

UNIVERSITÉ LIBRE DE BRUXELLES

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

Declaration of Authorship	iii
Abstract	v
Acknowledgements	vii
1 Introduction	1
1.1 Research context	1
1.2 Research question	1
1.3 Thesis objective	1
2 State of the art	3
2.1 Botnets	3
2.1.1 Definition	3
2.1.2 Life cycle	6
2.1.3 The Channel	7
2.1.4 Topology	8
2.2 Use and abuse of DNS protocol	11
2.2.1 DNS	11
Normal DNS message structure	12
Header section	12
Question section	13
2.2.2 Botnets abusing DNS	13
Domain flux	13
IP flux	14
DNS tunnelling	16
Maybe Domain shadowing (need more research)	17
2.3 Botnet detection related papers	17
2.3.1 classification of botnet research and detection	17
2.3.2 All-in solutions	20
Exposure	20
2.3.3 Possible approaches to provide better features	21
Domain-flux	21
Fast-flux	22
DNS tunnelling	25
Behavioral	26
3 Model creation	27
3.1 Pipeline of the research	27
3.1.1 Environment	27
3.1.2 Datasets	27
Information regarding the datasets	27
balance of the datasets	27

3.2	Assessment model (for features and models)	27
3.2.1	Machine algorithms	27
	Supervised	27
	Unsupervised	27
3.2.2	Training model	27
3.2.3	Testing model	27
3.2.4	Results metrics	27
4	All-in solution process	29
4.1	Features extraction and features analysis	29
4.1.1	Domain-flux Features	29
4.1.2	Fast-flux features	29
4.1.3	DNS tunnelling features	29
4.1.4	Features analysis	29
4.1.5	Features discussion	29
4.2	Features selection for All-in solution	29
4.2.1	Feature optimization cycle (adding/removing features, changing or modifying thresholds)	29
4.3	Comparison of the results	29
5	Sets run and result discussion	31
5.0.1	Results analysis	31
5.1	Current All-in solution assessment	31
5.1.1	Exposure	31
5.1.2	Recognizing Time-efficiently Local Botnet Infections (Heuer et Al.)	31
5.1.3	More to come	31
6	Conclusion	33
6.1	This will depend on results	33
6.2	Advantages of solution	33
6.3	Shortcomings	33
6.4	Improvements propositions	33
6.5	Welcome and Thank You	33
A	Frequently Asked Questions	35
A.1	How do I change the colors of links?	35

List of Figures

List of Tables

List of Abbreviations

CnC	Command and Control
DoS	Denial of Service
DDoS	Distributed Denial of Service
WSF	What (it) Stands For

For/Dedicated to/To my...

Chapter 1

Introduction

1.1 Research context

Vulnerabilities keep growing → making botnets even easier to spread, which means cheaper and more powerful.

[source]

This is a compilation of Botnet news by Trend Micro: Compilation of Botnets variants:

1.2 Research question

My research question is : "**How can we detect Botnets through passive traffic analysis?**" 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 ?
- Can I find features not yet exploited to improve detection?
- Can I create an all-in model fitted for purposes not yet covered by other solutions.
- 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 and acquire along the way correctly conduct a research process and learn machine learning techniques to solve interesting problems. 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. They can result in great economic damage. Especially with their continuous improvement to become more resilient and powerful which makes them an even more important threat.

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 flavors criminals bring to the market.

2.1.1 Definition

What is a botnet? A botnet is a network of infected machines with programs called bots, these bots owned and controlled by a remote attacker called the botmaster. Users get infected via the same vector attacks used by malware, email attachment, malicious website, unaware download, etc. When bots usually infect these machines in stealthy manner, staying as unnoticeable as possible. 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.

What is a bot? Bots are small programs allowing to remotely control and perform commands on computers. They are the foundation of botnets. The paper presented by the SANS institute considers two types of bots. Bots used to perpetuate attacks, bots used for their content and both. 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.

These programs are embedded with port scanning, vulnerability scanning, exploitation kits and payloads that allow them to spread the botnet and infect their victims. There are many different families of bots, some very modular such as the Agobot others less complete 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 but there are a lot of different protocols exploited as botnets channels. 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.

Why do botnets provide more powerful attacks? Botnets give the control to the botmaster of two critical resources: CPU (processing power) and IP addresses (anonymity). Even if the use of CPU stays low on the infected machines, the aggregate of bots can provide power equivalent to supercomputers with the additional perk of executing traffic from different addresses instead of a single IP.

What is the purpose of botnets? All these resources make botnets very powerful to execute network 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.

What are the advances in botnets? Another reason botnets are a big threat is that criminals have started to provide botnets as a Service (BaaS) which are considered a big part of the botnet economy. This popularized botnets are sold to anyone, this has made them an even bigger threat that they already were. This BaaS is possible with decentralized architectures that can subdivided into smaller botnets to sold and then reintegrated to the parent botnet after use.

What types of actions are performed by botnets? 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.

This first list presents general use of botnets:

- **Distributed Denial-of-Service Attacks** These attacks provoke a loss of service or connectivity. Used by hacktivist, criminals and companies to disturb targets for recognition, financial gain or advantage over competition respectively. (The services could be email servers, production servers, web servers but also any device reachable)
- **Spam email campaigns** Bots are set as proxy nodes and then used to send large amounts of spam and phishing emails.
- **Sniffing Traffic** Bots can start watching packets going through the compromised machine and start retrieving all valuable data passed in clear-text. Botnets have been even found to analyze others bots data and take over them if they belong to another botnet.

- **Spying through Keylogging and file monitoring** Sniffing packets effectiveness is reduced by encrypted traffic. The solution is then to log the key strokes made by the users and retrieve sensitive information. This is done with a keylogger and filtering mechanism that targets specific use-cases (logins, password, ...)
- **Spreading new malware** Botnets growth depends on their ability to expand. Compromised targets have an important task to keep spreading the botnet. They can download malware or send viruses via email, there are various methods depending of the botnet type and environment they want to spread the malware.
- **Installing Advertisement Addons, Browser Helper Objects (BHOs) and Google AdSense abuse** These techniques are used for financial gain instead of disruption. These are based on websites using clicking based ads. The criminals set fake sites using advertising programs and then automate the bots to click on them to create revenue. Since the bots have different IPs it is very hard to detect the fraud.
- **Manipulating online polls and games** These are known to exist to influence decisions and are expected to be further used in the future. This is also very effective since each bot uses different IP addresses.
- **Mass identity theft** Stealing personal data such as mail accounts, intellectual property, military secrets, embarrassing information or bank credential. This is a combination of all of the above that allow to create campaigns based on that data collected. These campaigns make this stolen data effective through fake websites and spear phishing email attacks. Regarding the personal information that can be found by bots on the home desktops, this paper explains that it must not be overlooked. The amount of data that can be contained in home applications can be very important(taxes, browsers, email contacts. They warn of the sensitive information that is often stored on home computers related to their company. This could expose intellectual property that can be then sold by the criminals.
- **Host illegal sites** Child pornography and black market sites are some examples.
- **Computation for cryptanalysis** This is a less expected use of botnets, but these distributed supercomputers can be used for cryptanalysis purposes. Computing rainbow tables, cracking passwords, bruteforcing keys or mining crypto currencies. With the success of cryptocurrencies in the last 2 years, this type of use for botnets has increased. The latest example is the Smominru Monero mining botnet, mining around 9000 moneros worth at the time 3 million\$.

This second list targets activities of bots on the compromised machines to take full control:

- **Secure the system(close NetBIOS shares, RPCDCOM) to avoid infection by other criminals** This could also mean remove existing bots on the machine. Bots will make sure their host is properly hardened to avoid overtake.
- **Redirect traffic for the botnet** Depending on the topology used, bots might be used as proxies to send commands, updates, data to the rest of the bots.

- **Kill unwanted process running on the system** This joins the hardening objective. Bots want to take full control and make sure no process is limiting their actions (usually trying to stay stealthy while doing it).
- **Test for virtual machines and/or debugger software** Part of the resilience of botnets resides in the obscurity of the mechanism they use. Honeypots will try to capture bots and do malware analysis to understand how they work. This tests will try to prevent this analysis to happen. (By deleting themselves or not executing in these environments)
- **Add or delete auto-start applications** To stay resilient after reboot or even fresh installs, bots have mechanisms to stay persistent on the machine after those events.
- **Run or terminate programs** This one is obvious but after exploiting the victim, their goal is to execute actions on the machine.
- **Download and execute files** This allows them to update their software, download exploits and payloads. It can also be used to upload normal programs used for some of the tasks they want to execute.
- **Perform address and port scan** Another important one to pivot inside networks and expand the botnet surface.
- **Communicates with a handler or controller via public servers or other compromised systems** This is the main channel communication with the botmaster.
- **Data storage** One of the tactics used by botmasters to keep their anonymity is to use their botnet as a distributed database and saving the data obtained on the bots, this gives more distance with the stolen data.

2.1.2 Life cycle

What are the steps that make up a botnet life cycle? Life cycle execution might differ from one bot to another but they have generally a common structure. Here is the common structure presented in these studies:

1. **Exploitation** The first phase is the infection of the host. The bot gets access to the victim host through different possible vectors (email attachment, vulnerability scanning and exploit, obtained credentials, malicious site, ...). The next step of this phase consists on uploading to the host the binary of the bot. The bot connects to a server of the botmaster and downloads it. This step is very important for this thesis because it is the first DNS lookup the bot will perform and it has been noticed as the most consistent behavior of bots. This is where the bots are going to start to hide their DNS activity.
2. **Rallying** This is the phase where the bots will establish the link with the botmaster command and control servers (CnC), join the botnet and wait for instructions. When establishing the connection with the botmaster bots have to use stealth techniques to avoid getting discovered and more importantly revealing the CnC. These techniques will be discussed in the Misuses and abuses of DNS.

3. **Attack/execution** From this point on the bot is ready to get the orders from the botmaster and start executing actions. This is where the different actions defined above are executed by the botnet.
4. **Update and maintenance** This phase allows the botmaster to update periodically the software of the bots, new exploits, new attacks, the same way administrators patch their software. This final phase is a loop that goes back to the second phase where the bot contacts the CnC server to proceed to this binary upload and commands fetching. This is the second phase where the DNS request will use evasion techniques to stay hidden.

2.1.3 The Channel

What does it mean to join the botnet? The bots will rarely directly connect to the CnC servers, they will go through proxies or peers bots, (structural nodes of the botnet) to obtain commands and updates. The knowledge of these nodes and the techniques used to communicate with them are the channel of a botnet.

What are the channels used by botnets? The channel's resilience of a botnet is critical to ensure good communication with the CnC server. It is also a critical component because its failure is usually the end of the botnet's life. There are multiple ways of securing and hiding their communication channel: tunneling through protocols, encryption, DNS evasion techniques. The typical protocols that are used by bots to reach their CnC are these: IRC, HTTP, HTTPS, DNS, MAIL, SSH, etc. The use of different protocols implies there are a multiple botnet's communication topologies. The different topologies provide trade-offs in terms of bandwidth, rallying, stealth, ...

What are the goals of these different channels? The main goal of the botnet channel is to provide a vector for bots to reach their CnC servers and maintain a connection with it. This is the only way the botmaster is able to keep control his botnet. This is why the means of communication are built around these main needs. If bots aren't able to reach the botnet or their CnC, they won't be able to update their software and receive commands.

Reaching and locating the CnC servers is the first challenge the channel needs to handle. Failing to do so will leave the bot unusable for the botmaster or left in a sleeping mode. In this state, the bot keeps on with the harvesting of the victim host and retry the missed CnC regularly.

The second challenge being its ability to maintain the channel. This is where resilient techniques have evolved to achieve this goal. These technologies will be detailed in the abuses of DNS section. CnC servers and their channels are really what differentiates botnets from other malware.

How do botnets achieve such channels? To stay invisible and persistent channels have gone through different methods, here are the main ones:

- **Hardcoded IP:** The bot software has the IP address of the CnC server hardcoded somewhere in its binary. The server can be found through reverse engineering and the botnet could be stopped or suspended for a certain period.
- **Dynamic DNS:** This is a solution to the hardcoded IPs. In this case the botnet will have multiple CnC servers migrating frequently on its will. In addition to

using a dynamic list of servers, it uses dynamic DNS in order to avoid detection or suspension and keep the botnet portable. This allows the queries to be redirected if they were to fail. This behavior is known as herding, it provides mobility and stealth.

- **Distributed DNS:** To avoid law, botmaster locate their DNS servers outside of the law's jurisdiction. Bots have the addresses of the DNS servers and contact them to resolve the IP address of the CnC servers.

2.1.4 Topology

How are the channels used ? Now that we know the purpose of channels and what they provide to botnets we are going to explore the different topologies used by botmasters using different channels and architectures.

What are the different topologies used by botnets? The differences between topologies are related to protocols of communication. Their structure will result as mentioned above in trade-offs for its different specifications.

As explained in this paper, there are two typical botnet topologies which all the other topologies are built on:

- Centralized
- Decentralized

What are the metrics used to assess these topologies? The important metrics for a botnet are a combination of the above sections:

-
-
-
-

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

What are the different topologies? CnC topologies encountered in the wild typically match one of the following types:

- empty

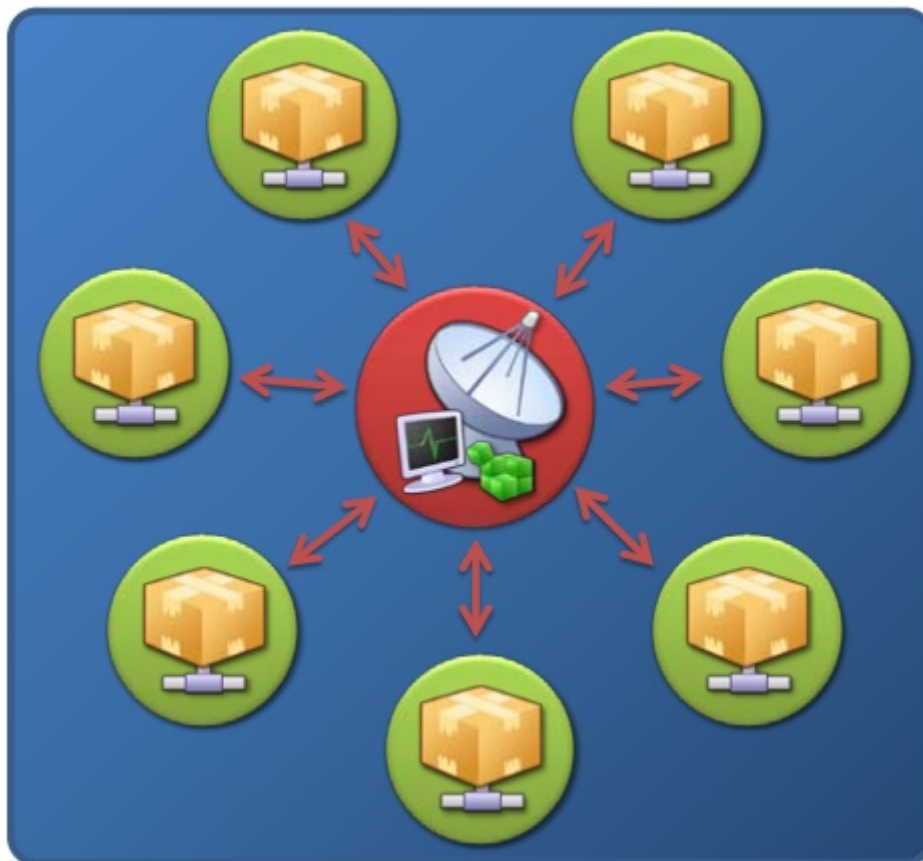
Star Multi-server Hierarchical Random

TODO: metrics analyzed to choose best option: cf slide(11)(<http://www.ijcttjournal.org/Volume4/issue1/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 Symposium 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 Conference 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 Understanding 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.

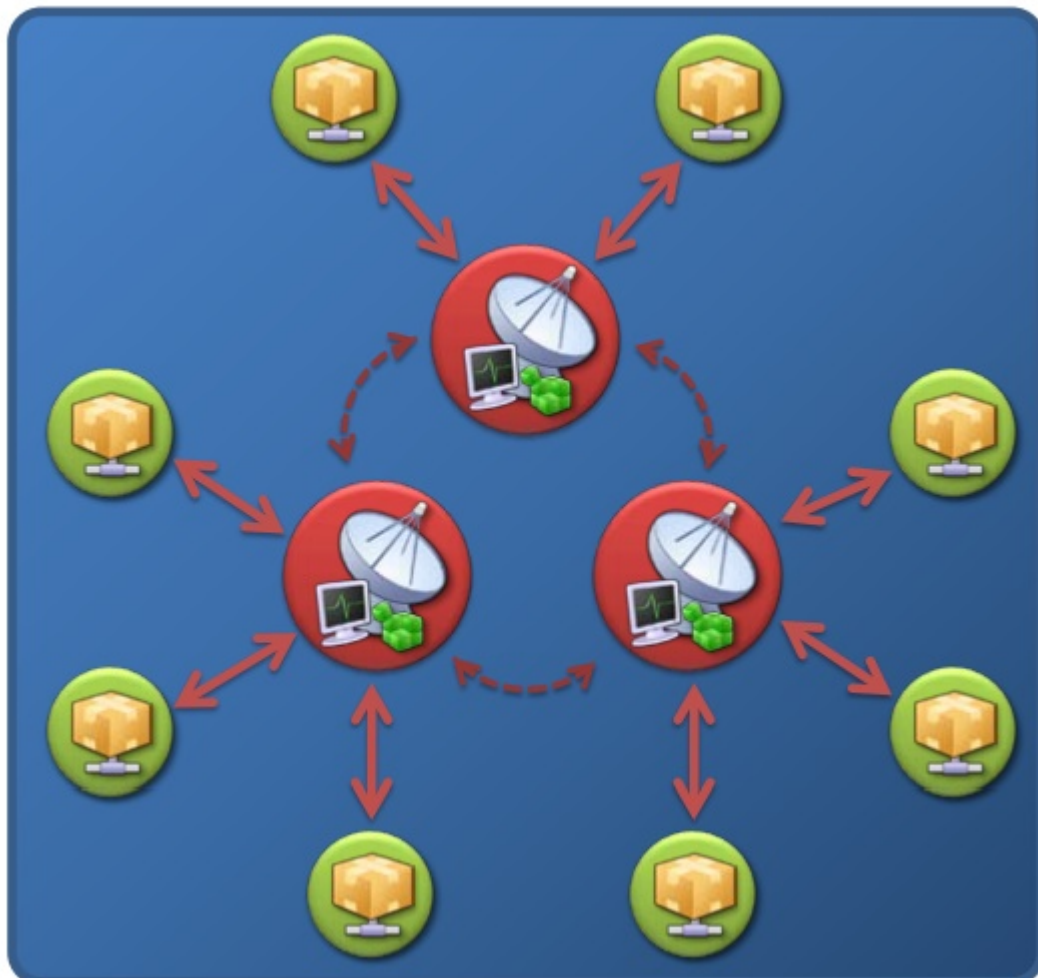
Pros Speed of Control The direct communication between the CnC and the bot agent means that instructions (and stolen data) can be transferred rapidly Cons Single point of failure If the central CnC is blocked or otherwise disabled, the botnet is effectively neutered.



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 agents make C&C communication unpredictable, which can result in 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 communication 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 servers can speed up communications between botnet elements.

Cons Requires advance planning Additional preparation effort is required to construct a multi-server 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 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 → query, 1 → Inverse query, 2 → 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

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

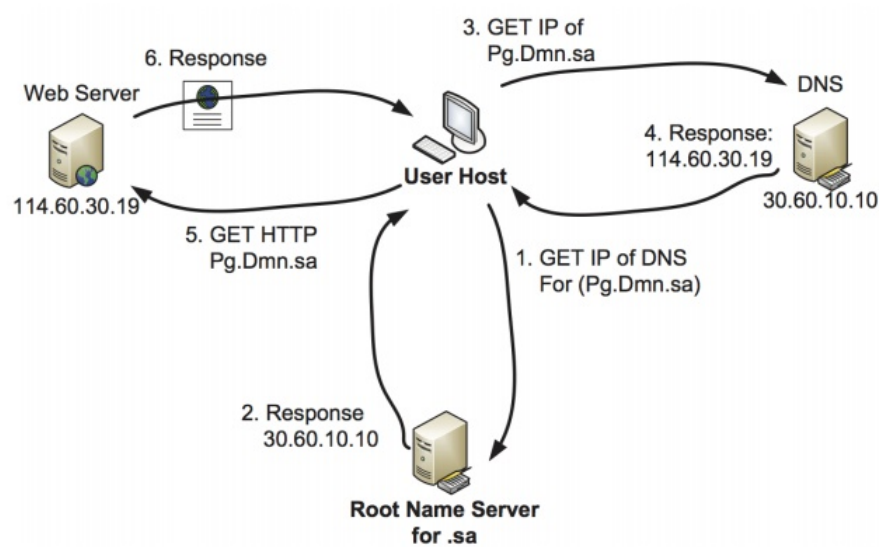
IP flux or fast flux,

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

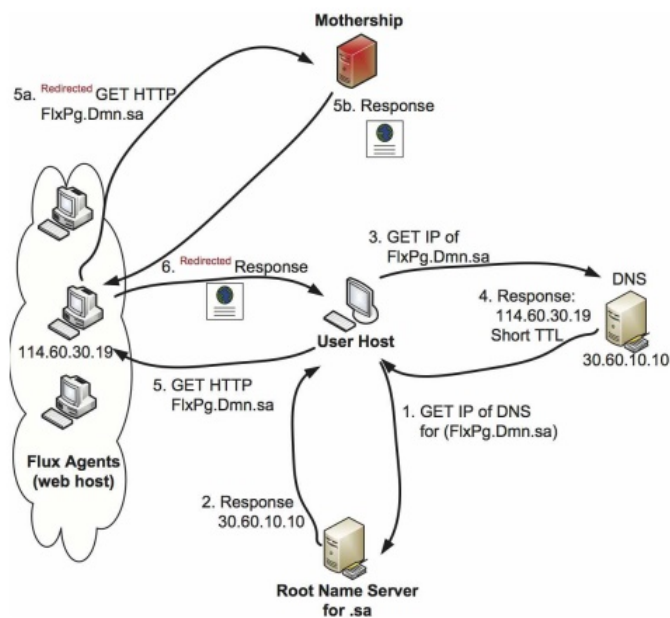
Fast-Flux Service Network (FFSN) allows for one domain name to have an unlimited number of IP addresses, short TTLs(Time to live) values and the IPs rotating in a round robin fashion. IP addresses belonging to such a domain act as a proxy for any device attempting a connection with their respective CnC 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.

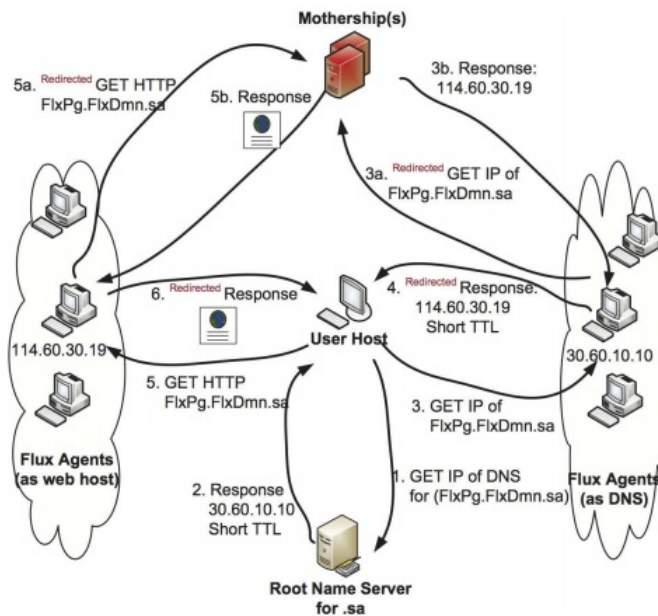
[source] Normal FF



single flux



double flux

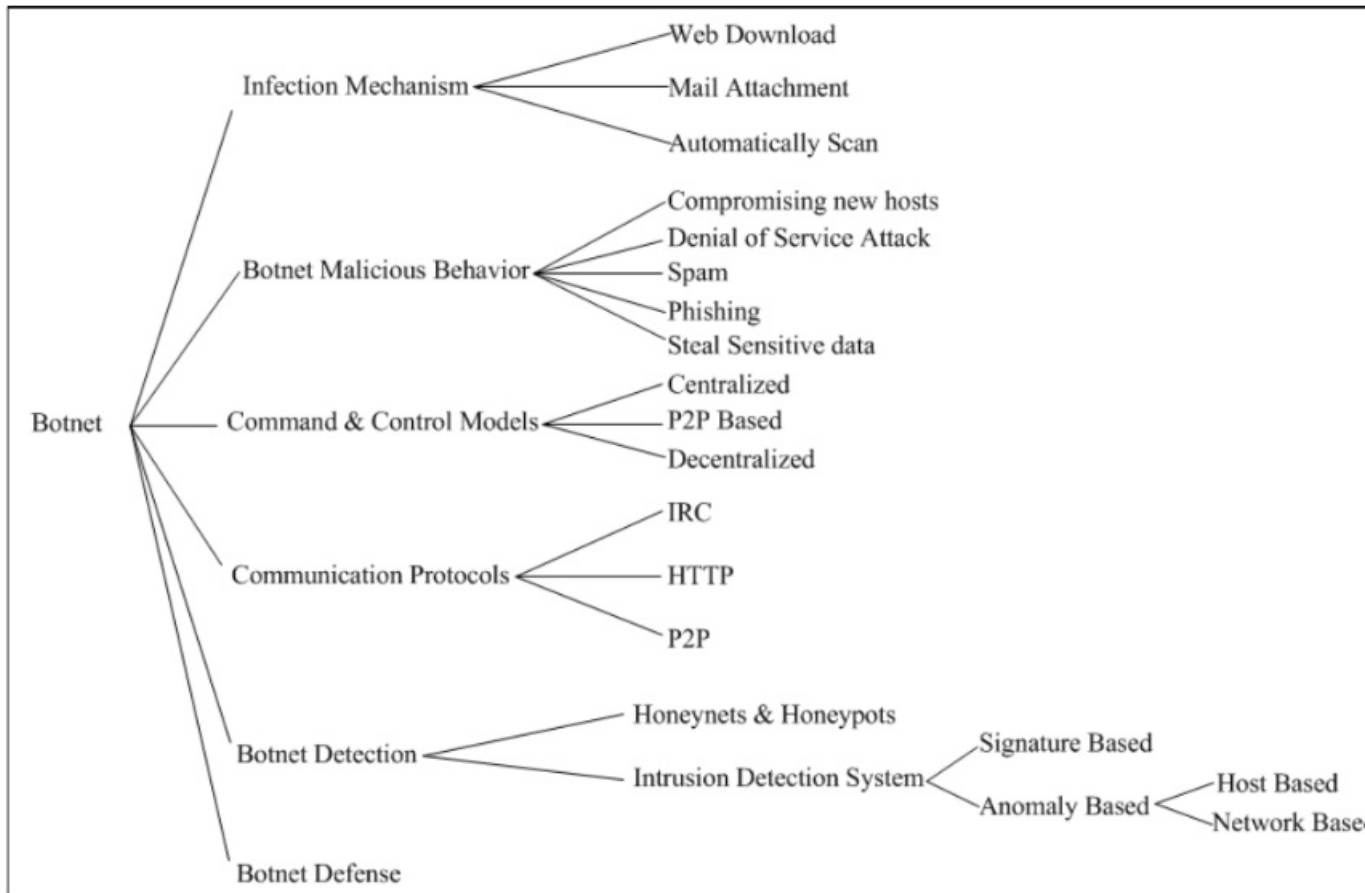


This is done to allow the botnet's domain name to have multiple IP addresses. In the meantime, involved DNS records are constantly changing every few minutes using a combination of round robin IP addresses and a very short TTL from any given particular DNS resource record. In FFSN, the victim client 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 Understanding 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 guarantee 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 Time-to-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 behavior: 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 detection 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 be 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 than 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
Domain Name-Based Features	13	Percentage usage of specific TTL ranges	5
	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 shortcomings 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 strict ones) to determine when domains can be considered DGAs. They use known malicious domains to determine their thresholds. Afterwards they propose a system 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)

```

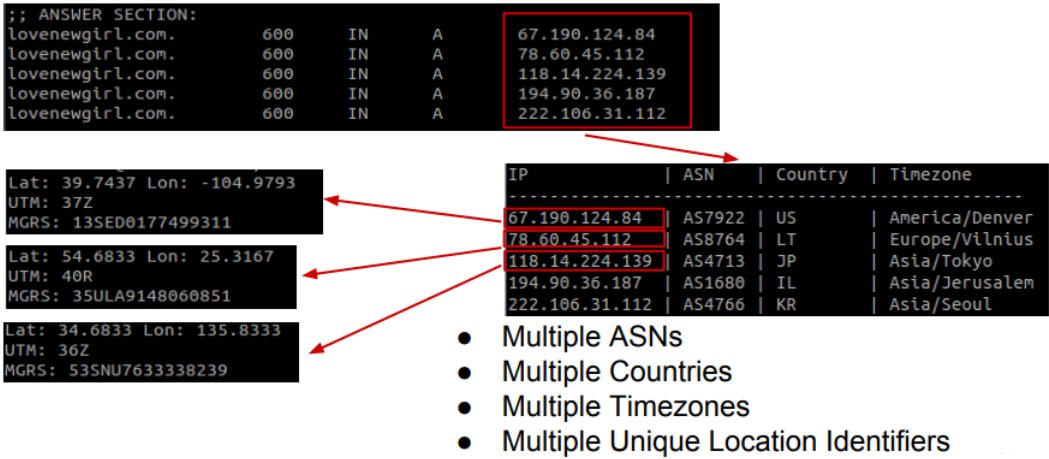
; <<>> DiG 9.8.1-P1 <<>> lovenewgirl.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 12744
;; flags: qr rd ra; QUERY: 1, ANSWER: 5, AUTHORITY: 5, ADDITIONAL: 0

;; QUESTION SECTION:
;lovenewgirl.com.
IN      A

;; ANSWER SECTION:
lovenewgirl.com. 600 IN A 67.190.124.84
lovenewgirl.com. 600 IN A 78.60.45.112
lovenewgirl.com. 600 IN A 118.14.224.139
lovenewgirl.com. 600 IN A 194.90.36.187
lovenewgirl.com. 600 IN A 222.106.31.112

```

- Short TTL
- Multiple A Records
- Different IP Ranges



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 HoneyNethoney**net** 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 guarantee. 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 (Truncated) 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}.
```