Details of selected DDoS Attacks

How the attacks work from a technical perspective

Klaus Möller
WP8-T1

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What we will cover today - and what not

- Layer 3 & 4 Attacks
  - ICMP
  - UDP
  - TCP
- Layer 5+ Attacks
  - HTTP
  - SSL
  - Regular expressions
  - Hash functions

- Local DoS Attacks
  - Even those that have network coordination, downloads, payment, etc.
  - Encrypting Ransomware
- Physical Attacks (Layer 1)
- Data-Link Attacks (Layer 2)

DDoS Attack Characterisation by OSI Layer

- Layer 1 (Physical)
  - Cutting cables, electronic jamming, breaking line-of-sight, …
- Layer 2 (Link Layer)
  - ARP spoofing/poisoning, CAM table floods, WiFi (de)authentication attacks, …
- Layer 3 (Network)
  - ICMP/UDP flood, too large packets (Ping of Death), overlapping fragments (Teardrop), …
- Layer 4 (Transport)
  - TCP <Flag> Flood, TCP Connect, Window size 0, …
- Layer 5+ (Session, Presentation, Application)
  - Slow GET/POST (HTML) Re(gular Expression) DoS, SSL DoS, XML (Billion Laughs), …

DDoS Attack Characterisation by Effect on Target

- Crashes (***vulnerability***)
  - Most severe: permanent hardware/firmware damage
  - Less severe: Kernel panics (Blue screens), Reboots, Lock-ups
  - Limited: Application Crashes/Core dumps or Lock-ups
- Exhaustion of (limited) resources (***volumetric***)
  - Line Bandwidth
  - Packet switching capacity
  - CPU cycles
  - Memory
    - # of Processes, # of half-open connections, # of semaphores, etc.
- Recovery may be immediate (after the attack ends) or take some time(out) period

TCP/IP Vulnerability Attacks

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The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 731122 (GN4-2).

Vulnerability Attack: *LAND*

- Local Area Network Denial
  - First discovered in 1997
  - Nearly all OS of that time were vulnerable
  - Similar application layer attacks have been found in other services (SNMP, Kerberos)
- Source and destination IP address are that of the victim
- Source and destination port are the same, needs open port on victims machine
- Attacker needs one packet to start, victims system then endlessly replies to itself, eventually locking up
- Simulate: `hping3 -S -p 80 -a target target`

Vulnerability Attack: *Teardrop*

- Very old: 1997 – today's OSes are not vulnerable
- Attackers sends TCP/IP packets with specially crafted IP fragments
  - Overlapping fragments
    - I.e. fragment offset + payload size ≠ fragment offset of next packet
  - Assembled payload will be bigger than the maximum IP packet size (65536 bytes)
- Triggers bug in kernel packet re-assembly code → OS crash
  - Windows 3.1x, Windows 95, and Windows NT
  - Linux < 2.0.32 and < 2.1.63
- Related vulnerabilities appeared 2018
  - ***Fragment Smack***, (IP) fragment re-assembly queue, CVE-2018-5391
  - ***Segment Smack***, TCP Segments with random offsets, CVE-2018-5390

Vulnerability ICMP Attack: *Ping of Death*

- Very old (mid 90s) attack that crashed systems
  - Exploits bug in the IP stack, when dealing with reassembled packets being larger than 65536 bytes, the maximum size of IP packets
  - Host OS needs to check that fragment offset + fragment size < 65536
- Attacker sends a number of fragmented IP-Packets to the victim host
  - Usually done with ICMP Echo Reply packets, hence the name
  - Last fragment has data part longer than 7 bytes
  - `ping -l 65510` ***`target`***
- Re-appeared in 2013 with ICMPv6 and in 2020 with ICMPv6 Router Advertisements
  - CVE-2013-3183 and CVE-2020-16898

ICMP Attacks

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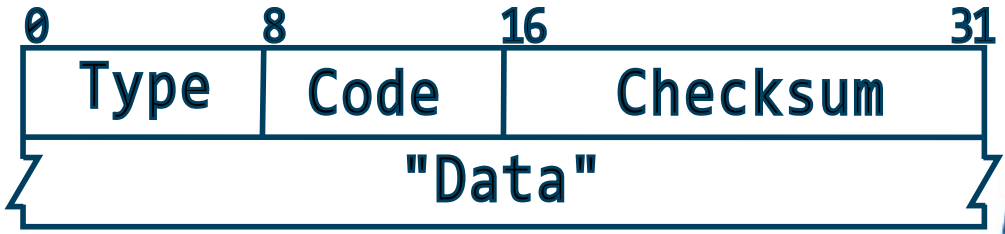
ICMP – Internet Control Message Protocol

- Management protocol integrated into IP layer
  - Most important: Type and Code
  - Checksum & “Data” irrelevant here



- Use cases
  - Connectivity test (Echo Request/Reply) type 8/0
  - Destination unreachable report: type 3, code 0 – 15
  - Re-routing of packets (Redirect) type 5, code 0 - 2
  - Router Advertisement/Solicitation: type 9/10 (usually not for IPv4)
  - Error Reporting (Time exceeded, Parameter Problem): type 11/12, code 0-2
  - Time synchronisation (Timestamp Request/Reply): type 13/14
- Everything else is not legit and can be discarded safely
  - Router adv. and Time sync can be blocked too

ICMP Flood Attacks

- PING: Pair of ICMP Echo Request & -Reply packets
- Attacker spoofs ICMP Echo Reply packets (type 0, code 0)
  - Echo request would DoS himself
  - Arbitrary “data”, checksum doesn’t need to be correct
- Other ICMP floods with other types/codes
- Destination address is that of the victim (unless reflection attack)
- Source address is usually spoofed, i.e. random
  - But may be constant or even that of the attacking bot
  - Depends on egress filtering at the source network
- Packet size varies, usually minimum (64) or maximum (1500)
  - Depending on whether the attacker wants to exhaust switch’s packet switching capacity or line bandwidth

Reflected ICMP Flood: *Smurf*

- One of the earliest Reflection/Amplification DDoS attacks
  - Attacker spoofs victims IP address as source address
  - Sends packet to directed broadcast address of a network, the **reflector**
  - E.g. 192.168.12.255 (if net mask is 255.255.255.0)
- All active hosts on the network would reply back to victim
  - Amplification factor varied in practice: usually 10 – 100
- Since deprecation of directed broadcast forwarding, this has lost significance in favour of other amplifiers
  - Host are also discouraged from answering directed broadcasts
- Simulate: `hping3 --icmp --flood -a` ***`target reflector`***

ICMP Attack: *Ping Flood*

- Saturation attack against line bandwidth
  - Secondary effect on CPU usage of the victims host
- Attacker sends ICMP Echo **Request** packets as fast as possible
  - Will elicit Echo Responses from Victim host
- Goal is to saturate both downlink (to the victim) and uplink
- Works well with asymmetric Lines (DSL)
- Source address is spoofed (or attacker would DoS herself)
- Other characteristics as in ICMP floods

UDP Attacks

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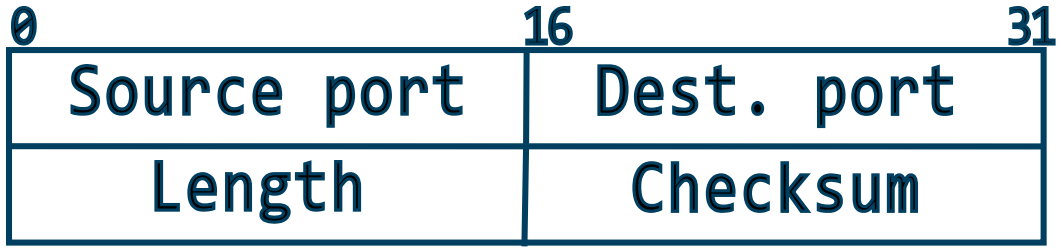
UDP – User Datagram Protocol

- Basically a minimum layer 4 when one just wants to send raw IP packets
  - Header is just source and destination port numbers, length, and checksum



- Used for a wide variety of purposes, mostly when minimum overhead is desired
  - Security considerations most often **not** a priority
- Connection-less nature of UDP makes applications vulnerable to IP address spoofing

UDP Amplification Attacks

- Same principle as with IP/ICMP flood attacks
  - I.e. volumetric attack against bandwidth and/or packet switching capacity
- In most of today's cases, makes use of amplifiers/reflectors
  - I.e. attacker uses victims IP address as query source address (spoofing)
  - Vulnerable service answers (reflecting), hiding attackers IP address in the process
  - Reply of the service is usually much bigger than the query → bandwidth amplification
    - *Bandwidth Amplification Factor (BAF)*
  - Sometimes, service sends out multiple packets for one query packet → packet per second (pps) amplification
    - *Packet Amplification Factor (PAF)*

UDP Amplifiers (and how to find them)

Protocol	BAF	PAF	Port No (udp)	Scenario/Command
DNS auth. NS	54.6	2.08	53	`dig @target +edns +ignore com ANY`
DNS open res.	28.7	1.32	53	`dig @target +edns +ignore com ANY`
mDNS	2 - 10		5353	`dig @target -p 5353 +ignore +noedns wpad`
NTP	556.9	3.84	123	`ntpdc –nc monlist target`
SNMPv2	6.3	1.00	161	`snmpbulkget -v2c -c public target 1.3`
NetBIOS NS	3.8	1.00	137	`nmblookup –A target`
SSDP	30.8	9.92	1900	M-SEARCH request
cLDAP	56 - 70	---	389	---
TFTP	60	---	69	`tftp` command trying to download well known files
Memcached	10K - 51K	---	11211	---
WS-Discovery	10 - 500	---	3702	---

Source: https://us-cert.cisa.gov/ncas/alerts/TA14-017A

UDP Amplifiers: P2P, Games & Other

Protocol	BAF	PAF	Port No (udp)	Scenario/Cmd
BitTorrent (P2P)	3.8	1.58	6671	File search
Kademlia (P2P)	16.3	1.00	varies	Peer list exchange
Quake (Game)	63.9	1.01	27950+	Server info exchange
Steam (Game)	5.5	1.12	27015, 27005	Server info exchange
CharGen	358.8	1.00	19	Character gen. request
Quote of the Day	140.3	1.00	17	Quote request
RIPv1	131.24	---	520	Malformed request
Portmap (RPCbind)	7 - 28	---	111	Malformed request
ARMS (Apple Net Assistant)	35.5	2.00	3283	---
Microsoft RDP	85	---	3389	---

Source: https://us-cert.cisa.gov/ncas/alerts/TA14-017A

UDP Fragmentation (Attacks)

- Seen as fragmented packets with UDP source and destination port 0
- An artefact of buggy/stateless packet counting/reporting
  - 2nd and later fragments don't carry the UDP header
  - Probe only sees IP header with IP protocol number 17 (UDP)
  - Without UDP header to look for port numbers, port 0 is reported
  - Unless probe is smart enough to re-assemble fragments
  - Would require memory for fragment storage → DoS vulnerability in the probe
  - Can't be done in hardware/at wire speed

TCP Attacks

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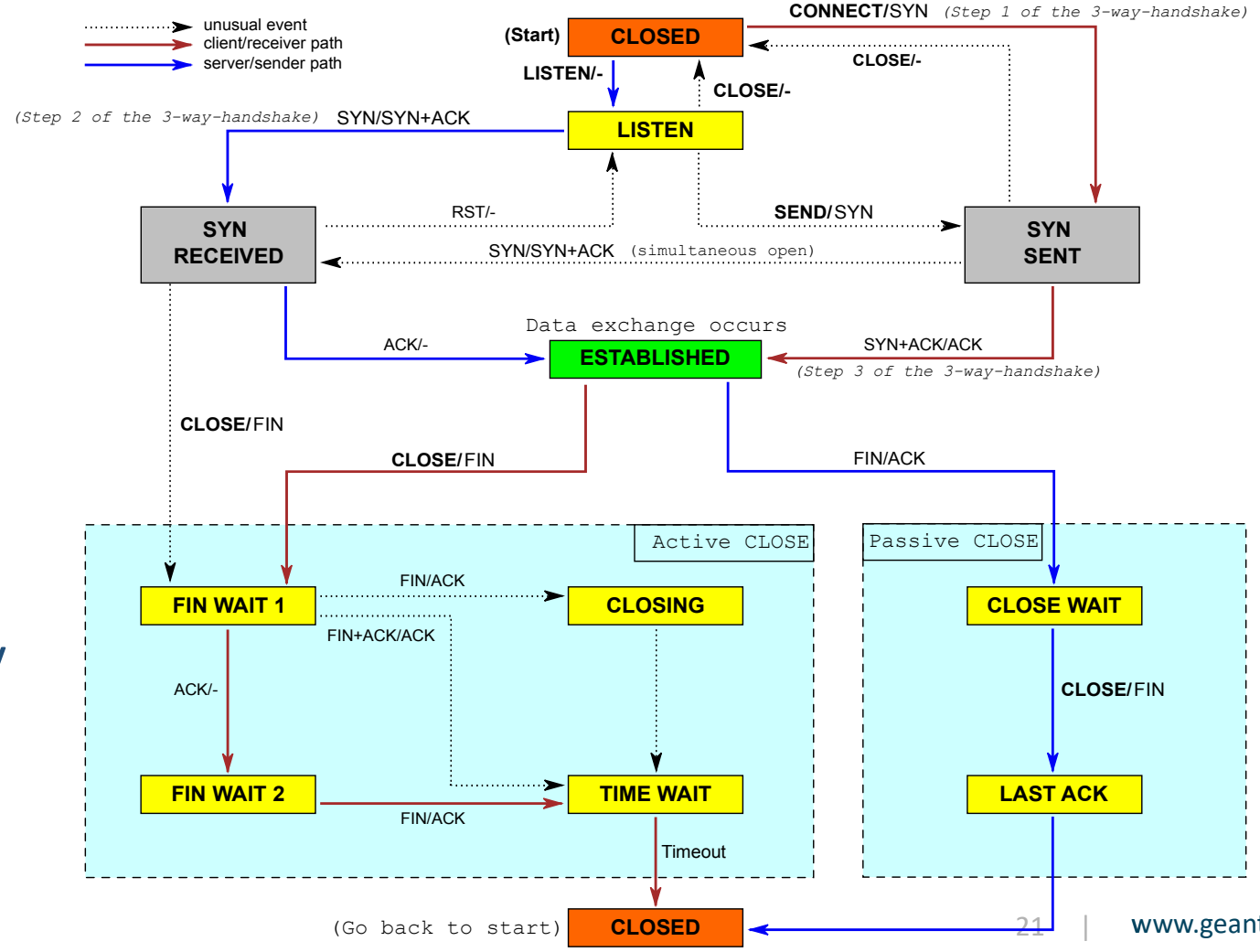
TCP: Transport Control Protocol

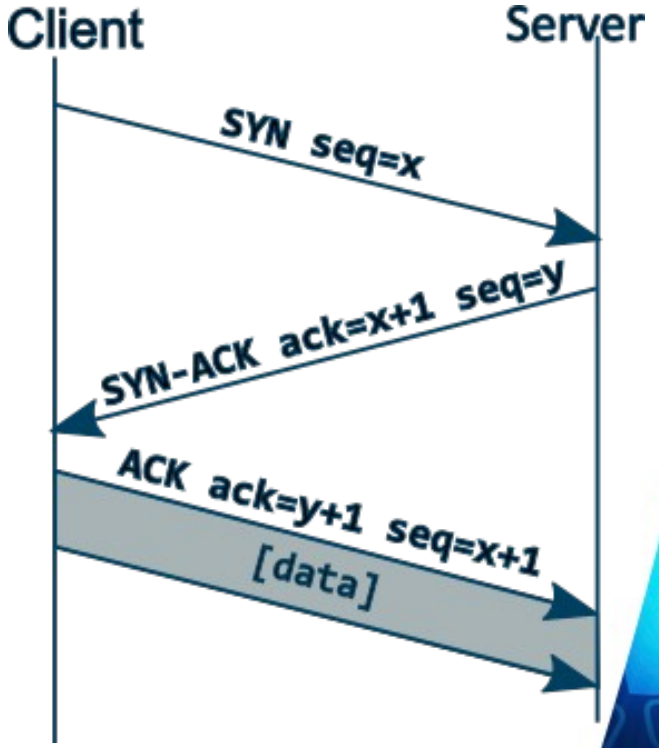
- Layer 4 Protocol for a bi-directional stream between applications
  - State of a TCP connection is modelled through a finite automaton, aka *state-machine*
  - Weaknesses in the automaton are exploited by attackers



Source: https://en.wikipedia.org/wiki/Transmission_Control_Protocol

TCP Attacks: *SYN-Flood*

- One of the oldest and still used attacks
- Exploits memory limit for the TCP 3-way handshake
  - Server has to keep state (seq & ack numbers, options, src/dst ip address & ports)
  - Attacker sends initial TCP SYN packet but never replies to SYN-ACK from server
    - Open port at victim IP address needed
    - Source IP address must not reply for timeout
  - Leaves connection in SYN_RECEIVED state
  - *Total timeout = timeout per SYN-ACK * # resends*




```
> sysctl net.ipv4.tcp_max_syn_backlog
net.ipv4.tcp_max_syn_backlog = 2048
```

TCP Attacks: *SYN-Flood* Detection

- Server side detection
  - Very high number of sockets in SYN-RECV state
- Client side detection:
  - Server doesn't respond / high number of connection failures
- Simulate: `hping3 -S -p` *`Port Target`* `(--flood)`
  - Only little bandwidth is needed
- Self-inflicted SYN-Floods
  - Routing misconfiguration drops SYN-ACK packet on the way back to clients
- How to tell apart from high traffic load
  - Server also has high number of normal (ESTAB) connections

TCP Attacks: *Syn-Flood* Example

```
 > ss -anto
State        Recv-Q   Send-Q        Local Address:Port                  Peer Address:Port

LISTEN       0        128                 0.0.0.0:22                       0.0.0.0:*
SYN-RECV     0        0              XX.XX.245.77:22                   ZZ.ZZZ.173.2:30487  timer:(on,10sec,7)
FIN-WAIT-1   0        1              XX.XX.245.77:22                   ZZ.ZZZ.173.2:50289  timer:(on,17sec,6)
ESTAB        0        0              XX.XX.245.77:22                  ZZ.ZZZ.173.21:13933  timer:
(keepalive,119min,0)
LISTEN       0        128                      *:80                             *:*
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3166   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3148   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3170   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3134   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3177   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3159   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3181   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3141   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3191   timer:(on,12sec,4)
ESTAB        0        36    [2001:xxxx:xxxx:xxx:1001::2002]:22 [2001:yyy:yyy:yyyy:6::4]:39666   timer:(on,240ms,0)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3169   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3174   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3136   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3188   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3137   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3186   timer:(on,12sec,4)
SYN-RECV     0        0     [::ffff:XX.XX.245.77]:80          [::ffff:YYY.YYY.208.44]:3153   timer:(on,12sec,4)
    […]
```

TCP Attacks: *SYN ACK Reflection*

- Reflection attack that was gaining popularity in 2019
  - TCP was thought to give not enough amplification for DoS attacks
- Perceived as a SYN-ACK flood at the victims host
- Attacker TCP SYN packets to the reflector host with victim's (spoofed) IP address
  - Open port needed
- Reflector sends SYN-ACK packet to victim
- If victim does not respond, will repeat SYN-ACK several times
  - Usually 2-5 times, but vulnerable hosts will re-try up to 255 times
  - See `net.ipv4.tcp_synack_retries` (Linux)
- Targeted resource is the networks packet switching capacity (pps)

Application Layer Attacks

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The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 731122 (GN4-2).

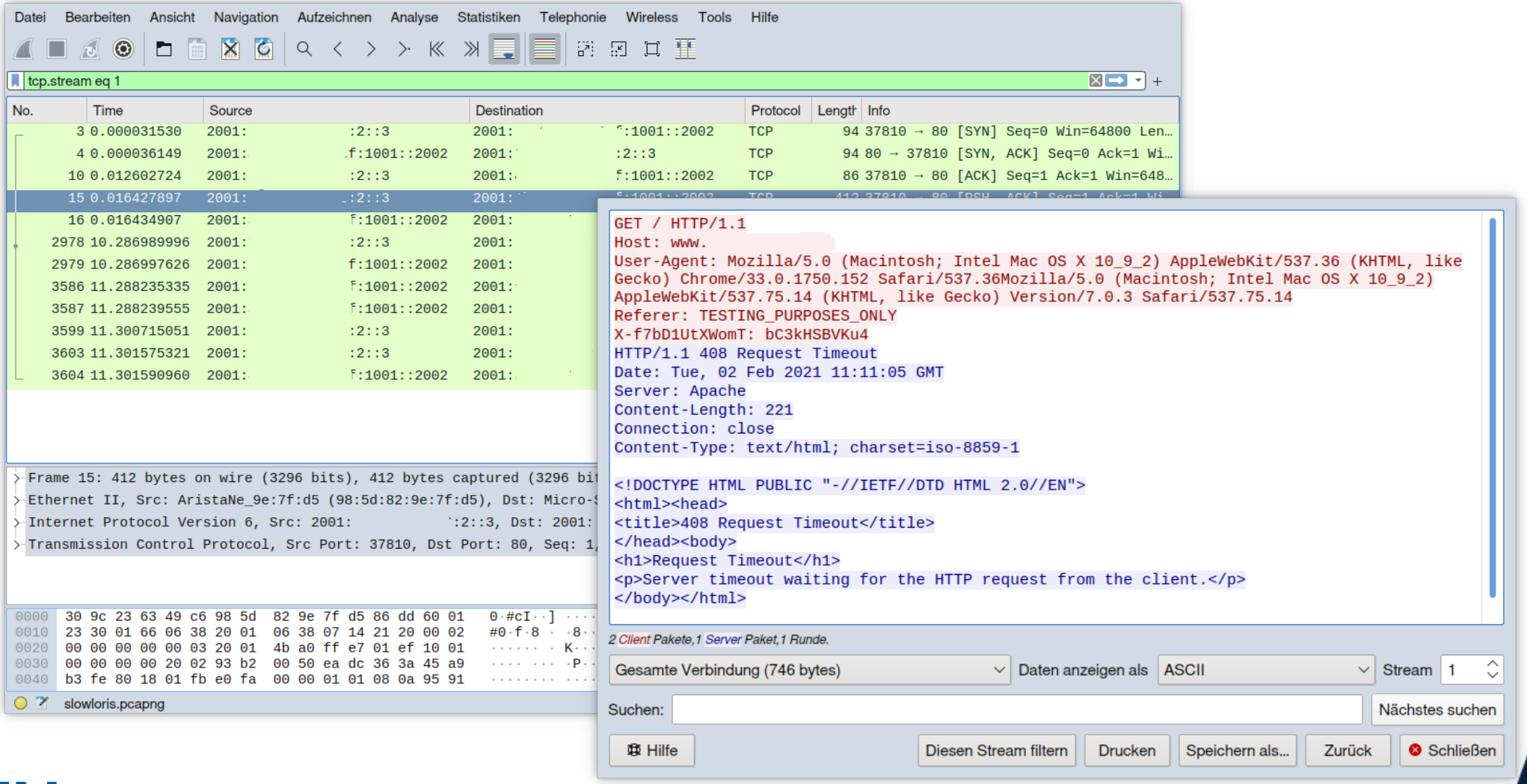
Application Attacks: *Slowloris*

- Attack directed against web servers
  - Destination port 80, 443, etc.
  - Exhausting number of open HTTP sessions
    - TCP connections
  - System will accept no new HTTP connections, hangs
- Attacker opens a number of TCP connections to a web server
- Each HTTP request is sent in small TCP packets, very slowly
  - Very low bandwidth usage
- Simulate
  - PyLoris: Supports connections through SOCKS and TOR
  - SlowHTTPTest: DDoS test tool for web servers

David Haring / Duke Lemur Center

Slow loris primates

Application Attacks: *Slowloris Packet Capture*



Application Attacks: *Slowloris* Variants/Derivates

- ***SlowDroid:*** Uses high number of spaces instead of HTTP (GET) requests
- ***SlowRead:*** Accept server response very slowly (TCP window size 0)
  - Forcing server to send response in very small packets, with a high number of seconds in between
- ***Slow HTTP Post:*** with HTTP POST requests
- ***R-U-Dead-Yet (R.U.D.Y.):*** Filling out HTTP forms very slowly (POST requests)
  - Sending chunks of the POST with a high number of seconds in between
- ***THC-SSL-DoS:*** Immediately request re-negotiation after SSL handshake
- ***#RefRef:*** Exploits SQL injection vulnerability to execute recursive SQL statements

Famous Application Attacks: *Billion Laughs*

- Targeted at XML parser code in web apps or elsewhere
- Memory exhaustion while parsing specially crafted XML files
  - CPU load as secondary effect
  - Aka XML Bomb, similar principle as in *Fork Bombs, Zip Bombs*, etc.
  - Works with other XML based formats too, like YAML

Example:

```
<?xml version="1.0"?>
<!DOCTYPE lolz [
 <!ENTITY lol "lol">
 <!ELEMENT lolz (#PCDATA)>
 <!ENTITY lol1 "&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;">
 <!ENTITY lol2 "&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;">
 <!ENTITY lol3 "&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;">
 <!ENTITY lol4 "&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;">
 <!ENTITY lol5 "&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;">
 <!ENTITY lol6 "&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;">
 <!ENTITY lol7 "&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;">
 <!ENTITY lol8 "&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;">
 <!ENTITY lol9 "&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;">
]>
<lolz>&lol9;</lolz>
```

Application Attacks: *ReDoS*

- Regular Expression Denial-of-Service
- Attacker sends a specially crafted message
  - ***evil RegExes*** **–** e. g. grouping with repetition, like **`([a-zA-Z]+)*`**
- Exploits weaknesses in regular expression library
- Exhausting/consume CPU on server when
  - Server regular expression is run against attacker supplied input strings
  - Server executes a regular expression supplied by the attacker

Application Attacks: *Hash Collision DoS*

- Exploiting Collisions in applications hash tables
  - Not cryptographic hash collisions
- Web application frameworks often use hash tables to index POST session parameters
  - Dealing with collisions in hash tables is computationally (much) more CPU intensive than lookups
- Attacker sends a specially crafted POST request with many specially crafted parameters
  - Built in a way that causes hash collisions
- Attack slows down responses, exhausting CPU
  - Vulnerabilities in hash-table code may also allow code execution in the application

Attack Tools: *LOIC & HOIC*

- **L**ow **O**rbit **I**on **C**annon
- Developed as a network stress test tool, modified and released as open-source by "Anonymous" group
- Flood attacks with TCP, UDP, or HTTP packets
- "Hive Mind Mode" connects to IRC channel for remote control/coordination

- **H**igh **O**rbit **I**on **C**annon
- Same group as LOIC
- Used for HTTP request floods
- "booster" (.hoic) files contain list of URLs, referrers, user agents, and HTTP headers, used randomly to avoid IPS filters
- No spoofing of source addresses

What have you learned?

- Denial-of-Service attacks come in many colours
  - And they keep changing and evolving
- How some of the most ”famous” DDoS attacks work technically
- Patching will help against vulnerability-based attacks
  - Ping-of-Death, LAND, Teardrop, etc.

- **Question 1:** If you can’t feel the impact of a DoS attack, was it real?
- **Question 2:** How can we discriminate attacks from self-inflicted Denial-of-Service?

→Next session: DDoS Detection

Thank you

Any questions?

Next course: ***DDoS Detection***

15th of February 2021

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- CISA Alert (TA14-017A) UDP-Based Amplification Attacks: https://us-cert.cisa.gov/ncas/alerts/TA14-017A
- Shadowserver foundation network reporting, https://www.shadowserver.org/what-we-do/network-reporting/
- Netscout: A Call to ARMS: Apple Remote Management Service UDP Reflection/Amplification DDoS Attacks: https://www.netscout.com/blog/asert/call-arms-apple-remote-management-service-udp

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- Cloudflare blog about UDP reflection attacks: https://blog.cloudflare.com/reflections-on-reflections
- OWASP ReDoS page: https://owasp.org/www-community/attacks/Regular_expression_Denial_of_Service_-_ReDoS
- Russ Cox: “Regular Expression Matching in the Wild”: https://swtch.com/~rsc/regexp/regexp3.html

Tools & Packet captures

- Packet Traces (Lab): https://rickfreyconsulting.com/downloads/
- hping3 (alpha) http://www.hping.org/hping3.html
- Nping (part of nmap): https://nmap.org/nping/
- Scapy: https://scapy.net/
  - Ufonet https://github.com/epsylon/ufonet
- SlowHTTPTest: https://github.com/shekyan/slowhttptest
- PyLoris: https://sourceforge.net/projects/pyloris/
- THC-SSL-DoS: https://thehackerschoice.wordpress.com/2011/10/24/thc-ssl-dos/,
  - Kali source mirror: https://gitlab.com/kalilinux/packages/thc-ssl-dos