aggressive client detection
  - 5. scale-out to cloud
- we will open source components



Project Status

- supported by NSF CICI
- started in Fall 2017
- builds on
  - B-Root revitalization (supported by USC and others)
  - prior NSF projects: FRADE (https://steel.isi.edu/Project/frade/ , USC)
  - prior studies of Root DNS DDoS (USC, U. Twente, and SIDN)
- complements other anti-DDoS projects
  - PAADDOS (https://ant.isi.edu/paaddos/ ; USC and U. Twente): anycast
  - LEADER (USC): anti-low-rate DDoS
  - DIINER (https://ant.isi.edu/diiner/ ; USC): shared DNS testbed around B-Root

Target Application: DNS

- our work should apply to many apps, but DNS is our focus
- why? DNS is important and particularly challenging
  - most queries are UDP => **spoofing is easy**
  - service-level expectations often ***require* answers**
    - particularly for Root DNS
    - (* although exceptions for under attack)
  - amplification can make **outbound traffic** a bottleneck

Testing and Transition using B-Root DNS

- Root DNS is a key Internet service
  - has been DDoS'ed multiple times
- Steps in transition plan:
  - Test on B-Root infrastructure first (committed to support research)
  - Work with other DNS operators
    - Letters of interest from two other root operators
    - Joint collaboration with .nl
  - Publish results and release software as open source

Current Results

- specific filters
- automatic filter selection
- curated datasets to support research
- future plans

Current Results

- **specific filters**
  - **(1) source address filtering**
  - **(2) hop-count filtering**
  - **(3) client modeling**
  - **(4) response-code blacklisting**
- **(5) automatic filter selection**
- curated datasets to support research
- future plans

(1) Source Address Filtering

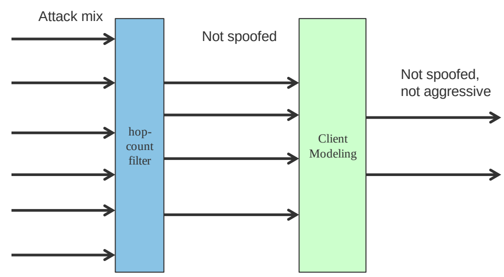
- idea: (not new)
  - build a *whitelist* of typical service users
  - when attacked, keep *only traffic from the whitelist*
- pros:
  - simple, safe
  - will reduce outgoing traffic volume
- cons:
  - some false rejection (if whitelist is not perfect)
  - volumetric attacks can overwhelm *incoming* traffic

Source Address Filtering Status

- testing of ipsets at scale **source address filtering**
  - plug-in to Linux kernel
  - extends iptables (firewall) to support millions of filters
- results:
  - *yes* we can handle the typical B-Root customer set
- deployment for B-Root completed
  - automated whitelist construction; module deployed; attack playbook updated

(2) Hop-Count with (3) Client Modeling

- idea:
  - learn typical *hop-count* and *rate* from each source IP
  - filter by hop-counts
  - filter remaining traffic by rate
- pro:
  - hop-counts are stable,
    so good filter with low false positive
  - traffic with spoof known clients gets wrong hop-count
  - client-modeling catches anything that slips through
- con:
  - need new iptables module to hop-count filter at scale
  - client modeling may not be easy

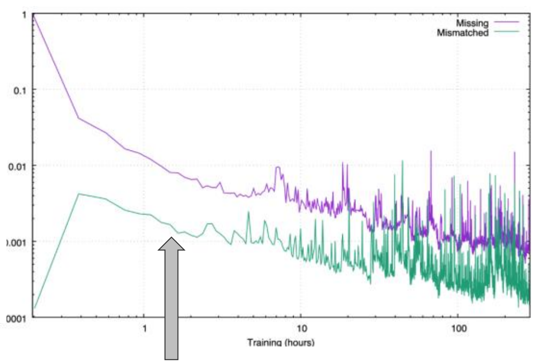


Hop-count Filtering Status

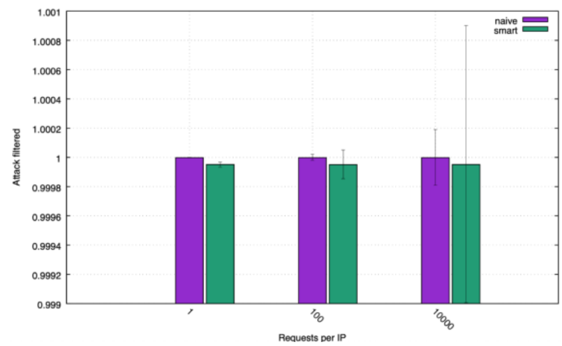
- preliminary analysis looks promising
  - high precision (0.1% false drops after 1h training)
  - very high recall: drops 99.4% of attack traffic with random spoofing
  - concern: must track ~10M values/~3M if working with /24 prefixes
- new **ipset extension to handle hop-count filtering**
  - prototyped and **evaluated in testbed**
  - not yet deployed

Hop-count Filtering – Performance

collateral damage (log scale)
more (bad)
little (good)



learning from 90 minutes is enough



filtering accuracy is very high
(even for a naïve approach and a smart attack)

Hop-count Filtering vs. Smart Attackers

TTL	Source	Entry size	Percent dropped
Random	In table	/32	98.4%
	In table	/24	98%
	Not in table	/32 or /24	100%
Most popular TTL	In table	/32	40%
	In table	/24	70%
	Not in table	/32 or /24	100%
Exact TTL	In table	/32 or /24	0%
	Not in table	/32 or /24	100%

very accurate vs. naïve attacker

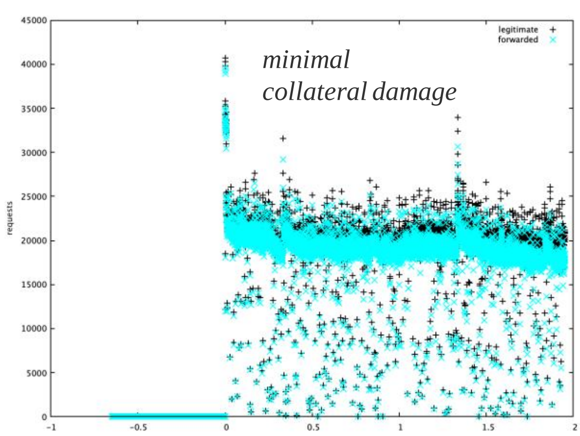
somewhat accurate vs. adversary

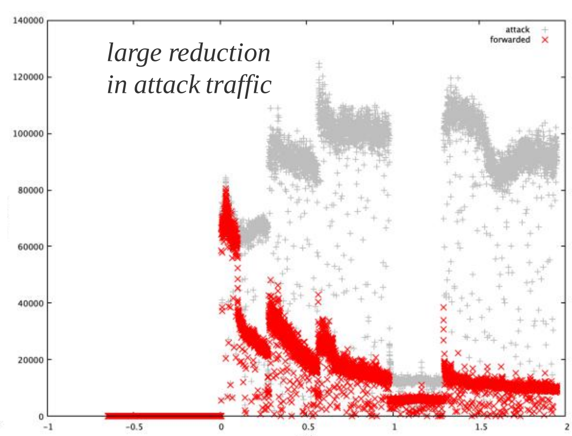
ineffective vs. omniscient oracle (but impractical adversary)

(3) Client Modeling Details

- model request and error rate from each client
- *filter when client's query rate increases suddenly*
  - intuition: tolerate typical aggressive users
  - but filter new ones
- also filter if client's *error rate increases* (NXDOMAIN)
  - intuition: attackers often use fake names to avoid caching
- status: tested on several 2017 B-Root events
  - Good attacker identification, acceptable collateral damage

Client Modeling – Performance





Client Modeling – Performance

Date	Precision	Recall	F1 score
2017-11-30	0.99	0.99	0.99
2017-02-21	0.97	0.89	0.93
2017-03-06	0.93	0.93	0.93
2017-04-25	0.96	0.89	0.92

very effective (high accuracy) against all 2017 attacks vs. B-Root

(4) Response Code Blacklisting

- idea: some attacks send random strings (all fail)
- when attacked, *ignore replies that are failure* (NXDOMAIN)
  - challenge: normal replies (like typos) are also NXDOMAIN
- pro:
  - greatly cuts outgoing bitrate
- con:
  - lots of legitimate queries are NXDOMAIN (typos!), so defense has a high false positive rate
- result: defense of last resort

(5) Automating Defenses

- in general, need *combination* of approaches
- possible filters on prior slides
- need to *automate* selection
  - to react quickly
  - and to keep re-evaluating
- how?
  - measure resource consumption directly
  - deploy most promising countermeasure
  - measure response and try alternative if unsuccessful

Automating Defenses: the Need for Choice

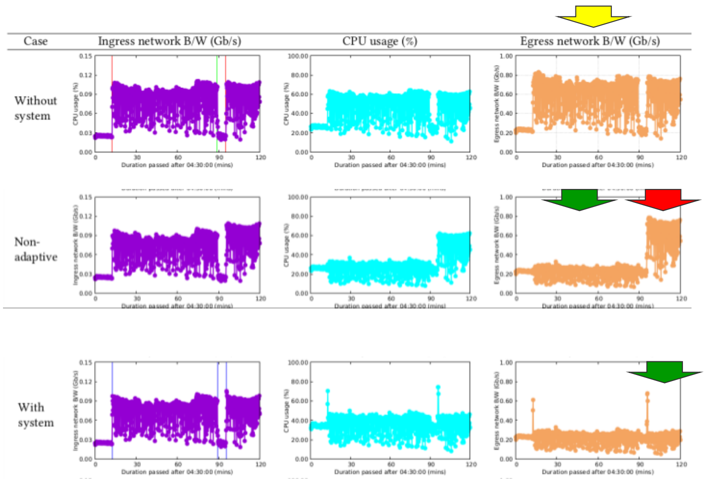
require different defenses (no single method works all the time)

we always find the best defense, although sometimes it takes several tries

different real-world attacks

Event	Source Whitelisting	Response Blacklisting	Query Blacklisting	Converge to the best?	Latency to detect attack (s) (from attack start)	Latency to select the best filter (s) (from attack start)	No. of selected filters before the best choice
2015-11-30	Good	No	**Good**	Yes	13.17	13.33	1
2015-12-01	Good	No	**Good**	Yes	5.05	5.22	1
2016-06-25	**Fair**	No	No	Yes	10.24	10.24	0
2017-02-21	No	Fair	**Good**	Yes	6.67	38.81	3
2017-03-06	No	Fair	**Good**	Yes	14.33	15.37	1
2017-04-25	No	Fair	**Good**	Yes	11.73	12.03	1

Automated Defense: Dynamic Adaptation



this DDoS stresses target's egress link

automatic defenses work (see drop in egress traffic and CPU)

*but it **fails** when the attack changes*

*we re-assess **during** attack to change filter => handles polymorphic attacsk*

(6) Towards the Cloud

- IoT-based attackers can hit (nearly) any bitrate
- defense *must* be able to scale capacity
- => “fail to the cloud”
  – when under attack, add capacity in the cloud

- very positive discussions with 3 different cloud providers
- challenges:
  – requires anycast that spans us *and* cloud
  – want to use our own DDoS defenses in the cloud
  – while not harming other tenants

Cloud Status

- working on cloud-native implemention of B-Root for AWS
  - one VM provides all services
  - scales vertically (bigger instance) *and* horizontally (many instances)
- work in progress
  - prototype in place
  - but needs integration with our instrumentation and measurement
  - and need to be very careful with BYO-IP mixed with anycast

Curating Datasets from B-Root

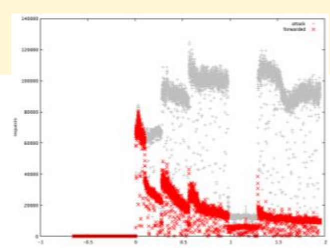
- 5 events so far (attacks or large traffic bursts)
- 10 DITL events (each 2 days long)
  - 48-hour period, synchronized with other root letters
- new full week of data

- DITL and other DDoS datasets distributed through IMPACT
  - https://impactcybertrust.org
  - https://ant.isi.edu/datasets/

Relationship to Other DDoS Projects

- LEADER (NSF, started 2018)
  - PIs: Mirkovic and Hauser (ISI)
  - Looking into low-rate DDoS attacks and OS mechanisms to prevent them
  - May be useful to harden OS on root servers
- PAADDoS (started 2018)
  - PIs: Heidemann and Pras (U. Twente in .nl)
  - will examine anycast routing
- ideas:
  - active use of anycast to adapt to attack load
  - anycast planning with Verfploeter
- DIINER (started 2019-10)
  - PIs: Heidemann and Hardaker (USC)
- ideas:
  - leverage B-Root into an open testbed
  - data availability
  - experiments on live traffic

Conclusion



- DDoS is important but hard problem
- earliest tools deployed in B-Root
- additional tools and cloud are underway
- tools and data for you to use
  - open-source tool release in 2020q1
  - datasets available today
- https://ant.isi.edu/ddidd/