Petya – Taking Ransomware To The Low Level

blog.malwarebytes.com/threat-analysis/2016/04/petya-ransomware/

Malwarebytes Labs April 1, 2016

Petya is different from the other popular ransomware these days. Instead of encrypting files one by one, it denies access to the full system by attacking low-level structures on the disk. This ransomware's authors have not only created their own boot loader but also a tiny kernel, which is 32 sectors long.

Petya's dropper writes the malicious code at the beginning of the disk. The affected system's master boot record (MBR) is overwritten by the custom boot loader that loads a tiny malicious kernel. Then, this kernel proceeds with further encryption. Petya's ransom note states that it encrypts the full disk, but this is not true. Instead, it encrypts the master file table (MFT) so that the file system is not readable.

[UPDATE] READ ABOUT THE LATEST VERSION: GOLDENEYE

PREVENTION TIP: Petya is most dangerous in Stage 2 of the infection, which starts when the affected system is being rebooted after the BSOD caused by the dropper. In order to prevent your computer from going automatically to this stage, turn off *automatic restart after a system failure* (see how to do this).

If you detect Petya in Stage 1, your data can still be recovered. More information about it is [here] and in this article.

UPDATE: 8-th April 2016 Petya at Stage 2 has been cracked by leo-stone. Read more: https://petya-pay-no-ransom.herokuapp.com/ and https://github.com/leo-stone/hack-petya. Tutorial helping in disk recovery is here.

Analyzed samples

Main executable from another campaign (PDF icon)

a92f13f3a1b3b39833d3cc336301b713

Special thanks to: Florian Roth – for sharing the samples, Petr Beneš – for a constructive discussion on Twitter.

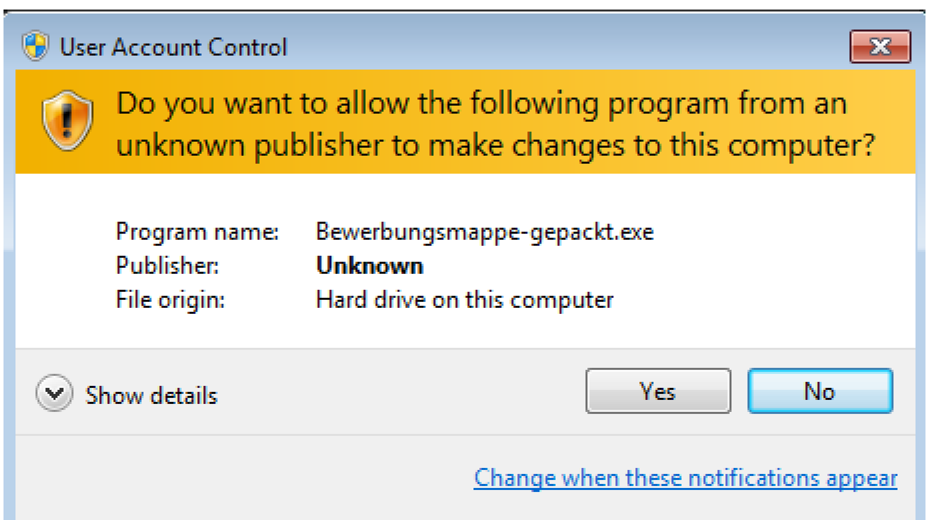
Behavioral analysis

This ransomware is delivered via scam emails themed as a job application. E-mail comes with a Dropbox link, where the malicious ZIP is hosted. This initial ZIP contains two elements:

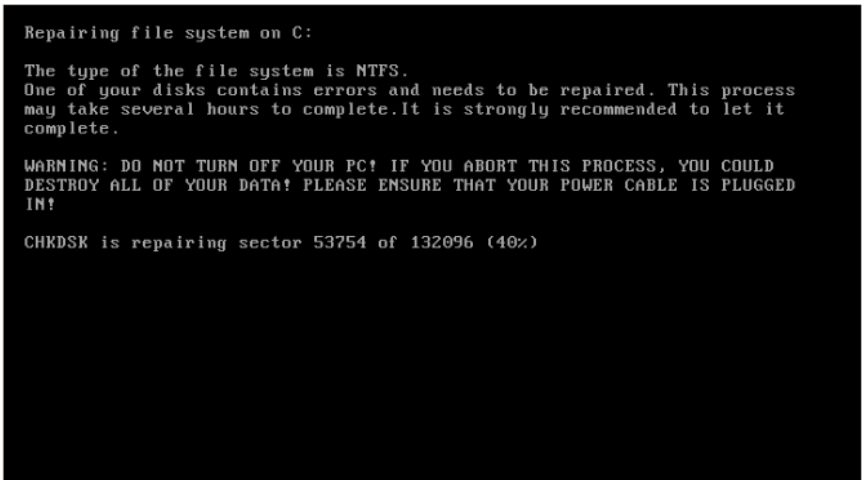
- a photo of a young man, purporting to be an applicant (in fact it is a publicly available stock image)
- an executable, pretending to be a CV in a self-extracting archive or in PDF (in fact it is a malicious dropper in the form of a 32bit PE file):

In order to execute its harmful features, it needs to run with Administrator privileges. However, it doesn't even try to deploy any user account control (UAC) bypass technique. It relies fully on social engineering.

When we try to run it, UAC pops up this alert:

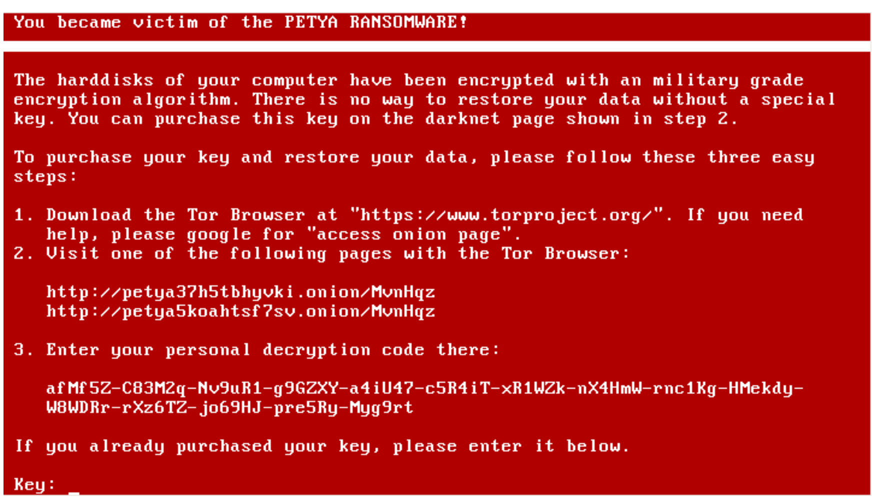


After deploying the application, the system crashes. When it restarts, we see the following screen, which is an imitation of a CHKDSK scan:



In reality, the malicious kernel is already encrypting. When it finishes, the affected user encounters this blinking screen with an ASCII art:

Pressing a key leads to the main screen with the ransom note and all information necessary to reach the Web panel and proceed with the payment:

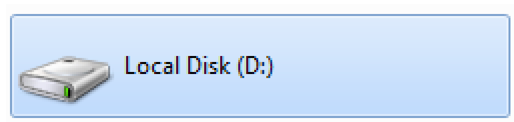


Infection stages

This ransomware have **two infection stages**.

The first is executed by the dropper (Windows executable file). It overwrites the beginning of the disk (including MBR) and makes an XOR encrypted backup of the original data. This stage ends with an intentional execution of BSOD. Saving data at this point is relatively easy, because only the beginning of the attacked disk is overwritten. The file system is not destroyed, and we can still mount this disk and use its content. That's why, if you suspect that you have this ransomware, the first thing we recommend is to not reboot the system. Instead, make a disk dump. Eventually you can, at this stage, mount this disk to another operating system and make the file backup. *See also: Petya key decoder.*

The second stage is executed by the fake CHKDSK scan. After this, the file system is destroyed and cannot be read.

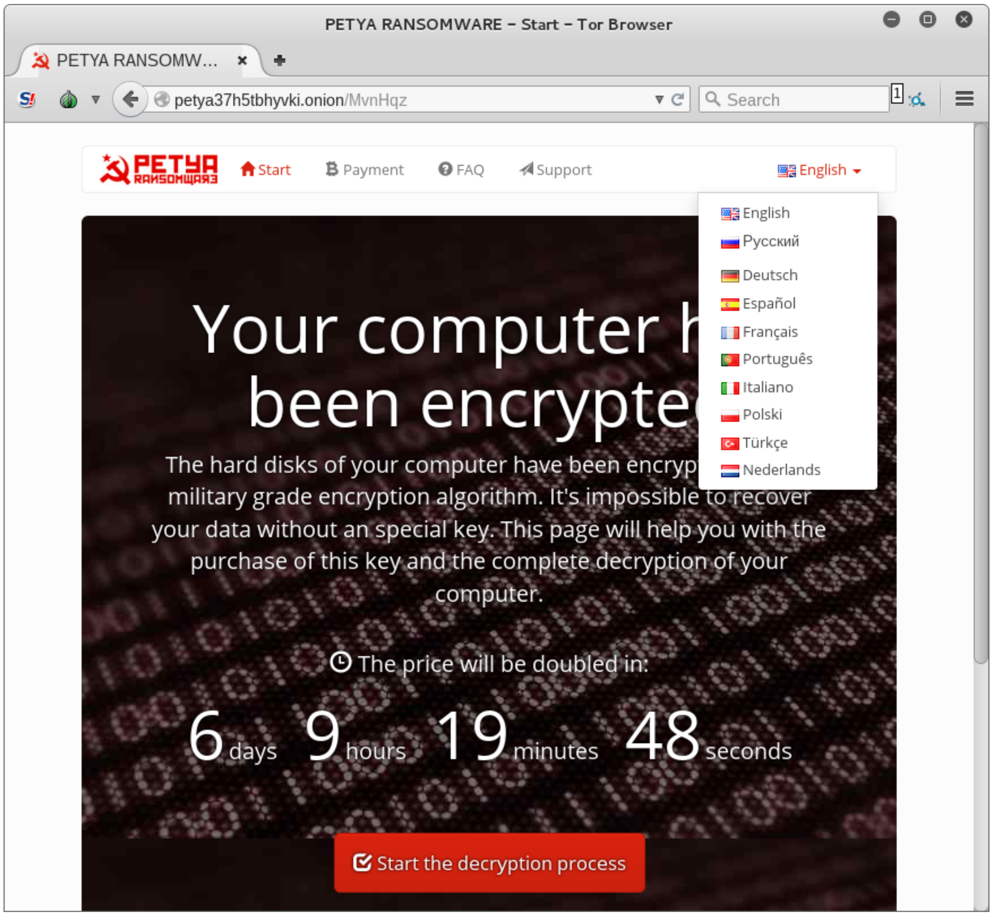


However, it is not true that the full disk is encrypted. If we view it by forensic tools, we can see many valid elements, including strings.

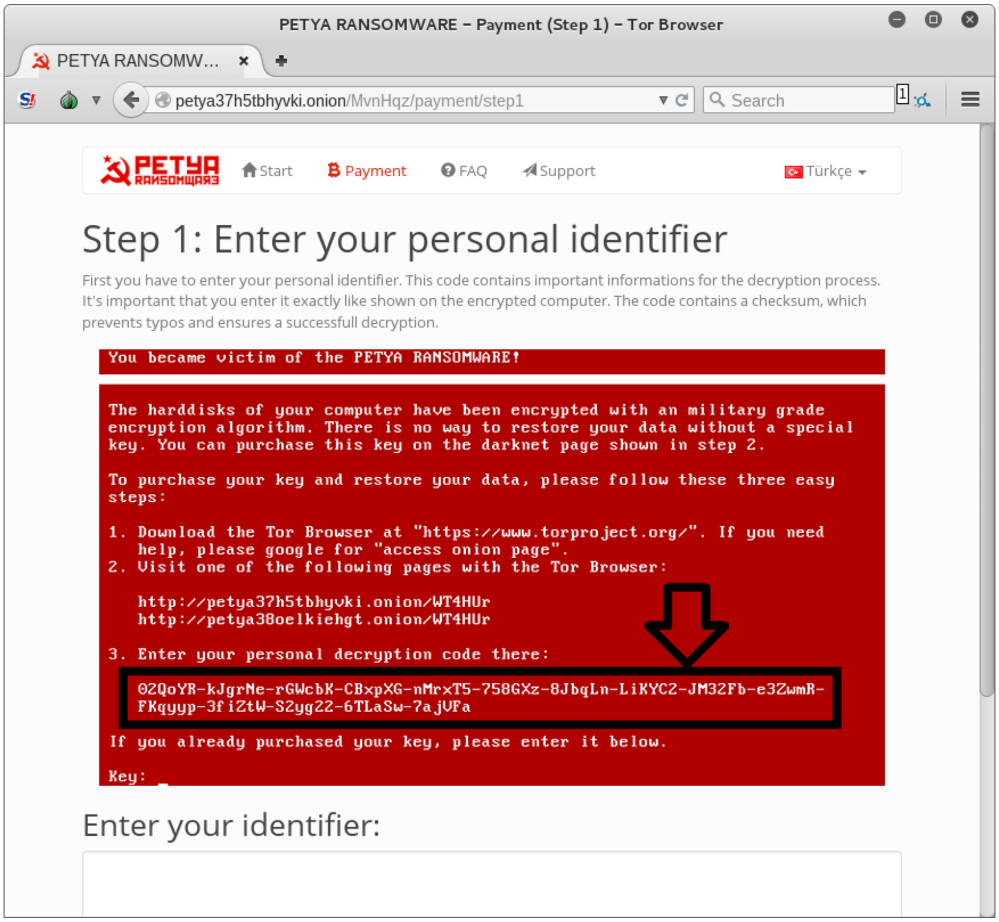
```
02BBAD30  04 00 00 00 01 00 00 00 7B 36 44 46 44 37 43 35  ........{6DFD7C5
02BBAD40  43 2D 32 34 35 31 2D 31 31 64 33 2D 41 32 39 39  C-2451-11d3-A299
02BBAD50  2D 30 30 43 30 34 46 38 45 46 36 41 46 7D 00 00  -00C04F8EF6AF}..
02BBAD60  F0 FF FF FF E0 02 7C 00 20 03 7C 00 88 05 7C 00  đ˙˙˙ŕ.|. .|...|.
02BBAD70  D8 FF FF FF 76 6B 10 00 04 00 00 80 00 00 00 00  Ř˙˙˙vk.....€....
02BBAD80  04 00 00 00 01 00 71 DB 53 68 75 74 64 6F 77 6E  ......qŰShutdown
02BBAD90  52 65 61 73 6F 6E 55 49 E0 FF FF FF 76 6B 08 00  ReasonUIŕ˙˙˙vk..
02BBADA0  12 00 00 00 B8 03 7C 00 01 00 00 00 01 00 00 00  ....¸.|.........
02BBADB0  30 30 30 30 33 43 30 41 E8 FF FF FF 2A 00 32 00  00003C0Ač˙˙˙*.2.
02BBADC0  35 00 30 00 2C 00 31 00 36 00 39 00 00 00 00 00  5.0.,.1.6.9.....
02BBADD0  E0 FF FF FF 76 6B 08 00 12 00 00 00 F0 03 7C 00  ŕ˙˙˙vk......đ.|.
02BBADE0  01 00 00 00 01 00 01 00 30 30 30 30 34 30 30 31  ........00004001
02BBADF0  E8 FF FF FF 2A 00 32 00 35 00 30 00 2C 00 31 00  č˙˙˙*.2.5.0.,.1.
02BBAE00  38 00 36 00 00 00 01 00 80 FE FF FF D8 D6 7B 00  8.6.....€ţ˙˙ŘÖ{.   Sector 89559
```

Website for the victim

We noted that the website for the victim is well prepared and very informative. The menu offers several language versions, but so far only English works:

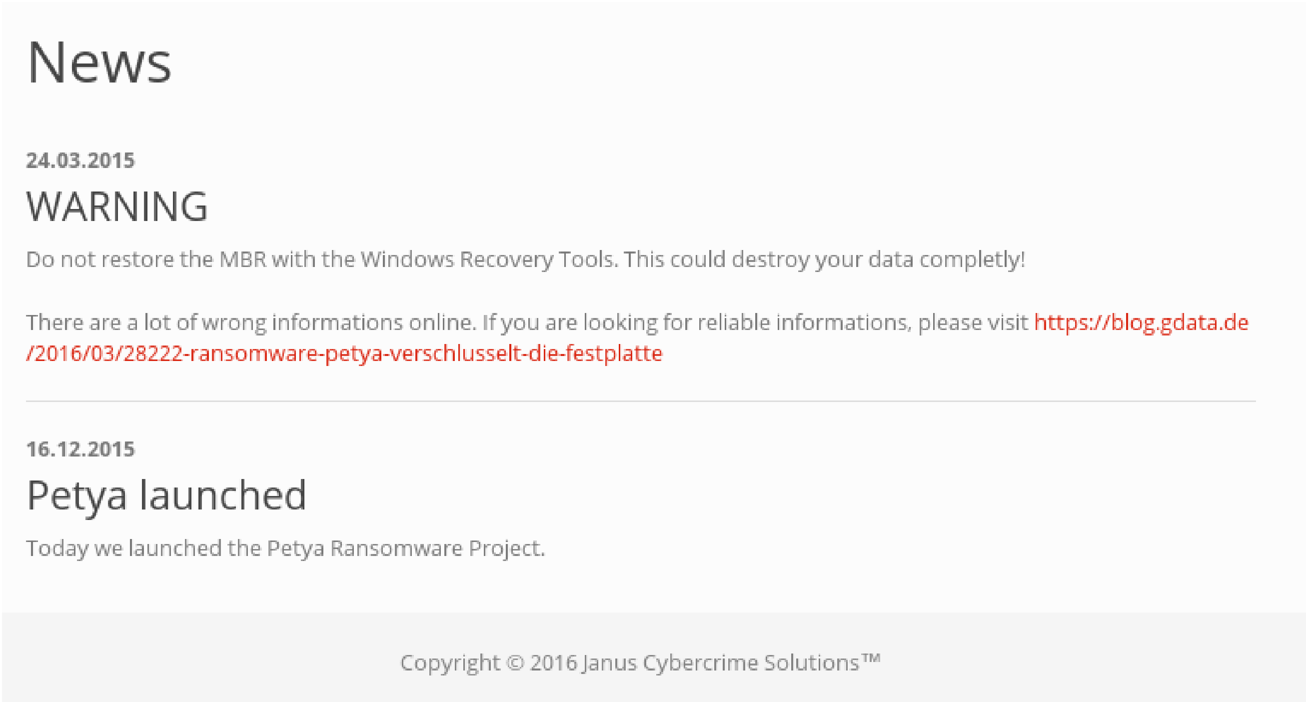


It also provides a step-by-step process on how affected users can recover their data:



- Step1: Enter your personal identifier
- Step2: Purchase Bitcoins
- Step3: Do a Bitcoin transaction
- Step4: Wait for confirmation

We expect that cybercriminals release as little information about themselves as possible. But in this case, the authors and/or distributors are very open, sharing the team name—"Janus Cybercrime Solutions"—and the project release date—12th December 2015. Also, they offer a news feed with updates, including press references about them:



News

24.03.2015

WARNING

Do not restore the MBR with the Windows Recovery Tools. This could destroy your data complety!

There are a lot of wrong informations online. If you are looking for reliable informations, please visit https://blog.gdata.de/2016/03/28222-ransomware-petya-verschlusselt-die-festplatte

16.12.2015

Petya launched

Today we launched the Petya Ransomware Project.

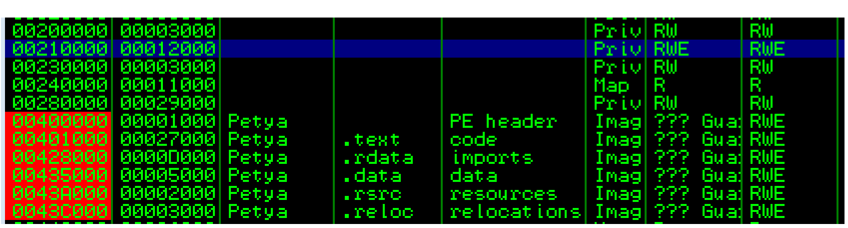
In case of questions or problems, it is also possible to contact them via a Web form.

Inside

Stage 1

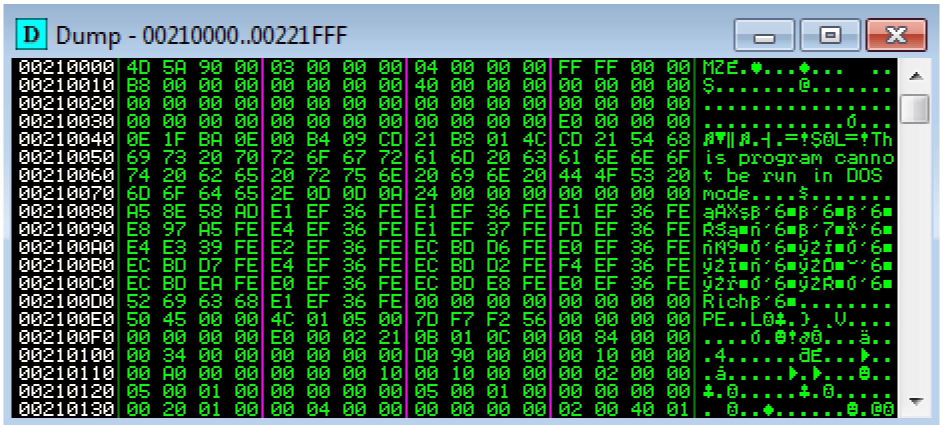
As we have stated earlier, the first stage of execution is in the Windows executable. It is packed in a good quality FUD/cryptor that's why we cannot see the malicious code at first. Executions starts in a layer that is harmless and used only for the purpose of deception and protecting the payload. The real malicious functionality is inside the payload dynamically unpacked to the memory.

Below you can see the memory of the running process. The code belonging to the original EXE is marked red. The unpacked malicious code is marked blue:



00200000	00003000				Priv	RW	RW
00210000	00012000				Priv	RWE	RWE
00230000	00003000				Priv	RW	RW
00240000	00011000				Map	R	R
00280000	00029000				Priv	RW	RW
00400000	00001000	Petya		PE header	Imag	??? Gua:	RWE
00401000	00027000	Petya	.text	code	Imag	??? Gua:	RWE
00428000	0000D000	Petya	.rdata	imports	Imag	??? Gua:	RWE
00435000	00005000	Petya	.data	data	Imag	??? Gua:	RWE
0043A000	00002000	Petya	.rsrc	resources	Imag	??? Gua:	RWE
0043C000	00003000	Petya	.reloc	relocations	Imag	??? Gua:	RWE

The unpacked content is another PE file:



However, if we try to dump it, we don't get a valid executable. Its data directories are destroyed. The PE file have been processed by the cryptor in order to be loaded in a continuous space, not divided by sections. It lost the ability to run independently, without being loaded by the cryptor's stub. Addresses saved as RVA are in reality raw addresses.

I have remapped them using a custom tool, and it revealed more information, i.e. the name of this PE file is *Setup.dll*:

Offset	Name	Value	Meaning
A7E0	Characteristics	0	
A7E4	TimeDateStamp	56F2F77D	
A7E8	MajorVersion	0	
A7EA	MinorVersion	0	
A7EC	Name	FE12	Setup.dll
A7F0	Base	1	
A7F4	NumberOfFunctions	1	
A7F8	NumberOfNames	1	
A7FC	AddressOfFunctions	FE08	
A800	AddressOfNames	FE0C	
A804	AddressOfNameOrdinals	FE10	

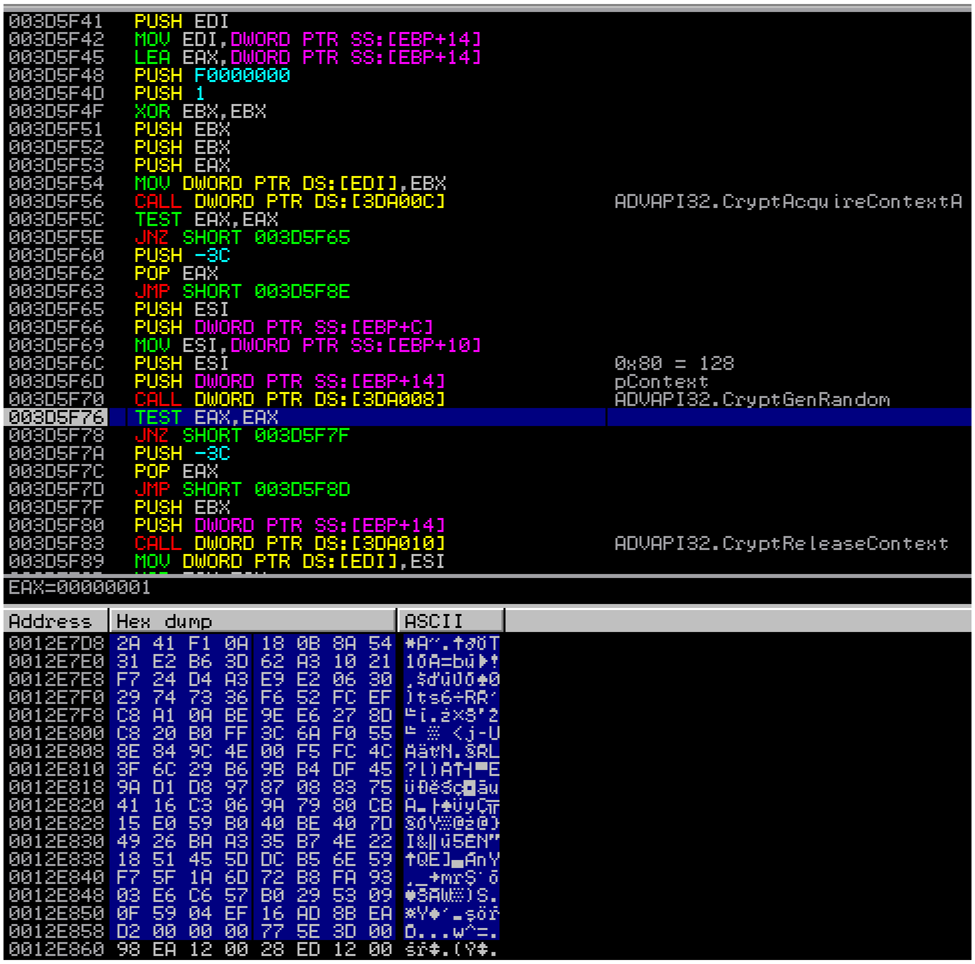
Details

Offset	Ordinal	Function RVA	Name RVA	Name
A808	1	1DC0	FE1C	_ZuWQdweafdsg345312@0

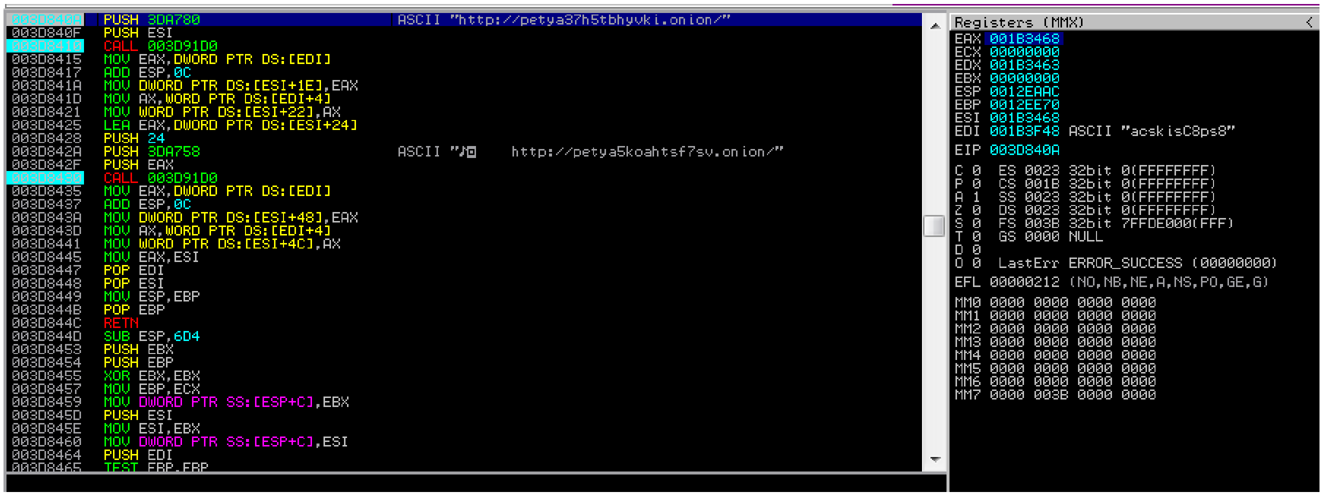
UPDATE: if we catch the process of unpacking in correct moment, we can dump the DLL before it is destroyed. The resulting payload is: 7899d6090efae964024e11f6586a69ce

As the name suggest, the role of the payload is to setup everything for the next stage. First, it generates a unique key that will be used for further encryption. This key must be also known to attackers. That's why it is encrypted by ECC and displayed to the victim as a personal identifier, that must be send to attackers via personalized page.

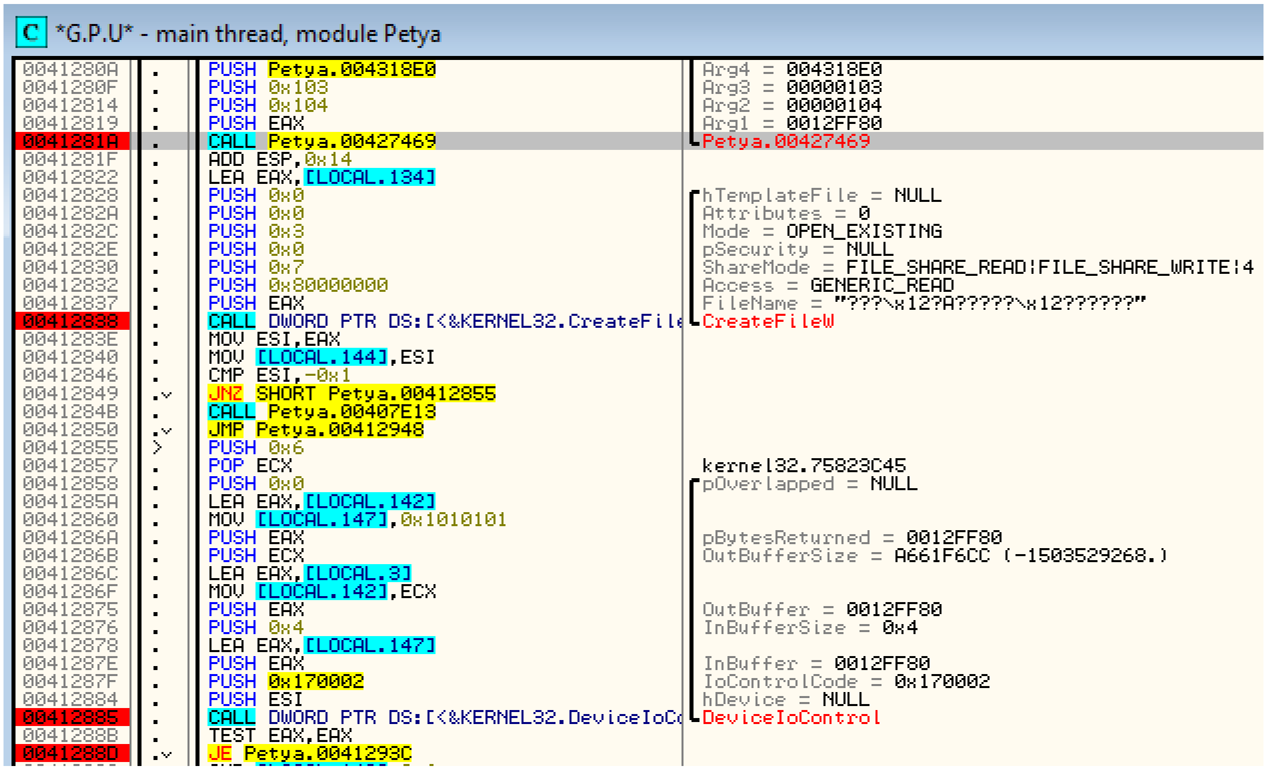
Random values are retrieved by Windows Crypto API function: CryptGenRandom. Below, it gets 128 random bytes:



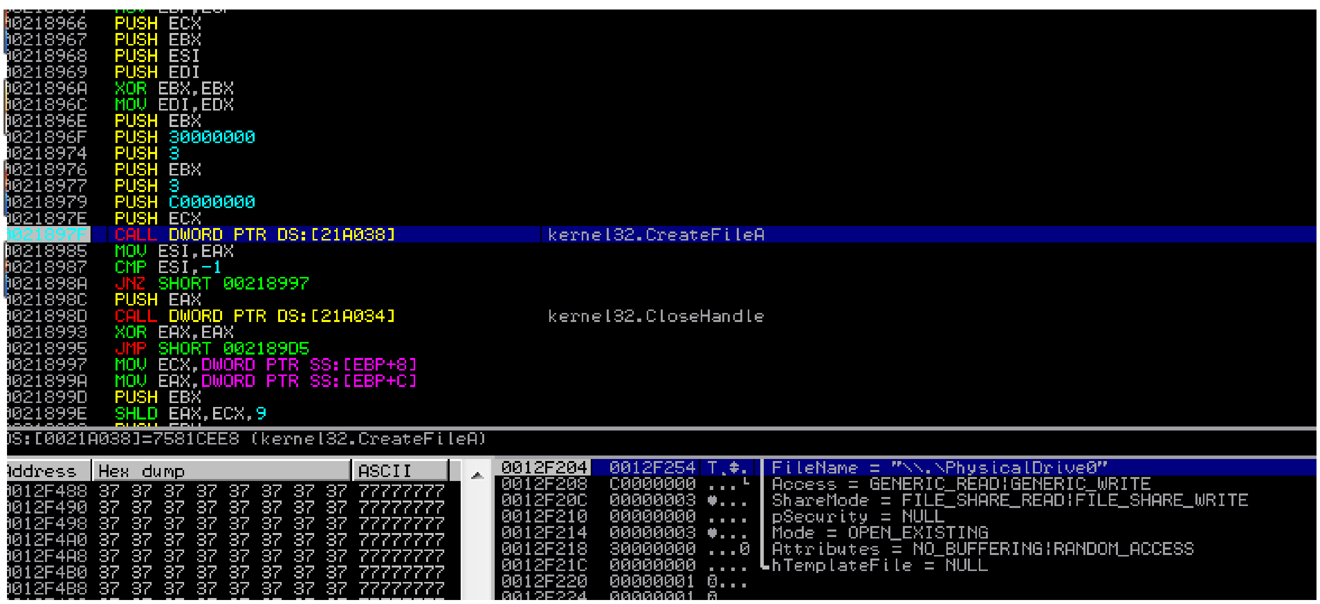
Making of onion addresses:



Retrieving parameters of the disk using DeviceIoControl

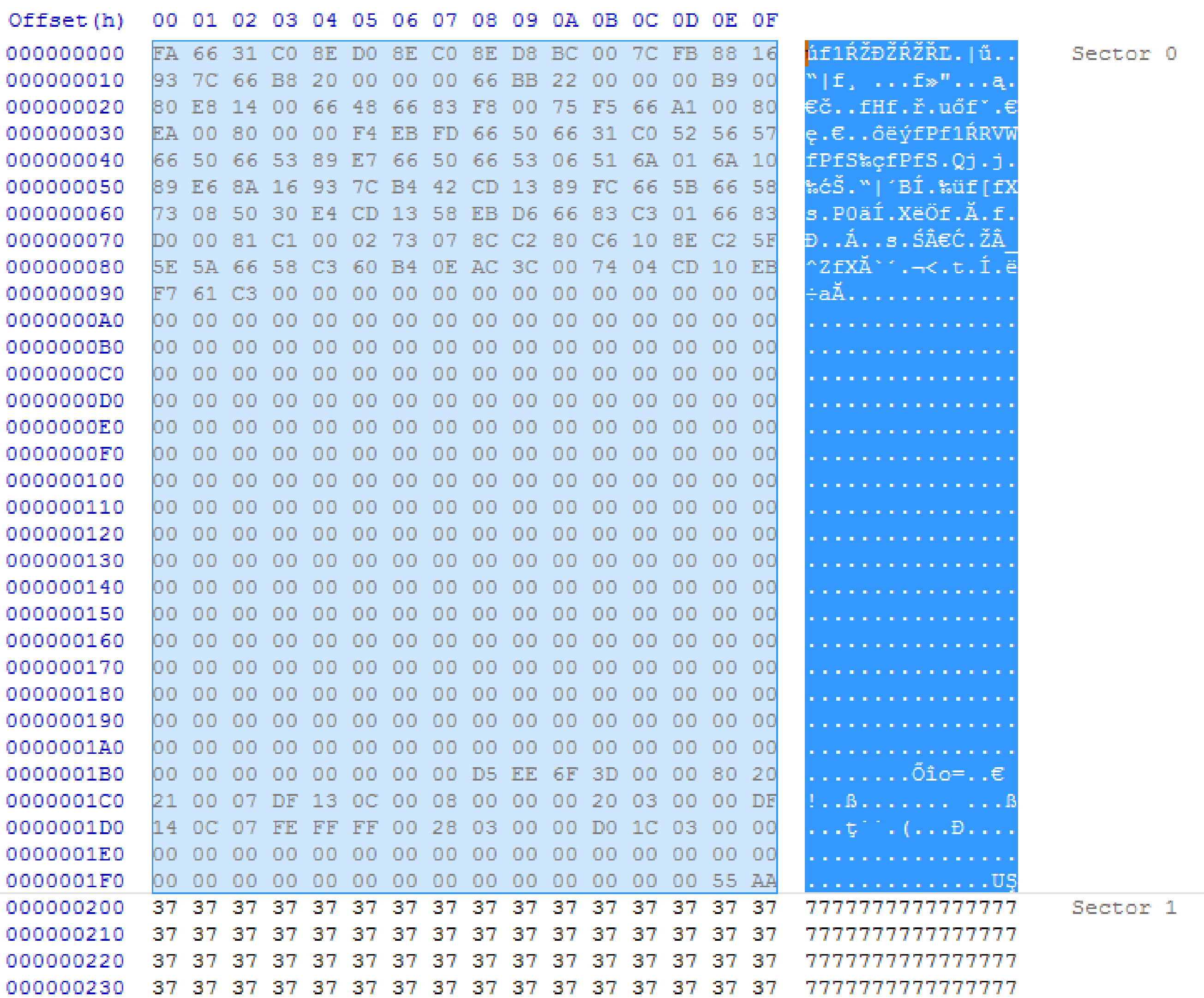


Read/write to the disk:



After overwriting the beginning of the disk, it intentionally crashes the system, using an undocumented function NtRaiseHardError:

At this point, first stage of changes on the disk have been already made. Below you can see the MBR overwritten by the Petya's boot loader:



Next few sectors contains backup of original data XORed with '7'. After that we can find the copied Petya code (starting at 0x4400 – sector 34).

We can also see the strings that are displayed in the ransom note, copied to the the disk:

```
000005D60  74 68 65 20 50 45 54 59 41 20 52 41 4E 53 4F 4D  the PETYA RANSOM
000005D70  57 41 52 45 21 0D 0A 00 0D 0A 20 54 68 65 20 68  WARE!..... The h
000005D80  61 72 64 64 69 73 6B 73 20 6F 66 20 79 6F 75 72  arddisks of your
000005D90  20 63 6F 6D 70 75 74 65 72 20 68 61 76 65 20 62   computer have b
000005DA0  65 65 6E 20 65 6E 63 72 79 70 74 65 64 20 77 69  een encrypted wi
000005DB0  74 68 20 61 6E 20 6D 69 6C 69 74 61 72 79 20 67  th an military g
000005DC0  72 61 64 65 0D 0A 20 65 6E 63 72 79 70 74 69 6F  rade.. encryptio
000005DD0  6E 20 61 6C 67 6F 72 69 74 68 6D 2E 20 54 68 65  n algorithm. The
000005DE0  72 65 20 69 73 20 6E 6F 20 77 61 79 20 74 6F 20  re is no way to
000005DF0  72 65 73 74 6F 72 65 20 79 6F 75 72 20 64 61 74  restore your dat
000005E00  61 20 77 69 74 68 6F 75 74 20 61 20 73 70 65 63  a without a spec    Sector 47
```

Stage 2

Stage 2 is inside the code written to the disk’s beginning. This code uses 16 bit architecture.

Execution starts with a boot loader, that loads into memory the tiny malicious kernel. Below we can see execution of the loading function. Kernel starts at sector 34 and it is 32 sectors long (including saved data):

```
seg000:0012                 mov     eax, 32         ; sectors_number
seg000:0018                 mov     ebx, 34         ; start_sector
seg000:001E                 mov     cx, 8000h       ; output_address
seg000:0021
seg000:0021 loc_21:                                 ; CODE XREF: seg000:002A↓j
seg000:0021                 call    read_sector
seg000:0024                 dec     eax
seg000:0026                 cmp     eax, 0
seg000:002A                 jnz     short loc_21
seg000:002C                 mov     eax, ds:8000h
seg000:0030                 jmp     far ptr 0:8000h ; jump to the copied code
```

Beginning of the kernel:

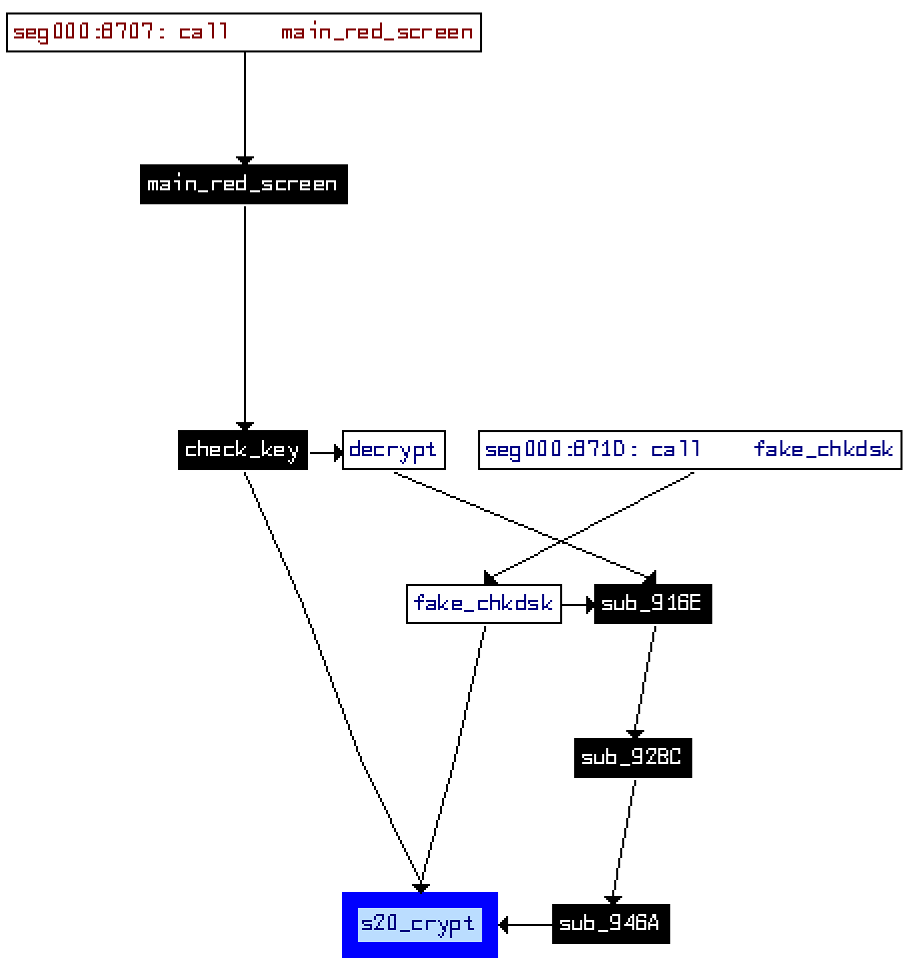
```
seg000:8000 loc_8000:
seg000:8000
seg000:8000                 jmp     loc_8640
```

Checking if the data is already encrypted is performed using one byte flag that is saved at the beginning of sector 54. If this flag is unset, program proceeds to the fake CHKDSK scan. Otherwise, it displays the main red screen.

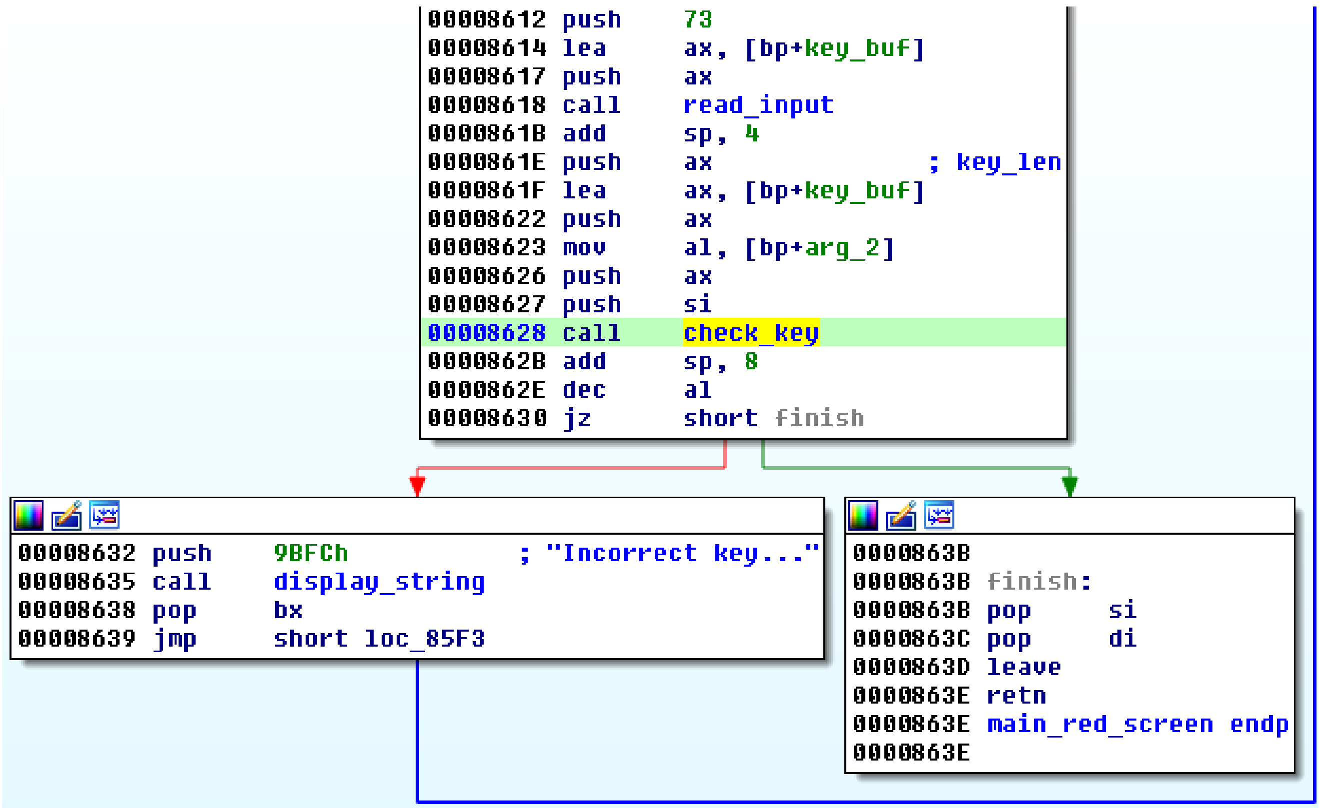
```
seg000:86D9                 push    0               ; read
seg000:86DB                 push    1
seg000:86DD                 push    0
seg000:86DF                 push    54              ; sector
seg000:86E1                 lea     ax, [bp-286h]   ; out_buf
seg000:86E5                 push    ax
seg000:86E6                 mov     al, [bp-2]
seg000:86E9                 push    ax
seg000:86EA                 call    disk_read_or_write
seg000:86ED                 add     sp, 0Ch
seg000:86F0                 or      al, al
seg000:86F2                 jz      short loc_86F7  ; is data encrypted?
seg000:86F4
seg000:86F4 error2:                                 ; CODE XREF: seg000:86D7↑j
seg000:86F4                 jmp     error
seg000:86F7 ; ---------------------------------------------------------------
seg000:86F7
seg000:86F7 loc_86F7:                               ; CODE XREF: seg000:86F2↑j
seg000:86F7                 cmp     byte ptr [bp-286h], 1 ; is data encrypted?
seg000:86FC                 jb      short to_fake_chkdsk
```

The fake CHKDSK encrypts MFT using Salsa20 algorithm. The used key is 32 byte long, read from the address 0x6C01. After that, the key gets erased.

Salsa20 is used in several places in Petya's code – for encryption, decryption and key verification. See the diagram below:



Inside the same function that displays the red screen, the *Key* checking routine is called. First, user is prompted to supply the key. The maximal input length is 73 bytes, the minimal is 16 bytes.

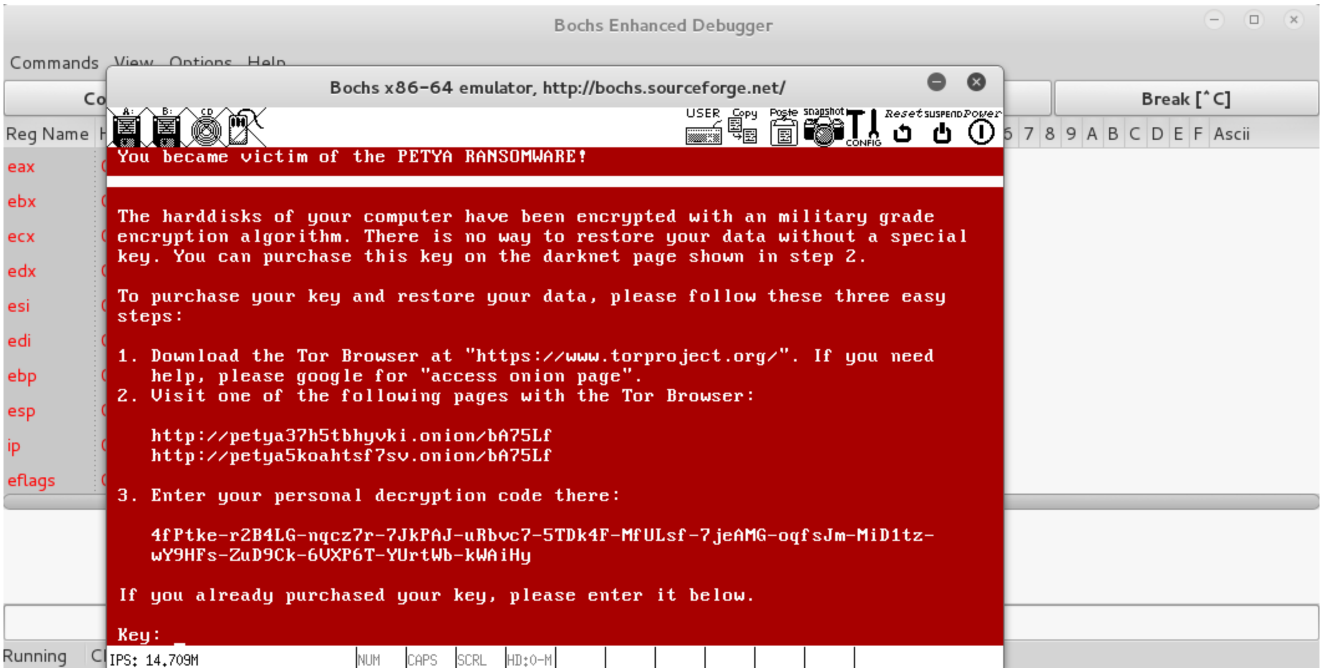


Debugging

Of course, we cannot debug this stage of Petya via typical userland debuggers that are the casual tools in analyzing malware. We need to go to the low level. The simplest way (in my opinion) is to use Bochs internal debugger. We need to make a full dump of the infected disk. Then, we can load it under Bochs.

I used the following Bochs configuration ('infected.dsk' is my disk dump): bochsrc.txt

This is how it looks running under Bochs:

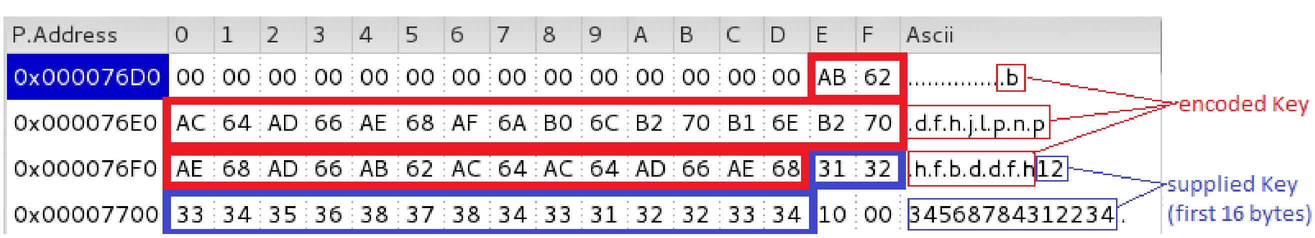


Key verification

Key verification is performed in the following steps:

1. Input from the user is read.
    - Accepted charset: *123456789abcdefghijkmnopqrstuvwxABCDEFGHJKLMNPQRSTUVWX* – if the character outside of this charset occurred, it is skipped.
    - Only first **16 bytes** are stored
2. The ***supplied key*** is encoded by a custom algorithm. ***Encoded key*** is 32 bytes long.
3. Data from sector 55 (512 bytes) is read into memory *// it will be denoted as **verification buffer***
4. The value stored at physical address 0x6c21 (just before the Tor address) is read into memory. It is an 8 byte long array, unique for a specific infection. *// it will be denoted as **nonce***
5. The ***verification buffer*** is encrypted by 256 bit Salsa20 with ***encoded key*** and the ***nonce***
6. If, as the result of applied procedure, ***verification buffer*** is fully filled with '7' – it means the ***supplied key*** is correct.

Example: ***encoded key*** versus ***supplied key***:



The algorithm for encoding the supplied key is very simple:

This file contains bidirectional Unicode text that may be interpreted or compiled differently than what appears below. To review, open the file in an editor that reveals hidden Unicode characters.
Learn more about bidirectional Unicode characters

Show hidden characters

```
bool encode(char* key, BYTE *encoded)
{
if (!key || !encoded) {
printf("Invalid buffer\n");
return false;
}
size_t len = strlen(key);
if (len < 16) {
printf("Invalid key\n");
return false;
}
if (len > 16) len = 16;

int i, j;
i = j = 0;
for (i = 0, j = 0; i < len; i++, j += 2) {
char k = key[i];

encoded[j] = k + 'z';
encoded[j+1] = k * 2;
}
encoded[j] = 0;
encoded[j+1] = 0;
```

```
return true;
}
```

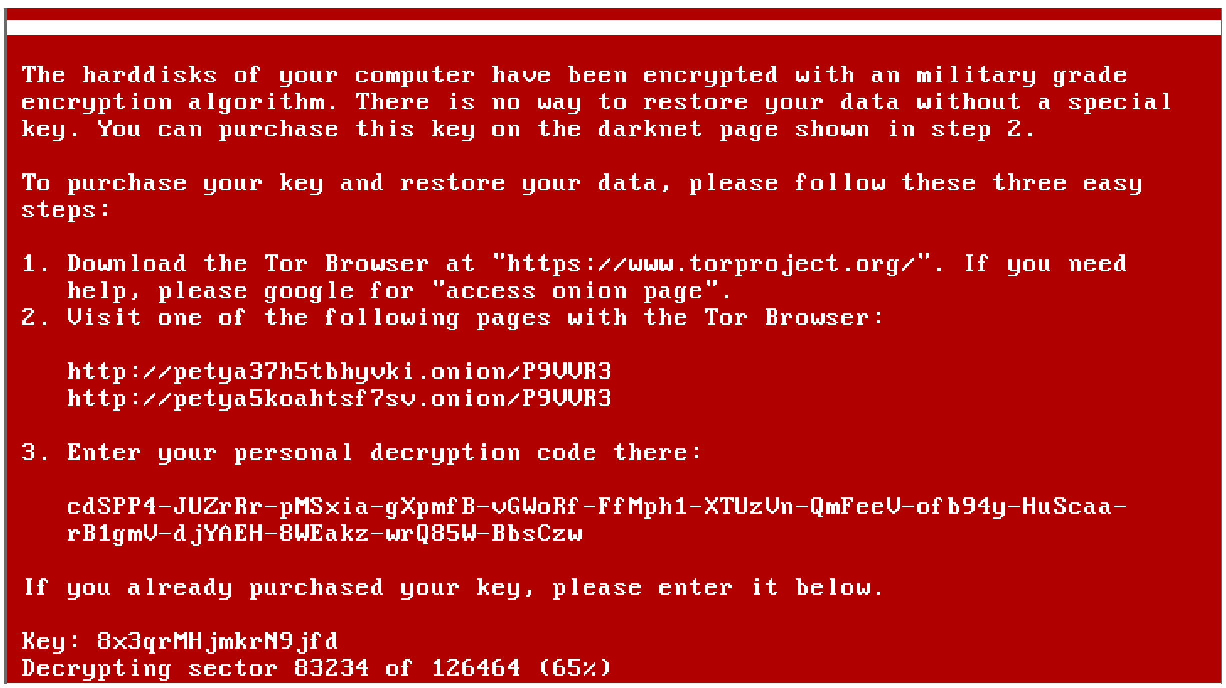
[view raw](#)

[petya_encoder.cpp](#)

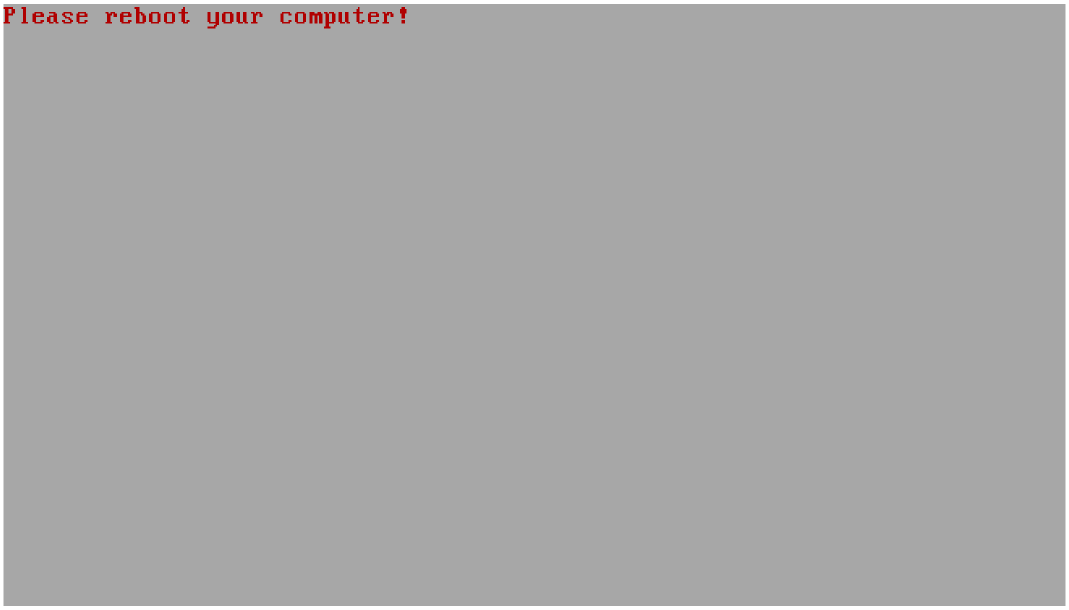
hosted with ❤ by [GitHub](#)

Valid key is important for the process of decryption. If we supply a bogus key and try to pass it as valid by modifying jump conditions, Petya will recover the original MBR but other data will not be decrypted properly and the operating system will not run.

When the key passed the check, Petya shows the message “Decrypting sectors” with a progress.



After it finishes, it asks to reboot the computer. Below is Petya’s last screen, showing that user finally got rid of this ransomware:



Conclusion

In terms of architecture, Petya is very advanced and atypical. Good quality FUD, well obfuscated dropper – and the heart of the ransomware – a little kernel – depicts that authors are highly skilled. However, the chosen low-level architecture enforced some limitations, i.e.: small size of code and inability to use API calls. It makes cryptography difficult. That's why the key was generated by the higher layer – the windows executable. This solution works well, but introduces a weakness that allowed to restore the key (if we manage to catch Petya at Stage 1, before the key is erased). Moreover, authors tried to use a ready made Salsa20 implementation and make slight changes in order to adopt it to 16-bit architecture. But they didn't realized, that changing size of variables triggers serious vulnerabilities (detailed description you can find in CheckPoint's article).

Most of the ransomware authors take care of the user experience, so that even a non technical person will have easy way to make a payment. In this case, user experience is very bad. First – denying access to the full system is not only harmful to a user, but also for the ransomware distributor, because it makes much harder for the victim to pay the ransom. Second – the individual identificator is very long and it cannot be copied from the screen. Typing it without mistake is almost impossible.

Overall, authors of Petya ransomware wrote a good quality code, that, however – missed the goals. Ransomware running in userland can be equally or more dangerous.

Appendix

About Petya by other vendors:

Read also:

- http://www.invoke-ir.com/2015/05/ontheforensictrail-part2.html – Master Boot Record
- http://sysforensics.org/2012/06/mbr-malware-analysis/ – MBR malware analysis
- https://socprime.com/en/blog/dismantling-killdisk-reverse-of-the-blackenergy-destructive-component/ – Dismantling KillDisk: reverse of the BlackEnergy destructive component (another malware attacking hard disk)

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