Network Security - part II

Srdjan Matic

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based on the material prepared by:
Emiliano de Cristofaro and Juan Caballero

Outline

Recap - SYN Flooding

How does SYN flooding work[a]?

[a] https://datatracker.ietf.org/doc/html/rfc4987

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Solution: SYN Cookies

IDEA: store the state info. *after establishing the connection* [Bernstein 1996].

How to achieve it: using a smart selection of server Initial Sequence Number.

- ISN = SYN Cookie
  - **t** = timestamp incremented every 64 seconds
  - **m** = Maximum Segment Size (MSS)
  - **K** randomly selected at boot
  - **s** = *hash*(src. IP, src. port, dst. IP, dst. port, t mod 32, K)

t mod 32	**m**	**s**
5 bits	3 bits	24 bits

- On reception of client's ACK, the server checks:
  - **t** against the current timestamp (to check if is expired)
  - **s** to verify if it is a valid SYN cookie
  - decodes **m** from the 3-bit encoding in the SYN cookie
    $\Longrightarrow$ if successful, create store the state for the connection

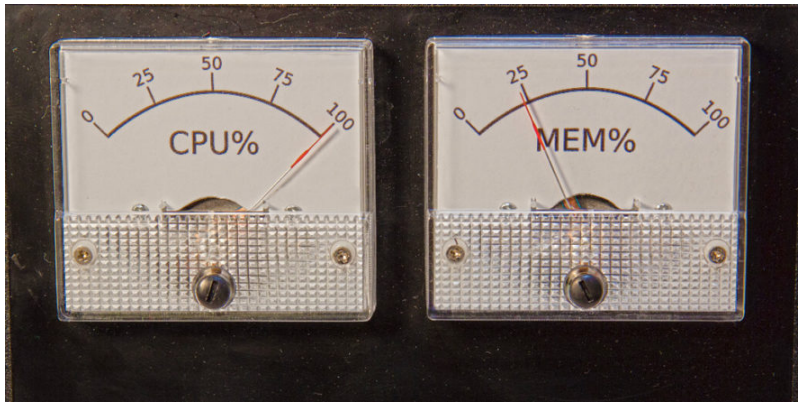
Limitations:

- Only 8 possible encodings for the MSS.
- Not support for TCP options $\Rightarrow$ partially supported since Linux 2.6.26.

Additional info:
`https://cr.yp.to/syncookies.html`
`https://www.geeksforgeeks.org/how-syn-cookies-are-used-to-preventing-syn-flood-attack/`

More Expensive DoS Attacks

- Force victim server to do work:
  - complete TCP connection;
  - establish SSL connection;
  - application layer attacks (e.g., HTTP).



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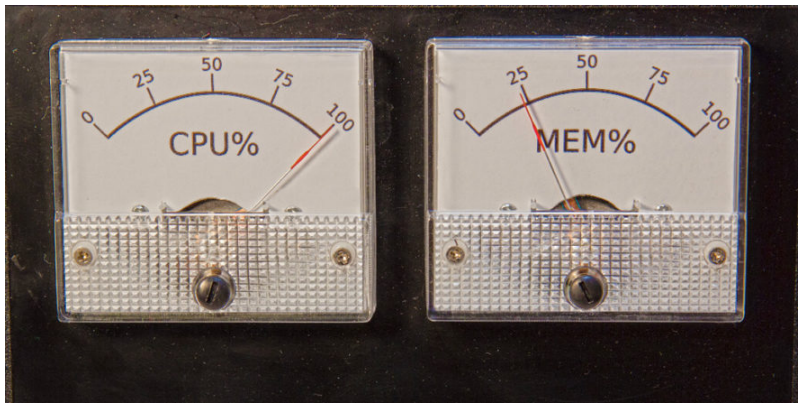

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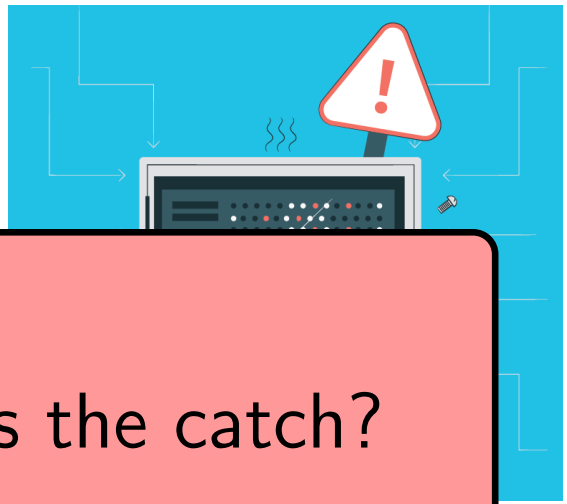

Looks great, where's the catch?

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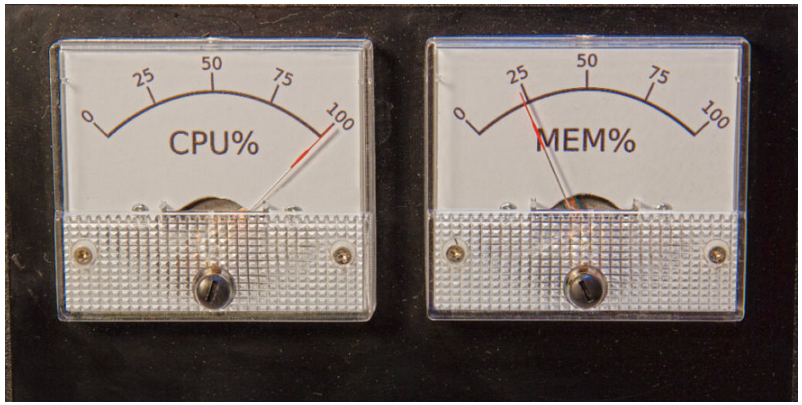

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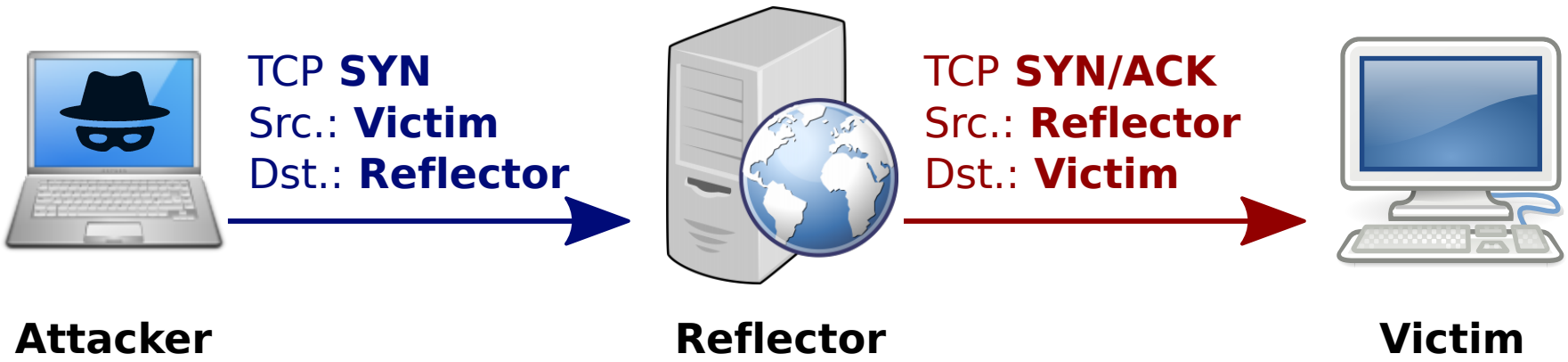
- Spoofing cannot be used:
  $\Rightarrow$ **It discloses the IP address of the attacker.**

Reflector Attacks

Procedure:

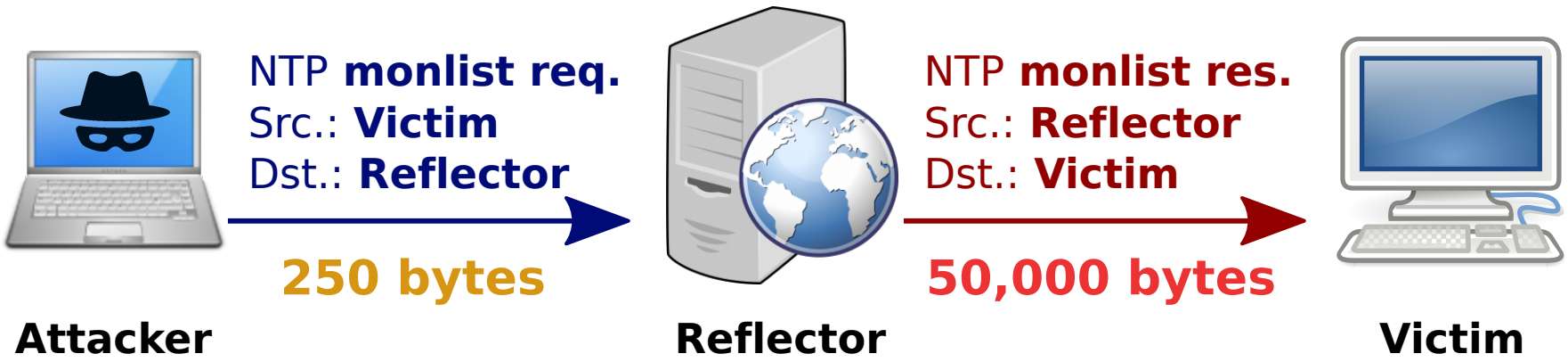
1. Sent traffic to the reflector using the IP of the victim as *source IP address*[1].
2. The response will be sent to the victim.
3. The victim will blame the reflector.



[1] http://ccr.sigcomm.org/archive/2001/jul01/ccr-200107-paxson.pdf

Reflector Amplification Attacks

- Attacker selects requests where:
  reflector response > **Attacker request**
- Bandwidth Amplification Factor
  BAF = size(payload_to_victim) / size(payload_to_reflector)
- Packet Amplification Factor
  PAF = packets_to__victim / packets_to_reflector



BAF = x200

The NTP *monlist* command: `https://nmap.org/nsedoc/scripts/ntp-monlist.html`

Smurf Attack

- Popular in 1990, nowadays almost disappeared.
- ICMP reflector amplification attack:
  1. Attacker sends ping request to a broadcast address;
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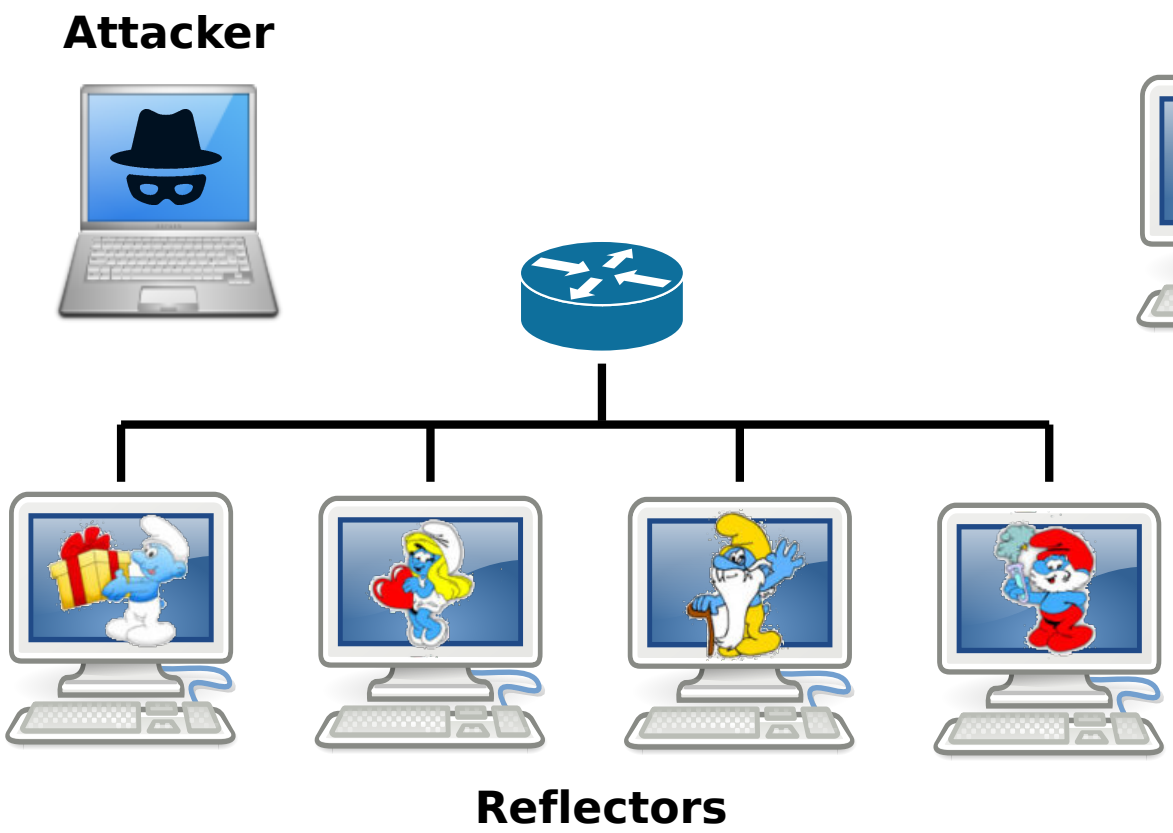

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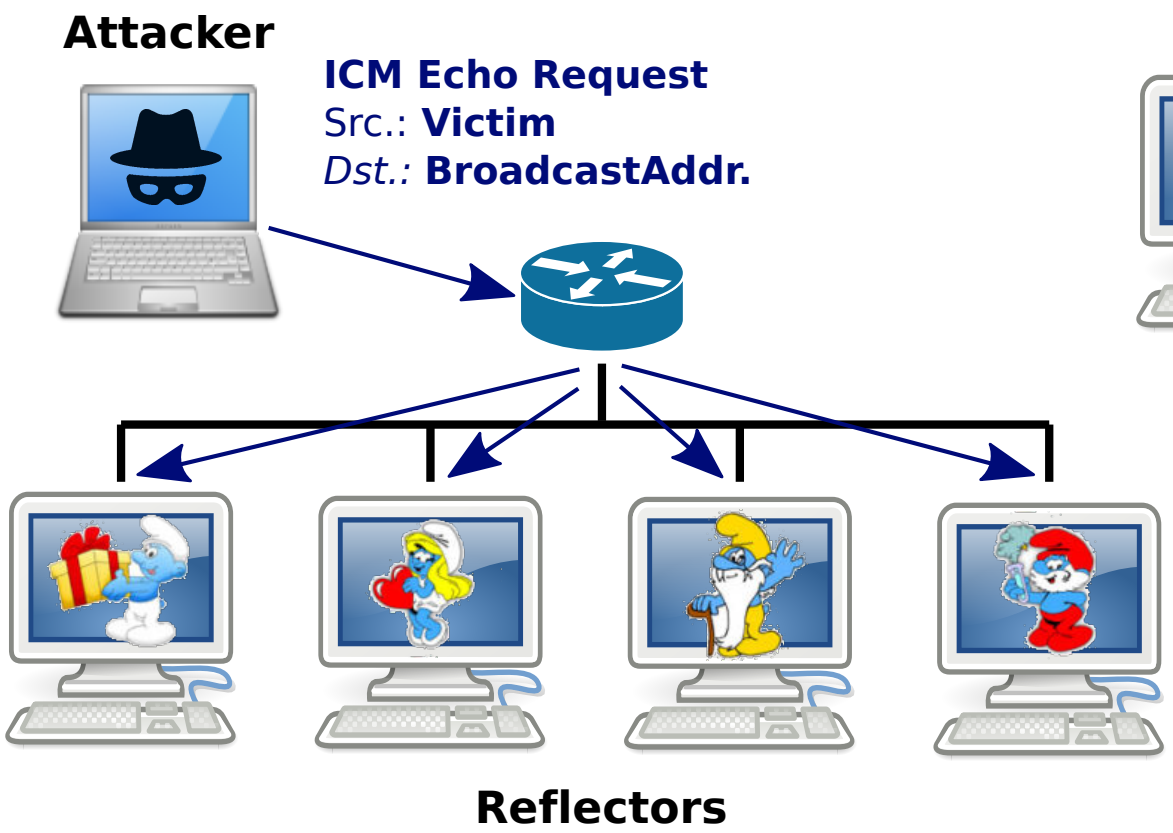

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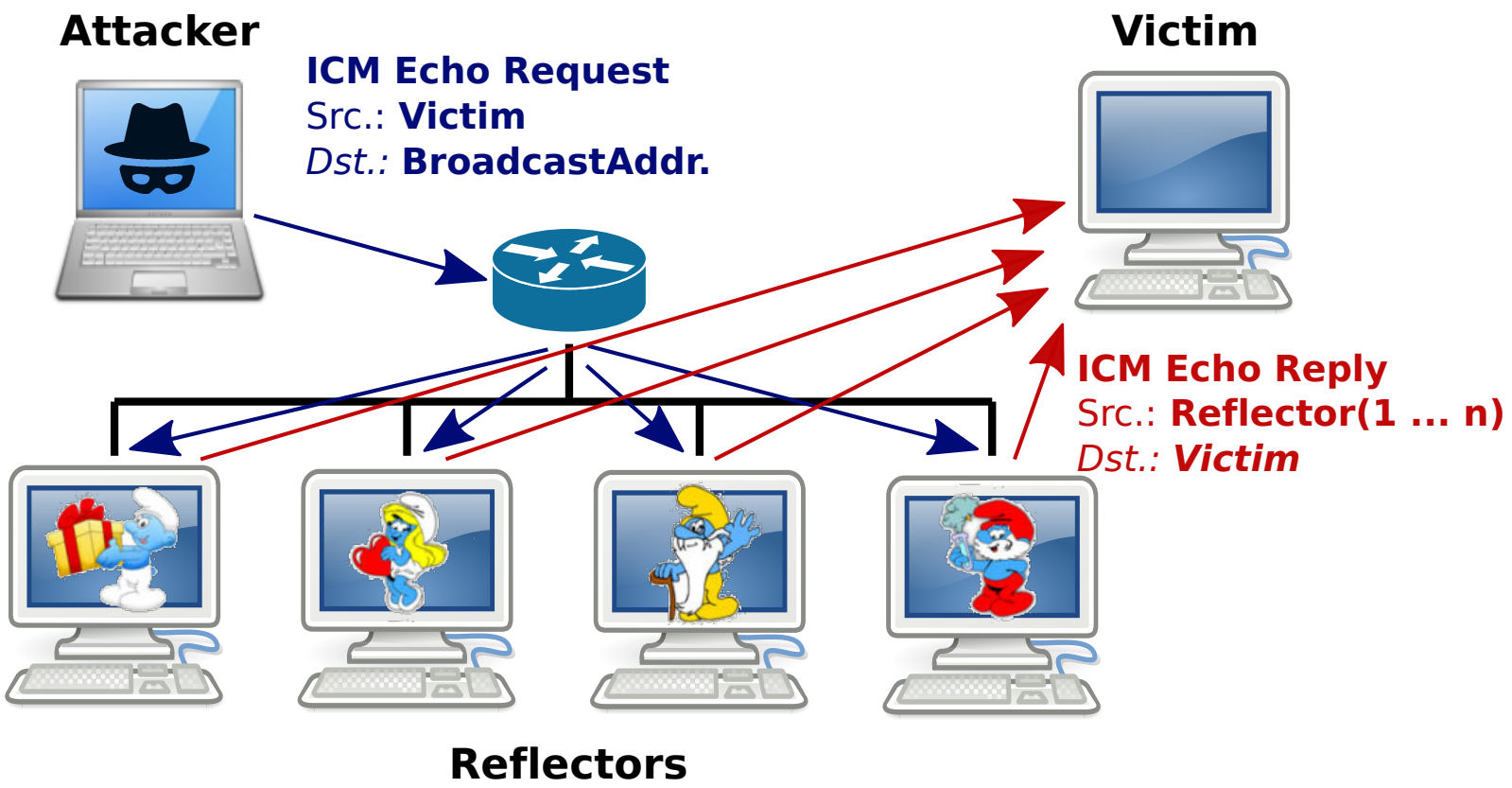

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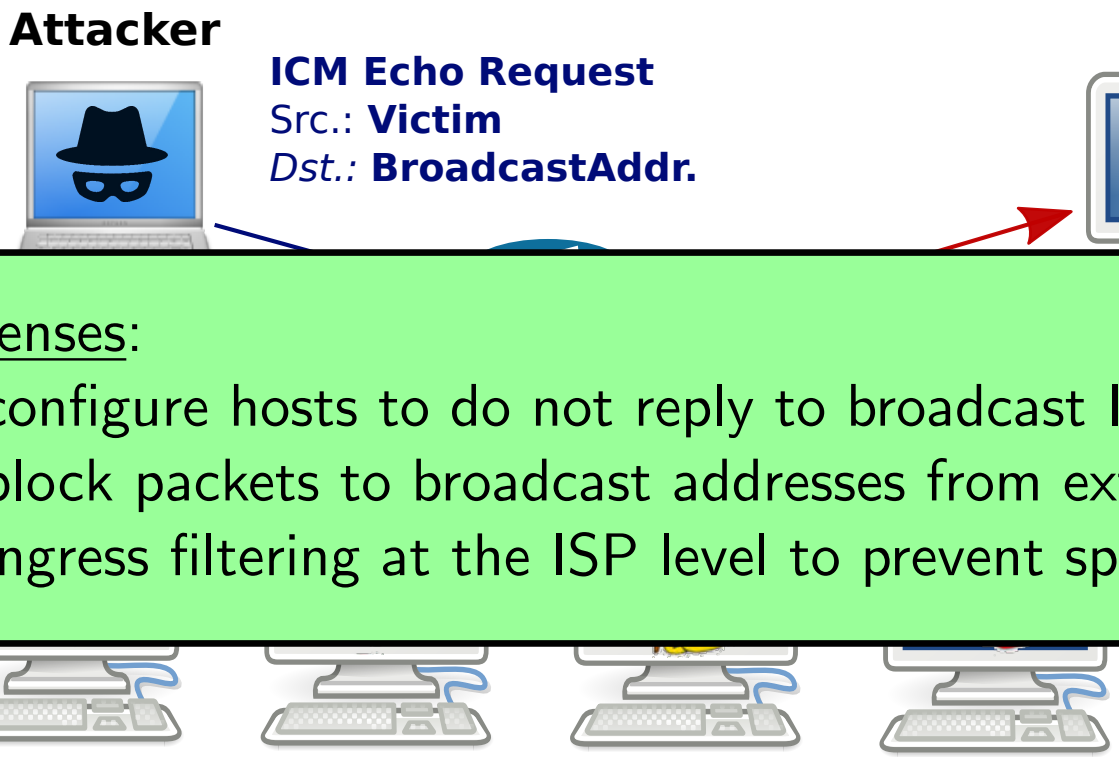

Defenses:

1. configure hosts to do not reply to broadcast ICMP requests;
2. block packets to broadcast addresses from external interfaces;
3. ingress filtering at the ISP level to prevent spoofing.

Botnets - I

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- **Botnet**:
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Overview of the botnet creation process:

Attacker's GOAL: take control of other machines.

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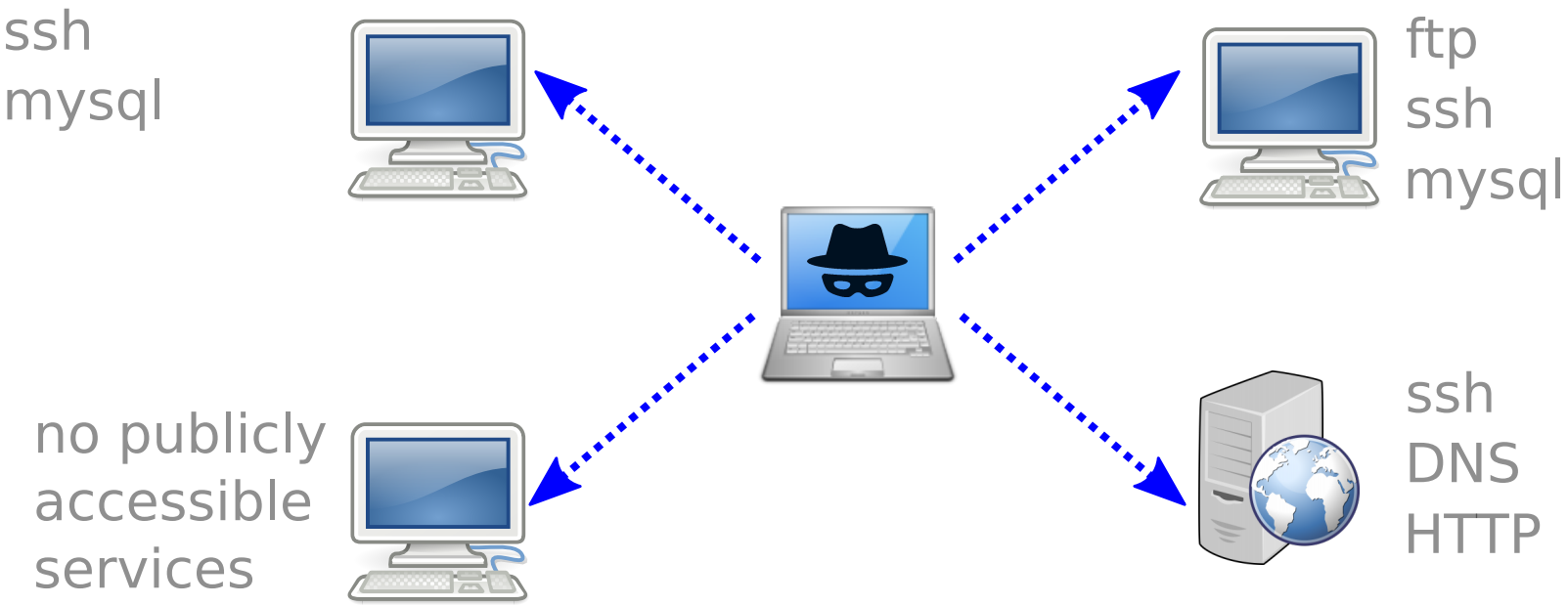

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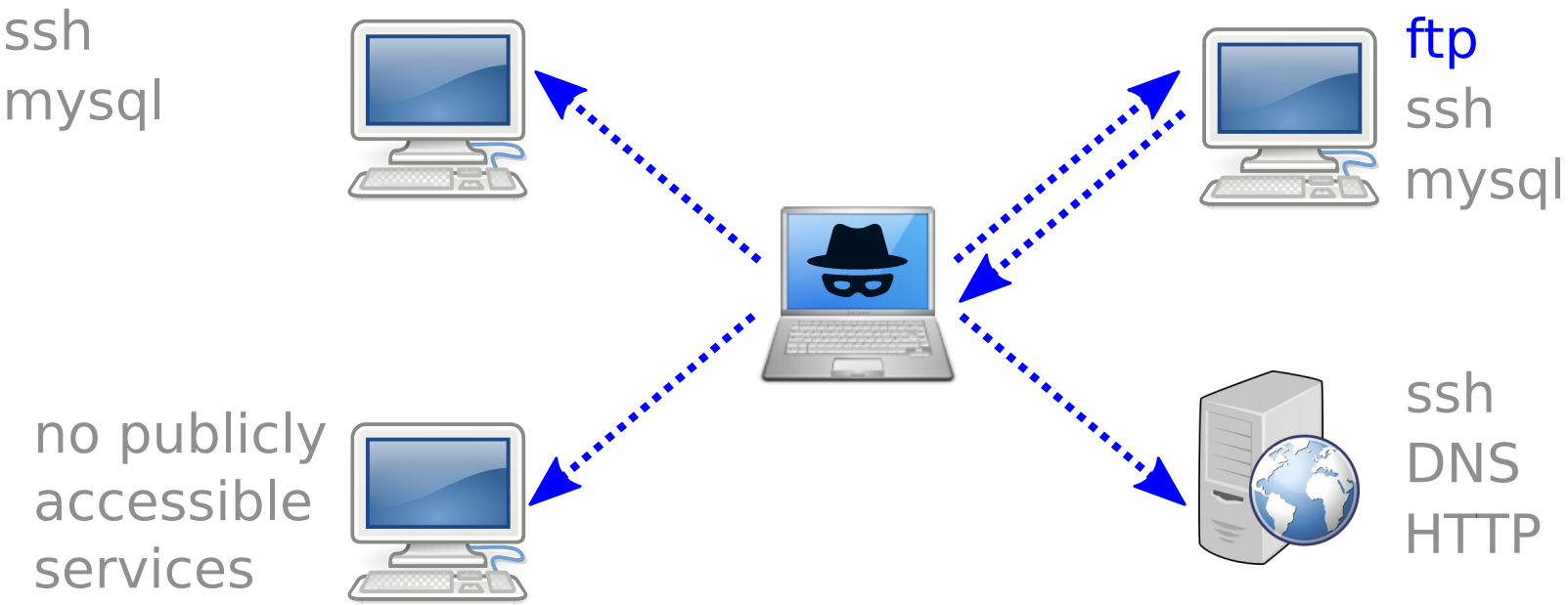

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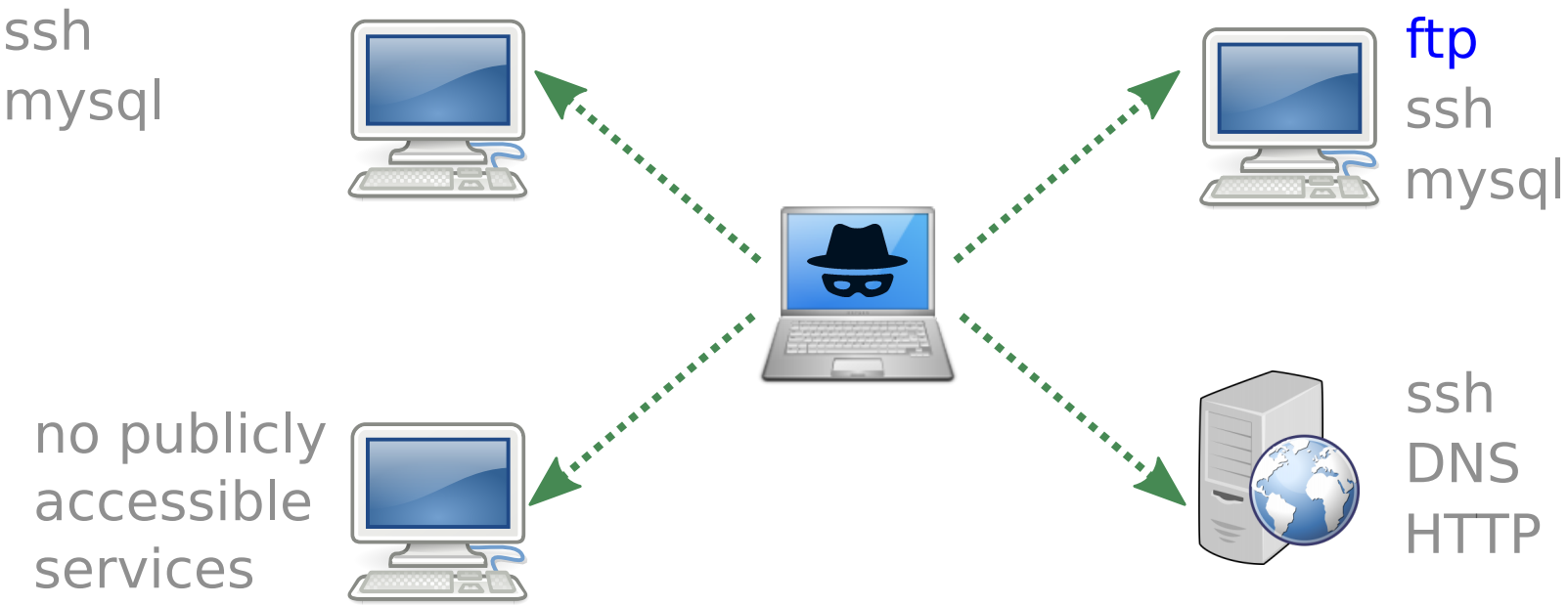

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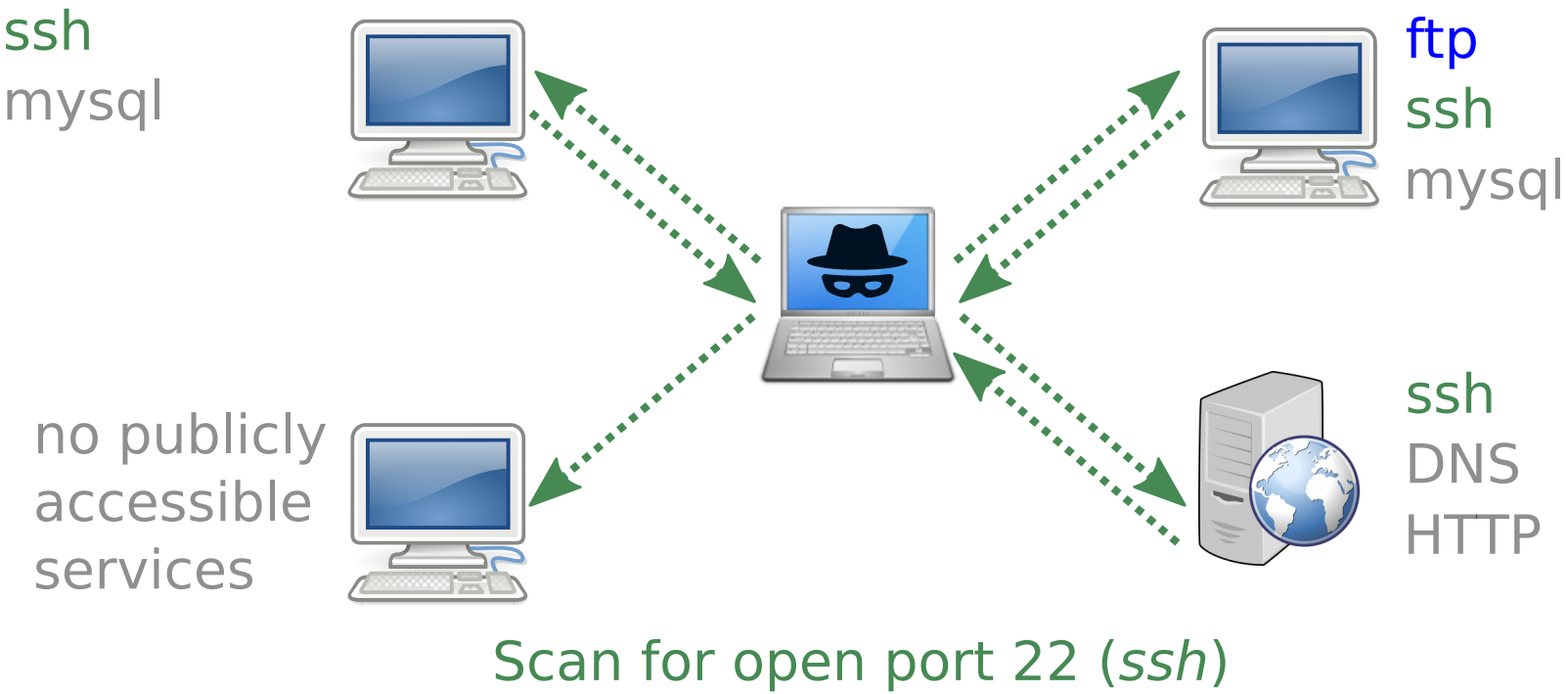

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Step#1: scan machines && identify services.

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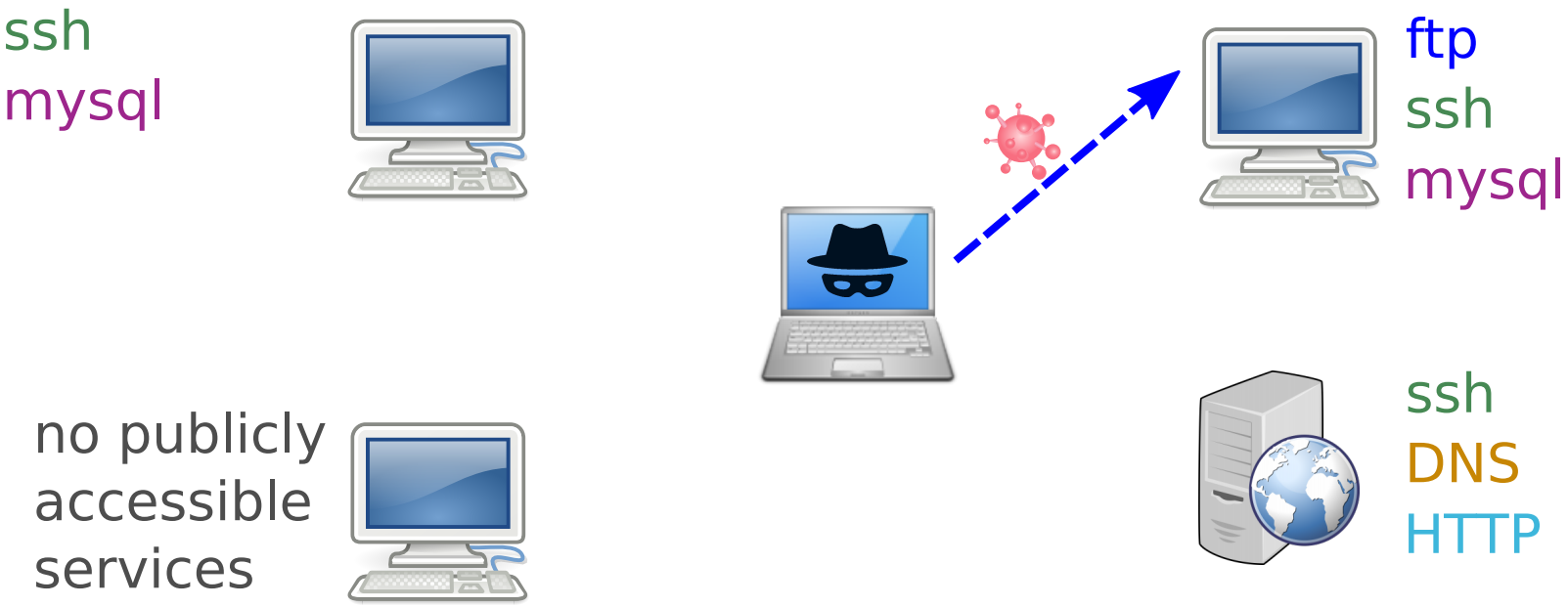

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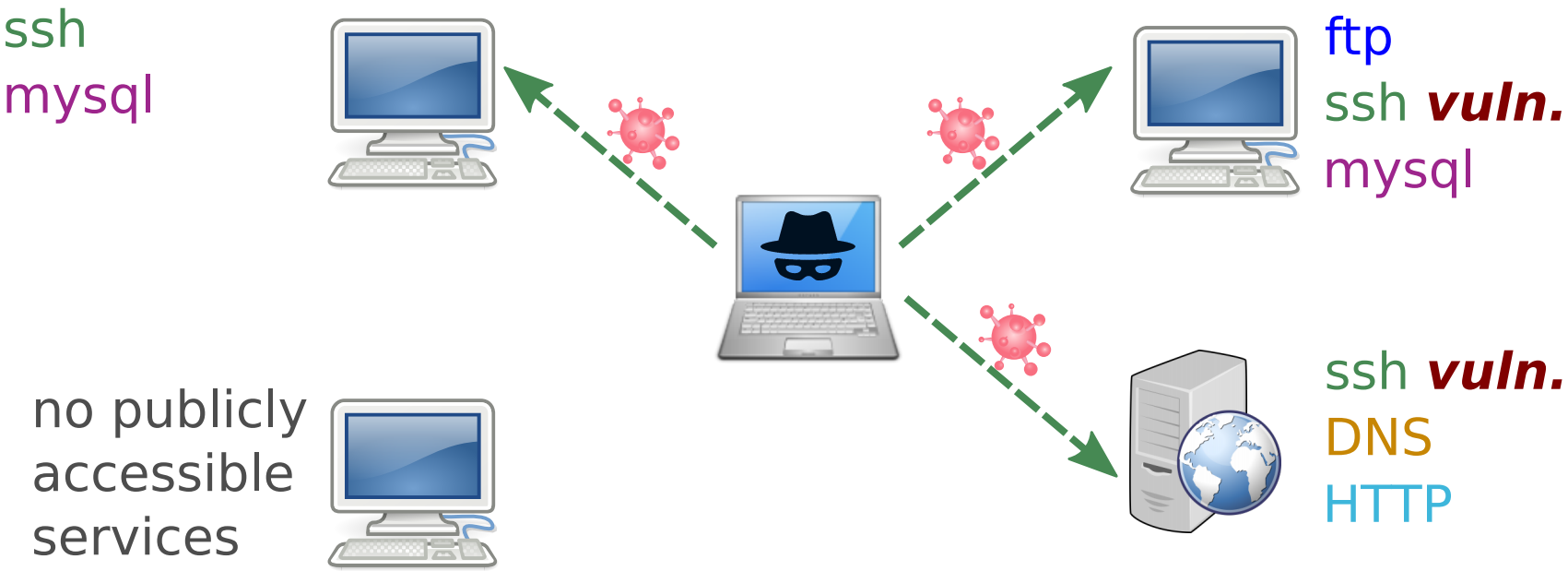

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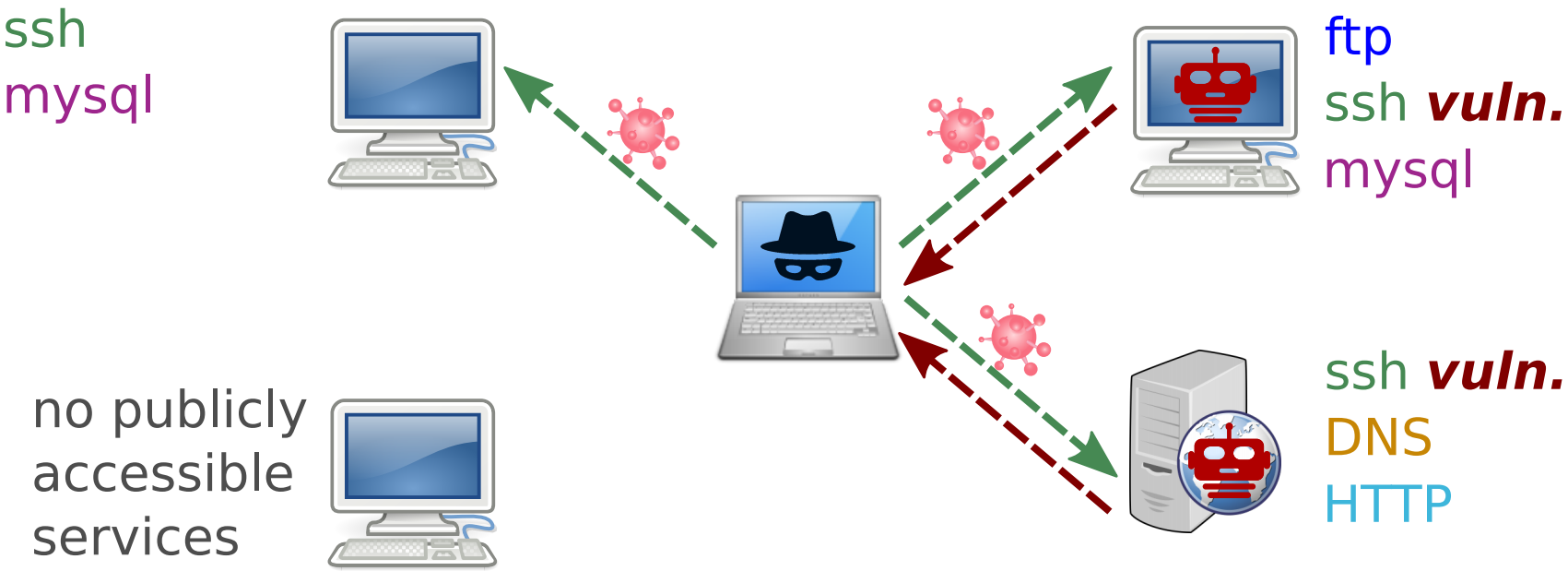

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Step#2: identify vuln. services and compromise machines.

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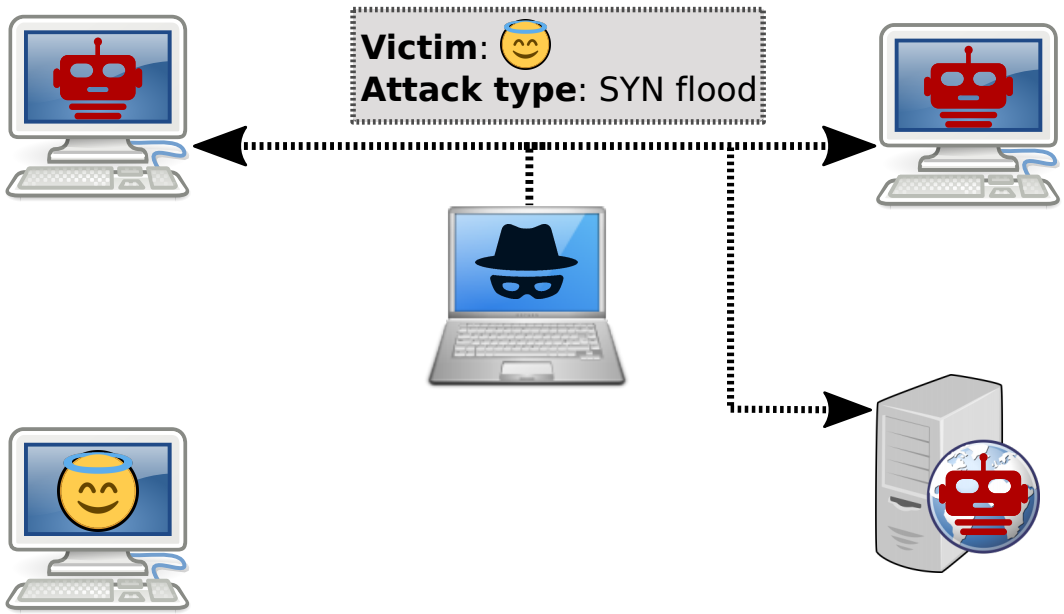

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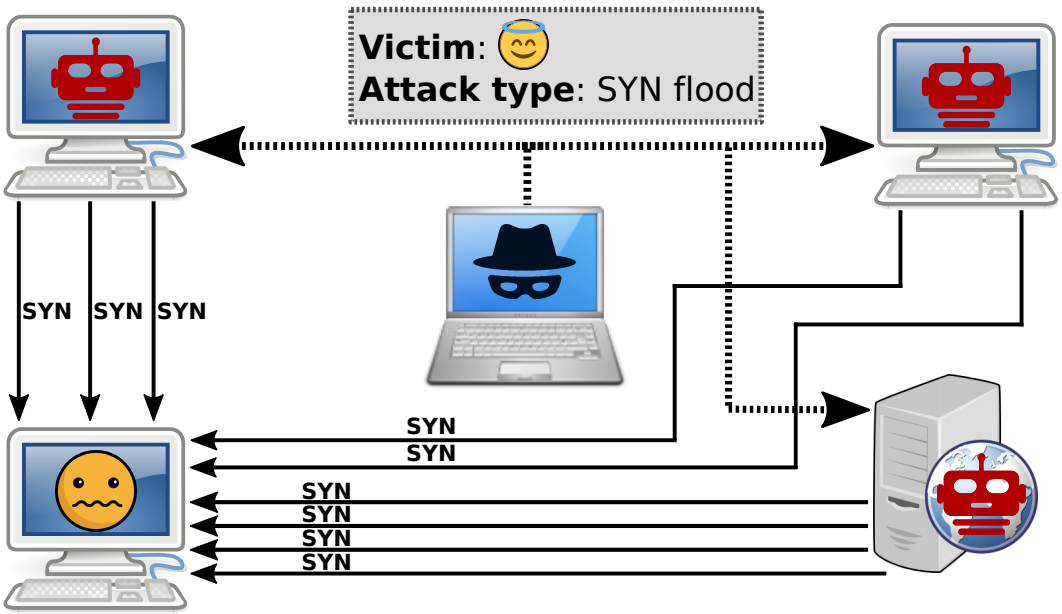

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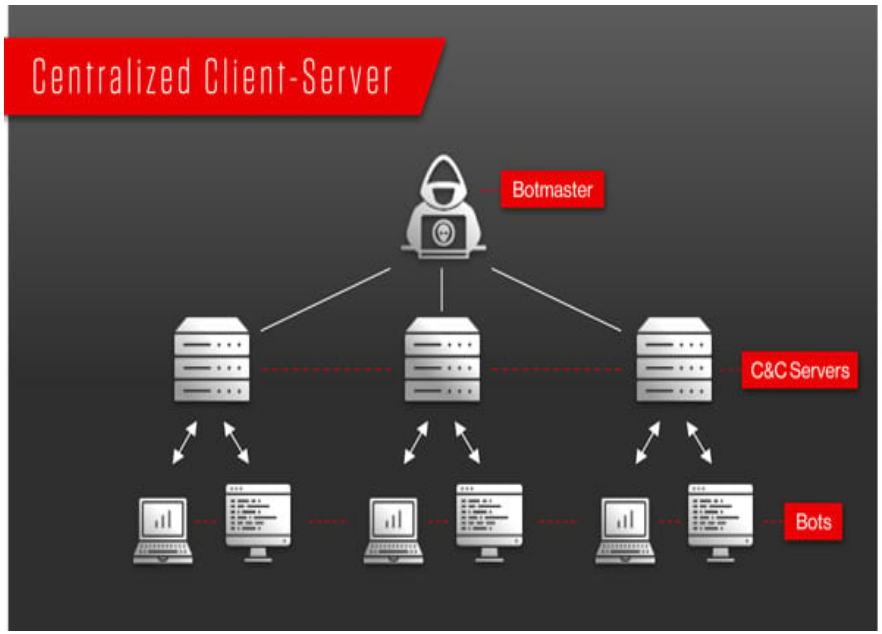
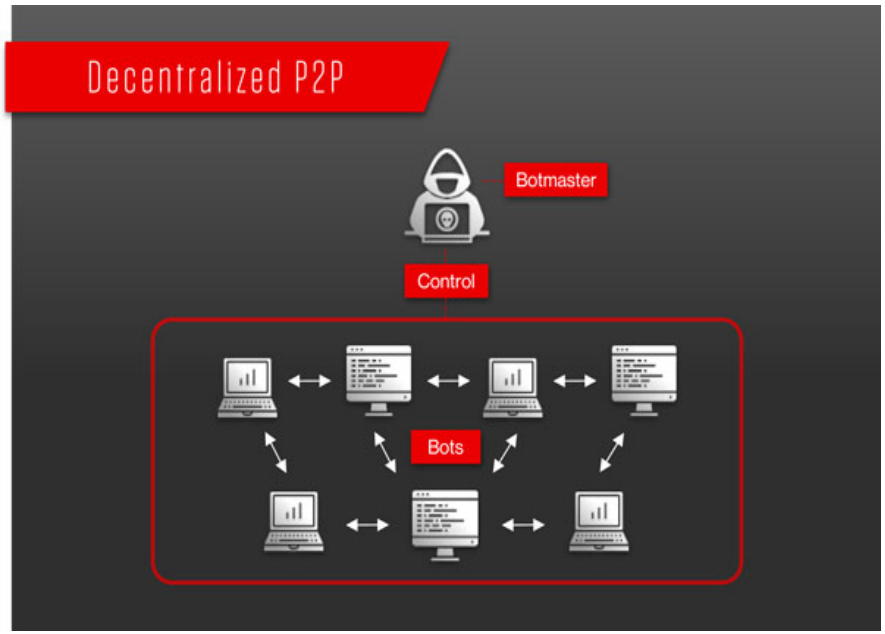
Botnets - II

- **Command and Control (C&C)**: the protocol that the botmaster leverages for controlling the infected machines.
  - Two communication models: *centralized* or *decentralized*.
- The bot software allows for multiple types of DoS attacks.





Source `https://www.crowdstrike.com/cybersecurity-101/botnets/`

DDoS Botnets - Lizard Stresser

- Written by the *Lizard Squad* group
  - Brute-forcing of Telnet using a list of credentials;
  - *bots*: home/university/company routers (pre-2015 malware).
    - **source code leaked** $\Longrightarrow$ *bots*: webcams and Digital Video Recording systems (post-2016 malware).
- Support for multiple DDoS attacks[2]:
  - HOLD: holds open TCP connections;
  - JUNK: random strings to TCP port(s);
  - UDP: random string on UDP port(s);
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[2] `https://www.securityweek.com/botnet-uses-iot-devices-power-massive-ddos-attacks`

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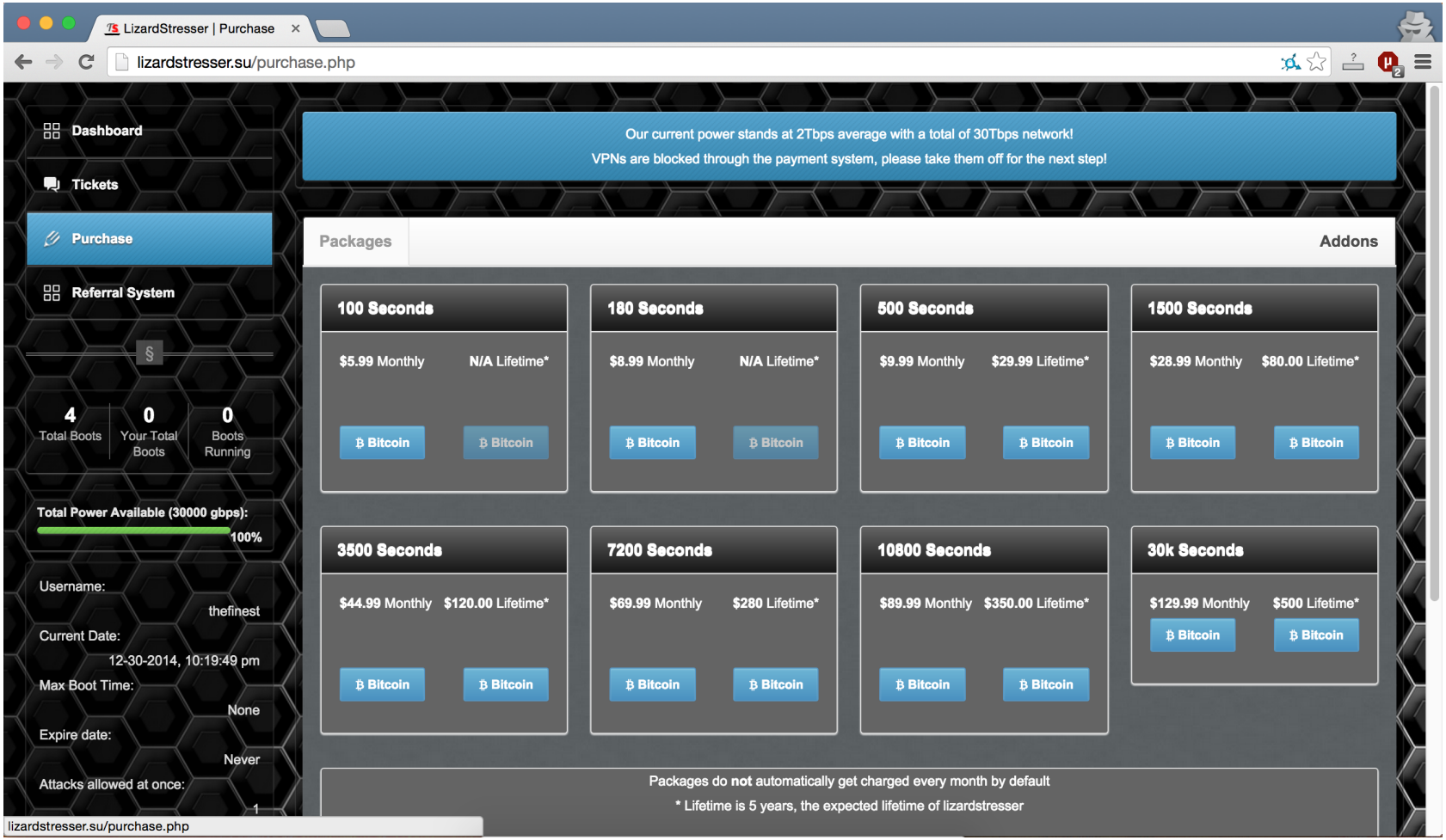
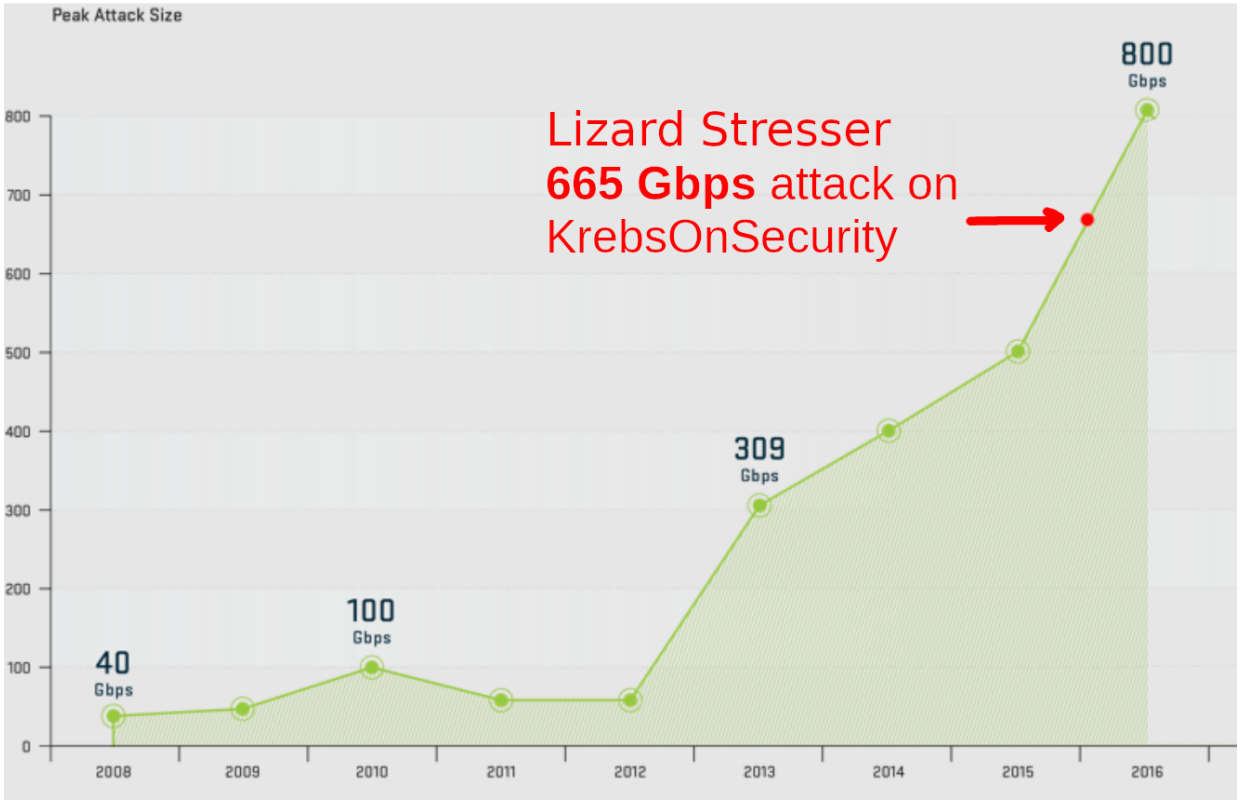
DDoS as a Service - Lizard Stresser



- Marketplace hosted on a *bulletproof provider*.
  - Multiple payment options (e.g., PayPal, card, Bitcoin)
  - Price proportional to the duration of the DDoS attack.

Largest DDoS Attack in 2016



- Brian Krebs investigated the Lizard Squad.
  - Lizard Stresser was used launch a **665 Gbps** attack on the blog KrebsOnSecurity!

Sources:
`https://blog.apnic.net/2018/04/03/the-ddos-threat-landscape-in-2017/` and
`https://krebsonsecurity.com/2014/12/lizard-kids-a-long-trail-of-fail/` and
`https://krebsonsecurity.com/2016/09/krebsonsecurity-hit-with-record-ddos/`

DDoS with Amplification

Largest DDoS attacks:

- GitHub (2018, **1.3 Tbps**)[3]

- Amazon AWS (2020, **2.3 Tbps**)[4]
- Microsoft (2021, **3.25 Tbps**)[5]

[3] https://www.wired.com/story/github-ddos-memcached/
[4] https://aws-shield-tlr.s3.amazonaws.com/2020-Q1_AWS_Shield_TLR.pdf
[5] https://www.thesslstore.com/blog/largest-ddos-attack-in-history/

DDoS with Amplification

Largest DDoS attacks: $\Rightarrow$ **amplification attacks**

- GitHub (2018, **1.3 Tbps**)[3]
  - no botnets involved $\rightarrow$ leveraged *memcache*;
  - 100,000 exploitable servers $\rightarrow$ attack increase by 50 times.
- Amazon AWS (2020, **2.3 Tbps**)[4]
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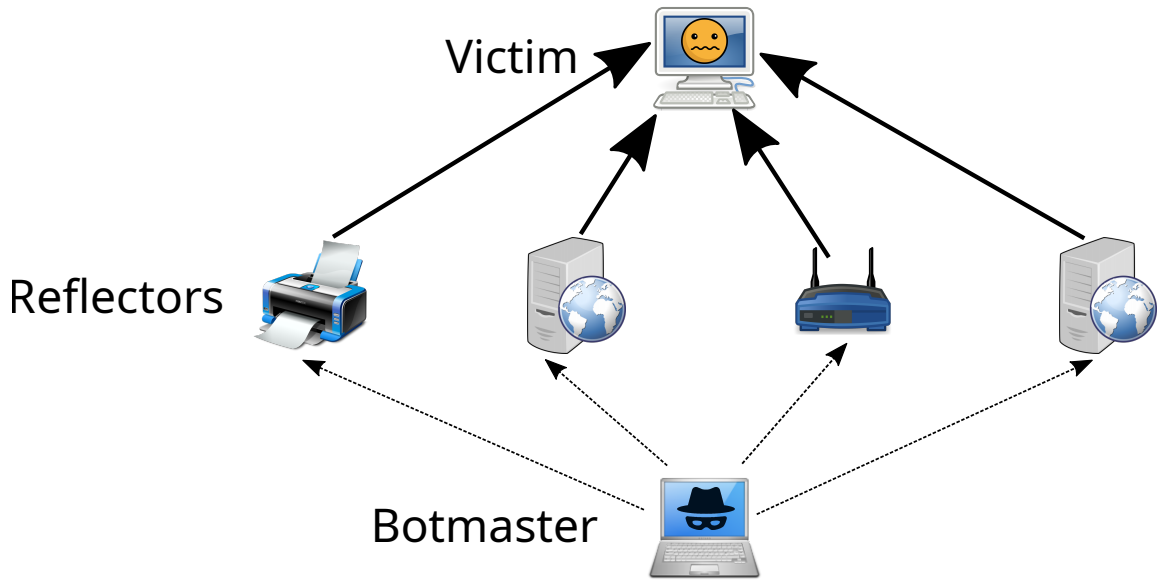

[3] https://www.wired.com/story/github-ddos-memcached/
[4] https://aws-shield-tlr.s3.amazonaws.com/2020-Q1_AWS_Shield_TLR.pdf
[5] https://www.thesslstore.com/blog/largest-ddos-attack-in-history/

Amplifier Example: Open DNS Resolvers

- **Open resolver**: DNS server that accepts remote requests.

[6] https://christian-rossow.de/publications/amplification-ndss2014.pdf.

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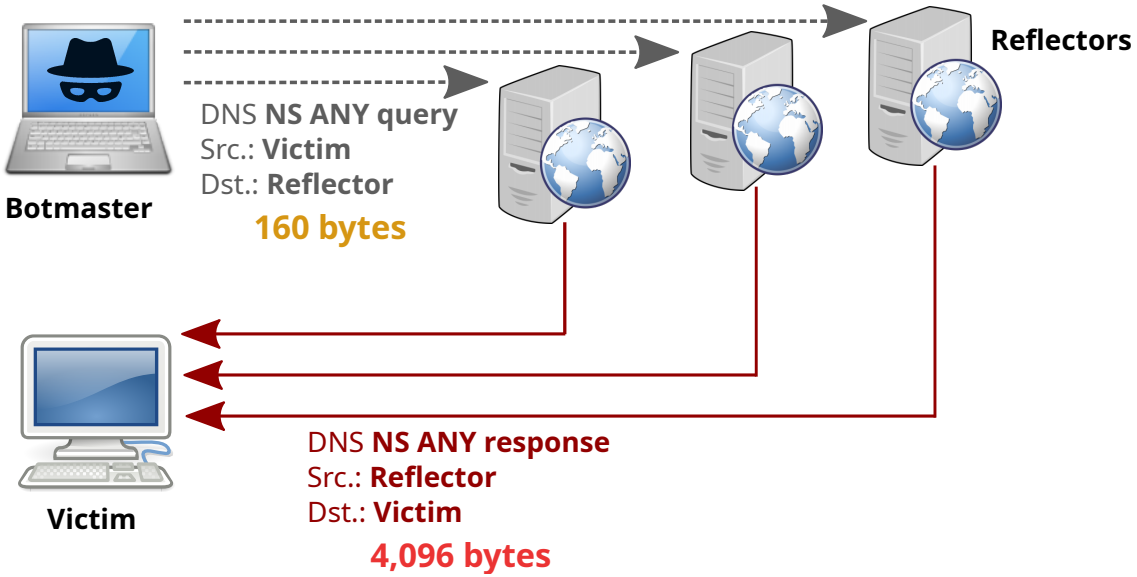

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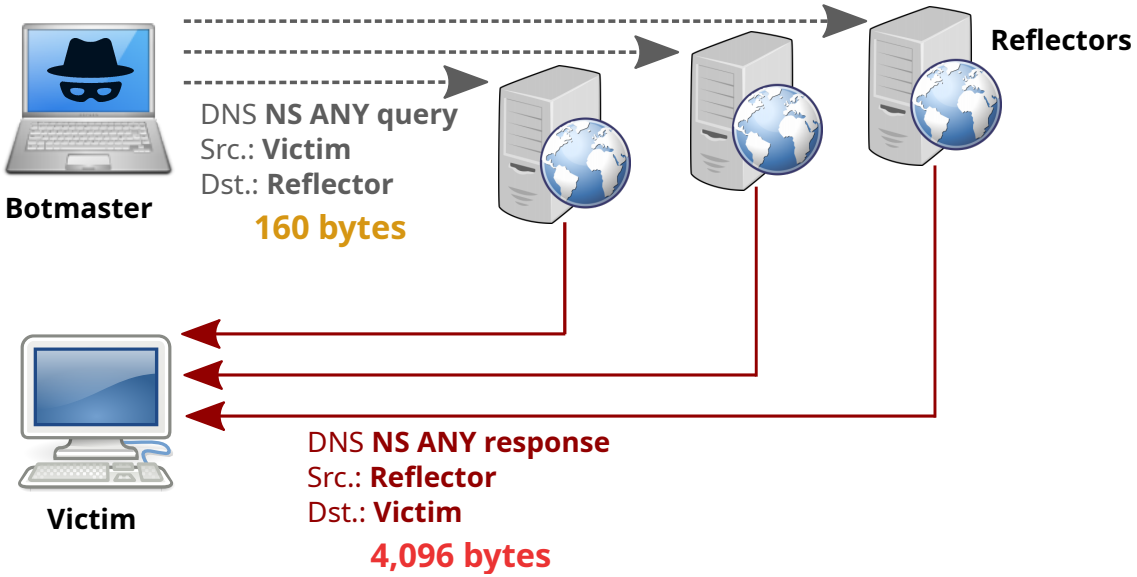

How many open resolvers are accessible on Internet?

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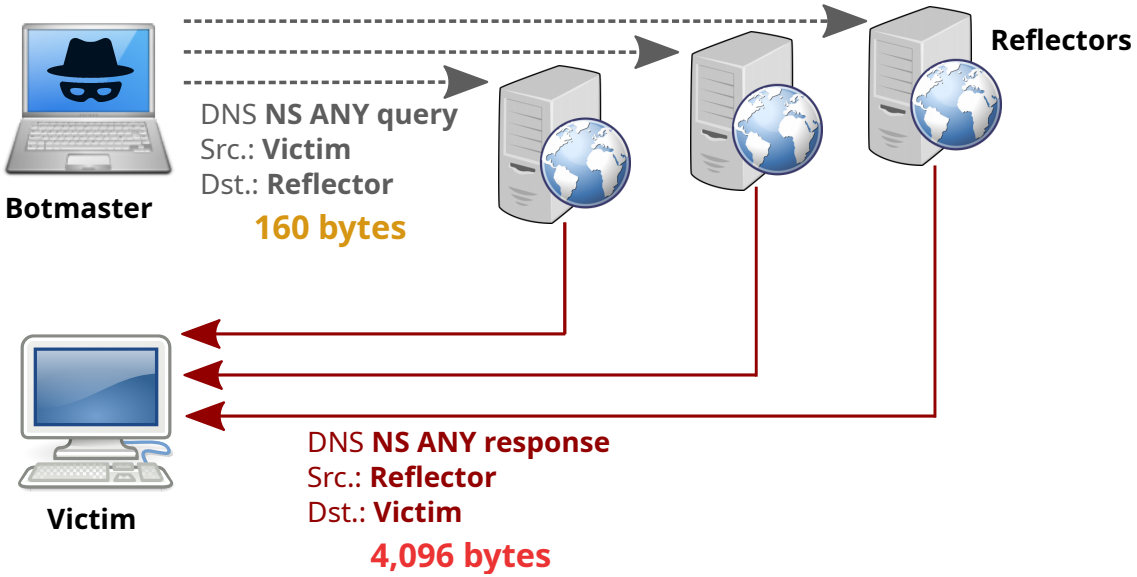

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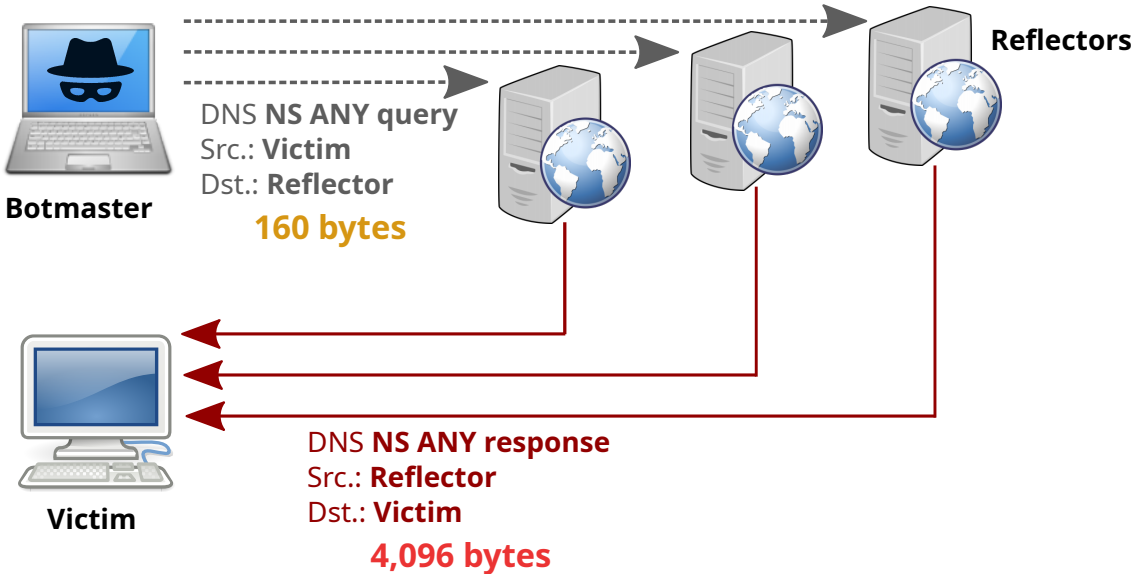

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[NDSS'14] Finding Amplifiers

Protocol	Amplifiers	Tech.	t_{1k}	t_{100k}
SNMP v2	4,832,000	Scan	1.5s	148.9s
NTP	1,451,000	Scan	2.0s	195.1s
DNS_{NS}	255,819	Crawl	35.3s	3530.0s
DNS_{OR}	7,782,000	Scan	0.9s	92.5s
NetBios	2,108,000	Scan	3.4s	341.5s
SSDP	3,704,000	Scan	1.9s	193.5s
CharGen	89,000	Scan	80.6s	n/a
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BitTorrent	5,066,635	Crawl	0.9s	63.6s
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TABLE II: Number of amplifiers per protocol, the technique we used to obtain the amplifiers, and the time it took to identify 1000 (t_{1k}) and 100,000 (t_{100k}) amplifiers, respectively.

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[NDSS'14] Amplification Factors

Protocol	BAF *all*	BAF 50%	BAF 10%	PAF *all*	Scenario
SNMP v2	6.3	8.6	11.3	1.00	*GetBulk* request
NTP	556.9	1083.2	4670.0	10.61	Request "monlist" statistics
DNS_{NS}	54.6	76.7	98.3	2.08	ANY lookup at author. NS
DNS_{OR}	28.7	41.2	64.1	1.32	ANY lookup at open resolv.
NetBios	3.8	4.5	4.9	1.00	Name resolution
SSDP	30.8	40.4	75.9	9.92	*SEARCH* request
CharGen	358.8	n/a	n/a	1.00	Character generation request
QOTD	140.3	n/a	n/a	1.00	Quote request
BitTorrent	3.8	5.3	10.3	1.58	File search
Kad	16.3	21.5	22.7	1.00	Peer list exchange
Quake 3	63.9	74.9	82.8	1.01	Server info exchange
Steam	5.5	6.9	14.7	1.12	Server info exchange
ZAv2	36.0	36.6	41.1	1.02	Peer list and cmd exchange
Sality	37.3	37.9	38.4	1.00	URL list exchange
Gameover	45.4	45.9	46.2	5.39	Peer and proxy exchange

TABLE III: Bandwidth amplifier factors per protocols. *all* shows the average BAF of all amplifiers, 50% and 10% show the average BAF when using the worst 50% or 10% of the amplifiers, respectively.

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Estonia DDoS Attack (2007)

- Trigger: relocation of the Bronze Soldier in Tallin.
  - (Estonian's) Russians disagree..
  - On the 27th of April 2007, a 22-days DoS started on several Estonian websites...
- Attack details:
  - ICMP and TCP SYN floods;
  - malicious traffic originated from outside Estonia $\Rightarrow$ ISPs block foreign traffic;
  - targeted critical systems: telephony and financial;
  - attack instruction published on Russian websites.

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- Attribution is hard!
  - State-sponsored cyberwarfare?
    $\Rightarrow$ Many attacks originated from Russia.
  - Cyber-riot?
    $\Rightarrow$ One Estonian student found guilty and fined.

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DoS via Routing Attacks

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  A. drop all traffic for victim's site to attacker's site;
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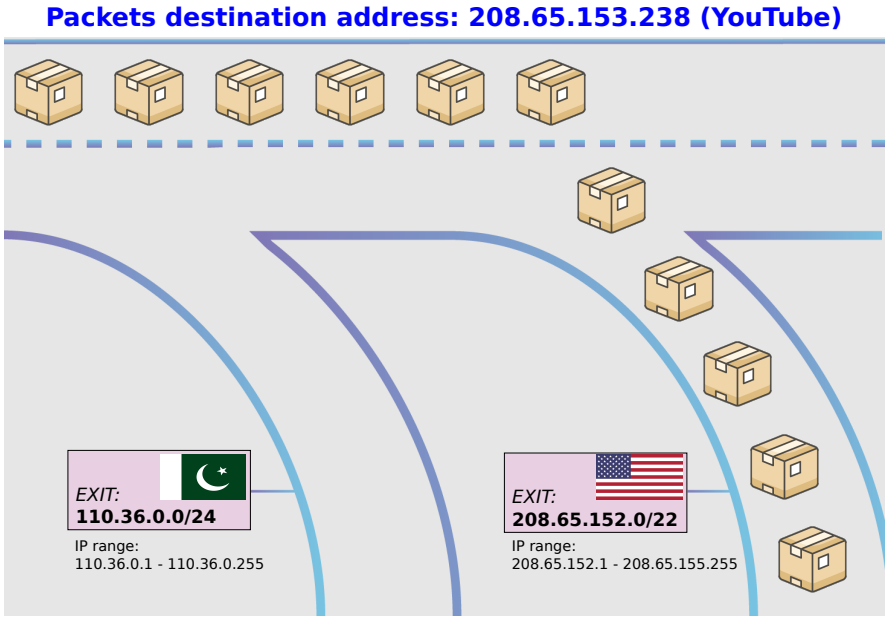
    $\Rightarrow$ *Most Internet users thought YouTube was in Pakistan.*



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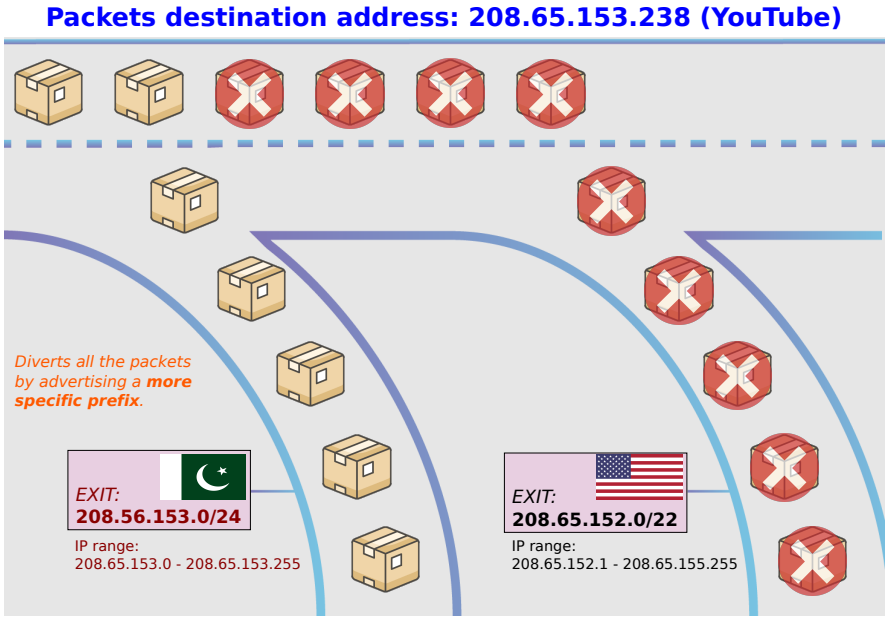

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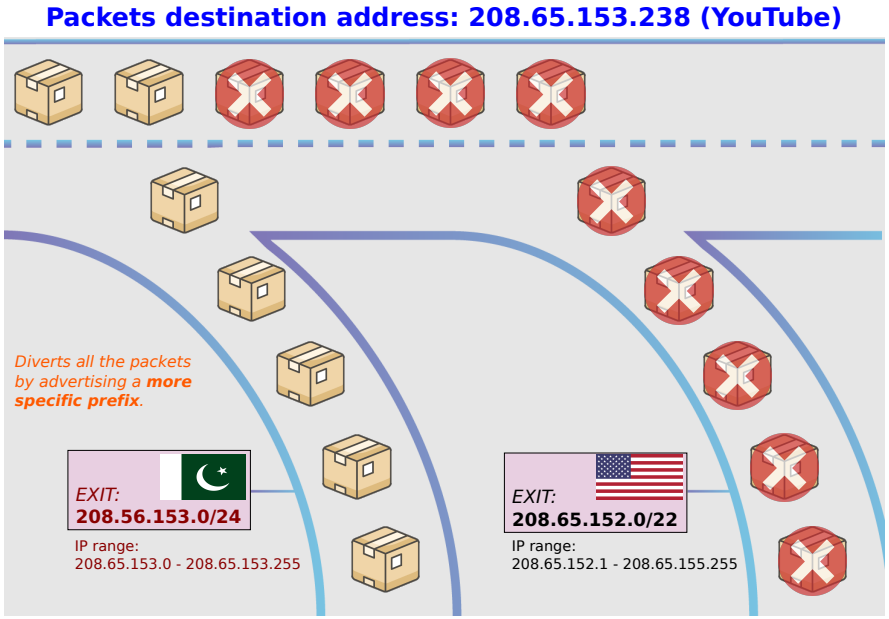

- 2014 **Bitcoin BGP hijacking attack**[8]
  - the attack lasted over 2 months, allowing to harvest $83,000 in cryptocurrency

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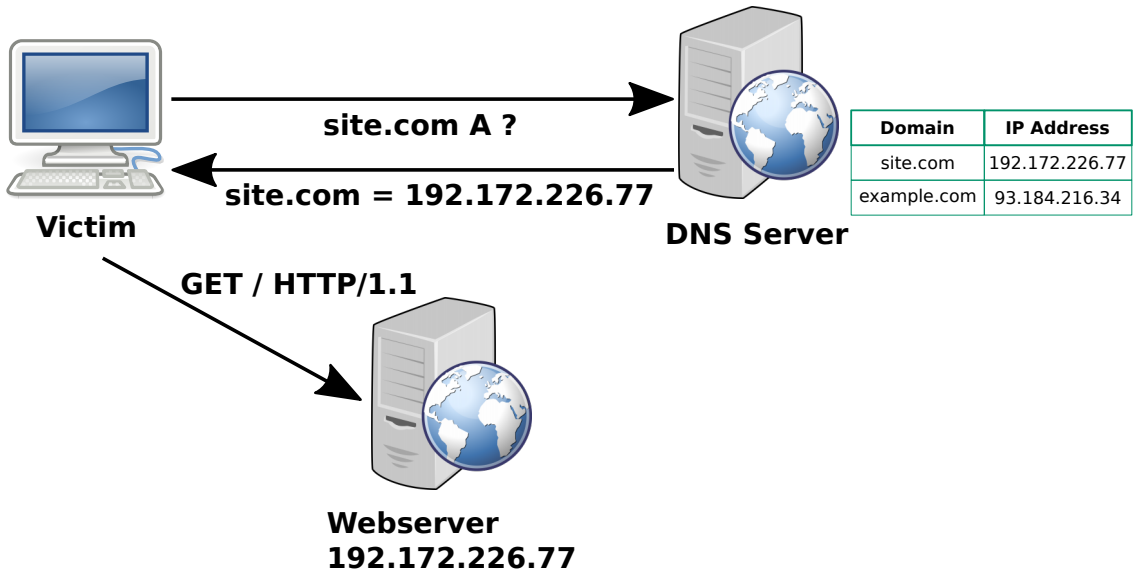
DNS DDoS

- Idea: instead of taking down the webserver, attack its DNS server



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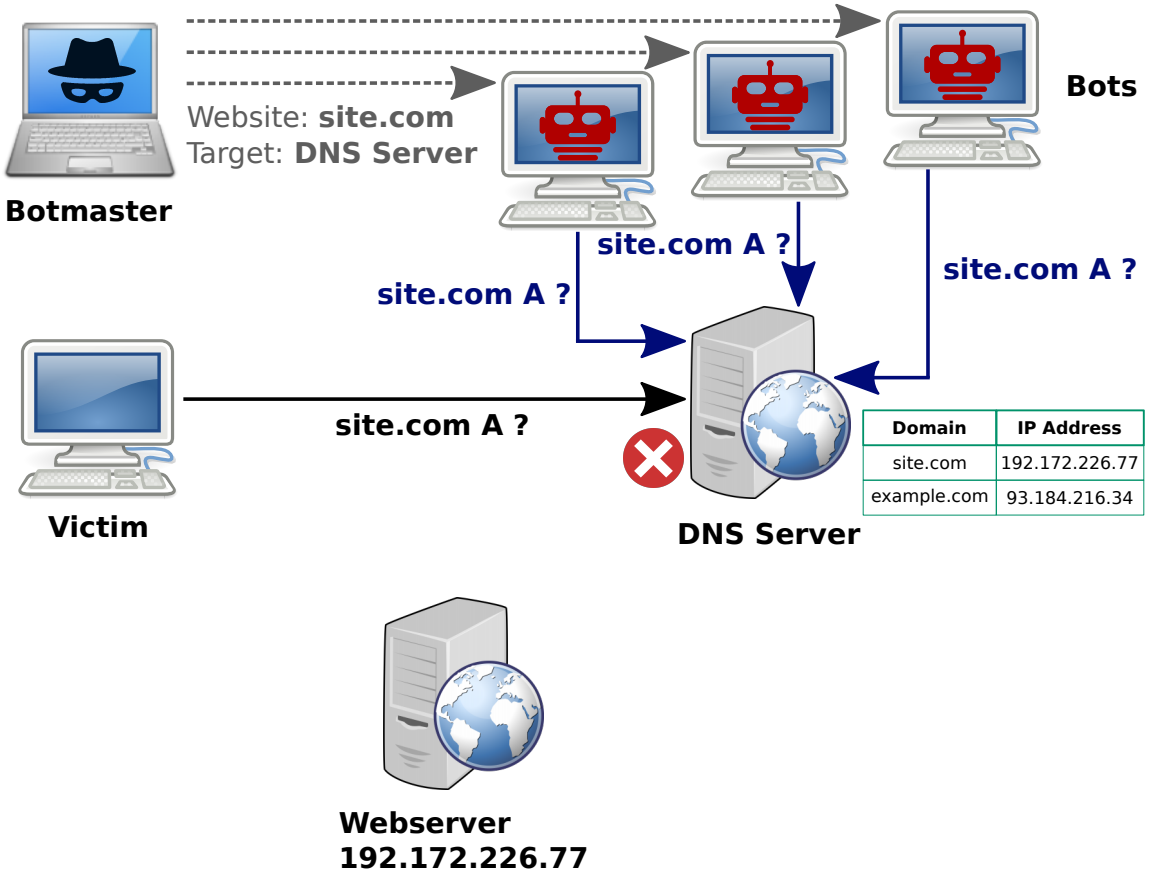

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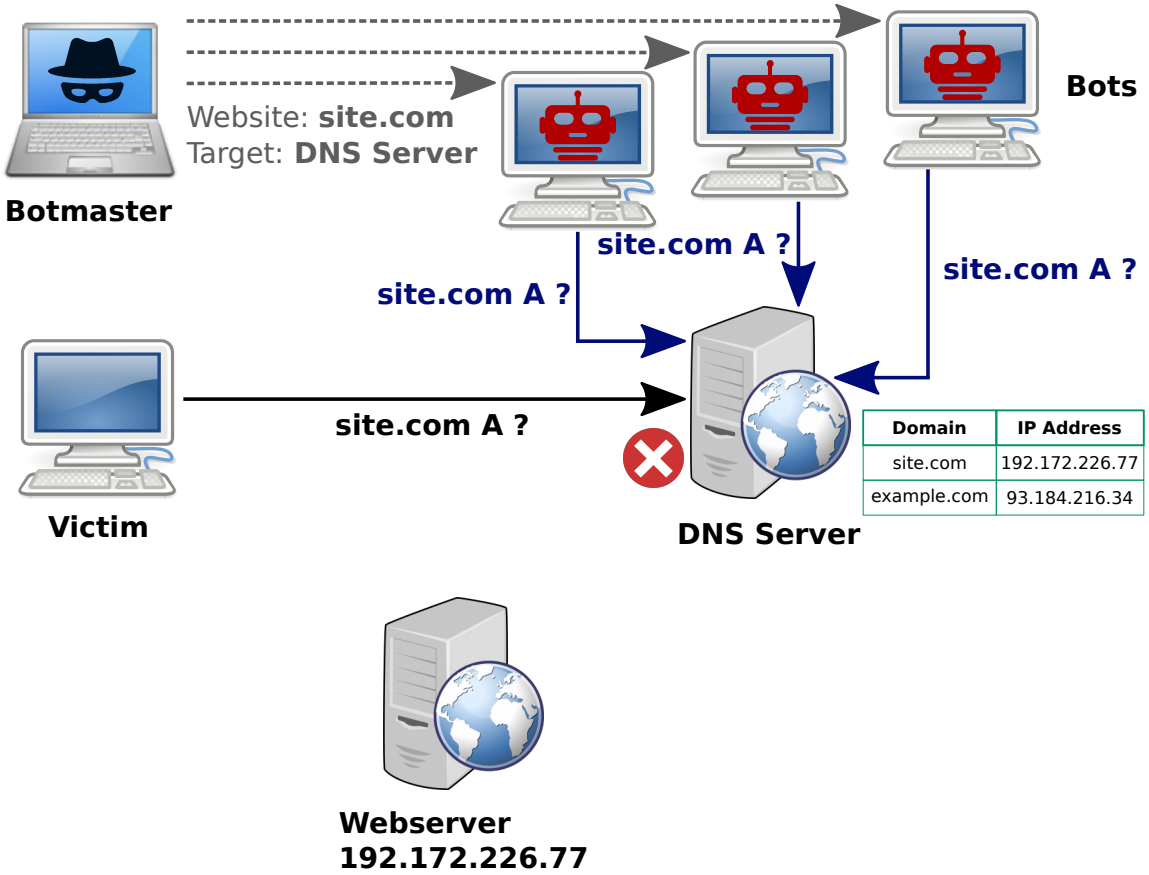

- Mirai-infected devices attack Dyn (2016)
  - Affected services: Amazon, PayPal, Slack, Twitter, CNN, NYT[9].

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JavaScript DDoS Attack

- Application layer attack.
- Attack: inject DDoS JavaScript into website's response.
  $\Rightarrow$ Everyone visiting the (malicious) website becomes a DDoS bot.

How to serve to clients malicious JS code:

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function imgflood() {
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DoS Defenses

- Ingress Filtering
- SYN Cookies

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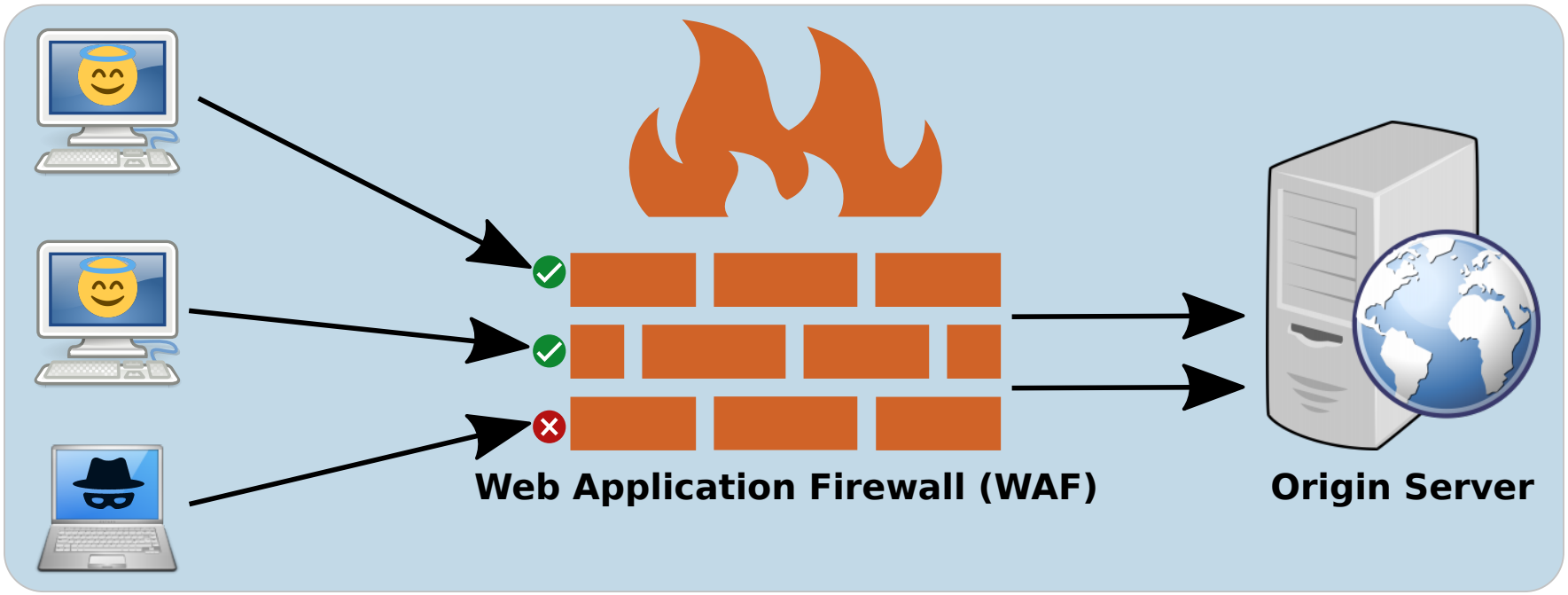
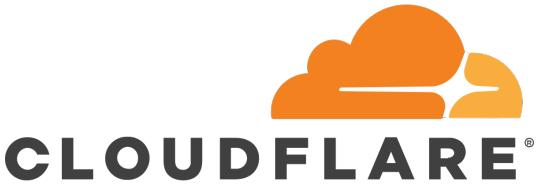
Web Application Firewall (WAF)

- WAF: a reverse proxy that intercepts HTTP traffic.
  - Filters malicious traffic (e.g., DDoS).
  - Forward valid requests to the website.



Dedicated DoS Protection Services

- Usually offered in conjunction with CDN service.
- These services route users to the closest WAF/CDN server that:
  1. filters malicious traffic;
  2. caches static content.



DoS protection service providers:
`https://www.esecurityplanet.com/products/distributed-denial-of-service-ddos-protection-vendors/`

CAPTCHAs

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- Load increases $\Rightarrow$ serve a CAPTCHA.
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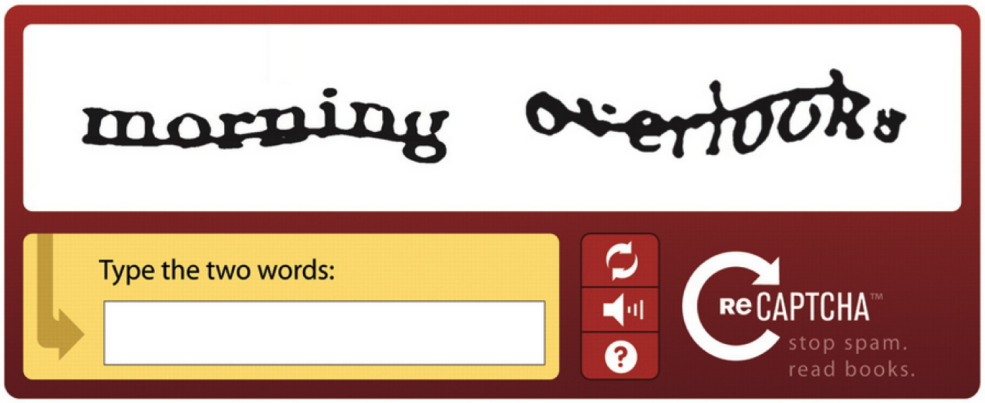

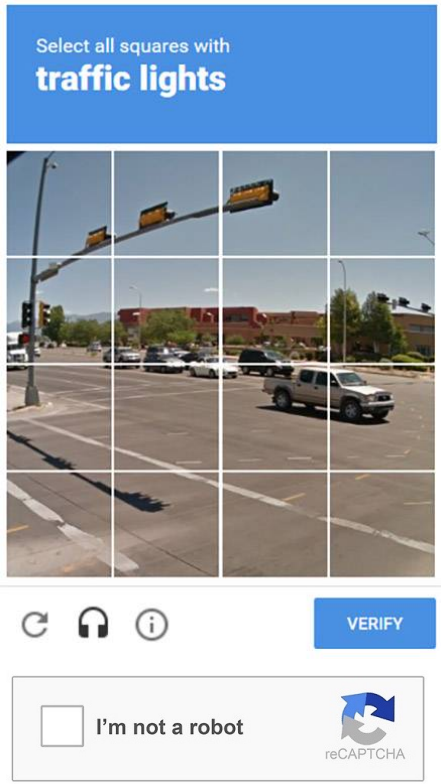

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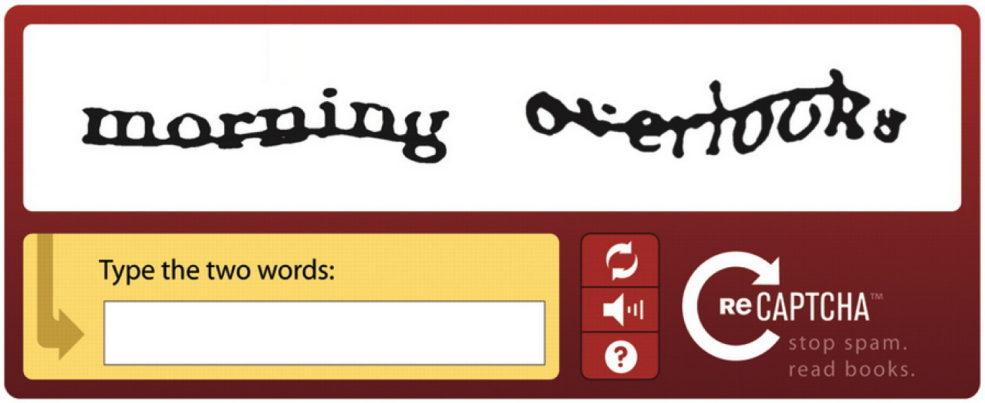

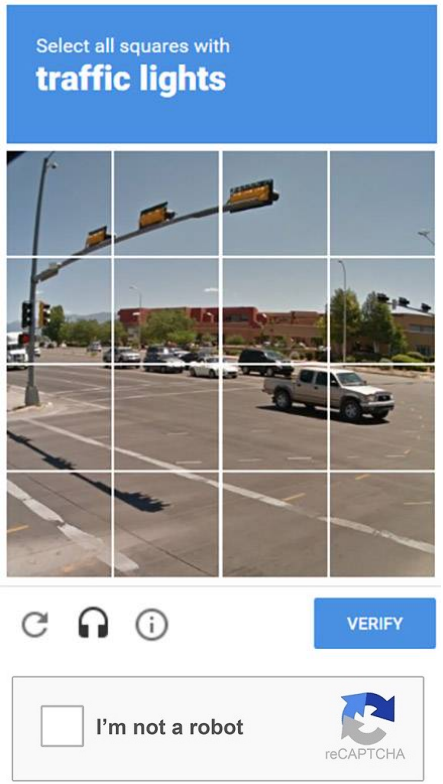

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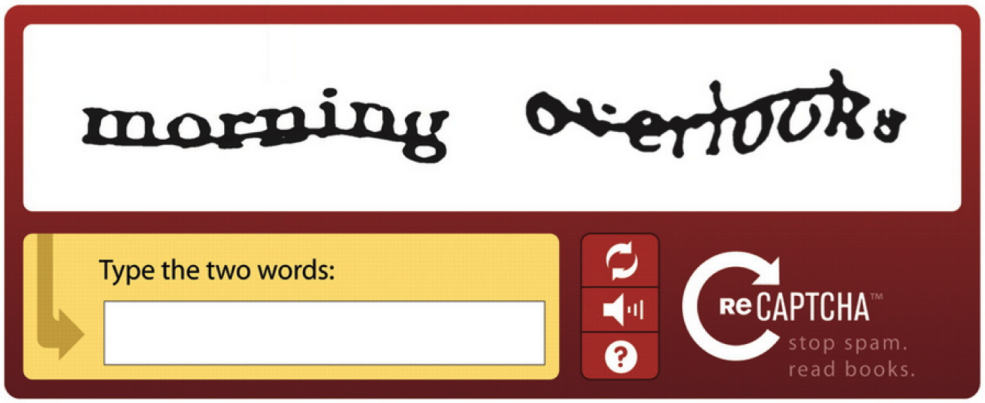

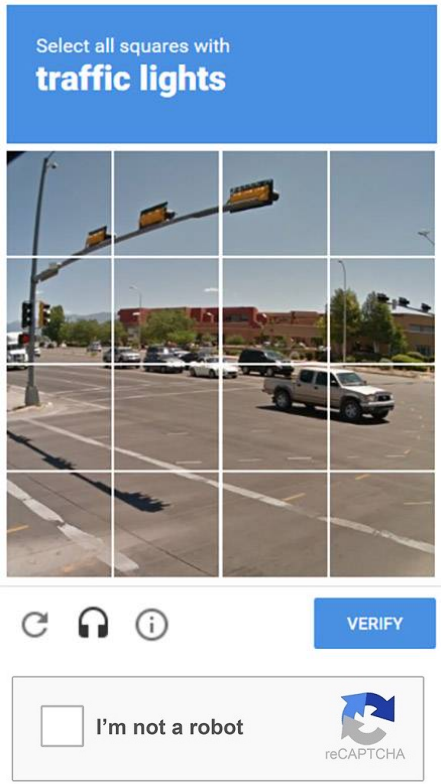

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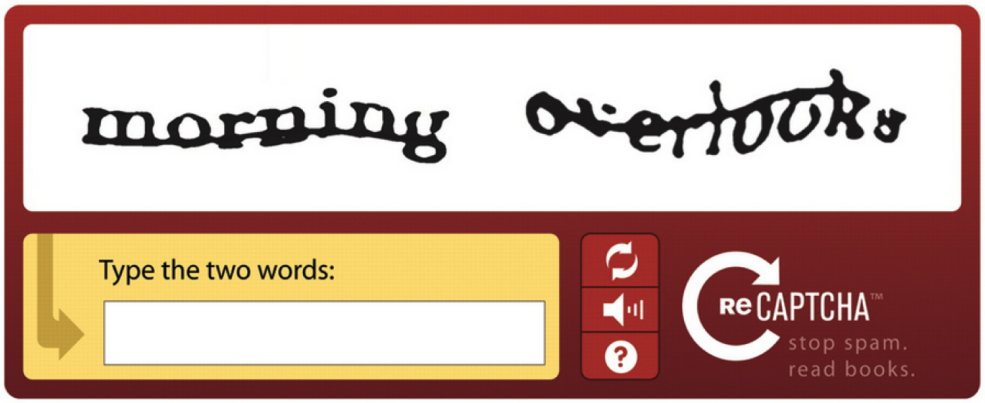

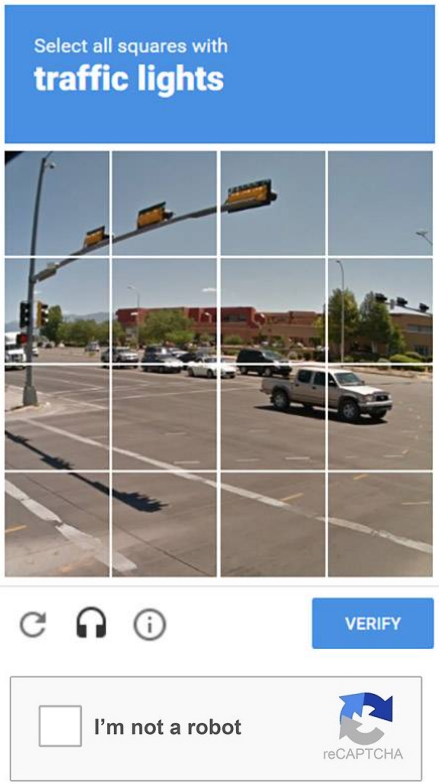

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- Idea: verify that the connection comes **from a human**.
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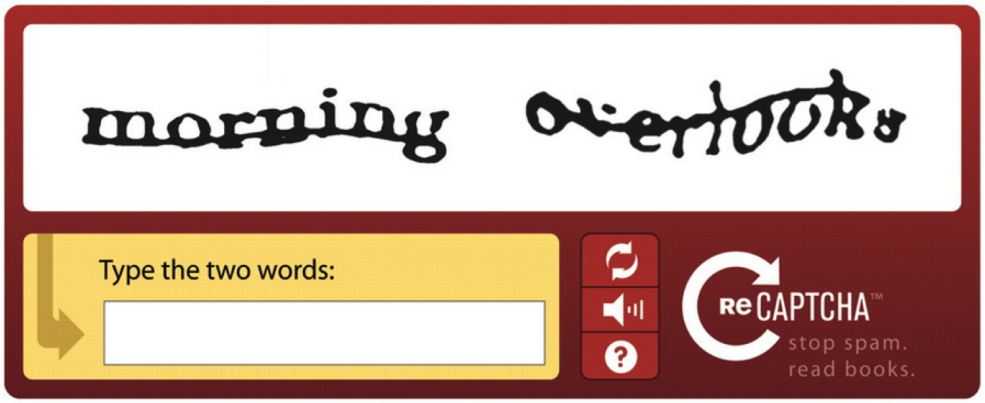
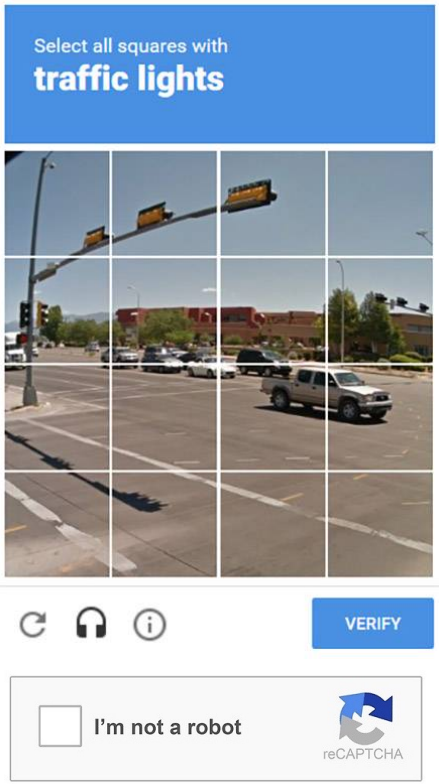
- Load increases ⇒ serve a CAPTCHA.
  - Accept *only* connections with a correct answer.





- **Limitations:**
  - works only for *application layer* attacks;
  - no defense against flooding;
  - False Positives (e.g., VPN, NAT).

Client Puzzle

- Idea: request client(s) to *do some work*, to slow down attacker(s).
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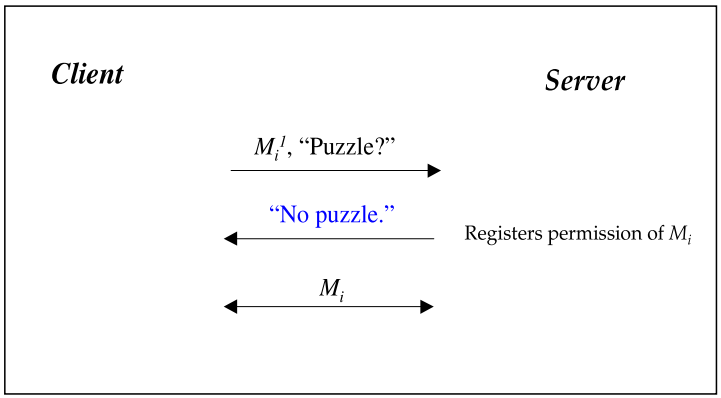

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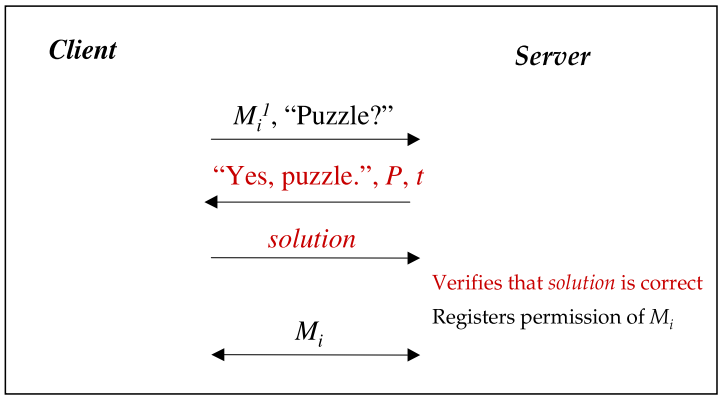

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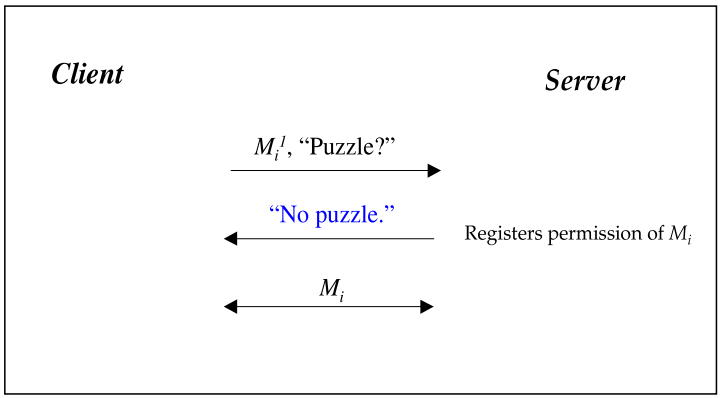

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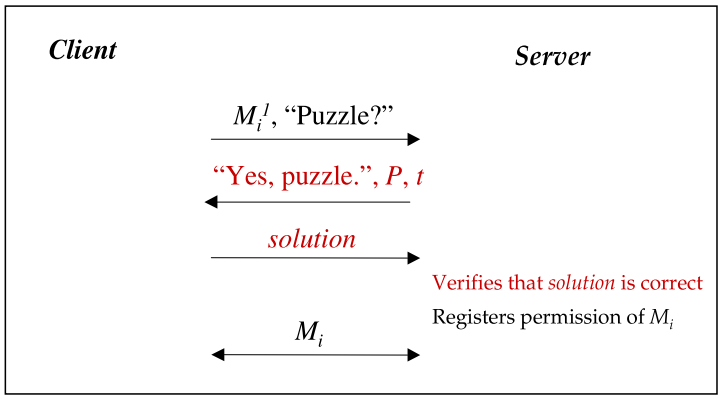

- Example: TCP SYN flood[10]:
  - Given the challenge **C**, find **X** such that:
    $LSB_n(\ SHA1(\ C\ ||\ X\ )\ ) = 0^n$
  - requires 2^n to solve $\Rightarrow$ for $n = 16$ it requires 0.3 second on a 1 Ghz machine

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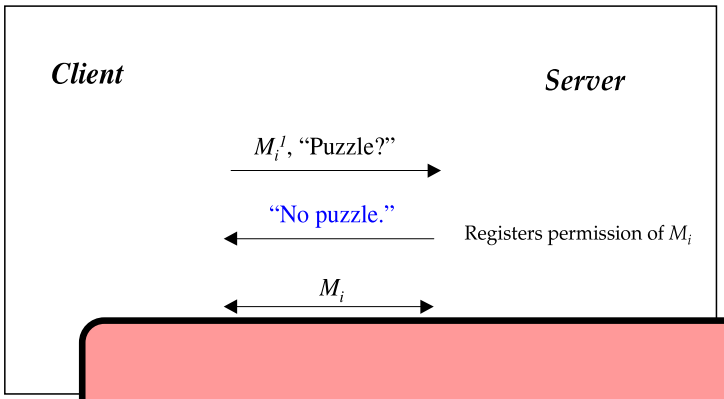

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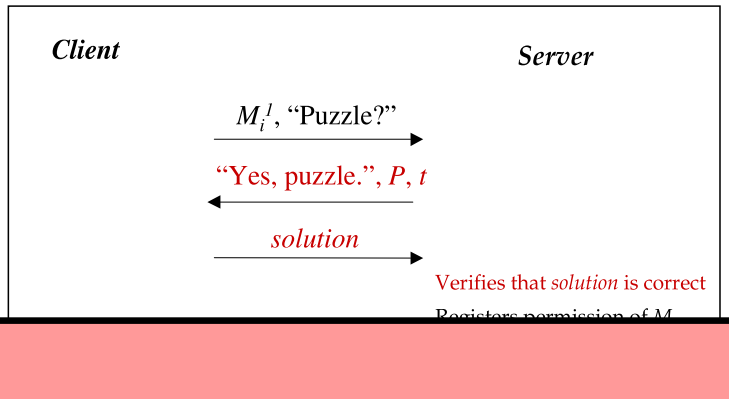

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2.
3.

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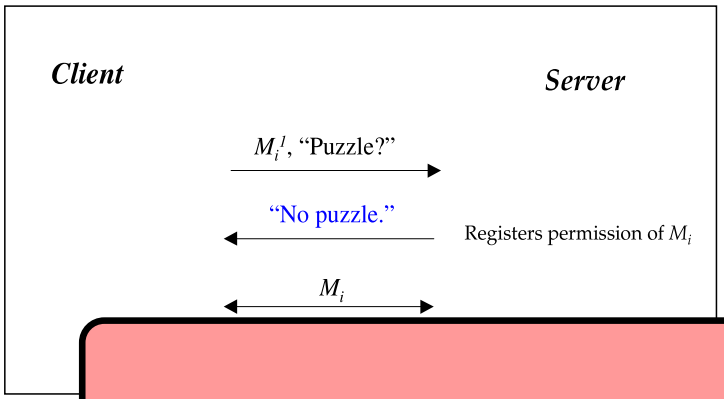

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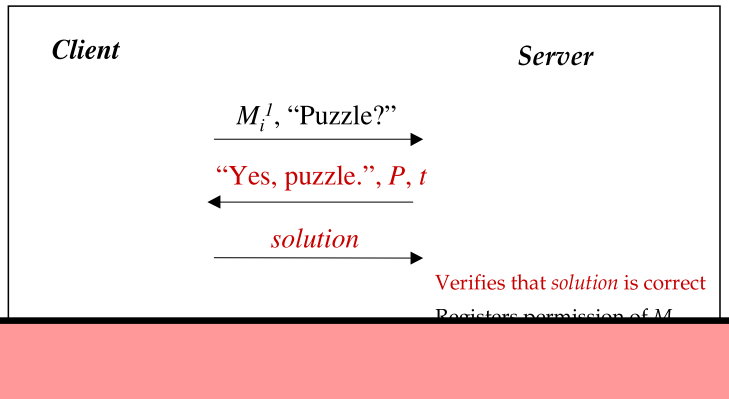

-

Limitation: **not deployed in practice**. Why?

1. Protects against *SYN flooding*, but not against *link flooding*.
2. It requires changes on both *client* and *servers*.
3. Is hard for low-powered clients/devices (e.g., IoT).

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Traceback

- Goal: determine packet source, despite spoofing.
- How: configure routers to include path information in each packet.

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Simple approach:

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Issue: *Where do we log this information?*.

- Paths can be very long.
- No usable fields in the IP datagrams.

Proposed solutions:

- *"Practical Network Support for IP Traceback", Savage, Wetherall, Karlin, Anderson [SIGCOMM'00]*
- "Hash-Based IP Traceback", Snoeren, Partridge, Sanchez, Jones, Tchakountio, Kent, Strayer [SIGCOMM'01]
- "An algebraic approach to IP traceback", Stubblefield, Dean, Franklin [NDSS'01]

Traceback Intuition [SIGCOMM'00]

Assumptions:

1. Most routers (on the path) are not compromised.
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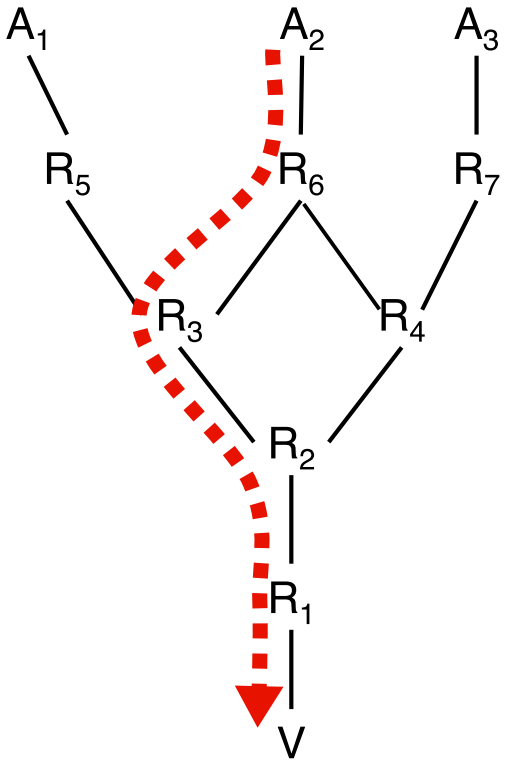

A_i = attacker
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Source: `https://www.cs.unc.edu/~jeffay/courses/nidsS05/traceback/savage-traceback-sigcomm00.pdf`

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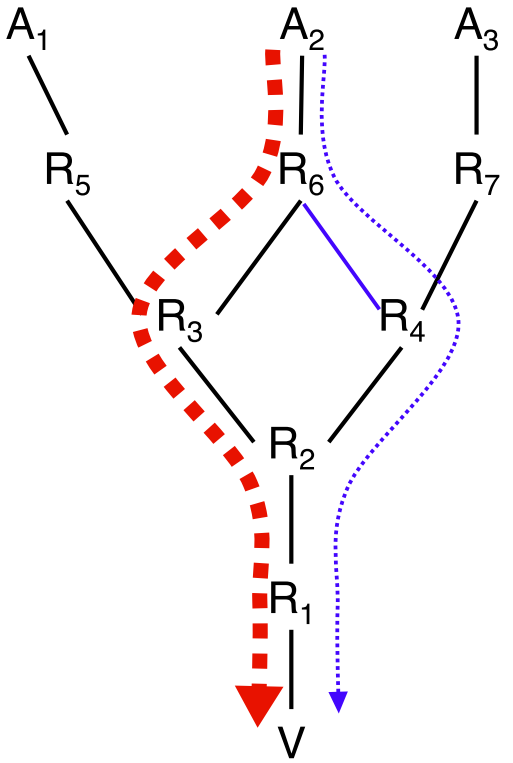

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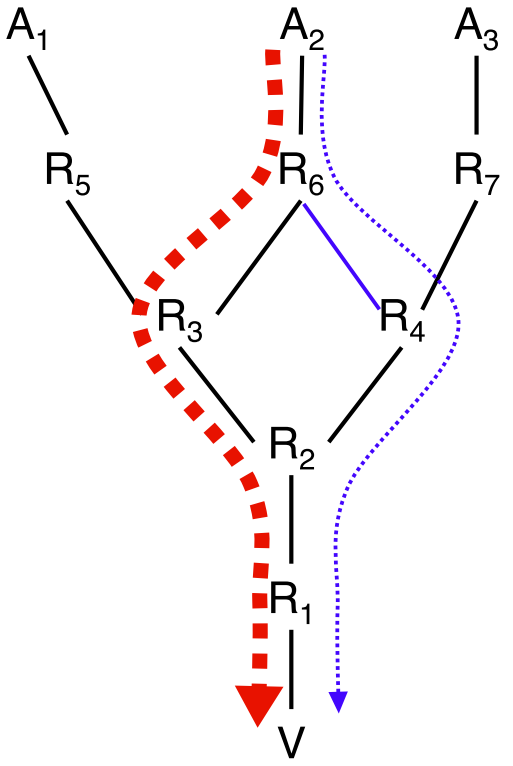
Approach: store *only one link* in each packet.

- Each router probabilistically stores only its own IP address.
  ⇒ Fixed space needed, regardless of the path.
- The full path (attacker → victim) can be reconstructed with enough packets.



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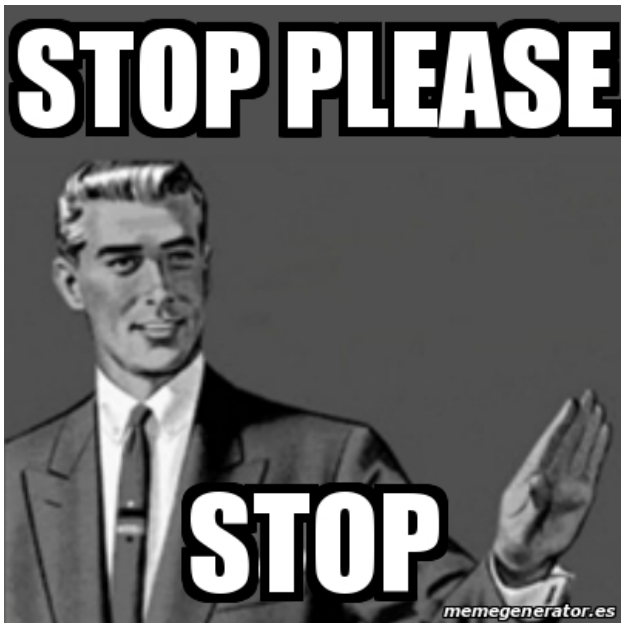
   Attacking packets can originate from:
   - Bullet-proof hosting providers.
   - Reflectors.
   - Bots.
   - States that deny any cooperation.



Pushback Filtering

Idea: dynamic traffic filtering on the backbone[11].

How: by detecting and controlling a high-bandwidth subsets of traffic.

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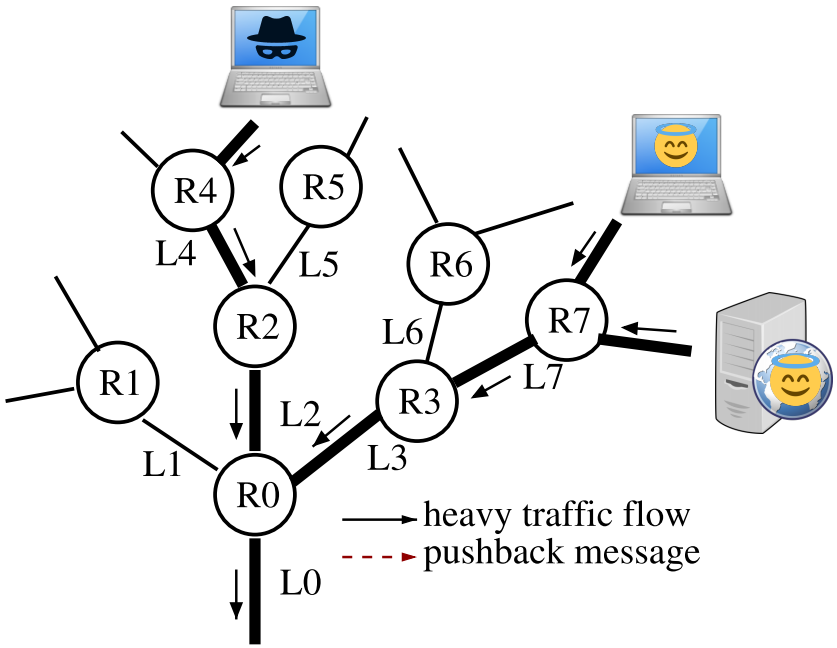

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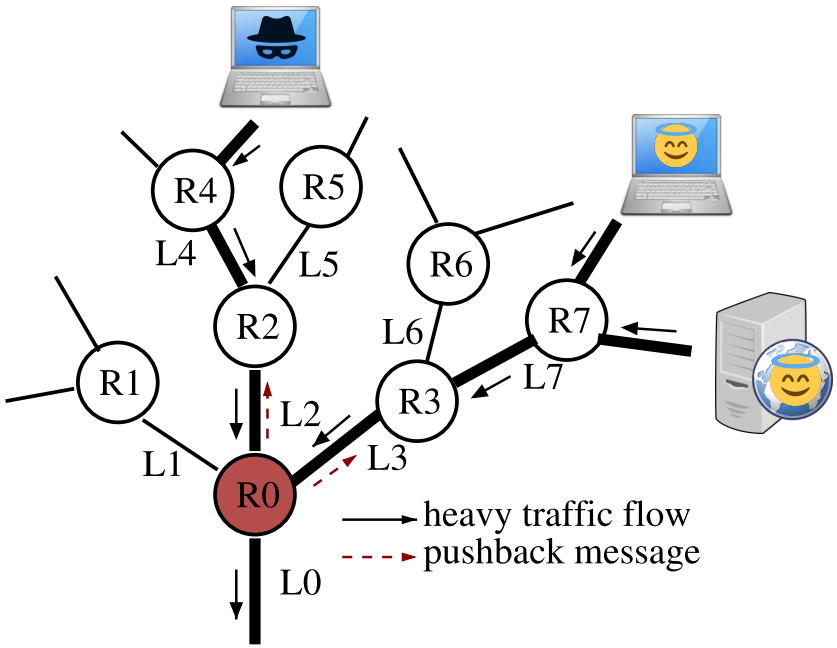

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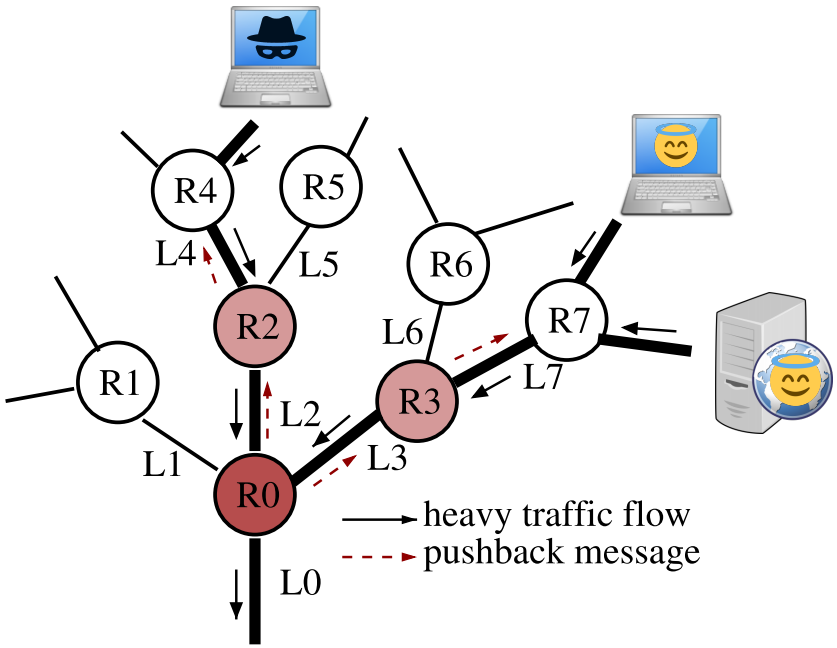

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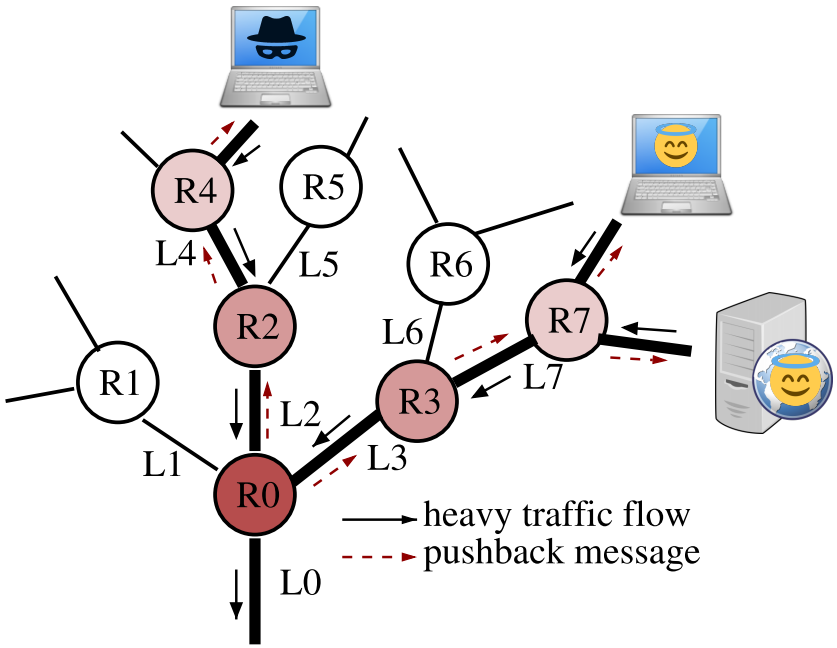

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Capabilities

Idea: before sending a packet, a node must first obtain the "permission to send" from the destination[12].

How: the receiver provides tokens, or capabilities, to those senders whose traffic it agrees to accept.

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- Routers forward only:
  A. request packets;
  B. packets with a *valid capability*.
     - Capabilities need to be updated across time[13]
       $\Rightarrow$ receivers notify senders.

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DoS - Conclusions

- (D)DoS has been a problem since 2000's
  ... and is still an important problem.

- Different solutions have been deployed:
  - ingress filtering;
  - SYN cookies;
  - DDoS protection services.

- Some problems still remain:
  - vulnerable and unpached **reflectors**;
  - spoofing is possible due to incomplete adoption of ingress filtering.

- Many researchers have proposed more robust solutions, that require a re-design of Internet services
  $\Rightarrow$ Traceback, pushback filtering, capabilities.

Mandatory readings

- RFC4987 - "TCP SYN Flooding Attacks and Common Mitigations"
  `https://datatracker.ietf.org/doc/html/rfc4987`

- Paper - "An analysis of using reflectors for distributed denial-of-service attacks"
  `https://ccr.sigcomm.org/archive/2001/jul01/ccr-200107-paxson.pdf`
  alternative download link
  `https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=16089cc1668f937fa4b0b24c2cc29a9a91d8ec39`

- Paper - "Amplification Hell: Revisiting Network Protocols for DDoS Abuse"
  `https://christian-rossow.de/publications/amplification-ndss2014.pdf`