A Comparative Assessment of Obfuscated Ransomware Detection Methods

Sergiu SECHEL
Bucharest University of Economic Studies
sergiu.sechel@gmail.com

Ransomware represents a class of malicious applications that encrypts the files of infected system and demands from victims a payment in cryptocurrency in order to receive the decryption key. The mainstream adoption of cryptocurrencies increased the number of ransomware attack. The outbreaks had risen in complexity and received mass-media attention in 2017 when two destructive campaigns crippled companies and institutions around the world. These outbreaks continue at an accelerated pace even though efforts are made to improve the detection and mitigation of ransomware. The purpose of this research is to assess the efficiency of current malware analysis methods and technologies in the detection of ransomware. The experiments presented here were performed using antivirus engines and dynamic malware analysis against live obfuscated ransomware samples.

Keywords: Malware, Ransomware, Detection Techniques, Malware Analysis, Malware Classification, Mutation, Cybersecurity.

1 Introduction

Ransomware represents a class of malware (malicious applications) that encrypts the files of the infected system and demands from affected users a payment in cryptocurrency in order to receive the decryption key. The idea of a crypto-virus has been around for some time, being first mentioned in research papers like "An "Implementation of Cryptoviral Extortion Using Microsoft's Crypto API" (Young, Yung, Moti, 2005)[1].

Ransomware evolved from another type of malware used to block access to the infected devices or systems and display a message to the user impersonating a state authority (local police) while demanding the user to pay a fine because he was caught performing illegal activities like video piracy, pornography or software piracy. The first major campaign of this type was discovered in 2012 using the ransomware family called "Reveton"[2].

An operational risk that stalled the rapid expansion of ransomware campaigns was the lack of anonymous or secretive mechanisms to receive the ransom without being tracked by the authorities and ultimately arrested. This risk was effectively mitigated with the mass adoption of cryptocurrencies, especially bitcoin.

The first ransomware family that used the "modus operandi" that is now considered standard when we are referring to ransomware was "Cryptolocker"[3]. Since then ransomware campaigns had risen in complexity and received mass-media attention in 2017 when two destructive campaigns crippled companies and institutions around the world. The first major outbreak was known as "Wannacry" in May 2017, with estimated infections of 230,000 computers, in a 3 days timespan, affecting companies and institutions in over 150 countries, including 16 hospitals in the UK. The second major outbreak occurred in 27 June 2017, cause by a ransomware called "NotPetya" [4] which in a 2 days timespan produced estimated damages of 10 billion USD, crippling the transport giant Maersk and companies like Fedex TNT, Mondelez and Reckitt Benckiser.[5]

These outbreaks continue at an accelerated pace even though efforts are made to improve the detection and mitigation of this type of malware. The purpose of this research is to assess the effectiveness of current antivirus detection technologies against obfuscated ransomware.

DOI: 10.12948/issn14531305/23.2.2019.05

2 Ransomware characteristics and behavior

From an operational perspective ransomware are a family of malicious applications used to encrypt files and data on various comouter systems using strong symmetric and asymmetric cryptographic algorithms like RSA [6] and AES [7]. Upon execution the modern ransomware performs the following main activities, with variations, depending on the ransomware family:

1) Connects to a command-and-control server (C2C) and requires the generation of an asymmetric RSA key pair. After the key pair is generated the ransomware downloads the public key (***PubKey***) from the C2C server;
2) The ransomware generates a symmetric key (***SymKey***) for the AES encryption algorithm;
3) The ransomware encrypts the files on the target system using the AES encryption algorithm with the previously generated ***SymKey***;
4) The AES ***SymKey*** is encrypted with the ***PubKey*** that was previously downloaded from the C2C server;
5) The malware deletes or encrypts the backups and disables any recovery mechanisms present on the system;
6) A ransomware note is generated for the user with instructions on how to receive the private key (***PrivKey***) required to decrypt the ***SimKey***. The decrypted ***SimKey*** will be used by the user to recover the encrypted files.

The generic encryption process is presented in Figure 1. Various ransomware families implement different variations of the encryption process depending on the technical knowledge or capabilities of the malicious actor.

After the encryption process is finished the ransomware will display a message to the user with instructions on how to recover the encrypted files.

Usually the instructions require the user to make a cryptocurrency payment (bitcoin or similar) to the attacker in order to obtain the decryption key (***PrivKey***) as presented in a note generated by the WannaCry ransomware presented in the Figure 18 and a note generated by the TeslaCrypt ransomware is presented in Figure 17.

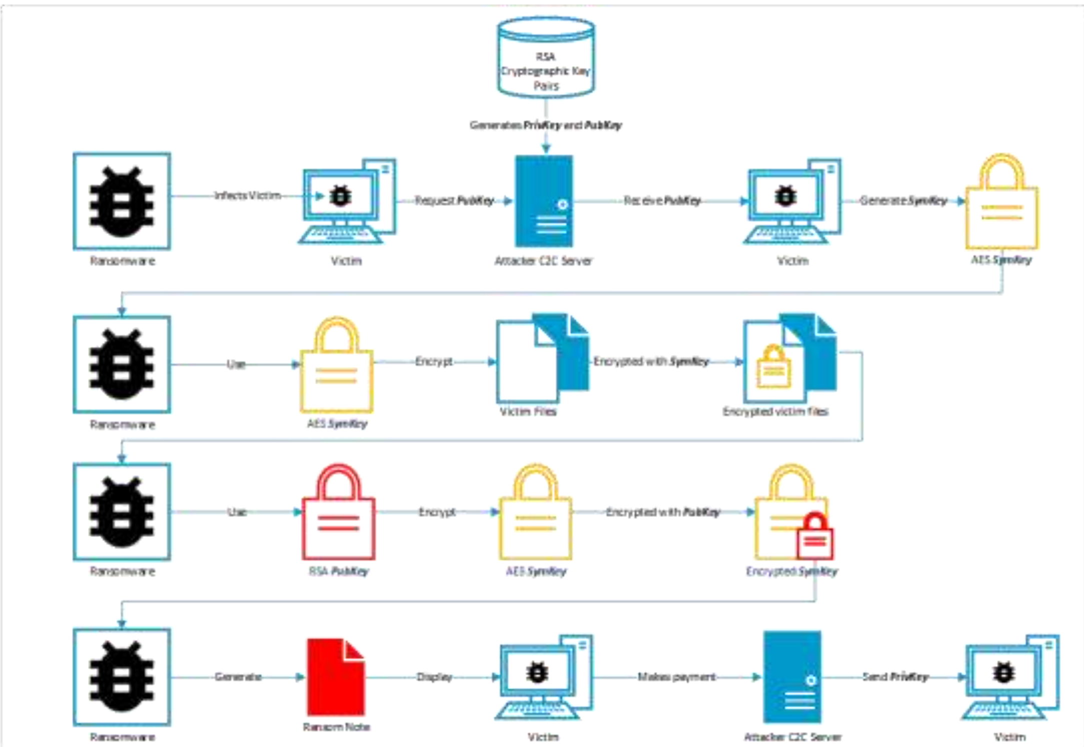


Fig. 1. Generic ransomware encryption workflow using symmetric and asymmetric cryptography

DOI: 10.12948/issn14531305/23.2.2019.05

Some ransomwares require the user to make the payment in a certain amount of time. Trying to delay the countdown timer is not usually a successful strategy because the ***PrivKey*** is not hosted on the victim system and as such it can be deleted at any given time by the attacker.

3 The difficulty of ransomware detection

Currently there are several methods employed for malware detection and classification. The most common methods deployed in a wide range of antivirus software products are the following:

a) **signature based detection** – the signature of the suspect code is compared against a database of known malicious signatures;
b) **heuristic detection** – suspect code functionalities are compared against a known malicious functionalities database;
c) **machine learning** - using supervised or unsupervised algorithms a model is trained to identify and classify new specimens of malware based of similar characteristics shared with the training set.

Professionals in the antivirus, forensics and cybersecurity industries use the following methods to detect and classify and analyze suspect code:

a) **static analysis** – the suspect code is analyzed using a disassembler with the purpose to understand the code structure and the code functionalities
b) **dynamic analysis** – the suspect code is executed in a controlled environment and its behavior is analyzed using different tools. The code execution in a debugger or in a sandbox are forms of dynamic analysis.

Ransomwares behave differently than other types of malware, mainly because of their destructive nature. The main purpose of a ransomware is to successfully execute the payload (encryption module) which will proceed to encrypt the files and folders on the infected system [8]. From a stealth perspective some ransomwares are employing different techniques to evade detection until the encryption process is finished, but in general ransomwares don't employ advanced stealth functionalities because the malware is designed to have a short life span. Another reason why ransomwares don't employ advanced stealth mechanisms is because once the ransomware's destructive actions are finished the user will be become aware that the system was infected.

4 Evasion techniques used by ransomware

Malware families are constantly seeking new ways to hide their code, thwart replication, and avoid detection. A recent trend for the delivery of ransomware is the use of the Nullsoft Scriptable Install System (NSIS) with an encrypted payload. The list of the most common families using this technique is diverse and includes Cerber, Locky, Teerac, Crysis, CryptoWall, and CTB-Locker.[9]

The antivirus industry published several research papers describing various obfuscated ransomware samples, ranging from the Loky ransomware analysis released by Avast[10], the recent analysis of the Synack ransomware released by Kaspersky Lab [11] or the analysis of the GandCrab ransomware released VMRay [12]. One common evasion method used by ransomware authors involves the use of *packers* and *crypters*:

- ***Packer*** - is a program that takes the executable as input, and it uses compression to obfuscate the executable's content. This obfuscated content is then stored within the structure of a new executable file; the result is a new executable file (packed program) with obfuscated content on the disk. Upon execution of the packed program, it executes a decompression routine, which extracts the original binary in memory during runtime and triggers the execution.
- ***Crypter*** - is similar to a *packer*, but instead of using compression, it uses encryption to obfuscate the executable's content, and the encrypted content is stored in the new executable file. Upon execution of the encrypted program, it runs a decryption

DOI: 10.12948/issn14531305/23.2.2019.05

routine to extract the original binary in the memory and then triggers the execution.

Packed or crypted ransomware is difficult to be analyzed by antivirus engines or by static analysis, because both the antivirus engine and the analyst are presented with only the packed code of the suspect application. The packing and unpacking process of an executable is presented in the Figure 2.

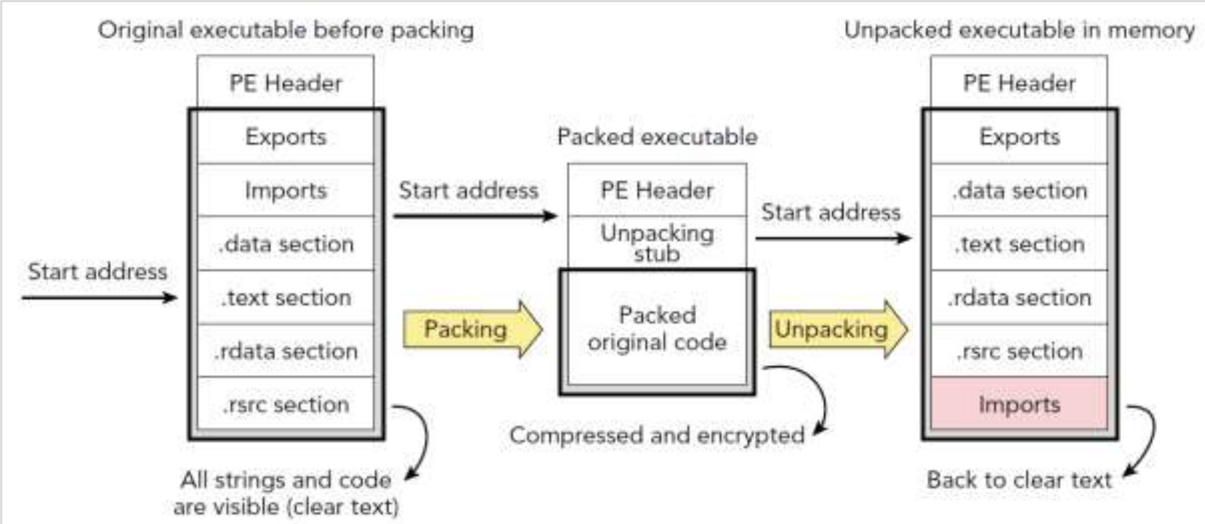
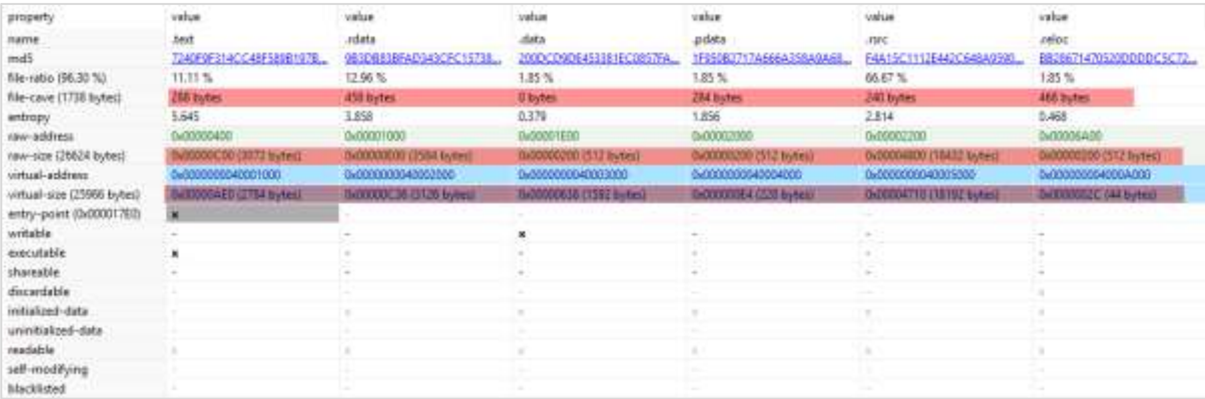


Fig. 2. The packing and unpacking process of a PE executable

To demonstrate the difficulty to analyze a packed executable the Microsoft Calculator (calc.exe) was packed with the Themida Packer [13]. The sections of the packed executable were inspected using PE Studio [14]. The sections of the packed executable have less available data for analysis because the code will be unpacked directly in memory after execution. In the Figure 3 are presented the sections of the original calc.exe and in Figure 4 are presented the sections of the packed calc.exe.



property	value	value	value	value	value	value
name	.text	.rdata	.data	.pdata	.rsrc	.reloc
md5	7240F9F314CC48F5898197B...	9B3DB83BFAD343CFC15738...	200DCD9DE453381EC0857FA...	1F950B2717A666A358A0A68...	F4A15C1112E442C648A9590...	BB2867147052DDDDC5C72...
file-ratio (96.30 %)	11.11 %	12.96 %	1.85 %	1.85 %	66.67 %	1.85 %
file-cave (1738 bytes)	288 bytes	458 bytes	0 bytes	284 bytes	240 bytes	466 bytes
entropy	5.645	3.858	0.379	1.856	2.814	0.468
raw-address	0x00000400	0x00001000	0x00001E00	0x00002000	0x00002200	0x00006A00
raw-size (26624 bytes)	0x00000C00 (3072 bytes)	0x00000E00 (3584 bytes)	0x00000200 (512 bytes)	0x00000200 (512 bytes)	0x00004800 (18432 bytes)	0x00000200 (512 bytes)
virtual-address	0x0000000040001000	0x0000000040002000	0x0000000040003000	0x0000000040004000	0x0000000040005000	0x000000004000A000
virtual-size (25966 bytes)	0x00000AE0 (2784 bytes)	0x00000C38 (3128 bytes)	0x00000638 (1592 bytes)	0x000000E4 (228 bytes)	0x00004710 (18192 bytes)	0x0000002C (44 bytes)
entry-point (0x000017E0)	x	-	-	-	-	-
writable	-	-	x	-	-	-
executable	x	-	-	-	-	-
shareable	-	-	-	-	-	-
discardable	-	-	-	-	-	x
initialized-data	-	x	x	x	x	x
uninitialized-data	-	-	-	-	-	-
readable	x	x	x	x	x	x
self-modifying	-	-	-	-	-	-
blacklisted	-	-	-	-	-	-

Fig. 3. Unpacked calc.exe PE sections

DOI: 10.12948/issn14531305/23.2.2019.05

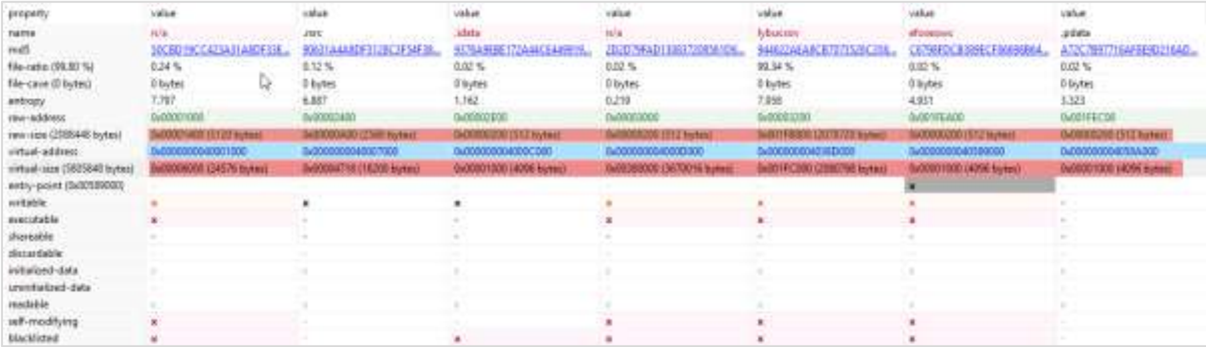


Fig. 4. Packed calc.exe PE sections (packed using the Themida Packer)

Comparing the code structure of the packed *calc.exe* with the unpacked *calc.exe* shows the significant differences between the two executables. When the unpacked calc.exe is loaded in the Ghidra Disassembler [15] the ***Import Table*** (10 libraries are imported) and the ***Functions*** of the application are displayed and can be analyzed, as shown in Figure 5.

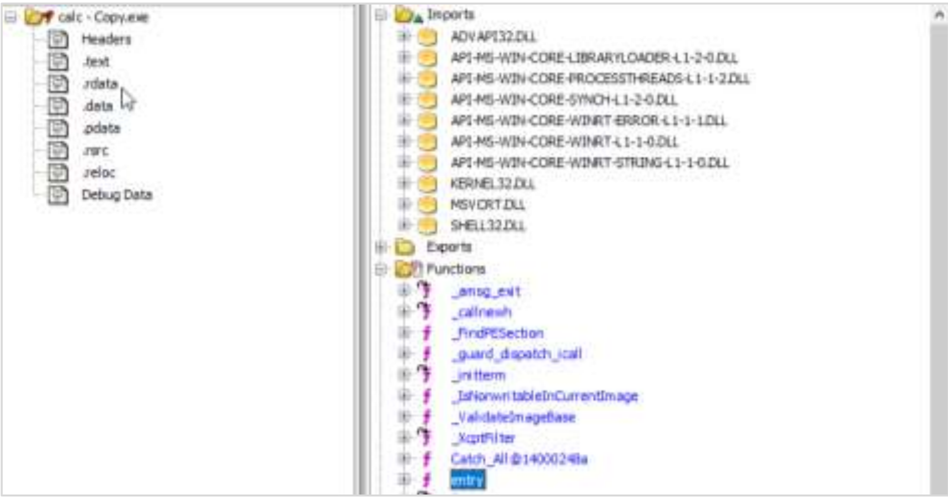


Fig. 5. Unpacked calc.exe import table and functions displayed in the Ghidra disassembler

Using the decompiling features of the Ghidra the pseudocode for each of the unpacked calc.exe functions can be analyzed alongside the assembly instructions as presented in the Figure 6 where the decompiled pseudocode of the calc.exe ***entry point*** can be inspected.

Fig. 6. Unpacked calc.exe's entry point function pseudo-code

DOI: 10.12948/issn14531305/23.2.2019.05

By comparison the packed calc.exe shows only 2 functions alongside the ***entry point*** and the ***Import Table*** has only 2 libraries. The decompiled pseudocode of the ***entry point*** calls the FUN_140589009, a function used for the unpacking of the code, as shown in Figure 7.

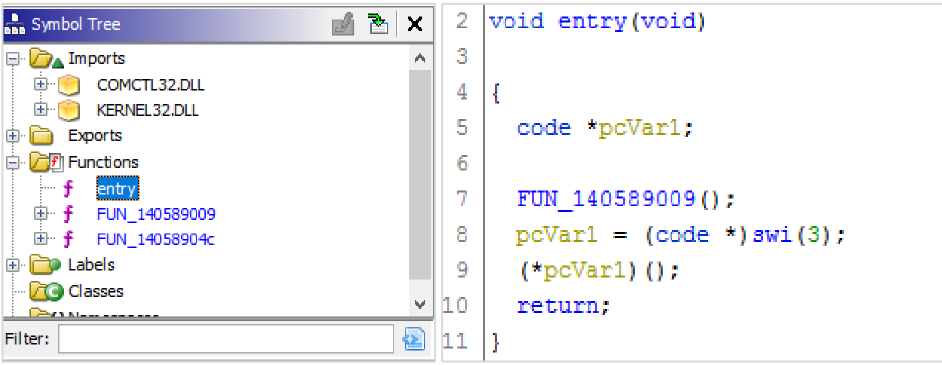


Fig. 7. Packed calc.exe import table, functions and entry point pseudo-code

The inspection of the FUN_140589009 pseudo code and assembly instructions do not reveal enough information about the purpose of the application, as shown in Figure 8.

Fig. 8. Packed calc.exe unpacking function pseudo-code

5 Methodology

To assess the effectiveness of current antivirus detection technologies against obfuscated ransomware the following experiment was designed involving 11 live ransomware specimens that were analyzed using the VirusTotal [16] platform. The detection rate was recorded for each ransomware sample and is presented in Table 1.

5.1 Ransomware sample selection

The 11 live ransomware samples were obtained from the Malware Zoo GitHub repository [17]. Each sample was executed in an isolated environment to validate that it can encrypt the files and folders on the system. The test was performed to gain assurance that each sample was performing as expected and in a malicious way.

DOI: 10.12948/issn14531305/23.2.2019.05

Table 1. The hash signatures for the 11 live ransomware samples

No.	Ransomware sample	SHA-256 Signature (searchable on VirusTotal)	VirusTotal Detection Rate (72 engines)
1	Cerber	e67834d1e8b38ec5864cfa101b140aeaba8 f1900a6e269e6a94c90fcbfe56678	84.72 %
2	Cryptowall	45317968759d3e37282ceb75149f627d64 8534c5b4685f6da3966d8f6fca662d	84.72 %
3	Locky	bc98c8b22461a2c2631b2feec399208fdc4 ecd1cd2229066c2f385caa958daa3	91.67 %
4	Mamba	2ecc525177ed52c74ddaaacd47ad513450 e85c01f2616bf179be5b576164bf63	80.56 %
5	Matsnu	7634433f8fcf4d13fb46d680802e48eeb16 0e0f51e228cae058436845976381e	77.78 %
6	Petrwrap	027cc450ef5f8c5f653329641ec1fed91f69 4e0d229928963b30f6b0d7d3a745	88.89 %
7	Petya	26b4699a7b9eeb16e76305d843d4ab05e9 4d43f3201436927e13b3ebafa90739	83.33 %
8	Satana	683a09da219918258c58a7f61f7dc4161a 3a7a377cf82a31b840baabfb9a4a96	87.50 %
9	TeslaCrypt	afaba2400552c7032a5c4c6e6151df374d0 e98dc67204066281e30e6699dbd18	79.17 %
10	Vipasana	c0cf40b8830d666a24bdd4febdc162e95aa 30ed968fa3675e26ad97b2e88e03a	75.00 %
11	WannaCry	ed01ebfbc9eb5bbea545af4d01bf5f10716 61840480439c6e5babe8e080e41aa	87.50 %

5.2 Ransomware samples obfuscation process

The same 11 live ransomware specimens went through an obfuscation process to increase the difficulty of detection and analysis. The mutated specimens were analyzed using the VirusTotal platform and the results and detection ratio were recorded. The VirusTotal platform was chosen for this research because it uses up to 72 antivirus engines for each submitted sample. All of the 11 ransomware samples are targeting Microsoft Windows based operating systems and they use the PE (portable executable) format.

For the obfuscation process the Themida packer was used to modify the ransomware samples. Themida 2.4.6.0, is currently considered the most difficult packer to reverse engineer and it uses anti-debugging and anti-virtualizations techniques to make protected software harder to reverse engineer. It offers features to run the packed executable inside a virtual machine to make the analysis of the packed executable even harder for reverse engineers. The main difference between Themida and other commercial packers is that Themida offers the ability to run different functions of the packed executable in multiple virtual machines making the analysis even more difficult.

The obfuscated ransomware samples were analyzed using the VirusTotal platform and using the Cuckoo Sandbox [18]. The Cuckoo Sandbox is a security mechanism for separating running programs. It is often used to execute untested code, or untrusted programs from unverified third-parties, suppliers, untrusted users and untrusted websites. A sandbox is used to run an unknown and untrusted application or file inside an isolated environment and observe its behavior. Malware sandboxing is a practical application of the dynamical analysis approach: instead of statically analyzing the binary file, the file is executed and monitored in real-time [19]. The Cuckoo sandbox was

DOI: 10.12948/issn14531305/23.2.2019.05

deployed using the concept of nested virtualization as presented in Figure 9.

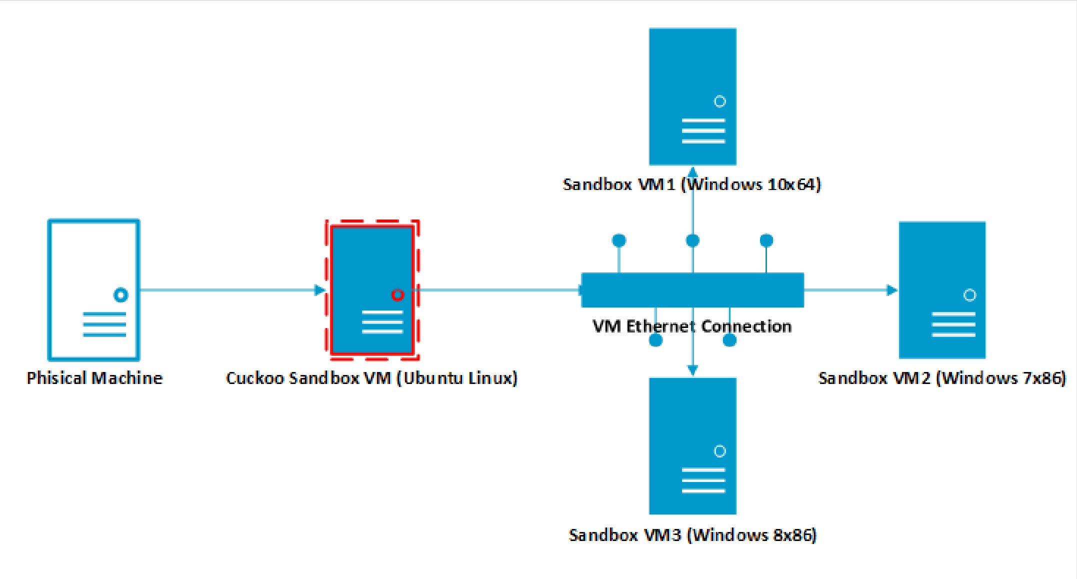


Fig. 9. Cuckoo sandbox architecture used for dynamic analysis

The ransomware sample is loaded in the packer's interface and the following protection mechanisms are configured, as presented in Table 2 and Figure 10.

Table 2. Themida packer configuration settings

No.	Themida Protection Feature	Feature Configuration
1	Anti-debugging	Advanced
2	Advanced API-Wrapping	Level 2
3	Compression	Application, Resources, SecureEngine
4	Anti-Dumpers	Yes
5	Anti-Patching	File Patching
6	Entry Point Obfuscation	Enabled
7	Taggant Information	Add Taggant
8	Monitor Blockers	File, Registry, Sandbox
9	Resource Encryption	Enabled
10	Memory Guard	Enabled
11	Delphi/BCB Form Protection	Enabled
12	VMWare/Virtual PC Execution	Enabled
13	When Debugger is detected	Exits silently

DOI: 10.12948/issn14531305/23.2.2019.05

Fig. 10. Themida packer protection options

The ransomware sample is configured to use two virtual machines for execution, as presented in Figure 11.

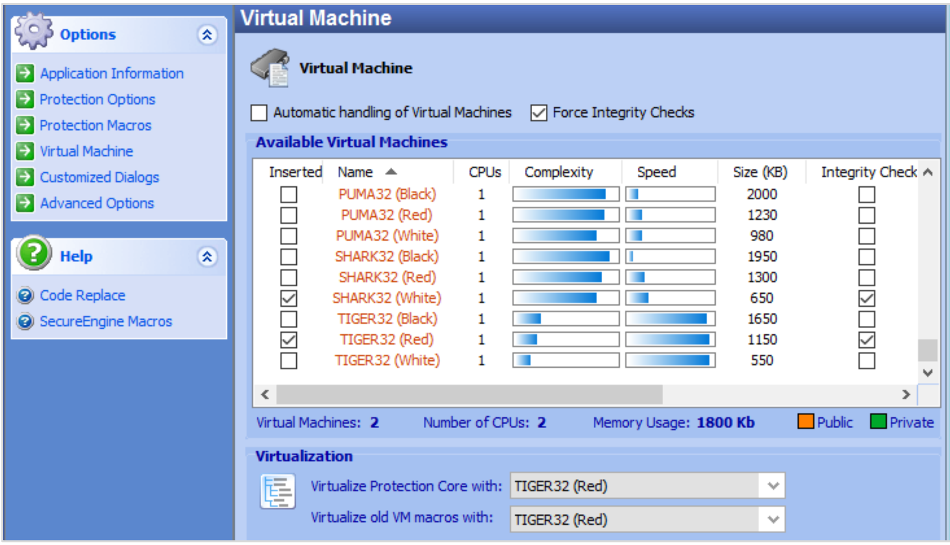


Fig. 11. Themida packer virtualization options

The packed ransomware sample will be encrypted, will we loaded as a .dll library (DLL plugin) and the packer will use techniques to hide from PE (portable executable) scanners as presented in Figure 12.

DOI: 10.12948/issn14531305/23.2.2019.05

Fig. 12. Themida packer protection options for PE initial execution

Like in the case of the packed calc.exe the code analysis of the packed ransomware samples is difficult. For example, the unpacked wannacry.exe ransomware sample, when disassembled, shows four libraries in the ***Import Table*** and more than 20 functions that can be analyzed, as presented in Figure 13.

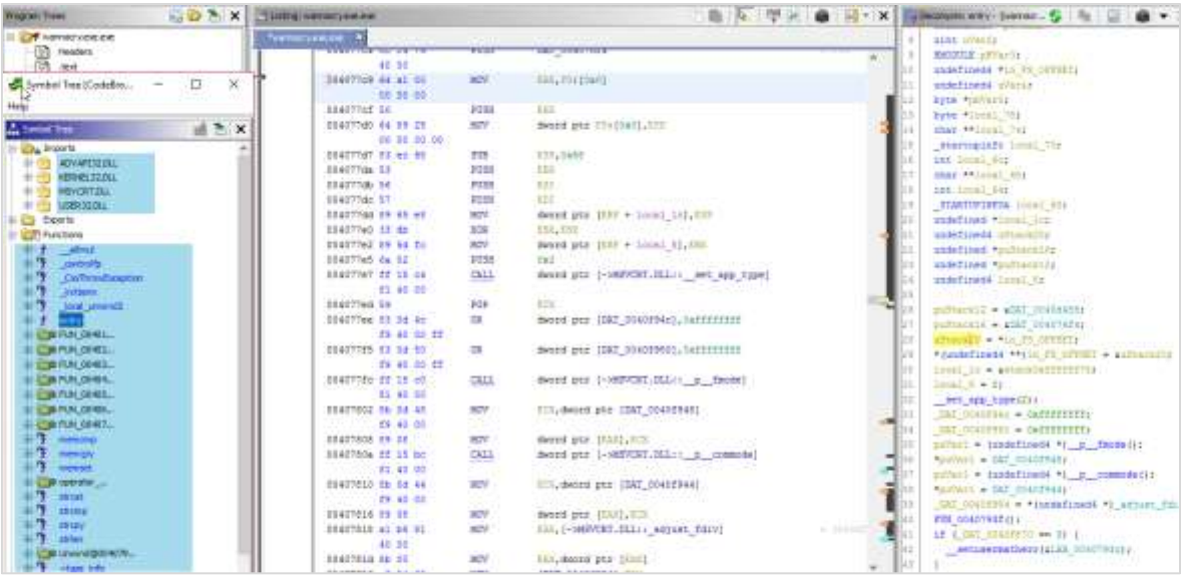


Fig. 13. Unpacked Wannacry import tables and functions loaded in Ghidra Disassembler

The packed wannacry.exe ransomware sample, when disassembled, shows 2 libraries in the ***Import Table*** and 6 functions that can be analyzed, as presented in Figure 14.

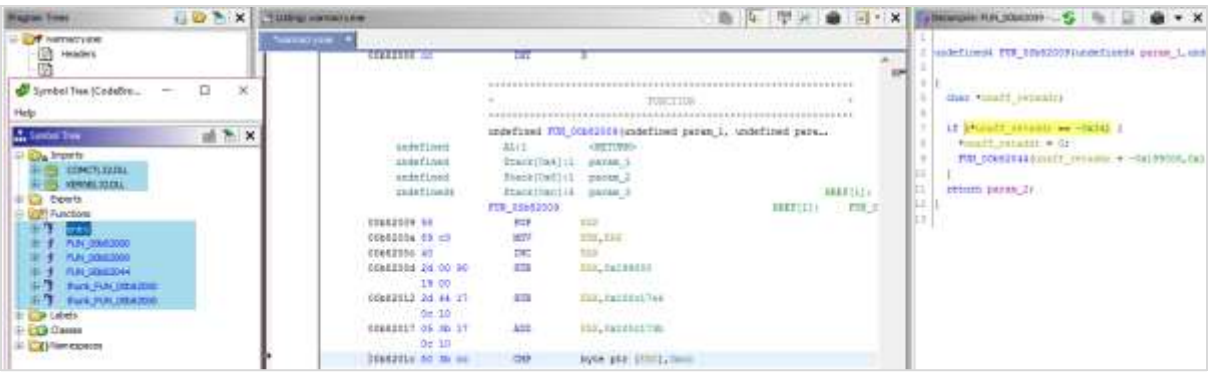


Fig. 14. Packed Wannacry import tables and functions loaded in Ghidra Disassembler

DOI: 10.12948/issn14531305/23.2.2019.05

6 Results

The packed ransomware samples were analyzed using the following methods:

1) Antivirus analysis using VirusTotal engines
2) Dynamic analysis using Cuckoo Sandbox

6.1 Antivirus analysis results using VirusTotal engines

The detection of each ransomware sample is presented in Table 4. The average detection rate was 32.58%. The average detection rate was increased to 44.95% after 24 hours from the samples submission. The spike in detection rate is attributed to the fact that VirusTotal shares submitted samples with all antivirus companies that didn't detect the sample as malicious. The samples can be independently verified by searching the SHA-256 signature on the VirusTotal website.

Table 3. Packed ransomware samples detection rates on VirusTotal

Ransomware sample packed with Themida	Signature (SHA-256)	VirusTotal Detection Rate (72 engines) after first submission	VirusTotal Detection Rate after 24 hours
cerber	dc9a03120c937119e644fe5dc3617be5e316dd6e146dc4080adeafb36e631e3c	34.72%	55.56%
cryptowall	7f4d77ae38707ab002446522e28cb0156c73c64ac963ffd2a81b914c797384e4	34.72%	34.72%
locky	6745220a083e7f1a0d69b7ca6d50e7cfdcd25c055e66866ddecde632437b5844	31.94%	55.56%
mamba	252f58bfad5ab2f5e1ce3f2d7e2780edd03f57d3e11dea7f2a0b92a374e3f397	20.83%	20.83%
matsnu	8687a45fa950a378b0d7a3ada06c574705cc12f31748355d8d29faa1e485c2a6	26.39%	47.22%
petrwrap	fa678168ef979afb511829a199eec56987d3ef07b88b5cfa2f927978f2f92a56	25.00%	51.39%
petya	4aef08aee19b79bb9a63bafb72d4d739394220e4523de56367f8f8caa5a30e9c	41.67%	41.67%
satana	c121c15e4e8739618f958b9065ebd16a3625f524bd34a2ad0fec5b2566af663e	34.72%	34.72%
teslacrypt	21e7daea747d6930dca953754cabdfe841d9b0b43f36b93b5c55b405ea71fa7c	29.17%	29.17%
vipasana	e1c9bb603b7e6269da664cb129fe6888fd2dec52a547d1cd31bde7174b40e0d3	34.72%	55.56%
wannacry	36e29655138b148fc84136ef39b86037533166f7f4b9fcf8d39566645f6fb747	44.44%	68.06%

Although the samples were flagged as malicious only an average of 7.20% of the antivirus engines flagged the samples as ransomware. This is an important aspect because as previously stated in the case of ransomware accurate classification is very

DOI: 10.12948/issn14531305/23.2.2019.05

important to prevent accidental infection. If a ransomware is obfuscated and distributed in what appears to be an important document or software application for a specific user, if the antivirus alert is ambiguous there are increased chances that the user will create an exception and execute the ransomware. The ransomware classification rate for the 11 samples is presented in Table 4.

Table 4. Packed ransomware samples classification rates on VirusTotal

Ransomware sample packed with Themida	Signature (SHA-256)	VirusTotal Classification Rate as Ransomware (72 engines) after 24 hours
cerber	dc9a03120c937119e644fe5dc3617be5e316dd6e146dc4080adeafb36e631e3c	11.11%
cryptowall	7f4d77ae38707ab002446522e28cb0156c73c64ac963ffd2a81b914c797384e4	4.17%
locky	6745220a083e7f1a0d69b7ca6d50e7cfdcd25c055e66866ddecde632437b5844	2.78%
mamba	252f58bfad5ab2f5e1ce3f2d7e2780edd03f57d3e11dea7f2a0b92a374e3f397	0.00%
matsnu	8687a45fa950a378b0d7a3ada06c574705cc12f31748355d8d29faa1e485c2a6	2.78%
petrwrap	fa678168ef979afb511829a199eec56987d3ef07b88b5cfa2f927978f2f92a56	16.67%
petya	4aef08aee19b79bb9a63bafb72d4d739394220e4523de56367f8f8caa5a30e9c	0.00%
satana	c121c15e4e8739618f958b9065ebd16a3625f524bd34a2ad0fec5b2566af663e	2.78%
teslacrypt	21e7daea747d6930dca953754cabdfe841d9b0b43f36b93b5c55b405ea71fa7c	2.78%
vipasana	e1c9bb603b7e6269da664cb129fe6888fd2dec52a547d1cd31bde7174b40e0d3	15.28%
Wannacry	36e29655138b148fc84136ef39b86037533166f7f4b9fcf8d39566645f6fb747	20.83%

6.2 Dynamic analysis results using Cuckoo Sandbox

The 11 packed ransomware samples were analyzed in an isolated environment with the Cuckoo Sandbox. Each packed sample was executed in a Windows 7 32bit virtual machine. The sandbox doesn't use any malware signatures or other heuristic detection methods. The analysis methodology is based on the antivirus industry best practices and methodologies for suspect code analysis.

The hypothesis is that any file submitted for analysis is unknown and suspicious. The behavior of the suspect sample is analyzed from a threat perspective and all actions that can have a malicious intent are flagged and reported to the analyst.

All 11 submitted samples were flagged as malicious by the Cuckoo Sandbox, as presented in Table 5, and upon execution 4 of the samples were identified as ransomware.

Table 5. Packed ransomware samples detection rates using Cuckoo Sandbox

No	Signature	Sample Name	Malicious Score
1	dc9a03120c937119e644fe5dc3617be5e316dd6e146dc4080adeafb36e631e3c	cerber.exe	75.2%
2	7f4d77ae38707ab002446522e28cb0156c73c	cryptowall.exe	57.6%

	64ac963ffd2a81b914c797384e4		
3	6745220a083e7f1a0d69b7ca6d50e7cfdcd25c 055e66866ddecde632437b5844	locky.exe	34.4%
4	252f58bfad5ab2f5e1ce3f2d7e2780edd03f57d 3e11dea7f2a0b92a374e3f397	mamba.exe	25.6%
5	8687a45fa950a378b0d7a3ada06c574705cc12 f31748355d8d29faa1e485c2a6	matsnu.exe	48%
6	fa678168ef979afb511829a199eec56987d3ef 07b88b5cfa2f927978f2f92a56	petrwrap.exe	13.6%
7	4aef08aee19b79bb9a63bafb72d4d739394220 e4523de56367f8f8caa5a30e9c	petya.exe	22.4%
8	c121c15e4e8739618f958b9065ebd16a3625f5 24bd34a2ad0fec5b2566af663e	satana.exe	80%
9	21e7daea747d6930dca953754cabdfe841d9b0 b43f36b93b5c55b405ea71fa7c	teslacrypt.exe	91.2%
10	e1c9bb603b7e6269da664cb129fe6888fd2dec 52a547d1cd31bde7174b40e0d3	vipasana.exe	27.2%
11	36e29655138b148fc84136ef39b8603753316 6f7f4b9fcf8d39566645f6fb747	wannacry.exe	65.6%

Given the fact that the Themida packer uses heavy anti-debugging and anti-analysis techniques not all of the 11 samples completed the encryption process while being analyzed in the sandbox. The 4 packed samples that started the encryption process and generated the ransom note were: Cerber, Satana, TeslaCrypt and WannaCry.

The remaining 7 samples were flagged as malicious based on activities ranging from process and code injection, the installation of boot-kits, connection to suspect internet servers without performing DNS checks etc.

The Cerber ransomware note retrieved during analysis is presented in Figure 15.

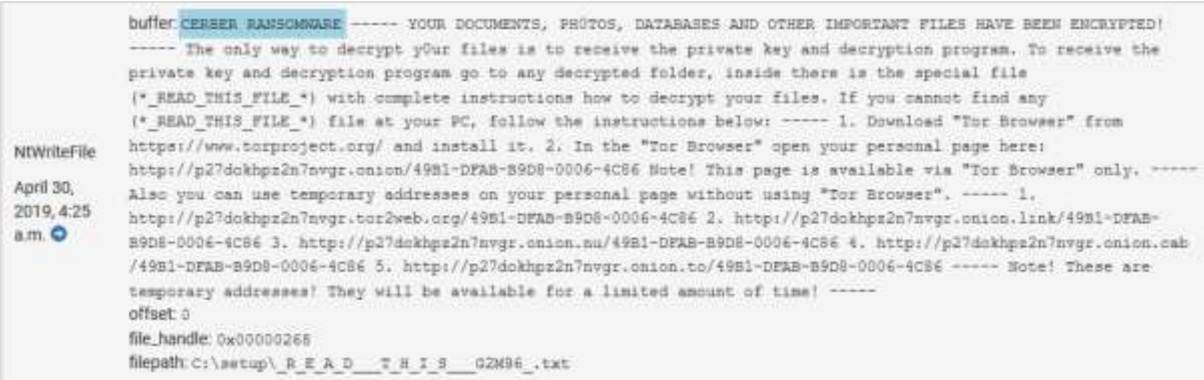


Fig. 15. Packed Cerber ransomware note retrieved during dynamic analysis

The Satana ransomware note retrieved during analysis is presented in Figure 16.

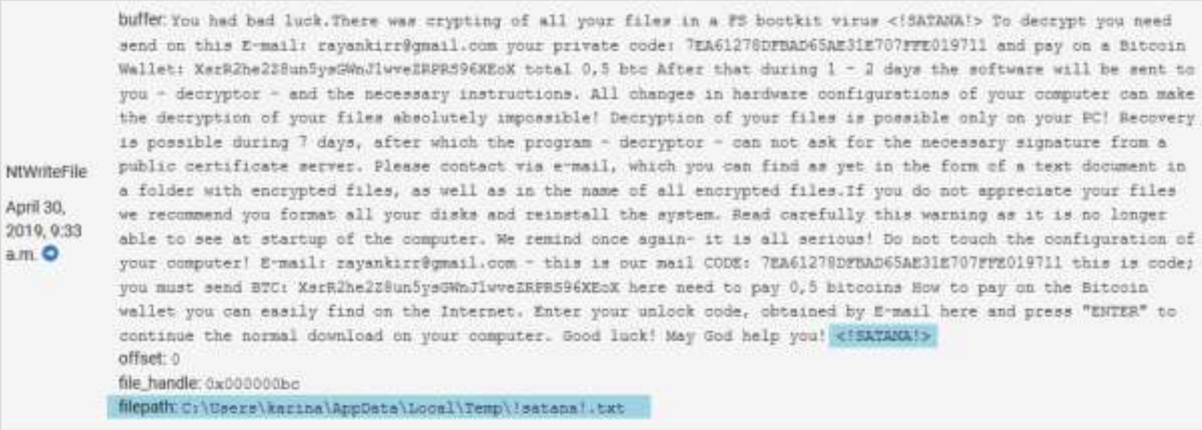


Fig. 16. Packed Satana ransomware note retrieved during dynamic analysis

The TeslaCrypt ransomware note retrieved during analysis is presented in Figure 17.

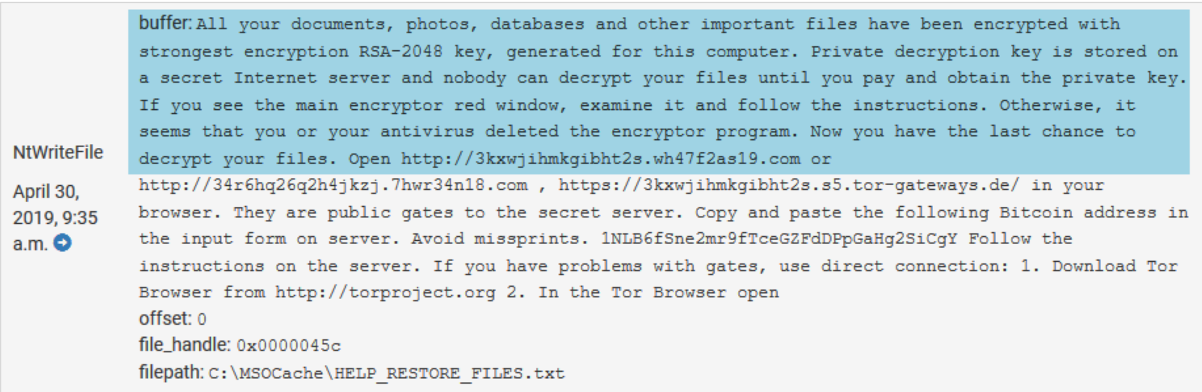


Fig. 17. Packed TesalCrypt ransomware note retrieved during dynamic analysis

The WannaCry ransomware note is presented in Figure 18.

Fig. 18. Packed Wannacry ransomware note retrieved during dynamic analysis

The malware analysis reports and relevant data extracted from the 11 ransomware samples are published on GitHub [20].

7 Conclusions

In a research paper published at DIMVA 2015 conference researchers stated that, by analyzing over 1395 ransomware samples between 2006 and 2014, the number of families with sophisticated destructive capabilities remains quite small. The analysis revealed that in a large number of samples, the malware simply locks the victim's computer desktop or attempts to encrypt or delete the victim's files using only superficial techniques. [21] The ransomware threat landscape has changed significantly in the last 5 year and ransomware attacks are currently

DOI: 10.12948/issn14531305/23.2.2019.05

representing a serious threat to organizations around the world. From a financial perspective ransomware can cripple business operations, e-business systems and were responsible for the biggest financial losses produced to organizations in a timespan measured in hours. From this perspective the experiments presented in this research follow the current cybersecurity narrative, that malicious actors are increasing their effort to protect the ransomware code against reverse engineering because in depth analysis can uncover the complex command-and-control network used to manage the ransomware infections. The narrative is supported by several reports and articles published by companies such as NTT Data [22] and IBM [23].

As such the results presented show that by using various obfuscation techniques (like packing and encryption) on known ransomware samples can hinder detection and classification by antivirus engines. By packing the ransomware executable with the Themida packer the detection rates dropped significantly as presented in the Table 6.

Table 6. VirusTotal detection rates comparison between the unpacked and packed ransomware samples

No.	Ransomware sample	VirusTotal Detection Rate (72 engines) – unpacked sample	VirusTotal Detection Rate (72 engines) - packed sample
1	Cerber	84.72 %	34.72%
2	Cryptowall	84.72 %	34.72%
3	Locky	91.67 %	31.94%
4	Mamba	80.56 %	20.83%
5	Matsnu	77.78 %	26.39%
6	Petrwrap	88.89 %	25.00%
7	Petya	83.33 %	41.67%
8	Satana	87.50 %	34.72%
9	TeslaCrypt	79.17 %	29.17%
10	Vipasana	75.00 %	34.72%
11	WannaCry	87.50 %	44.44%

The detection rates improved after 24 hours but that should not be considered a significant achievement because in the case of large ransomware outbreaks, like WannaCry, most of the damage was produced in less than 24 hours and at a global scale. Another conclusion is that each of the samples used in the experiment is more than 24 months old, and still by performing obfuscation on the executable code (not on the source code) it can evade the heuristic detection mechanisms found in modern antivirus engines.

Dynamic analysis of the packed ransomware samples, even by using an automated sandbox, proved to me more reliable in detecting the malicious behavior of the samples. The ability to analyze in real time the behavior of the suspect samples can provide all the necessary evidence if the analyzed sample is acting in a malicious way. From 11 packed ransomware samples analyzed in the Cuckoo Sandbox in 4 cases the analysis retrieved the ransom note and the encrypted files from the virtual machine. However, using dynamic analysis and sandboxes to analyze suspect code is not a mainstream activity and it requires both technical resources to deploy the sandbox and skilled personnel with expertise in malware analysis to actually interpret the results.

In March 2019, Norsk Hydro, an aluminum producer was the victim of a ransomware attack which caused more than 40 million USD in losses [24]. The ransomware responsible for the attack is called LockerGoga, as reported by Avira [25]. Although not initially included in the 11 ransomware samples tested in this research, the author obtained a live sample of LockerGoga, from VirusBay [26] and

DOI: 10.12948/issn14531305/23.2.2019.05

submitted the sample to VirusTotal. The sample identified with the SHA-256 signature presented in Table 7 was detected by 49/72 engines.

Table 7. Unpacked LockerGoga SHA-256 signature

2fe3c29913f66c255cb7aa5c34821ab182f889e7f96c25bad31267adc8a19e5b

The author packed the LockerGoga sample with the Themida packer and re-submitted the sample to VirusTotal. The sample with the SHA-256 signature. Presented in Table 8 was detected by 20/72 engines and classified as ransomware by two engines.

Table 8. Packed LockerGoga SHA-256 signature

974df521074fe3aba941e43e72f16882b9ea268c801ea3eea001fa39bad70525

Dynamic analysis of the packed LockerGoga sample revealed that the ransomware executed the encryption process successfully and also generated the ransom note, as presented in the Figure 19.

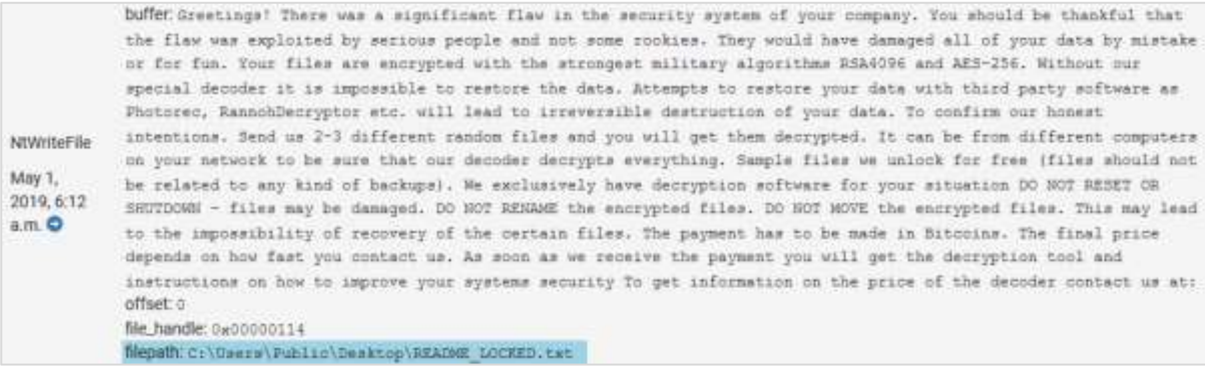


Fig. 19. Packed LockerGoga ransomware note retrieved during dynamic analysis

A general conclusion based on the limited number of samples tested is that signature and heuristic based malware detection algorithms have issues to detect new or obfuscated ransomware. Dynamic analysis and suspect code execution inside a sandbox currently remain the most reliable detection and classification method for ransomware. Ransomwares represents a group of malware applications so destructive that the need accurate detection prior to execution or during the initial stages of execution is crucial in order to mitigate the threat.

8. References

[1] Adam L.; Yung, Moti. "An Implementation of Cryptoviral Extortion Using Microsoft's Crypto API" Young. Available at https://www.cryptovirology.com/cryptovfiles/newbook/Chapter2.pdf

[2] The Register, "Fake cop Trojan 'detects offensive materials' on PCs, demands money". Available at https://www.theregister.co.uk/2012/04/05/police_themed_ransomware/

[3] Kelion, Leo, "Cryptolocker ransomware has 'infected about 250,000 PCs". Available at https://www.bbc.com/news/technology-25506020

[4] Tripwire, "NotPetya - Timeline of a ransomworm". Available at https://www.tripwire.com/state-of-security/security-data-protection/cyber-security/notpetya-timeline-of-a-ransomworm/

[5] Wired, "The Untold Story of NotPetya, The Most Devastating Cyberattack In History". Available at

https://www.wired.com/story/notpetya-cyberattack-ukraine-russia-code-crashed-the-world/
[6] Rivest, Shamir, Adleman, "A Method for Obtaining Digital Signatures and Public-Key Cryptosystems". Communications of the ACM, 21 (2), pp. 120-126, February 1978
[7] NIST, "The Advanced Encryption Standard FIPS – 197". Available at https://csrc.nist.gov/csrc/media/publications/fips/197/final/documents/fips-197.pdf
[8] Subedi, Kul & Budhathoki, Daya Ram & Dasgupta, Dipankar, "Forensic Analysis of Ransomware Families Using Static and Dynamic Analysis", 10.1109/SPW.2018.00033, 2018
[9] Charles Crofford, Douglas McKee, "Ransomware Families Use NSIS Installers to Avoid Detection, Analysis". Available at https://securingtomorrow.mcafee.com/other-blogs/mcafee-labs/ransomware-families-use-nsis-installers-to-avoid-detection-analysis/
[10] Avast, „A closer look at the Locky ransomware". Available at https://blog.avast.com/a-closer-look-at-the-locky-ransomware
[11] Kaspersky Lab, "SynAck targeted ransomware uses the Doppelgänging technique". Available at https://securelist.com/synack-targeted-ransomware-uses-the-doppelganging-technique/85431/
[12] VMRay, „Gandcrab ransomware evolution analysis". Available at https://www.vmray.com/cyber-security-blog/gandcrab-ransomware-evolution-analysis/#packer_gandcrabv4
[13] Oreans Technologies, "Themida – Advanced Windows Software Protection System". Available at https://www.oreans.com/themida.php
[14] Winitor, "PE Studio". Available at https://www.winitor.com/
[15] National Security Agency, "Ghidra Disassembler". Available at https://ghidra-sre.org/
[16] Google VirusTotal. Available at https://www.virustotal.com
[17] Malware Zoo. Available at github.com/ytisf/theZoo/tree/master/malwares/Binaries
[18] Cuckoo Sandbox. Available at https://cuckoosandbox.org/
[19] Cuckoo Sandbox Manual. Available at https://cuckoo.sh/docs/introduction/sandboxing.html
[20] Sechel Sergiu, "Ransomware dynamic analysis using sandboxes". Available at https://github.com/tornwire/Ransomware-Dynamic-Analysis-Cuckoo-
[21] Amin Kharraz, William Robertson, Davide Balzarotti, Leyla Bilge, Engin Kirda, "Cutting the Gordian Knot: A Look Under the Hood of Ransomware Attacks", Proceedings of the 12th International Conference, DIMVA 2015 Milan, Italy, July 9–10, 2015
[22] NTT Data, "Quarterly Report on Global Security Trends". Available at https://www.nttdata.com/global/en/-/media/nttdataglobal/1_files/media/securityreport/2018/fy2018_2q_sr_eng.pdf
[23] IBM, "GandCrab partners with NTCrypt for code obfuscation". Available at https://securityintelligence.com/news/gandcrab-partners-with-ntcrypt-for-code-obfuscation/
[24] ZDNET, "Norsk Hydro ransomware incident losses reach $40 million after one week". Available at https://www.zdnet.com/article/norsk-hydro-ransomware-incident-losses-reach-40-million-after-one-week/
[25] Avira, "Ransomware causes operation meltdown at Norsk Hydro". Available at https://blog.avira.com/ransomware-causes-operation-meltdown-at-norsk-hydro/
[26] Virus Bay, "Malware Samples". Available at https://beta.virusbay.io

DOI: 10.12948/issn14531305/23.2.2019.05

Sergiu SECHEL has graduated the Faculty of Automation and Applied Computer Sciences in 2009. He is a Ph.D. Candidate in Economy Informatics at the Bucharest University of Economic Sciences and an Advisory Manager at EY (Ernst & Young). His areas of research are cybersecurity, audit, risk management and malware research.

DOI: 10.12948/issn14531305/23.2.2019.05