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Ground-Truth for Traffic Affected by Security Attacks

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"*Your time is limited, so don't waste it living someone else's life. Don't be trapped by dogma - which is living with the results of other people's thinking. Don't let the noise of other's opinions drown out your own inner voice. And most important, have the courage to follow your heart and intuition. They somehow already know what you truly want to become. Everything else is secondary. (...)*
Stay hungry. Stay Foolish."

Steve Jobs, 2005

to my family.

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Abstract

Security is a main topic on network communications, where new threats or mutations of existing ones appear at frightening rates. Therefore, to prevent those security attacks several techniques based on traffic analysis have been developed. However, these methods should be evaluated in order to test their effectiveness. For that, researchers need to resort to traffic traces to obtain the *ground-truth*, which is very difficult to acquire in real networks. This Dissertation is focused on emulating network topologies based on real networks to acquire high quality *ground-truth.* In different scenarios were generated licit and illicit traffic according to real patterns. The captured traffic was processed and analyzed to produce some final results. This Dissertation intends also to provide all the results obtained to the research community in order to be used to evaluate statistical methods of detecting attacks and applications.

Keywords

Network emulation, licit traffic, illicit traffic, ground-truth, virtualization

Resumo

Hoje em dia a segurança nas redes de computadores é um requisito essencial que se encontra constantemente ameaçada por ataques, que vão surgindo a um ritmo cada vez mais acelerado. Para prevenir muitos destes ataques, existem varias técnicas baseadas na análise de tráfego que têm vindo a ser desenvolvidas. Contudo, essas técnicas devem ser avaliadas de modo a tornarem-se mais eficientes. Para tal é necessário recorrer a *traces*, de modo a obter um *ground-truth* que muito dificilmente se obtém nas redes em produção devido a questões de privacidade e por ser impraticável. Esta Dissertação foca-se na emulação de redes baseadas nas topologias reais de modo a obter um *ground-truth* de alta qualidade. Foram usados diferentes equipamentos e tecnologias, quer virtuais, quer físicas, para assim se criar as topologias. Nos diferentes cenários desenvolvidos foi gerado tráfego lícito e ilícito, de acordo com o que se verifica hoje em dia nas redes em produção. Esta Dissertação pretende também disponibilizar todos os dados obtidos à comunidade de investigação por forma a contribuir para uma avaliação do desempenho de métodos estatísticos para a detecção de ataques e aplicações.

Palavras Chave

Redes emuladas, tráfego lícito, tráfego ilícito, *ground-truth*, virtualização.

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List of Acronyms

BIND	Berkeley Internet Name Domain
BIND9	Berkeley Internet Name Domain version 9
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DoS	Denial of Service
FTP	File Transfer Protocol
GNS	Graphical Network Simulator
HTTP	Hyper-Text Transfer Protocol
IP	Internet Protocol
ISP	Internet Service Providers
IDS	Intrusion Detection System
IMAP	Internet Message Access Protocol
IST	Instituto Superior Técnico
LAN	Local Area Network
OSPF	Open Shortest Path First
P2P	Peer to Peer
POP	Post Office Protocol
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol

TCP	Transmission Control Protocol
UDP	User Datagram Protocol
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
VLC	VideoLan Client

1 Introduction

The world is becoming more interconnected with the progress of the Internet and new networking technologies. There is a large amount of information being exchanged all around the world. Nowadays, high and effective security is demanded on network systems. Recent advances in encryption, public key exchange, digital signatures and the development of related standards have set groundwork towards the preventing of security attacks. Despite of this, the number of attacks against Internet-connected systems continues to grow at frightening rates [5]. Therefore, efficient techniques to detect security attacks are required.

Most of Intrusion Detection System (IDS) [6] have been classified as signature detection systems. This kind of method recognizes an intrusion based on known intrusion attacks characteristics or signatures [7]. Its detection algorithm is based on traces, which are supposed to be uncovered by IDS in the observed system. However, these methods have some disadvantages. The detection of security attacks based on signatures of already known attacks can completely fail. Since they are signature-based methods for classifying anomalies and attacks on security, may not be able to detect changes in the anomaly. This is due to the fact that systems do not analyze the behaviour of network traffic but only rely on signatures.

Methods based on traffic analysis [8] appeared to be one alternative to this kind of techniques previously discussed. In this case, traffic behaviour that departs from the "normal" one, observed when only genuine applications are used in the network, is detected as a security attack or an anomalous event.

The efficiency evaluation of these methods requires that developers and researchers resort to traffic traces where the flows that correspond to attacks are known precisely. This is called the *ground-truth*. Ground-truth requires a complete list of the whole existing anomalies in the data set that is being evaluated [9]. However, it is almost impossible to acquire it, with traffic traces captured in real networks, since attacks can have patterns very similar to the ones of genuine applications. Moreover, there are a lot of concerns about sharing the traces with the rest of the scientific community due to privacy concerns.

Emulation and simulation emerge as a better option to obtain the ground-truth. These techniques allow to define the topologies of several scenarios and to generate licit and illicit traffic. It allows the execution of real network functionalities in a controllable and reproducible laboratory network environment. However, these methods have faced the challenge of simulating/emulating scenarios that faithfully represents real networks.

1.1 Goals

The primary goal of this thesis is to develop and test a set-up for networks emulation capable of representing real networks, applications and security attacks such that a high quality ground-truth can be obtained. This work aims to generate licit traffic according to the real network traffic observed nowadays representative of real applications such as HTTP, FTP, HTTP-Streaming, DNS and Bittorrent. In addition, the most common attacks, which have impact on traffic behaviour, will also be reproduced on the emulated networks.

1.2 Contributions

This dissertation shows the possibility of getting high quality data in order to generate a ground-truth. All that data obtained from different scenarios can be used to evaluate statistical methods for anomaly detection. Nowadays, there are a lot of apprehensions about sharing traffic traces captured in real networks due to privacy concerns. However, in this case, the gathered data of this work can be available to the research community because it was all captured in a controlled emulated network environment.

1.3 Document Outline

The remainder of the thesis is structured as follows:

Chapter 2 describes the context and the related work from an emulation technologies perspective, addressing the licit and illicit traffic that is common nowadays.

Chapter 3 presents all the process of the emulated networks construction. It will focus on the topologies that were developed, technologies for applications and attacks, traffic generation, capturing data and the process of grouping packets per Service/Attack.

Chapter 4 is focused on the results obtained from the emulated networks by analyzing and discuss the produced outcome.

Finally, Chapter 5 concludes the thesis and draws some directions for future work.

2 Context and Related Work

This thesis addresses an emulation environment running licit and illicit traffic. As was mentioned, in this work it is proposed to develop networks representative of real networks, applications and security attacks. For that, an offline emulation environment, which is able to generate real network traffic, is needed to analyze the traffic behaviour. The traffic generated shall be licit and illicit according to the real world. This section introduces the current state of the art in different fields of network traffic behaviour mainly focused on network evaluation. Then, both licit and illicit traffic that are common in real networks are also analyzed.

2.1 Emulation and Simulation

New protocols and applications keep on emerging as a consequence of the explosive progress of the Internet. Developing and implementing next-generation, robust, large-scale networked systems requires a deep understanding of system behaviour under a wide variety of circumstances. Both researchers and application developers need a test environment to assist this development and deployment. Furthermore, Internet Service Providers (ISP) require equipments and small-scale systems to estimate the performance of their networks in terms of Internet Protocol (IP) routing effectiveness, alternative route availability and security issues [10]. Besides, to put into effect security system, a trial testbed is required to test security attacks in order to prevent them.

Network emulators and simulators are commonly used to develop, test and debug new protocols, to explore and study a specific network-related research issue, to evaluate the performance of an existing protocol or a scheme or to test its behaviour towards security attacks.

Network simulation [11] offers a synthetic abstract network environment in a specific operating system. It is easy to configure and permit to create a protocol at some level of abstraction, making simulation a fast “prototype-and-evaluate” environment [12]. It also provides several protocol modules and configuration tools that can be easily used to perform customized simulation experiments. The weakness of using a simulator compared to a live network is the loss of realism. This kind of reproducing a network environment is supported on some basic conjectures about network requirements, traffic behaviour and, consequently, may weakly mimic the real network. Those functionalities that a network simulator may provide are merely logical operations rather than real implementations.

In the last few years, **network emulation** [13] has captured the attention of network researchers community. This technique has being considered important to evaluate the effectiveness of new protocols and applications in heterogeneous, controllable and realistic network scenarios. Emulation is often a more realistic way to reproduce a network environment since contain real components. An emulator can operate with router’s operating systems, which allows the network to use real protocols implementations. The main target of every network emulator is to achieve the highest possible conformance to the behaviour of a real network. It may mimic a real network more strictly than a network simulation. In an emulation environment the operation of network protocols and applications are “Real” instead of logical entities.

As previously discussed there are main differences between emulation and simulation. A primary difference between both of them is that while the simulation is executed in virtual simulated time, the emulation must run in real time. Another important difference is that it is impossible to have an absolutely repeatable order of events in emulation due to its real time nature. Emulation network uses real computers with restricted resources, and real applications, as well as operating systems running on them, to realistically represent every host. A simplified simulation model does not abstract flaws and vulnerabilities [14]. Internet is a moved target and is an extremely heterogeneous system that cannot be represented with simplified reproductions regularly used by simulators [15]. Emulation methods allow showing a real-time environment to acquire real traces and to build a platform for the estimation of new methodologies to detect security attacks.

So, emulation reveals to be the appropriately technique to reproduce network environments as close to reality as possible.

Network emulators provide a technique where the properties of an existing and/or planned network are reproduced in order to measure performance, to predict the impact of modifications or to optimize the technology. With this technique is possible to determine how a product or service would perform under assorted network conditions. Most of them can be connected to other emulation environments to structure a bigger network topology in order to acquire results from the designed topologies. Next, some of the network emulators, which are commonly used, are described.

Emulab

Emulab[1] is a network testbed that can be use by scientist and researchers to develop, debug and evaluate their network topologies. It is available without any charge to most researchers worldwide. It can be deployed in sites all around the world. The Emulab testbed provide an interaction between simulated and real networks through NS-2 emulation. Emulab works by controlling a PC cluster which allows to run any operating system.

Dummynet

Initially Dummynet [16] was developed to test network protocols. Though, over the years Dummynet became very popular among network emulators due its capabilities and features. This approach gives some of the advantages of both simulation and real-world testing: simplicity, good control over operating parameters, facility of using real traffic generators. Dummynet do not introduce overhead in the communication, so experiments can be done up to the maximum speed that the system can handle. The main platform of this emulator is FreeBSD and it is available for Linux and OpenWRT. Dummynet uses *ipfw* rules to capture packets. After being captured, the packages are affected by some objects (“queues” and “pipes”), which simulate the consequences of bandwidth limitations, delays, bounded-size queues and multipath.

NetEm

Another well-known network emulator is NetEm [17]. The Linux Foundation supports this approach and, as others network emulators, it pretends to provide a way to generate large networks in a lab environment. It can test new protocols on a Wide Area Networks environment. It is controlled by the

[1]http://www.emulab.net/

command line tool "tc" and is constructed using several modules. Lately, researchers also have been developing a GUI in order to run commands from NetEm.

Sinema

Sinema Network Emulator[2] is available in several different models in order to respect several user requirements. This solution works in the Ethernet layer therefore it does not require any change in the network. Sinema Network Emulator also provides a unidirectional and bidirectional emulation and a lot of others characteristics such as simultaneous emulations; layer 2 and layer 3; IPTV MPEG impairments; latency, jitter; packet loss; duplicate packet; congestion; queue size; fragmentation and others features that are useful for a network emulation.

Graphical Network Simulator (GNS)3

The GNS3 [3] (Graphcial Network Simulator 3) is a cross-platform open-source utility. It gives an easy-to-use graphical user interface along with several other features. GNS3 permits to emulate the Internetwork Operating System of the Cisco routers along with Dynamips and Dynagen in order to emulate network topologies. GNS3 is able to support all router commands, besides simulated topology can be connected to real world. Moreover it is guaranteed that an IOS image in GNS3 behaves exactly in the same way as an actual CISCO device (with the same image) does in the real world.

For this work it was decided to use GNS3 to emulate all network scenarios. This network emulator reveals to be a powerful tool, which fulfils the requirements of this work. With GNS3 it is possible to emulate networks in such a way to produce results that are similar (almost 100% identical) to those obtained in a real implementation. Plus, GNS3 allows connecting emulated topology to real world. Since the goal of this work is to develop and test emulated network environments representative of real networks, GNS3 emerge as the best option to proceed with the emulation.

2.2 Virtualization

Virtualization [18] is the creation of a virtual version of resource, such as a server, network or an operating system, where the framework divides it into one or more execution environments. Each guest operating system act like having the host's processor, memory and other resources to itself. Virtualization emerges as good option to build several servers and PC end-hosts, in order to run a lot of services and to produce a lot of network traffic.

[2]http://www.simena.net/
[3]http://www.gns3.net/

VirtualBox[4] is a system emulator in Ubuntu. It allows to load multiple guest Operating Systems under the host OS. With this tool it is possible to run several operating systems, as end-hosts, performing requests as clients to one (or more) specific server. Since the purpose of this work is execute traffic network according with daily patterns, VirtualBox emerge as a tool that is able to create several hosts, in one single physical machine, to generate different network traffic.

Xen Server[5] is based on the open source Xen hypervisor. It carries faster and efficient virtualization computing and allows users to manage advanced functions from their server and storage hardware. It also consists on management software and several features such as migration. For this work it was necessary to create several services running different services, in order to be able to produce network traffic. Xen Server allows to create several virtual servers, in a single server machine, executing common services that can be seen nowadays in deployed and realistic networks.

2.3 Illicit Traffic

As was mentioned this project seeks to acquire traffic traces representative of security attacks. Therefore, it is necessary emulate scenarios, where it will be generated illicit traffic, i.e., attacks. In this section it will be discussed the illicit traffic that was considered on this work. The discussion will provide basis to evaluate the illicit traffic later on this report. Several kinds of attacks, which have impact on traffic behaviour, are now expressed and characterized.

The attacks that will be considered on this work can be classified into four broad categories, namely:

- *Denial of Service*, which consists on an attacker preventing legitimate users from accessing information or services provided by a resource.
- *Spoofing*, which consists on forging ip source's address. It is the act of using one host to impersonate another by falsifying data and thereby getting illegitimate advantage.
- *Injection Code*, which involves code being injected straight into a program/script from an outside source for execution at some point in time.
- *Probing*, which consists on gathering as much information as possible about a Web application and its infrastructure. Basically, targeted web sites are scanned for known vulnerabilities in infrastructure software.

[4]https://www.virtualbox.org/

[5]Citrix Inc. Citrix XenServer. http://www.citrix.com

- *Fuzzers*, which consists on sending malformed or non-standard data do some remote host and observing how does that machine reacts. If the remote host's response is slowed or stopped by these attacks, it can be a clue of a serious vulnerability hosted in the protocol stack.

For the five categories shown above, different attacks were chosen for each category (Table 2.1). Every single of them has the particularity of having impact on the traffic behaviour.

Table 2.1: Attacks considered for each category.

Category	Attacks
Denial of Services	TCP SynFlood
Spoofing	Kaminsky
Code Injection	Buffer Overflow
Probing	Port Scan,FTP Authentication Scanner
Fuzzers	HTTP Malicious URI, HTTP incremented URL lengths

2.3.1 DoS Attacks

Nowadays, it is extremely important to protect computer network systems from Denial of Service attempts. There are some fault or flaws, which are exploited by this kind of attack. The flaw that is most exploited is the lack of header security in IPv4 [19]. The header of IPv4 holds both source and destination addresses of a packet. However, routing protocols do not focus on the source address to forward a packet. Therefore, by changing the source address it is almost impossible to trace back where the packet came from and then it can be used to attack a victim. Lately, network managers have been using ingress filter to forbid users inside their domain to spoof their IP address [20]. Usually, DoS attacks are carried out when an attacker aims to disrupt a server by abusing its resources, which can be either the CPU or bandwidth [21].

TCP SYN Flooding Attack [RFC 4987][6] is a well-known example of a denial of service attack, which causes a considerable impact on traffic behaviour. This attack (Figure 2.1) exploits a vulnerable characteristic of the TCP. It sends TCP connections requests faster than a machine can handle them. The attacker creates an unknown source address for each packet. The victim responds to the unknown IP address and keep on waiting for a confirmation that will never arrive. At some point the victim will not be able to handle more requests and legitimate requests will be ignored.

[6]http://tools.ietf.org/html/rfc4987

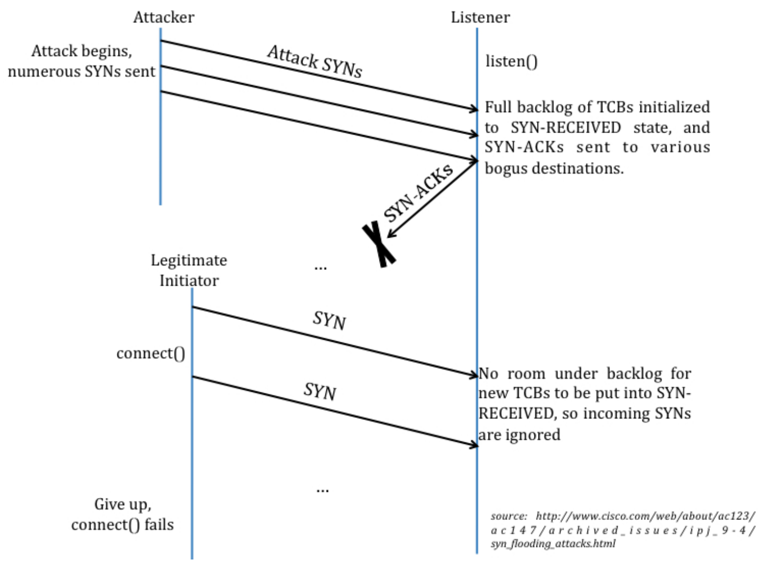

Attacker
Listener
Attack begins, numerous SYNs sent
Attack SYNs
listen()
Full backlog of TCBs initialized to SYN-RECEIVED state, and SYN-ACKs sent to various bogus destinations.
SYN-ACKs
Legitimate Initiator
...
SYN
connect()
No room under backlog for new TCBs to be put into SYN-RECEIVED, so incoming SYNs are ignored
SYN
...
Give up, connect() fails
source: http://www.cisco.com/web/about/ac123/ac147/archived_issues/ipj_9-4/syn_flooding_attacks.html

Figure 2.1: TCP Syn Flooding Attack

Impact on Traffic

In a DoS attack should be considered that in most situations the attack is performed by a group of attackers and the attacks are performed directly from their computers. In this kind of attacks it is usual an attacker generate a large amount of requests to a server. This will be only detectable if the attacker does not spoof the IPv4 source address. If the attacker spoofs the IPv4 source address, it will increase the number of hosts that contact a server during an attack. An increased number of contacts may indicate a possible attack.

Another warning sign, that might be experiencing an attack of this type, is the reduced number of responses. When a DoS attack is occurring, the attacked is overwhelmed with a considerable quantity of information in order to make the handling of requests a hard task. This should lead to the awareness that there are more queries to the server than replies from it. Those kinds of analysis have emerged to better understand the traffic behaviour of these attacks [22].

The average packet size may also indicate a possible attack. Typically, an attacker sends a large amount of small packets. The smallest query that will not trigger an error response is still bigger than the malicious packets. This happens because the malicious packets usually do not fill the Query field. The distribution of the average packet size could imply the existence of the anomalous packets [1]. If this factor is carefully analyzed it might be helpful to detect this kind of attacks.

2.3.2 Buffer Overflow

Broadly speaking, buffer overflow occurs, when software improperly handles more information into the buffer than the space it has allocated in the memory. Since buffers can only hold a precise quantity of data, when that capacity has been reached the data has to flow somewhere else, normally into a different buffer, which can damage data that is already contained in that buffer.

FTP Stack-Based Buffer Overflow is an common attack that has a significant impact on traffic networks. It exploits a flaw on ProFTPD servers. It sends to the server a large number of malicious requests in orer to corrupt memory and execute arbitrary code.

Impact on Traffic

It can be easily concluded that an attack of this kind has an impact on the packets. In order to perform a buffer overflow attack, the attacker may cause a malformed package in such a way that a buffer in the server software can be spread out. As well as, an attacker can also increase the packet size to execute a packet overflow. The manipulated data that is sent to the server needs to be large enough to perform the buffer and to execute a usable code [23].

Generally, in a Buffer Overflow attack several attempts are made in order to get succeed. Therefore a huge impact on traffic caused by those attempts may indicate that a buffer overflow attack is being performed. Analyzing the traffic behaviour and its pattern enables the detection of this attack.

2.3.3 Port Scan

A Port Scan is commonly used to send several messages by an attacker whose attempting to break into a computer to discover services. Mostly, a Port Scan attack approach is based on sending a message to each port, one at a time. The type of reaction received from the server specifies whether the port is used and then can be investigated for flaw. A port scan that does not provoke a reaction can be easily discovered, but if there is a reaction it is really hard to recognize the traffic as a port scan [24].

Impact on Traffic

This attack, as was mentioned earlier pretends to discover hosts' weaknesses by sending port probes. An attacker can perform a Port scan attack in several ways [24]. Those ways are following described:

- **Horizontal scan** this method is a scan that is done from one host to many hosts inside the same network on a service of a particular host.
- **Vertical Scan** this technique is executed by connecting a single host to a variety of ports, during

a short period of time.

- **Block Scan** Block scan is performed by a combination of a horizontal and a vertical scan.

The technique that has been the target of research studies is the horizontal scan, which cause some impact on the traffic. When a host make connections to a range of hosts in specific network it may indicate that a horizontal scan may be performed. When a host that is being scanned does not respond to scan it might also imply that a horizontal scan is being executed.

FTP Authentication Scanner

This attack explores the FTP protocol. It intends to make several attempts to successfully authenticate in a FTP server. It test FTP logins on a range of machines. This attack can be performed using a file, which contains usernames and passwords, to be used on the authentication attempts.

Impact on Traffic

As was mentioned, this attack performs several authentication attempts on a FTP server. This action produces a lot of FTP traffic. All the requests and server responses cause a considerable impact on traffic behaviour.

2.3.4 Atacking DNS Servers

The DNS is an essential part of the Internet. Therefore, it can be easy to deduce that DNS servers have also been labelled as targets of security attacks. Actually, DNS servers have been the main targets for attackers. As is well known, without DNS people would not be allowed to connect to their websites. Those attacks are possible due to the fact of bugs in the DNS software and exploits in the DNS protocol. It also can be possible practicing DoS attacks, overloading a host with packets taking up large amount of bandwidth in order to make the DNS server unavailable for legitimate users, as was mentioned before.

DNS Cache Poisoning - Kaminsky Attack

Security researcher, Dan Kaminsky, discovered a seriousness DNS cache poisoning (Figure 2.2) vulnerability, which raises the area for network security developers and administrators and it should cause development of an ample plan to focus on this dangerous threat.

This attack exploits the lack of any signature validation on DNS entries, which allows the attacker to inject forged resolves for a domain or host. It is possible to poison the cache of a DNS server with recursive querying enabled or an end host. It is initiated at the right moment that a victim nameserver ask for the address resolve. The attacker, knowing that the victim will shortly be asking to resolve an address, starts flooding the victim with forged DNS reply packets. This is possible only if the attacker knows which DNS server is the authoritative one for the address resolution. There are already several attempts to make the authoritative DNS server not responding effectively and quickly. Those attempts are focused on slowing down the server by performing DoS attack [26].

Lately, several approaches have been developed and implemented in order to prevent DNS servers from Kaminsky attacks. DNS Servers use Pseudo Random Number Generation (PRNG) for the QID field in order to generate random numbers for QIDs. However, those kinds of patches only make a cache poisoning attack a harder task [7].

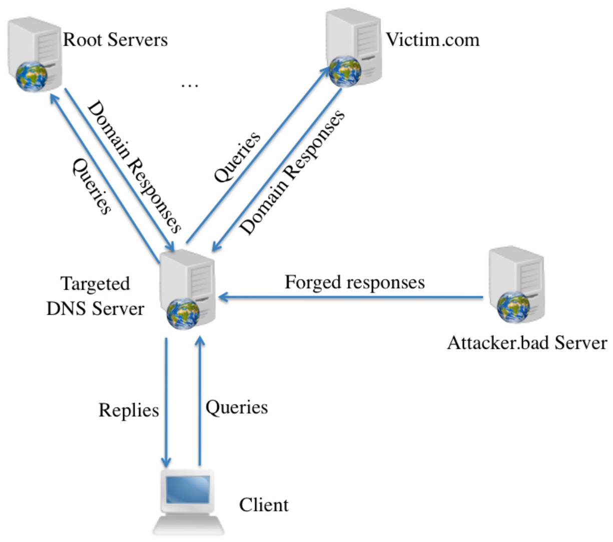


Figure 2.2: Cache poisoning by Dan Kaminsky [1].

So, how does Cache Poisoning works? The attacker asks for a random name within the target domain that is unlikely to be in cache. At one point Targeted DNS Server enquire all DNS hierarchy for the IP address of Victim.com and it uses a specific query ID (always one higher than the previous query). Meanwhile, the attacker starts flooding Targeted DNS Server with forged DNS reply packets with different queries ID. In each response packet, the attacker will be telling that he knows the IP address of the requested hostname. Though, that IP belongs to the attacker. Once the query ID match Targeted DNS Server thinks that Attacker's nameservers are authoritative for Victim.com. Consequently, Targeted DNS server will save in its own cache the name of the victim server associated to the IP address of the attacker. The DNS server of the victim may contain a lot of hostnames, so the probability that the attacker has to be quicker in his response that the authoritative DNS server is very high. [27].

[7]http://www.unixwiz.net/techtips/iguide-kaminsky-dns-vuln.html

This is a serious damaging attack. By possessing the whole target domain, the attacker is able to control everything that is associated to that resolving nameserver. For the attacker it is possible to redirect web visitors, route email, etc to his own servers.

Impact on Traffic

As was mentioned before, the goal of this attack is to fake out the victim into thinking that the attacker runs the domain in question. This attack causes a serious impact on the traffic behaviour.

A high number of responses to a query are a symptom of an unlawful attack. It is even more suspect when is realized that the only difference among all responses is the query ID field in the DNS header. The huge amount of replies is due to the query ID guessing. The number of replies from the attacker will fluctuate depending on the DNS servers PRNG (Pseudo Random Number Generator) [28]. This is due to the fact that it is still possible to guess within certain number of packets what is the next query ID that will be produced by the PRNG. In a network analyzer it is not possible to see the content of the packet, however it can be clearly seen the increasing number of responses. Therefore, a time sequence analysis of the ratio between the number of requests and the quantity of responses could be exploited to find the increased reaction to a DNS server request.

Another factor, which may have a serious impact on traffic behaviour, is the increased amount of recursive DNS requests to a DNS server. In the beginning of the attack, the attacker may request host resolutions for a huge number of hosts in a domain. However, by doing several analyses it is possible to observe this phenomenon and realize that at one point there is an amount of suspicious requests to a DNS server.

2.3.5 Fuzzing Attacks

Fuzzing attacks [25] consist on causing a software or network failure by feeding it randomly generated data. Usually it finds bugs or flaws in a target victim. It sends malformed data and observes how the device reacts. The response will indicate if there is a serious vulnerability or flaw, or not, in a certain point.

Fuzzer HTTP Malicious URI and **Fuzzer HTTP Incremented URI** are two typical attacks of this kind. Both of them overwhelm the target with malformed HTTP requests. Every single request is a different combination of a URI.

Impact on Traffic

As was mentioned, this kind of attack overwhelms the target with a several HTTP requests, therefore there is a large amount of data that is generated by fuzzing attacks in a network. These attacks have a huge impact on the traffic behaviour.

2.3.6 Frameworks

Throughout this section has been describing attacks and traffic that those attacks generate. However, it is necessary to produce that illicit traffic on the emulated networks. It was made an analysis of the various software packages that implement security attacks. Since this work focus on attacks, which have impact on traffic, NMAP and Metasploit emerged as the best option for this work.

NMAP

NMAP[8] ("Network Mapper") is an open source utility used to discover hosts and services on a computer network. This tool was designed to be performed in large networks but it also works fine in small networks and against single hosts. NMAP uses raw ip packets to know which hosts are available on the network. Plus, it can get more information such as: services and operating systems that those hosts are running, type of packet filters/firewalls used by those hosts, etc.
NMAP supports several methods of port scanning[9]. Each method intends to achieve a specific goal. Next, some relevant techniques will be described:

- **TCP SYN scan:** It is executed on many hosts very quickly on a network with no firewalls. It first opens a connection by sending a SYN packet, but it never finishes the connection.
- **TCP connect scan:** This scan is the default when SYN scan is not allowed to perform. It uses the OS to establish a TCP connection.
- **UDP scan:** It is used to determine the UDP port status by sending packages without UDP header to every single host.
- **TCP ACK scan:** It is used to map firewall rule sets.
- **Idlescan:** it is performed by sending packets with a forged ip address.
- **FTP bounce scan:** This kind of scan is used to scan for ftp servers configured as ftp proxies.

NMAP proves to be a powerful tool on port scanning procedures. It handles several of advanced techniques for mapping networks filled with routers, firewalls and any other obstacle.

[8]http://nmap.org/
[9]http://www.petri.co.il/port-scanning-with-nmap.htm

Metasploit

The Metasploit framework [29] shall be used to generate illicit traffic. Metasploit is an open source security software, which can be used to test vulnerabilities of computer systems and has a contribution of a large developer community. It intends to provide useful information and tools for penetration testers, security researchers and IDS signature developers.
In Figure 2.3 is illustrated an architecture overview[10] of the Metasploit Framework which expresses all the main components of this tool.

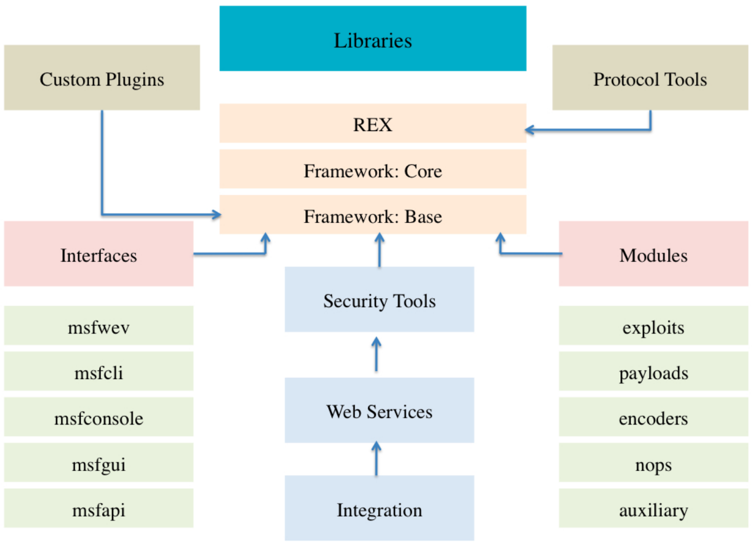


Figure 2.3: Metasploit Architecture Overview[7].

- **Framework Core:** the core provides plugins with the framework and also an interface. It is composed of several subsystems such as module management, session management, event dispatching, and others.

- **Framework Base:** provide an easy way to work with the framework. It has some tools, which allow functionalities such as configuration, logging and sessions.

- **Interfaces:** the Metasploit framework provides interfaces, which allows the user to interact with the framework. There are several kinds of interfaces such as:

  – *msfweb*, the metasploit web interface;

  – *msfgui*, the metasploit GUI application;

  – *msfconsole*, metasploit interactive session;

[10]http://netsec.cs.northwestern.edu/media/slides/metasploit.pdf

- **Exploits:** Metasploit contains more than 110 exploits, which can explore several protocols, such as UDP, TCP, HTTP, FTP, SMPT, SSH, etc. They all cover multiple platforms and also explore wireless (802.11) vulnerabilities.
- **Payloads:** After an exploit being executed the Metasploit provides a wide variety of choices to execute threads in the remote target. These include Meterpreter, which allows users to control the screen of a remote device and to browse, upload and download files.
- **NOP Generators:** NOP generators intend to obfuscate the NOP sequences and NOP sleds in order to avoid IDSs from triggering on traffic patterns.
- **Encoders:** Encoders allow the payloads not being detected by encoding them. Payloads can also trigger IDS signatures, so they must cross over the network without being detected.

As mentioned before this work intends to acquire traffic traces representative of security attacks. The Metasploit provides several attacks, which can represent the illicit traffic to be generated on the emulated networks. NMAP, in turn, provides several distinct port scans. It contains many port scanning mechanisms, OS detection, version detection, and more, which make NMAP a powerful tool to scan small and large networks. Therefore, these frameworks appear to be an appropriate tool to generate the illicit traffic.

All the attacks described on this section were considered on this work. All of them have impact on the network behaviour. So, they shall be generated and analyzed in an emulated network in order to identify anomalous events.

2.4 Licit Traffic

All attacks and illicit traffic described earlier shall be explored and analyzed in the most possible realistic environment. Therefore, licit traffic must be generated according to real networks implementations. In this section different research studies, which reports the current traffic breakdown, are described and analyzed.

Mainly, three different research studies [2, 4, 30] were considered in order to make a realistic characterization of the background traffic. In [4] was used packet traces acquired using a high speed monitoring box installed on the Internet link of two access networks. Every single packet seen on each direction of the link was captured. In Table 2.2 are listed three traffic traces (GN, UN1 and UN2), which are distinguished into several parameters: Date, time, period, source and destination IP addresses, number of packets, bytes perceived, average of utilization and the average number of flows per 5-minute interval.

The GN (Genome Campus) represents three institutions, which employ 1,000 researchers, administrators, etc. UN1 and UN2, in turn, are organized by numerous academic, research and residential complexes on-site. It was estimated a user population of 20,000.

Table 2.2: Traces Summary [4].

Set	Date	Day	Start	Dur	Direc	Src.IP	Dst.IP	Packets	Bytes	Aver.Util	Aver.Flows.
GN	2003-08-19	Tue	17:20	43.9 h	Bi-dir.	1455 K	14869 K	1000M	495 G	25Mbps	105 K
UN1	2004-01-20	Tue	16:50	24.6 h	Bi-dir	2709 K	2626 K	2308 M	1223 G	110.5 Mbps	596 K
UN2	2004-04-23	Fri	15:40	33.6 h	Bi-dir	4502 K	5742 K	3402 K	1652 G	109.4 Mbps	570 K

It can be concluded, by analyzing the table and its results that the two types of traffic traces (GN and UN) are similar except in *Peer to Peer (P2P)* category. In GN is verified a low percentage of *P2P* traffic, however that result it is not relevant due to the conditions of GN environments.

There are some interesting observations from these traces. In the UN network, *web* and *P2P* traffic are the most dominant. In spite of the difference of the time capture between UN traces, their traffic is generally similar. On the other hand, GN holds a considerable portion of *FTP* traffic. Researchers of this study also report that encrypted flows (such as SSH/SSL) correspond to 1%-2% of the traffic in all traces.

Another relevant fact is that *Nonpayload* flows report approximately for one third of all flows in both links. Researchers mention that a deep examination of these flows may indicate that the majority is related to failed TCP connections on ports of well-known exploits worms. It probably may indicate that several port scans were being performed while the traces were being captured.

The *Unknown* category, in turn, demonstrates that there are no guarantees that all flows in the traces represented can be classified. The analysis of the all applications cannot assure the classification of all applications participating on the Internet. In the case of the UN traffic, 4%-7% of all flows cannot be identified.

In another study [2] it was intended to investigate the use of several statistical traffic categorization methods for an ADSL provider managing many Point of Presence (PoPs).

In order to collect all traces it was used a passive probes located behind a Broadband Access Server (BAS). The traffic of the BAS routes to and from the digital subscriber line access multiplexers (DSLAM) and the Internet. Four packet traces were collected at three distinct ADSL PoPs in France from the same ISP: MS-I, R-II, R-III and T-I. Each trace has at least one hour of complete bidirectional traffic, with similar number of active consumers differing from 1380 to 2100.

In Table 2.3 are listed those four different situations, which have some relevant features related to space and time: two traces (RII and RIII) were captured at the same location with an offset of seventeen days between them. T-I was the earliest and longest trace captured. The remaining capture (MSI) was performed at exactly the same time as RIII.

Table 2.3: Traces Summary [2].

Set	Date	Start	Dur	Size[GB]	Flows[M]	TCP[%]	TCP Bytes [%]	Local users	Distant IPs
MS-I	2008-02-04	14:45	1h	26	0.99	63	90.0	1380	73.4 K
R-II	2008-01-17	17:05	1h 10m	55	1.8	53	90.0	1820	200 K
R-III	2008-02-04	14:45	1h	36	1.3	54	91.9	2100	295 K
T-I	2006-12-04	12:54	1h 48m	60	4.1	48	94.7	1450	561 K

For this work, researchers chose some Classes, which are mentioned in Table 2.4. As it can be seen in the table HTTP traffic is divided into several classes: Webmail is classified as mail, HTTP streaming as streaming, HTTP file transfers as FTP, and so on. P2P applications have their own class. However, *P2P* applications, which are not so popular, are represented into the P2P-REST class.

On Figure 2.4 the application breakdown of the four different traces is illustrated . Researchers concluded that the application breakdown on POPs is representative of the traffic witnessed on longer intervals. In Table 2.5 is represented the approximate percentage values for each application illustrated on 2.4.

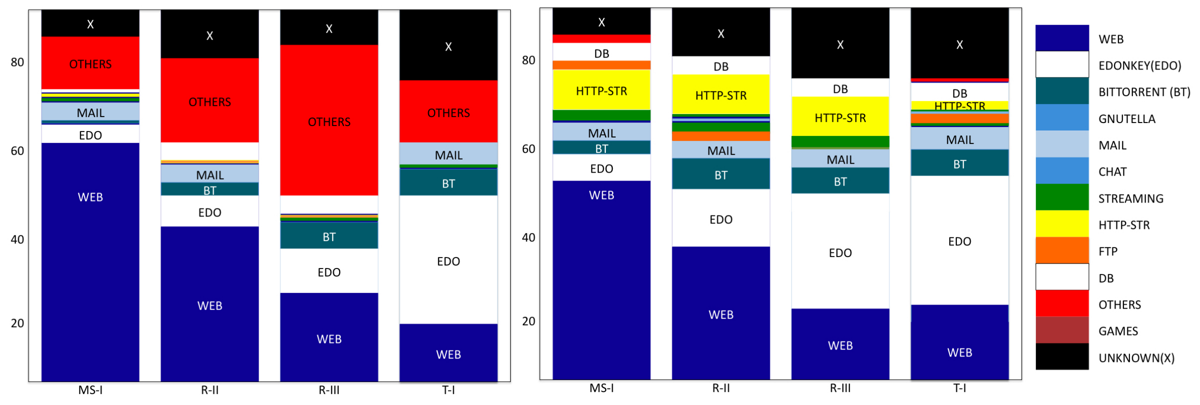


Figure 2.4: Breakdown in flows and bytes [2].

As in the previous research study it can be found some dominant applications. Once again, *web* and *P2P* traffic emerged as the most dominants. On *P2P* applications, it can be observed that most bytes and flows are related to eDonkey followed by Bittorrent and Gnutella. As it can be seen in Figure 2.4 a large portion of traffic is related to streaming. Great part of HTTP Streaming class is due to Dailymotion

Table 2.4: Breakdown in Flows (Bytes) [2].

Class	Application/Protocol
WEB	HTTP and HTTPs browsing
EDONKEY	eDonkey, eMule obfuscated
MAIL	SMTP, POP3, IMAP, IMAPs, POP3s, HTTP Mail
CHAT	MSN, IRC, Jabber, Yahoo, Msn, HTTP Chat
HTTP-STR	HTTP Streaming
OTHERS	NBS, Ms-ds, Epmap, Attacks
DB	LDAP, Microsoft SQL, Oracle SQL, mySQL
BITTORRENT	Bittorrent
FTP	Ftp data, Ftp control, HTTP file transfer
GAMES	NFS3, Blizzard Battlenet, Quake II/III, Counter Strike, HTTP Games
STREAMING	MS Media Server, Real Player, iTunes, Quick Time
GNUTELLA	Gnutella
ARES	Ares
TRIBALL	Triball
P2P-REST	Kazaa, SoulSeek, Filetopia, Others
NEWS	Nntp
UNKNOWN	-

and Youtube, which hold 80% of bytes. Some P2P streaming applications belongs to STREAMING class due to, e.g., sport events and they are active only for a short period. Perhaps that is the reason why sometimes such traffic cannot be seen in the analyzed data. The UNKNOWN class had generated bytes between 8% and 24%, depending on the trace.

The third research study [30] performed analysis of traffic statistics long-term evolutions, for traces collected every day, for 15 minutes, between 2001 and 2008, over trans-Pacific backbone links (the MAWI dataset [31]). The aim of this study was to perform a longitudinal study of the evolution of the traffic collected every year during seven years. The main datasets are on a daily basis packet traces and has some relevant features related to space and time. Those traces were captured at two different transit links of the WIDE network: One from 2001/01 to 2006/06 (hereafter link **A**) and then in another one from 2006/10 to 2008/03 (hereafter link **B**). Due to the fact that traffic is asymmetric researchers had to study the traffic separately for each direction: Traffic going to Japan (hereafter *US2Jp*) and outgoing traffic (hereafter *Jp2US*).

Table 2.5: Breakdown in Flows (Bytes) [2].

Set	Web	EDO	MAIL	Others	x	BT	HTTP-STR	FTP	DB	Streaming
MS-I	62% (50%)	5%(10%)	5%(5%)	15%(4%)	10%(5%)	1%(5%)	1%(10%)	1% (2%)	- (5%)	- (4%)
R-II	12% (35%)	10% (15%)	5% (5%)	20% (2%)	15% (10%)	5% (10%)	2% (10%)	1% (4%)	- (5%)	- (4%)
R-III	25% (20%)	15% (30%)	2% (5%)	30% (-)	12% (20%)	10% (5%)	2% (10%)	2%(-)	5% (5%)	2% (5%)
T-I	20% (25%)	25% (35%)	5% (5%)	15% (1%)	20% (20%)	10% (5%)	- (2%)	- (2%)	- (5%)	5% (-)

The results obtained are quite similar to those acquired on the previous research studies. During the all study period, TCP and UDP handled more than 90% of packets uninterruptedly. Also, ICMP packets showed to have a relevant impact on traffic: More than 50% packets in *Jp2US* and 25% packets for *US2Jp*. In TCP UDP mostly of packets consists of Web traffic. On **A** *web* traffic consists of 40% of valid traffic for *Jp2US*, and for *US2Jp* was around 50-55%. On **B**, in turn, *web* traffic raises to approximately 60% in both directions. *P2P* traffic also has a considerable impact in the traffic evaluated during those seven years. That kind of traffic represents around 30% of the packets, mainly Napster, Gnutella and more recently Bittorrent. However, this traffic had a tendency to vanish over the years. However, that decline does not represent a realistic traffic behaviour. Actually, it happens due to *P2P hiding* [32] .

All over the years the content of legitimate traffic did not change considerably. *Web* and *P2P* traffic have been emerged as important elements on the traffic behaviour. Researchers also observed that a significant number of anomalies were found to be consistent.

Three different and recent research studies were analyzed. All of them have their own results, however they all converged to the same idea: Nowadays, traffic behaviour is mostly represented by *web* and *P2P* traffic. Lately, streaming also emerged as an important element, which influences the traffic behaviour. Common Internet services such as FTP, mail (Simple Mail Transfer Protocol (SMTP), IMAP,...), new protocols, DNS, etc... also considerably characterized the traffic behaviour and it has been remained stable all over the years.

Those three studies represent the real traffic behaviour at the present time. Some common applications and services were considered on this work, based on these research studies, to generate background traffic. The applications and services that were intended to be deployed on the emulated networks are mentioned in Table 2.6.

As it can be seen on the table *web* and *P2P* traffic were seriously considered on this work. Streaming traffic was also considered due to the increasing number of streaming applications on the Internet. Other common services, such as FTP, were also intended to be implemented in order to generate the most possible genuine traffic on the emulated networks.

Table 2.6: Traffic percentages in flows (bytes) of the applications/services.

Application/Service	Flows (Bytes)
Web	35-40% (30-40%)
Mail	5-10% (5-10%)
Streaming	10-15% (10-15%)
P2P	20-25% (20-25%)
FTP	1-10% (5-15%)
Chat	1-5% (1-5%)
Games	1-5% (1-5%)
Network Management	5-15% (1-5%)

2.5 Previous Work

This project follows on from another one [3], which created a controlled emulation environment to establish and obtain the ground-truth of a given topology.

In the project [3] different topologies were built. Figure 2.5 is a scenario example which represents the interaction between two main routers of two departments of Universidade de Aveiro and a backbone router connected to the server. All of the three routers provide redundancy. On this scenario some services were configured in the routers and server: Dynamic Host Configuration Protocol (DHCP) server, DNS, OSPF, Simple Network Management Protocol (SNMP) Agent, Berkeley Internet Name Domain version 9 (BIND9) and ProFTPD.

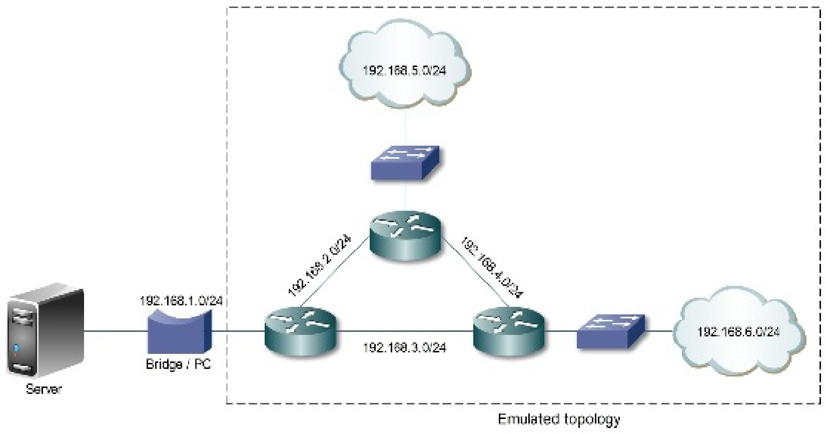


Figure 2.5: Scenario A [3].

The project of this document relied on the work made in Universidade de Aveiro. However, this project looked for further goals. It developed different emulated scenarios that faithfully reproduce networks implemented in the real world. Plus, in different scenarios were implemented more applications and services according to the statistics gathered in the previous section. More sophisticated attacks, as the ones described in 2.3, were implemented on the emulated networks.

Summary

In this chapter it was introduced the fundamental concepts, starting with a brief overview of the network evaluators which can provide a controlled network environment. For this project was adopted the emulation method due to its capabilities on mimic realistic scenarios. Furthermore, it was described the main attacks which have impact on traffic behaviour, with emphasis on the FTP Authentication Scanner, FTP Stack-based Buffer Overflow, Kaminsky's DNS cache poisoning attack, TCP SynFlood, Portscans and Fuzzers. For the licit traffic, three different studies were analyzed in order to get the real and actual traffic behaviour on common deployed networks. It was also described a previous work [3] made in the Universidade de Aveiro which has an important contribute to this project.

3 Emulated Networks

This chapter presents the architecture that will be used throughout the remainder of the document. All the necessary topologies, configurations and applications will be reported and discussed. Plus, the traffic production generated will be also explained. The traffic was divided in two categories: Licit and Illicit. The generation of both kind of traffic will be detailed and the amount of traffic produced for each service will be also analyzed. Finally, it will be explained how the data generated on the emulated networks was captured.

The main target of this project was to acquire a high quality ground-truth by emulating different network topologies where licit and illicit traffic shall be generated as it is shown on Figure 3.1. This work relied on the previous work described on previous chapter.

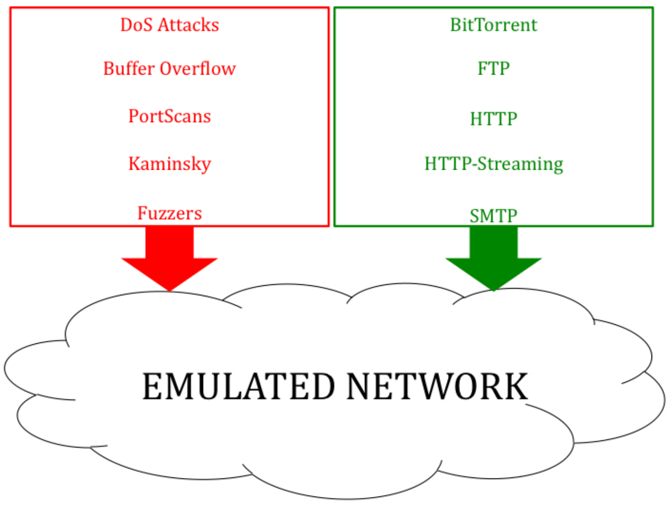


Figure 3.1: The proposed architecture.

Emulation is based on GNS3 and virtualization. All the network devices (emulated and real) are configured in order to create a network environment. For that, some important points were considered to develop the proposed work:

- In terms of network topologies it was proposed to develop the scenario described in 2.5. That topology represents an approximation to the network of Universidade de Aveiro. The motivation was focused on generate more licit and illicit traffic thus making the scenario more realistic in terms of traffic behaviour. However, this scenario was holding GNS3, which overwhelms PC resources. Therefore, this work intended to build an alternative, which would not need an emulation platform to develop it. It consisted in a topology similar to the Instituto Superior Técnico network to emulate in a high-level abstraction-modeling network with highly scalable model.

- In terms of licit traffic it shall include at least all the traffic described in the previous section, such as DNS, HTTP, HTTP-Streaming, FTP, P2P and SMTP with the respective percentage values stipulated on section 2.4.

- In terms of illicit traffic it intend to include at least the attacks described earlier in section 2.3. Those attacks have a considerable impact on traffic network which can causes changes in the traffic behaviour.

In a high level overview this is how this project looked to achieve the goal of acquire a high quality data to be used as a ground-truth for the evaluation of statistical methods used to detect security attacks. The development of this project was based on five different phases, as shown in Figure 3.2: Topologies Development and their configurations, Technologies for Applications and Attacks, Traffic Generation, Capturing Data and Grouping Packets per Service/Attack. From now on this chapter will focus on these five different phases and describe every single step of them.

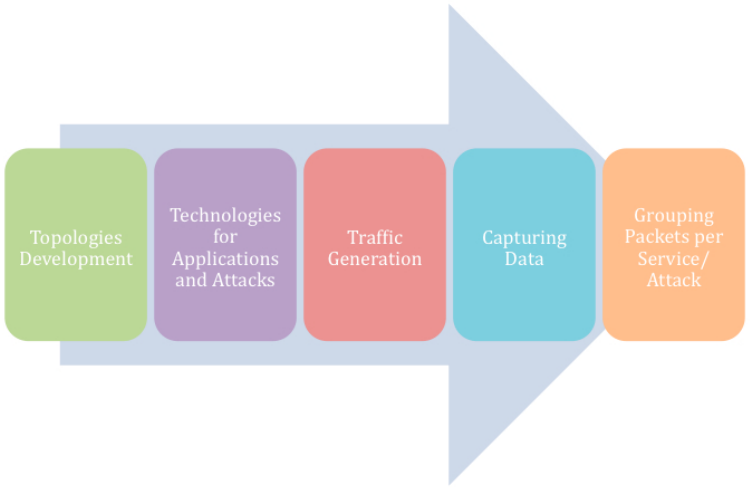

Topologies Development
Technologies for Applications and Attacks
Traffic Generation
Capturing Data
Grouping Packets per Service/ Attack

Figure 3.2: The five main phases of project development.

3.1 Topologies

For this work two different topologies were used. Both of them represent realistic scenarios which can be seen deployed in Universidade de Aveiro and Instituto Superior Técnico; those topologies were emulated in a high-level abstraction modeling network with highly scalable model.

Next, on Figure 3.3, is illustrated the emulated network (hereafter EN1) based on the network developed in the previous work earlier mentioned on section 2.5.

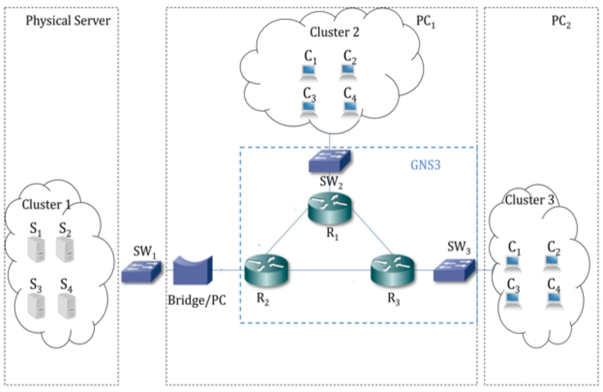


Figure 3.3: EN1 based on [3].

This emulated network was developed on three different physical machines. On the physical server were four virtual servers (Cluster 1) performing services, such as FTP, HTTP, HTTP-Streaming, SMTP and BitTorrent. On PC_1 was the emulated network supported by GNS3 and four virtual end-hosts (Cluster 2). Finally, on PC_2 were also four different virtual end-hosts (Cluster 3). One virtual terminal of Cluster 2 and 3 was executing licit and illicit traffic. The other end-hosts were all executing exclusively licit traffic.

On Figure 3.4 is shown the emulated network which represents a high scalable model of the IST's network (hereafter EN2). This network is represented by a star model where each Cluster is connected to a central switch.

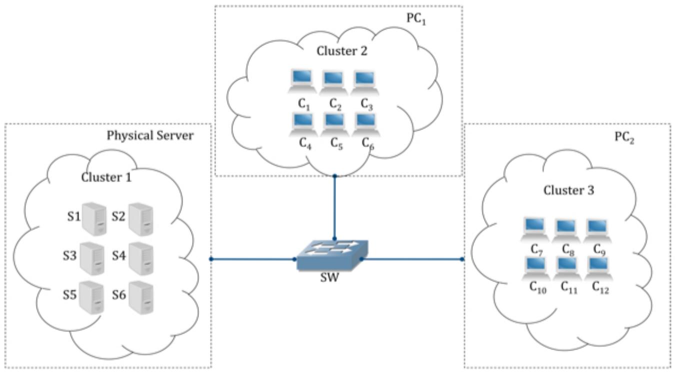


Figure 3.4: EN2 based on the IST's network. 1.

This emulated network was also developed on three different physical machines (one physical server and two PCs), which are represented as Clusters in the figure. Every physical machine had six different virtual end-hosts.

The Cluster 1 is represented by six virtual servers running services, such as FTP, HTTP-Streaming, SMTP, BitTorrent and HTTP. The Clusters 2 and 3 represent the Local Area Network (LAN)'s inside each department. Every LAN has a total of six virtual end-hosts, each of them making several requests to every single server on Cluster 1. On Cluster 2 there are 2 hosts executing attacks, as well as another legitimate applications, in order to perform illicit traffic. On Cluster 3, in turn, there is one end-host performing only attacks.

3.2 Configuration of Network Devices

This section describes all the configurations involved in all devices (emulated or real) of the both emulated networks. It is mainly focused on EN1 for having more emulated components. All the configurations made on EN2 are nearly the same on the EN1.

3.2.1 Servers

In both topologies the Cluster 1 is represented by different virtual servers. Those servers were virtual machines in one single physical server (Figure 3.5). In this work the servers would have to run multiple services at the same time. Therefore, the server virtualization in one single physical server emerged as a better option due to performance issues. Server virtualization is a proven technology that allows developing multiple virtual machines in one single physical server. Each virtual machine is totally isolated from other ones, which allows running different operating systems and applications.

Figure 3.5: HP ProLiant DL160 G6 L5630 4GB (1P) 4-core, 2,13 GHz, 12 MB L3, 40W.

Webmin

Webmin[1] is a web-based interface for system administrator for Unix. Instead of manually edit configuration files and run commands to create accounts, Webmin allows setting up a web server and performing a lot of tasks on it. It provides a web interface to manage all services that a single server handles. The web server and all its programs are written in Perl version 5. Using any browser that supports tables and forms, it is possible to setup accounts, Apache, DNS, file sharing and so on. It also performs automatically updates of the all required configuration files.

In all virtual servers of Cluster 1 was installed Webmin in order to have a better efficiency on installing and configuring every different services. The Webmin page can be accessed on port 10000 of each server (*http://ip.server.address:10000/*).

Xen Server

All the servers represented on Cluster 1 were implemented on XenServer virtual machine which is an enterprise version ox Xen from Citrix [2]. Four virtual machines (six in EN2) were setup for emulation matters. Each of those virtual machines were running four different services, named FTP, SMTP,

[1]http://www.webmin.com/

[2]Citrix Inc. Citrix XenServer. http://www.citrix.com/

HTTP-Streaming and HTTP. However one of those six servers was running two additional services: DNS and DHCP.

Each virtual machine is assigned 512MB of memory and adequate disk space. In the following table are represented some of the configurations and applications of each virtual machine.

Table 3.1: Servers Characteristics.

No.	Memory(MB)	Services
1	512	DHCP, DNS, FTP, HTTP, HTTP-Streaming, SMTP
2	512	FTP, HTTP, HTTP-Streaming, SMTP
3	512	FTP, HTTP, HTTP-Streaming, SMTP
4	512	FTP, HTTP, HTTP-Streaming, SMTP

Summarizing, every single server of Cluster 1 was a virtual machine implemented by XenServer in a HP ProLiant DL160 physical server. Each server was running different services remotely managed by Webmin program that was installed in every virtual server. The services implemented on Cluster 1 will be described in section 3.3.

3.2.2 Clients

The clients that were emulated are the hosts represented on Cluster 2 and 3. In this section it will be described how the emulated hosts were connected to the real equipment in order to mimic a realistic network. All the configurations are mainly related to the EN1 (Figure 3.3).

This work intends to emulate end-hosts requesting different kinds of services to externals servers. For that, as was earlier mentioned, it was resorted to the virtualization technology. It was used **Virtual Box**, which is available on linux repositories, to execute the virtualization of all end-hosts of Cluster 1 and Cluster 2 of both topologies. Virtual Box also provides bridged networking technology for its virtualized machines.

Since that in EN1 the PC$_1$ was handling an emulated network executed in GNS3 environment it was necessary to develop a combination of real, emulated and virtual equipment. For that, each virtual end-host, of Cluster 1, was associated to a virtual interface in order to connect to the emulated network in GNS3. Plus, it was needed to connect all the virtual and emulated components of PC$_1$ to the external and physical server. For that it was used the bridge technology in order to gather virtual interfaces, which were associated to the virtual end hosts, with the external interface of PC$_1$.

Linux repositories provides two tools that were used to guarantee the connection of real and emulated equipment:

- *Bridge*, is performed on the data link layer and allows to connect two networks segments. Ethernet bridges represent the software analog to a physical Ethernet switch, which can be used to connect multiple Ethernet interfaces.

- *TUN/TAP interface*, is a software that only exist in the kernel and has no physical hardware component. It can mimic a real network adapters and their main difference is that a tap interface outputs full Ethernet frames, while a TUN interface outputs raw IP packets. Since in TUN interfaces are no Ethernet headers added by the kernel, TAP interfaces emerged as a better option for this work. Plus, with TAP interfaces is possible to connect them to the bridge.

These two tools provided by Linux repositories allow the creation of a bridge to connect the emulation network to real devices and also the emulation of end-hosts inside the emulated network.

3.2.3 Emulated Routers

Network emulation can combine real equipments with emulated networks. As mentioned the emulated network of EN1 was developed on GNS3 platform, which contains several useful characteristics to build a network. In GNS3 can be found an entire list of all devices that can be emulated as routers, ATM switches, Ethernet switches PCs, Clusters among others. Although the platform contains PCs to be emulated, it was decided to use virtual end-hosts in order to support the execution of several services. The computers emulated by GNS3 are very limited for this purpose.

The GNS3 also provides a console where it can be seen the *Dynagen* commands and a topology summary where is described all the nodes involved in the emulated network and their links to other devices. It also permits to design the emulated network in an environment for that purpose. All the items that GNS3 allows to emulate can be used for that nature.

In GNS3, as was mentioned, is available a whole number of devices that can be emulated in GNS3 environment. However, some of these nodes (mainly routers) require an IOS image associated with it to be emulated. Next, in Table 3.2 is shown a list of IOS images that is supported by GNS3.

GNS3 has an additional tool in its environment to prevent the PC overwhelming resources. During the emulation time, GNS3 can waste PC resources in a fasting time period. In order to avoid that painful situation and optimize PC resources used by GNS3 the tool *Idle PC* emerged as a good option. The user for every single router in the emulated network calculates this value. Once a value is calculated and

Table 3.2: List of current Cisco IOS images supported by GNS3.

List of Cisco IOS images		
1710	2611	2691
1720	2611XM	3620
1721	2620	3640
1750	2620XM	3660
1751	2621	3725
1760	2621XM	3725
1760	2621XM	3745
2610	2650XM	7200

associated to a router the PC resources will be only used when needed.

Router Interface Configuration

In all routers was necessary to configure every single interface. For that, it was needed to execute IP addressing commands as shown in the Figure 3.6.

```
Router2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#interface Ethernet0
Router2(config-if)#ip address 192.168.30.1 255.255.255.0
Router2(config)#no shutdown
```

Figure 3.6: Router interface configuration example.

As it can be seen in the previous example, it was selected the Ethernet interface (Ethernet0) to address it with the *ip* 192.168.30.1 followed with the 255.255.255.0 as the subnet mask. The command *no shutdown* allows to set the interface on permanently.

Open Shortest Path First (OSPF)

The OSPF is a routing protocol for IP networks. It keeps track of a whole topological database of all connections in the local network. This protocol is performed as described bellow:

In EN1 all the routers emulated were configured with OSPF protocol in order to create their routing tables and get the same description of the topology of the local network. The Figure 3.7 presents the basic commands to use to configure OSPF protocol in a single router.

```
Router5#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router5(config)#router ospf 87
Router5(config-router)#network 0.0.0.0 255.255.255.255 area 0
Router5(config-router)#exit
Router5(config)#end
Router5#
```

Figure 3.7: OSPF configuration example.

In this configuration example is defined the OSPF process number 87. It is possible to use a different number for every router, since it does not propagate outside of the router. It is also define the area ID of a network that is directly connected to the router (0.0.0.0) and delineates the wildcard (255.255.255.255) mask for that network. Finally, it is defined the area of the OSPF process (area 0). In case of a small network, this can take always the value zero (0), however for larger networks, the area IDs should be accurately planned.

3.3 Technologies for Applications and Attacks

As was reviewed in section 2.4 and 2.3 some services and attacks has a huge impact on real networks and also characterize the real world wide networks behaviour. The main transport protocols (UDP and TCP) in common networks were faithfully explored and deployed in the emulated networks. For this work it was considered to explore services and attacks that usually run over these two protocols. Next, in Tables 3.3 and 3.4, is illustrated each service and each attack that was explored on the deployed emulated networks.

Table 3.3: Emulated services.

Services
BitTorrent
DHCP
DNS
FTP
HTTP
HTTP-Streaming
SMTP

Table 3.4: Emulated attacks.

Attacks
FTP Authentication Scanner
FTP Stack-based Buffer Overflow
Fuzzer HTTP Long String
Fuzzer HTTP String URI
Kaminsky
Port Scan
TCP SynFlood

Each server was running services, such as FTP, HTTP, HTTP-Streaming and SMTP, during the emulation time. Though, one server was running two additional services, named DHCP and DNS. BitTorrent was also another important service running on the emulated networks, but that was generated among hosts of Cluster 2 and 3.

Regarding the illicit traffic, in EN1 one host of Cluster 2 and 3 was executing licit and illicit traffic. In EN2, two hosts of Cluster 2 were running illicit traffic, as well as licit, while in Cluster 3 one single host was exclusively generating illicit traffic.

In this section all the applications that were generated and its configurations will be described. Plus, the illicit traffic and the attacks that were used during the emulation time will also be reported.

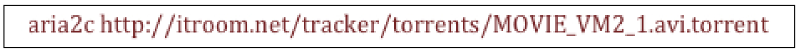
3.3.1 Licit Traffic

Seven different applications were chosen, according to the studies previously analyzed. Those services that were deployed on the emulated networks will be following described.

BitTorrent

BitTorrent [RFC 5694][3] is a peer-to-peer file sharing protocol that allows sharing out large amounts of data all over the networks. This protocol was implemented through all emulated hosts of both topologies. Two different tools were used to implement BitTorrent:

- *Transmission*[4], is a open source BitTorrent client with several features included such as encryption and tracker editing. It was used to create the torrent and make the content available for uploading purposes. This two actions were madden before the emulation period.
- *Aria2*[5], is a utility for downloading files, which has a segmented downloading engine in its core. It is able to download one file from several URLs. After downloading an entire file, aria2 put it available for any other request to download it. In Figure 3.8 is an example of using aria2 for download a torrent file and start the interaction between other peers.



```
aria2c http://itroom.net/tracker/torrents/MOVIE_VM2_1.avi.torrent
```

Figure 3.8: Example of a HTTP-Streaming client command.

To perform this protocol it was needed to install a Tracker in one server in order to assists in the communication among peers using BitTorrent. For that, it was installed the RivetTracker [6] on one server of the Cluster 1. It uses MySQL as the database backend and it works as most other trackers. It provides detailed connection statistics and optional support for HTTP Seeding.

[3]http://tools.ietf.org/html/rfc5694
[4]http://www.transmissionbt.com/
[5]http://aria2.sourceforge.net/
[6]http://www.rivetcode.com/software/rivettracker/

DHCP

DHCP [RFC2131][7] is a protocol to assign dynamic IP addresses to devices on a network. This protocol uses an amount of time that a given IP address will be valid for a computer. This time can diverge depending on how long a user is likely to require Internet service.

In order to provide DHCP service to the emulated networks it was used DHCPd. DHCPd is also a service available on the Linux repositories. It allows to allocate address pools in each subnet and enters them into the *dhcpd.conf* located in */etc/dhcp3/* directory. On start-up, dhcpd interprets that file and stores a whole list of available addresses on each subnet in memory. When a client requests for an ip address, dhcpd assigns an address for it.

DNS

DNS [RFC 1035][8] is an Internet service that translates a computer's fully qualified domain into an IP address when queries are made. It is implemented using two different elements: the DNS server and the DNS client (or resolver).

DNS is an hierarchical structure. On the top is the root, which is the start of all branches in the DNS tree. Every single branch moves down from level to level. DNS addresses are mentioned to from the bottom up with the root at the far right.

Berkeley Internet Name Domain (BIND)9 is available on Linux repositories and it permits to configure the DNS zone file, which is stored in */etc/bind/zones*. It is also possible to configure the reverse zone file, stored in the same directory, which allows to get run the process of Reverse DNS Lookup.

FTP

FTP [RFC 959][9] is a standard Internet protocol that runs over TCP. It provides a file transfer service between different hosts on the Internet. FTP is an uncommon service in that it utilizes two different ports: Data (20) and Command (21) ports.

In every single server of Cluster 1 of both topologies it was implemented FTP service by installing ProFTPD[10]. ProFTPD is available on linux repositories and it provides a FTP Server. This solution permits to emulate the process of download and upload files. The main configuration file of ProFTPD

[7]http://www.ietf.org/rfc/rfc2131.txt

[8]http://www.ietf.org/rfc/rfc1035.txt

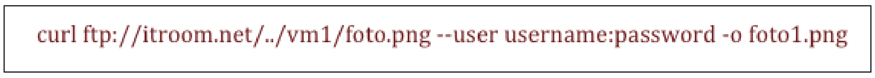
[9]http://tools.ietf.org/html/rfc959

[10]http://www.proftpd.org/

(*proftpd.conf*) can be found in the */etc/proftpd* directory.

To generate traffic in the emulated networks it was necessary to resort to a tool which allows download and upload using FTP protocol. Curl emerged as an adequate tool for these purposes. It is a command line tool available in Linux repositories. The command is designed to work without user interaction. It provides several of useful solutions such as user authentication, FTP download and upload and file transfer resume.

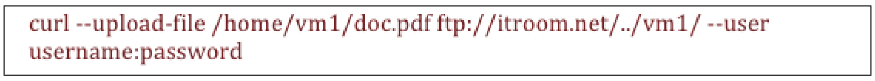
Below, in Figure 3.9 is an example of downloading a file with FTP protocol using Curl. As it can be seen, FTP is the protocol used to access the FTP server using specific credentials, such as password and username to download the file *foto.png*.



```
curl ftp://itroom.net/../vm1/foto.png --user username:password -o foto1.png
```

Figure 3.9: Example of FTP downloading using Curl.

The command line for upload from a FTP server, in turn, can be shown as the example of the Figure 3.10. As the previous example, the protocol used is FTP using credentials for the authentication.



```
curl --upload-file /home/vm1/doc.pdf ftp://itroom.net/../vm1/ --user
username:password
```

Figure 3.10: Example of FTP uploading using Curl.

HTTP

The HTTP [RFC 1945][11] is the underlying protocol exploited by the *World Wide Web*. HTTP clients (such as *Web Browsers*) and servers (such as *Web Servers*) interact via HTTP request and response messages. It runs over TCP connections. This application protocol uses TCP port 80 by default, although other ports, such as 8080, appear also as an alternative.

In order to perform HTTP traffic all over the emulated networks it was necessary to set up a LAMP[12](Linux Apache MySql PHP) server. It is the most commonly used combination for setting up a Web Server. All the components of a LAMP server can be found in the Linux repositories.

For this work it was used six different websites, named CNN, Eurosport, Público, A Bola, El Pais and Sky News, which were stored in the Apache's default document root(*/var/www/*). This is due to

[11]http://www.ietf.org/rfc/rfc2616.txt

[12]http://digitalfire.com/dreamsite/LAMP.html

the fact that this websites own several kinds of content which permits to generate even more traffic when is performed a HTTP request.

```
wget –bind-address=192.168.0.1 www.itroom.net/CNN.htm
```

Figure 3.11: Example of a HTTP request command.

HTTP-Streaming

HTTP-Streaming [RFC 6202][13] (also known as HTTP server push) is a method for sending data from a web server to a web client (e.g. browser). Usually the web server does not finish a connection after response data has been served to a client. Instead, the web server leaves the connection open such that if an event is alerted, it can be sent to one or several clients. Nowadays, as was discussed on section 2.4, this kind of service is common and has a huge impact on real networks. Web Servers, such as Youtube or Dailymotion, are a realistic example of that.

To perform HTTP-Streaming traffic on both emulated networks it was used VideoLan Client (VLC)[14] software. This is a free and open source cross-platform multimedia player that plays most multimedia files in several streaming protocols. For the reasons mentioned earlier it was adopted the approach of HTTP-Streaming in order to mimic as realistic as possible the real behaviour and impact that this protocol has nowadays in real networks implementations.

Next, in figure 3.12, is shown an example of executing a HTTP-Streaming service in the server. As it can be seen, the server with the IP address *192.168.0.1* is providing HTTP-Sreaming through the port 1234.

```
vlc -vvv input_stream –sout '#standard{access=http,mux=ogg,dst=192.168.0.1:1234}
```

Figure 3.12: Example of a HTTP-Streaming server command.

In Figure 3.21, in turn, is represented the command line executed from the client side for getting the HTTP-Streaming service provided by the server.

```
vlc -vvv http://192.168.0.1:1234
```

Figure 3.13: Example of a HTTP-Streaming client command.

[13]http://tools.ietf.org/html/rfc6202

[14]http://www.videolan.org/vlc/

SMTP

SMTP [RFC 2821][15] is an outgoing mail server protocol that is used to transfer e-mail messages among hosts. However, this protocol is limited on queuing messages at the receiving hosts. Due to this fact SMTP protocol is commonly used with on of two other protocols, named Post Office Protocol (POP)3 and Internet Message Access Protocol (IMAP). These two protocols let the host save messages in a server mailbox and download them from the server. Basically, users typically use a program, which employ SMTP protocol, for sending e-mail and either POP3 or IMAP for receiving them.

As alternative to the widely-used Sendmail program emerged POSTFIX[16]. POSTFIX was developed by Wietse Venema and is available on Linux repositories. It supports SMTP and runs in a chroot environment. In POSTFIX it can be found features such as POP3, Maildir and Mailbox format, Virtual domains and MySQL Database.

3.3.2 Illicit Traffic

As stated in section 2.3, five different categories were studied and analyzed for this work. For those categories were selected different scenarios attacks, named *TCP SynFlood*, *Kaminsky*, *Buffer Overflow*, *Port Scan*, *FTP Authentication Scanner*, *FTP Stack-based Buffer Overflow Fuzzer HTTP String URI*, and *Fuzzer HTTP Long String*. All these attacks were performed by the all-malicious end-hosts earlier reported. However, the Port Scan attack was executed only for one end-host due to reasons that will be later described.

To perform those attacks two different frameworks were used: Metasploit and NMAP. NMAP tool was mainly used to perform Port Scans in the emulated networks. Metasploit, in turn, had the purpose of executing other kind of attacks that have a serious impact on the networks. In Table 3.5 are mentioned those attacks used by Metasploit.

Table 3.5: Attacks deployed by each framework.

Metasploit
FTP Authentication Scanner
FTP Stack-based Buffer Overflow
Fuzzer HTTP Malicious URI
Fuzzer HTTP Incremented URI
Kaminsky
TCP SynFlood

[15] http://www.ietf.org/rfc/rfc2821.txt
[16] http://www.postfix.org/

In Metasploit every single attack can be used by a different module as noted in section 2.3. For this work were used two different Metasploit modules, such as Auxiliary and Exploit. The way that the attacks were generated and configured in the emulated networks differ among them. Then, it will be described all the attacks mentioned earlier, their configurations and module options[17].

FTP Authentication Scanner

This attack can be executed by model located in *auxiliary/scanner/ftp/ftp_login* on Metasploit framework. This attack executes FTP logins on a range of machines and reports succeeded logins. As it can be guessed this attack performs a large amount of traffic by doing all those attempts. Bellow, in Table 3.6, is described every single option of this module that was used to configure this attack.

Table 3.6: Module options for Scanner FTP Login.

BLANK_PASSWORDS	Try blank passwords for all users (default: true)
BRUTEFORCE_SPEED	How fast to bruteforce, from 0 to 5 (default:5)
PASSWORD	A specific password to authenticate with
PASS_FILE	File containing passwords, one per line
RHOST	The target address range or CIDR identifier
RPORT	The target port (default:21)
USERPASS_FILE	File containing users and passwords separated by space, one pair per line
FTPTimeout	The number of seconds to wait for a reply from an FTP command
TCP::max_send_size	Maxiumum tcp segment size. (0=disable)
TCP::send_delay	Delays inserted before every send. (0=disable)

FTP Stack-based Buffer Overflow

This attack can be found in the module on *exploit/linux/ftp/proftp_telnet_iac* Metasploit framework. It exploits a stack-based buffer overflow in ProFTPd servers. It sends malicious data in order to damage the server memory and execute arbitrary code. Some options of this module that were used in this work to configure the attack are described in Table 3.7.

Table 3.7: Module options for FTP Stack-based Buffer Overflow.

RHOST	The Target Address
RPORT	The target port (default 21)
CHOST	The local client address
ConnectTimeout	Maximum number of seconds to establish a TCP connection
TCP::max_send_size	Maxiumum tcp segment size. (0=disable)
TCP::send_delay	Delays inserted before every send. (0=disable)

[17]http://www.metasploit.com/modules/

Fuzzer HTTP Malicious URI

This module explore the HTTP protocol. It sends a chain of HTTP GET requests with malicious Uniform Resource Identifier (URI)s. This attack has a huge impact on traffic network. It performs several requests until being succeed. Every single request is a different combination of a URI.Next, in Table 3.8, are represented the options that were used for this module.

Table 3.8: Module options for Fuzzer HTTP Malicious URI.

RHOST	The target address
RPORT	The target port (default 80)
URIBASE	The base URL to use for the request fuzzer (default:)
VHOST	The virutal host name to use in requests
CHOST	The local client address
CPORT	The local client port
TCP::max_send_size	Maxiumum tcp segment size. (0=disable)
TCP::send_delay	Delays inserted before every send. (0=disable)

Fuzzer HTTP Incremented URI

Like the previous one this attack also explores the HTTP protocol. Its module is designed by *auxiliary/fuzzers/http/http_get_uri_long* on Metasploit framework. It also generates a large amount of traffic in a network. It sends a series of HTTP GET requests with incrementing Uniform Resource Locator (URL) lengths. In order to deploy this attack it was necessary to configure some options of this module. Those options are described in Table 3.9.

Table 3.9: Module options for Fuzzer HTTP Incremented URI.

MAXLENGTH	The longest string length to try (default: 16384)
RHOST	The target address
RPORT	The target port (default 80)
URIBASE	The base URL to use for the request fuzzer (default:)
VHOST	The virutal host name to use in requests
CHOST	The local client address
CPORT	The local client port
TCP::max_send_size	Maxiumum tcp segment size. (0=disable)
TCP::send_delay	Delays inserted before every send. (0=disable)

Kaminsky

The Kaminsky attack, as was described in section 2.3, has a huge impact on traffic due to the amount of queries and responses involved in the attack. Its module can be found on *auxiliary/spoof/dns/BailiWicked_domain*. This module attacks a flaw in DNS implementations which was discovered by Dan Kaminsky. It is performed by sending random hostname queries to the target DNS server with spoofed replies. Eventually, a query response ID will match and the packet will be accepted and the DNS cache will be poisoned from that moment. In Table 3.10 are described some options of this module that were used to implement this attack.

Table 3.10: Module options for Kaminsky Attack.

DOMAIN	The domain to hijack (default: example.com)
INTERFACE	The name of the interface
NEWDNS	The hostname of the replacement DNS server
RHOST	The target address
SRCADDR	The source address to use for sending queries (accepted: Real, Random) (default: Real)
SRCPORT	The target server's source query port (0 automatic)

TCP SynFlood

This attack performs a TCP SYN flooder and its module can be found in *auxiliary/dos/tcp/synflood.* It causes a DoS attack by sending several TCP SYN packets to a server or even a host. Due to this fact, this attack also generates a lot of network traffic and has a considerable impact on its behaviour. In Table 3.11 are represented some options of this module that were used to implement this attack.

Table 3.11: Module options for TCP SynFlood.

INTERFACE	The name of the interface
NUM	Number of SYNs to send (else unlimited)
RHOST	The target address
RPORT	The target port (default 80)
SHOST	The spoofable source address (else randomizes)
VERBOSE	Enable detailed status messages

Port Scan

As was earlier reported, a Port Scan is commonly used to send several messages in order to discover flaw in remote hosts. It is not easy to annotate this attack. Due to this fact, it was important to execute Port Scans attacks by an end-host that was producing exclusively illicit traffic. Therefore, this attack was performed in EN2 by one host of Cluster 3 that was executing only attacks. In this case, it is much easier to gather all the Port Scan traffic.

NMAP tool was used to perform this attack. NMAP allows getting any kind of information, such as services, firewalls, etc. Next, in Figure 3.14, is an example that was used to execute a portscan attack for this work.

```
> nmap -sT ip.server.address >> /path/to/save/output.txt
```

Figure 3.14: Example of a nmap command to perform port scans.

In the previous example is represented a TCP connect scan. In this case NMAP asks to establish a connection with the target machine and port by issuing the *connect()* system call. This level system call is used by *web browsers* and P2P clients to establish a connection.

3.4 Traffic Generation

In section 2.4 it was analyzed the impact of each application in common real networks. It was concluded that they all differ from each other in terms of their impact. HTTP and BitTorrent services emerge as the most representatives of traffic behaviour. FTP, SMTP and UDP traffic also have a considerably impact on real networks. Hence, this work intended to generate traffic in the emulated networks according to what has been previously studied.

Next it will be describe the process of automatization of each application and how different impact was guaranteed.

Cron

Cron is a job scheduler based on time that is available on Linux repositories. This tool allows tasks to be automatically executed in the background at periodically times. It is an effective way to schedule a routine background job at a specific time. For this work Cron tool was used to generate different kind of traffic by executing scripts periodically. The structure of a cron command is shown in Figure 3.15.

```
MIN   HOUR   DOM   MON   DOW   CMD
```

Figure 3.15: Structure of a Cron command.

As it can be seen the command is represented by six different elements that will be now described:

- *MIN*, represents the Minute field and its allowed value goes from 0 to 59.
- *HOUR*, in turn, is the Hour field and it goes from 0 to 23.
- *DOM*, is the Day of Month and it goes from 1 to 31
- *MON*, represents the Month field and its allowed value goes from 1 to 12.
- *DOW*, is the Day of Week and it goes from 0 to 6.

- *CMD*, is any command to be executed.

FTP, BitTorrent and SMTP were the services used on cron to be automatically generated in the emulated networks. Following, in Figure 3.16, is illustrated how these protocols were executed by cron.

```
* * * * * curl --upload-file /home/vm1/doc.pdf ftp://itroom.lan/../manuel/ --user manuel:idaivolta
```

Figure 3.16: Example of a Cron command.

In this example every field took the value '*'. That means that the command was executed every minute in every hour every day. However, as we shall see later, the emulated time considered for this work was for five minutes.

Scripts

Some protocols, such as HTTP, has a huge impact on real networks, as was analyzed before. Therefore it has to be executed more often comparing to other protocols. For that it was decided to write a script where commands, which were performing a random service (e.g. HTTP requests), were executed more often. Bellow, is an example of a script executing HTTP requests.

```
#! /bin/bash
while true; do
    wget http://192.168.0.1/CNN.htm
    sleep 5
done
```

Figure 3.17: Example of a script executing a HTTP Request.

As it can be seen in this example the script performs a HTTP request to the server with the IP address *192.168.0.1*. This request is performed every 5 seconds. As previously mentioned, each server was hosting six different *web pages*. Therefore this script was invoked for every single web page to all the six servers representing the Cluster 1.

As previously stated, each service was generated according to some patterns in order to realistically mimic the traffic behaviour. Some applications were executed more often than others. Basically, the process of traffic generation aimed to produce mostly HTTP and BitTorrent traffic. FTP and SMTP, in turn, were generated less often. The percentages that were considered for this work are represented in the Table 2.6 in Section 2.4.

Next, in the Table 3.12, is described the number of times a service was executed during the emulation time. In this table will be only represented the FTP, SMTP and HTTP services. Other services, such as HTTP-Streaming and Bittorrent, were executed once and lasted throughout the emulation period. Each attack, in turn, was also executed once by Metasploit framework during the emulation period.

Table 3.12: Execution process by each service.

Applications	#Hosts	#Servers	#Requests(per Server)	#Execution Period	Total of Executions
HTTP	12	6	6	5	25920
SMTP	12	6	1	60	21600
FTP	12	6	1	60	21600

3.5 Capturing Data

The goal of this Dissertation was focused on gathering data through the model, that has been described so far, in order to get a high level *Ground-Truth.* Throughout this chapter has come to describe the topologies, its configuration components and traffic generation. Particularly, in this section it will be described the process of gathering data during the emulation time.

The process of capturing data was practically the same in both emulated networks. As it can be seen in the Figure 3.18 all data was captured on the interface of each machine and Cluster.

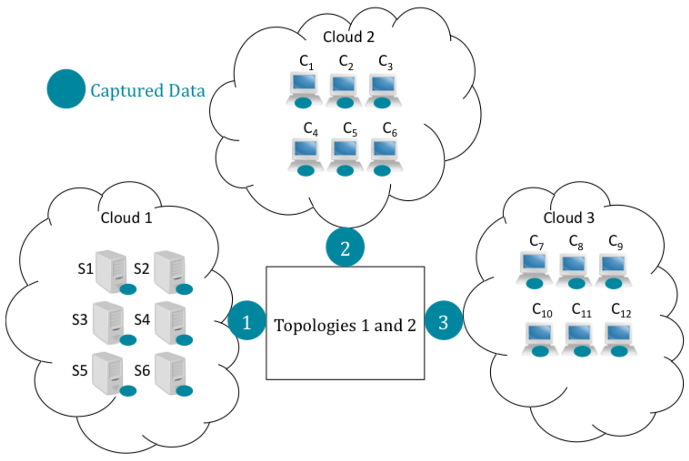


Figure 3.18: Points of Captured Data.

The emulation time for both topologies took five minutes. The procedure of capturing and organizing the data from the all different points was developed with two different tools, named *tshark* and *mergecap*.

Tshark is a Wireshark[18] terminal based (non-GUI). Basically it is a network protocol analyzer that is available on Linux repositories. It allows capturing data from a deployed network and also permits to read captured files in order to gather some statistics data.

For this work Tshark was used to capture and store all the traffic generated in the emulated networks. Following, in Figure 3.19 is an example of a Tshark command used in the three different machines in order to capture all the data generated.

```
tshark –b duration:value –i any –w $path_output
```

Figure 3.19: Example of a Tshark command.

Tshark tool allows to do a multiple file capture by using the *-b* parameter followed with the option *duration*. It permits to switch to the next file every *value* seconds. Since in this work the emulated time was for five minutes, it was decided to split the captured data into five files. It means that the field *value* took the number 60 (sixty seconds).

Mergecap is a program, available on Linux repositories, that allows multiple saved capture files into a single output file. It is based on timestamp, which means that the packets are written into the output file in an orderly manner. By default, it writes the output file in *libpcap*. In Figure 3.20 is an example of a mergecap command used to process the capture files.

```
mergecap -w - *.pcap > $path_final_capture_file
```

Figure 3.20: Example of a Mergecap command.

This command simply bundles all the capture files of a directory by placing the output file in the path set by *$path_final_capture_file*.

3.6 Grouping Packets per Service/Attack

Once the data was all gathered it was needed to separate it by service and attack for statistical purposes and to facilitate the data processing. This explains methods used to associate each packet to on application or attack.

[18]http://www.wireshark.org/

3.6.1 Illicit Traffic

All the attacks have a particular characteristic of their own even if it has to use a deep inspection packet method to find it. Below, in Table 3.13, the filters used for the traffic generated by each attack are described followed by a brief explanation for their use.

Table 3.13: Filters used for each attack.

Attack	Filter
FTP Authentication Scanner	ftp.request.arg==”username”||ftp.response.code==530
FTP Stack-based Buffer Overflow	ftp.request.command==SITE||ftp.response.code==220
Fuzzers HTTP Incremented URI and HTTP Malicious URI	not(http.user_agent)&&http.request
Kaminsky	dns.qry.name==example.com||dns.resp.name==newdns
TCP SynFlood	ip.len==40&&tcp.flags==0x02
Port Scan	ip.src==ip.from.the.attacker&&not(http||ftp||tcp.port==21||tcp.port==80)

- *FTP Authentication Scanner*: To perform this attack it was used a list of, already known, usernames and passwords that were attempts to successfully login in the FTP servers. Plus, this attack may generate a lot of attempts to get succeed in a Login interaction. That means that probably it will produce several login failures. So, the procedure of gathering the traffic generated by this attack was based on filtering by FTP request login. With this filter is possible to get all the traffic related to this attack. By performing this filter it was gathered all the malicious attempts on login in the FTP server and all the responses from the server indicating a *Login incorrect* (TCP flag = 530). Those are the main characteristics of this attack.

- *FTP Stack-based Buffer Overflow*: As was mentioned, this attack was performed by sending FTP requests, in order to damage the server memory and execute arbitrary code. This attack performed several FTP requests by sending commands followed by SITE. The server responses were also considered as a FTP Stack-based Buffer Overflow (TCP flag = 220). Mostly of those responses allowed the attacker to use and explore the FTP server.

- *Fuzzers HTTP, incremented URI and HTTP Malicious URI*: As earlier described this kind of attack is performed by sending HTTP requests. However, those requests do not include many HTTP headers. In particular, these attacks did not used the HTTP user agent header. This characteristic was used to identify them since all other HTTP packets generated by the emulator included this field.

- *Kaminsky*: This attack is performed by sending random hostname queries to a target DNS server followed by spoofed replies to queries from the authoritative nameservers for the targeted domain. Due to this fact, the main characteristics of this attack are the queries initially made to the DNS server and the several spoofed responses. The first parameter of the filter is related to the domain that was being hijacked and the second one to the hostname of the replacement DNS server.

- *TCP SynFlood*: As expected this attack contained a parameter that differed from other SYN packets. As stated in section 2.3, it is common to see DoS attacks using smaller size packets to attack a remote machine. Usually, a SYN packet has 60 (sixty) bytes but this attack, which was performed in the emulated networks, used SYN packets with 40 (forty) bytes. So, the data was filtered by SYN packets with 40 (forty) bytes of length, in order to gather all the information related exclusively to this attack.

- *Port Scan*: Only one host located on Cluster 2 of EN2 performed Portscan attack. This host was producing only illicit traffic. Therefore it was generating only HTTP and FTP apart from Portscans. To get all the traffic belonged to Portscan attacks it was necessary to filter by attacker IP address and all traffic that was no HTTP or FTP.

3.6.2 Licit Traffic

Applications and Services generate traffic using some known Application Layer protocols. Each of them has a particular signature in the networks. Every different protocol explore different TCP ports. However, the filtering process was not based only in TCP ports but also in host IP addresses and in application filters. Next, in Table 3.14, are the different filters used for each application followed by short description.

Table 3.14: Filters used for each service.

Attack	Filter
BitTorrent	(ip.src==X.X.X.X&&ip.dst==Y.Y.Y.Y)||bittorrent
FTP	(tcp.port==21||ftp-data)&&not((ftp.request.command==SITE||ftp.response.code==220)||(ftp.request.arg==”username”||ftp.response.code==530))
HTTP	http&&not(not(http.user_agent)&&http.request)
HTTP-Streaming	tcp.port==80&&not(http)
SMTP	tcp.port==25||smtp

- *BitTorrent*, this protocol was used only among hosts of Cluster 2 and 3 of both emulated networks. Plus, all the interaction between these hosts was exclusively done by BitTorrent protocol. Therefore, in this case, the filter to use would be a combination of a source and destination IP of all hosts of both Clusters in the topologies.

- *FTP*, in this case, the filtering process was based on TCP ports 20 and 21 because those are the ports mostly explored by FTP protocol.

- *HTTP*, in this case it was decided to get all the traffic by using the *http* filter. In this way it would be possible to gather only the traffic generated by the application layer.

- *HTTP-Streaming*, as is known, this type of traffic explores the TCP port 80. However, for the purposes of this project was necessary to distinguish the port 80 from the application layer, namely HTTP. This category was only focused on the traffic using the port 80 without using HTTP protocol interaction.
- *SMTP*, this protocol uses the TCP port 25 for its interactions.

3.6.3 Flows

Different flows were defined for the all traffic generated and captured. The flows were defined by **source IP**, **destination IP**, **source port**, **destination port** and **TCP**.

Each packet generated and captured in the emulated networks is associated to a respective flow. From the flow analysis at each 0.1 seconds it was extracted a set of features, which characterize it, such as: time, number of packets, number of bytes and number of each TCP flag (ACK; FIN; SYN; SYN,ACK; PSH and RST). For that, it was necessary to resort to *tshark* tool, in order to get all these features per packet. The specific information that was obtained from each packet in order to gather the packets by flow and characterize it by features was:

- *Time* (filter: frame.time_relative): The time when the packet was captured.
- *Packet Size* (filter: ip.len): The packet size in Bytes.
- *Source IP* (filter: ip.src): The Source IP address of the packet.
- *Destination IP* (filter: ip.dst): The Destination IP address of the packet.
- *Source Port* (filter: tcp.srcport): The TCP source port of the packet.
- *Destination Port* (filter: tcp.dstport): The TCP destination port of the packet.
- *TCP flag* (filter: tcp.flags): The TCP flag that represents the packet.

Following is an example of exporting, by using *tshark* with the filters above, all that information of every packets on a capture file into a text file in order to easier process and gather the information by flow.

```
> tshark -R "tcp" -r capture_file.pcap -n -T fields -e frame.time_relative -e ip.len -e ip.src -e ip.dst -e
tcp.srcport -e tcp.dstport -e ip.proto -e tcp.flags > ficheiro_final.txt
```

Figure 3.21: Example of a thsark command to gather specific information from a capture file.

For each flow the traffic was analyzed every 0.1 seconds. Since the emulation period took 5 minutes (300 seconds), it means that the time was divided in 3000 parts of 0.1 seconds. In each part was reported the number of packets, bytes and TCP flags generated in that period per flow. Next, in 3.15, it is an example of the characteristics of the packets generated every 0.1 seconds for a specific flow.

Table 3.15: Number of packets and their characteristics for a flow.

	0.1	0.2	0.3	...	299.9	300
#Packets	10	16	2	...	17	21
#Bytes	600	960	120	...	1020	1260
#ACK	6	8	0	...	7	15
#FIN	0	1	0	...	2	1
#SYN	2	3	2	...	3	4
#SYN,ACK	2	3	0	...	3	1
#PSH	0	0	0	...	1	0
#RST	0	1	0	...	1	0

As it can be seen for every 0.1 seconds is reported the quantity of each feature. The number that each feature generates over the time may indicate a pattern for an attack or service.

Once gathered all the necessary data in a text file, the aggregation process of the flows was undertaken. For that, all the packets related to a specific flow were collected in order to perceive the typical features of each application and attack.

Summary

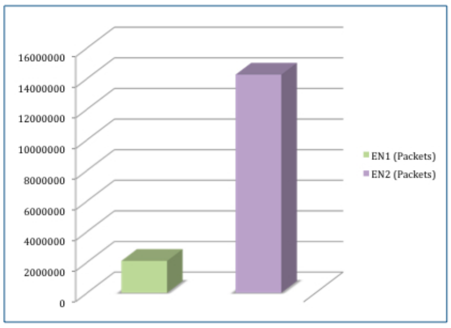
In this chapter it was introduced the architecture and its implementation. Five different phases were described: Topologies Development, Technologies for Applications and Attacks, Traffic Generation, Capturing Data and Grouping Packets per Service/Attack. Two different topologies were adopted for the emulation purposes: EN1 and EN2. It was described the configurations of network devices of each emulated network and their implementations. In both topologies were generated two kinds of traffic: Licit and Illicit. All the applications and services that were chosen to represent licit traffic were according to the research studies analyzed in the section 2.4 . The illicit traffic generated was based on attacks that have a considerable impact on network traffic behaviour. The method of capturing data, while the emulation time and the process of gathering data by each application and attack, was also described.

4 Results and Discussion

The main goal of this chapter is to perform an analysis of the traffic generated in both emulated networks and verify if it is in agreement with the objectives initially defined. It also seeks to investigate traffic signatures that can be used to detect the attacks. The analysis, which is held in this chapter, shall have regard to traffic generation process described in the previous chapter. As previously mentioned, the procedure of traffic generation was focused on the studies earlier analyzed. Therefore, the results should be in accordance with the conclusions drawn in section 2.4.

4.1 Aggregated Traffic

Starting from analyzing the amount of traffic generated in both emulated networks it can be seen that there was a considerable difference. This is due to the fact of both topologies were different from each other. Next, in Figure 4.1, is shown the traffic generated in both emulated networks in terms of Bytes and Packets.



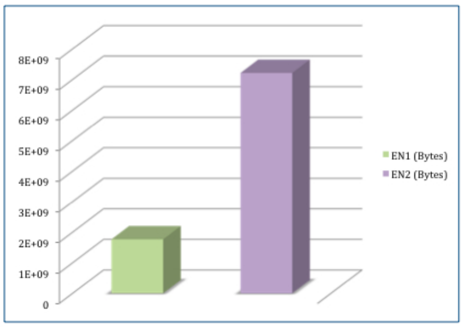
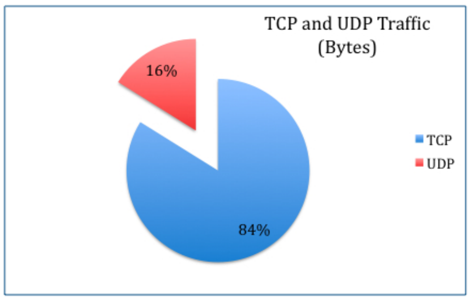


Figure 4.1: Packets and Bytes generated by each emulated network.

As it can be seen there was much more traffic generated in EN2 comparing to EN1. This is due to the fact that the load balance in EN2 was more or less equally distributed among all physical machines while in the EN1, the machine that was holding a great part of the emulated network was not capable to process and capture so much traffic. However, the main reason for this discrepancy was the fact of EN2 having more end-hosts generating traffic. In each Cluster of EN2 there were two more machines comparing to EN1 topology. Services, such as, HTTP, HTTP-Streaming, FTP and SMTP were significantly increased in the amount of traffic generated.

The traffic generated in both emulated networks was mainly TCP and UDP. All the services and attacks were running over these two transport protocols. Each of those two protocols was differently generated thus producing different traffic patterns. By comparing the quantity of traffic generated by TCP and UDP it can be seen a significant divergence. In Figure 4.2, is illustrated the balance of TCP and UDP traffic generated in EN1.



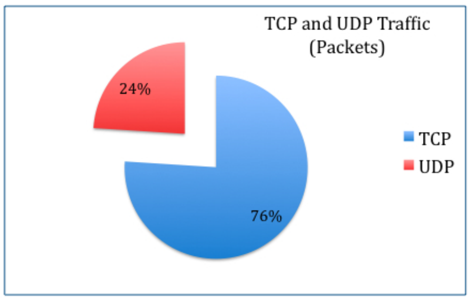
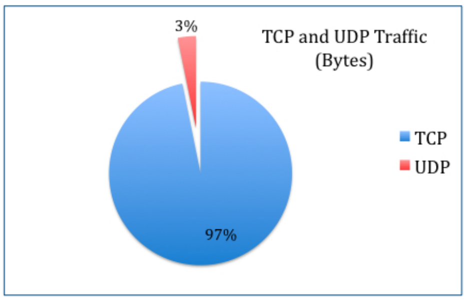


Figure 4.2: TCP and UDP traffic generated in EN1.

As it can be concluded, by the graphics shown above, great part of the traffic generated was TCP. As expected UDP only represents ∼20% of the traffic produced. Most of the services and attacks deployed in the topology were running over TCP. These values are according with the ones analyzed and concluded in section 2.4. In the EN2, in turn, it was verified a bigger difference on those values previously obtained for the EN1 (Figure 4.3).



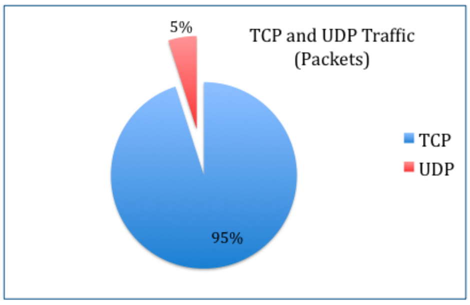
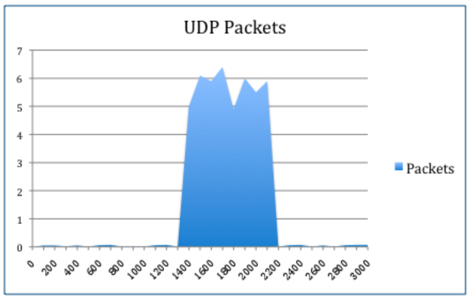


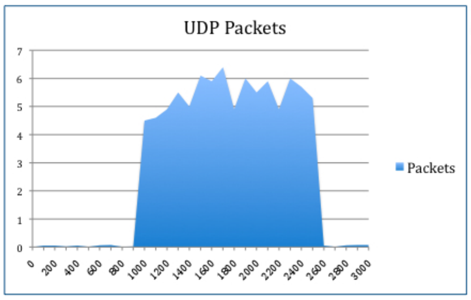
Figure 4.3: TCP and UDP traffic generated in EN2.

In EN2, UDP emerged with less impact on the traffic generated in the network. This is due to the fact there was more end-hosts in EN2. All the new end-hosts were executing much more TCP than UDP traffic. Since there were two more servers running services, such as, HTTP, HTTP-Streaming, FTP and SMTP it was expected that the amount of TCP traffic had increased comparing to UDP. Obviously, that also UDP traffic increased with the number of emulated machines, however it was not so significant.

UDP traffic was produced on the emulated networks by services, such as DHCP and DNS, and cache poisoning attack (Kaminsky). Over the emulation time, it was verified an unusual UDP traffic behaviour. In Figures 4.5 and 4.4 is illustrated the performance of UDP traffic throughout the emulation period.



Axis	Unit
Time	0,1s
Packets	1K



Axis	Unit
Time	0,1s
Packets	1K

Figure 4.4: UDP traffic behaviour in EN1.

Figure 4.5: UDP traffic behaviour in EN2.

As it can be confirmed there is a very unusual traffic behaviour. The UDP traffic grows at frightening rates somewhere in time during a short period. This is due to the fact that Kaminsky attack was being performed during that phase. Regarding this attack it overwhelms the DNS server with a lot of DNS responses. This attack causes a significant increase in DNS traffic and therefore in UDP traffic. This attack can not be detected with the aggregated traffic of TCP and UDP. The filtering process must be exclusively focused on UDP traffic.

In Figure 4.6 is shown the UDP traffic breakdown in EN1. DNS traffic is the most representative UDP traffic generated on the emulated network comparing to other services, such as DHCP.

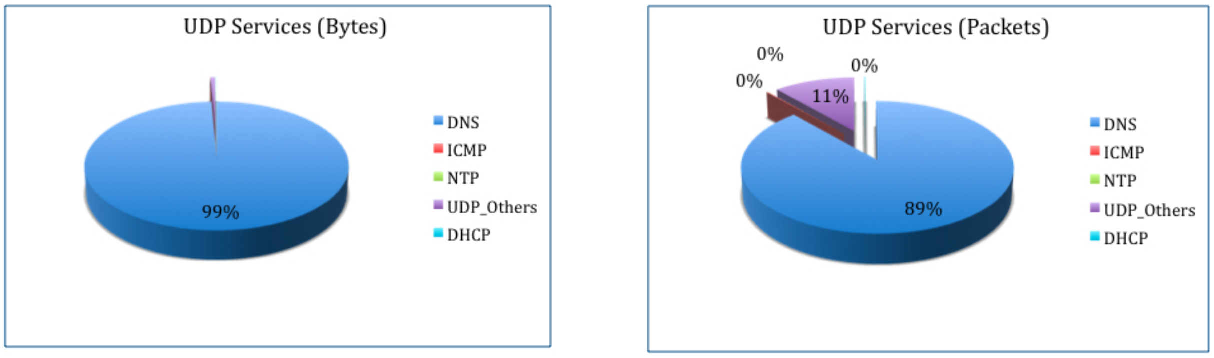


Figure 4.6: UDP services in EN1.

In EN2, Figure 4.7, was also verified the same kind of behaviour in UDP traffic. The DNS traffic generated represented most of UDP traffic due to the DNS cache poisoning attack that was deployed on the network.

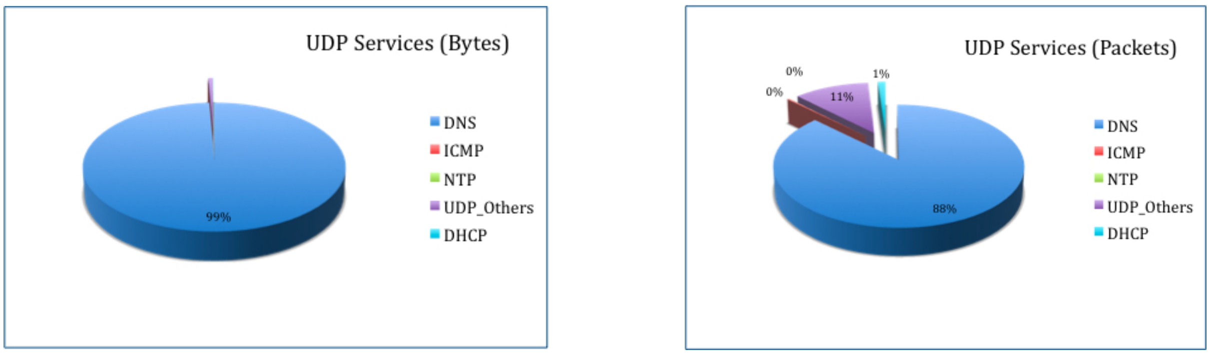
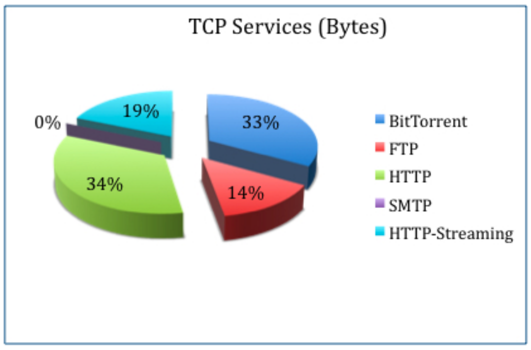


Figure 4.7: UDP services in EN2.

Summarizing, DNS traffic is the most common UDP traffic verified in both emulated networks. Despite the fact that the DNS licit traffic had a considerable contribution, the Kaminsky attack was the prime contributor for the UDP traffic.

Focusing now on TCP traffic that was produced on both topologies it can be verified that all the services that were described earlier had a considerable impact on the traffic behaviour.

As earlier mentioned each service was carefully configured in order to cause the impact according to conclusions drawn on 2.3. All the services mentioned above, such as BitTorrent, FTP, HTTP, SMTP and HTTP-Streaming were captured and analyzed. On Figure 4.8 is the impact of each protocol, that runs over TCP, in the EN1.



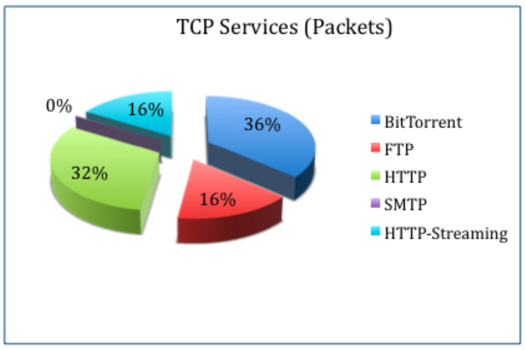
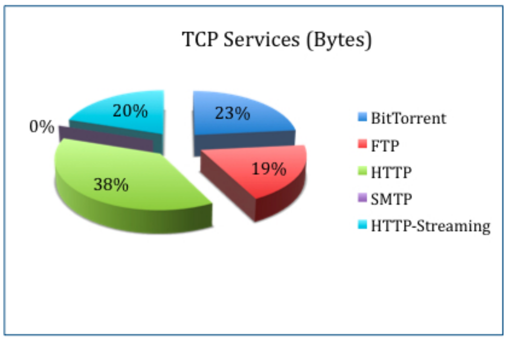


Figure 4.8: TCP services in EN1.

As is illustrated in the figure HTTP and BitTorrent traffic were the services that generate more traffic in the network followed by other two services (HTTP-Streaming and FTP) with a considerable impact on the traffic. The high number of HTTP packets is due to the fact that several requests had been done to all the four servers of Cluster 1 and to the both Fuzzers attacks that were exploring HTTP. BitTorrent traffic represents about 35% of the TCP traffic and FTP 15%. FTP had a huge impact on the traffic behaviour comparing to the real networks. This is due to the fact of two different attacks that exploit FTP were deployed thus increasing the amount of its traffic. The HTTP-Streaming(∼17%) and SMTP (∼1%), in turn, had the expected impact.

In Figure 4.9 it is represented the impact of each protocol that runs over TCP in EN2. Regarding the previous topology there are some similarities related to the TCP traffic behaviour.



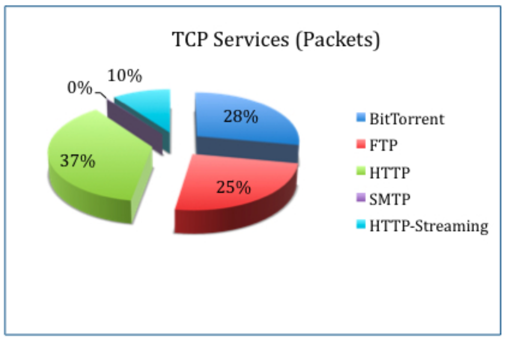
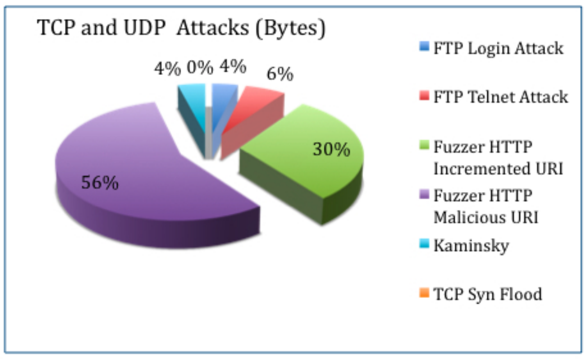


Figure 4.9: TCP services in EN2.

In EN2, HTTP(∼37%) and BitTorrent(∼ 25%) also represented great part of the traffic generated due to the same reasons explained for the EN1. The HTTP-Streaming also represents a considerable part of TCP traffic (∼ 15%). There was a increase in the amount of FTP traffic compared to the previous topology, about 15% to 22%. The SMTP is still represented by a rather low traffic compared to the other services.

Some of the attacks that have been described throughout this document affected the impact of some applications. This factor was already expected because the attacks were chosen under the condition of generating a lot of traffic. Next, it will be analyzed the impact of the attacks in the traffic generated by each service.

All the attacks that were earlier described were deployed in the EN1. In Figure 4.10 is illustrated the impact of each attack, whether it runs over TCP or UDP, in the traffic behaviour generated on the emulated network.



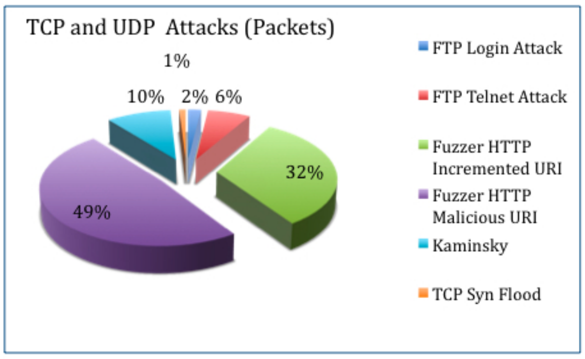
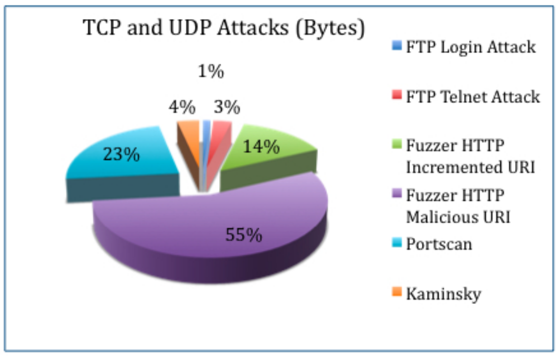


Figure 4.10: TCP and UDP attacks in EN1.

As it can be seen the attack that generated more traffic during the emulation time was Fuzzer HTTP Malicious URI (∼53%). The other fuzzer attack (Fuzzer HTTP Incremented URI) also was considerably representing the illicit traffic generated since it represents around (∼31%) of attacks that were executed. The Kaminsky attack (∼7%), in turn, did not have as much impact as the others.

Focusing now on the impact of the attacks executed in the EN2 it can be seen a similar behaviour in relation to the previous topology. However, in this emulated network was also deployed Port Scan attacks. Next, in Figure 4.11, is shown the balance of the attacks generated in the emulated network.



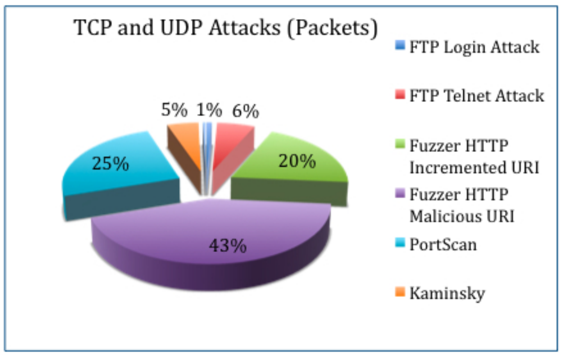
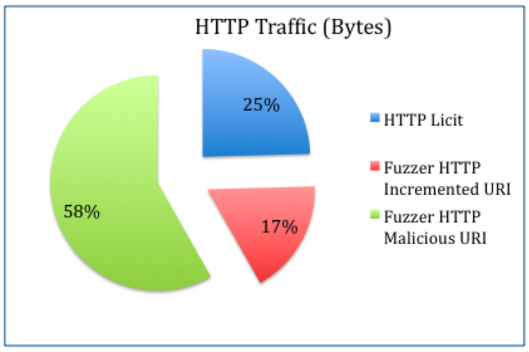


Figure 4.11: TCP and UDP attacks in EN2.

Although there was port scan traffic in this topology, the impact of each attack was found to be similar to the one seen in the previous topology. The Fuzzer attacks remain the predominant generator of illicit traffic in the emulated network (together ∼66%) followed by Port Scan with ∼24%. The DNS cache poisoning had also a considerable impact on the traffic behaviour since it represents approximately 5% of the illicit traffic but it is still very low compared to the amount of TCP traffic that was generated.

Two protocols were affected by illicit traffic, named HTTP and FTP. The HTTP was mostly represented by the Fuzzer attacks in EN1 as it can be seen in Figure 4.12.



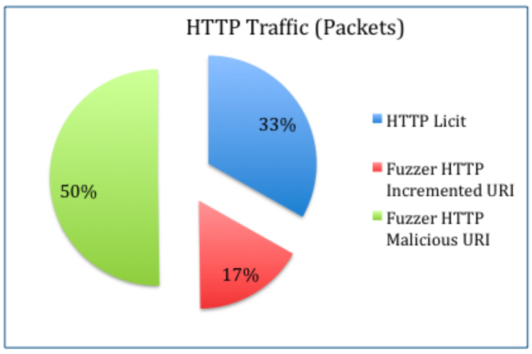


Figure 4.12: HTTP traffic in EN1.

HTTP Licit represents the legitimate interaction (HTTP requests, etc.) between servers and hosts. As it can be seen on the figure, the HTTP Licit traffic did not represent the majority of HTTP traffic (∼29%). On the other hand Fuzzer attacks represent most of the HTTP traffic. It produced about 70% of the HTTP traffic. This is due to the fact that both attacks generate a lot of traffic when they are executed.

On EN2 the behaviour of the Fuzzer attacks and HTTP Licit was not too different from the previous case. In Figure 4.13 is represented the impact of fuzzer attacks and Licit traffic on HTTP.

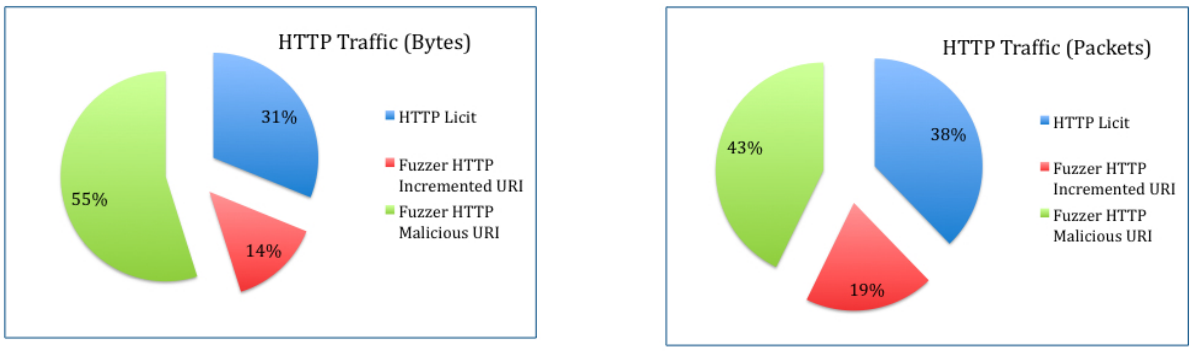


Figure 4.13: HTTP traffic in EN2.

Once again, HTTP is mostly represented by illicit traffic (∼60%). The Fuzzer HTTP Malicious URI attack emerged as the greatest producer of HTTP traffic. Therefore, in the EN2, the licit traffic represents only a small part of the HTTP traffic (∼16%).

FTP was also affected by illicit traffic that was generated by the security attacks mentioned above. Unlike the previous case, it was found that licit traffic had far more impact that the illicit one. In the Figure 4.14 is represented the FTP traffic behaviour on EN1.

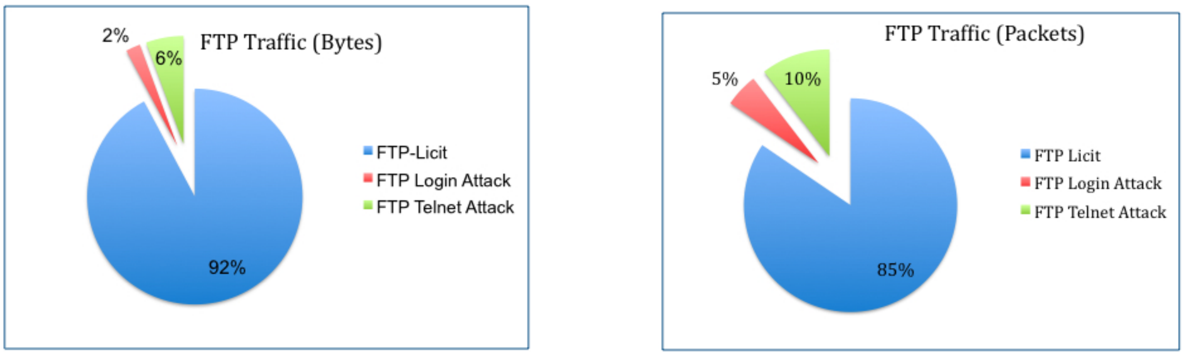
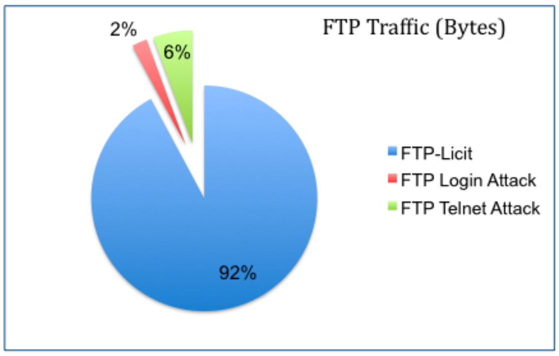


Figure 4.14: FTP traffic in EN1.

Despite the attacks that were generated have a significant impact on the traffic behaviour it was found that licit traffic was the most abundant in the FTP (∼88%). The illicit traffic that was generated by the attacks FTP Authentication and FTP Stacked-based Buffer Overflow Attack only represented a small part of the FTP traffic(∼12%).

In EN2 the FTP traffic behaviour was not so different of the one verified in EN1. Then, in Figure 4.15, is shown the impact of licit and illicit FTP traffic in that the traffic generated in EN2.



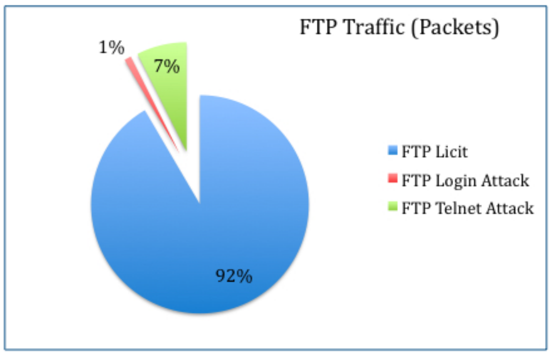


Figure 4.15: FTP traffic in EN2.

In this case, the FTP Licit remains as the most common FTP traffic in the emulated network (∼92%). Illicit traffic that was generated by the attacks mentioned above only represents around (∼8%) of the FTP traffic.

4.2 Per Flow Traffic

One of the main goals of the emulator is to acquire a *ground-truth* (annotated traffic) which can be used to evaluate statistical methods of detection attacks and/or applications. For that it was needed to first understand how each kind of traffic behaved during the emulation period, in order to perceive the impact of each application and attack in the traffic network. Then, for each attack, it was required to analyze its traffic generated by evaluating the features throughout the emulation period. In case of finding a type of behaviour that occurs only in traffic where attacks have been generated, it may indicate that a specific pattern is symptom of an attack.

As had been described each application and attack has a different traffic characteristics. Every application revealed to have a typical pattern in the network environment. The attacks, in turn, were deployed in order to generate a considerable amount of traffic.

Seven different attacks were considered for this work: FTP Authentication Scanner, FTP Stack-based Buffer Overflow, Fuzzer HTTP Long String, Fuzzer HTTP String URI, Kaminsky DNS cache poisoning, Port Scan and TCP Syn Flood. Each of them had a particular pattern on the traffic network.

In some attacks, it can be found a signature that is unique of it. As was mentioned in section 2.3, the IP packet size may indicate that a DoS attack is being performed. Usually, when an attacker is performing a DoS attack it sends a large amount of small packets. In this work the TCP Syn Flood attack represented a DoS attack. In section 3.6 it was mentioned that a specific filter was used to get all the traffic related to this attack. The filter used was the *ip.len==40* because the SYN packets size generated by the attacker were all with 40 bytes instead of the SYN packets with 60 bytes generated by legitimate traffic.

Kaminsky DNS poisoning attack also shows to have a particular characteristic that obviously shown when this attack is being executed. Figures 4.4 and 4.5, which were earlier discussed, show that it is evident when this attack is performed. When the UDP, specially DNS, traffic significantly increases means that an DNS cache poisoning is being performed. This is due to the amount of responses packets that the attacker sends to the DNS Server. Therefore, the high number of DNS responses in a short time period can be considered as a signature of a Kaminsky's attack.

As earlier mentioned, different flows were defined for all the traffic generated and captured in EN2. Those flows were identified by Source IP, Destination IP, Source Port, Destination Port and TCP. The number of flows produced was different among the applications (licit traffic) and attacks (illicit traffic).

In Figure 4.16, is shown the percentage of flows generated by each service in EN2.

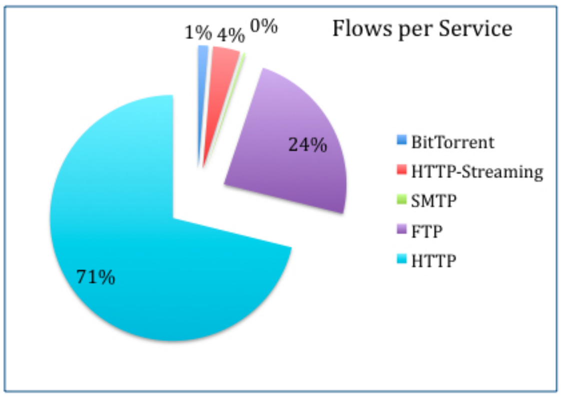


Figure 4.16: Flows per service in EN2.

By analyzing the chart, the low percentage number of BitTorrent flows is what draws the most attention (∼1%). This is due to the fact that the peers did not use so many ports for the interaction and data transfer. This is related to the fact that the flows could be bigger in terms of bytes and packets. HTTP emerged as the service with more flows (∼71%) followed by FTP with ∼24%. HTTP-Streaming, in turn, produced about 4% of the flows. This low percentage value was due to the fact that the same ports were used during the video streams.

As well as the services, it was also defined flows representative of illicit traffic. In Figure 4.17, is shown the percentage values of the flows generated for each attack.

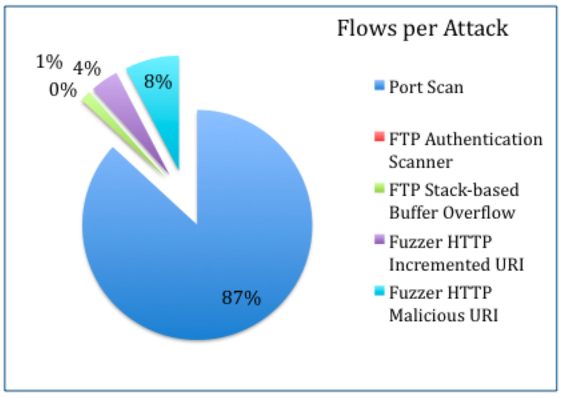


Figure 4.17: Flows per attack in EN2.

Port Scan was the attack that generated more flows (∼87%) because it scans and explores all the possible ports in a network. The rest of the attacks generated a low number of flows comparing to Port Scan attack. Only the Fuzzer HTTP Malicious URI stands out with ∼8%. This fact may indicate that the frequency of flows generation during a short time period may indicate if a Port Scan is occurring. If the number of flows increases very fast in a short time period it departs from normal traffic behaviour, therefore illicit traffic is likely to be generated.

4.3 Interesting Features to Detect the Attacks

As stated in section 3.6, each flow was characterized at each time interval of 0.1 seconds, throughout the emulation period, for different features, which were: the number of packets, bytes and each TCP flag. The purpose of the features on this work was to find if there is a significant change on the way that they are generated, during the emulation period, when an attack is being performed.

Fuzzers attacks explored the HTTP protocol, as have been mentioned throughout this document. The six virtual servers of the EN2 were attacked by this attack. Therefore, the main concern was on focusing on the HTTP traffic that was involving those six servers. For that, all the traffic represented by HTTP licit and illicit traffic was analyzed in order to better understand the features generation frequency. In Figure 4.18, is represented the number of generated features per each kind of traffic.

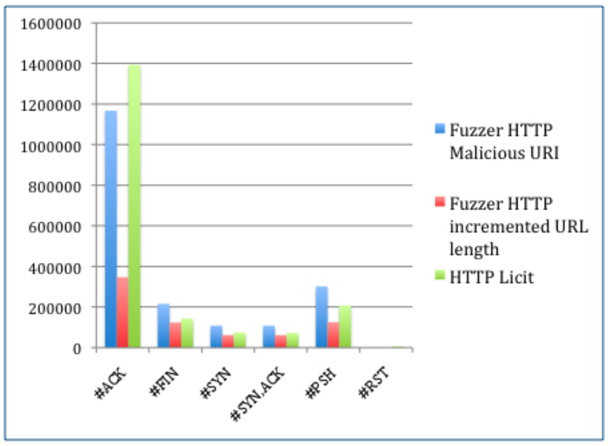
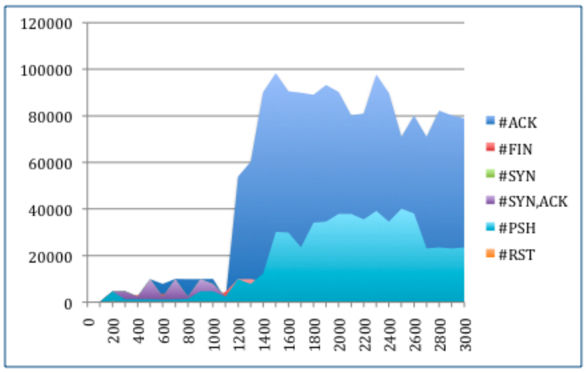


Figure 4.18: Features generated by HTTP.

The ACK flag was clearly the most generated. However it was the only one that was produced more often by licit traffic. All the rest of the features were mostly produced by Fuzzer HTTP Malicious URI attack. In the opposite, the Fuzzer HTTP Incremented URL attack, in turn, was the type of traffic that produced less features.

The main purpose of the features was to understand how often they are generated during a specific time period. For that, all the HTTP traffic licit and illicit were gathered in order to analyze the traffic behaviour during the emulation time. In Figure 4.19, is illustrated the production frequency of each feature.



Axis	Unit
Time	0,1s
Packets	1

Figure 4.19: Features produced throughout the emulation time for HTTP traffic.

The generation of the features remains stable, which means that is unlikely to be an attack being performed. However, at a given point three features start being generated at frightening rate. The HTTP protocol uses several times the TCP flags ACK and SYN. Since the Fuzzers attacks consist on sending many HTTP requests to a server it is normal that those flags start being generated more often. The PSH is used to tells the TCP stack to flush all buffers and send any up to the application including the data that hold the PSH flag set. Since there are many HTTP requests and HTTP “Not Found” (due to the high number of attempts) the number of PSH feature increases.

FTP protocol was also affected by illicit traffic in the EN2. Like in the previous case, all the FTP traffic (licit and illicit) was gathered in order to perceive if there are any pattern that can identify an attack that is exploiting the FTP. In Figure 4.20, is represented the number of FTP packets that had specific flags set in the EN2.

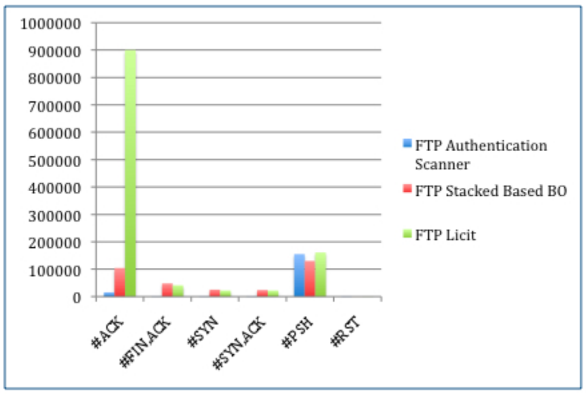


Figure 4.20: Number of features generated by FTP.

As was expected the most frequent feature was ACK. Clearly the licit traffic produced much more packets with this feature than the illicit traffic. Whether licit or illicit traffic it was produced a considerable number of PSH packets. As it will be shown in the figure 4.21 this feature may indicate when the FTP Authentication Scanner might be occurring.

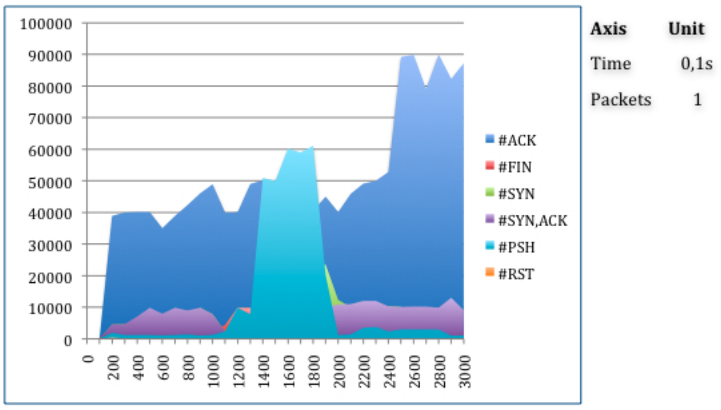


Figure 4.21: Features produced throughout the emulation time for FTP traffic.

Until a certain moment the feature PSH remains stable in time. However, at some point it considerably increases during a short period. It is a clearly sign that an attack FTP Authentication Scanner may be occurring. As it was mentioned this attack attempts to successfully authenticate in a FTP server. The interaction between the attacker and the server uses this feature due to the number of requests and responses generated among them. Since there are a lot of authentication failures, due to the several attempts that the attack performs, more PSH features are generated than ACK. Therefore, it can be concluded that when PSH are generated more often than ACK it may be a symptom of a FTP authentication attack.

The FTP Stacked-based Buffer overflow, in turn, was not clearly identified by the behaviour of TCP flags during the emulation time.

By looking to the previous charts it can be concluded that some attacks have an impact on the way that some features are generated. In Table 4.1, is shown how those attacks, which have been discussed so far, can be detected by analyzing the traffic behaviour.

Table 4.1: Parameters to detect the attacks.

	Detectable by Signature	Detectable by Traffic Conditions	Flow Features that Better Detect the Attack
FTP Authentication Scanner	✗	✓	PSH
FTP Stack-based Buffer Overflow	✗	✗	-
Fuzzer HTTP Long String	✗	✓	SYN and PSH
Fuzzer HTTP String URI	✗	✓	SYN and PSH
Kaminsky	✗	✓	#Packets, #Bytes
TCP SYN Flood	✓	✓	SYN

As was previous discussed, most of the attacks can be detected by analyzing how often the features PSH and SYN are generated. FTP Authentication Attack, in particular, can be detected if the PSH increases more than ACK feature during a short period of time. Fuzzers attacks can also be detected by looking to the SYN and PSH feature. DNS cache poisoning attack, in turn, can be detected by analyzing the UDP traffic behaviour. Finally, TCP SYN Flood can be detected by signature since the typical DoS attacks use smaller IP packet size to be performed. Port Scan attack, in turn, can be detected by how often different flows are generated during a short time period.

Summary

In this section it was presented the results obtained from the emulated networks described in the previous section. It was compared the impact of each application and attack in the traffic behaviour. Then, from those results was discussed how an attack can be detected by the way that TCP flags are generated. It was concluded that some attacks can be also detected by signature or traffic conditions.

5 Conclusions and Future Work

This thesis was focused on the development of emulated networks in order to acquire a high quality ground-truth. The cornerstones of this work are the topologies developed and the variety of traffic that was generated. Two kind of traffic were considered for this work: Licit and Illicit.

For the licit traffic three different research studies were analyzed in order to perceive which kind of traffic is produced in common networks. It was concluded that the main applications produced were Web, P2P, Streaming, FTP, SMTP and Network Management. Each of them revealed to have different impact on the traffic that is common on real networks: The most representatives were Web ($\sim$35%-40%) and P2P ($\sim$20%-25%) followed by Streaming ($\sim$10%-15%), Mail ($\sim$5%-10%) and FTP ($\sim$1%-10%). Network Management, in turn, showed to be the kind of traffic that was less often generated ($\sim$1%-5%). For each kind of licit traffic different applications were adopted as is shown in Table 5.1.

Table 5.1: Application for each kind of licit traffic.

Traffic	Service	Application
Web	HTTP	LAMP server
P2P	BitTorrent	Aria2c and Transmission
Streaming	HTTP-Streaming	VLC
Mail	SMTP	Postfix
FTP	FTP	ProFTPd
Network Management	DNS, DHCP	BIND9

Each kind of traffic was generated according with the research studies analyzed in order to realistic mimic the traffic patterns in real networks.

For the illicit traffic it was necessary to deploy in the emulated networks attacks that have a considerable impact on the traffic behaviour. Several attacks were analyzed and it was decided to execute the following ones: DNS Cache Poisoning (Kaminsky), FTP Authentication Scanner, FTP Stack-based Buffer Overflow, Fuzzer HTTP Malicious URI, Fuzzer HTTP Incremented URI, Portscan and TCP SYN Flood. Each of them explores different Internet services, which allowed studying the illicit traffic in different fields.

To perform those attacks two different frameworks were adopted: NMAP and Metasploit. The purpose of NMAP was to execute Port Scan attacks. Metasploit, in turn, allowed deploying all the other attacks. Every single attack was properly configured in order to have an impact on traffic behaviour.

Two different topologies were adopted in order to generate the licit and illicit traffic: EN1 and EN2. Realistic networks inspired both of them. Part of the EN1 was a triangle network emulated on GNS3 framework which was connecting three different Clusters. However, the network emulated on GNS3 overwhelmed the PC resources. Instead, for the EN2 was adopted a switch to connect all Clusters.

All the licit and illicit traffic described above was generated in those two emulated networks during an emulation time period of 5 minutes. Then, all the data was gathered and processed. Plus, for each kind of traffic different flows were defined by Source IP, Destination IP, Source Port, Destination Port and TCP. For each flow, it was extracted a set of features at each 0.1 seconds, such as: time, number of packets, number of bytes and number of each TCP flag (ACK; FIN; SYN; SYN,ACK; PSH and RST).

The results obtained show that there was much more traffic generated in EN2 comparing to EN1. In both emulated networks was produced more TCP traffic then UDP. The application that was more representative of the traffic obtained was HTTP followed by BitTorrent. That fact was in accordance to the research studies that were analyzed. The Attack that generate more traffic was Fuzzer HTTP Malicious URI. DNS Cache Poisoning and FTP attacks did not have a considerable impact comparing to the Fuzzers.

For different attacks it was verified that different features may indicate when an attack is occurring. TCP flags, such as, SYN and PSH can designate an attack depending on how often they are generated during a short time period. DNS Cache Poisoning, in turn, can be detected by traffic conditions. TCP SYN Flood, in turn, can be easily discovered by its signature, which consists on its IP packet size. Finally, a Port Scan attack can be identified by observing how often different flows are generated during a short time period.

As future work, it might be interesting to develop another topologies with other characteristics. Plus, it can be deployed more attacks, mainly Denial of Service, in order to cause different illicit traffic to be analyzed.

For this kind of work it would be helpful to determine the ideal computational load for each kind of emulation. Knowing in advance what equipment to use, for a particular topology, to maintain a certain balance in the computational load, it would help to efficiently develop this kind of solutions.

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