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MASTER THESIS

Bonet Detection Through Passive DNS analysis

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A thesis submitted in fulfilment of the requirements for the degree of Masters in Cyber Security

Declaration of Authorship

I, Gérard Tio Nogueras, declare that this thesis titled, "Bonet Detection Through Passive DNS analysis" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: Gérard Tio Nogueras

Date: 01/01/2019

"The Domain Name Server is the Achilles heel of the Web. The important thing is that it's managed responsibly."

Tim Berners-Lee

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Abstract

Faculty of Science
Cyber Security

Masters in Cyber Security

Bonet Detection Through Passive DNS analysis

by Gérard TIO NOGUERAS

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

keywords:botnet detection; botnet detection model; machine learning-based botnet detection; domain generation algorithm botnet detection; fast flux botnet detection

Acknowledgements

The acknowledgements and the people to thank go here, don't forget to include your project advisor…

Contents

List of Figures

List of Tables

List of Abbreviations

CnC	**Command and Control**
DoS	**Denial of Service**
DDoS	**Distributed Denial of Service**
WSF	**W**hat (it) **S**tands **F**or

For/Dedicated to/To my…

Chapter 1

Introduction

1.1 Research context

Vulnerabilties keep growing $\rightarrow$ making botnets even easier to spread, which means cheaper and more powerful.

TODO: Put some context on why it is still a relevant subject today [source]
This is a compilation of Botnet news by Trend Micro: Compilation of Botnets variants:

1.2 Research question

My research question is : "**Can we improve current botnet detection?**" TODO: define proper sub-questions that build the paper. With the following sub-questions:

- What are the current trends of Evasion and detection?
- Can we create a solution that detects effectively all botnets ?
- What effective model can help organisations detect botnets faster and more reliably?

1.3 Thesis objective

The objective of this master thesis in Cyber Security is to improve the all-in solutions for botnet detection through DNS traffic analysis with a machine learning approach. Different papers haven't always provided a deep study of the choice of features or provided a model adapted to certain environments which we will try to do and see if this can improve the existing models.

[source]
The objective of this thesis is to answer the research questions above. This will be done by reviewing the current (scientific) literature on botnets, in particular with relation to DNS, Honeypots, Law and future threats. The authors technical experience will also be used to answer the research questions. It is hoped that others can benefit from the knowledge that this thesis provides to implement better security measures within their own organisations. The information provided in this thesis will provide the reader with in depth knowledge on the subject of botnets, and how they the threat of them within an organisation can be migrated.
TODO: Description of the thesis (chapter by chapter)

Chapter 2

State of the art

2.1 Botnets

As stated in the introduction botnets are an important problem for anyone involved somehow with the internet. Botnets can result in great economic damage.

Botnets continuous improvement to become more resilient and powerful makes them an important threat to information security.

Botnets can become very lucrative and can infect very large amounts of devices resulting in scary entities. Here are some of these enormous entities: **Flashback** with 600k compromised targets, **Grum** with 840k compromised devices and sending 40 Billion spam emails per month, **TDL-4** with 4.5 Million victims in first the 3 months and **Gameover ZeuS** with 1 Million infections, because of its resilience mechanisms this botnet was one of the hardest to take down.

The reason botnets are still an ongoing research topic is that there isn't a complete solution for their detection and mitigation. Researchers and organisations have to keep working to keep updated with all the new flavours criminals bring to the market.

2.1.1 Definition

A botnet is a network of infected machines called bots, these bots owned and controlled by a remote attacker called the botmaster. Bots usually infect these machines without their owners' knowledge or consent . The control of such bots is done through the Command and Control (CnC) server. The CnC server allows the master to issue commands to and receives responses from individual bots or aggregations of bots. These exchanges are done to update the software of the malware, execute attacks, exfiltrate data and more actions explained down below.

Bots are small programs allowing to remotely control and perform commands on computers. They are the foundation of botnets. Their spreading mechanisms, infection and utilization are defined in the Botnet lifecycle in the structure section. These programs are embedded with port scanning, vulnerability scanning, exploitation and payloads that allow them to spread the botnet and infect their victims.
There are many different bots, some very modular such as the Agobot others simpler ones but easier to use such as the SDBot family. Bots families are also classified depending on the channel type and attack type, for example GT-Bots are a IRC bots. These 3 families are the most often found. Lesser usual ones have specific functions or plugins to fill in the gaps left by developers to customize the bots, a good examples would be the Dataspy Network X bots. There are very small bots such as the Q8 Bots and Perl-based bots that still allow for a large range of commands and attacks.

Finally some bots are composed of a single file like kaiten bot which makes it very easy to upload to compromised machines.

In fact, botnets have specific characteristics as compared to other types of malware. For instance, the botmaster can control the infected machines and send commands without directly communicating with them. There are also a lot of bots working in a coordinated way and taking instructions from the botmaster to instantiate coordinated attacks.

Cybercriminals use botnets to execute a long list of malicious activities and structure related actions, we have listed some of these but any type of cyber attack can be uploaded to these bots and executed.

Another reason botnets are a big threat is that criminals have started to provide botnets as a Service (BssS) which are considered a big part of the botnet economy. This popularised botnets to be used by anyone.

Because botnets are a large network of infected machines, they are able to carry out large scale attacks.
A victim host could be infected by targeting known vulnerability or by infected programs. When the victim is infected, the botnet will try to stay stealthy and with the exploit kit installed, it can do an extensive amount of damage. Here are some of the methods to control the infected hosts.

- Distributed Denial-of-Service Attacks. These attacks provoke a
- Spam email campaigns,
- Sniffing Traffic
- Spy through Keylogging, file monitoring,
- Spreading new malware
- Installing Advertisement Addons and Browser Helper Objects (BHOs)
- Google AdSense abuse
- Manipulating online polls and games
- Mass identity theft, stealing personal data such as mail accounts, intellectual property, military secrets, embarrassing information or bank credentials
- Secure the system(close NetBIOS shares, RPCDCOM)
- host illegal sites
- redirect traffic for the botnet
- kill unwanted process running on the system
- test for virtual machines and/or debugger software
- add or delete auto-start applications
- run or terminate programs
- download and execute files
- perform address and port scan

- simulate key presses
- Communicates with a handler or controller via public servers or other compromised systems.
- A botmaster commands bots to perform any of an number of different functions.
- System of bots and controller(s) is referred to as a botnet or zombie network.

A clear distinction between a bot agent and a common piece of malware lies within a bot's ability to communicate with a Command-and-Control (CnC) infrastructure. CnC allows a bot agent to receive new instructions and malicious capabilities, as dictated by a remote criminal entity. This compromised host then can be used as an unwilling participant in Internet crime as soon as it is linked into a botnet via that same CnC.

The goals of an attacker in terms of bot recruitment can be categorized into two broad categories. In the first case, the target of the attack is the computer that is being recruited. In the second case, the recruited bot is used to attack another target. Computers in a botnet are either the target of the attack, the perpetrator of the attack, or both. When bots are the perpetrator of the attack, the effectiveness of the attack is usually dependent upon the collective power of the botnet. Stated differently, the attacker is either after the valuable information on the computer or the storage, processing, and communication capabilities of the computer, or both.
The value of information on a personal computer is often overlooked. There are many applications for home use, like tax preparation software, that store volumes of key personal and financial information. Browsers can cache website and account information. Email clients store contact information. Many home computers have sensitive work information on them, exposing a company's intellectual property to potential disclosure. These are just a few examples of the type of information that can be exfiltrated and abused by an attacker or sold to cyber criminals.
A common botnet usage is the sending of spam emails. The spam emails can be used to carry malicious payloads in an attempt to infect the recipients of the spam emails. Spam can also be used to influence or manipulate user behavior such as the purchasing of advertised products, visiting of infected websites, or downloading of music or videos with malicious content. Most cryptographic controls just buy the user time, in hopes that by the time the control is no longer good, the protected asset no longer has value. That is the theory behind password expirations. Password lifetime is set to be less than the time it takes to discover the password by brute force or other methods. The processing capabilities of a bot can be used for cryptanalysis purposes. Password cracking, brute force key discovery, and rainbow table creation are but a few examples. The collective power of a botnet greatly reduces the time a control is effective. Data storage is another bot resource an attacker can use without permission. Anonymity is important to the attacker, so storing ill-gotten gain across the botnet keeps incriminating evidence away from the attackers' machines. Additionally, there are efficiency, redundancy, and availability benefits from having a distributed data store. Ill-gotten gains can include personal information seized, pornography, intellectual property and malware.
Botnet rental has become a lucrative business. Botnets are rented and sold, usually for malicious purposes. Decentralized botnet architectures allow massive botnets to be partitioned into groups of smaller children botnets that can be parceled out for use and then reintegrated into the parent botnet after usage. This paper will discuss botnet detection tools and techniques. This paper gives a brief introduction, a

brief background on botnet characteristics, a summary of detection techniques, an overview of the BotMiner tool, reviews of two case studies where botnets were used to characterize behavior, and a conclusion.

2.1.2 Structure

Life cycle

Life cycles might differ from one bot to another but they have generally a common structure. This life cycle is composed of four steps The exploitation/infection

Botnet Lifecycle exploitation phase: This is where the infection happens by exploiting a vulnerability on the victim's host.(25) Then the binary of the bot is downloaded onto the host. To find this binary a DNS lookup has to be done. Which can't be avoided but can be hidden.(26) This is the most dominant behavior throughout all botnets(16)
rallying phase: dd
attack execution phase:
update and maintenance:
Infection behavior 4 phases: 1) Infection: vulnerability scanning
2) Injection: exploited + download of bot's binary code
3) connection to the cnc and start to control the host
4) action on behalf of botmaster + maintain and upgrade periodically
For P2P 1 and 2 are similar but in searches until finds an alive peer 4) phase 1: update of peer list + download any available updates phase 2: starts malicious activities based on STORM but similar for all P2P botnets pp. 18-27, Dec. 2007.

Channel

TODO: after presenting the botnet structure we focus on the part where botmasters have turned their focus in evading detection and becoming more resilitent. In this section we want to discuss how the CnC channel works.

Command and Control (CnC) CnC servers is what differentiates Botnets from other malware.

Means of receiving and sending commands and information between the botmaster and the zombies. Typical protocols: IRC, HTTP – HTTPS, DNS, etc
Protocols imply (to an extent) a botnet's communication topology. The topology provides trades-off in terms of bandwidth, affectivity, stealth, and so forth.

TODO: explain the different techniques used to rally bots to an IP or a Domain (how do they regroup with master?) 2.4.2 Command and Control Rallying Mechanisms According to Choi et al. [20], botmasters want their bots to be invisible but portable, therefore they use different methods for bots rallying. They stated that not all bots can have mobility and invisibility at the same time. They described three rallying methods, namely; hard-coded IP address, dynamic DNS, and distributed DNS. In hard-coded IP address method; the bot binary has a hard-coded IP address of its CnC server, the server can be detected through reverse engineering, and the botmaster can be quarantined or the botnet can be suspended. As hard-coded IP address cannot be changed, this method cannot provide mobility and does not make the botnet invisible as well. On the other hand, in dynamic DNS botnets migrate their CnC server frequently, upon the instruction of botmaster. Using a list of servers provided in the bot binary, a botmaster uses several CnC servers. It uses dynamic DNS in order not to be detected or suspended, and to keep the botnet portable. When connection to the CnC server fails or shutdown, the bots will perform DNS queries and will be redirected to a new CnC server [2]. This redirection behavior of botnets is known as "herding". This method provides mobility and some invisibility to the botnets. Finally, with distributed DNS, botnets run their own distributed DNS service at locations that are out of the reach of law enforcement. Bots include the addresses of these DNS servers and contact these servers to resolve the IP address of CnC servers [2]. This method provides both mobility and invisibility to their botnets. In summary, while the hard-coded IP botnet makes very easy for the newly infected nodes to join the botnet, it also makes easy for law enforcement to track and shutdown the botnet. On the other hand, using DNS to migrate CnC servers make it harder for the newly infected nodes to join the botnet. Some infected nodes might never be able to join the botnet -in case they stay offline long enough for all the addresses in the initial communication list to be obsolete, however, it gives the botnet the flexibility to hide its CnC severs.

Rallying mechanism monitoring group activities in dns traffic," in The 7th IEEE International Conference on Computer and Information Technology, pp. 715–720, Oct. 2007. Objective for bots: invisible but portable -> different methods fo bot rallying: - ip hardcoded: the bot binary has a hard-coded IP address of its CnC server, the server can be detected through reverse engineering, and the botmaster can be quarantined or the botnet can be suspended. As hard-coded IP address cannot be changed, this method cannot provide mobility and does not make the botnet invisible as well. dynamic DNS botnets migrate their CnC server frequently, upon the instruction of botmaster. Using a list of servers provided in the bot binary, a botmaster uses several CnC servers. It uses dynamic DNS in order not to be detected or suspended, and to keep the botnet portable. When connection to the CnC server fails or shutdown, the bots will perform DNS queries and will be redirected to a new CnC server. This redirection behavior of botnets is known as "herding". This method provides mobility and some invisibility to the botnets. distributed DNS botnets run their own distributed DNS service at locations that are out of the reach of law enforcement. Bots include the addresses of these DNS servers and contact these servers to resolve the IP address of CnC servers. This method provides both mobility and invisibility to their botnets.

ME The channel resilience of a botnet is critical to ensure good communication with the CnC server. It is a crtitical component of botnets, its failure is usually the end of the botnet's life.

ME

[source]

The ability for a bot agent to locate CnC infrastructure is a critical requirement for maintaining control of the entire botnet for botnets that rely upon centralized CnC. If the CnC cannot be found, a bot agent will not be able to receive new instructions. While some bot agents may opt to function in an alternative autonomous "zombie" mode – reverting to embedded instructions for propagation and infection – most bot agents will continue to harvest local host information and poll the missing CnC at regularly scheduled times. Botnet Communication Topologies Page 6 Botnet operators use a number of technologies to increase the probability that bot agents will be able to locate the central CnC infrastructure. These tools and techniques also make botnets more resilient to shut-down and hijacking maneuvers. One key technology that enables CnC location resolution and failover resilience is referred to as "fluxing". Fluxing comes in two major flavors: • IP Flux • Domain Flux Both technologies are used extensively by professional botnet operators

TODO: ways of securing their communication channel: encryption, rootkit and a number of DNS evasion techniques

Topology

[sources]

Based on CnC channels, there are two typical botnet topologies: Centralized Decentralized (P2P) Traditional botnet metrics: Resiliency A botnet ability to cope with a loss of members (zombies) or servers Latency Reliability in message transmission Enumeration An ability to accurately estimate a botnet size Difficulty for security analysis Re-sale A possibility to carve off sections of the botnet for lease or resale to other operators.

Botnets come in all kinds of shapes and sizes. As a result, they employ a range of CnC topologies in response to commercial defenses, legal shutdowns and hijacking attempts. This evolution means that a criminal botnet operator has a number of wellstudied CnC topology options to base a new botnet upon – each of which have relative strengths and weaknesses

Botnet CnC topologies have been optimized to minimize network chatter and system failures, just like commercial-grade technology tasked with remotely managing tens of thousands of hosts. The precise CnC topology selected by a botnet operator often reflects that individual's perceived risk to continued command access and the financial business model of that botnet

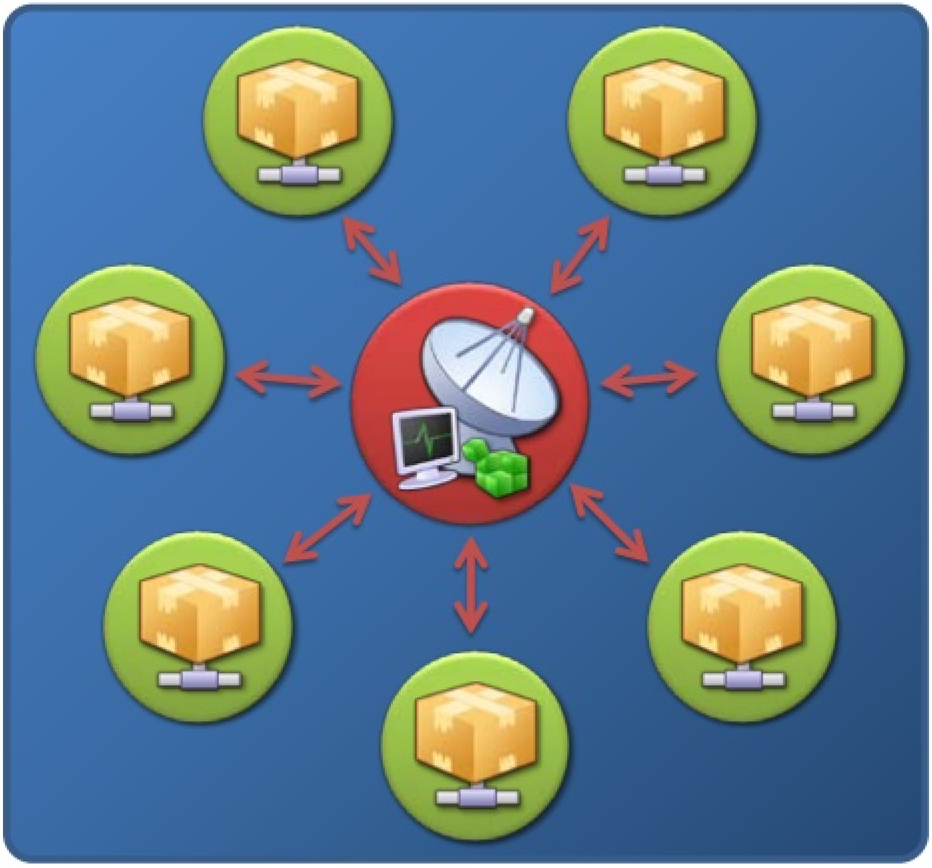
CnC topologies encountered in the wild typically match one of the following types: • Star • Multi-server • Hierarchical • Random

TODO: centralized vs decentralized botnets TODO: metrics analyzed to choose best option: cf slide(11)(http://www.ijcttjournal.org/Volume4/issue-1/IJCTT-V4I1P104.pdf TODO: present with visuals the different topologies and their purpose.

Modeling Botnets architectures: diurnal propagation model propagation using time zones," in Proceedings of the 13 th Network and Distributed System Security Sym- posium NDSS, 2006 Super botnet model Proceedings of Network and Distributed System Security Symposium (NDSS'07), pp. 111– 123, Reston, VA, USA, Feb. 2007 Stochastic P2P model botnets," in Fifth International Confer- ence on Quantitative Evaluation of Systems, pp. 307– 316, Sep. 2008 advanced P2P hybrid model peer-to-peer botnet," in Proceedings of the first Conference on First Workshop on Hot Topics in Un- derstanding Botnets, pp. 2, Berkeley, CA, USA, 2007.

Star [source] The Star topology relies upon a single centralized CnC resource to communicate with all bot agents. Each bot agent is issued new instructions directly from the central CnC point. When a bot agent successfully breaches a victim computer, it is normally preconfigured to "phone home" to this central CnC, whereupon it registers itself as a botnet member and awaits new instructions.

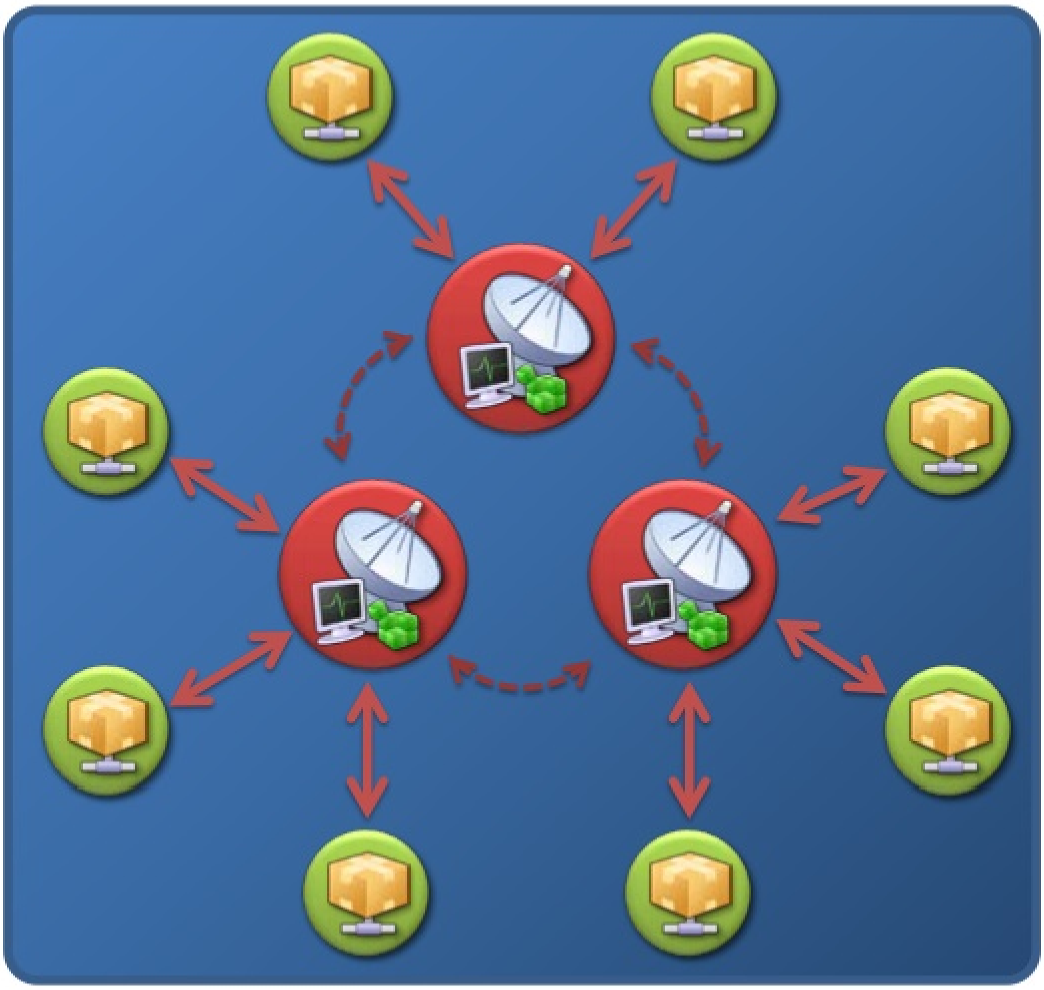
Pros Speed of Control The direct communication between the CnC and the bot agent means that instructions (and stolen data) can be transferred rapidly Cons Single point of failure If the central CnC is blocked or otherwise disabled, the botnet is effectively neutered.



Pros	Pros	Cons
Botnet awareness Interception or hijacking of bot agents will not enumerate all members of the botnet and is unlikely to reveal the C&C server.	**Highly resilient** Lack of a centralized C&C infrastructure and the many-to-many communication links between bot agents make it very resilient to shutdown.	**Command latency** The ad hoc nature of links between bo agents make C&C communication unpredictable, which can result in high levels of latency for some clusters of bot agents.
Ease of re-sale A botnet operator can easily carve off sections of their botnet for lease or resale to other operators.		**Botnet enumeration** Passive monitoring of communications from a single bot-compromised host can enumerate other members of the botnet.

Multi-server Pros No single point of failure Should any single CnC server be disabled, the botnet operator can still maintain control over all bot agents. Geographical optimization Multiple geographically distributed CnC severs can speed up communications between botnet elements.

Cons Requires advance planning Additional preparation effort is required to construct a multi-sever CnC infrastructure.



Hierarchical Pros Botnet awareness Interception or hijacking of bot agents will not enumerate all members of the botnet and is unlikely to reveal the CnC server. Ease of re-sale A botnet operator can easily carve off sections of their botnet for lease or resale to other operators. Cons Command latency Because commands must traverse multiple communication branches within the botnet, there can be a high degree of latency with updated instructions being received by bot agents. This delay makes some forms of botnet attack and malicious operation difficult.

dynamic/P2P Pros Highly resilient Lack of a centralized CnC infrastructure and the many-to-many communication links between bot agents make it very resilient to shutdown. Cons Command latency The ad hoc nature of links between bot agents make CnC communication unpredictable, which can result in high levels of latency for some clusters of bot agents. Botnet enumeration Passive monitoring of communications from a single bot-compromised host can enumerate other members of the botnet

2.2 Use and abuse of DNS protocol

The current trend of botnets is to hide their channel using the DNS services to hinder their identification and rallying process.

2.2.1 DNS

Most of the time users send DNS requests with a particular question for the DNS server. The server will the reply a DNS responses, similar to the request with the "answer" field filled with the information requested. Here is the structure of the packets transmitted to help with the understanding of the sections used as features later on.

Normal DNS message structure

```
+---------------------+
|        Header       |
+---------------------+
|       Question      | the question for the name server
+---------------------+
|        Answer       | RRs answering the question
+---------------------+
|      Authority      | RRs pointing toward an authority
+---------------------+
|      Additional     | RRs holding additional information
+---------------------+
```

Header section

Here is a detailed description of the header of the DNS packets.

```
                                  1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      ID                       |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|QR|   OpCode  |AA|TC|RD|RA| Z|AD|CD|   RCODE   |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                QDCOUNT/ZOCOUNT                |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                ANCOUNT/PRCOUNT                |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                NSCOUNT/UPCOUNT                |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ARCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

value	explanation
identifier	id of request
opcode	Operation Type: 0 $\rightarrow$ query, 1 $\rightarrow$ Inverse query, 2 $\rightarrow$ DNS status
aa_flag	Authoritative Answer: response
tc_flag	Truncation: flag set on truncated messages due to length greater than that permitted.
rd_flag	Recursion Desired: if set, asks the NS to pursue query recursively.
ra_flag	Recursion available: recursive query supported by NS
rcode	Response Code: ignored in request, useful in answers to provide query information.(ex: type of errors)
questions_count	Number of entries in the Question section
answers_count	Number of RR in the Answer section
authority_count	Number of NameServer RR in the Authority section
additional_count	Number of RR in the additional section

Question section

```
                               1  1  1  1  1  1
 0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                                               |
/                     QNAME                     /
/                                               /
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                     QTYPE                     |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                     QCLASS                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

value	explanation
q_name	Domain name requested
q_type	Type of RR record requested
q_class	Class of the request (often IN for internet)

2.2.2 Botnets abusing DNS

TODO: Present the different abuses of the DNS protocol to evade detection (use previous descriptions but revisit writing and add more visualization and explanations on how exactly it works. (it is important for future arguments regarding the evasion methods. We need to inform our reader to be able to convince him later of our arguments)

Studies have shown that to avoid detection, botnets have been using multiple techniques utilizing the DNS protocol capabilities to reach their CnC. The DNS protocol has some features that have been exploited maliciously: DNS tunnelling, fast-flux and domain flux.

TODO: Explain with the growing services of the internet "new"(research if they were part of the original protocol) capabilities arisen to allow this growth.(find an article supporting that). Explain Fast flux, domain flux and tunnelling used for legitimate purposes. (find an article explaining how these are used by normal services or the standard of the protocol)

Domain flux

Domain-flux is a type of flux where bots are equipped with a special Domain Generation Algorithm (DGA). They use this algorithm to generate an ensemble of domains. The idea is to generate domains until one of them returns an IP address they can use to contact their CnC. The botmaster knows which domains are generated at a particular point in time and can register them before they are queried by the bots to be reached. This improves the resilience of botnets infrastructure a lot.

TODO: present DF [source]

Domain Wildcarding abuses native DNS functionality to wildcard (e.g., *) a higher domain such that all FQDN's point to the same IP address. For example, *.damballa.com could encapsulate both mypc.atl.damballa.com and myserver.damballa.com. This technique is most commonly associated with botnets that deliver spam and phishing content – whereby the wildcarded information that appears random (e.g. "asdkjlkwer" of asdkjlkwer.atl.damballa) is Botnet Communication Topologies Page 7 used by the botnet operator to uniquely identify a victim, track success using various delivery techniques, and bypass anti-spam technologies. • Domain Generation Algorithms are a more recent addition to bot agents. They create a dynamic list of multiple FQDN's each day, which are then polled by the bot agent as it tries to locate the CnC infrastructure. Since the created domain names are dynamically generated in volume and typically have a life of only a single day, the rapid turnover makes it very difficult to investigate or block every possible domain name.

Location Resilience Most botnets today rely upon DNS as the service for location of CnC infrastructure. Fluxing DNS records provides varying degrees of resilience to shutdown and hijacking that can be best summed up as: Brittle: Single domain Less brittle: Single flux Resilient: Double flux Very resilient: Domain flux

IP flux

IP flux or fast flux,

Unfortunately, botnets use the DNS traffic as any other legitimate host, which makes differentiating the legitimate DNS traffic from the illegitimate one a very challenging problem [16]. Moreover,botnet owners attempt to hide their communication with the bots to obstruct any deployed botnet detection processes [17]. The attackers or botmasters use the DNS services to hide their command and control (CnC) IP address ;to make the botnet reliable and easy to migrate from server to another without being noticed

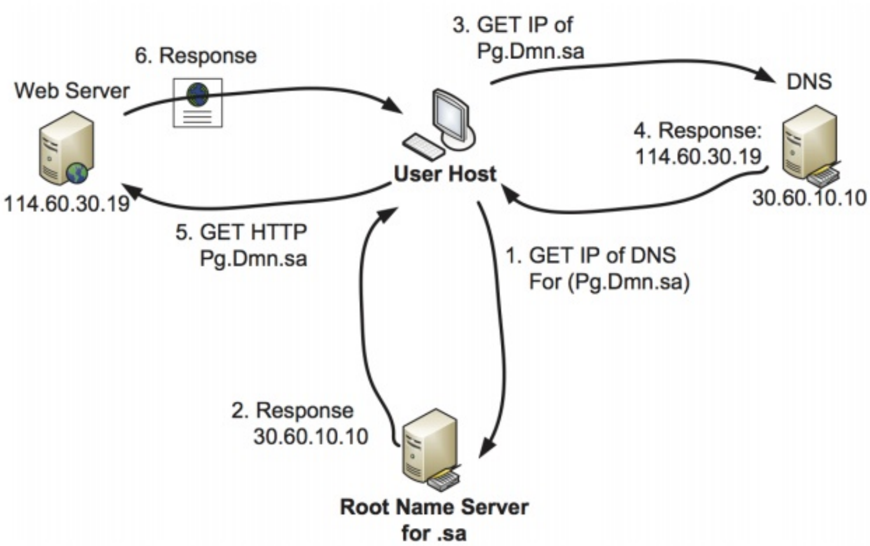
Fast-Flux Service Network (FFSN) allows for one domain name to have an unlimited number of IP addresses, short TTLs(Time to live) values and the IPs rotating in a round robin fashion. IP addresses belonging to such a domain act as a proxy for any device attempting a connection with their respective CnC server. This process helps botnet controllers avoid detection and blacklisting. But can be confused with real traffic. It has a different categories:

1. Single-flux: Multiple IP addresses are assigned to the same domain (either CNAME or A records). (low TTL, multiple autonomous system(AS) locations, proxies for master)

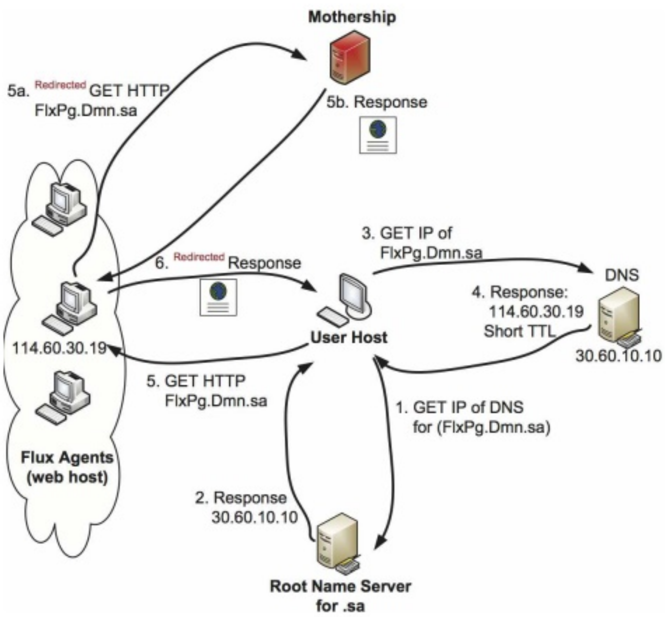
2. NS flux: Multiple NS records assigned to the same domain

3. Double-flux: Multiple name servers are assigned to the same domain and then use single-flux for the multiple IP addresses of the master. This provides a second layer of redundancy. This also means that the TTLs are short for the A records and the NS records too.

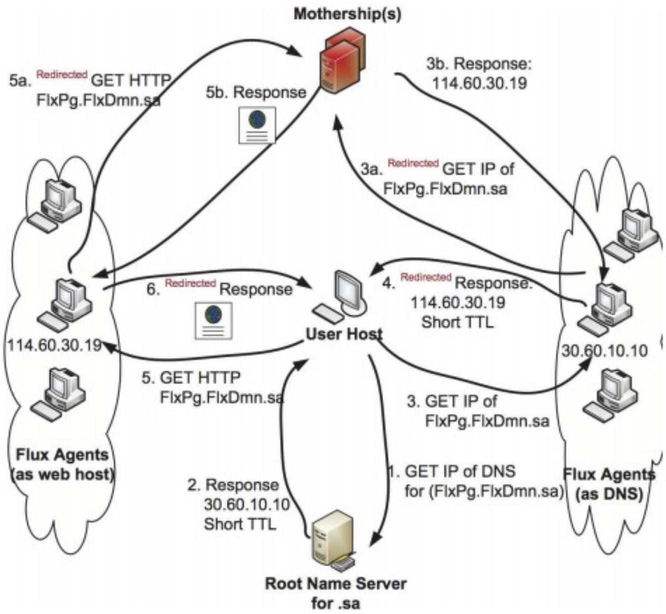
[source] Normal FF



single flux



double flux



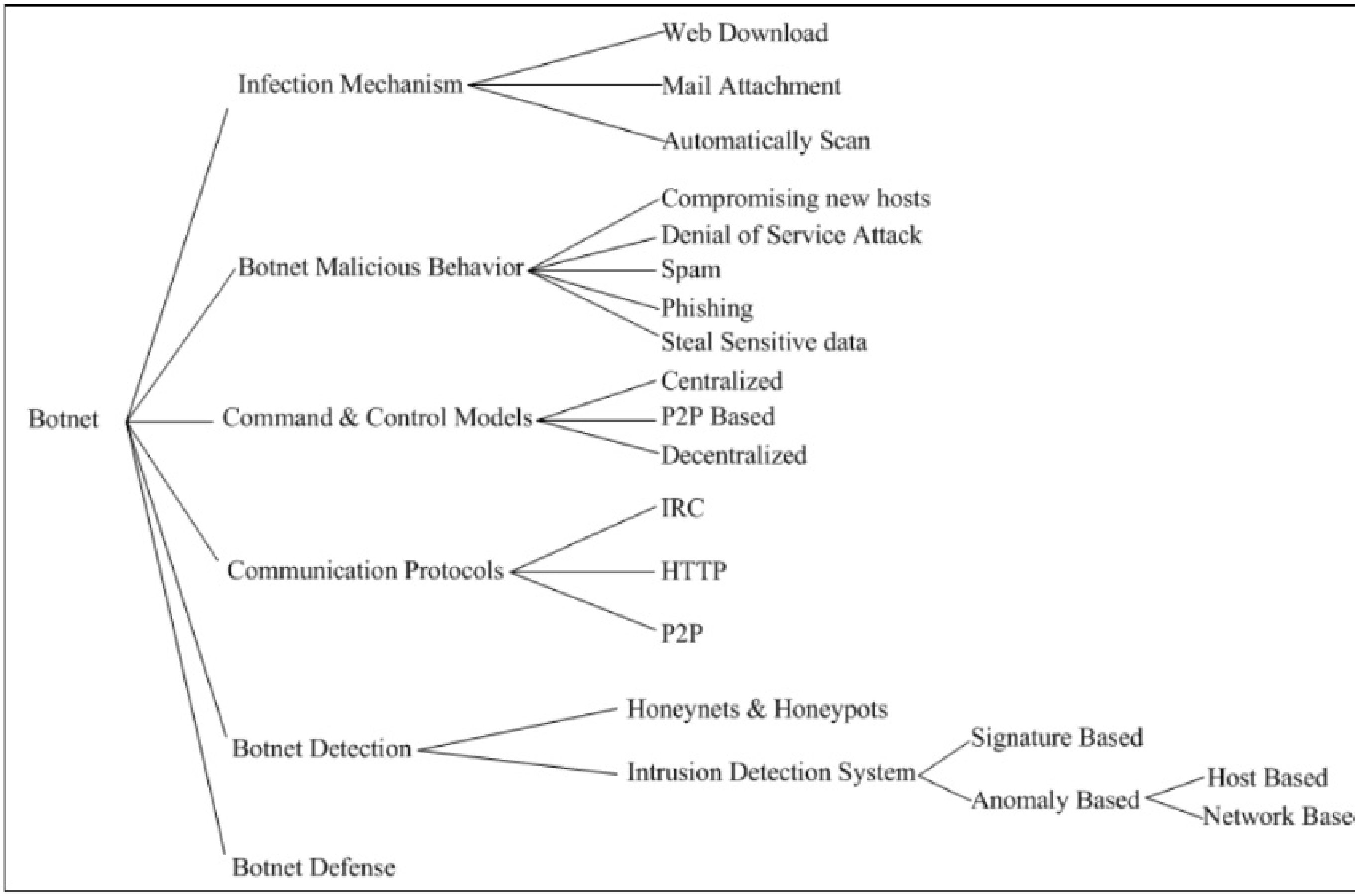
This is done to allow the botnet's domain name to have multiple IP addresses. In the meantime, involved DNS records are constantly changing every few minutes using a combination of round robin IP addresses and a very short TTL from any given particular DNS resource record. In FFSN, the victim client first sends an address query to DNS. Then, the DNS returns the IPs of a subset of active flux-agents. After that, the flux-agent relays the client's request to the mothership3. The key factor in FFSN is the combination of a very short TTL and the round-robin answer from a large pool of active agents Proceedings of the first Conference on First Workshop on Hot Topics in Un- derstanding Botnets, pp. 2, Berkeley, CA, USA, 2007. Some features for FF detection: nb of A records returned: 1-3 normal, 5 or more ff nb of NS: normal -> small, ff -> several NS + several A records for the NS AS: small nb of A from 1 AS -> normal, located in different AS -> ff Hardware and IP: range of IP is diverged -> ff No physical agent -> ff no garantee uptime. FIGURE NORMAL FF AND BAD FF (single and double)

DNS is an Internet service which translates names of sites into their numeric IP addresses. For every host, DNS has a list of A records each with a given Timeto-Live (TTL) value (normally from 1 to 5 days). DNS returns these A records in round-robin way. CDN use a lower TTL to provide their content more efficiently Fast-Flux Service Network (FFSN) is a distributed proxy network -built on compromised machines (flux-agents)- that direct incoming DNS requests to the botnet's desired address on the fly.

DNS tunnelling

DNS tunnelling implies the act of tunnelling other protocols or data through DNS, for example using the TXT as q_type and using the requests to actually send data. This has been done to avoid restrictions but is now also used to hide malicious traffic from botnets. They can also use DNS tunnelling to remain undetected while exfiltrating data. **Botnet1**

Maybe Domain shadowing (need more research)



2.3 Botnet detection related papers

2.3.1 classification of botnet research and detection

In this section related to papers focused on Botnet detection, we are going to present the classifications of botnets and what part of the research we have decided to focus on.

A number of botnet, detection measures, such as honeynet-based and Intrusion Detection System (IDS)-based, have been proposed. However, IDS-based solutions that use signatures seem to be ineffective because recent botnets are equipped with sophisticated code update and evasion techniques

Botnet detection and defence Early bots detected through signature -> vulnerable to any new botnet, but useful for old ones

classification: passive and active 3 types of behavior: - network based behavior: observable network traffic between botmaster and bots, can be used to detect individual bots and their CnC server. - host based beavior: observable calls on the systems infected by botnets. - global correlated behavior: global behavior characteristics, structure will be similar to current structures; same for all mechanisms

"4.1.3 DNS Traffic Botmaster use DNS rallying to make their botnets invisible and portable. Choi et al. [20] proposed botnet detecdetection mechanism by monitoring their DNS traffic. According to the authors, bots use DNS queries either to connect or to migrate to another CnC server. The DNS traffic has a unique feature that they define as group activity. Bots can be detected by using the group activity property of botnet DNS traffic while bots are connecting to their server or migrating to another server. There are three factors that help in distinguishing botnet DNS queries from legitimate DNS queries [20]; (1) queries to CnC servers come only from botnet members (fixed IP address space size), (2) botnet members migrate and act at the same time, which leads to temporary and synchronized DNS queries, (3) botnets usually use DDNS for CnC servers. For a botmaster to keep its bot hidden and portable, it relies on DNS to rally infected hosts. In botnets, DNS queries can appear for many reasons. They appear during rallying process after infection, during malicious activities like spam or DoS attacks, during CnC server migration, during CnC server IP address change, or after CnC server or network link failure. Based on the aforementioned five situations of DNS query used in botnets, the authors have developed a Botnet DNS Q Detection algorithms, which distinguishes the botnet. This algorithm starts by building a database for DNS queries comprised of the source IP address, domain name and timestamp. Then, they group DNS query data using the domain name and timestamp field. After that, they remove redundant DNS queries. Finally, botnet DNS queries are detected using a numerically computed some similarity factor [20] This algorithm cannot detect botnets migrating to another CnC server. Therefore, they developed a Migrating Botnet Detection algorithm by modifying the botnet DNS query detection algorithm. Similarly, this algorithm starts by building a database for DNS queries comprised of the source IP address, domain name and timestamp. Then, it groups DNS query data using the domain name and timestamp field. After that, it removes redundant DNS queries. The next step will be to compare IP lists of different domain name with same size of IP list, because bots use two different domain names for the CnC server during migration [20]. These algorithms are protocol and structure independent and are capable of detecting unknown and encrypted botnets. However, these are not for real-time detections and have low accuracy for small networks. Furthermore, they are very sensitive to threshold values which need to be chosen very carefully to balance false positives and false negative rates.

Honeynet: capture and analyze Pros: Easy to build, low ressources requirements Cons: Hard to scale, limited interactions + can be reverted by hackers to learn new evasion techniques. IDS: monitor and look for signs 2 types: signature or anomaly based through DNS analysis(most promising) Anomaly detection approaches that work: - DNS Blacklist (for malware, botnets and spambots) - detect botnets when they try to communicate with their CnC: NXDomains - recursive DNS queries detecting botnet related services - DGA 1) Main DGA 2) Decision tree + Bayes for DGA classification - Kopis = high level DNS query analysis (upper hierarchy) - Exposure graph analysis - reputation system

ME TODO: In the beginning we explain the detection classification proposed by the large survey. Then we explain what we have researched and how we'll use it in our work. Keep in mind that it isn't a list of papers, it is a list of information that will be used or not later in the paper, that has to cover that topics current research state and that we need to argue on reasons we want to keep articles or not and what information we'll use.

After this presentation on the techniques used by Botmaster to set their botnets into certain topologies and evading the best they can current detection systems. We are now presenting the research papers that have tried to detect botnets using this different evasion techniques. Since the end goal is to find the best features for an all-in solution, we have structured the current state of research as follows: First we will present the current all-in solutions that exist, the features they extract and what model they have created. Secondly, to achieve our goal towards improving these solutions, the objective is to find better features and better models. We will present studies focused on single detection models that cover the field of detection through passive DNS analysis. For each study we will list the features proposed, understand their purpose and do a first selection if a thorough comparison has been made with the features presented. Otherwise they will saved for further analysis.

In a recent survey of the state of the art regarding Botnet detection based on DNS traffic analysis**survey**, they present a classification of botnet techniques (A survey of botnet detection based on DNS). They divide the classification into 2 categories, the honeynets and IDS(Snort). The later having evolved the most and where we want to focus. Most IDS were for a long time using signature-based techniques(check the IDS section for more details, p6). These are effective but only work with known botnets. Because they are signature-based there is a need to keep a blacklist updated very often, because a simple change creates a new signature and would be undetected if the database isn't updated with the latest signatures.
Newer techniques, described as "anomaly based" have emerged for 2 reasons: to detect unknown botnets and to respond to the new type of evasions that followed. Botnets have become a lot more resilient and stealthy. It has pushed the research to focus on features that would allow to distinguish between benign and malicious traffic. These new researches capable of detecting new bots are divided into 2 sections: host-based and network-based. This means anomalies focusing on a single host or the traffic of a network. The host-based research focused on detecting bots in single hosts by monitoring local processes and kernel level routines.(BotSwat) The big problem of these propositions were the inability to scale them, we would need large monitoring system on each host with complex capabilities to communicate with each other and do correlation(EFFORT framework, the only one apparently. Do a bit more research on this framework and correct any mistakes in its previous description). This is what the second section aims to solve by monitoring networks. This activity can be done passively by simply collecting the traffic and analysing it (passive monitoring) or actively by injecting packets into the network forged to make the bots react, and then analyse the network response. Active monitoring: explain in more detail the rest of the approaches. The part that our study focus on because "explain a valid reason for this part having more weight then the other ones, explain that our study could be a model combining different steps of the classification." Finally explain the different passive approaches:
Explain that these passive detection can also be divided into specific counters for certain evasion systems such as DF, FF, tunnelling. Or be put together in an all-in solution to detect botnets independently of the evasion technique used.
The first step in the research was to find the models that would be the current baseline for all-in solutions: Here we can start with 2 already gathered ones, and used the survey papers to find all-in solutions (if there are more than EXPOSURE), present them completely (features, dataset, model, purpose). IDEA: use the survey study chart to show strengths and weaknesses of papers.
- Step needed before presentation of these papers: classify them into the folders, create a summary for each one with the following information: Model (data processing, dataset used, classification process, features) finally for each relevant paper either do a summary with the 4 components or simple summary if redundant information.

After this part we are supposed to be done with the research, we have a last discussion of how the following step is planned and what information from this chapter will be translated into the rest of the thesis. ASK: should we introduce the research on datasets in the SOTA or the model presentation? ME

2.3.2 All-in solutions

Exposure

[source]

> EXPOSURE, a system that employs large-scale, passive DNS analysis techniques to detect domains that are involved in malicious activity. They use 15 features extracted from DNS traffic.

Time-based When we analyse many requests to a particular domain over time, patterns indicative of malicious behaviour may emerge.
These were supposed to be the features with the most weight, unfortunately due to lack of the same caliber of capture available to the authors of Exposure, we could not test out the 4 features related to time. Either because the datasets are compositions of smaller datasets, or because the timestamps are too short.

DNS answer based Here are some domain-flux features: A domain name can map to multiple IP addresses. In such cases,the DNS server cycles through the different IP addresses in a round robin fashion and returns a different IP mapping each time.
Malicious domains typically resolve to compromised computers that reside in different locations. The attackers typically use domains that map to multiple IP addresses, and IPs might be shared across different domains.

- the number of different IP addresses that are resolved for a given domain during the experiment window
- the number of different countries that these IP addresses are located in
- the reverse DNS query results of the returned IP addresses
- the number of distinct domains that share the IP addresses that resolve to the given domain (false positive can be reduced with google reverse DNS which will have hosting providers in top answers)

TTL value based Low TTL and Round-Robin DNS:

- high availability (Content Delivery Networks (CDNs))
- botnets using this, makes them resistant to DNS Blacklists(DNSBL) and take downs. Often using Fast-Flux Service Networks (FFSN).

Because FFSN are usually detectable because of low TTL and growing list of distinct IP addresses for a domain, it explains the purpose of the TTL features.

Domain name based Finally 2 simple features to expect detection of DGA: there is a big difference between legit domain names and domains generated by DGAs(Domain Generation Algorithms(DGAs).

This can be noticed with 2 simple features:

- ratio numerical chars to length of domain name
- length of the longest meaningful substring to length of domain name

Feature Set	#	Feature Name	# of Atomic Features
Time-Based Features	1	Short life	2
	2	Daily similarity	1
	3	Repeating patterns	2
	4	Access ratio	2
DNS Answer-Based Features	5	Number of distinct IP addresses	1
	6	Number of distinct countries	1
	7	Reverse DNS query results	5
	8	Number of domains share the IP with	1
TTL Value-Based Features	9	Average TTL	1
	10	Standard Deviation of TTL	1
	11	Number of distinct TTL values	1
	12	Number of TTL change	1
	13	Percentage usage of specific TTL ranges	5
Domain Name-Based Features	14	% of numerical characters	1
	15	% of the length of the LMS	1

2.3.3 Possible approaches to provide better features

Domain-flux

TODO: domain-flux can is mostly about analyzing domain names, here is a list of papers that attempt to do that with different metrics and features: DGA specific
Detecting Algorithmically Generated Malicious Domain Names,

Domain flux is mainly used with DGAs and so here are some papers that have proposed an approach to detect it.

In **dga**, they analyse the basic features that are common to most domain generated by DGA. The first is the length that can be an identifier because DGAs have long domain name. Recent DGAs have shown to have shorter lengths to blend with the other domains. They then propose 3 primitive features that capture linguistic and structural characteristics. They end with 2 more advanced features that cover the shortcomings of the primitive ones. They propose these features to detect DGAs:

length of the domain name excluding TLD (top level domain)
Number of vowels in the Second Level Domain (SLD)
Number of consonants in the SLD
Number of digits in the SLD
SLD trigram entropy
SLD trigram conditional probability

These 6 features are very simple but have obtained really good results. The reason for the last 2 features is to improve the quality of the classification since some of the features could belong to botnets or legit domains. The definition of the features is explained in the section where this approach is analysed.

In this paper**dga3**, they propose an unsupervised approach based on anomaly detection with a set of metrics analysing ngrams of the SLD. They use the Kullback-Liebler divergence measure with unigrams and bigrams, they also used the Jaccard index between bigrams and the last feature is the Edit distance. These 3 features are used widely in the DGA detection research because of their efficiency.

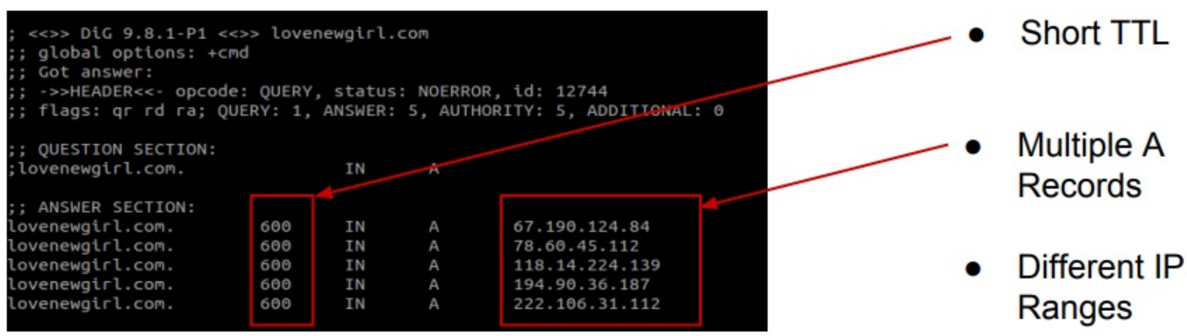
In this paper**dga4**, they realize that during the generation algorithm, most of the domains will not be up, this will generate a lot of NXDomain responses. Furthermore, the caching of NXDomains is limited which means that they cannot hide this traffic. Their contribution consists of a clustering technique based on domain names and request patterns; and similarity metrics for malicious domains detection. What can be retrieved from this study is the feature related to NXDomains, and the clustering process for big datasets.

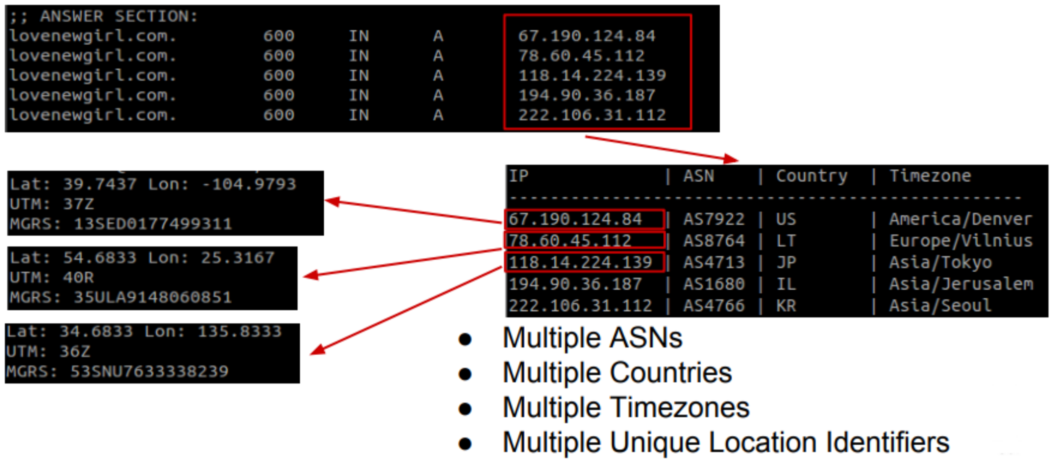
In **phoenix**, they explain the shortcomes of some of the other approaches. The study works in 2 phases: DGA discovery and DGA detection. In the discovery phase they apply the following filters that focus on linguistics: percentage of meaningful word in the domain name; popularity of the ngrams of the domain. They construct a base generated with the top 100.000 domains from Alexa. Then they define a distance (Mahalanobis distance) and thresholds(loose and stric ones) to determine when domains can be considered DGAs. They use known malicious domains to determine their thresholds. Afterwards they propose a sytem to cluster DGAs. They create a graph where each node is a domain and edges are created if both nodes resolve to similar IPs, the weight is proportional to the number of common resolved IPs. From all the "communities" discovered, they extract different common features to be reintroduced in the detection phase for each family of DGAs.

Fast-flux

For IP flux, most papers have similar features they propose to detect fast-flux. The big challenge is to find the small differences and detect malicious fast-flux networks(FFSN) from content delivery networks(CDNs). Both use fast-flux for different reasons such as load balancing, high availability and evasion.
The features most papers **honeynetff2ff3**bring forward are shown on the figures below**ff_botconf**, and listed here:

Numerous unique A records for a domain
Numerous unique NS records for a domain
Different Autonomous Systems (ASN) for the IPs of linked to the same domain
Different countries for the IPs of linked to the same domain
Short Time-To-Live (TTL)





We present now the different features and approaches proposed to distinguish the CDNs from FFSN.

Before the approach taken by **ff2**, most of the detection was based on DNS Blacklisting (DNSBL), their new approach was a passive analysis of recursive DNS traffic. Recursive DNS when your query is send to your DNS server, it starts by checking its cache and then will recursively ask other DNS servers until finding the address. Their purpose was to allow direct analysis of DNS requests and detect malicious ones. They want to improve the HoneyNet**honeynet** features(short time-to-live (TTL), set of resolved IPs returned at each query changes rapidly, usually after every TTL, the overall set of resolved IPs obtained by querying the same domain name over time is often very large, the resolved IPs are scattered across many different networks)
They start by applying filters to cluster the different networks of FF using the list above. On these clusters they then applied statistical supervised algorithms to do the classification. They used a base of features provided by **fluXOR** and added their own.
It starts with the passive features:

Number of resolved IPs
Number of domains (in a cluster = domains with similar IPs)
Avg. TTL per domain in a cluster
Network prefix diversity = ratio between the number of distinct /16 network prefixes and the total
number of IPs (measures the scattering)
Number of distinct domain names that resolved to at least one of the IP addresses in the considered cluster
IP Growth Ratio. This represents the average number of new IP addresses discovered per each DNS response related to any domain

Then the active ones:

Autonomous System (AS) diversity (ratio between the number of distinct ASs where the IPs of a cluster reside and the total number of resolved IPs. Same for the following diversities)
BGP prefix diversity
Organization diversity
Country Code diversity
Dynamic IP ratio (ratio of dynamic vs total IPs using keywords in reverse DNS lookups)
Average Uptime Index (average uptime for the IPs in a cluster, Uptime tested through probing)

They use these features on a Decision Tree classifier (efficient, easy to interpret and auto pruning of useless features) to classify malicious and legit FF networks.

In the following paper**ff3**, they propose some novel features compared to the other papers. To avoid redundancy, only the features not explored in previous papers will be detailed. In the paper they present the restrictions FFSNs face compared to CDNs: FFSN cannot choose the location which makes the IP address very scattered and no Uptime garantee. Possible distinctions: the lack of control results in number of unique A records returned different and the number of NS records in a single lookup (because the NS can be hosted inside the FFSN and return many NS records whereas legitimate CDNs return a very small set of NS records). The IP diversity restriction brings another feature which is the number of unique ASNs. Legitimate CDNs tend to return a single ASN for all their A records where FFSN are dispersed.
They decide not to include TTLs as a feature because both CDNs and FFSN have low TTLs. Finally, they introduce functions of the different features above to classify FFSN and CDNs.
Fluxiness is the total of unique A records for a domain divided by the number of A records returned for each lookup. This measures consistency in the unique A records returned.
Flux-score an hyperplane that separates benign from malicious fast flux where $x = (n_A, n_{ASN}, n_{NS})$ (unique A records, ASN and SN records) and the plane is defined as follows
From $F(x)$ they induce a metric $f(x) = w^T x$ with w the weight of the vector and b a bias. $f(x) > b$ would mean x is a FFSN. By empirically testing this on a labelled dataset they determined the value of w and b. $w = (1.32, 18.54, 0)$ and $b = 142.38$. We can notice that n_{NS} does not have any impact. It could be argued that FFSN will try to mimic CDNs to have the same metrics, but as argued earlier, the metrics used take into account the restrictions FFSN have. The rest of the study approaches the detection of FFSN using the HTML content returned by the spam websites.

This paper**ff5** regroups the large majority of features encountered in the other papers accompanied with to some novel additions resulting a long list of 16 features:

Type	Features
DNS Answer-based	Number of unique A records Number of NS records DNS packet size TC (Tnmcated) Flag is set
Domain name-based	Edit Distance KL (Kullback-Leibler) Divergence (unigrams and bigrams) Jaccard Index (unigrams and bigrams)
Spatial-based	Time Zone Entropy of A records Time Zone Entropy of NS records Minimal service distances (mean and standard deviation)
Network-based	Number of distinct autonomous systems Number of distinct networks
Timing-based	Round Trip Time of DNS request Network delay (mean and standard deviation) Processing delay (mean and standard deviation) Document fetch delay (mean and standard deviation)

DNS tunnelling

In **tunn1**, use of TXT RR with segmented and encrypted data. Rdata features: we look for the Shannon entropy of the strings. Measures the randomness of the string. Since encrypted data as a high level of entropy this is one of the things we'll be looking for. We are looking for "high byte entropy".Because of inherent reasons this entropy for a small string can't reach the max, we are looking at the "statistical byte entropy" instead.

The complete list of features for the Rdata:

- number of distinct byte values in m
- minimum byte value in m
- maximum byte value in m
- number of ASCII capital letters (byte values 65-90) in m
- number of ASCII digits (byte values 48-57) in m
- length of m in bytes
- absolute difference of the statistical byte entropy at given length of m and the entropy of m
- size of all Rdata messages

They expect these behavioural communication features to be effective enough in order to extend a classifier based on the rdata features.

In this paper**tunn**, they propose a visual approach to detecting DNS tunnelling, by plotting the following features, you can detect by "visual anomaly detection" the presence of DNS tunnelling. The features are:

- x-axis: destination IP
- y-axis: character count
- radius: hostname length
- colour: request type

Behavioral

Chapter 3

Model creation

Experiment Dataset Pre-Processing = feature extraction (I LIKE HOW HE EXPLAIN BI-TRI GRAMS)

3.1 Pipeline of the research

3.1.1 Environment

3.1.2 Datasets

Information regarding the datasets

Sources
Content
Labelling

balance of the datasets

3.2 Assessment model (for features and models)

3.2.1 Machine algorithms

Supervised

List of algorithms (to be decided)

Unsupervised

List of algorithms (to be decided)

3.2.2 Training model

3.2.3 Testing model

3.2.4 Results metrics

List of metrics used to analyse the models

Chapter 4

All-in solution process

4.1 Features extraction and features analysis

4.1.1 Domain-flux Features

4.1.2 Fast-flux features

4.1.3 DNS tunnelling features

4.1.4 Features analysis

Distribution of the features for the different datasets,Correlation between features

4.1.5 Features discussion

4.2 Features selection for All-in solution

4.2.1 Feature optimization cycle (adding/removing features, changing or modifying thresholds)

4.3 Comparison of the results

Chapter 5

Sets run and result discussion

5.0.1 Results analysis

5.1 Current All-in solution assessment

5.1.1 Exposure

5.1.2 Recognizing Time-efficiently Local Botnet Infections (Heuer et Al.)

5.1.3 More to come

Chapter 6

Conclusion

6.1 This will depend on results

6.2 Advantages of solution

6.3 Shortcomings

6.4 Improvements propositions

6.5 Welcome and Thank You

Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:
`\hypersetup{urlcolor=red}`, or
`\hypersetup{citecolor=green}`, or
`\hypersetup{allcolor=blue}`.
If you want to completely hide the links, you can use:
`\hypersetup{allcolors=.}`, or even better:
`\hypersetup{hidelinks}`.
If you want to have obvious links in the PDF but not the printed text, use:
`\hypersetup{colorlinks=false}`.