Abstract

A botnet is a network of compromised machines (bots), under the control of an attacker. Many of these machines are infected without their owners’ knowledge, and botnets are the driving force behind several misuses and criminal activities on the Internet (for example spam emails). Depending on its topology, a botnet can have zero or more command and control (C&C) servers, which are centralized machines controlled by the cybercriminal that issue commands and receive reports back from the co-opted bots.

In this paper, we present a comprehensive analysis of the command and control infrastructure of one of the world’s largest proprietary spamming botnets between 2007 and 2012: Cutwail/Pushdo. We identify the key functionalities needed by a spamming botnet to operate effectively. We then develop a number of attacks against the command and control logic of Cutwail that target those functionalities, and make the spamming operations of the botnet less effective. This analysis was made possible by having access to the source code of the C&C software, as well as setting up our own Cutwail C&C server, and by implementing a clone of the Cutwail bot. With the help of this tool, we were able to enumerate the number of bots currently registered with the C&C server, impersonate an existing bot to report false information to the C&C server, and manipulate spamming statistics of an arbitrary bot stored in the C&C database. Furthermore, we were able to make the control server inaccessible by conducting a distributed denial of service (DDoS) attack. Our results may be used by law enforcement and practitioners to develop better techniques to mitigate and cripple other botnets, since many of findings are generic and are due to the workflow of C&C communication in general.

1 Introduction

Botnets, networks of compromised computers under the control of the same cybercriminal, have been the tool of choice of miscreants committing illicit actions on the Internet for the last 10 years [10, 23, 29]. Security researchers and law enforcement experts are constantly engaged in an arms race with cybercriminals, finalized to disrupt botnet operations [23, 32]. Unfortunately, this arms race is difficult to win, because cybercriminals have the advantage that they can react to the countermeasures deployed by the security community and make their botnets more resilient to takedowns [31]. Moreover, the fact that botnet operations are distributed across the globe, and that different critical parts of the malicious infrastructure are typically located in different countries makes it particularly difficult for law enforcement to effectively coordinate and take down such operations [22, 34].

Due to the complexity of the botnet phenomenon, a wealth of research has been conducted on understanding such cybercriminal operations. A category of work focuses on understanding the monetization of botnet operations [2, 16, 17, 20]. Botnets need to generate a profit for their administrator (botmaster), and this usually happens by renting them out to other cybercriminals or by using them directly to perform illicit activities such as sending email spam or stealing financial information from the vic-
tim’s computer. Since the monetization part of these operations often involves financial transactions with legitimate institutions, researchers have identified the monetization of botnets as one of the weak links of cybercriminal operations, and as a good point of intervention for law enforcement [20]. A second line of research focused on understanding the command and control infrastructure used by botnets [6, 24, 31]. These systems typically aim to reverse engineer the C&C protocol with the goal of infiltrating the botnet and collecting important information about the cybercriminal operation [16] or developing systems to detect and block such communication in the wild [13]. A third line of research focused on understanding the modus operandi of cybercriminals using botnets, and what makes their operations successful [14, 32]. The focus of such research is to identify possible weak points in the workflow followed by cybercriminals, and use such weak points for botnet mitigation. As an example of such research, Stringhini et al. [33] discovered that spammers routinely clean up their email lists from non-existing addresses by having their bots report back the error codes that they received while sending emails. As a possible mitigation, they proposed that email servers send false replies to detected bots, forcing the botmaster to remove existing addresses from their email lists, and reducing the amount of spam that such servers end up receiving.

In this paper, we bring the understanding that we as researchers have of botnet operations even further. We analyze the source code of the command and control infrastructure of the Cutwail botnet [11, 32], which was one of the world’s largest spamming botnets between 2007 and 2012. This source code was obtained as part of a take-down operation that involved academics, Internet service providers, and law enforcement in late 2010. Having access to the source code of the C&C infrastructure provides us with a complete view on the logic behind the command and control communication of a botnet, which so far could have only been inferred by researchers from observation [6, 24]. This allowed us to identify bottlenecks and vulnerabilities in the workflow required for C&C communication, which could be used by researchers and practitioners to cripple the effectiveness of the botnet.

For our experiments, we developed a stub bot implementation to connect to the C&C server, similar to what done by researchers in the past [2, 30]. We then set up a network of bots connecting to a C&C server under our control, and performed a number of attacks ran by the bots against their controller. We show that misbehaving bots have the capability to enumerate the number of bots currently registered with the C&C server, impersonate an existing bot and reporting false information to the C&C server, and make the control server inaccessible by mounting a distributed denial of service (DDoS) attack. Interestingly, we show that 2,000 bots are enough to completely overwhelm the C&C channel and make the botnet non operational — such number is much smaller than the number of bots that C&C servers can deal with in the wild [14, 31, 32].

The insights presented in this paper can help researchers and practitioners develop better techniques to mitigate and cripple botnets. Although the analysis was performed on a single botnet, many of our findings are generic and are due to the workflow of command and control communication in general, rather than on implementation problems. The attacks that are demonstrated in this paper could be used to solve the problem of reliably enumerating the size of botnets [28], deceiving botmasters by making them believe that their bots are performing worse than they are, or that they have been blacklisted, or helping practitioners and law enforcement deploy fake bots to dilute the communication capability of the botnet and making it unusable for the cybercriminal.

In summary, this paper makes the following contributions:

1. We present an analysis of the command and control infrastructure of Cutwail, a large spamming botnet. As part of this analysis, we provide a detailed description of the workflow and the logic behind the C&C communication of spamming botnets.

2. We develop a number of attacks against the command and control logic of Cutwail. We set up a fake botnet in a restricted environment and demonstrate the feasibility and effectiveness of our attacks in gaining information about the botnet itself and crippling its operations.

3. We discuss how our results generalize to other botnets different from Cutwail, and how similar techniques to the ones presented in this paper could be used by law enforcement and practitioners to take down botnets.
2 Background: the Cutwail botnet

In this section, we provide an overview of the key components of the Cutwail botnet and its propagation mechanism.

2.1 Generic C&C operations

To achieve its goals, a spamming botnet C&C needs to perform three operations:

- Sending instructions to bots: the bots need to receive instructions from the C&C server in order to determine which emails to send, and to whom.

- Communicating with bots in general: the C&C server needs to manage its bots (e.g., keeping track of active bots) by communicating with them periodically.

- Receiving reports from bots: the botmaster needs to receive spamming statistics from the bots to measure the performance of the botnet, and to tune the botnet operation to make it more effective [14].

Regardless of the botnet's implementation and topology, the three operations described above are generic operations of any spamming botnet. Intuitively, the botmaster must be able to reach his bots to communicate and send instructions, and receiving reports from the bots for the outcome of their spamming operations is important to measure the performance of the botnet, and to tune its operations.

The factors that make spam campaigns successful presented by Iedemska et al. [14], state that experience is what matters most for a spammer. Botmasters have to housekeep their botnets well, and by manually tuning botnet parameters, one can dramatically increase the outcome of spamming campaigns. The attacks that we present in this paper can be used to tamper with statistics about the infected machines and overall spam operations stored in the C&C database. Since botmasters rely on this information to tune their botnets, these attacks can be used to deceive the botmaster into reducing the effectiveness of his own botnet by providing false information.

2.2 Cutwail botnet structure

Cutwail has a fairly simple structure consisting of three different layers (as shown in Figure 1). Firstly, the botmaster/spammer configures a spam campaign on the C&C server. Then, the bots connect directly to the C&C server and receive instructions about emails they should send. After the co-opted bots have accomplished their task, they report back spamming statistics (e.g., successful delivery, blacklisted by domain, etc.) to the C&C server.

2.2.1 Encrypted communication protocol.

The original Cutwail botnet emerged in 2007, and has evolved in sophistication using simple HTTP request to a proprietary, encrypted protocol [32]. The encrypted protocol is implemented using a block cipher in electronic codebook (ECB) mode. More details of the implementation of the protocol is available in [11].

2.2.2 Cutwail installation and infection process.

A typical Cutwail infection occurs when a compromised machine executes a so-called "loader" called Pushdo. Examples of infection vector include drive-by download, or an attachment in a spam email. Pushdo behaves as an installation framework for downloading and executing various malware components including rootkits that hide the presence of the malware in the infected machine, and the Cutwail engine. After executing the Cutwail engine, the Cutwail bot attempts to contact a command and control server in order to receive several critical pieces of information to begin a spam campaign. Specifically, the C&C server provides the bot with the actual spam content through "spam templates". More details in the infection process and the technical aspects of the operation of the Pushdo loader are available in different studies [11, 32].

2.2.3 Spam contents.

The contents of the spam template include (i) a list of target email addresses (also known as bases) where a spam will be delivered. (ii) a dictionary consisting of 71,377 entries for generating random sender/recipient names and domains. (iii) a configuration file containing details that control the spam engine’s behaviour (e.g., timing intervals, error handling, etc.). The content of the email mes-
sages sent by Cutwail included pornography, online pharmacies, phishing, money mule recruitment and malware. The malware (e.g., the Zeus banking Trojan) is typically distributed by persuading a user to open an attachment in the form of greeting card, resume, invitation, mail delivery failure, and a receipt of recent purchase. In addition, many of the emails contained links to malicious websites that attempted to install malware on a victims system through drive-by-download attacks.

2.2.4 Blacklisting.

One of the most important aspects of a spam campaign is the ability to pass through both IP-based blacklists and content-based filters. Bots that are not blacklisted are the most valuable since they increase the chance of successfully delivering spam. Each Cutwail bot periodically queries several blacklists (i.e., SORBS, SpamCop, DNSBL), in order to determine its reputation (as shown in Figure 1). This information is reported back to the C&C server and recorded. The C&C server also queries the blacklists periodically to determine the reputation of bots currently registered in its database.

In order to evade detection by content-based filters, a tool called macros can be used to instruct each bot to dynamically generate unique content for each email by modifying fields such as sender address, email subject line, and body based on the spam template. Also, each Cutwail C&C server runs a local instance of SpamAssassin, a free open source email spam filter based on content-matching rules. Once an email template has been generated, it is passed through SpamAssassin and tweaked until it successfully evades detection.

2.2.5 Infiltrating Cutwail.

Previous work on gaining insights into the operation of botnets via infiltration (running clone bots, the so-called “milkers” in controlled environments) is available from [2,7,18,19,30]. Such work has primarily aimed at monitoring the instructions issued to bots in order to investigate how botmasters employ their botnets. In this paper, we bring forward the idea of employing milkers as a tool not only to monitor the Cutwail C&C operations, but also to explore vulnerabilities in the C&C workflow and logic to develop attacks against them.

3 Analysis of the Cutwail C&C software

In this section, we present an analysis of the command and control infrastructure of Cutwail. As part of this analysis, we provide a detailed description of the workflow and the logic behind the C&C communication. We obtained the source code of the botnet by collaborating with Internet
Service Providers and law enforcement during a takedown operation in 2010.

3.1 Installation process

The developer of Cutwail provides a shell script to assist the installation of the Cutwail C&C software. The software can be installed on a server running either Linux or FreeBSD operating system. The installation script first downloads libraries required to compile the program code, initialises a MySQL database, and configures the SpamAssassin service. Then, it configures the Makefile that generates five binary executable files, which are installed under the /usr/local/psyche directory.

The database consists of 34 tables that stores information about bots and information required to operate spam campaigns. The bot table stores the bot identity number (BID), IP address, timestamps (e.g., last seen, born date), and spamming statistics for each registered bot. There are 17 status codes for reporting the delivery result of a spam email, including SENT (status code: 1), NO_USER (2), BLACKLISTED (5), NO_MX (8), SMTP_TIMEOUT (11), and NO_HOSTNAME (17). The botstatus table contains general information about the botnet, e.g., the number of bots currently online. The base table has records that reference files containing target emails addresses that are used by bulk operations. The header, message, mail-from, and macros tables contain information used to generate a spam template, which is sent to the bots, and instructions for dynamically generating a unique spam content based on the template.

3.2 Command and control program

The main executable file responsible for running the spam operation is called spcntrl (spam control). Also an executable called spsupport is run to support the spam operation by, for example, querying the IP-based blacklists in order to determine the reputation of bots registered in the database. Every time the spcntrl program is executed, it immediately computes and compares the hash code of the host’s network interface configuration to the one generated during the installation process, and terminates if they do not match. This is a mechanism for preventing security analysts from debugging the program that has been moved onto a different environment.

After the program has successfully started, it loads what are called common configurations from the database. These are general configurations that control the spam engine’s behaviour, which are independent from the configuration of each bulk operation. Common configurations define constants such as the IP address of the C&C server, the current version of the C&C software, timing intervals, and the maximum number of bots the server can control. After loading these configurations, the control program creates three threads for managing bots, bulk operations, and TCP connections from port number 43,242.

Figure 2 shows a flowchart of the operation of the bot management thread. Firstly, the C&C server waits for a bot to establish a TCP connection and sends a valid request to the server. After receiving the request, the server processes the header field, which contains the bot identifier number (BID) of the bot. If the BID is zero, the bot is identified as "new" and the server will assign a new BID to the bot and also record its information (e.g., BID, IP address, and timestamps) in the database. Otherwise, the server will expect an encrypted spamming report from the bot, which is decrypted and recorded in the database.

The C&C server runs an Apache web server that hosts a web interface, which allows the botmaster/spammer to configure and manage bulk operations (or spamming operations) from a browser. If there are any bulk operations currently in the "working" state, the server will send the corresponding spam template to the bot (if it has not been sent before). Also it will distribute a portion of the email database list if it is not empty, and the target email addresses (also known as bases) that are distributed to the bots are removed from the list. If the bot is identified as blacklisted, the server will not send any spam templates or bases to that bot.

The bot management thread has no mechanism for verifying the integrity of the BID field in the server request header other than using it to determine if a bot with that BID is currently registered in the database. This makes the command and control logic vulnerable to various exploits that are described later in this paper.

3.3 Encrypted communication protocol

As previously described, Cutwail encrypts its communication using a block cipher in ECB mode with an encryption key 29 characters long: "Pashel-ka ti na hui drug
After conducting a white box analysis by studying 13,904 lines of uncommented C source code and debugging the command and control program, we have gained an understanding in what each field in the server request mean, how they are processed, and how the server response is generated.

Figure 3 shows the dissection of the 2-field type messages sent and received from the server. The server request consists of an unencrypted request header, followed by an encrypted data package consisting of zero to one bot bulk info structure, followed by zero or more bulk info structures. The "size" field in the request header defines the size of the encrypted data package that follow (in bytes), which is used by the decryption function. Also, the header contains fields such as the BID, local IP address, Windows version, common configuration version, and the version of the bot (or the Pushdo loader). The bot bulk info structure contains general information about the bulk operation that is assigned to the bot (e.g., the bulk ID, and the spam template version number), and its "logsize" field defines the number of bulk info structures, i.e., the number of spam email reports that follow (default maximum of 1500). The email ID number and the delivery status code (previously described, e.g., SENT, BLACKLISTED, NO_HOSTNAME, etc.) of each spam email is stored individually in each of the bulk info structures.

The server response simply consists of an unencrypted response header, which contains the command type and the size of the encrypted data package that follow. There are nine command types including RC_SLEEP, RC_GETWORK, RC_RESTART, RC_UPDATE, RC_BID, and RC_TEMPLATE (RC stands for Response Command), which determine the content of the data package, e.g., a new BID of the bot, bases, or the spam template.

4 Cutwail clone implementation

The Cutwail clone implements the encryption/decryption algorithm described in [11], and the protocol operation that is used to communicate with the C&C server is described below.

1. Establish a TCP connection with the C&C server on port 43,242.
2. Send a server request with the structure described in section 3.3 (with the BID initially set to zero), and wait for the server response.

3. Upon receiving a response, extract the first four bytes of the (unencrypted) header, which correspond to the command type, and the remaining four bytes in the header to see the size of the encrypted data package. Decrypt the encrypted data package if its size is greater than zero.

4. If the command type is:
   - **RC_BID.** Extract the BID value from the decrypted data and change the BID of the clone bot accordingly.
   - **Otherwise.** Record the command type and the decrypted data (e.g., RC TEMPLATE and the spam template data), and continue.

5. Return to step 2.

The clone bot only implements the communication feature of the botnet and does not cause any harm by sending spam emails, etc. The only difference between a real bot and the clone is the interpretation of the command type in step 4.

4.1 SSH botnet

We have set up a SSH botnet, which in our experiment consists of 19 virtual machines each capable of running up to 1024 instances of the Cuttawail clone. This gives us the capability of controlling up to 19,456 Cuttawail clones, which can be used mount a distributed denial of service attack against the Cuttawail command and control server by just instructing each clone to speak the communication protocol described above. We are by no means limited to using more virtual machines for the SSH botnet, and if necessary, the number of virtual machines can be increased to raise the total population of the clone bots.

5 Attacks against the Cuttawail botnet

In the following section, we describe four attacks against the command and control logic of Cuttawail that can be used to gain information about the botnet itself and cripple its operations. Specifically, we aim to exploit vulnerabilities in the three generic C&C operations of spamming botnets (described in section 2.1) that we can discover to disrupt the operation of Cuttawail. By doing this, we aim to showcase attacks that can be used for mitigation and take-down purposes against any spamming botnet, regardless of its specific implementation.

Firstly, the C&C operation of sending instructions to bots is exploited by using the clone bots to continuously request the C&C server for bases, thereby preventing those bases to be received by real bots, and eventually, exhausting the base list maintained by the control server. Secondly, the C&C operation of communicating with bots
in general is exploited by mounting a distributed denial of service attack to saturate the server with external communication requests and make it respond so slowly as to be rendered non operational. We show that it is possible to completely disrupt the Cutwail C&C operation by using 2000 bots, which is a much smaller number than the number of bots typically controlled by C&C servers in the wild. Finally, the C&C operation of receiving spamming reports from bots is exploited by using the clone bot to report false spamming reports on behalf of an arbitrary bot currently registered by the C&C server. We also describe an attack to enumerate the number of bots currently registered in the server database. Although this attack does not exploit any of the three generic C&C operations, it is used as an auxiliary attack for reporting fake spamming reports.

5.1 Exhausting the base list

This attack exploits the generic C&C operation of sending instructions to bots. Each bulk operation must reference a file containing a finite list of bases (i.e., target email addresses) that are loaded during the start up of the spctrl program. These bases are distributed to bots upon request, and bases that have been distributed are removed from the list. When the base list becomes empty, the bulk operation simply stops distributing spam templates and bases to bots, and waits for spamming statistics to be reported. Therefore, it is possible to constantly request the C&C server from the clone bot to receive bases until the list of bases become exhausted/empty. This will prevent real Cutwail bots from receiving spam templates and bases, which are required to perform their spamming operations.

5.2 Distributed denial of service attack

This attack exploits the generic C&C operation of managing bots by communicating with them in general. We use the SSH botnet described in section 4.1 to mount a distributed denial of service (DDoS) attack against the botnet control server. The C&C server has a limited bandwidth and is limited to the number of concurrent connections it can manage from bots. Like other DDoS attacks, it is difficult to distinguish legitimate traffic from real bots and those generated by bots under our control. This makes this attack difficult to defend against, and it will overload the server by saturating it with external communication requests and/or making it respond so slowly as to be rendered non operational.

5.3 Enumerating the number of bots registered

This attack is used as an auxiliary task, and is needed to report fake spamming reports. In addition, this attack could be used to solve the problem of reliably enumerating the size of botnets. Previous research [7,30,32] underlined the difficulty of estimating the size of botnets, which makes this attack particularly useful.

The BID column in the bot table in the C&C database is an auto-incremented primary key. When a new bot contacts the control server, it is given the largest BID in the current table incremented by one. As previously mentioned in our analysis, the control server has no mechanism for verifying the integrity of the BID field in the server request header except for checking whether a record exists for that identifier in the table. Therefore, it is possible to impersonate an existing Cutwail bot by just spoofing the BID field in the request header. An interesting behaviour is observed when doing this. If a record for the spoofed BID already exists in the table, the server replies with the RC_BID command, followed by a data package containing the same BID in the request. On the other hand, if the record does not exist in the table or the BID is equal to zero, the server identifies the bot as “new” and replies with a new BID.

Based on these observations, it is possible to enumerate the number of bots registered in the database by going through the following steps:

1. Firstly, send a request to the server with the BID field set to zero in the header.
2. The server will reply with the largest BID value in the table, incremented by one. This value is used as the upper bound to the number of bots currently registered in the database.
3. Send a server request with a spoofed BID field for each BID between one and the upper bound (obtained in step 2) decremented by one.
4. For each server response, compare the BID contained in the response header to the one in the request...
header. If they are equal, increment the bot count by one; otherwise, the BID does not exist in the table.

The value obtained in step 2 is used as the upper bound, since some BID records less than that value is not guaranteed to exist because an experienced botmaster will remove records of bots that are performing badly to increase the effectiveness of his spam campaign. This is why steps 3 and 4 are executed to account for the missing BID records.

5.4 Reporting fake spamming reports

This attack exploits the generic C&C operation of receiving spamming reports from bots. After identifying the bot records that exist in the database (from the auxiliary enumeration attack), we can manipulate the spamming statistics of an arbitrary bot that is currently registered in the database by spoofing its BID and sending bot bulk info and bulk info data containing false spamming reports. As explained in section 3.3, the bulk info structure has a status field, which can be set to any email delivery status, e.g., BLACKLISTED (status code: 5), which will cause the bot appear to be blacklisted by the domain of the target email address, for example, gmail.com. By making the bots appear to be performing worse than they are, botmasters may be deceived into abandoning those bots in an attempt to increase the effectiveness of the botnet.

Also, we have observed that whenever a Cutwail bot establishes a TCP connection with the control server, the IP address, and the "last seen" field in the bot database is updated for the specified BID record. This means that by impersonating a currently registered bot, we can overwrite its IP address with the IP address of the clone, and the "last seen" field with the current time. Assuming that the real bot is not going to connect back anytime soon, we can deceive the botmaster by making old or inactive bots appear to be active. Additionally, the IP address of the clone can be spoofed to the one that is known to be in the blacklist (e.g., DNSBL), thus it is possible to blacklist all the bots that are currently registered in the database by overwriting their IP addresses. This could cripple the spamming operation of the botnet as the C&C server avoids distributing work to blacklisted bots.

6 Evaluation

This section presents the feasibility and effectiveness of each of the attacks described in the previous section.

6.1 Experimental setup

We have been careful to design experiments that we believe are ethical. The attacks were tested in a controlled environment with our Cutwail C&C server and clone bots running on VMware virtual machines with the host-only network configuration. However, by simulating the communication between the control server and bots over a virtual network adapter, we may have simulated the communication channel with a higher bandwidth compared with that of the Internet.

6.2 Exhausing the base list

During the attack, a clone bot queried the C&C server for some bases used for the bulk operation. As previously explained, the bases that are distributed to the bots are removed from the base list containing a finite number of bases. As a result, the base list maintained by the C&C server quickly became empty, and the server stopped sending spam templates and bases to all the bots in the botnet thereafter. By exhausting the base list, the attack will essentially prevent real Cutwail bots from receiving information required to perform their spamming operation. By default, Cutwail distributes 1000 target email addresses to each bot, which means that 1000 clone bots would deplete a list of 1 million email addresses. The attack will therefore, reduce the number of spam emails that are sent to the bases distributed to the clone bots, and thus, reducing the effectiveness of the spam campaign. This attack can also be conducted in conjunction with the DDoS attack to use multiple clones to speed up the process of exhausting the list of bases.

6.3 Distributed denial of service attack

To test the effect of the DDoS attack, the C&C server is initialised with a bulk operation with a base list containing 2048 entries. The rate at which bots are registered (shown in Figure 4) and the server response time against the number of online bots (shown in Figure 5) are measured while
the server is attacked by 1000 bots or 19,456 bots controlled by the SSH botnet. During the course of the attack, each clone bot is instructed to overload the C&C server by continually sending server requests.

In Figure 4a, we can see that the C&C server manages to register all 1000 clone bots in 40 seconds. In Figure 4b, since 19,456 Cutwail clones are running, the C&C server is expected to register around 19,456 bots. However, the number of bots that get successfully registered decreases dramatically once the server has registered above 2000 bots. The C&C server at this point is overloaded with communication from the clone bots that are already registered, such that it cannot process requests from new bots. Therefore, the DDoS attack essentially prevents any new real Cutwail bots from even registering with the C&C server. It is interesting that only 2000 bots are enough to completely overwhelm the C&C channel and make the botnet non operational - such a number is much smaller than the number of bots that C&C servers can deal with in the wild. The only difference is that the clone bots are instructed to flood the server with requests whereas real bots would only contact the server once they have accomplished their tasks.

Notice that the y-axis in Figure 5 is using a logarithmic scale. During the DDoS attack, as we increased the number of online (clone) bots, the server response time increased exponentially. The maximum number of bots used to record the response time was around 2000 due to the server overload. This result shows that not only the DDoS attack prevents new bots from registering, but it also slows down the server response time exponentially to existing bots. Furthermore, the botnet is expected to perform worse than the results presented, since the communication channel on the Internet would have a narrower network bandwidth compared to that of the virtual network adapter used in the experiment.

6.4 Enumerating the number of bots

To simulate the situation where the Cutwail server has registered some bots and is waiting for their response, the bot table in the database is initialised with dummy records with 100 as the largest BID. The records for BIDs, 20 to 29 and 50 to 59, are removed from the table to simulate poor performing bots deleted by the botmaster.

6.5 Reporting fake spamming reports

The BIDs that exist in the database can be identified by running the enumeration attack. In this experiment, the clone impersonates a "real" bot by spoofing its BID in the server request header. The clone is instructed to send a false spamming report (BLACKLISTED) on behalf of the real bot. However, we also test the situation where
The real bot is currently connected with the C&C server in order to see how the C&C server responds to connections from duplicate BIDs.

The result of reporting fake spamming reports is shown in Figure 7. The real bot first reports the SENT status for two of the spam emails assigned. Then the clone bot reports the BLACKLISTED status, which is stored in the same BID record. By debugging the command and control program, we have found that although the real bot and the clone bot share the same BID, they are internally treated as different bots by the control server and the BID value is only used to reference a row in the database to store the spamming statistics. This logic could be exploited to manipulate the spamming statistics of an arbitrary bot currently registered in the database regardless of whether it is currently connected to the control server.

This attack could be used to deceive botmasters by making them believe that their bots are performing poorly. Previous research showed that successful spammers take this feedback into account, and stop using bots that are blacklisted or email addresses that are non existent [14, 33]. This is an effective strategy for mitigating spamming
operations of botnets since it leads to a double bind for the botmaster/spammer: on one hand if the botmaster considers the feedback, he will remove a valid bot from his botnet. Effectively, this will reduce the size of the spamming botnet. On the other hand, if the botmaster does not consider the feedback, this reduces the effectiveness of his spam campaigns since the C&C server will continue to use bots that are actually performing badly.

7 Discussion

The attacks presented in this paper may not be specific to the Cutwail botnet since they exploit the generic C&C operations of spamming botnets. The base list exhaustion attack, DDoS attack, and reporting fake spamming reports all exploit the generic operations of sending instructions to bots, communicating with bots in general, and receiving reports from bots respectively. Our findings have a number of implications as follows.

7.0.1 Deceiving the botmaster.

We have shown that it is possible to enumerate the number of bots currently registered with the Cutwail C&C server. Also by spoofing their BIDs, it is possible to impersonate an arbitrary bot to report false information to the C&C. These attacks exploit the the generic operation of bots reporting back the outcomes of their operations to the C&C server. This gives us the capability of manipulating information that botmasters use to tune their botnets, and they may be deceived into abandoning bots that appear to be performing worse that they are or that they have been blacklisted, therefore reducing the size of the botnet. Additionally, this will have an economic impact on the botmaster as he will need to replenish his supply of bots, thinking that they are not suitable to the task anymore. This could lead him to buy new bots from the underground market or by using pay-per-install (PPI) services.

Since all of the attacks are implemented by just instructing the clone bot to speak the communication protocol of the botnet, in order to defend against the attack the botmaster has to first solve the problem of distinguishing legitimate server requests with those generated by the clones.

Although the analysis was performed on a single botnet (i.e., Cutwail), the insights presented in this paper can help law enforcements and practitioners develop better techniques to mitigate and cripple other spamming botnets since many of our finding are generic and are due to the workflow of command and control communication in general (e.g., distributing bases, communicating with bots, and reporting spamming statistics), rather than on implementation problems.

8 Related Work

Computer security researchers have paid a considerable amount of attention to the threats posed by botnets and their operations [10]. Existing research in the field of bot-
nets mostly falls in two categories: botnet analysis and botnet mitigation.

**Botnet Analysis.** At their beginning, botnets mostly used Internet Relay Chat (IRC) as their C&C channel. In 2006, Abu Rajab et al. tracked 192 unique IRC botnets and gained precious insights on how these networks operated [1]. Once botnets moved away from IRC and started using proprietary C&C protocols, researchers started writing their own bots speaking such protocols and infiltrated multiple botnets [2,7,18,19,30]. Their analysis and results provided valuable information on how botnets are operated. In this project, we implemented our own stub bot to speak Cutwail’s C&C protocol. Unlike previous work, who had to reverse engineer the protocol from observations or binary analysis, we were fortunate enough to have access to the server-side code. Chiang et al. studied the Rustock spambot and provided an analysis of this spamming botnet, which was the most active between 2010 and 2011 [5]. Decker et al. performed a similar analysis based on the Pushdo trojan [11]. Rossow et al. presented a taxonomy of peer-to-peer botnets [29].

Recently, Nadji et al. discussed how to perform effective botnet takedowns [23]. The issue of botnet takedowns is very complex, and this paper could help practitioners and law enforcement in devising possible techniques to perform effective ones.

Previous analysis of the Cutwail botnet was presented by Stone Gross et al. [32], and it was based on the data collected from multiple C&C servers as a result of an attempted takedown. Our work integrates the one conducted previously, offering a detailed view of the C&C protocol used by Cutwail as well as presenting some weak points in the control workflow of the botnet, which could be used to cripple it and make it less efficient. In addition, we show how our observations could be applied to different botnets than Cutwail, because many of them tackle weaknesses in the workflow of a botnet, rather than in its specific implementation.

**Botnet mitigation.** A number of projects dealt with automatically reverse engineering the C&C protocol used by botnets, by performing dynamic analysis on the bot binaries. Such systems allowed researchers to gain a better understanding of the C&C protocols, and use that knowledge to infiltrate multiple botnets [3,4,8,9,21,35]. In this project, we analyzed the server-side code of the C&C communication of a large botnet. This allowed us to get a better understanding of the workflow followed by botmasters in managing their bots, and identifying weak points in such workflow.

Other work focused on identifying C&C traffic in network data, and use this for detection [12,13,25,36,38]. A problem that this type of projects faces is the increasing use of cryptography by botmasters, which makes the creation of signatures difficult. In this project, having access to the source code of the C&C server allowed us to get a deep knowledge of the cryptographic protocol used by Cutwail, without need to reverse engineer it.

Other work looked at the activity performed by bots and used that for detection. Prominent examples used the email spam activity of bots to this purpose [15,26,27,37,39]. The observations in this paper are more general, and could generalize to botnets that are used for other purposes, such as performing DoS attacks.

Stringhini et al. [33] proposed a system to provide false information to botmasters and makes their operations less effective. Their system works by having a mailserver send false information to a known bot (for example a blacklisted one). In this paper, we bring forward this idea, and show the feasibility of creating fake bots that impersonate existing ones, and provide the botmaster with false information about them, forcing him to dropping such bots and purchasing new ones. We believe that this type of strategy could help greatly in the task of botnet mitigation.

9 Conclusions

We have presented an analysis of the command and control infrastructure of Cutwail, one of the world’s largest spamming botnet between 2007 and 2012. Also we have developed a number of attacks against the command and control logic of the server, which were made possible by setting up a network of clone Cutwail bots in a controlled environment. Our experiments show that misbehaving bots have the capability of not only being able to extract information about spamming campaigns operated by the botnet, but also to manipulate critical information stored in the server database to deceive the botmaster, and to cripple the effectiveness of the botnet by overloading the control server. Our inside view of the command and control infrastructure of Cutwail and the infiltration strategies developed offer new insights to law enforcement and
practitioners to devise similar techniques to take down other botnets.

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