CM3203 – One Semester Individual Project – 40 Credits
Final Report

# Cyber-Incident Response Tool for Smart Grid

Author: Jorge Correa Merlino
Supervisor: Neetesh Saxena
Moderator: Angelika Kimmig

BSc Computer Science with Security and Forensics
School of Informatics

# Acknowledgements

I would like to express my gratitude to all the people that made the project presented today possible.

Firstly, I would like to thank my supervisor Neetesh Saxena for all of his support in this project, especially in these challenging times.

I would also like to thank my family, that have supported me throughout the degree, encouraging to pursue the subject I love.

Lastly, I would like to thank my Computer Science High School teacher Iván López, for inspiring me and making me passionate about computing.

# Table of Contents

## List of Tables

## List of Figures

# 1. Introduction

With the increasingly digitalization of the world, it is important that we have measures to ensure it remains safe and secure. Traditionally, when the law was broken, it happened in the physical world. Then it was the police's job to stop the crime or to investigate the evidence left behind by the perpetrator at the scene. With analysis we determine where a clue came from, discover the criminal's identity, or learn how the crime took place. However, many crimes nowadays happen on the internet. In fact, in August of 2016, Cybersecurity Ventures (Morgan 2016) predicted that cybercrime will cost the world $6 trillion annually by 2021, up from $3 trillion in 2015.

In the same way some shops now have guards in order to deter crime as well as responding should anyone try to commit a crime, companies have a group of people called first responders. The first responders have the job of acting when a security breach is detected and minimise the damage until authorities are notified. The amount of data captured related to the incident will become vital evidence for the ensuing police investigation. But, in order for all this to happen, the company must first detect that a breach has happened.

## 1.1 Motivation

Smart grids are also vulnerable to cyber-crime and cyberattacks on these can have disastrous implications. For example, in an energy generating plant in a smart grid, the generators and the control room communicate automatically to receive data such as status of generators, amount of energy produced and where to send it. If an attack impairs this means of communication, the control room will not be able to see if a generator is in critical state or not leading to a power blackout in the area. The cascading effects of this can have serious repercussions as critical services like hospitals could be at risk without power.

Since DDoS (Distributed Denial of Service) attacks are one of the most difficult to prevent (Melnick 2018), we decided to focus on these types of attacks for our tool.

## 1.2 The Scope and Context

To understand why this work is relevant we need to explore the context surrounding the issues of smart grids and cyberattacks. This provides a better understanding of the problems that are being faced. However, due to the broadness of the subject, a scope has to be defined to set limits for the extent of this project. A scope too broad could make this work too challenging to finish.

### 1.2.1 The Scope

DDoS cause something we call Denial of Service which is when a server is overloaded with requests and stops working. An in-depth explanation is provided in the background section, but essentially these attacks are one on the easiest to perform, therefore their popularity. Imagine a train system in a smart grid, where the trains automatically communicate with stations to inform of estimated time of arrival and the platform they have to stop in. If the server handling that communication stops working, the train could be forced to wait outside the station which would cause delays in transport. If a traveller is travelling with intermediate stops, this means they could miss their next connection.

For this work we are considering scenarios where DDoS attacks can be targeted on smart grid infrastructure. More specifically, the project will focus on three types of DDoS attacks – DNS amplification, NTP amplification and SNMP attacks.

### 1.2.2 Context of the Problem

Not so long ago, cybersecurity was related only to big corporations. Since they had big amounts of sensitive and valuable information, they became the targets for the first big breaches by hackers. Back in 2012 this was the case for Yahoo, three billion accounts were exposed by this hack and it resulted in a 117.5 million settlement for the affected parties (Matthews 2019). But nowadays we are seeing a rise in cybercrime and all the big data breaches from renowned companies are not accountable for all of that rise. Ransomware is a type of attack that is getting more popular. During this attack, an individual's access to their data is restricted by the hacker, demanding a ransom to be paid to get the data back. Cybersecurity Ventures predicts that a business will fall victim to a ransomware attack every 11 seconds by 2021 (Morgan 2019).

Ransomware requires more technical knowledge to implement at a larger scale than other attacks, but the higher technical complexity does not mean that easier to implement attacks are weaker. Automating simple attacks has given birth to category of hackers called "script kiddies", and these hackers have little knowledge of what the program is actually doing but are still causing a lot of damage to the victim. DDoS attacks are quite common due to the simplicity and effectivity of them.

These attacks can be especially devastating in a smart grid network. The major problem with DDoS detection is that it is difficult to distinguish between legitimate and DDoS traffic. For example, a smart grid could regulate which areas of a city require more energy than other based on consumption, therefore distributing energy accordingly. However, if legitimate data is discarded when detecting DDoS attacks then energy might be wasted as the smart grid will not be able to communicate with the city areas, and this can be very costly.

## 1.3 Problem Statement

Smart grids used to have the protection of airtight gaps, which means that since they were isolated form the network, they did not have risks of being cyber attacked. However, with the implementation of Internet of Things devices into the smart grid system, vulnerabilities in these devices can disrupt the normal operation of the grid. DDoS reflective attacks are becoming more dangerous due to the rise on internet connectivity speeds.

There are tools out there that provide operational technology cyber security, however since reflective attacks are starting to regain popularity now, most tools do not provide appropriate protection against these attacks.

Therefore, we have identified that the problem is the lack of protection options against DDoS reflective attacks in the smart grid environment. Cybersecurity is a relatively new area of computing so there are not that many easily accessible resources for it.

So, our problem statement is *to close the gap between the user's knowledge and the skills required for operating the tool and, to provide DDoS protection*.

## 1.4 The Aim and Objectives

In order to have a clear sight of what we want to accomplish, we set an aim and a set of objectives to be completed by the end of this work.

### 1.4.1 The Aim

Large-sized businesses will typically have a specialised team with professional formation to deal with these incidents, but many medium-sized and most small businesses will likely not have the funding required to have a team of their own. This gives rise to incident response tools, the only downside being that most tools require of technical knowledge in order to use. Therefore, the aim of the project is *to create an easy to use tool to aid in DDoS incident response with as little technical knowledge as possible.*

### 1.4.2 Objectives

This work will aim to complete the following objectives:

- Provide the user with information to understand the attacks and indicators of compromise.
- Analyse data from the data set to predict and understand the behaviour of DDoS attacks.
- Develop a tool for demonstrating log analysis, indicators of compromise events and actions, and suggesting countermeasures.

Attackers are not so considerate as to attack with one type of attack at a time, therefore we want the tool to be able to detect various types of attacks at the same time.

The tool is all about making the user understand what is happening in their network when it is being disrupted, so the tool should be able to give some feedback to the user as well as recommendations to mitigate the impact of these attacks in the future.

At the end of the analysis of the data, the user might want to run analytics or statistics on the data that shows the compromised state of the network, hence why the tool should give logs to the user for further investigation.

## 1.5 Assumptions

The business or individuals that use this tool will have some familiarity with capturing network traffic. At the moment the tool only accepts input as csv files, therefore the network capture would need to be exported into a csv format.

# 2. Background

## 2.1 Overview

In this section, the terms and context needed to understand the project will be explained, including constraints used in order to simplify the scope of it.

## 2.2 Terms

### 2.2.1 DNS (Domain Name System)

The DNS protocol allows the conversion of domain names (e.g. example.com) into IP addresses. It works as a phonebook, the same way we register a telephone under a name, the DNS protocol registers IP addresses under domain names (Brain et al. 2000). This is easier to remember since it is closer to human language. DNS servers are set up that can be accessed in order to search for the IP address of a domain name. Traffic related to DNS usually travels through port 53.

### 2.2.2 NTP (Network Time Protocol)

The NTP protocol is used to synchronize the same time (often called the true time) of many different computers and systems (Network Time Foundation [no date]). If a program is running concurrently in different computers, then a desirable feature would be that the time is the same in all computers, as having the program hopping forwards and backwards in time can lead to issues. In a database system it could lead to inconsistent data. Traffic related to NTP usually travels through port 123.

### 2.2.3 SNMP (Simple Network Manager Protocol)

The SNMP protocol allows devices to communicate within a same network irrespective of the hardware and software each of them has (Oros 2016). For example, this allows computers to communicate to a networked printer and send printing requests remotely. The traffic related to SNMP normally travels through port 161.

### 2.2.4 Botnet

The word comes from the mix between robot and network, a botnet is a network of bots where bots are infected computers that due to the malware are now being controlled by the attacker (Cloudfare [no date]a).

### 2.2.5 IP Spoofing

IP spoofing is the act of changing the source IP address from a packet. The address is changed to hide the identity of the attacker or to impersonate another system. The latter is used in DDoS attacks to redirect data to the victim. To avoid this, compare the spoofed packet's origin, rejecting it if it is suspicious (Cloudfare [no date]b).

### 2.2.5 DDoS (Distributed-Denial-of-Service) Attack

The main idea is to send so many requests to a server that it makes the server stop working since it cannot handle the overflow of traffic. The attacker in a DDoS attack needs a botnet in their control to launch this attack with (Cloudfare [no date]c). This is because just one computer is not enough to generate the number of requests needed to collapse a server nowadays. Therefore, the attacker commands the botnet to attack the victim's server IP address so that each bot in the botnet is sending requests to the server.

### 2.2.6 DNS Amplification Attack

The attacker uses a compromised computer or similar to send UDP packets with spoofed IP addresses to a DNS resolver. The spoofed address on the packets is actually the real IP address of the victim. Each one of the UDP packets makes a request to a DNS resolver, often passing an argument such as "ANY" in order to receive the largest response possible. After receiving the requests, the DNS resolver, sends a large response to the victim's IP address. The victim receives the response and the network becomes overwhelmed with the overflow of traffic, resulting in a denial-of-service (Cloudfare [no date]d).

### 2.2.7 NTP Amplification Attack

The attacker uses a botnet to send UDP packets with spoofed IP addresses to a NTP server which has its monlist command enabled. The monlist command responds with the last 600 source IP addresses of requests which have been made to the NTP server. The spoofed IP address on each packet is the real IP address of the victim. Each UDP packet makes a request to the NTP server using its monlist command, resulting in a large response. The monlist request from a server with 600 addresses in its memory will be 206 times larger than the initial request. The server then responds to the spoofed address with the resulting data. The victim receives the response and the network becomes overwhelmed with the overflow of traffic, resulting in a denial-of-service (Cloudfare [no date]e).

### 2.2.8 SNMP Amplification Attack

First the attacker scans a network looking for connected devices that can be used as amplification factors. As the attacker finds networked devices, a list is created of all the devices that respond. The attacker creates a UDP packet with the spoofed IP address of the targeted victim. The attacker then uses a botnet to send a spoofed packet to each networked device with a request for as much data as possible by setting certain flags. As a result, each device will send a reply to the targeted victim with an amount of data up to about 600 times larger than the attacker's request (Imperva [no date]). The target then receives a large volume of traffic from all the devices and becomes overwhelmed, potentially resulting in denial-of-service to legitimate traffic.

## 2.3 Existing Tools

Cyber security threats in industrial environments are relatively new, but some solutions already exist to help tackle these issues. Below are three existing tools that provide cybersecurity and incident response which will be used to contrast my work.

***Table 1**. Operational Technology tools and their strengths and weaknesses*

| Tool Name | Company/Owner | Pros – idea | Cons – limitations | Impact on a system |
|---|---|---|---|---|
| Next Generation Firewall | Forcepoint | Provides good control over network and help with cyberattacks | DDoS protection does not cover amplification attacks | High |
| Tenable.ot | Tenable powered by Indegy | Good visibility of all incidents happening | Does not specify if it handles DDoS attacks | Medium |
| Claroty Platform | Claroty | Comprehensive tool that covers many security aspects | Does not specify if it handles DDoS attacks | Medium |

The first solution is Forcepoint's Next Generation Firewall, which provides visibility of the entire network and deals with most cyber-attacks. However, as I was researching this tool I found that the DDoS protection only covers flood attacks, not amplification attacks. With fast internet connections nowadays, an amplification attack could have a big impact in the system.

Tenable's Tenable.ot (powered by Indegy) also offers great visibility of all the devices in the industrial environment and has a proactive approach for dealing with vulnerabilities. Nevertheless, I could not find anywhere what sort of DDoS protection they offered. It seems unlikely that they would not offer this type of service, but it could provide protection against only some type of attacks. Since I do not know for sure, I set the impact to the system to medium.

Claroty also suffers from the same issue as Tenable, even though they offer excellent protection in almost all aspects of security (monitoring, visualization, and data collection), they do not specify anywhere what type of DDoS protection they offer.

For this project, we decided to focus on DDoS protection, more specifically, DDoS reflection/amplification attacks. Even though this work lacks many features the other existing tools offer, DDoS reflection attacks are still important and are worth investing on. With this tool our objective is to bring more attention to these types of attacks.

The detection algorithms for this tool are admittedly not the most efficient or accurate, however that is not the objective of this research. As mentioned in the Aims section, we want to create a tool that helps operators understand the information that comes from DDoS attacks. Nonetheless, precise and accurate algorithms for detections are still needed for this to be a successful tool, so I researched some detection methods that could be implemented in the future in this tool.

*Table 2. DDoS Detection Methods with strengths and weaknesses*

| Author, Year | Research idea for detecting DDoS attacks | Pros | Cons | Impact | Gap |
|---|---|---|---|---|---|
| Thomas et al., 2017 | Monitoring scanners previous to attacks to predict and prevent them | Research focuses on amplification attack, has very good detection rate | – | High | – |
| Özer and İskefiyeli, 2017 | Set average number of packets for real time detection | Many different types of DDoS can be detected | No data on type of DDoS attack | Medium | Lack of attack identification |
| Maheshwari et al., 2018 | Using MapReduce to detect DDoS attacks | Most DDoS attacks are detected and fast detection | No data on type of DDoS attack | Medium | Lack of attack identification |

Özer and İskefiyeli's (2017) research is the simplest method out of the three, it reads the packets and has a threshold value for the number of packets received from the same address that if exceeded, flags it as a DDoS. The user is able to select what that threshold is. However, this detection algorithm does not differentiate one type of DDoS from another, making it harder for the prevention stage.

Maheshwari et al. (2018) identified that the problem with DDoS identification was the speed at which the attacks were identified. This is why they chose to use MapReduce, which allows them to break a problem is smaller parts are process simultaneously. While this is an improvement from the detection method above, it still does not identify the nature of the attack.

The only research from these three that detects the types of DDoS attacks is the one conducted by Thomas et al (2017). Not only it improves detection rate by monitoring scanners that indicate that an attack is going to happen, but by detecting the protocol ports it also identifies different types of attacks. It detects the attacks we are working with, so this research is a good reference for future expansion of this tool.

## 2.4 Summary

The attacks and terms related to this research were explained, which includes the NTP, DNS and SNMP amplification attacks as well as their protocols. A comparison of the existing solutions developed by Forcepoint, Tenable and Claroty with this tool highlighted the fact these solutions lacked proper DDoS protection. Finally, a comparison of different detection methods established that Thomas et al's research provided the best detection methods.

# 3. Specification and Design

## 3.1 Overview

This section will cover the project planning, and what methodology was used when developing the tool. The functional and non-functional requirements identified for this work are also presented. Furthermore, it will explain the intended functioning of the tool through diagrams such as system models and UML diagrams.

## 3.2 Project Planning

For this project we designed and initial plan and some research in the topic before starting to implement the tool. Our objective was to finish the tool before the Easter recess so we could focus on the report for the remaining of the time. Due to the COVID-19 pandemic, an extra week was given for the deadline, the Gantt Chart in the appendix shows how the time was divided for the different project tasks.

## 3.3 Methodologies Used

To clearly structure how to implement this project, a methodology is needed to establish the implementation cycles. The following paragraphs explore which methodologies were investigated and which methodology was chosen for this work's development.

After researching different methods for software development, for this project we have decided to adopt an iterative approach for software development. Agile and Kanban methodologies were also studied but ultimately, the iterative model was deemed the most appropriate for this work.

Due to the reduced complexity of the project when compared to bigger projects carried out by companies, the iterative model seemed as the most appropriate methodology as it is the easiest to implement. In the iterative model, you keep improving the product by adding and removing features in each cycle.

First the requirements for the project are collected; this was accomplished by discussing with my supervisor what we wanted the project to be and do. Then in the design stage, an outline of the project was drawn to structure the order for implementation. Before implementation began, we drew a sketch of how we thought the GUI should look like and what the different elements in it should do. Afterwards comes implementation where the design is realised, during this stage the first draft of prototype was coded. Afterwards, I met with my supervisor for feedback and implemented improvements on the prototype or started on new areas. Every week we would repeat this cycle until prototype was finished.

In agile development, the focus is on delivering software as quickly as possible, receive feedback and improving on it. While this could have been an advantage if the project involved more team members, since there was only one person working on this, there is not enough time to produce many versions of the software. However, we did keep an aspect of agile, the idea of making changes to the scope as problems appeared.

For Kanban development, tasks are divided into three categories: To-Do, Doing and Done. Depending on the progress on each of the tasks they are placed in the corresponding category. This is great to have a general view of the progress of the project and what other team members are accomplishing and what still needs to be done. Nonetheless, without any team members it just feels like a checklist since as only one person is working, only one task can be done at a time.

Given that most methodologies are used to improve team synchronisation in project development, the iterative model is an appropriate choice as it can work without having team members. The freedom of the iterative model to implement changes in each cycle was useful as many changes needed to be implemented week after week.

## 3.4 Requirements Specification and Analysis

During implementation of the tool, we need to have clear requirements to accomplish to ensure that the main objectives of the project are completed.

### 3.4.1 Functional Requirements

*Requirement 1: Read a network capture file*
The network capture file is the only input of data the tool receives, therefore its importance. For this work, only csv files can be entered of past incidents. The tool should have a button that opens a file dialog file finder to select the file they want to analyse. This file dialog should only accept the selection of csv files to avoid errors. When the file is selected it should be loaded into the program.

*Requirement 2: Analysis and detection of NTP amplification DDoS attacks*
When the file entered by the user is loaded, an algorithm should search for signs of NTP amplification attacks and flag the relevant information. Any suspicious IP addresses should be found at this stage.

*Requirement 3: Analysis and detection of DNS amplification DDoS attacks*
When the file entered by the user is loaded, an algorithm should search for signs of DNS amplification attacks and flag the relevant information. Any suspicious IP addresses should be found at this stage.

*Requirement 4: Analysis and detection of SMNP amplification DDoS attacks*
When the file entered by the user is loaded, an algorithm should search for signs of SMNP amplification attacks and flag the relevant information. Any suspicious IP addresses should be found at this stage.

*Requirement 5: Analysis and detection of one or more attacks*
Since DDoS attacks usually happen in waves, it is not unreasonable to think that more than one attack could be found in a capture file. The tool should be able to identify all attacks simultaneously and inform the user about which attacks have been detected.

*Requirement 6: Display indicators of compromise*
During analysis, the different indicators of compromise mentioned in the background section should be identified. The tool should then inform the user which indicators have been detected and from which attack.

*Requirement 7: Display recommended actions*
Depending on the attack or attacks that have been detected, the tool should display some recommended countermeasures to avoid being vulnerable to the attack again.

*Requirement 8: Provide logs on analysed information*
All records from the identified suspicious IP addresses should be extracted from the input file and exported into another csv file. In the case where multiple attacks have been detected, multiple files should be created dividing the information by attack.

### 3.4.2 Non-functional Requirements

*Requirement 9: Provide feedback while running tasks*
When the file is being loaded and analysed, a considerable amount might pass where the program does not appear to be doing anything. Therefore, a progress bar could be implemented to inform the user that the tool is working or has frozen. When preparing the logs for download, the tool could also take a long time to finish so another progress bar here could also be coded.

*Requirement 10: GUI has only necessary elements*
The emphasis of this tool is that it is as easy to use as possible, so having as few elements on the tool as possible can help with this. Too many options can make the user feel overwhelmed and end up restricting the user instead of giving more freedom.

*Requirement 11: Easy to deploy*
The tool should be easy to deploy since intricate steps for deployment only serve to deter a potential user from using the tool. After development, the code should be packed into an executable file since most users will be familiar with this type of files.

*Requirement 12: Information displayed in orderly manner*
The same way too many options can be overwhelming for a user, the same can be said of too much information. The information displayed should be concise and ordered in a sensible way. For the indicators of compromise, a table indicating which indicators have been detected and for which attacks could help in simplifying the data.

*Requirement 13: Use colour for emphasis*

Colour is a powerful tool to bring attention to details and using colour conventions that a user is used to can help making a program more intuitive. For example, for the indicators of compromise table, the colour green could be used to highlight the indicators if no attacks are happening, while using red to highlight indicators that have been detected in an attack.

## 3.5 System Design

In this subsection, diagrams are provided to give a better understanding of how the tool operates including, a system model, class diagram and various UML diagrams.

### 3.5.1 System Model

For any scenario this tool might be used in, we are considering two main actors: operators and malicious hackers. During the normal operation of the smart grid, industrial devices will send data through the server back to the operators. If any action is required, the operators will send instructions to the smart grid via the server.

If the smart grid server were under attack by a DDoS attack, the DDoS tool would detect it and give feedback to the operators. The operators would then need to act based on this information to mitigate the attack. Figure 1 shows a system model demonstrating this.

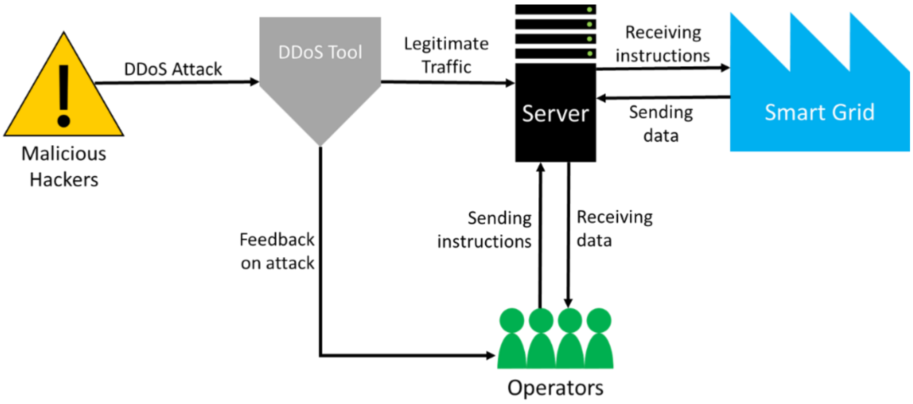


***Figure 1***. *System Model of the Tool*

Figure 2 demonstrates a class diagram for the coding of the tool. The main program is ran within the Tool class, which controls how the GUI looks like and makes the appropriate calls for analysing the data. The NTP, DNS and SNMP classes contain the algorithms relevant for the detection of the NTP, DNS and SNMP attacks, respectively. The variables that are updated within these classes are retrieved in the Tool class and these updates are applied to the corresponding variables.

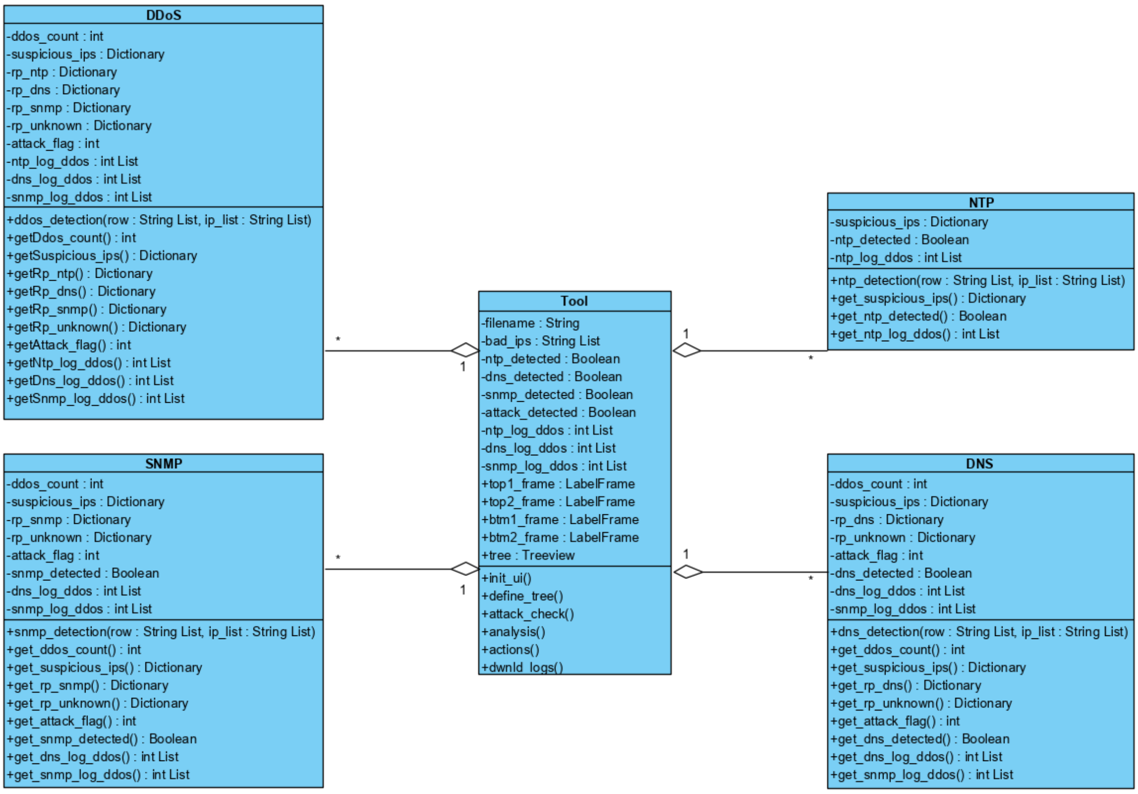

DDoS
-ddos_count : int
-suspicious_ips : Dictionary
-rp_ntp : Dictionary
-rp_dns : Dictionary
-rp_snmp : Dictionary
-rp_unknown : Dictionary
-attack_flag : int
-ntp_log_ddos : int List
-dns_log_ddos : int List
-snmp_log_ddos : int List
+ddos_detection(row : String List, ip_list : String List)
+getDdos_count() : int
+getSuspicious_ips() : Dictionary
+getRp_ntp() : Dictionary
+getRp_dns() : Dictionary
+getRp_snmp() : Dictionary
+getRp_unknown() : Dictionary
+getAttack_flag() : int
+getNtp_log_ddos() : int List
+getDns_log_ddos() : int List
+getSnmp_log_ddos() : int List
SNMP
-ddos_count : int
-suspicious_ips : Dictionary
-rp_snmp : Dictionary
-rp_unknown : Dictionary
-attack_flag : int
-snmp_detected : Boolean
-dns_log_ddos : int List
-snmp_log_ddos : int List
+snmp_detection(row : String List, ip_list : String List)
+get_ddos_count() : int
+get_suspicious_ips() : Dictionary
+get_rp_snmp() : Dictionary
+get_rp_unknown() : Dictionary
+get_attack_flag() : int
+get_snmp_detected() : Boolean
+get_dns_log_ddos() : int List
+get_snmp_log_ddos() : int List
Tool
-filename : String
-bad_ips : String List
-ntp_detected : Boolean
-dns_detected : Boolean
-snmp_detected : Boolean
-attack_detected : Boolean
-ntp_log_ddos : int List
-dns_log_ddos : int List
-snmp_log_ddos : int List
+top1_frame : LabelFrame
+top2_frame : LabelFrame
+btm1_frame : LabelFrame
+btm2_frame : LabelFrame
+tree : Treeview
+init_ui()
+define_tree()
+attack_check()
+analysis()
+actions()
+dwnld_logs()
NTP
-suspicious_ips : Dictionary
-ntp_detected : Boolean
-ntp_log_ddos : int List
+ntp_detection(row : String List, ip_list : String List)
+get_suspicious_ips() : Dictionary
+get_ntp_detected() : Boolean
+get_ntp_log_ddos() : int List
DNS
-ddos_count : int
-suspicious_ips : Dictionary
-rp_dns : Dictionary
-rp_unknown : Dictionary
-attack_flag : int
-dns_detected : Boolean
-dns_log_ddos : int List
-snmp_log_ddos : int List
+dns_detection(row : String List, ip_list : String List)
+get_ddos_count() : int
+get_suspicious_ips() : Dictionary
+get_rp_dns() : Dictionary
+get_rp_unknown() : Dictionary
+get_attack_flag() : int
+get_dns_detected() : Boolean
+get_dns_log_ddos() : int List
+get_snmp_log_ddos() : int List
*
1
*
1
1
*
1
*

***Figure 2***. *Class Diagram of the Tool's Code*

### 3.5.2 Detailed Design

This tool is intended to be used only by one type of actor: the operators of the smart grid where the tool is deployed. As shown in Figure 3, the operator can only perform two actions; entering the data to be analysed and retrieving the logs of the data.

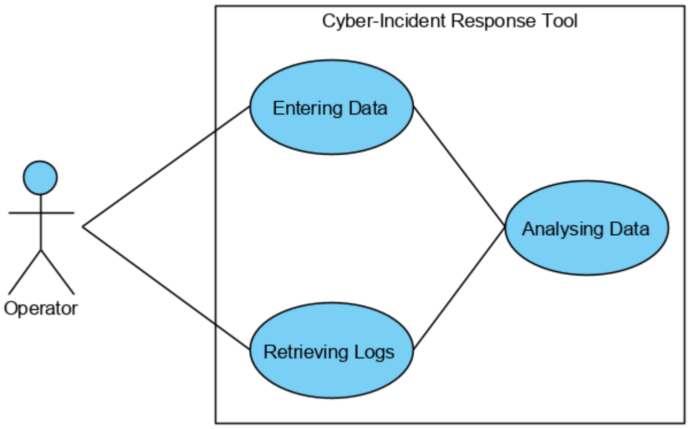


***Figure 3***. *Use Case Diagram of Tool*

Figure 4 demonstrates the sequence in which these actions are taken. The operator first enters the network capture, then the tools starts processing the data. Once it is done, it will return feedback to the user as well as the option to download the logs. If the user then decides to download the logs, the tool will generate them. When generation is finished the user will have access to the logs. Logs cannot be generated without previously entering data into the tool.

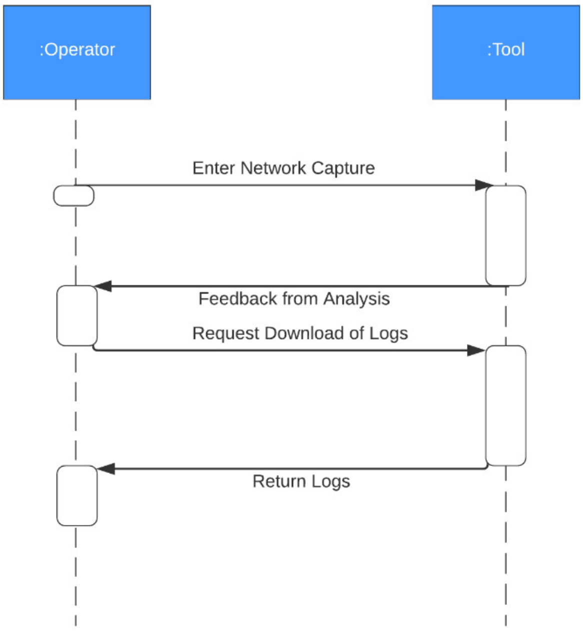


*__Figure 4__. Sequence Diagram of Tool*

A more comprehensive explanation of how the tool operates is presented in Figure 5. When the tool launched, the user will need to enter the network data capture that they wish to analyse. The tool will analyse the data and detect if any attacks have happened. If no attacks were detected, then the tool is on standby until the next data capture is input. If attacks are detected, the tool will display the logs, indicators of compromise and recommended actions for each of the attacks that were detected. A download button for the logs will appear on the screen too, and if the user presses it, they will be prompted to enter a directory where to download the logs. After the logs are generated the user can find the logs in the directory they chose. Then the tool is on standby until the next data capture is input.

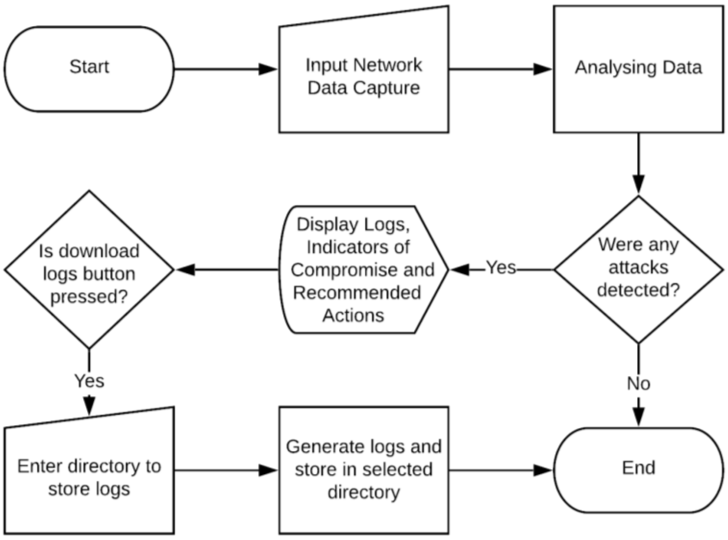

Start
Input Network Data Capture
Analysing Data
Were any attacks detected?
Yes
Display Logs, Indicators of Compromise and Recommended Actions
Is download logs button pressed?
Yes
No
Enter directory to store logs
Generate logs and store in selected directory
End

*__Figure 5__. UML Activity Diagram of Tool*

### 3.6 Summary

The project planning was presented as a Gantt Chart that can be found in the Appendix. The Gantt Chart also considered the extra week given due to the Covid-19 pandemic. The iterative model was used to develop the tool since it allowed the most liberty to continuously change the work as it progressed. The requirements for this project were also defined, and the operation of the tool was explained with the help of a system model and UML diagrams.

# 4. Solution Idea and Implementation

## 4.1 Overview

In this section, the platforms used to develop this tool will be mentioned. A general overview of how the programming of the tool works will be explained, including the different features and functionality that construct the tool. Snapshots of the tool will also be provided to explain how the tool operates. A discussion of the issues faced when developing the tool will be given at the end of the section.

## 4.2 Platforms Used

In this section I will discuss which programming language, operating system and other relevant tools used for the development of the project

### 4.2.1 Computer Specifications

The whole project has been coded form my personal laptop, an ASUS Notebook UX430U. The following are its specifications:

- Processor: Intel Core i7-7500U generation
- RAM: 8GB
- Architecture: 64 bits
- Operating System: Windows 10 Home

### 4.2.2 Programming Language

The programming language used was Python version 3.5. The reason I chose to use this programming language is that since I have been coding in python for the last 7 years, it was the language I was more comfortable coding in. Additionally, Python allows for easier coding than most programming languages. For example, I needed to do some array slicing for the detection algorithm. In most languages you would need to use functions form the Array class, however in Python with the use of square brackets and a specified range it is enough.

Example:

```
Java:           Arrays.copyOfRange(array, startIndex, endIndex);

Python:         array[startIndex:endIndex]
```

Python also has incredibly good in-built libraries to use, and for this project I used two in particular: csv and tkinter.

The csv library allows your code to manipulate csv files with actions such as open, write and read multiple files at the same time. This was used to read the dataset input from the user as well as writing the logs after the program finished execution.

The tkinter library is used for GUI design, which was used for the development of the tool's appearance. tkinter is very flexible when placing objects into the GUI as it offers three different placement methods: pack, grid and place. Place uses absolute values so for compatibility purposes it was not used in this tool, but grid was extensively used for the layout of the GUI. As the name implies, grid places objects in grids so it allows for easy arrangement of objects. Pack is the simplest of the three since it places objects on the widget without the need of many parameters, this was excellent for testing new objects as they were being included in the tool without needing to worry about object placement.

## 4.3 Overall Workflow of the Idea

When the tool starts up the user only has the option to open a csv file containing the dataset that they want to analyse. Once the file is opened, it is analysed, and the DDoS detection algorithms are ran. Once the analysis is finished, if any of the three attacks is detected, the indicators of compromise, logs and recommended actions are displayed. If no attacks were detected the tool will give feedback telling there is nothing suspicious.

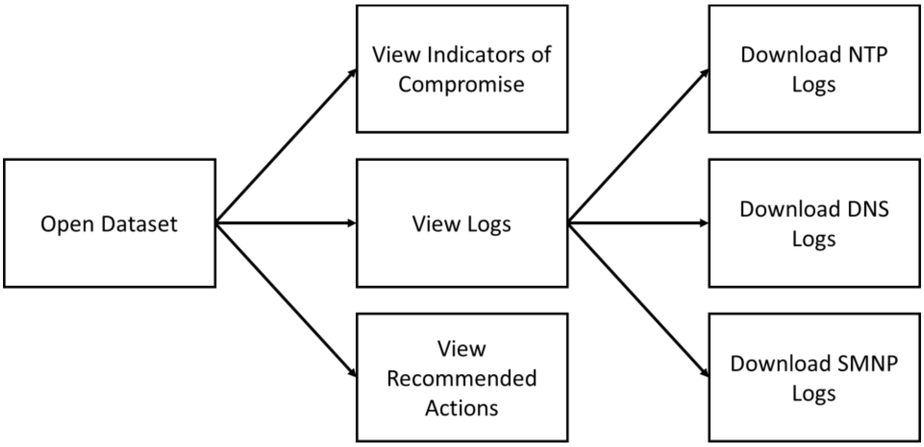


***Figure 6**. Structure of Tool*

If the user wishes to download the logs for the attacks, they can do so by clicking on the button provided in the Logs section. This will provide csv files with the packets sorted by indicator of compromise found. Figure 6 shows an overview of the structure of the tool.

## 4.4 Overall Execution

### 4.4.1 Data Access and Processing

The Open File button will start the *attack_check* function to start the analysing, and it will call the *open_file* function first. A file dialog will appear so the user can choose the file they want to open. The *analysis* function will be called to open the data of the csv, which is then analysed by the detection algorithms.

### 4.4.2 DDoS Attacks Detection Technique

For this work we have considered three indicators of compromise to analyse while detection DDoS attacks.

- Response Sizes – If response sizes are abnormally large this could mean a DDoS attack is happening.
- Mismatch in Port-Application – If the data is being sent from unusual ports, a malicious attack could be occurring.
- DDoS Activity – If an IP address is sending multiple packets in short amount of time it could be an indicator of a DDoS attack.

The *analysis* function will start reading the csv file row by row. For each row, it will perform some checks to decide with which algorithm it should be analysed. If it shows signs of an NTP attack, it will call Algorithm #1 for analysis. The signs of an NTP attack in a packet are protocol is UDP, source port is 123, packet is inbound and packet size is 440.

**Algorithm #1 – NTP Detection**

```
Variable(s)
Suspicious IP list – Counts how many times an IP is counted suspicious

If source IP is not known and the server is the target IP
    NTP attack has been detected
    If source IP is in suspicious IP list
        Update counter by 1
    Else
        Add source IP to list and set counter to 1
```

If it shows signs of a DNS attack, it will call Algorithm #2 for analysis. The signs of a DNS attack in a packet are protocol is UDP, source port is 53, packet is inbound and packet size is larger than 1000.

**Algorithm #2 – DNS Detection**

```
Variable(s)
Suspicious IP list – Counts how many times an IP is counted suspicious

If source IP is not known and the server is the target IP
    DNS attack has been detected
    If attack was not previously detected
        In suspicious IP list update the counter for the source IP by the number
        of counts in the unidentified attack
    Else
        If source IP is in suspicious IP list
            Update counter by 1
        Else
                Add source IP to list and set counter to 1
```

If it shows signs of an SNMP attack (DDoS signs + port 161), it will call Algorithm #3 for analysis. The signs of an SNMP attack in a packet are protocol is UDP, source port is 161, packet is inbound and packet size is larger than 1000.

**Algorithm #3 – SNMP Detection**

```
Variable(s)
Suspicious IP list – Counts how many times an IP is counted suspicious

If source IP is not known and the server is the target IP
    SNMP attack has been detected
    If attack was not previously detected
        In suspicious IP list update the counter for the source IP by the number
        of counts in the unidentified attack
    Else
        If source IP is in suspicious IP list
            Update counter by 1
        Else
            Add source IP to list and set counter to 1
```

If it does not show signs of any particular attack, it will call Algorithm #4. Algorithm #4 will try to determine by packet size and frequency of incoming packets if a group of packets belong to an NTP, DNS or SNMP attack.

**Algorithm #4 – Identifying DDoS Attack Type**

```
If packet is UDP, is inbound, the source IP is not known, and the target is the server IP
    If packet size is 440
        Go to Algorithm #5
    Else if packet size is bigger than 1000
        If attack is unidentified
            Go to Algorithm #5
        Else if attack is identified as DNS
            Go to Algorithm #5
        Else if attack is identified as SNMP
            Go to Algorithm #5
```

**Algorithm #5 – Attack Detection**

```
Variable(s)
Suspicious IP list – Counts how many times an IP is counted suspicious

If packet belongs to ongoing attack
    If five seconds have passed since start
```

```
        If the source IP was already in suspicious IP list
            Add the number of packets in attack to list
        Else
            Add source IP to list with count set as number of packets
            detected in attack
    Else
        Set packet as start of new ongoing attack
Else
    Set packet as start of new ongoing attack
```

### 4.4.3 Notifying the Indicators of Compromise and Recommended Actions

For the detection of Indicators of Compromise a list was created to flag rows that showed sign of DDoS activity. For Response Sizes, depending on the size of packet it will be flagged during the log generation. For Mismatch Port-Application, if a suspicious IP is sending packets from unknown/unusual ports (ports greater than 1023), these packets will also be flagged.

Depending on the attacks detected, the recommended actions for each attack will be displayed. There are three text files for the recommended actions for each attack. The information in them is read and then loaded into the tool. This allows to easily update information if needed.

### 4.4.4 Log Analysis

When the program has finished analysing, if no attacks were detected then no logs will be created. If attacks were detected it will first give feedback on the information found and display a button for downloading logs. When the button is pressed the user will be prompted to choose a place where to save the files. Once selected, the program will create four files for each attack detected.

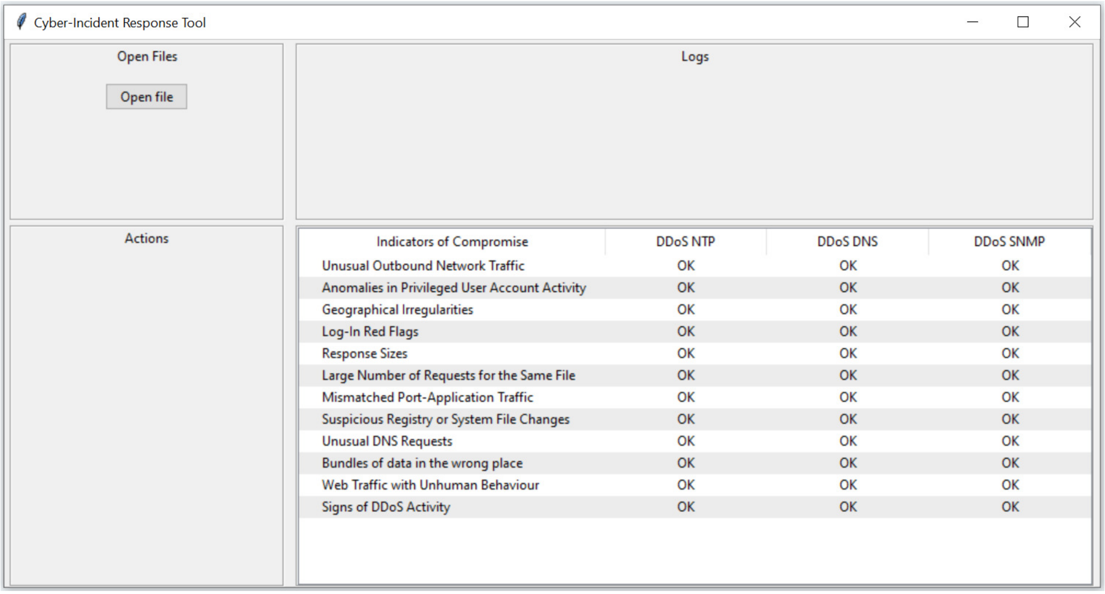
The first three files will each contain the rows on the data where indicators of Response Size, Mismatch Port-Application and DDoS activity were found respectively. The last one will contain all traffic by the suspicious IPs listed. This is because since for data to be detected if it is not using the attack protocol port (123 for NTP for example), 10000 packets have to be found in 5 seconds, but the last set of packets before the attack ends may only reach 9000 and not be recorded. So all the traffic for the suspicious IPs is shown to ensure all packets sent by the suspicious Ips are recorded.

### 4.4.5 Progress Bar

Since loading the data can take a large amount of time depending on the size of the dataset, the user will need some feedback that the program is running, and it is not frozen. Therefore, a progress bar was implemented to show the user the program is running. It shows that there is work in progress but not the duration of the work.

## 4.5 Tool Snapshots

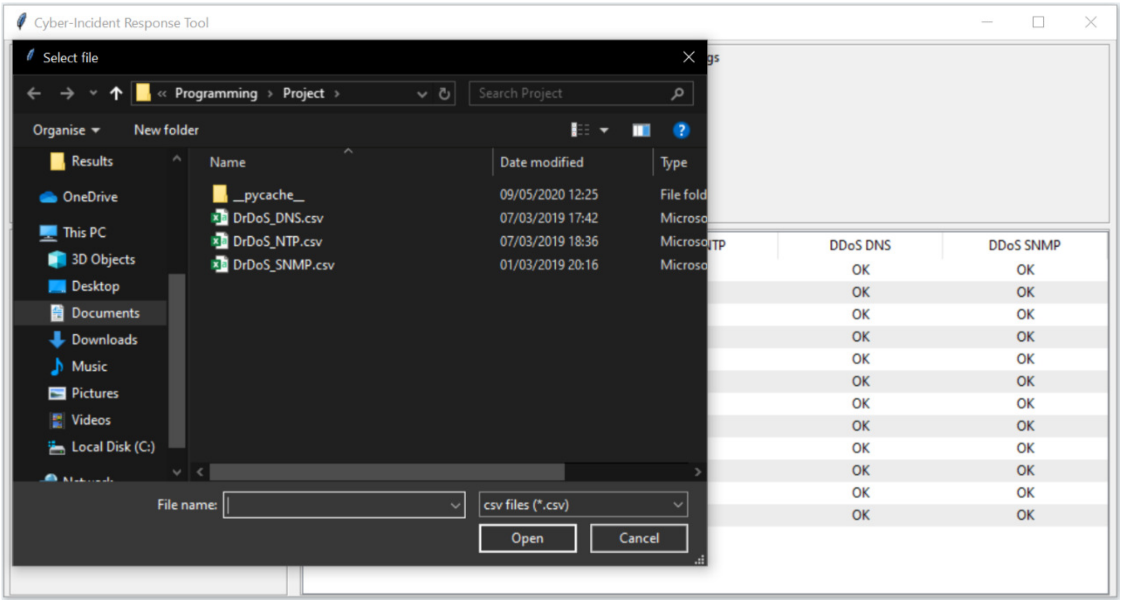
Figure 7 shows the initial state of the GUI; from here the user can only click on the open file button to select the file they want to analyse.



| Indicators of Compromise | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| Unusual Outbound Network Traffic | OK | OK | OK |
| Anomalies in Privileged User Account Activity | OK | OK | OK |
| Geographical Irregularities | OK | OK | OK |
| Log-In Red Flags | OK | OK | OK |
| Response Sizes | OK | OK | OK |
| Large Number of Requests for the Same File | OK | OK | OK |
| Mismatched Port-Application Traffic | OK | OK | OK |
| Suspicious Registry or System File Changes | OK | OK | OK |
| Unusual DNS Requests | OK | OK | OK |
| Bundles of data in the wrong place | OK | OK | OK |
| Web Traffic with Unhuman Behaviour | OK | OK | OK |
| Signs of DDoS Activity | OK | OK | OK |

***Figure 7**. Initial GUI State*

After the button is pressed, a file dialog window will appear to allow the user to select the file they want. For demonstration purposes I chose the NTP csv file. Select the file and click “Open”.

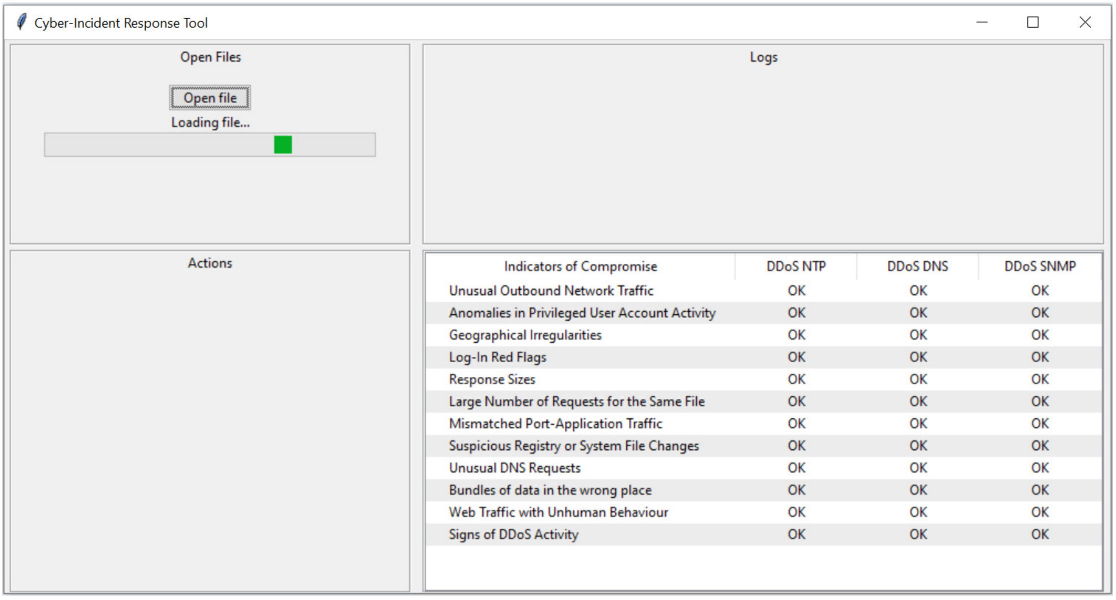


| Name | Date modified | Type |
|---|---|---|
| __pycache__ | 09/05/2020 12:25 | File fold |
| DrDoS_DNS.csv | 07/03/2019 17:42 | Microso |
| DrDoS_NTP.csv | 07/03/2019 18:36 | Microso |
| DrDoS_SNMP.csv | 01/03/2019 20:16 | Microso |

| DDoS DNS | DDoS SNMP |
|---|---|
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |
| OK | OK |

***Figure 8**. Selecting Data to Enter*

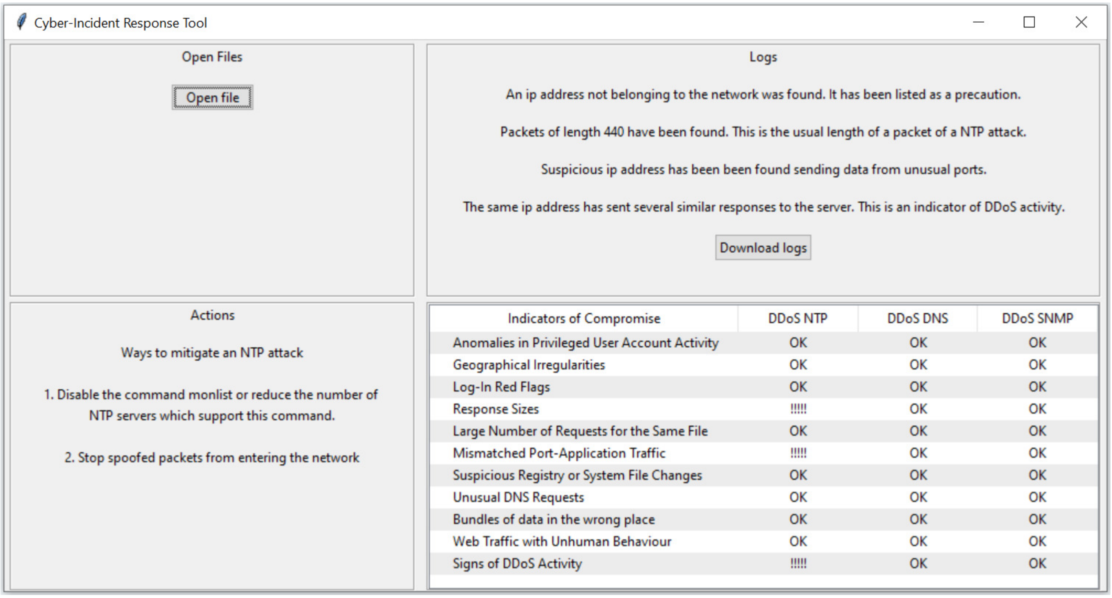
Now the file will start to be analysed, a progress bar is displayed that will keep moving until the tool has finished the detection algorithms.



| Indicators of Compromise | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| Unusual Outbound Network Traffic | OK | OK | OK |
| Anomalies in Privileged User Account Activity | OK | OK | OK |
| Geographical Irregularities | OK | OK | OK |
| Log-In Red Flags | OK | OK | OK |
| Response Sizes | OK | OK | OK |
| Large Number of Requests for the Same File | OK | OK | OK |
| Mismatched Port-Application Traffic | OK | OK | OK |
| Suspicious Registry or System File Changes | OK | OK | OK |
| Unusual DNS Requests | OK | OK | OK |
| Bundles of data in the wrong place | OK | OK | OK |
| Web Traffic with Unhuman Behaviour | OK | OK | OK |
| Signs of DDoS Activity | OK | OK | OK |

***Figure 9**. Analysing File*

Once analysing is complete, if an NTP attack was found, the tool will look like Figure 10. From here, the user can choose to download the logs by pressing the “Download logs” button.



An ip address not belonging to the network was found. It has been listed as a precaution.

Packets of length 440 have been found. This is the usual length of a packet of a NTP attack.

Suspicious ip address has been been found sending data from unusual ports.

The same ip address has sent several similar responses to the server. This is an indicator of DDoS activity.

Ways to mitigate an NTP attack

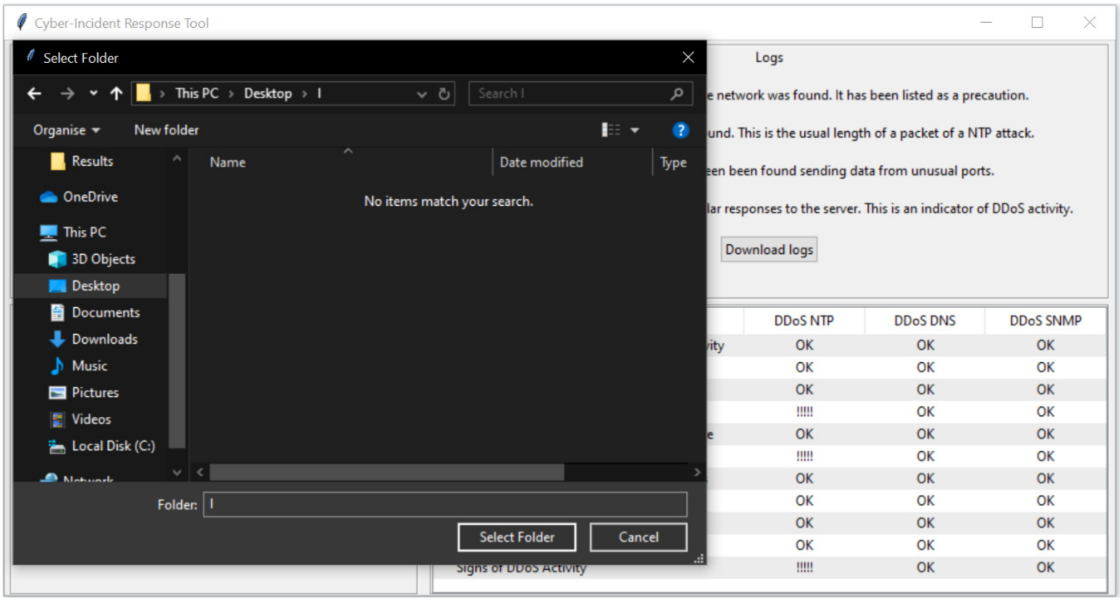
1. Disable the command monlist or reduce the number of NTP servers which support this command.

2. Stop spoofed packets from entering the network

| Indicators of Compromise | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| Anomalies in Privileged User Account Activity | OK | OK | OK |
| Geographical Irregularities | OK | OK | OK |
| Log-In Red Flags | OK | OK | OK |
| Response Sizes | !!!!! | OK | OK |
| Large Number of Requests for the Same File | OK | OK | OK |
| Mismatched Port-Application Traffic | !!!!! | OK | OK |
| Suspicious Registry or System File Changes | OK | OK | OK |
| Unusual DNS Requests | OK | OK | OK |
| Bundles of data in the wrong place | OK | OK | OK |
| Web Traffic with Unhuman Behaviour | OK | OK | OK |
| Signs of DDoS Activity | !!!!! | OK | OK |

***Figure 10**. Display of Recommended Actions, Indicators of Compromise and Logs*

If the download button is pressed, a directory dialog window will appear as shown in Figure 11. The logs will be stored in the directory the user chooses here. To choose the directory, browse to the directory then press “Select Folder”.



No items match your search.

Folder: I

e network was found. It has been listed as a precaution.

und. This is the usual length of a packet of a NTP attack.

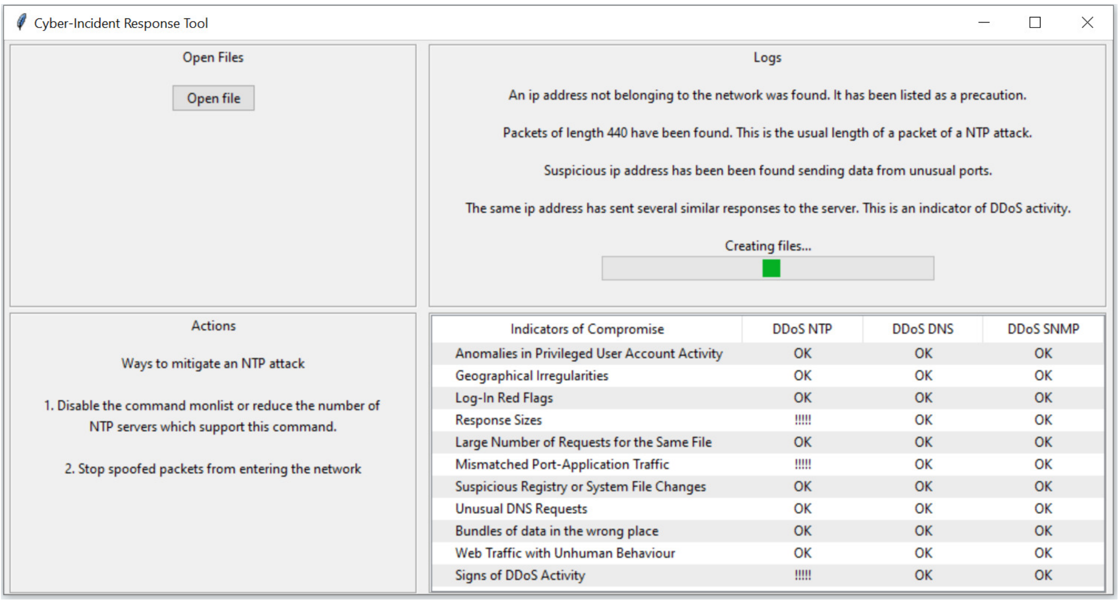
een been found sending data from unusual ports.

lar responses to the server. This is an indicator of DDoS activity.

| | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| ity | OK | OK | OK |
| | OK | OK | OK |
| | OK | OK | OK |
| | !!!!! | OK | OK |
| e | OK | OK | OK |
| | !!!!! | OK | OK |
| | OK | OK | OK |
| | OK | OK | OK |
| | OK | OK | OK |
| | OK | OK | OK |
| Signs of DDoS Activity | !!!!! | OK | OK |

***Figure 11****. Selecting Folder for Storing Logs*

After the directory has been chosen, the tool will start generating the logs and storing them in the specified directory. A progress bar will be displayed until the logs generation is finished.



An ip address not belonging to the network was found. It has been listed as a precaution.

Packets of length 440 have been found. This is the usual length of a packet of a NTP attack.

Suspicious ip address has been been found sending data from unusual ports.

The same ip address has sent several similar responses to the server. This is an indicator of DDoS activity.

Creating files...

Ways to mitigate an NTP attack

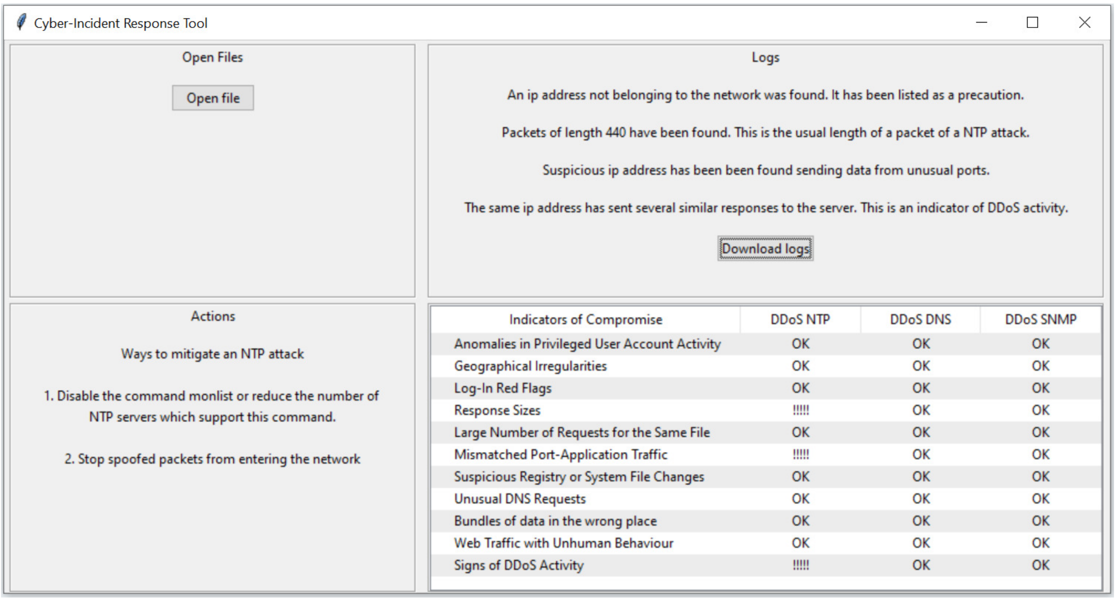
1. Disable the command monlist or reduce the number of NTP servers which support this command.

2. Stop spoofed packets from entering the network

| Indicators of Compromise | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| Anomalies in Privileged User Account Activity | OK | OK | OK |
| Geographical Irregularities | OK | OK | OK |
| Log-In Red Flags | OK | OK | OK |
| Response Sizes | !!!!! | OK | OK |
| Large Number of Requests for the Same File | OK | OK | OK |
| Mismatched Port-Application Traffic | !!!!! | OK | OK |
| Suspicious Registry or System File Changes | OK | OK | OK |
| Unusual DNS Requests | OK | OK | OK |
| Bundles of data in the wrong place | OK | OK | OK |
| Web Traffic with Unhuman Behaviour | OK | OK | OK |
| Signs of DDoS Activity | !!!!! | OK | OK |

***Figure 12****. Generation of Logs*

When the logs are created, the tool will look like in Figure 13.



An ip address not belonging to the network was found. It has been listed as a precaution.

Packets of length 440 have been found. This is the usual length of a packet of a NTP attack.

Suspicious ip address has been been found sending data from unusual ports.

The same ip address has sent several similar responses to the server. This is an indicator of DDoS activity.

Ways to mitigate an NTP attack

1. Disable the command monlist or reduce the number of NTP servers which support this command.

2. Stop spoofed packets from entering the network

| Indicators of Compromise | DDoS NTP | DDoS DNS | DDoS SNMP |
|---|---|---|---|
| Anomalies in Privileged User Account Activity | OK | OK | OK |
| Geographical Irregularities | OK | OK | OK |
| Log-In Red Flags | OK | OK | OK |
| Response Sizes | !!!!! | OK | OK |
| Large Number of Requests for the Same File | OK | OK | OK |
| Mismatched Port-Application Traffic | !!!!! | OK | OK |
| Suspicious Registry or System File Changes | OK | OK | OK |
| Unusual DNS Requests | OK | OK | OK |
| Bundles of data in the wrong place | OK | OK | OK |
| Web Traffic with Unhuman Behaviour | OK | OK | OK |
| Signs of DDoS Activity | !!!!! | OK | OK |

***Figure 13**. View after Logs are Created*

## 4.6 Discussion

Originally, the idea was that the tool should accept pcap files instead of csv files. However, for datasets this large the amount of time it took to process was unfeasible since the pcap files were too big. We went with the csv representation of these pcap files instead which were much smaller than their pcap counterparts.

In earlier stages of development, the data entered was read and written to an array which was then passed on to the analysing function. This was to avoid having all the code clustered in just one function. The downside was than doing this made the program very slow since the data was being read twice, once from the file and the other from the array.
To solve this the data was analysed as the file was being read, but the code was moved to different classes to reduce the amount f coding in the analysing function. This was helpful afterwards since the code became more maintainable.

Another issue was the progress bar, which we tried to make it a completion progress bar rather than a loading one. However, since it was difficult to estimate how many lines the program was going to read, the steps at which the progress bar had moved could not be determined. Therefore, a progress bar that would not stop loading until the operation finished was implemented.

## 4.7 Summary

The project was developed with Python in a computer running Windows. The coding that comprises the tool was explained, including the different detection algorithms for the NTP, DNS and SNMP attacks. Tool snapshots were included to demonstrate the normal operation of the tool and the discussion at the end mentioned the issues faced when programming the tool, such as the file types the tool was able to use.

# 5. Results and Evaluation

## 5.1 Overview

This section will describe the dataset used, which attacks were considered and why. An evaluation of the findings on the three attacks chosen will be provided followed by a comparison of the three attacks. This will compare the duration and number of packets sent by each attack. Finally, I will evaluate the success of this project and comment on the evaluation provided by an expert of this field.

## 5.2 Dataset and Pre-processing

The dataset used for analysing in this work was produced by the Canadian Institute for Cybersecurity, the authors of this dataset being Ghorbani et al. (2019). We chose this dataset for our work as it is one of the few datasets currently that provide data on DDoS reflective attacks.

The dataset contained naturalistic traffic mixed with illegitimate traffic to give a realistic scenario of the network traffic during a DDoS attack. It offered data on many different types of attacks, from reflection-based attacks to exploitation-based attacks. The dataset presented the network captures in both pcap and csv format.

We decided to analyse DNS, NTP and SNMP reflective attacks due to their popularity. More popular than the SNMP attack was the SSDP attack but as explained in the Future Work section, some issues with analysing this attack prevented us from researching it.

Each packet had 88 different fields of information, but only nine of the fields were used in this project:

- Source IP – The IP address of the sender
- Destination IP – The IP address of the receiver
- Source Port – The port from where the packet was sent
- Protocol – The protocol used for communication
- Timestamp – The time at which the packet was sent
- Forward Packet Length Max – The packet size of the packet
- Inbound – Flag to specify is packet came from outside the network

The source IP and the destination IP were used to identify the possible different malicious Ips. The source port was used to identify the different types of attack. The protocol was used to identify UDP packets. The timestamp was used to identify multiple packets sent in a short time, a DDoS sign. The packet size was used to determine if a packet was malicious if it was too large. The inbound flag was used to discard traffic from inside the network while doing the analysis.

## 5.3 NTP Attack Evaluation

When analysing the NTP attack results only one IP was found to be malicious: 172.16.05. The following charts and explanations will prove this claim.

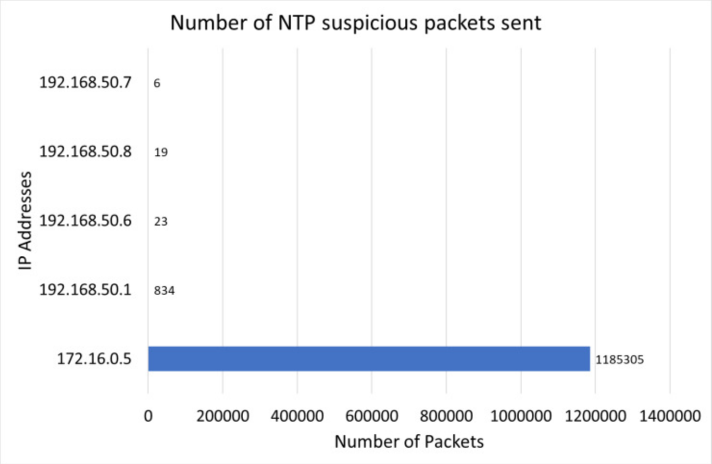


*Figure 14. Graph Displaying Number of NTP Suspicious Packets Sent*

Firstly, for every source IP that appeared in the dataset, each packet that showed any sign of an NTP attack was flagged. The packets were flagged if the source port was 123 or the packet size was 440, which is the typical length of a packet in an NTP attack. As Figure 14 shows, IP address 172.16.0.5 qualified exceedingly more times than other IP addresses.

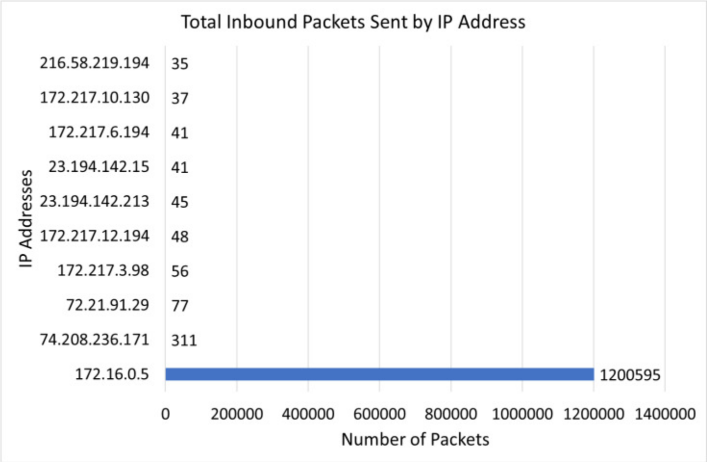


*Figure 15. Graph Displaying Total Inbound Packets Sent by IP Address*

Secondly, for every source IP that is sending a packet from outside the network, the packets it sent were counted. The reason for investigating the inbound packets, is to avoid counting the packets sent by the devices in the network, which cannot cause a DDoS attack. As demonstrated in Figure 15, once again, IP address 172.16.0.5 sent a large number of packets compared to other addresses.

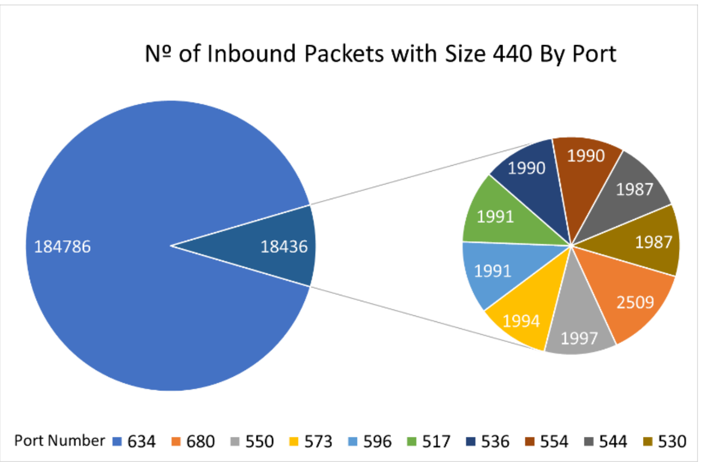


***Figure 16****. Pie Chart Displaying Nº of Inbound Packets of Size 440 by Port*

Finally, for every source port in the dataset, the inbound packets of size 440 that were sent through that port were counted. This was to investigate the Indicator of Compromise from a mismatch in ports. Most of these ports are not officially recognised and were sending repeated packets with the characteristics of a DDoS attack, another Indicator of Compromise. Specifically, Figure 16 shows that port number 634 was used repeatedly for the transmission of this packets. The packet size from these packets indicate the packet size of an NTP attack, which is the Indicator of Compromise corresponding to response sizes. Moreover, all inbound packets of size 440 were sent by IP address 172.16.0.5.

## 5.4 DNS Attack Evaluation

When analysing the DNS attack results only one IP was found to be malicious: 172.16.05. The following charts and explanations will prove this claim.

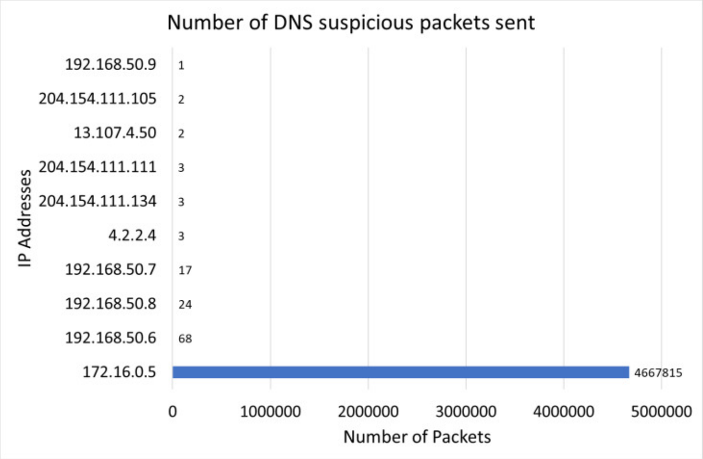


***Figure 17****. Graph Displaying Number of DNS Suspicious Packets Sent*

Firstly, for every source IP that appeared in the dataset, each packet that showed any sign of a DNS attack was flagged. The packets were flagged if the source port was 53 or the packet size was greater than 1000, since large packets are a sign of a reflective attack. As Figure 17 shows, IP address 172.16.0.5 qualified exceedingly more times than other IP addresses.

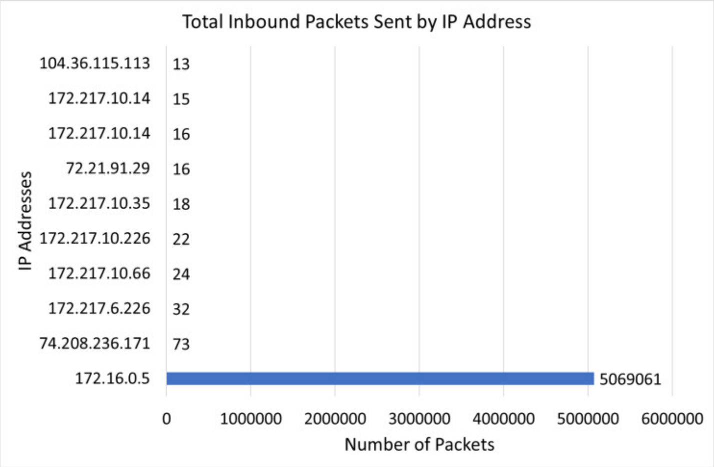


*Figure 18. Graph Displaying Total Inbound Packets Sent by IP Address*

Secondly, for every source IP that is sending a packet from outside the network, the packets it sent were counted. The reason for investigating the inbound packets, is to avoid counting the packets sent by the devices in the network, which cannot cause a DDoS attack. As demonstrated in Figure 18, once again, IP address 172.16.0.5 sent a large number of packets compared to other addresses.

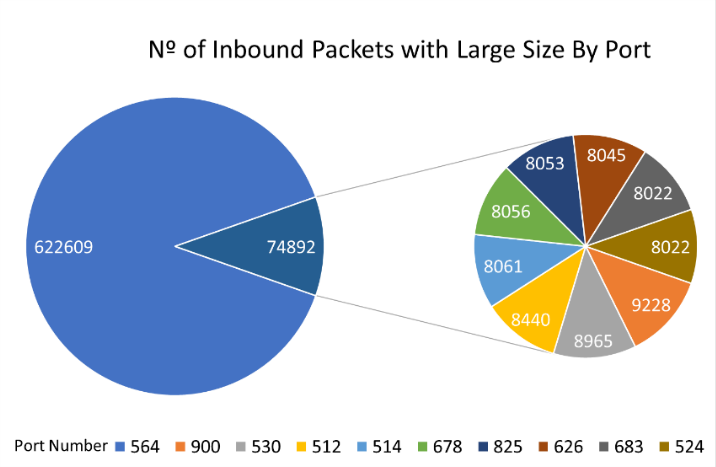


*Figure 19. Pie Chart Displaying Nº of Inbound Packets of Large Size by Port*

Finally, for every source port in the dataset, the inbound packets of size greater than 1000 that were sent through that port were counted. This was to investigate the Indicator of Compromise from a mismatch in ports. Most of these ports are not officially recognised and were sending repeated packets with the characteristics of a DDoS attack, another Indicator of Compromise. Specifically, Figure 19 shows that port number 564 was used repeatedly for the transmission of this packets. The packet size from these packets indicate the typical packet size of a DNS attack, which is the Indicator of Compromise corresponding to response sizes. Moreover, only 14 inbound packets of size greater than 1000 were not sent by IP address 172.16.0.5. 11 packets were sent by port 443 and the other three by port 80. Ports 80 and 443 belong to HTTP and HTTPS protocols respectively, so we can assume is legitimate traffic.

## 5.5 SNMP Attack Evaluation

When analysing the SNMP attack results only one IP was found to be malicious: 172.16.05. The following charts and explanations will prove this claim.

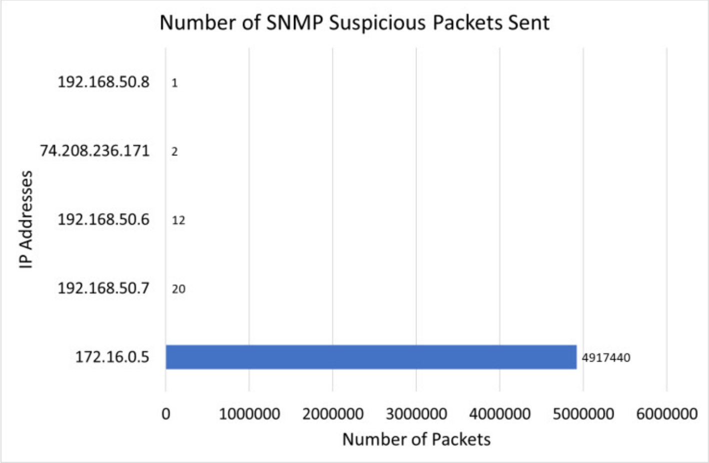


*Figure 20. Graph Displaying Number of SNMP Suspicious Packets Sent*

Firstly, for every source IP that appeared in the dataset, each packet that showed any sign of an SNMP attack was flagged. The packets were flagged if the source port was 161 or the packet size was greater than 1000, since large packets are a sign of a reflective attack. As Figure 20 shows, IP address 172.16.0.5 qualified exceedingly more times than other IP addresses.

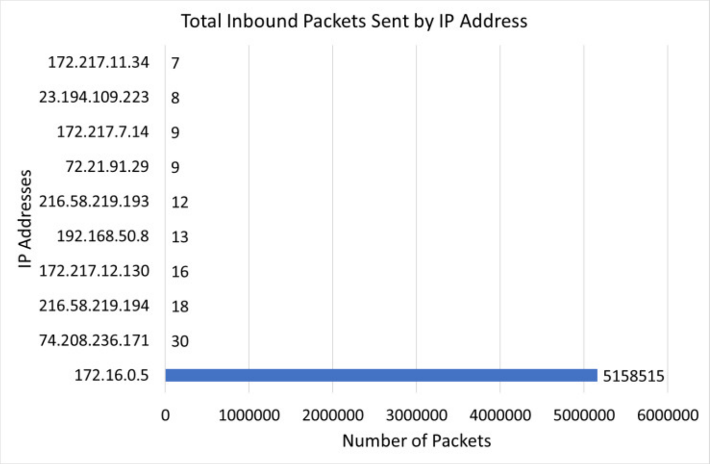


*Figure 21. Bar Chart Displaying Total Inbound Packets Sent by IP Address*

Secondly, for every source IP that is sending a packet from outside the network, the packets it sent were counted. The reason for investigating the inbound packets, is to avoid counting the packets sent by the devices in the network, which cannot cause a DDoS attack. As demonstrated in Figure 21, once again, IP address 172.16.0.5 sent a large number of packets compared to other addresses.

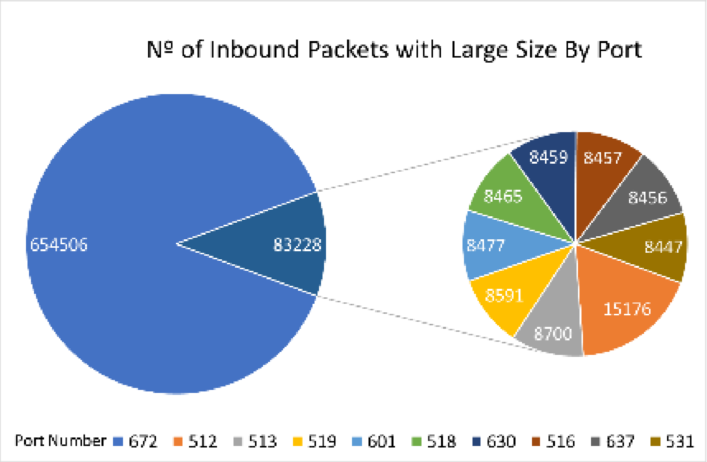


***Figure 22**. Pie Chart of Nº of Inbound Packets of Large Size by Port*

Finally, for every source port, the inbound packets of size greater than 1000 that were sent through that port were counted. This was to investigate the Indicator of Compromise from a mismatch in ports. Most of the ports are not officially recognised and were sending repeated packets with signs of a DDoS attack, another Indicator of Compromise. Specifically, Figure 22 shows that port number 672 was used repeatedly for the transmission of packets. The packet size indicates the typical packet size of an SNMP attack, which corresponds to the Indicator of Compromise of response sizes. Moreover, only 2 inbound packets of size greater than 1000 were not sent by address 172.16.0.5. The packets were sent by port 80, so we assume it was legitimate traffic.

## 5.6 Key Highlights

Comparing the number of malicious packets sent in each attack, it was discovered that in an SNMP attack more packets are sent than in other attacks, and NTP was the attack with least packets sent. The SNMP attack sent almost 5 million packets, the DNS attack almost 4.7 million packets and the NTP attack almost 1.2 million packets.

When comparing the attack that held the longest streak, SNMP held the highest. The duration of a streak was counted by how many seconds passed with the attack being uninterrupted. The SNMP attack's longest streak was 495 seconds, the NTP attack was second at 190 seconds, and the shortest streak was the DNS attack at 70 seconds.

The duration of each attack was also recorded, with the DNS attack being the longest attack. The DNS, NTP and SNMP attacks lasted 994, 932 and 594 seconds respectively. Comparing this data with the number of packets sent by attack, it was discovered that the SNMP attack sent the most packets per second, sending 8200 packets per second. The DNS and NTP attacks sent 4700 and 1300 packets per second respectively.

## 5.7 Evaluation

Evaluation is needed to determine if the project has been successful or not. In this section, I evaluate the work explaining want was accomplished and what shortcomings did the project have. An expert opinion is also included to give more insight on how the project can be further improved.

### 5.7.1 Self Evaluation

Overall, I believe the main objectives of this project were accomplished. A tool to demonstrate log analysis, indicators of compromise events and actions, and suggesting countermeasures was successfully developed. The tool accepted input from the user and through the detection algorithms was able to analyse data from the dataset to predict and understand the behaviour of DDoS attacks. Information on which attack was identified and which countermeasures to use were also displayed.

However, I also believe there are some shortcomings regarding this project. Due to my lack of technical expertise, the recommended actions provided were vague so it could be troublesome to implement these actions. Another problem was that this tool will only work from data from the dataset mentioned at the beginning of this section. This is because the data is presented in columns which are unique to this type of dataset. If a pcap file was exported into csv, it would not set the same columns so this tool would be useless. Finally, the way the results are presented are biased due to the way the data from the dataset was recorded. Compared to malicious traffic there is not much legitimate traffic in the csv files. Therefore, statistics such as the number of packets sent by address may differ if more legitimate traffic was included.

### 5.7.2 Expert Evaluation

We reached out to Dr Zubair Baig for an opinion on the project. Dr Baig is knowledgeable in the area of smart cities and IoT (Internet of Things) and after reading his paper “An Analysis of Smart Grid Attacks and Countermeasures” (Baig and Amoudi 2013) we felt he could give us good insight on what we could include in this work.

Dr. Baig believed this work already had many good components to conduct good research on the attacks and developing the tool. He suggested that we should focus on the efficacy of the identified indicators in detecting the 3 cyber-attacks. However, due to time constraints, implementing effective detection algorithms was not possible. Therefore, we will consider Dr. Baig’s advice for future expansion of this tool.

## 5.8 Summary

For this project we used a DDoS dataset provided by the Canadian Institute of Cybersecurity. We decided to use the three attacks chosen due to their popularity and after an evaluation of the three attacks, it was found that the SNMP attack generated the largest amount of traffic. My self-evaluation of the project determined that the project had accomplished the main objectives, however there is still room for improvement. Dr. Zubair Baig provided advice on working on the efficacy of the detection of algorithms which we will consider for future work.

## 6. Future Work

This section will discuss improvements that would be made to the tool if we had more time to develop it.

### 6.1 Live Data Stream

This work currently only takes pre-recorded network data captures as input, and only csv files rather than pcap files. This is not useful practically cause the attack would be detected after it has already happened, and it may be too late to act then. Therefore, one of the improvements we would like to introduce would be to analyse live data.

This means changes in the code beyond changing the type of input would have to be made. Firstly, the code would need to accommodate changes in logic for the analysing of the new type of data. Secondly, an option to deactivate the warnings in the table of indicators of compromise when an attack has been dealt with should also be included. Finally, the logs would need to be created simultaneously as the program runs and the button for downloading them should always be available.

### 6.2 More Variety of DDoS Attacks

For simplicity when developing the tool, we decided to go only with three different types of attack DNS, NTP and SNMP amplification attacks. Originally, we had decided to do SSDP rather than SNMP as it is a more popular attack. However, it was challenging to identify the SSDP (Simple Service Discovery Protocol) apart from other attacks, so we decided to go with a similar protocol which is SNMP.

Aside from SSDP we would also like to include more different types of amplification attacks in the future. Once all of these attacks are properly being detected, we would also want to expand the tool to cover all types of DDoS attacks so that it provides full DDoS protection.

### 6.3 Better Detection Methods

For future work of this tool, it is essential to improve the detection methods. Another indicator of compromise from DDoS attacks that was not possible to implement is Geographical Irregularities. To achieve this the tool should be able to detect where in the world an IP address is coming from. In the smart grid scenario this is extremely useful since they are vulnerable to attacks from other nations. Therefore, this could block attacks from outside the smart grid’s home country.

# 7. Conclusions

## 7.1 Motivation and Problem

In this project it was concluded that smart grids are vulnerable to cyber-crime and cyberattacks on these can have disastrous implications. DDoS attacks can affect the communication of different devices interrupting the operation of the smart grid. In an energy smart grid this could have serious implications such as area blackouts. The problem is that not many operational technology tools provide reflective DDoS protection, a type of attacks that is rising in popularity due to the increase in internet connectivity speeds.

Therefore, we created a  tool to demonstrate log analysis, indicators of compromise events and actions, and suggesting countermeasures. It accomplished its objectives as the detection algorithms were able to analyse data from the dataset to predict and understand the behaviour of DDoS attacks. After the analysis on the data, information on which attack was identified and which countermeasures to use were also displayed.

## 7.2 The Idea and Tool

The idea for the creation of the tool was that it had to be as easy to use as possible and provide the DDoS protection other tools were not providing. A tool in Python was developed that read network capture csv files and analyse them for attacks. The three attacks this tool analysed were NTP, DNS and SNMP amplification attacks. A malicious hacker sends a request to a server that returns as much data as possible and uses that victim's IP address as the source to direct all the data to them. The tool was able to detect any of the three attacks including if more than one attack was detected in the dataset. It provided recommended action actions to take to mitigate the attacks, indicators of compromise to understand the nature of the attacks and logs to further understand how the attack was being carried out.

## 7.3 The Results

The results showed how each different attacked behaved and made a comparison between them. It was found that the SNMP attack sent the most packets per second, however this could be interpreted in two ways. It could be the hardest attack to deal with this it sends more packets in a short amount of time. However, it is the attack that lasts less therefore it disrupts the system for a shorter amount of time, making the DNS attack the most troublesome.

## 8. Reflection on Learning

During the development of this project, I expanded my technical knowledge and skills in many different aspects. When I was looking for a project to do, I wanted it to be as closely related to cybersecurity as possible since that is my area of interest. The first time I saw this project I did not know anything about smart grids and I only knew very little about incidence response, which was taught in the Forensics module. However, I wanted my last work in university to be a challenge, so I took on this project since it looked very interesting. Through my meeting with my supervisor and the various research papers I gradually expanded my knowledge and learned new skills such as finding and going through research papers. Before this project, I knew how the general operation of a DDoS attack worked, however, I did not know that different types of these attacks existed and how they are different from each other. I believe I have a better understanding of DDoS attacks through this work.

On the other hand, I had to overcome many obstacles that I did not foresee. The biggest challenge was how to detect that a DDoS attack was happening. For the NTP attack it was easier since packets in this type of attack have a fixed size of 440. Nonetheless, DNS and SNMP attacks were more difficult to detect since they do not have a fixed size. I had to find a packet size that was large enough to be able to be considered malicious but still did not label legitimate traffic as illegitimate. I decided to go with packets of size 1000 to solve this issue which gave a satisfactory result.

Moreover, I was able to use the programming knowledge I built up these last three years to use it in the project. My main programming language throughout the degree was python and being able to use it in my project allowed me to finish tasks more quickly since I was already familiar with the language. I had to learn GUI design in Python from scratch, so the familiarity with the language was very useful since I could focus on learning the skill required to build the GUI.

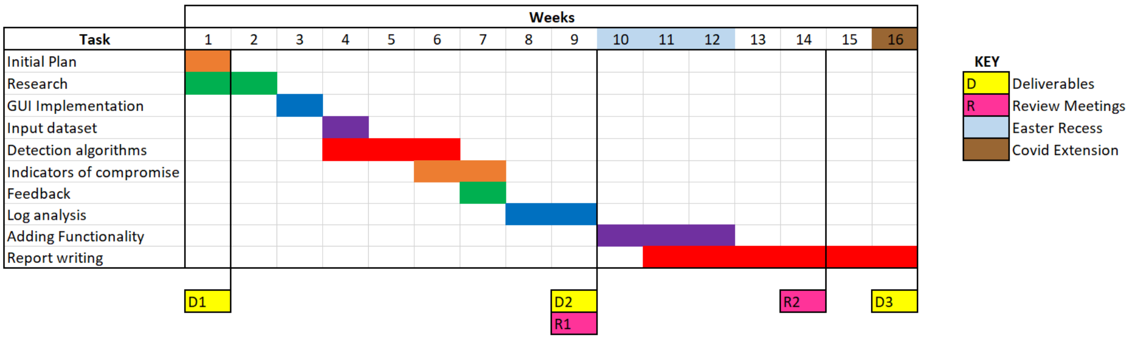
Additionally, I improved on my project management skills thanks to the weekly meetings with my supervisor. As I had to report my work each week, it allowed me to structure the work and when to complete each milestone. This will be favourable when I start working since I will be able to manage my tasks more efficiently.

## Table of Abbreviations

| | |
|---|---|
| **DoS** | Denial of Service |
| **DDoS** | Distributed Denial of Service |
| **SSDP** | Simple Service Discovery Protocol |
| **NTP** | Network Transfer Protocol |
| **DNS** | Domain Name System |
| **SNMP** | Simple Network Manager Protocol |
| **IP** | Internet Protocol |
| **GUI** | Graphical User Interface |
| **CSV** | Comma Separated Values |
| **PCAP** | Packet Capture |
| **IoT** | Internet of Things |

# Appendices

## Gantt Chart



| Task | Weeks<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Plan | 🟧 | | | | | | | | | | | | | | | |
| Research | 🟩 | 🟩 | | | | | | | | | | | | | | |
| GUI Implementation | | | 🟦 | | | | | | | | | | | | | |
| Input dataset | | | | 🟪 | | | | | | | | | | | | |
| Detection algorithms | | | | 🟥 | 🟥 | 🟥 | | | | | | | | | | |
| Indicators of compromise | | | | | | 🟧 | 🟧 | | | | | | | | | |
| Feedback | | | | | | | 🟩 | | | | | | | | | |
| Log analysis | | | | | | | | 🟦 | 🟦 | | | | | | | |
| Adding Functionality | | | | | | | | | | 🟪 | 🟪 | 🟪 | | | | |
| Report writing | | | | | | | | | | | 🟥 | 🟥 | 🟥 | 🟥 | 🟥 | 🟥 |
| | D1 | | | | | | | | D2<br>R1 | | | | | R2 | | D3 |

| KEY | |
|---|---|
| D | Deliverables |
| R | Review Meetings |
| 🟦 | Easter Recess |
| 🟫 | Covid Extension |

## Use Cases

| | |
|---|---|
| **Use Case No:** 1 | **Use Case Name:** Entering Data |
| **Purpose:** Allows user to input the network capture data. | |
| **Pre-conditions:** None | |
| **Trigger:** Open File button pressed | |
| **Description:** A file dialog will appear to allow the user to select the network capure file they want to open. Only csv files will be allowed, so other file types will not show on the dialog. After the file is selected, it will be loaded into the program for analysing where the different attacks will be detected. At the end of analysing it will return data based on the analysis results. | |
| **Post-Condition:** If a NTP attack is detected: Use Case 2.1 is available. If a DNS attack is detected: Use Case 2.2 is available. If a SMNP attack is detected: Use Case 2.3 is available. If more than one attack is detected: Use Case 2.4 is available. | |

| | |
|---|---|
| **Use Case No:** 2.1 | **Use Case Name:** NTP Attack Detected |
| **Purpose:** Give the user information on the NTP attack detected. | |
| **Pre-conditions:** NTP attack detected. | |
| **Trigger:** Use Case 1 is completed | |
| **Description:** In the indicators of compromise table, the indicators corresponding to a NTP attack will be highlighted. Recommended actions for mitigating a NTP attack will be displayed under the Actions tab. Download of logs will become available under the Logs tab. | |
| **Post-Conditions:** Use Case 3.1 now available. | |

| | |
|---|---|
| **Use Case No:** 2.2 | **Use Case Name:** DNS Attack Detected |
| **Purpose:** Give the user information on the DNS attack detected. | |
| **Pre-conditions:** DNS attack detected. | |
| **Trigger:** Use Case 1 is completed | |
| **Description:** In the indicators of compromise table, the indicators corresponding to a DNS attack will be highlighted. Recommended actions for mitigating a DNS attack will be displayed under the Actions tab. Download of logs will become available under the Logs tab. | |
| **Post-Conditions:** Use Case 3.2 now available. | |

| | |
|---|---|
| **Use Case No:** 2.3 | **Use Case Name:** SMNP Attack Detected |
| **Purpose:** Give the user information on the SMNP attack detected. | |
| **Pre-conditions:** SMNP attack detected. | |
| **Trigger:** Use Case 1 is completed | |
| **Description:** In the indicators of compromise table, the indicators corresponding to a SMNP attack will be highlighted. Recommended actions for mitigating a SMNP attack will be displayed under the Actions tab. Download of logs will become available under the Logs tab. | |
| **Post-Conditions:** Use Case 3.3 now available. | |

| | |
|---|---|
| **Use Case No:** 2.4 | **Use Case Name:** Multiple Attacks Detected |
| **Purpose:** Give the user information on the attacks detected. | |
| **Pre-conditions:** More than one attack detected. | |
| **Trigger:** Use Case 1 is completed | |
| **Description:** The following are the possible cases: Both DNS and NTP/DNS and SNMP/NTP and SMNP or all three attacks have been detected. In the indicators of compromise table, the indicators corresponding to the detected attacks will be highlighted. Recommended actions for mitigating the detected attacks will be displayed under the Actions tab. Download of logs for each detected attack will become available under the Logs tab. | |
| **Post-Conditions:** Use Case 3.4 now available. | |

| | |
|---|---|
| **Use Case No:** 3.1 | **Use Case Name:** NTP Logs Download |
| **Purpose:** Provide user with logs of the NTP incident. | |
| **Pre-conditions:** Use Case 2.1 Completed | |
| **Trigger:** Download Logs button pressed | |
| **Description:** A file dialog will appear to allow the user to select where the logs are going to be downloaded. Once the directory is selected, the program will search through the data and extract all the information relating the suspicious IP that have been carrying out the attack. A csv file will be generated in the directory the user chose. | |
| **Post-Conditions:** None | |

| | |
|---|---|
| **Use Case No:** 3.2 | **Use Case Name:** DNS Logs Download |
| **Purpose:** Provide user with logs of the DNS incident. | |
| **Pre-conditions:** Use Case 2.2 Completed | |
| **Trigger:** Download Logs button pressed | |
| **Description:** A file dialog will appear to allow the user to select where the logs are going to be downloaded. Once the directory is selected, the program will search through the data and extract all the information relating the suspicious IP that have been carrying out the attack. A csv file will be generated in the directory the user chose. | |
| **Post-Conditions:** None | |

| | |
|---|---|
| **Use Case No:** 3.3 | **Use Case Name:** SMNP Logs Download |
| **Purpose:** Provide user with logs of the SMNP incident. | |
| **Pre-conditions:** Use Case 2.3 Completed | |
| **Trigger:** Download Logs button pressed | |
| **Description:** A file dialog will appear to allow the user to select where the logs are going to be downloaded. Once the directory is selected, the program will search through the data and extract all the information relating the suspicious IP that have been carrying out the attack. A csv file will be generated in the directory the user chose. | |
| **Post-Conditions:** None | |

| | |
|---|---|
| **Use Case No:** 3.4 | **Use Case Name:** Multiple Logs Download |
| **Purpose:** Provide user with logs of the incident. | |
| **Pre-conditions:** Use Case 2.4 Completed | |
| **Trigger:** Download Logs button pressed | |
| **Description:** A file dialog will appear to allow the user to select where the logs are going to be downloaded. Once the directory is selected, the program will search through the data and extract all the information relating the suspicious IP that have been carrying out the attack. A folder will be created to contain the different files created. A csv file will be generated in this folder for each attack detected. | |
| **Post-Conditions:** None | |

# References

Baig Z. and Amoudi A. 2013. An Analysis of Smart Grid Attacks and Countermeasures. *Journal of Communications* Vol. 8, No. 8. DOI: 10.12720/jcm.8.8.473-479

Brain et al. 1 April 2000. *How Domain Name Servers Work*. Available at: https://computer.howstuffworks.com/dns.htm [Accessed: 6th March 2020]

Cloudfare [no date]a. *What is a botnet?*. Available at: https://www.cloudflare.com/learning/ddos/what-is-a-ddos-botnet/ [Accessed: 7th March 2020]

Cloudfare [no date]b. *What is IP Spoofing?*. Available at: https://www.cloudflare.com/learning/ddos/glossary/ip-spoofing/ [Accessed: 7th March 2020]

Cloudfare [no date]c. *What is a DDoS attack?*. Available at: https://www.cloudflare.com/learning/ddos/what-is-a-ddos-attack/ [Accessed: 7th March 2020]

Cloudfare [no date]d. *DNS Amplification Attack*. Available at: https://www.cloudflare.com/learning/ddos/dns-amplification-ddos-attack/ [Accessed: 7th March 2020]

Cloudfare [no date]e. *NTP Amplification DDoS Attack*. Available at: https://www.cloudflare.com/learning/ddos/ntp-amplification-ddos-attack/ [Accessed: 7th March 2020]

E. Özer and M. İskefiyeli. 2017. Detection of DDoS attack via deep packet analysis in real time systems. *2017 International Conference on Computer Science and Engineering (UBMK)*. Antalya, Turkey, 2017. IEEE. Available at: 10.1109/UBMK.2017.8093526.

Imperva [no date]. *SNMP Reflection/Amplification*. Available at: https://www.imperva.com/learn/application-security/snmp-reflection/ [Accessed: 21st April 2020]

Maheshwari et al. 2017. Faster detection and prediction of DDoS attacks using MapReduce and time series analysis. *2018 International Conference on Information Networking (ICOIN)*. Chiang Mai, Tailand, 2018. IEEE. Available at: 10.1109/ICOIN.2018.8343180.

Matthews, K. 10th September 2019. *Incident Of The Week: Multiple Yahoo Data Breaches Across 4 Years Result in a $117.5 Million Settlement*. Available at: https://www.cshub.com/attacks/articles/incident-of-the-week-multiple-yahoo-data-breaches-across-4-years-result-in-a-1175-million-settlement [Accessed: 8th March 2020]

Melnick, J. 15th May 2018. *Top 10 Most Common Types of Cyber Attacks.* Available at: https://blog.netwrix.com/2018/05/15/top-10-most-common-types-of-cyber-attacks/ [Accessed: 20th April 2020]

Morgan, S. 26th August 2016. *Hackerpocalypse: A Cybercrime Revelation.* Available at: https://cybersecurityventures.com/hackerpocalypse-original-cybercrime-report-2016/ [Accessed: 5th March 2020]

Morgan, S. 21st October 2019. *Global Ransomware Damage Costs Predicted To Reach $20 Billion (USD) By 2021*. Available at: https://cybersecurityventures.com/global-ransomware-damage-costs-predicted-to-reach-20-billion-usd-by-2021/ [Accessed: 8th March 2020]

Network Time Foundation [no date]. *What is NTP?*. Available at: https://www.ntp.org/ntpfaq/NTP-s-def.htm [Accessed: 6th March 2020]

Oros, D. 26th July 2016. *Network Basics: What Is SNMP and How Does It Work?.* Available at: https://www.auvik.com/franklymsp/blog/network-basics-what-is-snmp/ [Accessed: 21st April 2020]

Thomas et al. 2017. 1000 days of UDP amplification DDoS attacks. *APWG Symposium on Electronic Crime Research (eCrime).* Scottsdale, AZ, USA, 2017. IEEE. Available at: 10.1109/ECRIME.2017.7945057.

DATASET

Sharafaldin et al. 2019. Developing Realistic Distributed Denial of Service (DDoS) Attack Dataset and Taxonomy. *IEEE 53rd International Carnahan Conference on Security Technology*. Chennai, India, 2019. IEEE, Available at: https://www.unb.ca/cic/datasets/ddos-2019.html

The email from Dr. Zubair Baig is attached in the next two pages.

## RE: Final Year Project Comments

Zubair Baig <zubair.baig@deakin.edu.au>
Mar 28/04/2020 1:49
**Para:** Jorge Correa Merlino <CorreaMerlinoJ@cardiff.ac.uk>

Dear Jorge,

Thanks for reaching out – and I must say that your project has all the ingredients to be a successful one!
A key objective in your research must be the efficacy of the identified indicators in detecting the 3 cyber attacks.
I would probably go with 1 cyber attack as a start and identify the what, where, how? For each defined indicator.

Will also depend on the type of data that exists in the dataset – normal and/or anomalous.

Can work out a plan based on my advice – if you feel appropriate.

Regards,
Zubair

**Zubair Baig, BS, MS, PhD, CISSP, MIEEE, MACS**
Senior Lecturer, Cyber Security | Director, Post Graduate Studies in Cyber Security
School of Information Technology, Faculty of Sci Eng & Built Env

**Deakin University**
Locked Bag 20000, Geelong, VIC 3220
+61 3 522 73525
zubair.baig@deakin.edu.au
www.deakin.edu.au
Deakin University CRICOS Provider Code 00113B

***Important Notice:*** *The contents of this email are intended solely for the named addressee and are confidential; any unauthorised use, reproduction or storage of the contents is expressly prohibited. If you have received this email in error, please delete it and any attachments immediately and advise the sender by return email or telephone.*

*Deakin University does not warrant that this email and any attachments are error or virus free.*

---

**From:** Jorge Correa Merlino <CorreaMerlinoJ@cardiff.ac.uk>
**Sent:** Tuesday, 28 April 2020 1:48 AM
**To:** Zubair Baig <zubair.baig@deakin.edu.au>
**Subject:** Final Year Project Comments

Dear Dr. Zubair,

While researching information for my final year undergrad project at university, I came across your research on smart grid attacks and their countermeasures. As an expert, I would like to receive your feedback and suggestions on my on-going project work.

The project aims to help operators in the smart grid by facilitating them with a cyber incident-response tool to detect the behavior of cyber-attacks. We are focusing on DDoS attacks, specifically three types: DNS amplification, NTP amplification, and SMNP attacks.

Currently our tool reads the data from a dataset, analyses it to detect indicators of compromise, and allows operators to make appropriate decisions. Then some recommended actions to prevent the attacks detected are shown and logs are provided to analyse the information from where the indicators were found in the network or the system.

I would really appreciate, if you could spend a few minutes on this email and provide me your comments.

Thank you very much for your time.

Kind regards,
Jorge Correa

***Important Notice:*** *The contents of this email are intended solely for the named addressee and are confidential; any unauthorised use, reproduction or storage of the contents is expressly prohibited. If you have received this email in error, please delete it and any attachments immediately and advise the sender by return email or telephone.*

*Deakin University does not warrant that this email and any attachments are error or virus free.*