A Case Study of the Rustock Rootkit and Spam Bot

In this paper we present a case study of the steps leading up to the extraction of the spam bot payload found within a backdoor rootkit known as Backdoor.Rustock.B or Spam-Mailbot.c. Following the extraction of the spam module we focus our analysis on the steps necessary to decrypt the communications between the command and control server and infected hosts. Part of the discussion involves a method to extract the encryption key from within the malware binary and use that to decrypt the communications. The result is a better understanding of an advanced botnet communications scheme.

In this analysis we examine a backdoor rootkit known as Backdoor.Rustock.B [7] or Spam-Mailbot.c [8] but hereafter referred to simply as rustock. While work has been done to deobfuscate the malware and study the rootkit [7,9], little information is available about the functionality of the spam bot that is contained within rustock. We are particularly interested in the communications between the command and control (C&C) server and infected hosts since they provide a glimpse into an advanced botnet communications scheme. The remainder of this paper presents a case study of the steps necessary to extract and reverse engineer the spam bot component.

First, we provide some information gleaned from observing the network traffic produced by the bot. Then, we walk through the three phases of deobfuscation leading to the extraction of the spam bot component. Next, we describe the reverse engineering of the spam bot leading up to the extraction of the session encryption key from memory that makes it possible to decrypt the C&C communications between client and server. Finally we summarize a sample decrypted C&C communication session between client and server.

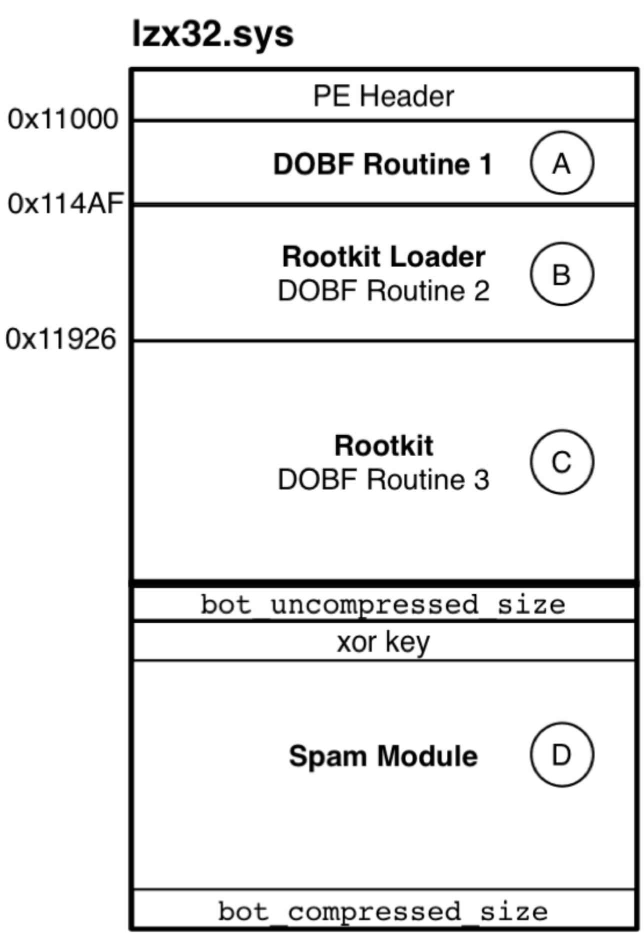
The key exchange phase is similar in all C&C sessions we observed. The HTTP POST from the client contains a 96-byte encrypted payload and is sent to the `login.php` page on the server. This is followed by a response from the server containing a 16-byte payload.

The instruction phase of the C&C communications consists of a variable number of HTTP POSTs from the client and corresponding responses from the server. The size of the payloads contained within these packets is also variable and therefore assumed to be dependent upon the variable nature of the underlying C&C instructions.

In addition to the information we gained through observation of the network traffic the people at Symantec helped us recognize that the encryption algorithm used to encrypt the data was RC4.

As shown in Figure 2, the malware contains four main components: the initial deobfuscation routine, the rootkit loader, the rootkit, and the spam module.

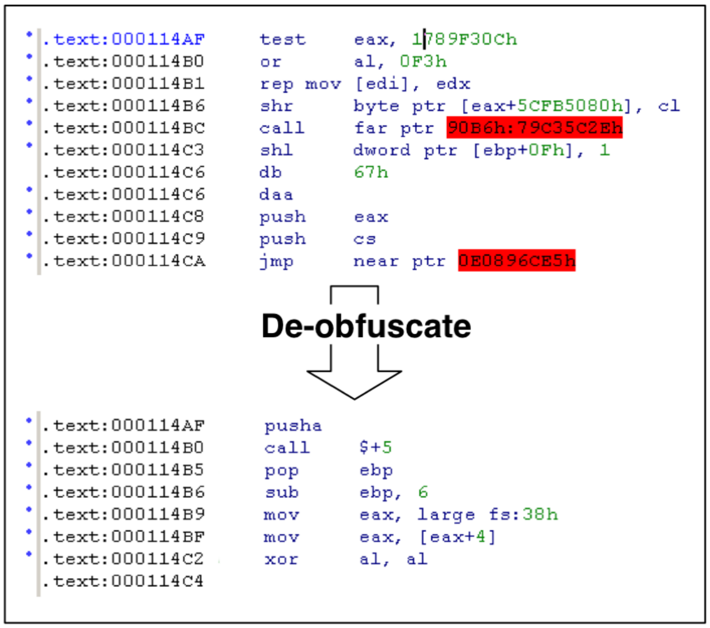
Figure 2: *Overview of the lzx32.sys malware. In our analysis we break it down into four parts: A. The first deobfuscation routine, B. The rootkit loader which contains the second deobfuscation routine, C. The rootkit containing the third deobfuscation routine, and D. The spam module.*



IDA Pro 5.0 Standard Edition [10], an interactive disassembly tool is used to study the code. A useful plug-in to the disassembly tool called idax86emu [11] is also employed to deobfuscate the malware. The plug-in tool emulates the x86 CPU instruction set and can modify the disassembly as it walks through the obfuscated code.

Using the emulator, we follow the deobfuscation routine to address `0x000114AF`. At this address, the deobfuscated code looks different and makes more sense than the code prior to running through deobfuscation, see Figure 3. This is the beginning of the rootkit loader.

Figure 3: *View of the disassembled code at the rootkit loader's entrypoint before and after deobfuscation.*



After a careful study of the code contained within the rootkit loader, we learn it takes the following steps:

- Searches for the ntoskernl.exe image in memory and imports the functions: `ExAllocatePool`, `ZwQuerySystemInformation`, `ExFreePool`, and `stricmp`.
- Using these imported functions, the malware allocates a chunk of memory of about 34k (`0x8800` bytes) and deobfuscates the memory chunk starting at address `0x00011926` into the allocated memory. The deobfuscation routine used at this stage (DOBF Routine 2 in Figure 2) can be recognized by the parameters passed to the function; they are the address of the encrypted `0x8800` bytes embedded in the binary and the address of the `0x8800` bytes of newly allocated memory. The deobfuscation routine is called at `0x00011593`. The deobfuscated memory turns out to be another PE executable, which is then mapped back to location `0x00011926`. This executable is the embedded rootkit component that we will discuss in section .

- Using the PE header of the embedded rootkit component starting at `0x00011926`, the rootkit loader sets up the import tables by using the strings table located within the deobfuscated rootkit component. Some example function names are `ZwEnumerateKey`, `ZwCreateKey`, and `ZwQueryKey`. These functions will be used by the rootkit component later to hide itself. The rootkit loader then does any necessary relocation using the relocation section of the embedded binary.
- Since the rookit component is now decoded and mapped into the malware, its PE header is no longer needed. Therefore, in an attempt to defeat RAM forensics, the rootkit loader deletes the MZ and PE signatures bytes from the decoded rootkit executable from memory before passing control to the embedded rootkit binary.
- The rootkit loader now jumps to `0x00011D92`, the entry point of the rootkit component, which will be discussed next.
- A pointer to an object representing the original malware driver file, i.e. `lzx32.sys`. It appears that this object is created by the Windows operating system when driver files are loaded into memory as a service.
- The registry path pointing to the registry key that loaded the malware driver file into the operating system. This path is Unicode encoded.

Knowing that the first argument is a pointer to the file object representing the original malware driver file is key in understanding how a modular component can be loaded and executed by the rootkit component.

After storing the two arguments in global variables, a system thread is created. This thread has the following functionality:

- Creates a handle to the rootkit kernel driver named: `\BaseNamedObjects\{DC5E72A0-6D41-47E4-C56D-024587F4523B}` (Since this handle name is hard-coded into the binary, it may serve as a way to detect the presence of the rootkit module).
- Checks whether the loaded malware driver file is stored in an Alternate Data Stream (ADS).
- Deletes all sub-keys in the hive: `HKLM\system\CurrentControlSet\Enum\Root\Legacy_lzx32.sys`
- Replaces the registry functions to hide the registry key created to load the malware at boot.
- Creates a notify routine using `PsSetCreateProcessNotifyRoutine` which gets called for all process activity. This notify routine creates at most two threads to inject the spam component into the services.exe process. By doing this, the malware ensures its survivability.
- The rootkit then replaces the `ZwQuerySystemInformation`, and `ZwTerminateProcess` functions.
- The same routine that injects the spam component discussed in step 5 is called at this point to start the spam component. This routine will be discussed in detail next.

The spam component is encrypted and appended to the original driver file `lzx32.sys`. The rootkit uses the first argument to extract this encrypted executable. One way to detect the presence of the appended component is to parse the PE header of the original malware driver file. By so doing, one will notice that there is additional data past the end of the PE executable. To extract and decrypt the appended data, the rootkit takes the following steps:

- Reads the last four bytes of the original file, this is the size of the encrypted and compressed executable, we will call it `bot_compressed_size`.
- Moves the file pointer back by `bot_compressed_size + 4`, and reads in four bytes that represent the xor key.
- Reads in the next four bytes after the xor key, this is the uncompressed size of the appended file, we will call it `bot_uncompressed_size`.
- The xor key is then used to xor-decrypt the data four bytes at a time, starting from the byte after `bot_uncompressed_size`.
- Allocates and uses a memory chunk of size `bot_uncompressed_size`, the xor-decrypted data is then deobfuscated using deobfuscation routine 3 (DOBF Routine 3 is the same as DOBF Routine 2).

The resulting file is another PE executable that is the modular spam bot component. To properly extract this module, it is important to use the size variables detailed above. Using the wrong sizes results in an incomplete spam module.

It was previously mentioned that the spam module is injected into the `services.exe` process, this is another step taken by the malware to thwart detection. The rootkit component follows these steps to inject the module into the `services.exe` process:

- Finds the process ID of `services.exe` by using the `ZwQuerySystemInformation` API function to return all system thread and process information and searching the returned results. Once found the process ID is stored in a global variable.
- Creates another copy of the `services.exe` process.
- Sets up networking capabilities by hooking the `tcpip.sys`, `wanarp.sys`, and `ndis.sys` driver functions.
- Extracts, decrypts, and deobfuscates the spam module as described above.
- Maps the spam module into non-paged allocated memory.
- Calls `KeAttachProcess` to switch the memory context to the `services.exe` process.
- The rootkit then sets up an asynchronous procedural call that provides a method to run the spam module code.

The RC4 encryption algorithm consists of two main parts, the key-scheduling algorithm, and the pseudo-random generation algorithm [12]. To generate the keystream the two algorithms make use of an internal state consisting of two parts, a permutation of all 256 possible bytes, and two 8-bit index pointers. By comparing the two functions found within the assembly code with a C code implementation of RC4 [13], we are able to determine that the assembly functions are direct implementations of the two algorithms that make up RC4. Additionally, the struct stored in global memory is the secret internal state consisting of a 256 byte char array and two index pointers into the array. The function containing the key-scheduling algorithm is called once during `login.php`. This function initializes the internal state variable and stores it in the global struct. The session key itself is not stored in global memory and is therefore difficult to extract. Fortunately, having the internal state variables is as good as having the original key generated by the infected host.

The code snippet in Figure 4 is from the IDA pro disassembly and shows the instructions leading up to the storage of the global struct containing the state variables. We have named the global struct `g_prepped_session_key`.

Figure 4: *Disassbled code for the routine that stores the prepared session key in a global struct. The hex equivalent of the first 4-bytes of the highlighted code is used to generate a signature that will be used later to extract the prepared key.*

```
CODE:00405CC2 008                lea     eax, [ebp+L_MD5_CTX_Struct]
CODE:00405CC8 008                call    Check_message_digest ; returns 1 if match
CODE:00405CCD 008                mov     ebx, eax
CODE:00405CCF 008                test    bl, bl
CODE:00405CD1 008                jz      short populate_eax
CODE:00405CD3 008                mov     eax, ds:g_prepped_session_key
CODE:00405CD8 008                push    eax
CODE:00405CD9 00C                push    47
CODE:00405CDB 010                lea     eax, [ebp-37h]
CODE:00405CDE 010                push    eax
CODE:00405CDF 014                call    Prep_session_key_and_store_in_global_memory
CODE:00405CE4
CODE:00405CE4     populate_eax:                          ; CODE XREF: Login_php+E0j
CODE:00405CE4                                            ; Login_php+109j
CODE:00405CE4 008                mov     eax, esi
CODE:00405CE6 008                call    @@FreeMem       ; __linkproc__ FreeMem
CODE:00405CEB
CODE:00405CEB     Clear_eax:                             ; CODE XREF: Login_php+A7j
CODE:00405CEB                                            ; Login_php+DAj
CODE:00405CEB 008                xor     eax, eax
CODE:00405CED 008                pop     edx
CODE:00405CEE 004                pop     ecx
CODE:00405CEF 000                pop     ecx
CODE:00405CF0 -04                mov     fs:[eax], edx
CODE:00405CF3 -04                push    offset cleanup
```

The instruction `jz short loc_405CE4` is the instruction that precedes the code that prepares the session key and stores it in global memory. Converting this instruction and subsequent instructions to hexadecimal results in a unique signature `0x74 0x11 0xA1 0x64` that we will use later to search and extract from memory the internal state variables used to decrypt the encrypted network communications.

We used Microsoft's User Mode Process Dumper [14] to dump the memory space of the `services.exe` process to a file. Timing of the memory dump is critical since it must occur after the key exchange and instruction phases of the C&C session but before the next key exchange. Because the client typically initiates another C&C session with the server every few minutes it is important to keep track of the various sessions and the corresponding memory dumps. In order to prevent the possibility of the state variable being overwritten one could use a remote kernel debugger to break execution after the C&C session has completed rather than dumping the memory. The disadvantage of this method is that it affects the timing of subsequent C&C sessions and could be noticed by the server.

Once we have a memory dump and a corresponding network capture of the C&C session, we load the memory dump into Microsoft's windbg [15]. The log file shown in Figure 5 enumerates the steps we took to extract the key. First, we locate the signature isolated in the previous section (`0x74 0x11 0xA1 0x64`). Next, we disassemble several instructions starting at the memory address we just found. The `mov` instruction at address `0x00d35cd3` loads a pointer to the struct containing the RC4 state variables, so to find the key we simply dereference the pointer. Finally we dump the state variables to a file.

Figure 5: *windbg log file with comments. This shows how to extract the RC4 state variables from memory.*

```
0:000> s 00000000 L?30000000 74 11 a1 64
00d35cd1  74 11 a1 64 47 d4 00 50-6a 2f 8d 45 c9 50 e8 2c  t..dG..Pj/.E.P.,
0:000> u 00d35cd1
00d35cd1 7411            je      00d35ce4
00d35cd3 a16447d400      mov     eax,dword ptr ds:[00D44764h]
00d35cd8 50              push    eax
00d35cd9 6a2f            push    2Fh
00d35cdb 8d45c9          lea     eax,[ebp-37h]
00d35cde 50              push    eax
00d35cdf e82cf8ffff      call    00d35510
00d35ce4 8bc6            mov     eax,esi
0:000> db 00D44764 00D44767
00d44764  a0 5d 0d 00                                      .]..
0:000> db 000d5da0 000d5ea1
000d5da0  e0 6d 55 4f 88 f2 6b 0a-45 bf 65 f8 a5 37 58 a0  .mUO..k.E.e..7X.
000d5db0  33 13 93 79 5a 4e 18 66-2f d4 fd a1 49 d1 22 3f  3..yZN.f/...I."?
000d5dc0  c7 31 32 21 fe 3c 73 1a-91 4b a8 bb 67 a3 c2 53  .12!.<s..K..g..S
000d5dd0  2a ad 6e 8d 4a 43 b0 7a-ec 46 b6 92 25 8f 35 db  *.n.JC.z.F..%.5.
000d5de0  5b 6c c4 a6 e3 83 f6 eb-8c 61 71 f1 84 56 e8 c9  [l.......aq..V..
000d5df0  8b 7d fa 05 c3 39 30 36-8a 7f f9 b2 a9 00 27 3e  .}...906......'>
000d5e00  ae b3 e5 b8 a2 ce 44 ff-2b 40 ed 2e 08 8e d9 9d  ......D.+@......
000d5e10  9f 69 c1 a4 0b 4d bd 02-9a 0c 89 df 16 dd 41 95  .i...M........A.
000d5e20  1c 14 86 9b c0 c6 0e 06-26 b4 85 1d 80 20 ca 59  ........&.... .Y
000d5e30  c5 a7 dc cb ea 09 50 19-7e d5 62 47 ab 9c 94 5f  ......P.~.bG..._
000d5e40  75 d2 de e7 fc 78 0f 81-b7 9e f4 af 64 87 98 cc  u....x......d...
000d5e50  90 b1 c8 ee 7b 1b d7 be-d6 97 e6 6f 99 23 cd 48  ....{......o.#.H
000d5e60  6a 15 e9 52 12 3b ef 29-01 03 60 f3 f5 e1 4c aa  j..R.;.)..`...L.
000d5e70  bc 68 24 10 d0 38 7c 74-1f e2 d8 e4 da 54 f7 5e  .h$..8|t.....T.^
000d5e80  82 fb 3d 1e 5d b9 5c 76-96 11 d3 cf 70 2d 2c 77  ..=.].\v....p-,w
000d5e90  57 3a ba 42 b5 17 f0 51-07 ac 63 72 28 34 0d 04  W:.B...Q..cr(4..
000d5ea0  00 00                                            ..
0:000> .writemem d:\key.bin 000d5da0 000d5ea1
Writing 102 bytes.
```

Search for signature

Address of struct pointer

Find Pointer

Dump Key

To decrypt the captured C&C session we use the global struct we have extracted from the memory dump containing the state variables. We modify the C code implementation of RC4 [13] to read the key-scheduling state variables from disk rather then generating a new instance. For us to decrypt the communication we need to apply the RC4 encryption/decryption function (pseudo random generation algorithm) to the POST message from the client followed by the response from the server. This keeps the state variables synchronized and allows us to decrypt both sides of the communication. Each exchange consisting of a POST to `data.php` and reply from the server can be decrypted separately since the state variable is copied from the global struct to the stack each time.

One thing to note is that the first fourteen bytes of the client message are ignored when encrypting the message. This was noticed during the static analysis of the spam module. In order to keep the state variables synchronized, we also must ignore the first fourteen bytes of the message.

Table 1 is a summary of a sample C&C session we decrypted and consists of seven data exchanges. The client initiates the conversation by sending the "kill.txt" string for which the server responds with a list of processes to terminate and files to delete from the client. Some examples of processes are `CAPP.exe`, `syswire.exe`, `Ravmond.exe`. Some examples of files are `m_hook.sys`, `comdlj32.dll`, and `secure32.html`. Web searches for the processes and file names indicate that these are other malicious programs that the client may be infected with. This provides a way to eliminate other infections that may conflict with this bot.

Table 1:*Summary of decrypted C&C communications between the infected client and the server.*

Message	Message Contents or Summary
Client 1	"kill.txt"
Server 1	Server response specifies processes to terminate and files to delete from the client
Client 2	Information about the client
Server 2	Information for the client about the client and file names to create or request for subsequent communications with the server
Client 3	"neutral.txt"
Server 3	List of domain names to query for mail servers to use
Client 4	"unlucky.txt"
Server 4	List of SMTP server responses that indicate failure
Client 5	"tmpcode.bin"
Server 5	Binary data that specifies the formatting of spam message to be sent by the client
Client 6	"tmpcode.bin"
Server 6	Binary data including spam content
Client 7	"-"
Server 7	List of target email addresses

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Next, the client sends information about itself to the server including bandwidth, OS version, SMTP availability (if outbound TCP/25 is allowed), if it is a virtual machine, and if it is blacklisted on a DNS blacklist. The server responds with additional information including the client's external IP address, machine name, task id that the server assigns to the client for a given spamming job, whether an update of the client is available, and names of additional command strings that the client can use for subsequent communications. An example of the command strings are "filesnames=neutral.txt" and "unluckystrings=unlucky.txt".

The next packet sent by the client is "neutral.txt", this request results in a list of domain names from the server. The client puts these domain names in a double-linked list and queries them for the presence of mail servers.

The fourth client request in this session is "unlucky.txt". This request results in a list of error messages that an SMTP server could return. Some examples are "Please use your provider SMTP" and "your mail rejected"

In the fifth and sixth exchange, the client sends the request string "tmpcode.bin" and the server responds with binary code and spam content that is used by the client to generate spam messages that are dynamic in nature to bypass spam filters.

Finally, in the last session, the client send a single dash ("-") to which the server responds with a list of email addresses where spam messages will be sent.

Based on our observation that the starting address of the deobfuscated code changed between versions of `lzx32.sys` as well as different obfuscation techniques we conclude that the outer most binary packer/obfuscator was changed. It is likely that the reason for this is that the authors of the code were attempting to avoid antivirus detection as well as to increase the amount of time that it takes to deobfuscate the code. Our technique for deobfuscation was not affected much by the different techniques since we step through the code using an emulator.

Our analysis of the C&C communications indicates ordinary spam bot functionality. Aside from this functionality the spam module also has the ability to download and execute arbitrary code. This could be used for other nefarious purposes. In addition, the modular design of the rootkit and embedded spam module makes it easy to update the spam module. During our experiments, we observed multiple updates to the spam module. These updates were confined to changes of C&C server domain names and search terms used to build the spam, but it indicates that it would be simple for those controlling the botnet to update the module with other features.

Future work is also needed to better understand the details of the rustock rootkit. Since our focus was on getting to the spam module, we did not do a detailed analysis on the rootkit itself. Further details can be found in [9]. One element of the rootkit that needs more analysis is the alternative behavior exhibited when the malware driver detects that it is not stored in an ADS.

Additional work should be done to automate the key extraction and C&C decryption. One way to do this would be to continually monitor the network traffic from an infected client. Anytime a post to `login.php` is seen, a remote procedure call could be initiated to the infected host to dump the memory space of the `services.exe` process. Given the network captures and memory dumps it would be easy to write a script to extract the key from the dumps and decrypt the C&C communications in a way similar to our method.