Automatic DDOS Attack Rule Generation Applied to Bro SIDS

René Boschma
University of Twente
r.boschma@student.utwente.nl

Abstract

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1 Introduction

A Denial of Service (DoS) attack is an attack that aims to disable services of a target system. There are two main types of DoS attacks: *vulnerability DoS* and *flood DoS* [10]. 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 [12], in 2015, 500 Gb/s and in 2016 1.1 Tb/s [4]. In the third quartile of 2016 more than 5000 attacks where observed, whereas 200 in the entire 2012 [3]. 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 (IDS) are such systems that can fulfill this task. An IDS is a system that 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* and *Signature-based* [6]. An Anomaly-based IDS (AIDS) bases its detection on a constructed baseline and detects deviations from this baseline. A Signature-based IDS (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 [9].

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 for this problem is to generate signatures for new attacks. This can be done either manually or automatically. As a manual approach requires significant amount of manual effort [10], we propose an automatic method. For this research we generate rules from extracted features of DDoS attacks for the Bro SIDS[1]. Bro is an open source network security monitor that offers the functionality of a SIDS. The features of DDoS attacks are extracted by a different research of DDoSDB[2].

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 accuracy and efficiency for Bro automatic generated rules when applied on an ongoing DDoS attack?

The first RQ will be answered by analyzing the most common DDoS attack vectors described by Akami [5]. The second RQ will be answered by building a proof of concept that generates signatures based on a given stream of features of DDoS attacks. 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.

2 Content

2.1 DDoS Attacks and BRO

In this section we will first define the notion of a DDoS attack by explaining how the infrastructure looks like. Then we will elaborate on various DDoS attacks used nowadays and discuss their main characteristics. After this we will discuss the syntax of the detection rules of the BRO SIDS.

2.1.1 The DDoS Attack

Figure 2.1.1 shows the infrastructure of a DDoS attack. Actors involved in a DDoS attack are denoted by a letter (A-D) whereas data streams are denoted by numbers (1-5).

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

[2] `http://ddosdb.org/`

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 named as a botnet. The C&C servers send a message (2) to the infected machines. In case of the Ramnit botnet, only the infected machines counted 3.2 million machines [11]. 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). The second path possible is using public services (D) like a DNS to reach the target (5).

In the next subsection we will describe various types of DDoS attacks.

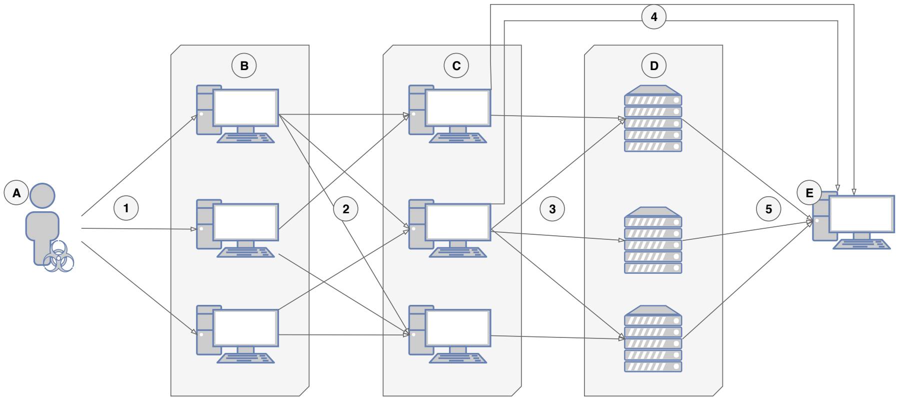


Figure 1: Overview of DDoS attack infrastructure

2.1.2 Types of Attacks

In this section we will briefly elaborate on the most common types of attack mentioned in the security report of Akami Q4 2017 [5]. An overview of the main characteristics per attack can be found in Table 1.

UDP The UDP attack exploits UDP. 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 packet. Looking at Figure 2.1.1, path 4 is used.

UDP Fragment The UDP Fragmantation attack exploits the fragmentation used in the IP protocol [7]. When a packet is to 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, fraudulent UDP packets are sent which are larger than the maximum transmission unit (MTU) of the network. The idea is that the packets can not be reassembled and thereby consuming the server's resources.

DNS The DNS attack exploits the public Domain Name System (DNS) services on the internet. DNS is used to resolve IP adresses from website names. In a DNS attack the attacker spoofs its IP replacing its IP with that 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. Looking at Figure 2.1.1, path 5 is used. The attack runs over UDP.

NTP The NTP attack exploits the public Network Time Protocol (NTP) services on the internet. NTP services allow for time synchronization between machines. This attack is similar to the DNS attack, but this time the NTP services instead of the DNS services are used.

Chargen The Chargen attack exploits the public Character Generator Protocol (Chargen). Once a Chargen services receives a packet via UDP, it responds by sending a datagram containing a random number between 0 and 512 characters long [8]. The attack approach works the same as the NTP and DNS attacks.

CLDAP The CLDAP attack exploits the Connection-less Lightweight Directory Access Protocol (CLDAP). CLDAP is designed to provide access to directories while not needing the recourse requirements of the Directory Access Protocol (DAP) [2]. The attack is similar to the DNS, NTP and Chargen attack.

SYN The SYN attack exploits the three-way handshake of TCP. During this attack a large number of SYN packets are send 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. In this attack, path 4 is used.

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
RPC	?
HTTP	HTTP && HTTP_request && src_port==80

Table 1: Attack types main characteristic overview.

SSDP The SSDP attack exploits the Simple Service Discovery Protocol (SSDP). SSDP is used to discover network services. The attack is similiar to DNS, NTP and Chargen but when looking to Figure 2.1.1 the machines in D are for instance home routers, printers or other IOT devices rather than a dedicated server.

ACK The ACK attack exploits TCP. During this attack a large number of ACK packets are send 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. The attack runs via path 4.

RPC ?

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. Looking at Figure 2.1.1, path 4 is used.

2.1.3 Bro Rule Syntax

This section discusses the parts used of the Bro signature framework [3] and Bro scripting language.

Bro's primary focus is on its scripting language. With this language one can define various analyzing detection policies. Besides the scripting language, Bro offers also a signature language. This language is similar to Snort rules and rely on low level pattern matching. In this paper we will focus mainly on the Bro signature language to detect various types of DDoS attacks.

Bro Signature Framework The format of a signature is defined in Listing 1. As can be observed, each signature starts with the *signature* keyword followed by a signature identifier. In the body the attributes to match on and the event that needs to be raised are defined. The used attributes will be explained in the next paragraph. The *event* keyword is used to define a message that is to be passed to the event listener.

```
signature [SIGNATURE-ID] {
  ATTRIBUTES
  event "message to display"
}
```

Listing 1: Bro Signature Format

Bro Attribute Rules An attribute rule has format defined in Listing 2. Here *KEYWORD* indicates a certain field to match, *CMP* indicates the way to compare and *VALUE* indicates the value to compare to. Each element of the attribute rule is explained below.

```
KEYWORD CMP VALUE
```

Listing 2: Bro Signature attribute rule format

Various keywords are known to the Bro signature language. We will briefly discuss the ones used in this research. *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 are: *tcp, udp, icmp, icmp6, ip* and *ip6*. It is also possible to define a general condition to match on the header of the packet. This allows to compare on

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

specific parts of the header. An example of how the keyword can look is given in Listing 3. First the attribute rule starts with the keyword *header*. Then the protocol is specified (which can be any of the ip-proto values mentioned earlier). Then one defines within the square brackets the offset and size in bytes separated by a colon. In the example an offset of 0 and size of 1 is defined which indicates in the ICMP protocol the type.

```
header icmp[0:1]
```

Listing 3: Bro Signature header condition

Bro Signature Framework has various comparator to match packets on. For instance, it is possible to specify that a certain address needs to be higher than a certain value. In our research, we only used the == comparator.

Bro Scripting Language One can define an email address to which a message is sent whenever a signature is matched. This, however, is not suitable for our intended research. Therefore we also need to define our own Bro script in order to receive an adequate message that a signature is matched. The script used can be found in Listing . . . . This script is responsible for loading the signatures as well as executing a python script whenever a packet is matched against a signature. The contents of the python script will be explained in Section 2.2.

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 the value specified by the event keyword in the signature.

2.2 Methodology

In this section we will discuss the test setup used to achieve the results presented and discussed in Section 2.3.

For this research we created a test setup which is schematically shown in Figure 2.2. This setup knows 4 actors. 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. The fourth actor (4) is the target machine. The fifth and final actor (5) is the Bro machine: the machine that runs the Bro IDS. The Bro machine receives all egress packets of the target machine.

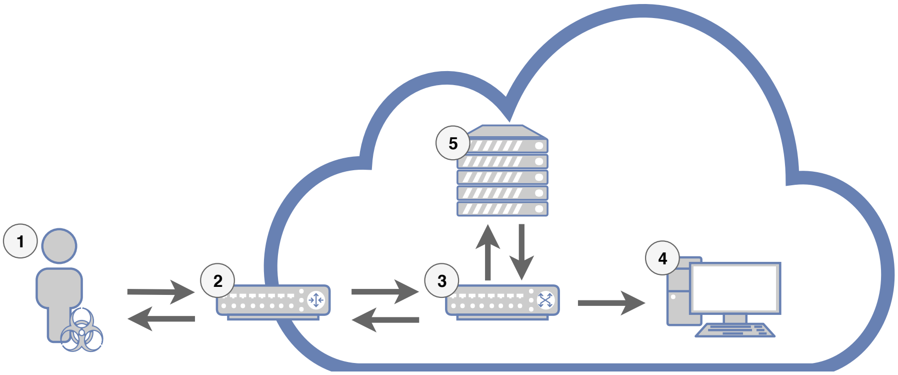


Figure 2: Schematic overview test setup

For this research we choose 8 attacks to test against our setup. Each attack has a pcap file which contains only the data captured from an actual attack. From this, DDoSDB generated a json file which describes the main attack vectors used in that attack. Each attack has been assigned a four digit identifier to which we will refer to further on in this paper. A brief summary of each attack based on the received json file can be found in Table 2.

ID	Type	# src IPs	# src ports	# dst ports	special
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 answer the second RQ a python script has been created that generates the signatures for the Bro IDS. This script receives as input a json file received from DDoSDB and converts it to a valid Bro signature rule. Each attack has its own generated signature rule. For each attack the signature is generated on the Bro machine and is measured how long it takes. The results of this can be found in Figure . . . .

To answer the third RQ first the maximum bandwidth of the target and Bro machine are determined. This is done using iperf3[4]. 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. Second, the attacker will rewrite the destination ip and mac address of the supplied pcap using tcprewrite[5]. The command used is *tcprewrite –dstipmap=0.0.0.0/0:[target_ip]/32 –enet-dmac=[target_mac] –infile=[supplied_pcap] –outfile=attack.pcap*. Third, Bro is started in bare mode with the Bro script described in Listing **??**. This way only the needed files are loaded. The command used to start Bro is: *sudo [path_Bro]/bro -b -i [network_device] [path_script]*. Fourth, the attack against the target machine is launched using tcpreplay. The command used to launch the attack is: *sudo tcpreplay -i [network_device] –mbps=[speed_limit] attack.pcap*. Fifth and lastly, when a signature match is received, the Bro machine will sent a message to the attacker. The times it took of each attack between launching it and receiving the message are displayed in Figure

[4]https://iperf.fr/
[5]http://tcpreplay.synfin.net/

??.

2.3 Evaluation and Discussion

In this section we will evaluate and discuss our findings we found by executing the methodology described in Section 2.2.

In our first attempt of gathering results we used as the attacker a laptop with Intel i7-4700MQ @ 2.4 GHz with 8 GB of RAM, 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. From iperf we measured a maximum bandwidth of 90 Mbps. The Pi could not handle a single attack vector signature at this speed. We then decided to scale down 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 small signature set, is not suitable to run the Bro IDS.

We then switched to using the attacking laptop as Bro machine and as attacker a different laptop. We again used iperf3 to measure the bandwidth that could be accomplished. This again measured 90 Mbps.

Several measurements were done during the experiment. Every measurement is done 10 times. The first measurement done is the time needed to generate the Bro rules from the supplied signatures. The results are shown in Figure 3. As can be seen the attacks e6ee, 072a and 39b6 took considerable more time than the other attacks. When looking at Table 1 one can see that these attacks are the ones with the most overall entries.

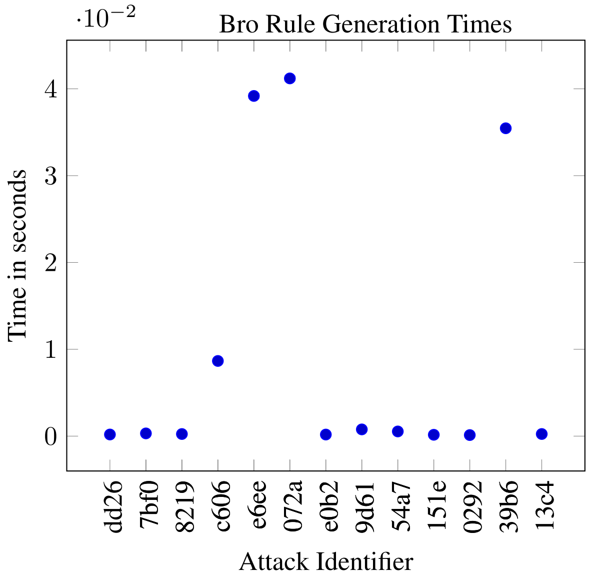


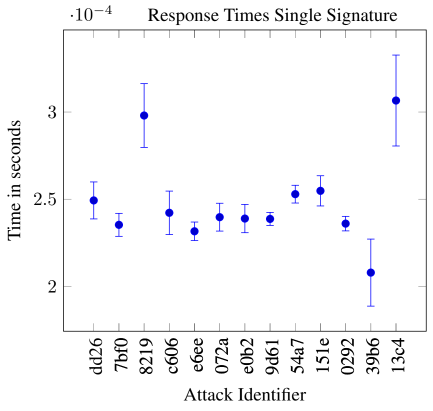
Figure 3: Bro Rule Generation Times

The second measurement done is the time it takes to send a message from the Bro machine to the attacker. The time measurement includes setting up a TCP connection, sending a message and then closing it again. The average of these measurements was 8.41E-5 seconds with a standard error of 1.29E-5 seconds.

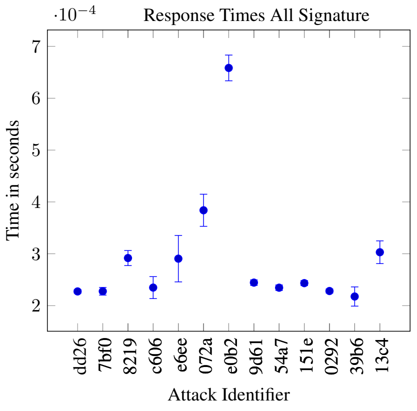
The third and final measurement done is the time it took for the Bro machine to react to an incoming attack. The time includes detecting the attack and sending a message to the attacker. The results of this measurement are shown in Figure **??**. This measurement was done twice, once with only a single signature specific to the attack active and once with all signatures active. The result of the single signature active is shown in Figure 4a. The results of all the signatures is shown in Figure 4b.

When looking to the single attack vectors it is interesting to note that the attack vectors 8219 and 13c4 take significantly longer to detect than the other attack vectors. 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.

When looking to Figure 4b it can be seen that Bro does not increases significantly for all attack vectors. For a big part times roughly stay the same. Most interesting are the increases in 072a and e0b2. Our initial guess was that was due to the order in which the rules were listed in the signature files. The order was e0b2, 0292, dd26, e6ee, 54a7, 8219, 39b6, 13c4, c606, 7bf0, 151e, 9d61, 072a. From this we conclude that the order is not what causes the increase in response time.



(a) Single Signatures



(b) All signatures

Figure 4: Graphs Showing response times after attack is launched

3 Conclusion

In this paper we try to show whether Bro is a suitable IDS which is capable of detecting attacks with automated generated rules based on the signatures retrieved from DDoSDB. We tried to show this by building a test setup that resembles a common internet setup. In this setup we replayed various attack vectors to a target machine which port was mirrored to a machine running the Bro IDS.

From this we can conclude that (1) it is possible to automatically generate Bro signature rules based on signatures received from DDoSDB, (2) generation time of the signature rules is based on the number of fields the signature has and (3) Bro's response time does not increase dramatically when more signatures are added.

For future work one could look at the Bro scripting language. The Bro scripting language allows for more detailed analisys of packets. Also one could increase the number of signatures to discover the limit of signatures the Bro IDS can handle. Furthermore, it would also be nice to see how the generated rules behave in terms of accuracy (false positives and false negatives).

4 Acknowledgements

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