Automatic DDoS Attack Rule Generation for SIDS applied to BRO

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Abstract

A Distributed Denial of Service (DDoS) attack aims to disable services of a target system using multiple machines. As the number of attacks increase and downtime costs are exceeding on average $300K per hour [1] a need for an efficient and effective mitigation method has become crucial. Our hypothesis is that Signature-based Intrusion Detection system is a suitable system that can detect DDoS attacks when their downside of keeping an up-to-date signature list is tackled. In this paper, we will implement automatic signature generation for Bro. We will test these signatures by replaying various DDoS attack vectors retrieved from DDoSDB against a common network architecture.

In this paper, we show that it is possible for the selected attack vectors to automatically generate Bro signature within 4.2 milliseconds. Also that Bro is capable of detecting and responding to all attacks within 0.31 milliseconds when only one signature is active and within 0.7 milliseconds with all our generated signatures.

1 Introduction

A Denial of Service (DoS) is an attack that aims to disable services of a target system. There are two main types of DoS attacks based on, *vulnerability* and *flood* [11]. In one hand, a vulnerability DoS aims to exploit a vulnerability of a target system to reduce its performance or render it useless. An example of such an attack is to send a malformed message to the target machine which can not deal with this message and as a result stops working. On the other hand, a flood DoS attack tries to exhaust the resources of the target. An example of such an attack is to fill the entire bandwidth of the target with messages of the attacker. The attacker can accomplish such bandwidth flood by using multiple machines to produce traffic. When multiple machines are used in the attack, it is called a Distributed Denial of Service (DDoS) attack.

DDoS attacks have increased in power and frequency. In 2011, the peak attack was measured at 60 Gb/s [13], in 2015, 500 Gb/s and in 2016 1.1 Tb/s [5]. In the third quartile of 2016 more than 5000 attacks where observed, whereas 200 in the entire 2012 [4]. As the number of attacks increase and downtime costs are exceeding on average $300K per hour [1] a need for an efficient and effective mitigation method has become crucial. The first task before the mitigation is the detection of an attack. Intrusion Detection Systems (IDSs) are such systems that can fulfill this task. An IDS monitors a system or network for malicious and/or suspicious activities. Based on the detection methods of IDSs, two categories can be identified: *Anomaly-based* (AIDS) and *Signature-based* (SIDS) [7]. An AIDS bases its detection on a constructed baseline and detects deviations from this baseline. A SIDS bases its detection on key characteristic of an attack for which predefined signatures are known. An AIDS has as benefit that it can detect unknown attacks but with the weaknesses that it has a low accuracy, needs time to learn a baseline of a system and has difficulties to trigger alerts before an attack scales up. A SIDS has as benefit that it has a high accuracy but with the weaknesses that it is ineffective in detecting unknown attacks and it is hard to maintain an up to date signature list [10].

Our hypothesis is that due to the high accuracy a SIDS is a suitable system that can fulfill the requirement of successfully and efficiently detecting DDoS attacks when the major downside of keeping an up to date signature list is tackled. The solution to this problem is to generate signatures for new attacks. This can be done either manually or automatically. As a manual approach requires a significant amount of manual effort [11], we propose an automatic method. For this research, we choose to generate rules from extracted features for Bro[1]. Bro is an open source network security monitor that offers the functionality of a SIDS. The reason why we choose

[1] `https://www.bro.org/`

Bro is that it allows for more than just detection. For instance, compared to the SIDSs Suricata[2] and Snort[3] it allows to execute a script whenever a packet is matched against a signature list. Furthermore, Bro also comes with the BSD license allowing free use which lowers the threshold for people to adopt the SIDS.

To pursue our goal we have defined the following research questions (RQ) as the basis of the proposed research:

- **RQ1:** What are the DDoS characteristics that could be used for generating BRO detection/mitigation rule?
- **RQ2:** What is the performance of automatic rule generation against a DDoS attack for the Bro SIDS?
- **RQ3:** What is the efficiency for Bro automatic generated rules when applied on an ongoing DDoS attack?

In the following section, the first RQ will be answered by analyzing the most common DDoS attack vectors described by Akamai [6]. Akamai is a cloud delivery platform and is recognized by Forrester as one of the three leaders in web application firewalls [2]. It also publishes every quarter a safety report which describes the state of the internet. The report also includes figures on the number of measured DDoS attacks. Therefore, it gives a nice overview on which attack vectors are most in use at the time of writing. In Section 2, the second RQ will be answered by building a proof of concept that generates signatures based on fingerprints of DDoS attacks. These fingerprints will be obtained from DDoSDB[4]. DDoSDB is an initiative of the University of Twente on sharing (semi) anonymized DDoS attack data from victims. DDoSDB also shares a summary of each attack, the fingerprint, from which we will generate the Bro rules. The third and last RQ will be answered by replaying an attack for which a signature was generated and analyze what the performance of Bro is with these signatures implemented. In Section 5, we present our conclusions and directions to future work.

2 DDoS Attacks and BRO

In this section, we will first define the notion of a DDoS attack by explaining the infrastructure. Then we elaborate on the most common DDoS attacks used according

[2] https://suricata-ids.org/about/
[3] https://www.snort.org/
[4] http://ddosdb.org/

to Akamai's Q4 2017 report [6] and discuss their main characteristics. After this, we will discuss the syntax of the signature rules of the BRO SIDS.

2.1 The DDoS Attack

Figure 2.1 shows the infrastructure of a DDoS attack. Actors involved in an attack are denoted by a letter (A-E) whereas data streams are denoted by numbers (1-5).

A DDoS attack starts with an attacker (A). The attacker sends data needed to start the attack (1) to the Command and Control (C&C) servers (B). The C&C servers control the infected machines (C). The infected machines are also known under the name of bots. The C&C servers plus the infected machines are more commonly known as a botnet. In case of the Ramnit botnet [12], only the infected machines counted 3.2 million machines. When the C&C servers receive a message from the attacker, they at their turn send a message (2) to the infected machines. At this point, two paths are used to get to the target machine (E). The first path possible is aiming the infected machines directly to the target (4). This means that traffic from the infected machines will go directly towards the target. The second path possible is using public services (D). This means that traffic from the infected machines will first go through a public service, like a DNS, to reach the target (5).

A technique for an attacker to use the public services is by spoofing its IP. In this process, the attacker sends a request towards a public service where the packet's source IP is replaced by the one of the target. This way the response of the service is reflected towards the target. A benefit for an attacker to use this path is that it is possible, due to the asymmetry between request and response sizes, to amplify once initial request. In the next subsection, we describe various types of DDoS attacks and relate them to the architecture described above.

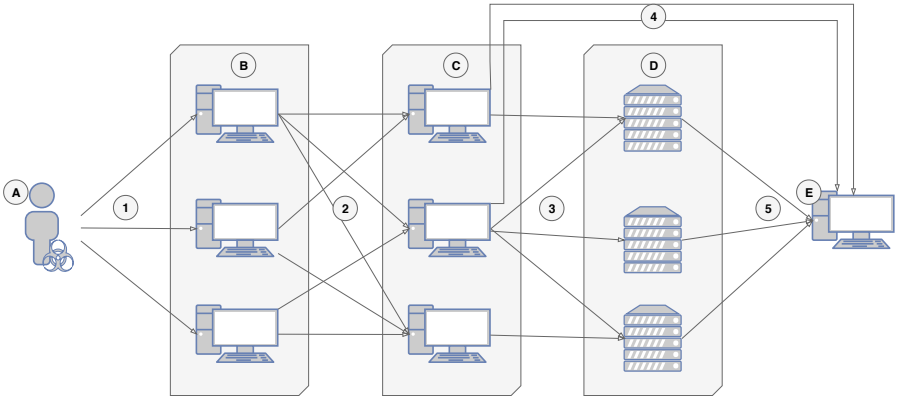


Figure 1: Overview of DDoS attack infrastructure

2.2 Types of Attacks

In this subsection, we briefly elaborate on the top 10 most common types of DDoS attacks. This top 10 is retrieved from, at the time of writing, the latest report that gives an overview of the types of the most used DDoS attacks of Akamai [6]. Of each attack, we discuss which protocol is used and which mechanism is exploited. An overview of the main characteristics per attack type can be found in Table 1.

UDP: The UDP attack exploits UDP protocol. The attack consists of sending a large number of packets to random ports of the target. Hereby the target machine will check if an application listens to this port and if not will reply with an ICMP Destination Unreachable (ICMP type 3) packet. At Figure 2.1, for this type of attack, path 4 is used.

UDP Fragment: The UDP Fragmentation attack exploits the fragmentation used in the IP protocol [8]. When a packet is too big to be sent across a network link, it will be broken down into smaller packets and later on resembled again. In a UDP Fragmentation attack, UDP packets are sent which are larger than the maximum transmission unit (MTU), usually 1500 bytes, of the network thereby forcing fragmentation. This results in a higher number of packets than a normal UDP attack. At Figure 2.1, for this type of attack, path 4 is used.

DNS: The DNS attack exploits the public Domain Name System (DNS) services on the internet. DNS runs over UDP and is used to resolve IP addresses from website names. In a DNS attack, the attacker spoofs its IP replacing it by the one of the target. The DNS server sees the request as it came from the target and replies as if it were a normal request. This way of attacking allows an attacker to amplify its own bandwidth by using the asymmetry between request and response size. At Figure 2.1, for this type of attack, path 5 is used.

NTP: The NTP attack exploits the public Network Time Protocol (NTP) services on the internet. NTP uses the UDP protocol and allows for time synchronization between machines. This attack is similar to the DNS attack, but this time the NTP services are used instead of the DNS services. At Figure 2.1, for this type of attack, path 5 is used.

Chargen: The Chargen attack exploits the public Character Generator Protocol (Chargen) services. Once a Chargen service receives a packet via the UDP protocol, it responds by sending a datagram containing a random number between 0 and 512 characters long [9]. The attack approach works the same as the NTP and DNS. At Figure 2.1, for this type of attack, path 5 is used.

CLDAP: The CLDAP attack exploits the Connection-less Lightweight Directory Access Protocol (CLDAP). CLDAP runs over UDP and is designed to provide access to directories while not needing the resource requirements of the Directory Access Protocol (DAP) [3]. The attack is similar to the DNS, NTP and Chargen attack. At Figure 2.1, for this type of attack, path 5 is used.

SYN: The SYN attack exploits the three-way handshake of TCP. During this attack, a large number of SYN packets are sent to the target machine. The target machine will respond by sending a SYN-ACK packet. The attacker at this point does not respond by sending an ACK packet, leaving the connection half initialized. This way the attacker keeps connections from being used by legitimate users. Compared to the attacks mentioned above, this one runs over TCP rather than UDP. At Figure 2.1, for this type of attack, path 4 is used.

SSDP: The SSDP attack exploits the Simple Service Discovery Protocol (SSDP). SSDP runs over UDP and is used to discover network services. The attack is similar

Attack Type	Main Characteristics
UDP Frag	IPv4 && fragments
DNS	UDP && src_port==53 && DNS_query && DNS_type
CLDAP	UDP && src_port==389
NTP	UDP && src_port==123
UDP	UDP
Chargen	UDP && src_port==19
SYN	TCP && flag==SYN
SSDP	UDP && src_port==1900
ACK	TCP && flag==ACK
HTTP	HTTP && HTTP_request && src_port==80

Table 1: Attack types main characteristic overview.

to DNS, NTP and Chargen but at Figure 2.1 the machines in D are for instance home routers, printers or other IOT devices rather than a dedicated server.

ACK: The ACK attack exploits the TCP protocol. During this attack, a large number of ACK packets are sent towards the target. These ACKs do not belong to any connection and are therefore dropped at the target machine. This, however, does deplete resources of the target. At Figure 2.1, for this type of attack, path 4 is used.

HTTP: Rather than the attacks mentions above, the HTTP attack targets the application layer. The attack consists of sending a large number of HTTP requests (like GET, PUSH and POST) to the target, hereby depleting its resources. At Figure 2.1, for this type of attack, path 4 is used.

2.3 Bro Rule Syntax

This section discusses the various parts used of Bro to implement the rule generation for the types of attacks discussed in Section 2.2. Bro's primary focus is on its scripting language. With this language, one can define various analyzing scripts and detection policies. Besides the scripting language, Bro also offers also a signature language[5]. This language is similar to Snort rules and relies on low-level pattern matching. In this section, first, an introduction to the signature language is given.

[5] https://www.bro.org/sphinx/frameworks/signatures.html

Second, the signature language is applied to some of the attack types described in Section 2.2. Third and lastly, a brief explanation of the Bro scripting language is given.

The format of a signature is shown in Listing 1. As can be observed, each signature starts with the *signature* keyword followed by a signature identifier. The body contains attributes. These attributes can be rules to match on. Besides rules, it is also possible to specify in the attributes whether an event must be raised when all attribute rules within a signature are matched for a specific package. Both possibilities will be explained further.

```
1 signature [SIGNATURE-ID] {
2   ATTRIBUTES
3 }
```

Listing 1: Bro Signature Format

An attribute rule follows the format *KEYWORD CMP VALUE*. Here the *KEYWORD* indicates a certain field to match, *CMP* indicates the way to compare and *VALUE* indicates the value to compare to. Various keywords are known to the Bro signature language. In this paper, we will only mention the ones used. *src-ip* and *dst-ip* specify the source and destination address respectively. Addresses can be IPv4 or IPv6. *src-port* and *dst-port* specify the source and destination port respectively. *ip-proto* specifies the protocol used. Values possible for proto are: *tcp, udp, icmp, icmp6, ip* and *ip6*. It is interesting to note that Bro allows supplying a list of values in the format $v_1, \ldots, v_n$. Whenever one of those values matches a value within a received packet, the match of that rule will be evaluated to true. Furthermore, Bro allows six comparators: $==, <=, >=, >, <$ and $!=$.

```
1 signature icmp-type-3 {
2   ip-proto == icmp
3   header icmp[0:1] == 3
4   event "ICMP Type 3 Detected"
5 }
```

Listing 2: Bro signature which matches all ICMP type 3 packets

Besides matching on general conditions it is also possible to match specific bytes of a header. An example of this is given in line 3 of Listing 2 where an attribute rule is written which matches all ICMP type 3 packets. As can be seen, the attribute rule starts with the keyword *header*. Then the protocol is specified (which can be any of the ip-proto values mentioned above). Then one defines within the square brackets the offset and size in bytes separated by a colon. In the example, the value of byte position 0 (which indicates the ICMP type) is matched against the value 3. It must

be noted that not every protocol defines values that fall perfectly within the space of bytes such as the ICMP type. For instance the TCP flags.

The TCP SYN flag is indicated by a single bit at bit position 111. To check whether this flag is set, one needs to compare the value of the entire byte where this flag is located in. An example of a signature which matches all TCP SYN packets is given in Listing 3. At rule 3 of this example, it is shown that byte position 13 (which corresponds to bit positions 105 up to and including 112) is compared to the value of 2. This means that this signature will only match whenever the SYN flag is set to 1 and all of the other bits (including one reserved bit) are set to 0. If one wants to write an attribute rule that matches whenever the SYN flag is set, and does not care about the values of the other flags, the rule has to contain 2^7 entries.

```
1 signature icmp-type-3 {
2   ip-proto == tcp
3   header tcp[13:1] == 2
4   event "TCP SYN Detected"
5 }
```

Listing 3: Bro signature which matches all TCP SYN packets targeted at port 80

Both Listing 2 and Listing 3 illustrate in line 4 the *event* keyword followed by a string. The Bro scripting language is event based. Scripts are defined to be executed whenever a certain event is triggered. One of the events defined in the language is the *signature_match* event. This event is triggered whenever a signature, which has an event defined in its body, is matched against a package. When this signature matches, the contents of the string is passed to the event listener, including various other parameters. For our experiment, we used one Bro script which can be found in Listing 4. The purpose of this script is to execute a python script whenever a signature match has occurred. The Bro script has some things to note. The first is the *@load-sigs ./sig* line. This line is responsible for loading the signatures files. The second is the *event signature_match(. . .)* line. This rule illustrates the event-driven programming script of Bro. Whenever a signature is matched, the contents defined within the curly brackets is executed. The *msg* parameter is given string specified after the event keyword in the signature.

3 Setup and Experiments

In this section, we discuss the experiment used to achieve the results presented and discussed in Section 4. The aim for this setup is to prove that it is possible to add Bro to a network without interfering the with the connected machines. In this setup

```
@load base/utils/exec
@load-sigs ./sig

redef exit_only_after_terminate=T;

event signature_match(stage: signature_state, msg: string, data:
    string)
{
        local t= fmt("python3 send_to_attacker.py '%s'", msg);
        local cmd = Exec::Command($cmd=t);
        when (local res = Exec::run(cmd))
        {
                print msg;
        }
}
```

Listing 4: Bro script which executes whenever signature match occurs

we will use the knowledge presented in Section 2.3 to automatically generate the signatures for 13 different attack vectors. First, we explain how we implemented the automatic rule generation. Second, explain the test setup. Third, we discuss the data used for the experiment. fourth and lastly, we discuss the tools and commands used to run the experiment.

For this research, we created a python script that takes as input a JSON fingerprint of an attack vector from DDoSDB. DDoSDB supplies both a summary in JSON format as the actual (semi-anonomyzed) attack in pcap format. DDoSDB obtains its data by directing DDoS attacks on themselves and capturing all data. After this, the attack is anonymized, analyzed and divided in the individual attack vectors after which they are put onto DDoSDB.org. The output of our script is a Bro signature. The python script is publicly available on GitHub[6].

The test setup we created is depicted in Figure 3. There are four actors in our setup. The first actor (1) is the attacker. The second actor (2) is a router. The attacker is directly connected via cable to this router to not hinder any other networks. The third actor (3) is a switch that allows port mirroring. When a port is mirrored to a different port, all data received and send through the first port is also sent towards the second port. The reason for using port mirroring is that it allows to funnel all data from different ports to one single port. One then can connect a machine to this port which runs Bro. This way of connecting allows receiving all data send and received to various machines to be copied to a single port. This yields that all data

[6] https://github.com/boschma2702/DDoS_Scripts

can be analyzed by a single machine without interfering with the other connected machines. The fourth actor (4) is the target machine. The fifth and final actor (5) is a machine that runs Bro. The Bro machine receives all egress packets of the target machine.

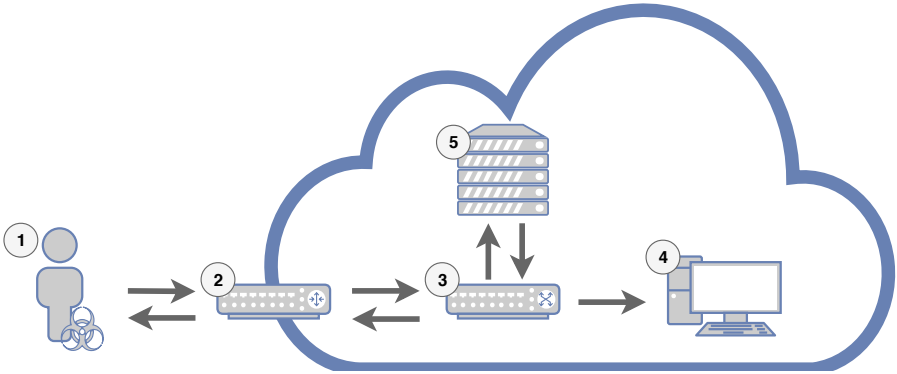


Figure 2: Schematic overview test setup

For this research, we choose 13 attack vectors retrieved from DDoSDB to test against our setup. Each vector has a pcap file which contains only the data belonging to a single attack vector extracted from a real attack. From each attack vector, DDoSDB makes available a JSON file which describes the main characteristics of that vector (called fingerprint). Each vector has been assigned a four-digit identifier to which we refer to in the remainder of this paper. The four-digit identifiers are the first four digits from the key value of each attack. Each attack can easily be retrieved from DDoSDB by using a wildcard (*) in the following query: *('key: [ID]*')*. A brief summary of each attack vector based on the received JSON file can be found in Table 2. For each vector the signature is generated on the Bro machine and is measured how long generation takes, depicted in Figure 3b.

ID	Type	# src IPs	# src ports	# dst ports	additional information
e0b2	ICMP	83	0	0	icmp_type = 5
0292	TCP	6	1	1	tcp_flags = ··········S·
dd26	Chargen	439	1	5	
e6ee	DNS	25027	1	60219	dns_query = hoffmeister.be
54a7	ICMP	270	2821	1	icmp_type = 11
8219	UDP	12	1	96	
39b6	TCP	66610	41757	1	tcp_flags = ·····
13c4	UDP	12	1	83	
c606	TCP	13452	12110	1	tcp_flags = ····CE····S·
7bf0	NTP	1288	1	11	
151e	ICMP	244	12	1	icmp_type = 3
9d61	ICMP	6245	0	0	icmp_type = 3
072a	DNS	30551	1	62591	dns_query = diasp.org

Table 2: Attack charasterics

To determine the response time of the Bro SIDS against an ongoing DDoS attack, first, it is crucial to determine the maximum network traffic the setup can handle. This is done using by executing a preliminary experiment. In this experiment we use the setup as described above and use iperf3[7] on both the attacker as other machines. The attacker runs the script: *iperf3 -s* and the other machine runs *iperf3 -c [attacker_ip] -R*. This way the server sends the data to the connecting machine. Times between 91.2 and 98.0 Mbps were measured. To be sure that the network would not hinder the performance of Bro, we decided to put the network limit on 90 Mbps.

To replay the attack vectors we first rewrite the destination IP and MAC-address of the supplied pcap using tcprewrite[8]. The command used is *tcprewrite –dstipmap=0.0.0.0/0:[target_ip]/32 –enet-dmac=[target_mac] –infile=[supplied_pcap] –outfile=attack.pcap*. Second, Bro is started in bare mode with the written Bro script described in Listing 4. This way only the needed files are loaded. The command used to start Bro is: *sudo bro -b -i [network_device] [path_script]*. Third, the attack against the target machine is launched using tcpreplay (which is included in tcprewrite). The command used to launch the attack is: *sudo tcpreplay -i [network_device] –mbps=[speed_limit] attack.pcap*. Fourth and lastly, when a signature match is received, the Bro machine will send a message to the attacker. The times it took of each attack between launching it and receiving the

[7] https://iperf.fr/
[8] http://tcpreplay.synfin.net/

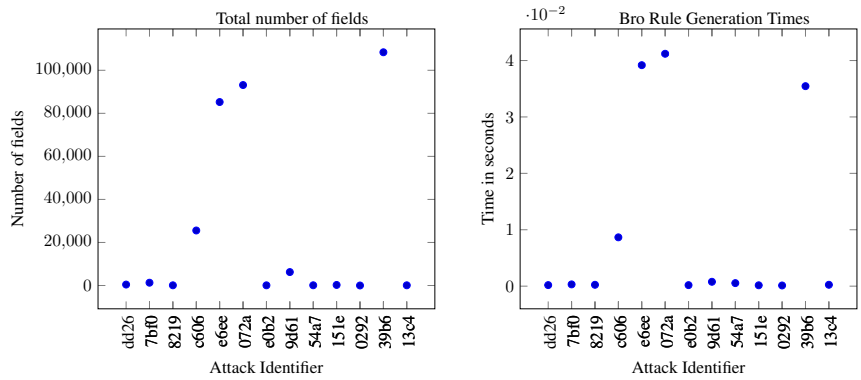
message are displayed in Figure 4.

In our first attempt at gathering results we used as the attacker a Lenovo Thinkpad W540 running Ubuntu 18.04 LTS, as router the D-Link DIR-605L, as switch the tp-link TL-SG105E, as target machine a Raspberry Pi 2 and as Bro machine a Raspberry Pi 3 Model B. When replaying an attack vector at 90 Mbps, the Pi could not cope with it. We then decided to turn down the replay speed and concluded that even at a speed of 1 Mbps the Pi could not handle every attack. Therefore we concluded that a Pi, even for a signature set consisting of one signature, is not suitable to run the Bro SIDS. We then switched to using the attacking laptop as Bro machine and as attacker a Dell m2800 running Ubuntu 16.04. We again used iperf3 to measure the bandwidth that could be accomplished. This yielded the same results as before.

4 Evaluation and Discussion

In this section, we evaluate and discuss our findings we found by executing the methodology described in Section 3.

Every measurement is executed 10 times. From this, the average and standard deviation are calculated. The first measurement performed is the time required to generate the Bro rules from the supplied JSON signatures. The results are shown in Figure 3b. This figure shows average time it took in seconds to generate the signature on the Bro machine for each attack vector. Due to the small standard deviation, it is not possible to see it in the plot. As can be observed, the vectors e6ee, 072a and 39b6 took considerable more time than the other vectors. When we combine this data with Figure 3b we observe that there is a strong correlation between the number of fields and the time it takes to generate the figure. We suspect that the reason that 39b6 generates faster than e6ee and 072a while it has more fields is due to that the special field of TCP takes less time to generate than the one of the DNS. More research is needed to confirm this hypothesis.



(a) Number of fields

(b) Bro Rule Generation Times

Figure 3: Number of fields (left) and time it took to generate the signature (right)

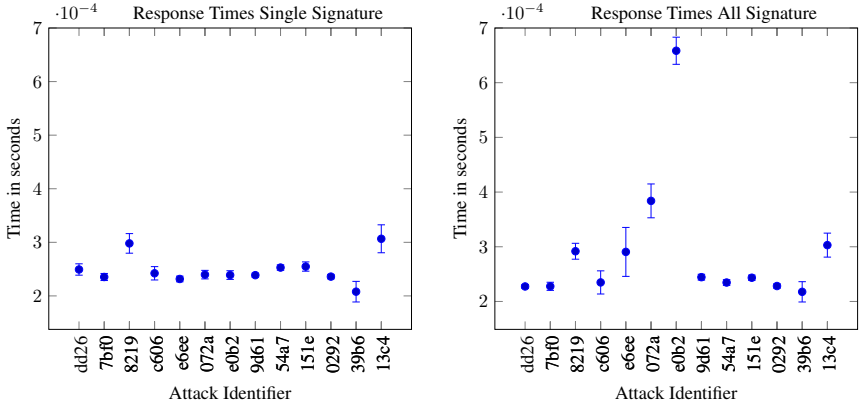
The second measurement performed is the time it takes to send a message from the Bro machine to the attacker. We choose to let the Bro machine send a message to the attacker as this way the attack could be stopped when detection took place. The time measurement includes setting up a TCP connection, sending a message and then closing the connection. The average of these measurements was 0.0841 milliseconds with a standard deviation of 0.0129 milliseconds.

The third and final measurement performed is the time it took for the Bro machine to react to an incoming attack. The results of these measurements are shown in Figure 4. This measurement is executed in two variants. The first variant is shown in Figure 4a and pictures the response times when every attack vector has only its own signature active in the Bro machine. The second variant shown in Figure 4b pictures the response times when all attack vector's signatures are active.

In Figure 4a we observe that one vector, 39b6, takes less time than the other vectors. It is, however, visible that this measurement has quite a large variance compared to the other ones and might be that the reason for its speed is due to irregularities in the test setup. Furthermore, vectors 8219 and 13c4 take significantly longer to detect than the other attack vectors. It is interesting to note that both attack vectors are UDP attacks. One would more likely expect that the DNS attack vector would take longer to detect due to the fact that regex matching needs to be done against a packet's payload. Furthermore, the DNS attack vector e6ee has also more source IPs and destination ports to match against than both the UDP attacks. Reasons explaining this could be that Bro has a harder time dealing with these types of packets or that certain types of packets take longer to send in the network. Due to time constraints

we could not investigate this further.

In Figure 4b we observe that Bro does not increase significantly for all attack vectors. For most of the vectors, the times roughly stay the same. Most interesting are the increases in 072a and e0b2. Especially the latter as it increased by more than 2.5 times the time it took with only a single signature. One of the reasons for this increase is that this might be due to the order in which the rules were listed in the signature file. The order in the file was e0b2, 0292, dd26, e6ee, 54a7, 8219, 39b6, 13c4, c606, 7bf0, 151e, 9d61, 072a. As can be seen e0b2 and 072a both have an significant increase whereas not all others do. From this, we conclude that the order is not what causes the increase in response time. We are unsure what causes the increase in response time and more research should be done on this point.



(a) Single signatures

(b) All signatures

Figure 4: Graphs Showing response times after attack is launched

5 Conclusion

In this paper, we investigated whether Bro is capable of detecting attacks with automated generated rules based on the signatures retrieved from DDoSDB. We first show that it is possible for the selected attack vectors to automatically generate Bro signature within 4.2 milliseconds. Secondly, we executed an experiment in which we replayed various attack vectors on a common network architecture to which we added a switch which supports port mirroring. From these experiments, we conclude that Bro is capable of detecting and responding to all attacks within 0.31 milliseconds

when only one signature is active and within 0.7 milliseconds with all our generated signatures active. From this, we conclude that Bro does not increase dramatically in response time when more signatures are added.

For future work, we intend to investigate the accuracy of the automatically generated rules when applied to traffic which includes both normal and malicious traffic. There is some place for improvement on the investigation of the limit number of signatures Bro is able to handle.

6 Acknowledgements

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