Protocol Security and DoS Attacks

CS155 Computer and Network Security

Stanford University

Ethernet

Provides connectivity between hosts on a *Local Area Network*

Frames are addressed to a device's physical (MAC) address

Switches forward frames based on *learning* where different MACs are located. *No guarantees not sent to other hosts!*

No security (confidentiality, authentication, or integrity)

Every host announces its presence, IP address, and MAC via ARP

ARP (Address Resolution Protocol)

ARP allows hosts to find each others' MAC addresses on the local network

Client: To Broadcast (all MACs): Which MAC address has IP 192.168.1.1?

No inherent security. Attacker can impersonate a host by faking its identity and sending gratuitous ARP announcement or responding to ARP requests

Internet Protocol (IP)

Provides routing between hosts on the Internet. Unreliable. Best Effort.

Routers simply route IP packets based on their destination address.

No inherent security. Packets have a checksum, but it's non-cryptographic.
Attackers can change any packet.

Source address set by sender—can be faked by an attacker

BGP (Border Gateway Protocol)

Internet Service Providers announce their presence on the Internet

No authentication—possible to announce someone else's network

Commonly occurs (often due to operator error)

TCP (Transmission Control Protocol)

TCP provides reliable stream of data on top of unreliable lower layers (i.e., IP and Ethernet)

Data is split into segments and sender/receiver acknowledge received data and retransmit dropped packets

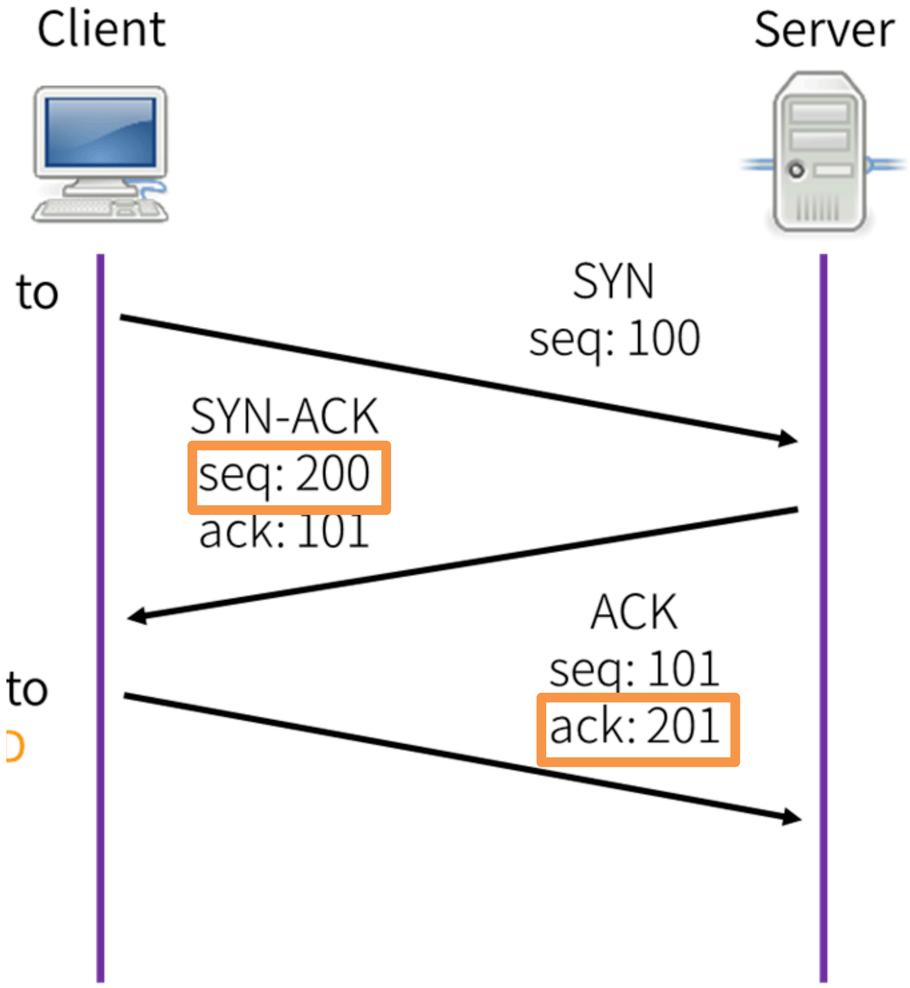
Every TCP connection starts with a three way handshake

TCP Connection Spoofing

Can we impersonate another host when *initiating* a connection?

Off-path attacker can send initial SYN to server …
… but cannot complete three-way handshake without seeing the server's sequence number

1 in 2^{32} chance to guess right if initial sequence number chosen uniformly at random



TCP Reset Attack

Can an off path attacker reset an *existing* TCP connection?

Need to know port numbers (16 bits)
- Initiator's port number usually chosen random by OS
- Responder's port number may be well-known port of service

There is leeway in sequence numbers B will accept
- Must be within window size (32-64K on most modern OSes)

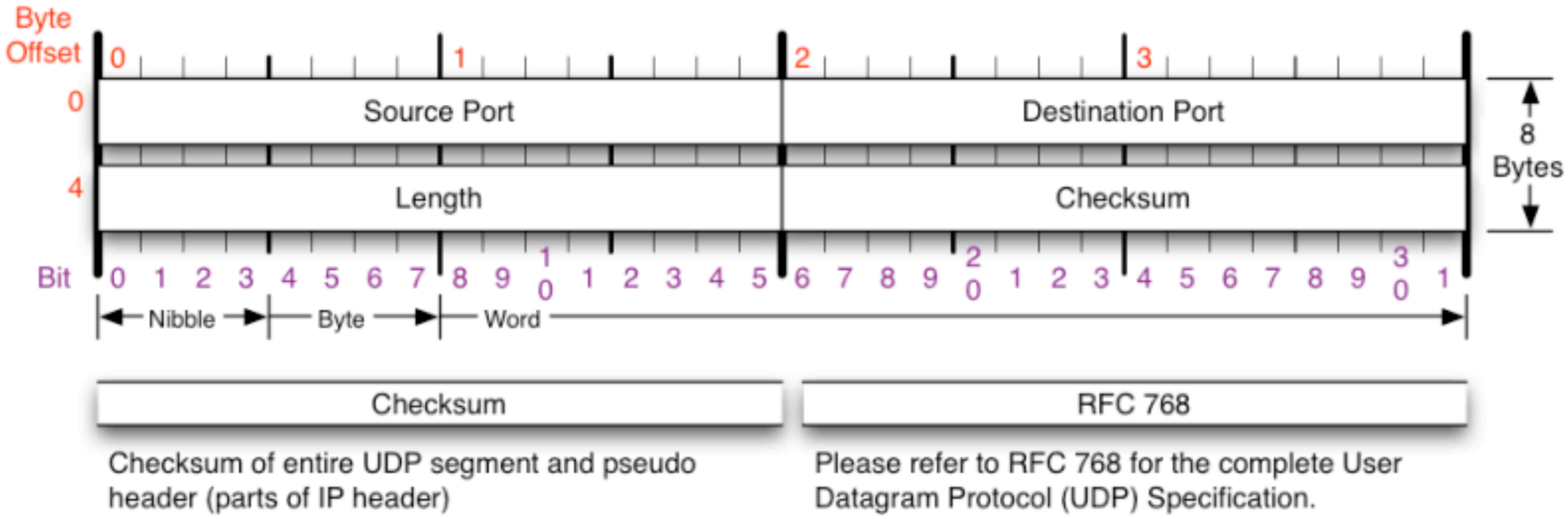
1 in $2^{16+32}/W$ (where W is window size) chance to guess right

UDP (User Datagram Protocol)

Sometimes we *do* only want best-effort delivery

User Datagram Protocol (UDP) is a transport layer protocol that is essentially a wrapper around IP

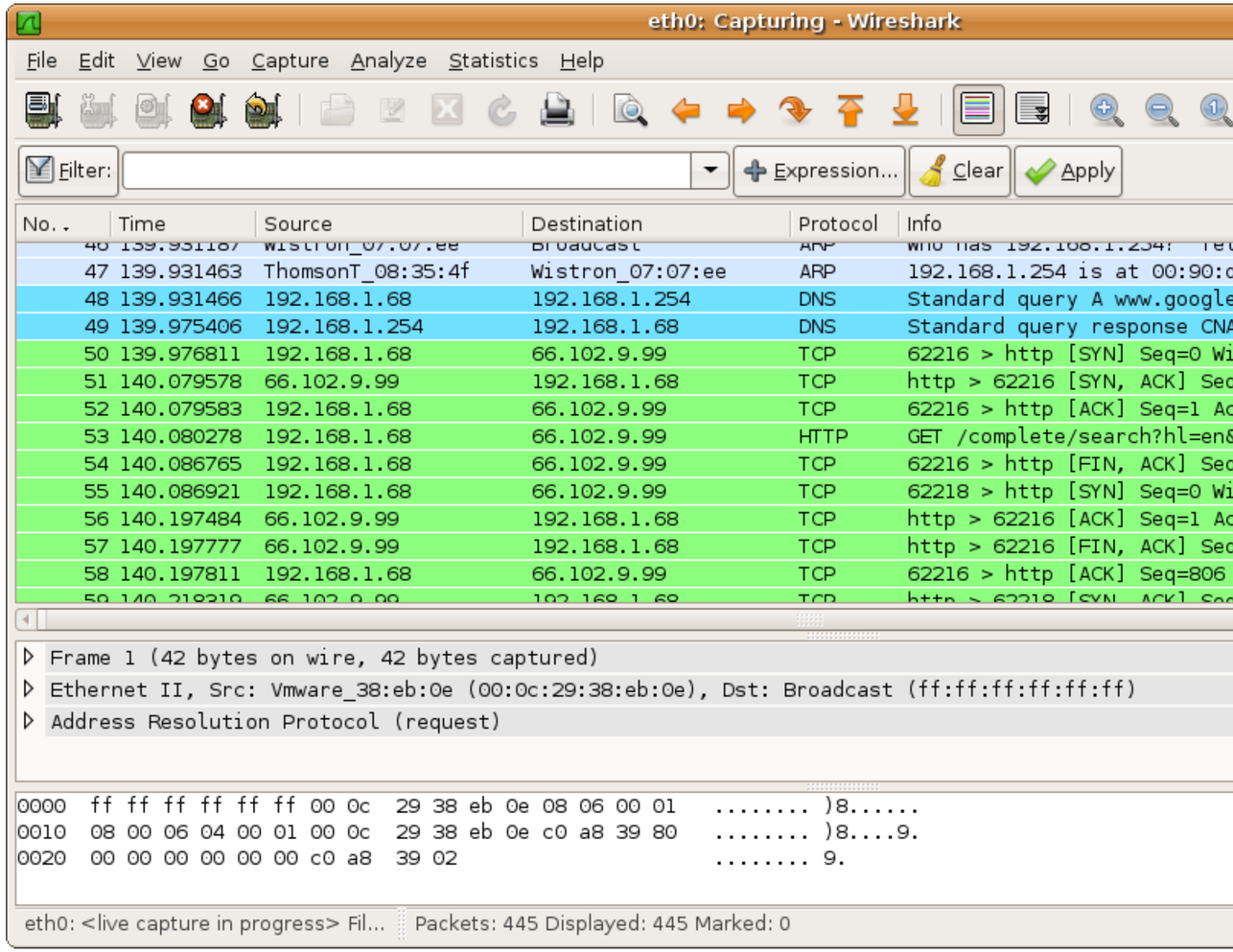
Adds ports to demultiplex traffic by applications



Packet Sniffing

Program to intercept and log all network traffic that computer sees regardless of packet's destination MAC and IP address

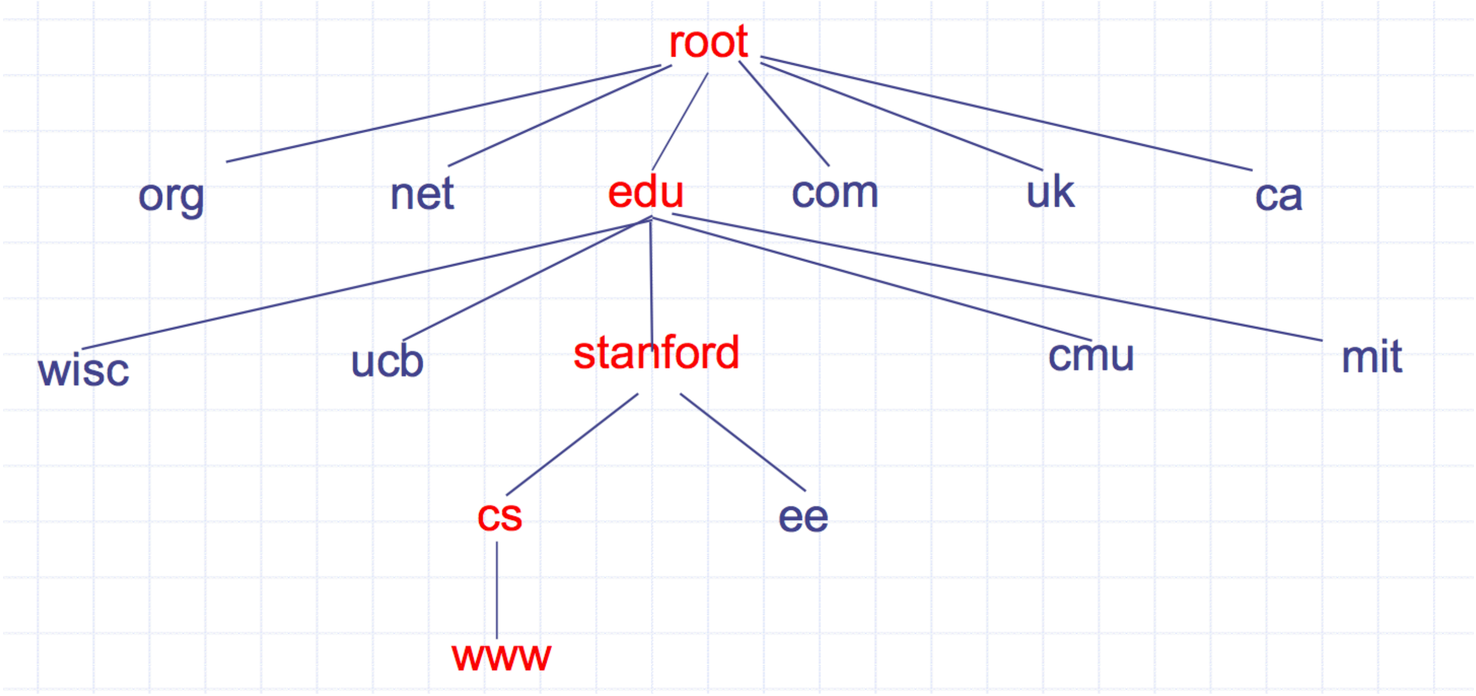
Most programs are built on top of a library called `libpcap`. Wireshark — GUI version. tcpdump — CLI tool



DNS (Domain Name System)

Application-layer protocols (and people) usually refer to Internet host by host name (e.g., google.com)

DNS is a delegatable, hierarchical name space



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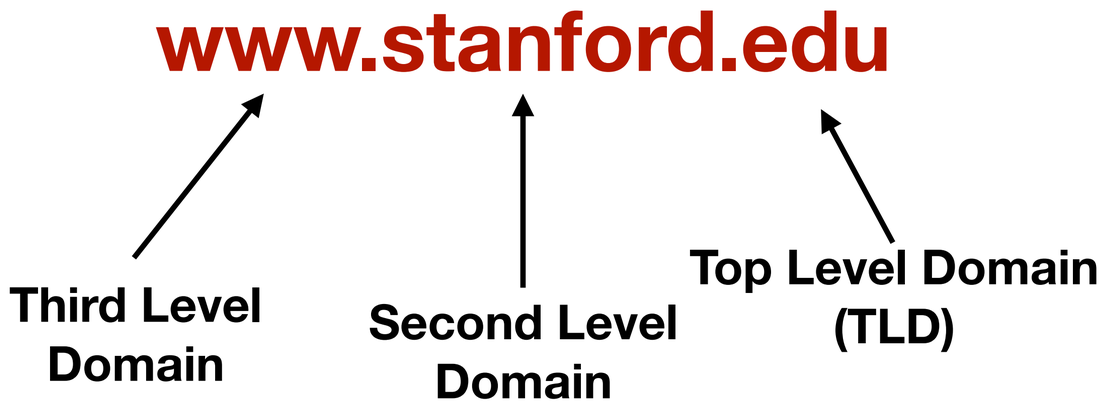


DNS Hierarchy

Each level allocates names to next level

TLDs allocated by ICANN

- ccTLD: country-based TLDs, e.g., .us
- gTLD: arbitrary names, e.g., .com and .google

TLD operated by different registries

Registrars are agents that register domains for a person or organization in a particular TLD

DNS Record

A DNS server has a set of records it authoritatively knows about

```
$ dig bob.ucsd.edu

;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 30439
;; flags: qr aa rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 6

;; QUESTION SECTION:
;bob.ucsd.edu.      INA

;; ANSWER SECTION:
bob.ucsd.edu.   3600 INA 132.239.80.176

;; AUTHORITY SECTION:
ucsd.edu.     3600 IN NS ns0.ucsd.edu.
ucsd.edu.     3600 IN NS ns1.ucsd.edu.
ucsd.edu.     3600 IN NS ns2.ucsd.edu.
```

DNS Root Name Servers

In total, there are 13 main **DNS root servers**, each of which is named with the letters 'A' to 'M'.

HOSTNAME	IP ADDRESSES	MANAGER
a.root-servers.net	198.41.0.4, 2001:503:ba3e::2:30	VeriSign, Inc.
b.root-servers.net	199.9.14.201, 2001:500:200::b	University of Southern California (ISI)
c.root-servers.net	192.33.4.12, 2001:500:2::c	Cogent Communications
d.root-servers.net	199.7.91.13, 2001:500:2d::d	University of Maryland
e.root-servers.net	192.203.230.10, 2001:500:a8::e	NASA (Ames Research Center)
f.root-servers.net	192.5.5.241, 2001:500:2f::f	Internet Systems Consortium, Inc.
g.root-servers.net	192.112.36.4, 2001:500:12::d0d	US Department of Defense (NIC)
h.root-servers.net	198.97.190.53, 2001:500:1::53	US Army (Research Lab)
i.root-servers.net	192.36.148.17, 2001:7fe::53	Netnod
j.root-servers.net	192.58.128.30, 2001:503:c27::2:30	VeriSign, Inc.
k.root-servers.net	193.0.14.129, 2001:7fd::1	RIPE NCC
l.root-servers.net	199.7.83.42, 2001:500:9f::42	ICANN
m.root-servers.net	202.12.27.33, 2001:dc3::35	WIDE Project

Caching

DNS responses are cached

- Quick response for repeated translations
- NS records for domains also cached

DNS negative queries are cached

- Save time for nonexistent sites, e.g. misspelling

Cached data periodically times out

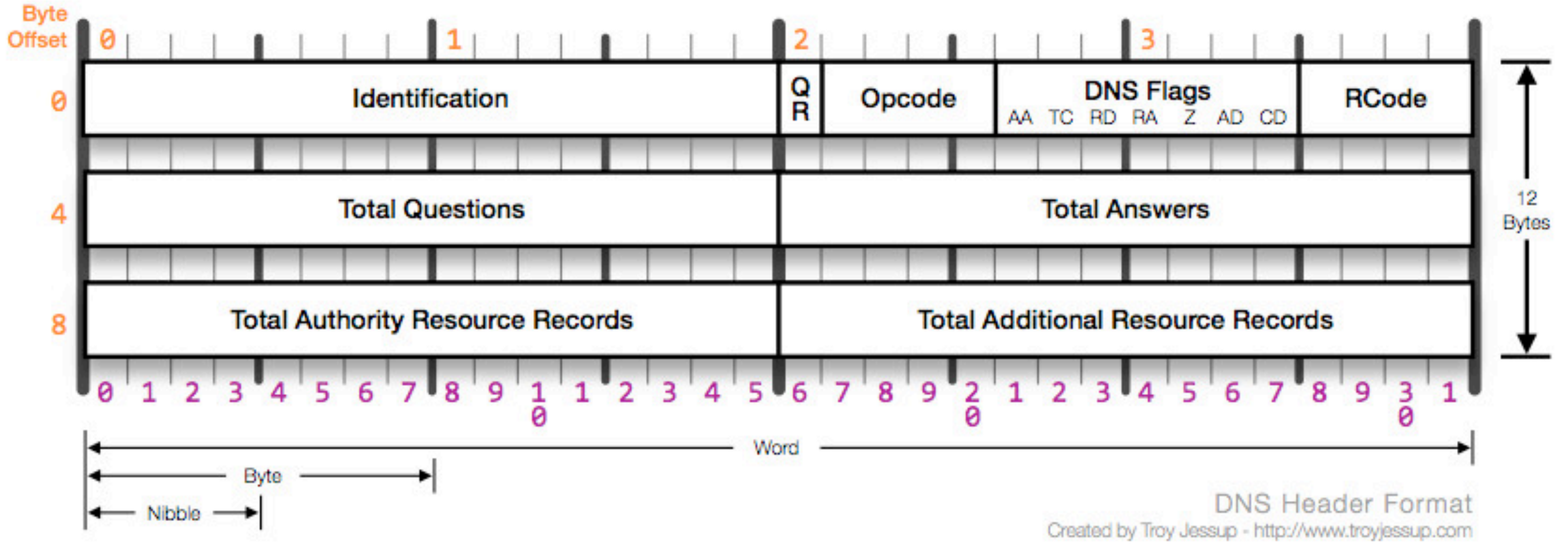
- Lifetime (TTL) of data controlled by owner of data
- TTL passed with every record

DNS Packet

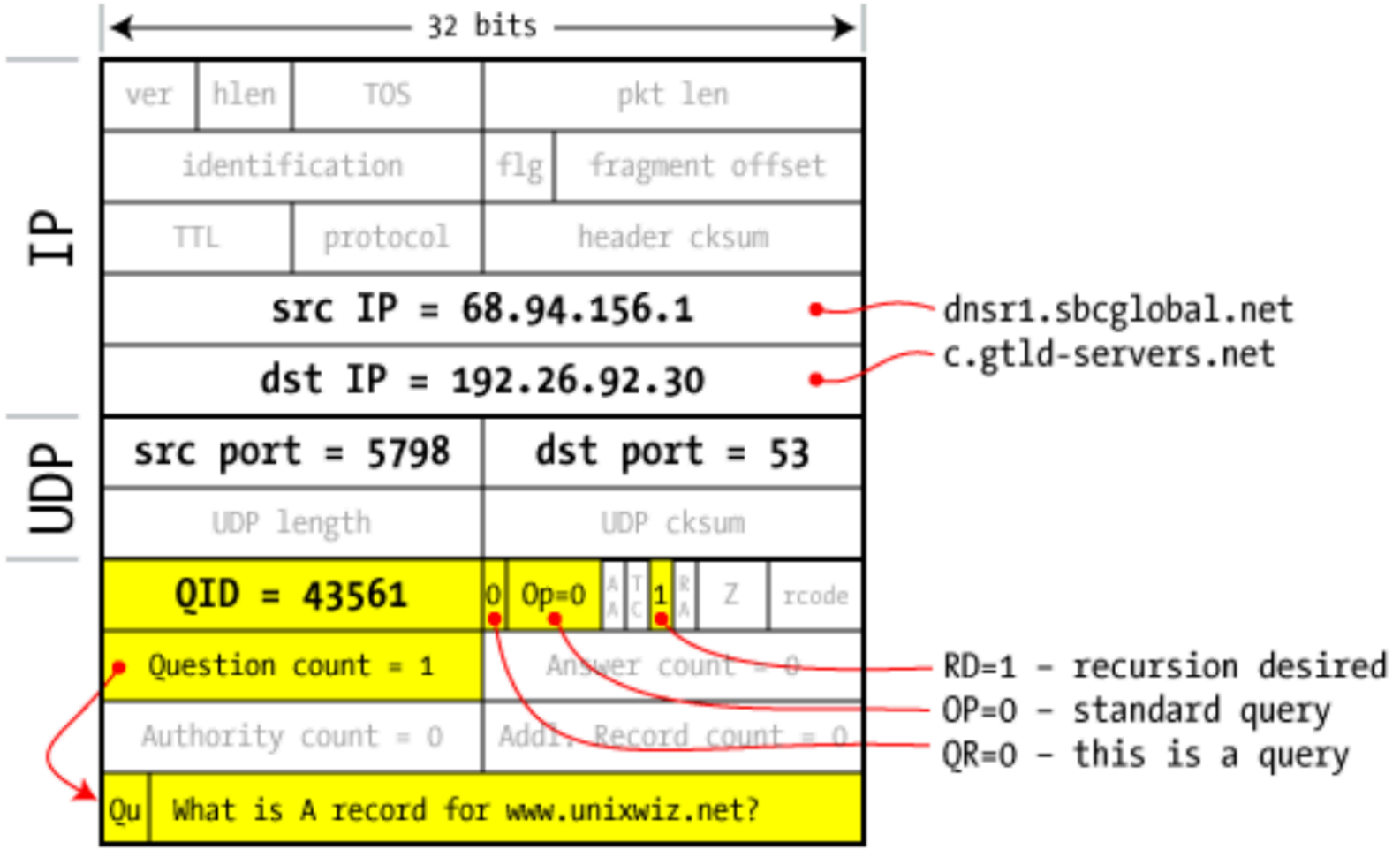
DNS requests sent over UDP

Four sections: questions, answers, authority, additional records

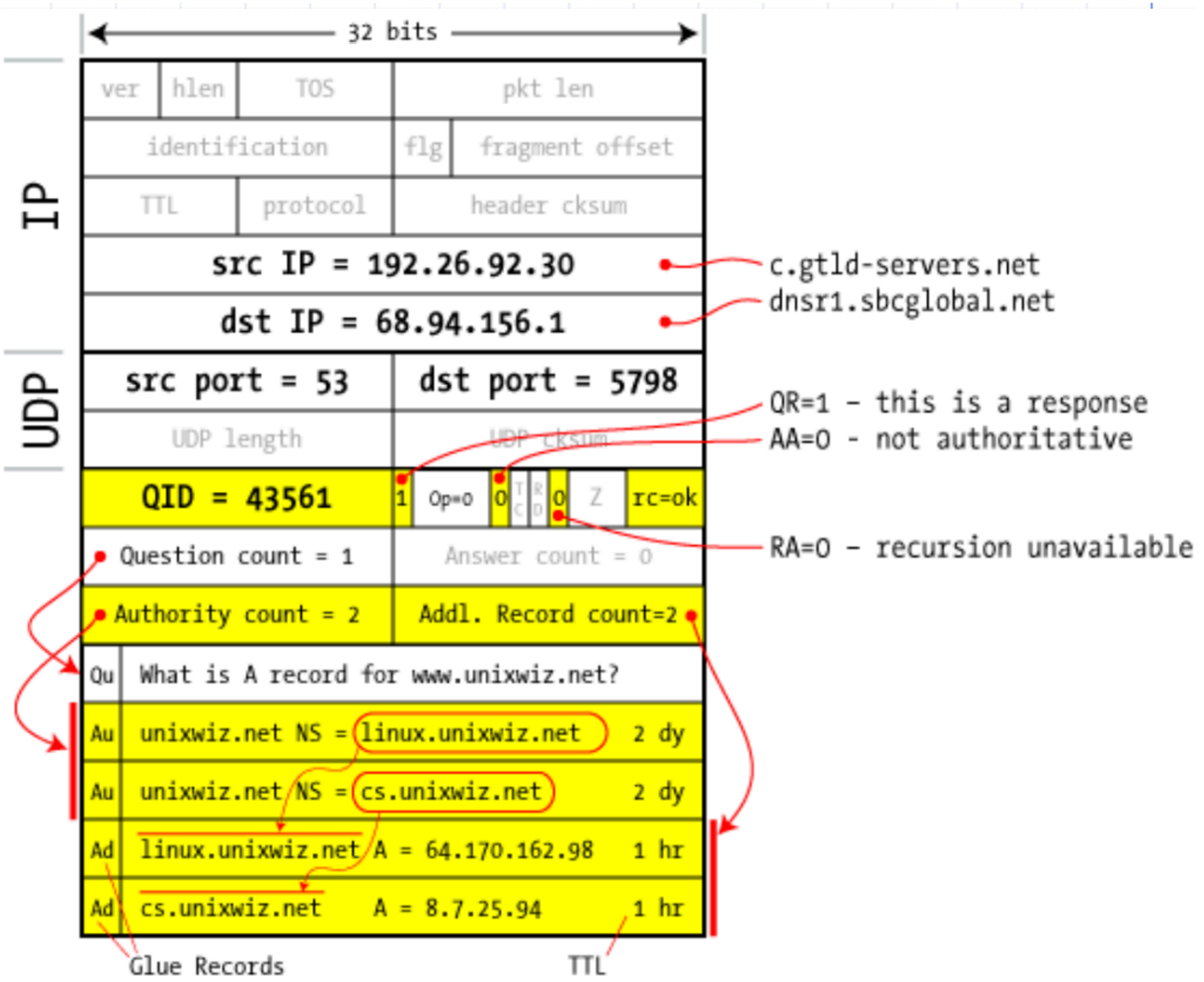
Query ID:
16 bit random value
Links response to query



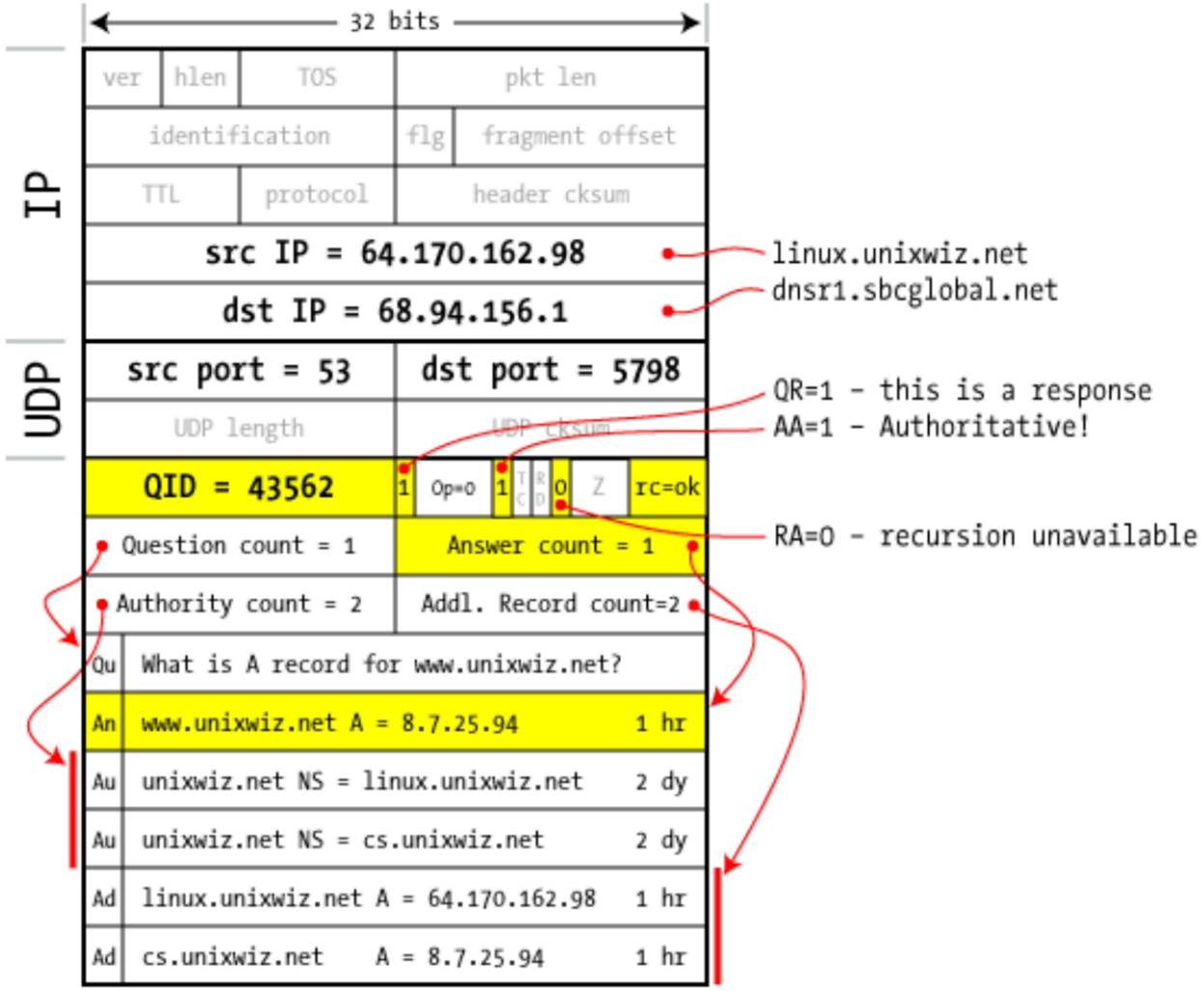
Request


32 bits
IP
UDP
ver
hlen
TOS
pkt len
identification
flg
fragment offset
TTL
protocol
header cksum
src IP = 68.94.156.1
dst IP = 192.26.92.30
src port = 5798
dst port = 53
UDP length
UDP cksum
QID = 43561
0
Op=0
1
Z
rcode
Question count = 1
Answer count = 0
Authority count = 0
Addl. Record count = 0
Qu
What is A record for www.unixwiz.net?
dnsr1.sbcglobal.net
c.gtld-servers.net
RD=1 - recursion desired
OP=0 - standard query
QR=0 - this is a query

NS Response


32 bits
IP
UDP
ver
hlen
TOS
pkt len
identification
flg
fragment offset
TTL
protocol
header cksum
src IP = 192.26.92.30
dst IP = 68.94.156.1
src port = 53
dst port = 5798
UDP length
UDP cksum
QID = 43561
1
Op=0
0
T C
R D
0
Z
rc=ok
Question count = 1
Answer count = 0
Authority count = 2
Addl. Record count=2
Qu
What is A record for www.unixwiz.net?
Au
unixwiz.net NS = linux.unixwiz.net
2 dy
Au
unixwiz.net NS = cs.unixwiz.net
2 dy
Ad
linux.unixwiz.net A = 64.170.162.98
1 hr
Ad
cs.unixwiz.net A = 8.7.25.94
1 hr
Glue Records
TTL
c.gtld-servers.net
dnsr1.sbcglobal.net
QR=1 - this is a response
AA=0 - not authoritative
RA=0 - recursion unavailable

Authoritative Response



DNS Security

Users/hosts trust the host-address mapping provided by DNS

Used as basis for many security policies:

Browser same origin policy, URL address bar

Interception of requests or compromise of DNS servers can result in incorrect or malicious responses

DNS Spoofing

Scenario: DNS client issues query to server

Attacker would like to inject a fake reply
  Attacker does not see query or real response

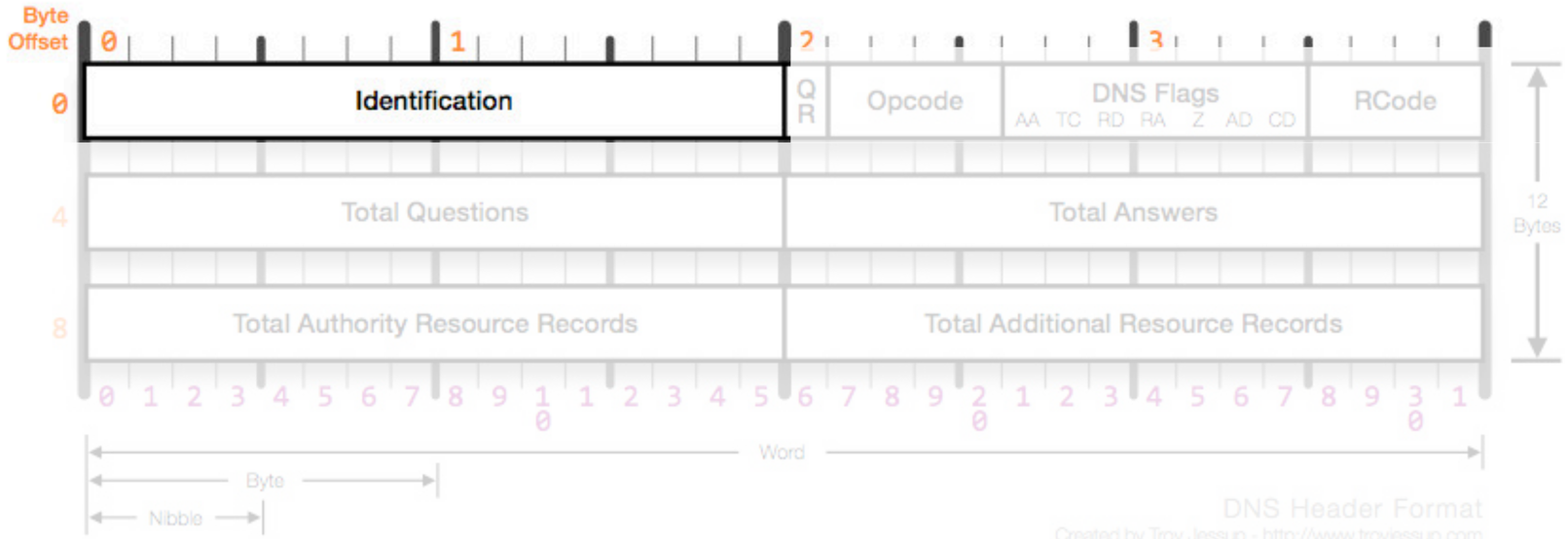
How does client authenticate response?

DNS Spoofing

How does client authenticate response?

UDP port numbers must match
Destination port usually port 53 by convention

16-bit query ID must match



DNS Caching

Recursive resolvers cache records to avoid repeating recursive resolution process for each query

Lifetime of record determined by record TTL
Could also be evicted from cache due to limited memory

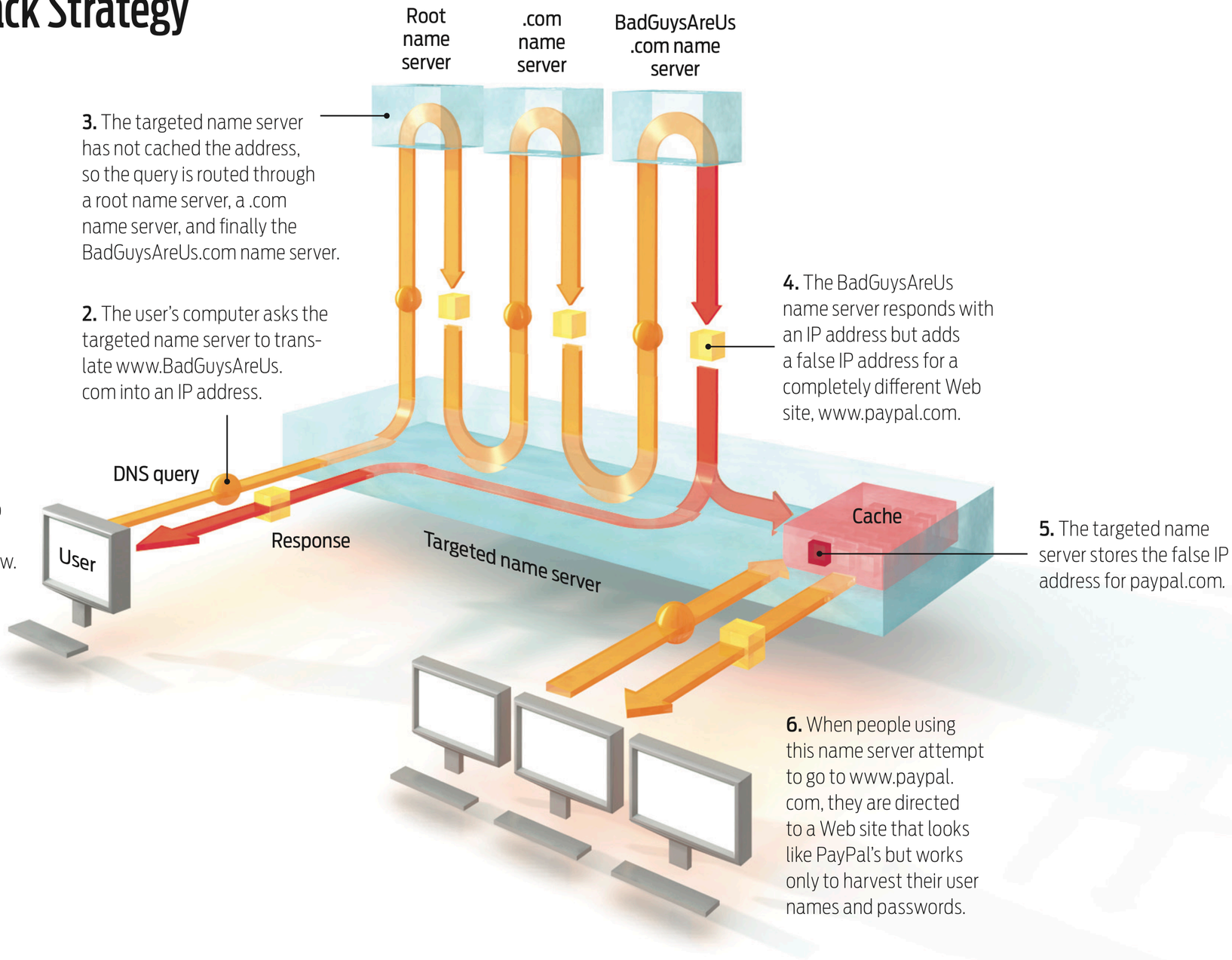
Injecting spoofed records into a resolver's cache is called *DNS cache poisoning*

DNS Cache Poisoning

DNS query results include Additional Records section
– Provide records for anticipated next resolution step

Early servers accepted and cached all additional records provided in query response

Early Attack Strategy



Glue Records

Can we just stop using additional section?

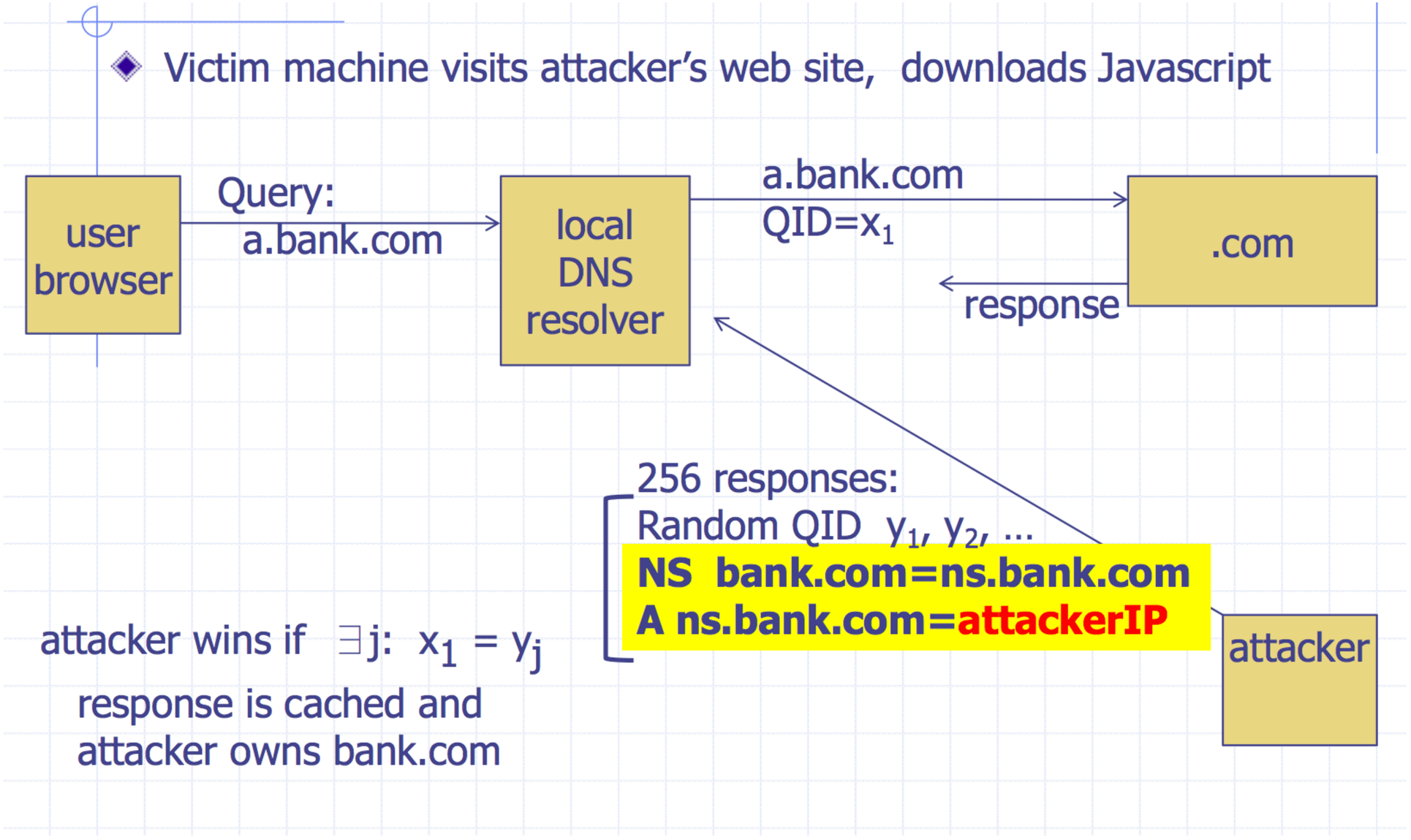
– Only accept answers from authoritative servers?

Glue records: non-authoritative are records necessary to contact next hop in resolution chain

– Necessary given current design of DNS

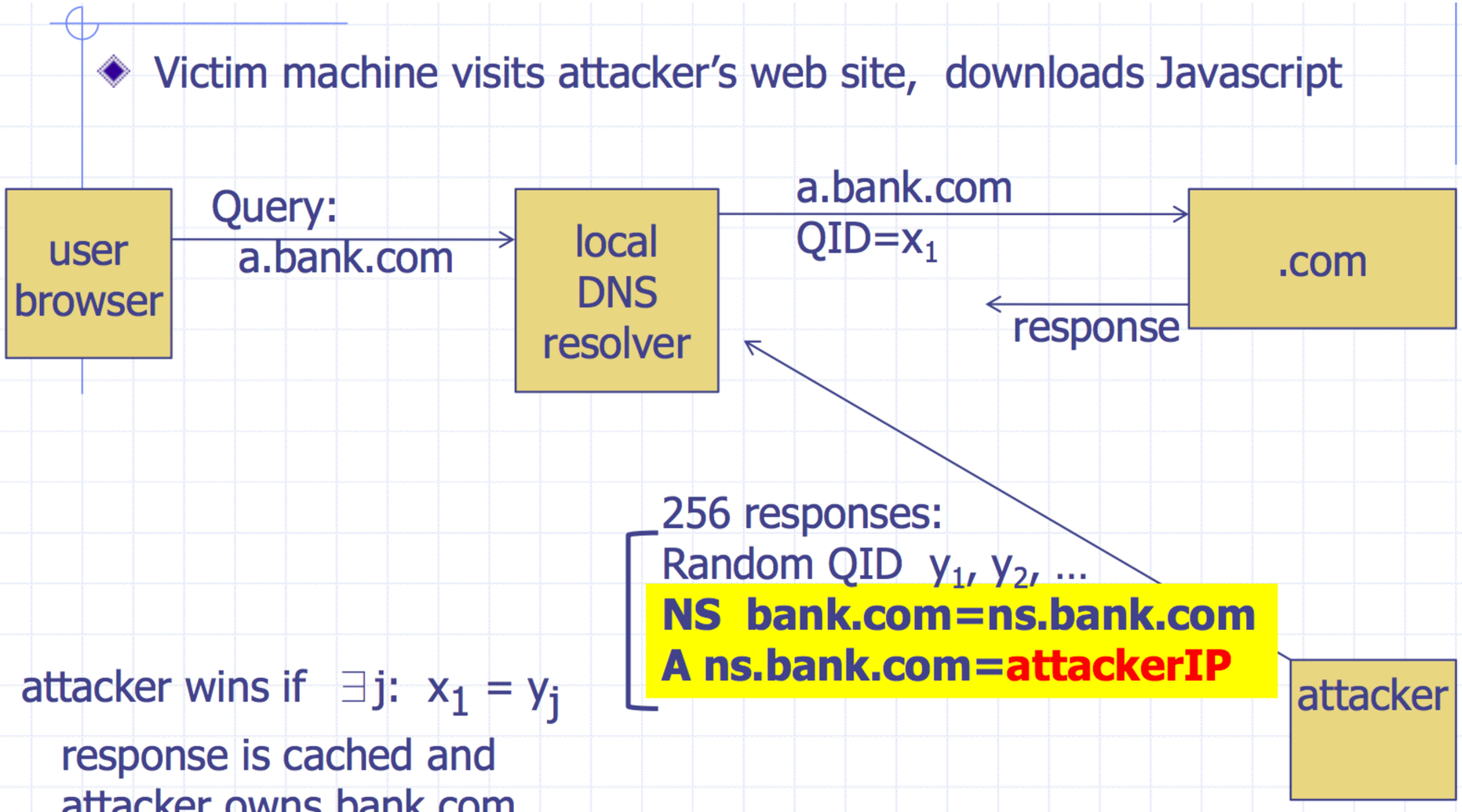
Bailiwick Checking: Only accept additional records that are for a domain in the original question.

Kaminsky Attack



Try Again!

- Victim machine visits attacker's web site, downloads Javascript



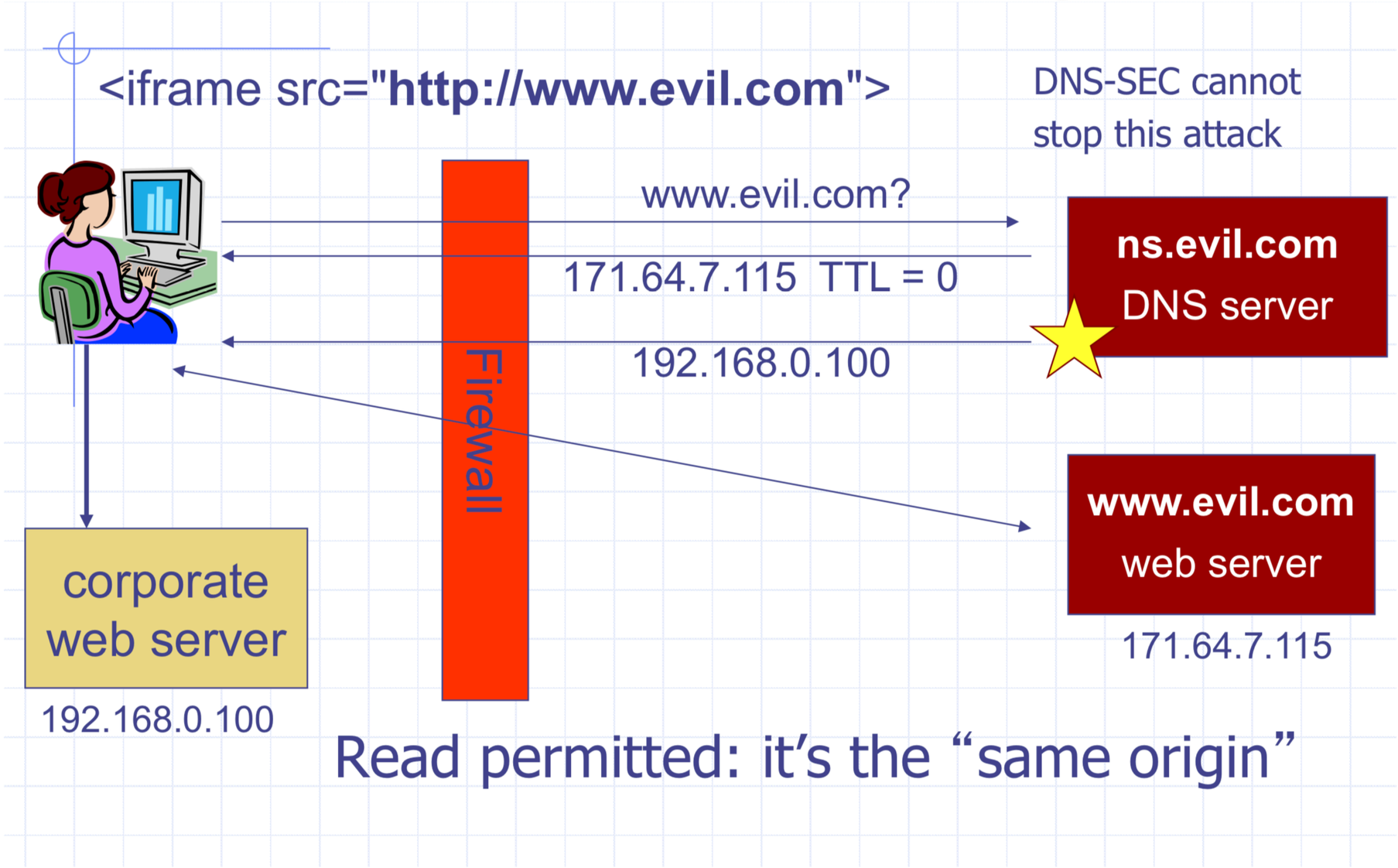
Defenses

Increase QueryID. But how? Don’t want to change packet.

Randomize src port, additional 11 bits of entropy

- Attack now takes several hours

DNS Rebinding



Rebinding Defenses

Browser Mitigations:

- Refuse to switch IPs mid session
- Interacts poorly with proxies, VPNs, CDNs, etc
- Not consistently implemented in any browser

Server Defenses

- Check Host header for unrecognized domains
- Authenticate users with something else beyond IP address

DNSSEC

Adds authentication and integrity to DNS responses

Authoritative DNS servers sign DNS responses using cryptographic key

Clients can verify that a response is legitimate by checking signature through PKI similar to HTTPS

Most people don’t use DNSSEC and never will. Use TLS instead.

Takeaway

Assume the network is out to get you.

If you want *any* real guarantee of security, use TLS.

Denial of Service Attacks

Goal: take large site offline by overwhelming it with network traffic such that they can't process real requests

How: find mechanism where attacker doesn't have to spend a lot of effort, but requests are difficult/expensive for victim to process

Types of Attacks

DoS Bug: design flaw that allows one machine to disrupt a service. Generally a protocol asymmetry, e.g., easy to send request, difficult to create response. Or requires server state.

DoS Flood: control a large number of requests from a botnet of machines you control

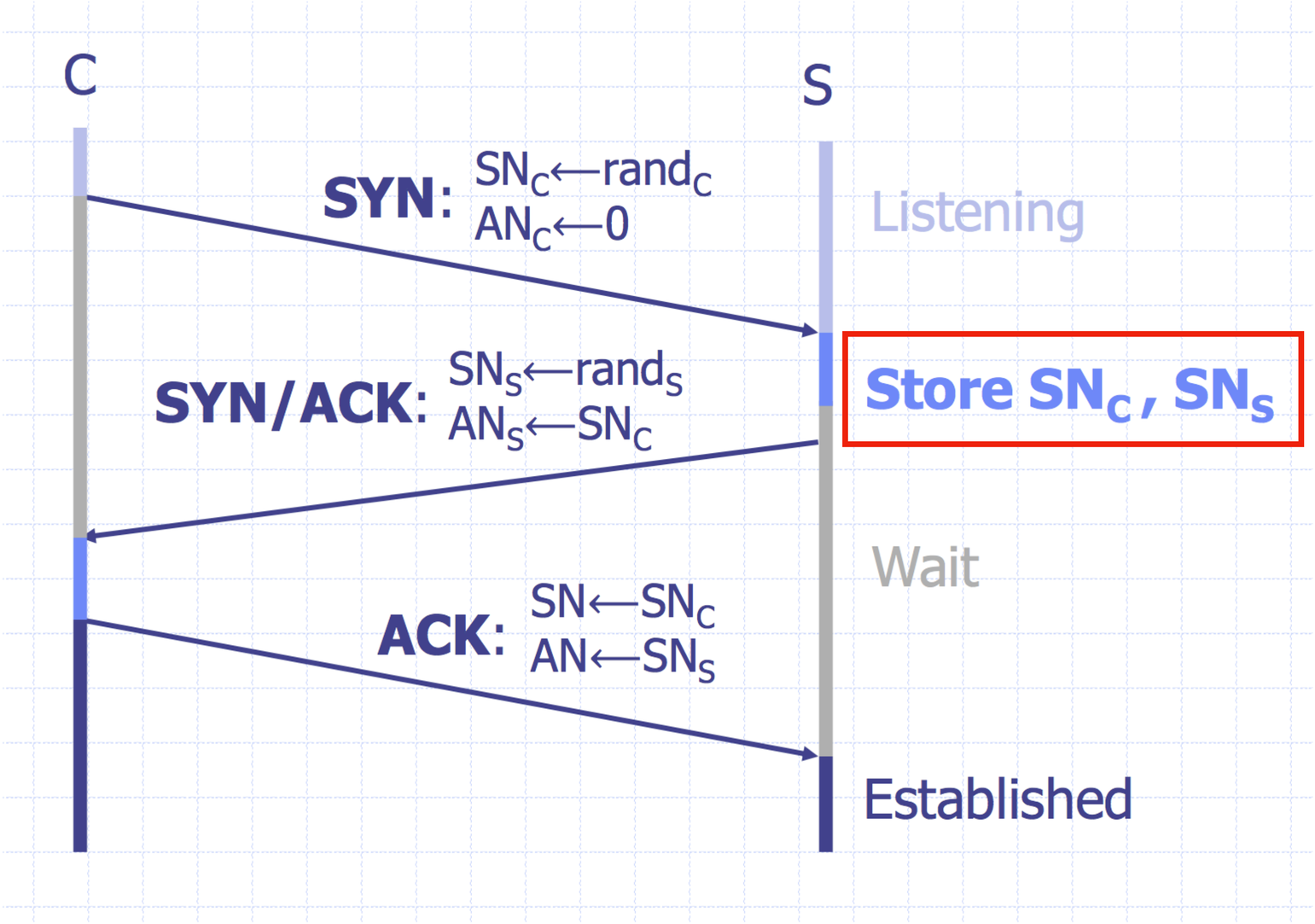
Possible at Every Layer

Link Layer: send too much traffic for switches/routers to handle

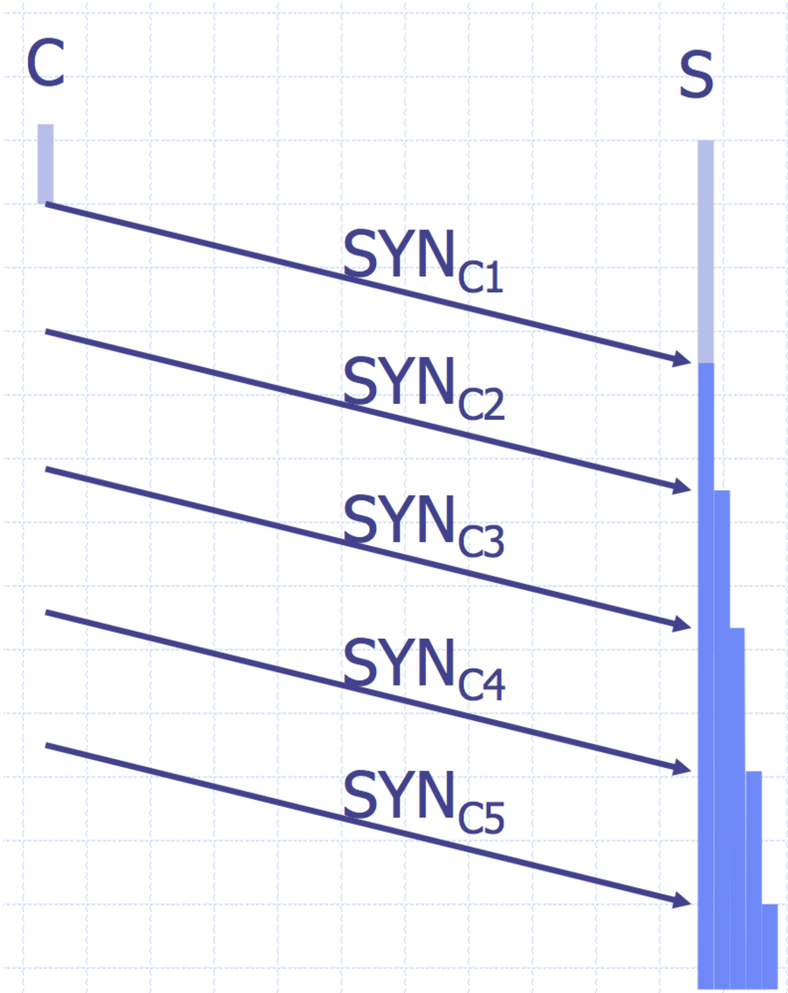
TCP/UDP: require servers to maintain large number of concurrent connections or state

Application Layer: require servers to perform expensive queries or cryptographic operations

TCP Handshake



SYN Floods



Single machine:

- SYN Packets with **random source IP addresses**
- Fills up backlog queue on server
- No further connections possible

Core Problem

Problem: server commits resources (memory) before confirming identify of client (when client responds)

Bad Solution:

- Increase backlog queue size
- Decrease timeout

Real Solution: Avoid state until 3-way handshake completes

SYN Cookies

Idea: Instead of storing SNc and SNs…
send a cookie back to the client.

$L = MAC_{key}$ (SAddr, SPort, DAddr, DPort, SN_C, T)

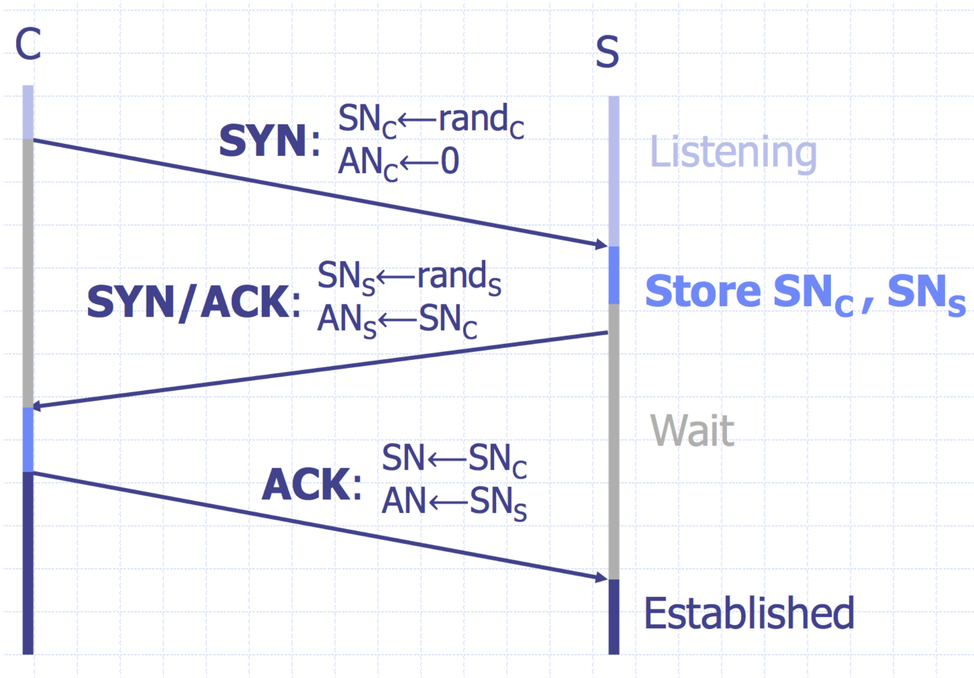
key: picked at random during boot

T = 5-bit counter incremented every 64 secs.

$SN_s = (T \| mss \| L)$

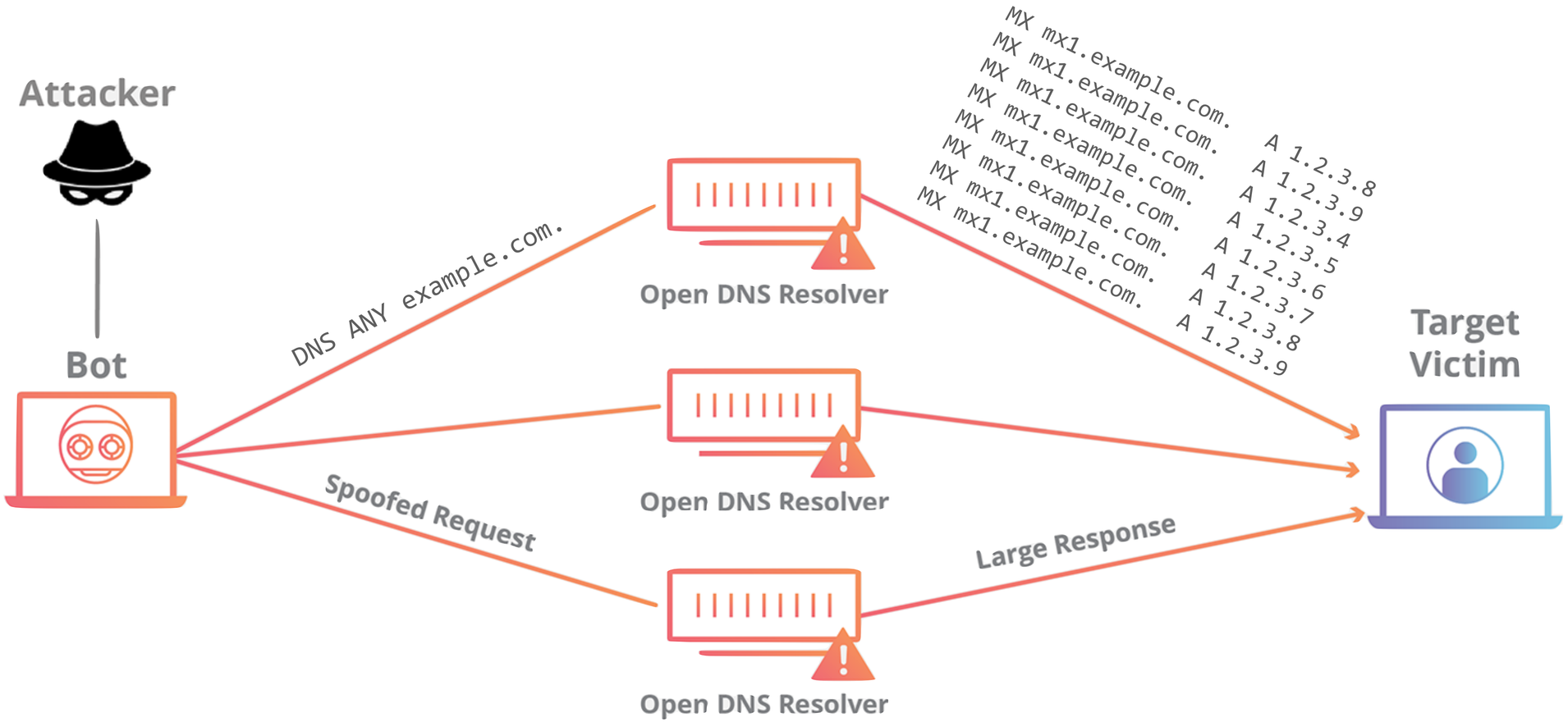
Honest client sends ACK ($AN=SN_s$, $SN=SN_C+1$)

Server allocates space for socket only if valid SNs



Server does not save state
(loses TCP options)

Amplification Attacks



60-70x Increase in Size

Image: Cloudflare

Common UDP Amplifiers

DNS: ANY query returns *all* records server has about a domain

NTP: MONLIST returns list of last 600 clients who asked for the time recently

Only works if you can receive a big response by sending a single packet — otherwise spoofing doesn't help you.

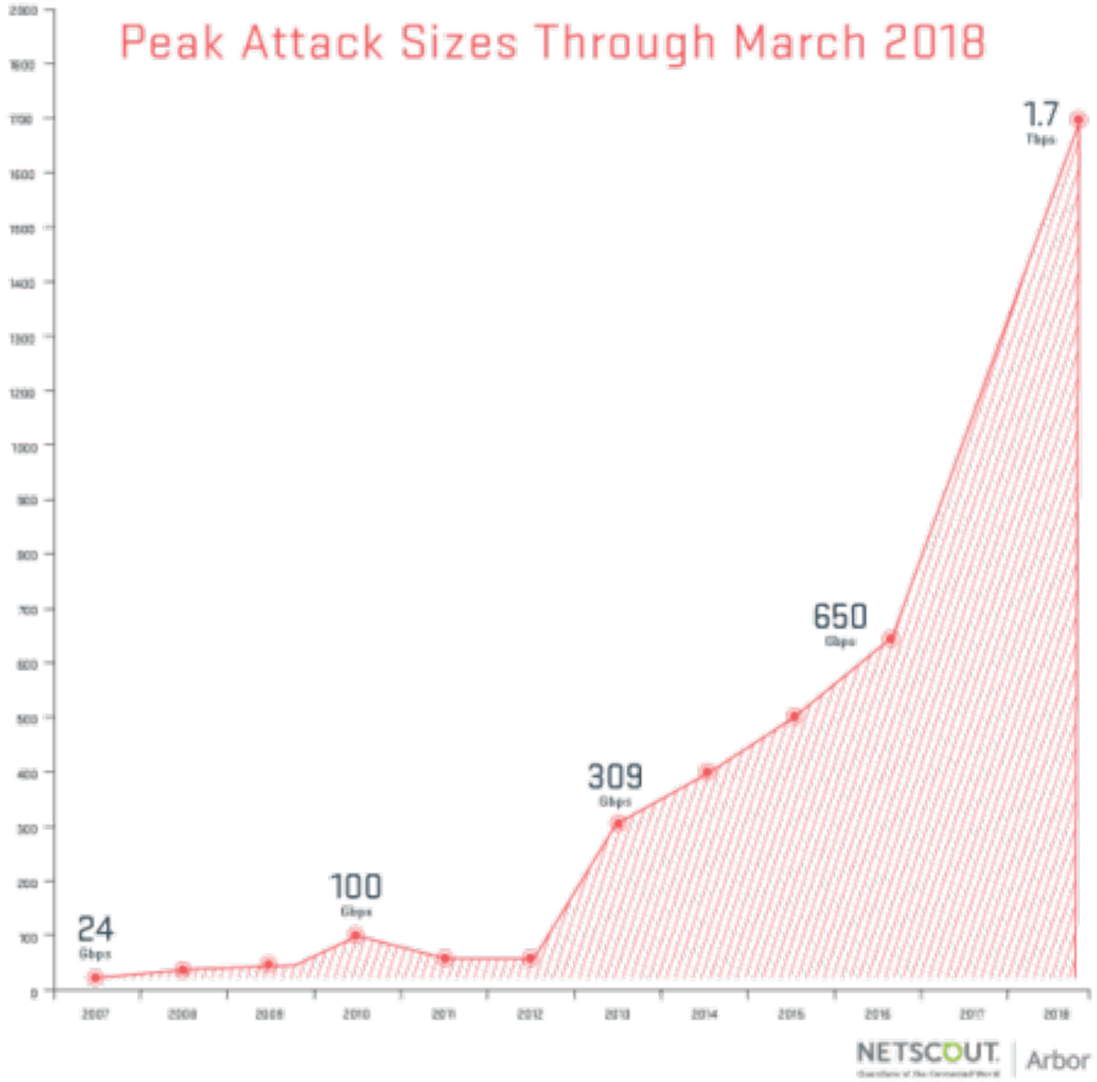
Amplification Attacks

2013: DDoS attack generated 300 Gbps (DNS)

- 31,000 misconfigured open resolvers, each at 10 Mbps
- Source: 3 networks that allowed IP spoofing

2014: 400 Gbps DDoS attacked used 4500 NTP servers

Memcache



Memcache: retrieve large record

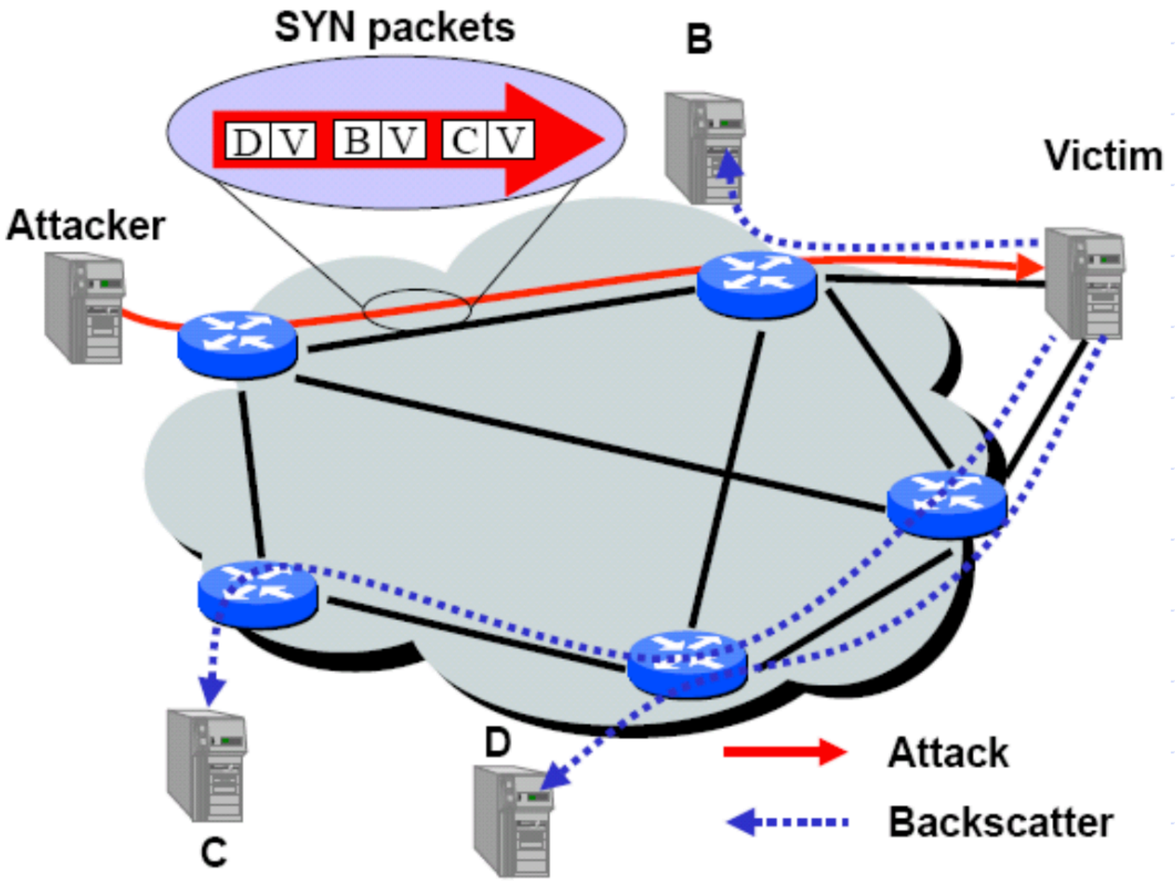
The server responds by firing back as much as 50,000 times the data it received.

Backscatter

SYN with forged source IP ->
SYN/ACK to random host

Listen to unused IP addresss
space (darknet)

Lonely SYN/ACK packet likely to
be result of SYN attack



THE WALL STREET JOURNAL.

October 21, 2016

Cyberattack Knocks Out Access to Websites

Popular sites such as Twitter, Netflix and PayPal were unreachable for part of the day

twitter

amazon web services™

PayPal

NETFLIX

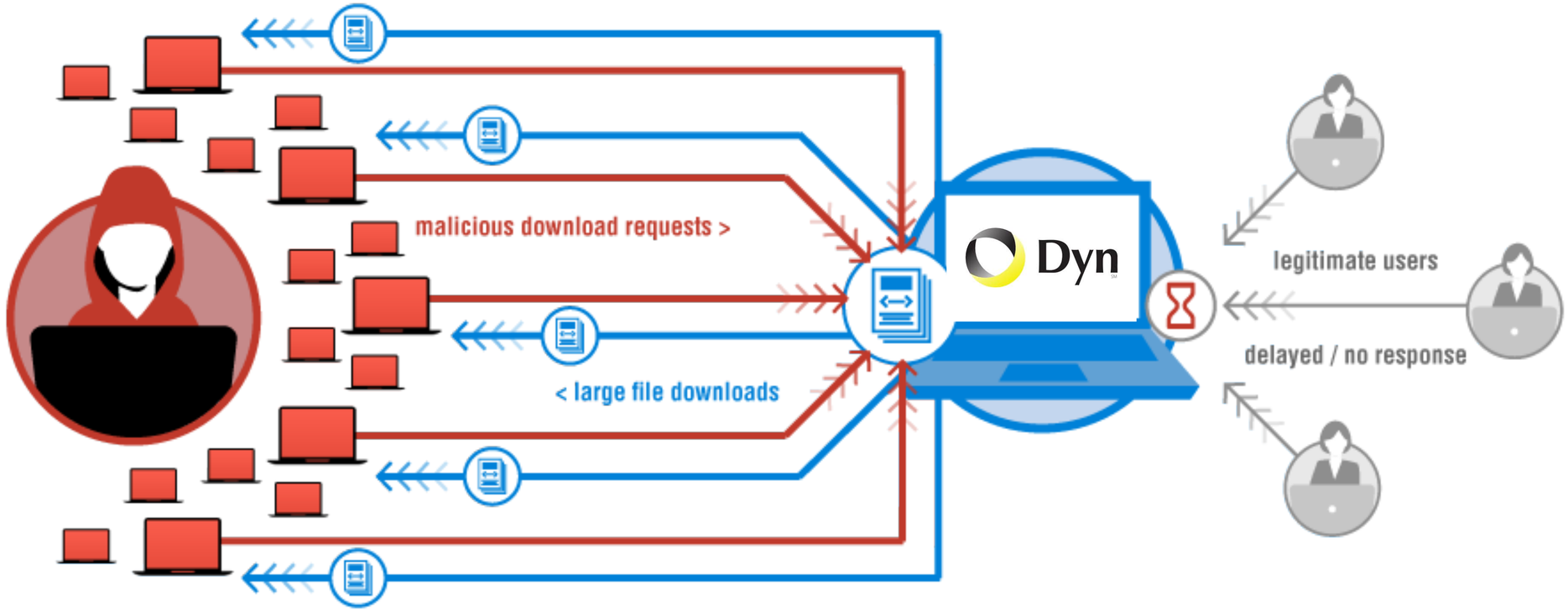
SOUNDCLOUD

Spotify

GitHub

reddit

New York Times



> “We are still working on analyzing the data but the estimate at the time of this report is up to 100,000 malicious endpoints. […] There have been some reports of a magnitude in the 1.2 Tbps range; at this time we are unable to verify that claim.”

Image: Verisign

A Botnet of IoT Devices

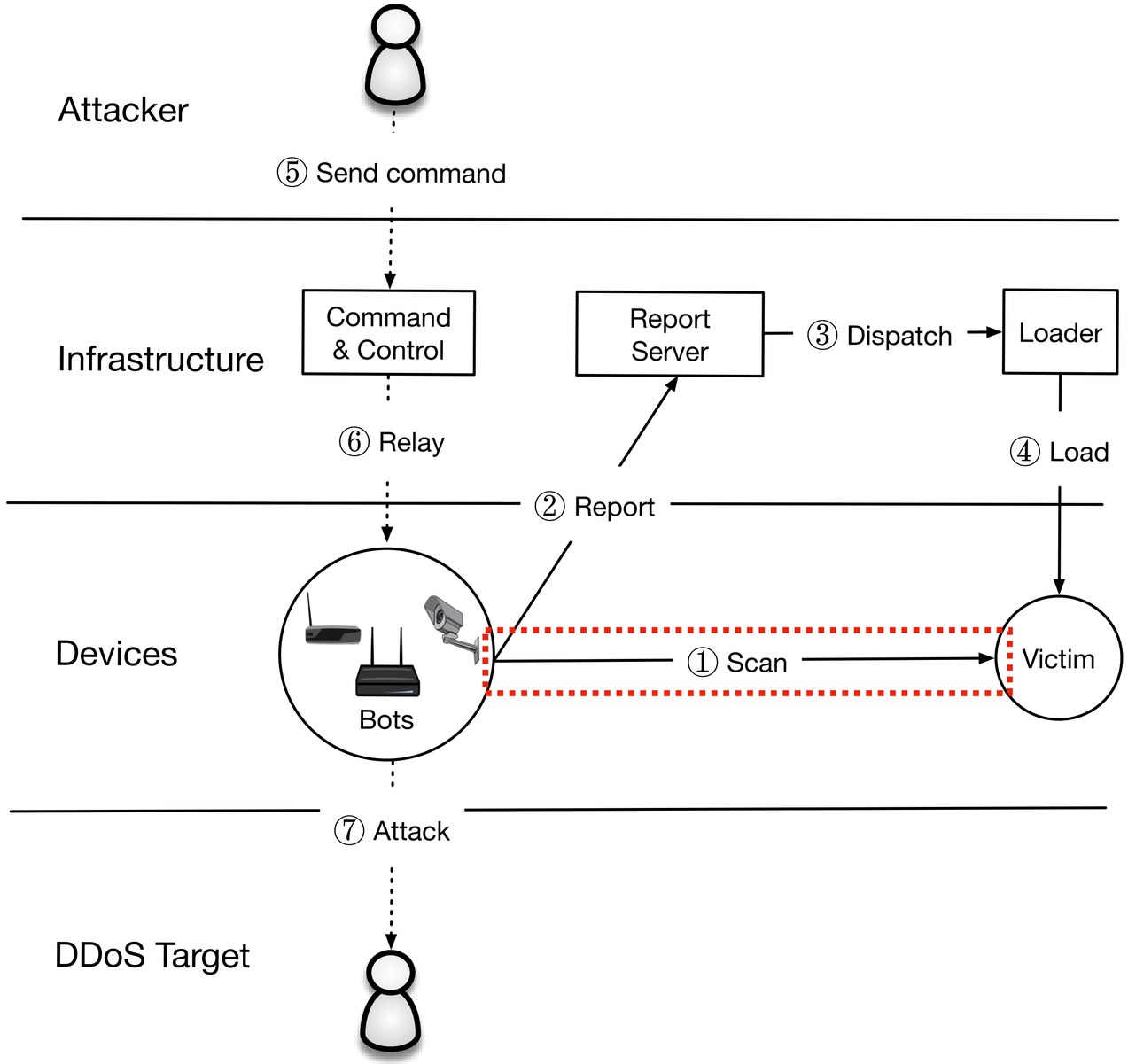
≈ ~~200K Hosts~~

200K IoT devices

Not Amplification.
Flood with SYN, ACK, UDP, and GRE packets

The Mirai Malware

1. Bots statelessly scan for victims on TCP/23 and TCP/2323. They attempt to login over telnet with a set of hardcoded credentials



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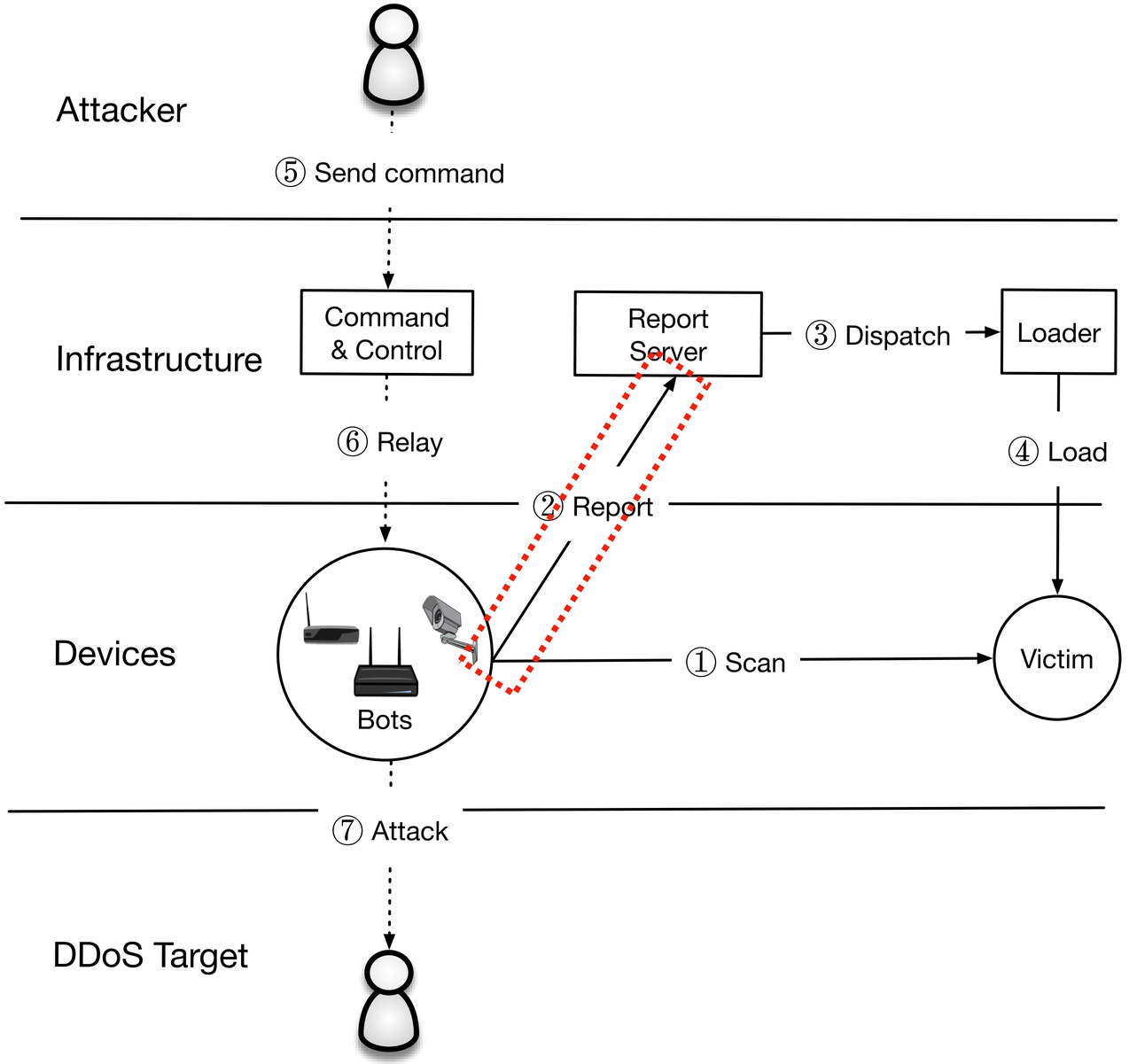
2. **Scanner** reports details about vulnerable host to central **C2 server**



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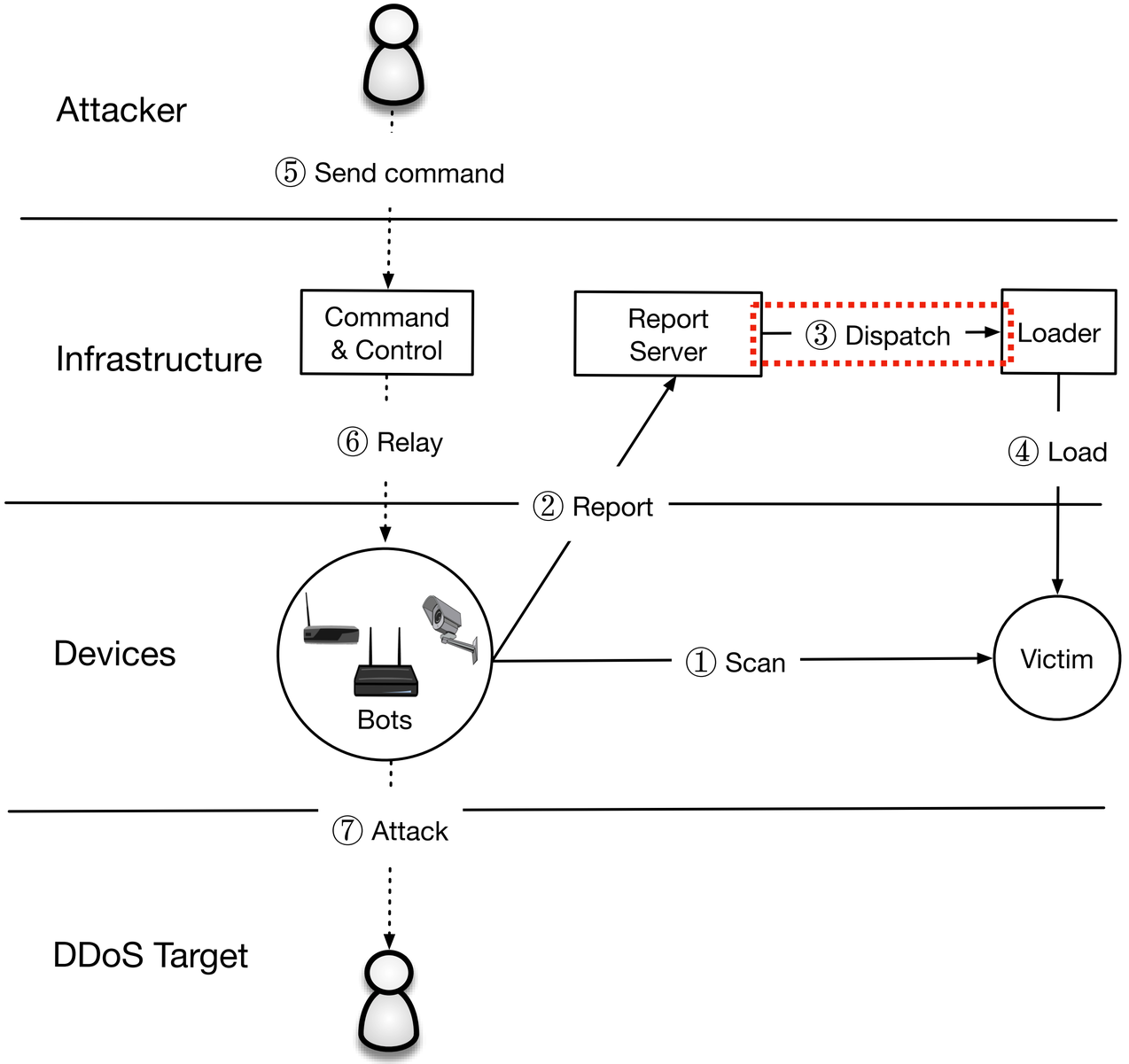

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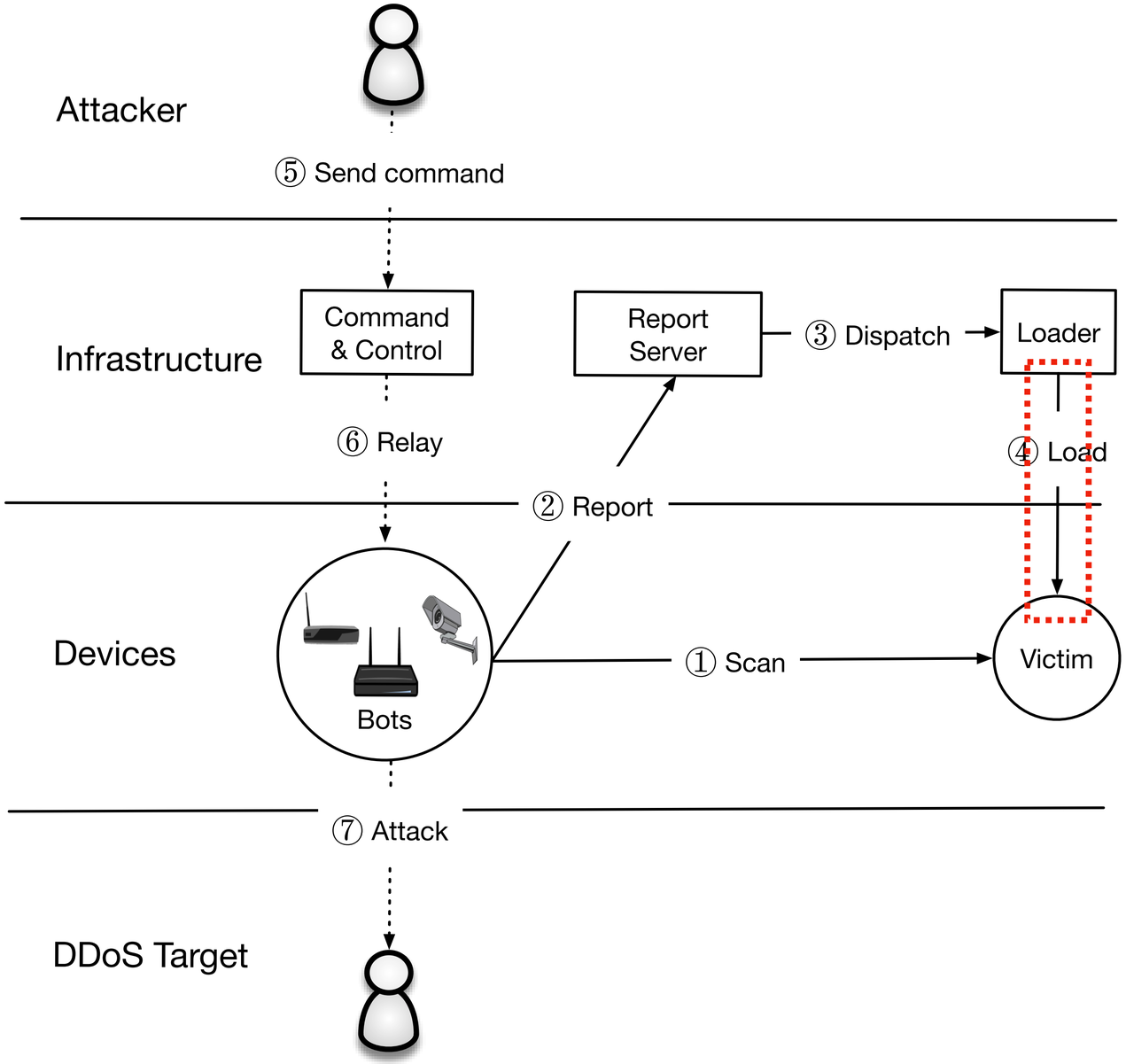
2. **Scanner** reports details about vulnerable host to central **C2 server**
3. **C2 server** dispatches command to **loader** to load malware onto IoT device
4. **Loader** logs into device, downloads and installs architecture-specific malware, kills telnet service, removes other malware, and waits for instructions

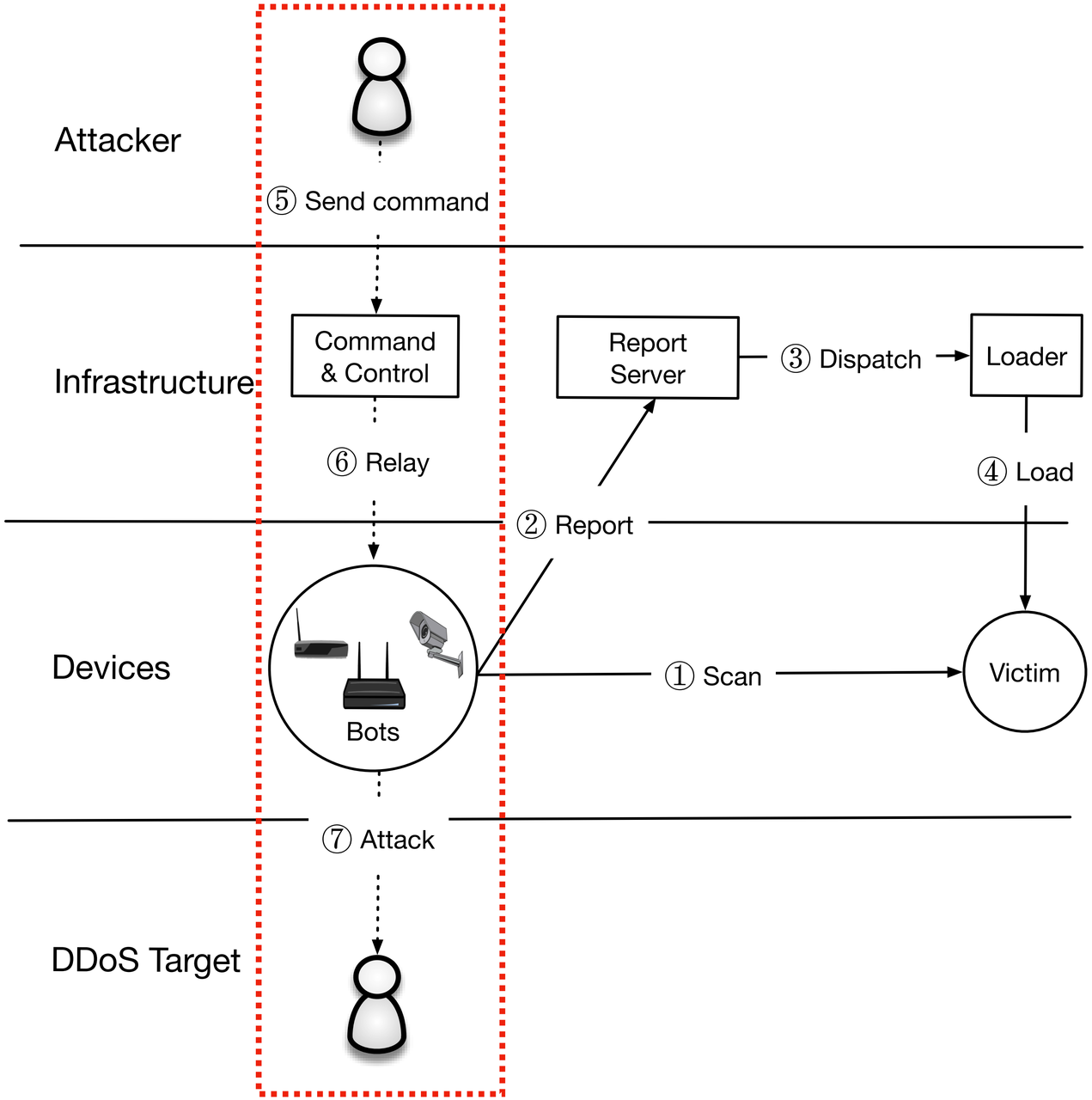


The Mirai Malware

5-7. Later, the **bot master** will issue commands to pause scanning and to start an attack

Attack Command:

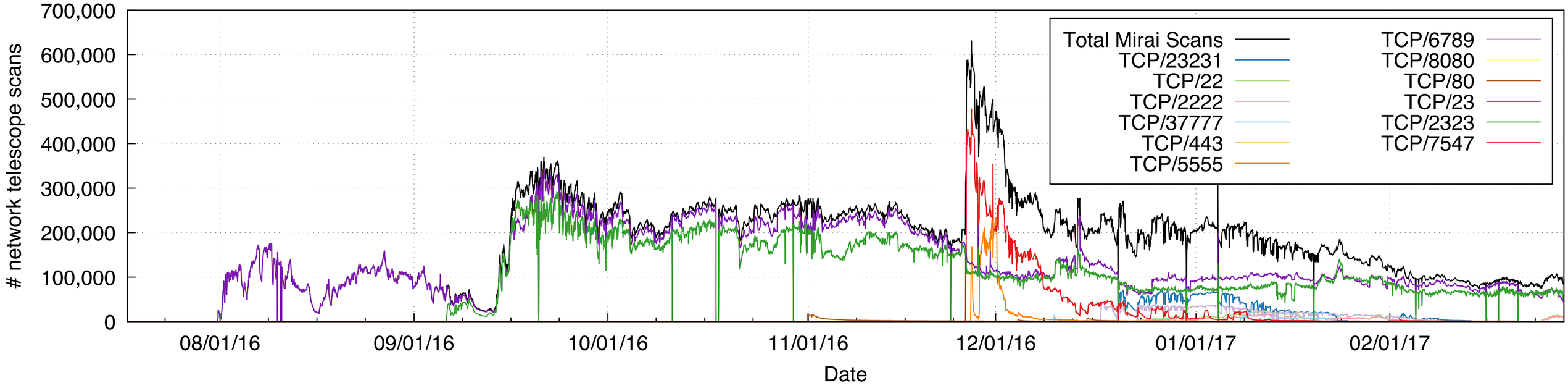
- Action (e.g., START, STOP)
- Target IP(s)
- Attack Type (e.g., GRE, DNS, TCP)
- Attack Duration



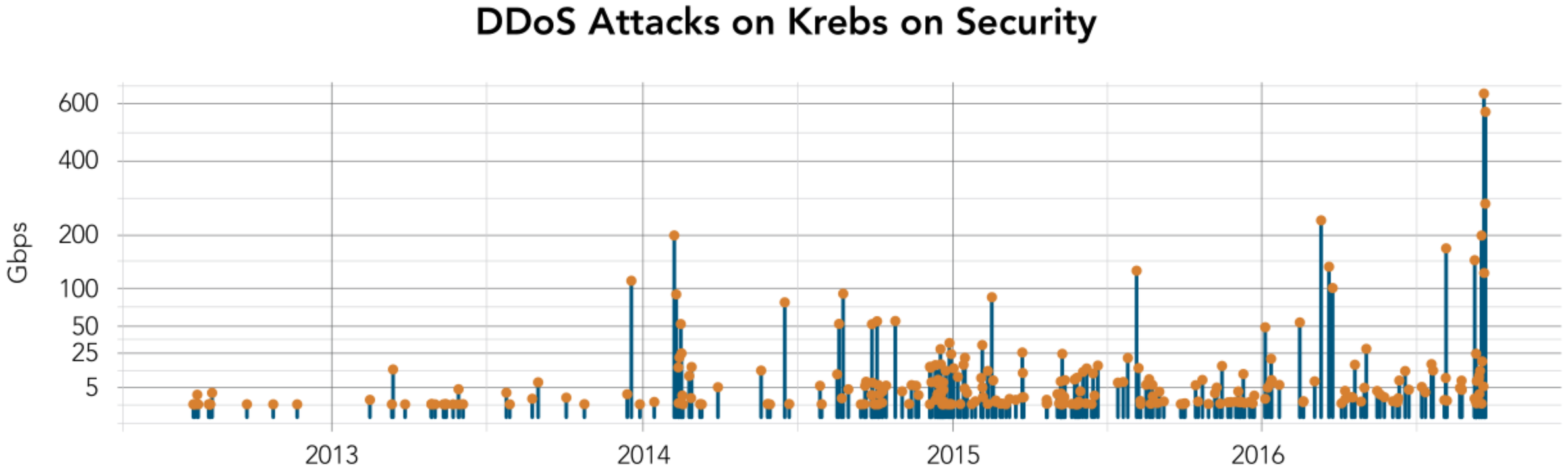
Password Guessing

Password	Device Type	Password	Device Type	Password	Device Type
123456	ACTi IP Camera	klv1234	HiSilicon IP Camera	1111	Xerox Printer
anko	ANKO Products DVR	jvbzd	HiSilicon IP Camera	Zte521	ZTE Router
pass	Axis IP Camera	admin	IPX-DDK Network Camera	1234	Unknown
888888	Dahua DVR	system	IQinVision Cameras	12345	Unknown
666666	Dahua DVR	meinsm	Mobotix Network Camera	admin1234	Unknown
vizxv	Dahua IP Camera	54321	Packet8 VOIP Phone	default	Unknown
7ujMko0vizxv	Dahua IP Camera	00000000	Panasonic Printer	fucker	Unknown
7ujMko0admin	Dahua IP Camera	realtek	RealTek Routers	guest	Unknown
666666	Dahua IP Camera	1111111	Samsung IP Camera	password	Unknown
dreambox	Dreambox TV Receiver	xmhdipc	Shenzhen Anran Camera	root	Unknown
juantech	Guangzhou Juan Optical	smcadmin	SMC Routers	service	Unknown
xc3511	H.264 Chinese DVR	ikwb	Toshiba Network Camera	support	Unknown
OxhlwSG8	HiSilicon IP Camera	ubnt	Ubiquiti AirOS Router	tech	Unknown
cat1029	HiSilicon IP Camera	supervisor	VideoIQ	user	Unknown
hi3518	HiSilicon IP Camera	<none>	Vivotek IP Camera	zlxx.	Unknown
klv123	HiSilicon IP Camera				

Mirai Population

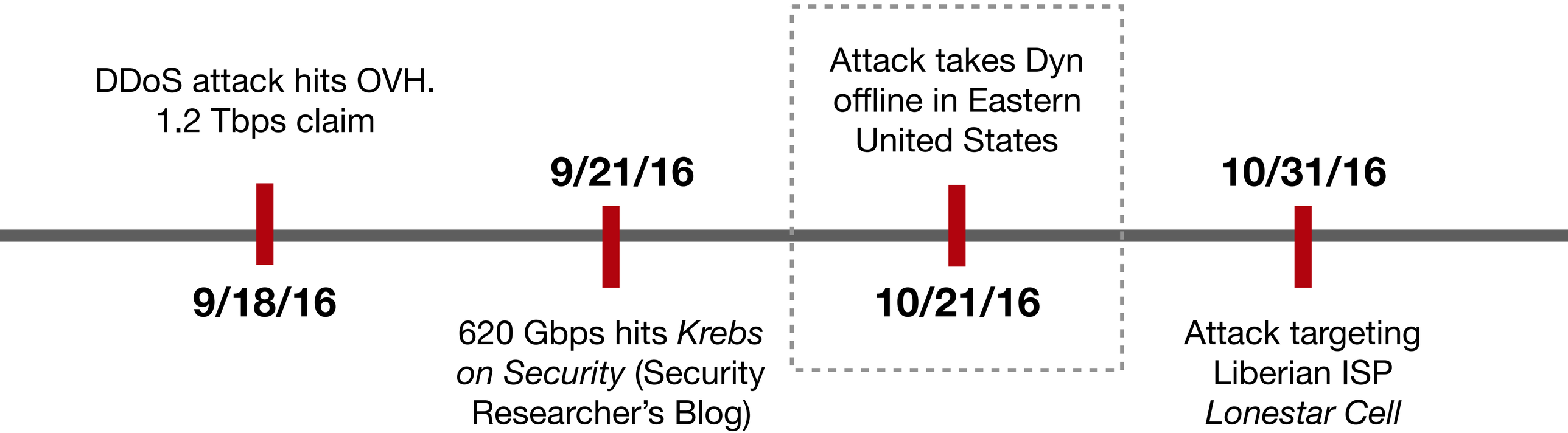


~600K devices compromised



> “The magnitude of the attacks seen during the final week were significantly larger than the majority of attacks Akamai sees on a regular basis. […] In fact, while the attack on September 20 was the largest attack ever mitigated by Akamai, the attack on September 22 would have qualified for the record at any other time, peaking at 555 Gbps.”

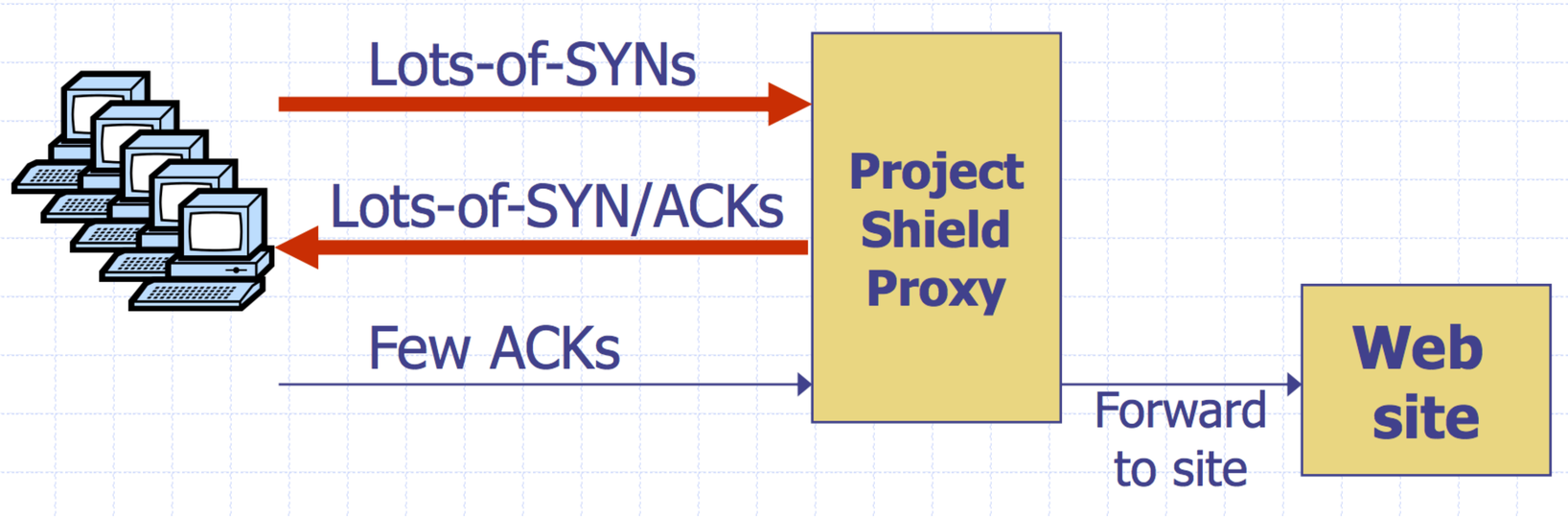
Source: 2017 Akamai State of the Internet


DDoS attack hits OVH.
1.2 Tbps claim
9/18/16
9/21/16
620 Gbps hits *Krebs on Security* (Security Researcher's Blog)
Attack takes Dyn offline in Eastern United States
10/21/16
10/31/16
Attack targeting Liberian ISP *Lonestar Cell*

Google Project Shield

DDoS Attacks are often used to censor content. In the case of Mirai, Brian Kreb's blog was under attack.

Google Project shield uses Google bandwidth to shield vulnerable websites (e.g., news, blogs, human rights orgs)



Moving Up Stack: GET Floods

Command bot army to:

* Complete real TCP connection
* Complete TLS Handshake
* GET large image or other content

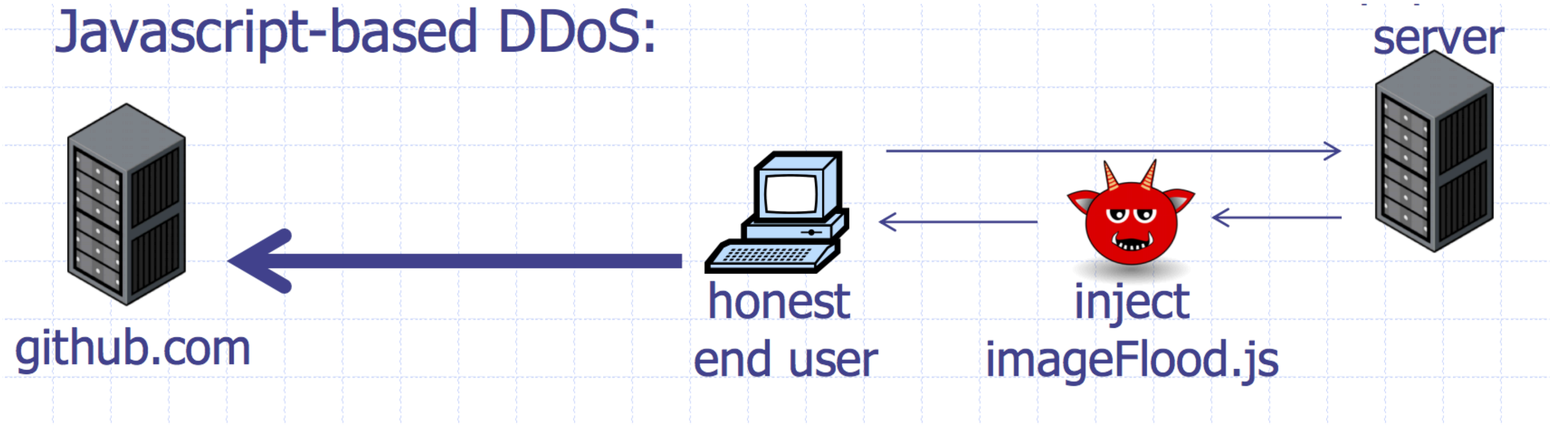
Will bypass flood protections…. but attacker can no longer use random source IPs

Victim site can block or rate limit bots

Github Attacks

1.35 Tbps attack against Github caused by javascript injected into HTTP web requests

The Chinese government was widely suspected to be behind the attack



Client Puzzles

Idea: What if we force every client to do moderate amount of work for every connection they make?

Example:

1) Server Sends: C

2) Client: find X s.t. $LSB_n(SHA\text{-}1(C||X)) = 0^n$

Assumption:

Puzzle takes 2^n for the client to compute (0.3 s on 1Ghz core)

Solution is trivial for server to check (single SHA-1)

Client Puzzles

Not frequently used in the real world

Benefits:

* Can change *n* based on amount of attack traffic

Limitations:

* Requires changes to both protocols, clients, and servers
* Hurts low power legitimate clients during attack (e.g., phones)