REvil Ransomware-as-a-Service: An analysis of a ransomware affiliate operation

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By the Intel 471 Malware Intelligence team.

Summary

REvil aka Sodinokibi, Sodin is a ransomware family operated as a ransomware-as-a-service (RaaS). Deployments of REvil first were observed in April 2019, where attackers leveraged a vulnerability in Oracle WebLogic servers tracked as CVE-2019-2725.

REvil is highly configurable and allows operators to customize the way it behaves on the infected host. Some of its features include:

- Exploits a kernel privilege escalation vulnerability to gain SYSTEM privileges using CVE-2018-8453.
- Whitelists files, folders and extensions from encryption.
- Kills specific processes and services prior to encryption.
- Encrypts files on local and network storage.
- Customizes the name and body of the ransom note, and the contents of the background image.
- Exfiltrates encrypted information on the infected host to remote controllers.
- REvil uses Hypertext Transfer Protocol Secure (HTTPS) for communication with its controllers.

Capabilities Overview

Ransomware.

Behaviour Overview

- Uses a persistence mechanism.
- Encrypts additional resources.
- Supports privilege escalation.

Adversary intelligence

Developers

REvil ransomware first was advertised on a Russian language cybercrime forum in June 2019. The main actor associated with advertising and promoting REvil ransomware is called **Unknown** aka **UNKN**. The RaaS is operated as an affiliate service, where affiliates spread the malware by acquiring victims and the REvil operators maintain the malware and payment infrastructure. Affiliates receive 60% to 70% of the ransom payment.

Due to source code and behavior similarities between REvil and GandCrab, it was suggested there might be a connection tying the developers of the two ransomware families together. In addition to the similarities in the code, supplemental evidence tying GandCrab and REvil together is that GandGrab officially "retired" just before REvil appeared in the wild. REvil is maintained actively and is under constant development, just as GandCrab was. The most recent REvil ransomware at the time of this report was version 2.1.

The actor **Unknown** acknowledged the public reports linking REvil to GandCrab with the following statement:

`“We used to be affiliates of the (GandCrab) affiliate program. We bought the source code and started our own business. We developed custom features for our purposes”`

Despite the plausible alibi given by actor **Unknown**, the evidence suggests that REvil is a continuation of the GandCrab RaaS operation with new software, but operated by the same individuals.

The actors behind REvil include their master public key in all REvil binaries. Therefore, they are able to decrypt the files independently of the affiliates running the campaigns.

Operators

REvil is a RaaS, in the sense that a single group operates and manages the development of the ransomware while access is sold to affiliates. A field in the configuration file named **pid** is used to identify the affiliate that the sample belongs to. We have confirmed that a field in the malware configuration named **sub** is used to identify affiliate campaigns, and not the affiliates themselves, as frequently is reported. In addition, the attacker's public key can identify the same operator when used across multiple samples.

Two prominent users on the aforementioned Russian language cybercrime forum vouched for **Unknown's** ransomware service:

- **kerberos** - A moderator on the aforementioned forum and long-standing cybercriminal.
- **lalartu** - A cybercrime actor known to participate in GandCrab and REvil ransomware affiliate programs.

The actor **lalartu's** personal information possibly was released for malicious purposes or "doxxed" by an information security researcher known as UnderTheBreach (see: https://medium.com/@underthebreach/tracking-down-revils-lalartu-by-utilizing-multiple-osint-methods-2bf3a6c65a80). We have not been able to verify the conclusions asserted in this post.

Infrastructure

REvil ransomware configurations contain more than 1,000 controllers. Interestingly, the live domains we verified all were WordPress websites, so it is probable they might be compromised by the operators or purchased from other cybercriminals.

The configuration also contains domain names that were not registered at the time of this report, for example:

```
$ whois andersongilmour[.]co[.]uk

No match for "andersongilmour[.]co[.]uk."
```

This domain name was not registered at the time of this report.

It is likely most of the domains present in the configuration are decoys, with only a few real REvil controllers scattered inside the list.

Detection

This section describes the methods used to detect a REvil sample.

Static Detection

Unpacked REvil samples can be detected statically by looking up patterns in the code and in cryptographic functions used by the ransomware.

Dynamic Detection

Dynamic detection of REvil samples is possible by running Yara signatures on the memory resident image. In addition, the ransomware creates the following interesting artifacts:

- A **.txt** file with a ransom note on each directory encrypted by the ransomware.
- A **.bmp** image in the temporary directory set as the desktop background after the encryption.
- A registry key **SOFTWARE** which can be present under either **HKEY_LOCAL_MACHINE** or **HKEY_CURRENT_USER**.
- An alphanumeric file extension between 5 and 10 characters in length appended to the original extension of an encrypted file.

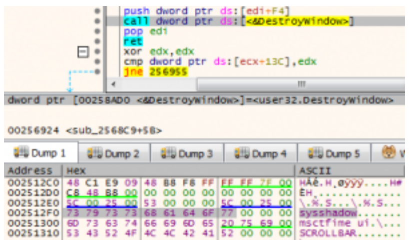
Yara Signatures

We decided not to release Yara signatures to avoid burning them and affecting the work of other researchers. However, we will release them to network defenders and infosec professionals upon request. Email us at revil-yara-req*REMOVEME*@intel471[.]com (remove the "*REMOVEME*" text from the email address) from your corporate email address (for validation purposes only) and we will send through our Yara signatures.

Exploits

REvil ransomware exploits a kernel privilege escalation vulnerability in win32k.sys tracked as CVE-2018-8453 to gain SYSTEM privileges on the infected host. If the configuration instructs a sample to execute this exploit, it will allocate executable memory, decrypt the exploit code in the newly allocated region and invoke it.

The screenshot below shows the window name **sysshadow** and the application programming interface (API) **DestroyWindow** inside the embedded exploit, proving it is the CVE-2018-8453 vulnerability.



```
push dword ptr ds:[edi+F4]
call dword ptr ds:[<&DestroyWindow>]
pop edi
ret
xor edx,edx
cmp dword ptr ds:[ecx+13C],edx
jne 256955

dword ptr [00258AD0 <&DestroyWindow>]=<user32.DestroyWindow>

00256924 <sub_2568C9+5B>
```

```
Address  | Hex                                             | ASCII
002512C0 | 48 C1 E9 09 | 48 B8 F8 FF | FF FF 7F 00 | HÁé.H.øÿÿÿ....H#
002512D0 | C8 48 B8 00 | 00 00 00 00 | 00 00 00 00 | ÈH..............
002512E0 | 5C 00 25 00 | 53 00 00 00 | 5C 00 25 00 | \.%.S...\.%.S...
002512F0 | 73 79 73 73 | 68 61 64 6F | 77 00 00 00 | sysshadow.......
00251300 | 6D 73 63 74 | 66 69 6D 65 | 20 75 69 00 | msctfime ui.\...
00251310 | 53 43 52 4F | 4C 4C 42 41 | 52 00 00 00 | SCROLLBAR.......
```

Open Source Intelligence (OSINT)

For more information on REvil, we suggest the following public resources:

- REvil/Sodinokibi Ransomware (see: https://www.secureworks.com/research/revil-sodinokibi-ransomware).

- McAfee ATR Analyzes Sodinokibi aka REvil Ransomware-as-a-Service – What The Code Tells Us (see: https://www.mcafee.com/blogs/other-blogs/mcafee-labs/mcafee-atr-analyzes-sodinokibi-aka-revil-ransomware-as-a-service-what-the-code-tells-us/).
- Tracking REvil (see: https://www.kpn.com/security-blogs/Tracking-REvil.htm).
- Defeating Sodinokibi/REvil String-Obfuscation in Ghidra (see: https://blag.nullteilerfrei.de/2020/02/02/defeating-sodinokibi-revil-string-obfuscation-in-ghidra/).

Static Analysis

REvil ransomware incorporates techniques to make the task of static analysis more difficult for an analyst. Most of the strings used during execution are decrypted at runtime only when needed. In addition, the imports are resolved dynamically from 32-bit hashes and placed into global variables early in execution.

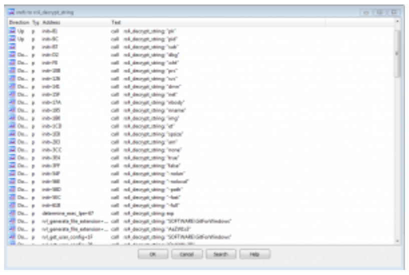
Hard-coded Strings

Very few strings are hard coded inside REvil ransomware samples and the most interesting are:

- **L"ServicesActive"**: This string is passed to the **OpenSCManagerW** API to retrieve active services.
- **"expand 32-byte kexpand 16-byte"**: The constants used by the Salsa20 symmetric encryption algorithm.

String Encryption

REvil ransomware decrypts most of the strings it uses during execution at runtime.

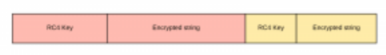


As the screenshot above reveals, these strings are Rivest Cipher 4 (RC4) encrypted and are decrypted using a function we renamed to **rc4_decrypt_string**. Below is its prototype and the meaning of each parameter:

```
void rc4_decrypt_string(BYTE *rc4_array, int rc4_key_offset, int
rc4_key_length, int buffer_length, BYTE *out_buffer)
```

- **rc4_array**: A pointer to a contiguous array in the .data section containing the RC4 keys and the encrypted strings. Each RC4 key is followed directly by the string it decrypts.
- **rc4_key_offset**: The offset to the RC4 key within the array.
- **rc4_key_length**: The length of the RC4 key.
- **buffer_length**: The length of the RC4 encrypted buffer.
- **out_buffer**: Pre-allocated memory or stack space where the decrypted string is copied.

The image below shows the layout of two adjacent elements of the array:



The decrypted strings are not terminated by NULL characters, therefore, the code must terminate these strings explicitly.

Malware Behavior

The behavior of the following samples was analyzed for this report:

Sample	SHA256
REvil packed	6953d86d09cb8ed34856b56f71421471718ea923cd12c1e72224356756db2ef1
REvil not packed	372c8276ab7cad70ccf296722462d7b8727e8563c0bfe4344184e1bc3afc27fc
REvil not packed	ec0c653d5e10fec936dae340bf97c88f153cc0cdf7079632a38a19c876f3c4fe

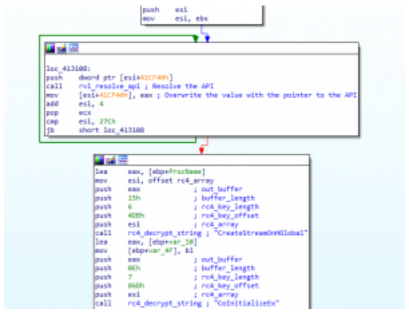
Process Execution

During its initialization phase, REvil starts by dynamically resolving the imports it needs to function correctly. This is accomplished in a loop that reads hard-coded 32-bit values from an array in the .data section, then each value is decoded and resolved to the correct API by the responsible function **rvl_resolve_api**. Then the 32-bit value is overwritten with the pointer to the API.

As shown in the disassembly above, additional APIs are resolved by their names with the help of the **GetProcAddress** API.

With everything in place, REvil creates a global mutual exclusion object (mutex) with a hard-coded name i.e., **Global\1DE3C565-E22C-8190-7A66-494816E6C5F5**. This is used to ensure only a single instance of the ransomware sample is running.

The REvil ransomware always attempts to run with elevated privileges and does so using two techniques. One technique relies on exploiting the CVE-2018-8453 vulnerability to gain SYSTEM privileges on the host. However, to determine whether it should execute the exploit or not, REvil checks its configuration. Another technique always is executed if the process is not elevated. It relies on calling **ShellExecuteW** to prompt the user to run the sample as an administrator. This is accomplished in an infinite loop until the user agrees to run the elevated process. Starting with version 2.1, the privilege escalation exploit code was removed.

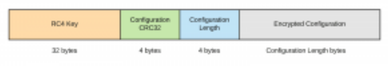


```
push    esi
mov     esi, ebx

loc_413108:
push    dword ptr [esi+41CF40h]
call    rvl_resolve_api ; Resolve the API
mov     [esi+41CF40h], eax ; Overwrite the value with the pointer to the API
add     esi, 4
pop     ecx
cmp     esi, 27Ch
jb      short loc_413108

lea     eax, [ebp+ProcName]
mov     esi, offset rc4_array
push    eax             ; out_buffer
push    15h             ; buffer_length
push    6               ; rc4_key_length
push    4D8h            ; rc4_key_offset
push    esi             ; rc4_array
call    rc4_decrypt_string ; "CreateStreamOnHGlobal"
lea     eax, [ebp+var_10]
mov     [ebp+var_4F], bl
push    eax             ; out_buffer
push    0Eh             ; buffer_length
push    7               ; rc4_key_length
push    86Dh            ; rc4_key_offset
push    esi             ; rc4_array
call    rc4_decrypt_string ; "CoInitializeEx"
```

REvil's configuration is in JavaScript Object Notation (JSON) and is initially RC4 encrypted. It is stored in the following fashion at the beginning of a portable executable (PE) section named **.yhwfq9**:



It is important to mention the cyclic redundancy check (CRC32) value is calculated and validated for the encrypted configuration.

After decrypting the configuration in dynamically allocated memory, REvil parses it using the open-source json-parser C library (see: https://github.com/udp/json-parser). For an example of a REvil configuration, see the Appendix section below.

The first JSON field checked is **exp**, which can be **true** or **false** and indicates whether the CVE-2018-8453 vulnerability should be exploited. If the exploit isn't executed or failed, REvil resorts to the second technique previously described in this section.

When REvil executes with higher privileges, it starts its main initialization phase where it reads the necessary JSON fields into the .data section and initializes registry values inside a new subkey named **SOFTWARE**. When doing registry operations in general, REvil first tries to use the **HKEY_LOCAL_MACHINE** hive and it switches to use **HKEY_CURRENT_USER** only if that fails. The configuration fields, registry keys and their values are described in the below Configuration section.

The other important task in this phase is filling the ransom note template, which is present in base64 inside the configuration field **nbody**.

`---=== Welcome. Again. ===---`

[+] Whats Happen? [+]

Your files are encrypted, and currently unavailable. You can check it: all files on your computer has extension {EXT}.
By the way, everything is possible to recover (restore), but you need to follow our instructions. Otherwise, you cant return your data (NEVER).

[+] What guarantees? [+]

Its just a business. We absolutely do not care about you and your deals, except getting benefits. If we do not do our work and liabilities - nobody will not cooperate with us. Its not in our interests.
To check the ability of returning files, You should go to our website. There you can decrypt one file for free. That is our guarantee.
If you will not cooperate with our service - for us, its does not matter. But you will lose your time and data, cause just we have the private key.
In practise - time is much more valuable than money.

[+] How to get access on website? [+]

You have two ways:

1) [Recommended] Using a TOR browser!
a) Download and install TOR browser from this site: https://torproject.org/
b) Open our website: hxxp://aplebzu47wgazapdqks6vrcv6zcnjppkbxbr6wketf56nf6aq2nmyoyd[.]onion/{UID}

2) If TOR blocked in your country, try to use VPN! But you can use our secondary website. For this:
a) Open your any browser (Chrome, Firefox, Opera, IE, Edge)
b) Open our secondary website: hxxp://decryptor[.]cc/{UID}

Warning: secondary website can be blocked, thats why first variant much better and more available.

When you open our website, put the following data in the input form:
Key:

{KEY}

Extension name:

{EXT}

!!! DANGER !!!
DONT try to change files by yourself, DONT use any third party software for restoring your data or antivirus solutions - its may entail damge of the private key and, as result, The Loss all data.
!!! !!! !!!

ONE MORE TIME: Its in your interests to get your files back. From our side, we (the best specialists) make everything for restoring, but please should not interfere.
!!! !!! !!!

REvil fills this template with a file extension (EXT), a user identifier (UID) and a key (KEY):

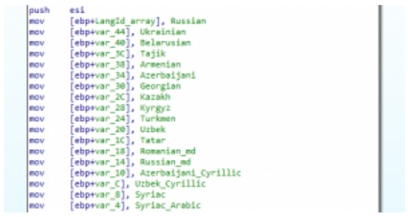
- The extension is generated randomly from alphanumeric characters and is between 5 and 10 characters in length.
- The user identifier is a hardware ID generated from the main volume's serial number and the system's CPU information. This ID is calculated as follows:
  - Retrieve the main volume 32-bit serial number.
  - Generate a CRC32 checksum of the volume serial with a seed value equal to 1337.
  - Retrieve central processing unit (CPU) information i.e., "Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz."
  - Generate a CRC32 checksum of the CPU information string with the volume serial CRC32 hash as a seed value.
  - Concatenate the CPU information CRC32 hash with the volume serial number into a 16-byte hexadecimal string i.e., 8100F233BC097E90.

  The key submitted by the victim to the operator through the website is a JSON string:

```
 { "ver":"%d", # REvil's version: hard coded to 0x200 (v2.00). "pid":"%s", # The "pid" field in the configuration.
"sub":"%s", # The "sub" field in the configuration. "pk":"%s", # The public key "pk" field in the configuration.
"uid":"%s", # The hardware ID. "sk":"%s", # The victim's generated secret key encrypted with the "pk" public key.
This key is necessary for decryption. "unm":"%s", # The username of the Windows account. "net":"%s", # The computer
name. "grp":"%s", # The domain name. "lng":"%s", # Language i.e., "fr-FR". "bro":%s, # "true" or "false". Is immune
to infection, whitelisted language and keyboard layout. "os":"%s", # Windows product name. "bit":%d, # CPU
architecture: 86 or 64. "dsk":"%s", # A base64 encoded structure with information on the mounted volumes. "ext":"%s"
# The encrypted files extension i.e., ".g19b9wy" }
```

This is encrypted with a hard-coded public key in the binary code before it is stored in the registry and the template. It also is communicated to the controllers later in execution. See the Encryption section below for information on how REvil encrypts data.

Next, REvil checks the configuration field **dbg** to see if it's running in debug mode. If that is not the case, geolocation checks based on the system's language and the keyboard layout are conducted so the ransomware does not attempt to encrypt files on whitelisted systems. The following are whitelisted system language IDs for the analyzed sample:



```
push    esi
mov     [ebp+LangId_array], Russian
mov     [ebp+var_44], Ukrainian
mov     [ebp+var_40], Belarusian
mov     [ebp+var_3C], Tajik
mov     [ebp+var_38], Armenian
mov     [ebp+var_34], Azerbaijani
mov     [ebp+var_30], Georgian
mov     [ebp+var_2C], Kazakh
mov     [ebp+var_28], Kyrgyz
mov     [ebp+var_24], Turkmen
mov     [ebp+var_20], Uzbek
mov     [ebp+var_1C], Tatar
mov     [ebp+var_18], Romanian_md
mov     [ebp+var_14], Russian_md
mov     [ebp+var_10], Azerbaijani_Cyrillic
mov     [ebp+var_C], Uzbek_Cyrillic
mov     [ebp+var_8], Syriac
mov     [ebp+var_4], Syriac_Arabic
```

The whitelisted keyboard layouts include:

- Romanian
- Russian
- Ukrainian
- Belarusian
- Estonian
- Latvian
- Lithuanian
- Tajik
- Persian
- Armenian
- Azerbaijani
- Georgian
- Kazakh
- Kyrgyz
- Turkmen
- Uzbek
- Tatar

For the check to succeed and REvil to exit, both a whitelisted system language and a whitelisted keyboard layout must be present. Otherwise, the ransomware continues its execution normally.

At this stage, REvil performs the following actions before starting the encryption. First, it will try to stop and delete services if the names match one of the regular expressions in the **svc** JSON configuration list, for example:

```
<strong>"svc":</strong>[ "memtas", "crm", "quickbooks", "svc$", "veeam", "oracle", "mepocs", "exchange", "pos",
"vss", "sql", "backup", "qb", "sophos", "sage" ]
```

Then it will terminate all processes with names that match the elements of the **prc** JSON array, for instance:

```
<strong>"prc":</strong>[ "w3wp", "thunderbird", "mydesktopqos", "powerpnt", "outlook", "srv", "infopath",
"msaccess", "ocautoupds" ]
```

Finally REvil will delete the volume shadow copies. The way this is accomplished depends on the Windows version:

Windows versions 5.1 and earlier:

```
cmd.exe /c vssadmin.exe Delete Shadows /All /Quiet & bcdedit /set {default} recoveryenabled No & bcdedit /set
{default} bootstatuspolicy ignoreallfailures
```

Windows versions 5.2 and later, under PowerShell:

```
Get-WmiObject Win32_Shadowcopy | ForEach-Object {$_.Delete();}
```

At this stage, REvil enters the file encryption phase. It is possible to run REvil with command-line arguments that will impact how encryption is carried out. The following table describes these arguments:

Argument	Description
-full	Encrypts all the data in the target files.
-fast	Only encrypts the first MB of each file. Mutually exclusive with the -full argument.
-path	Recursively encrypts the files inside a single directory specified after the argument. The desktop background image remains unchanged when this argument is supplied.
-nolan	Does not encrypt files on shared network storage.
-nolocal	Does not encrypt files on local storage.

Two values that the **et** configuration field can take are equivalent to the command-line arguments **-full** and **-fast**. Additionally, the presence of one of these command-line arguments overrides the value of this field. Below are the values this field can take with a description of each value:

Encryption type values	Description
0	Equivalent to the command-line argument -full
1	Equivalent to the command-line argument -fast
2	Encrypts 1 MB then skips the number of MBs supplied in the **spsize** field repeatedly, until the end of the file is reached.

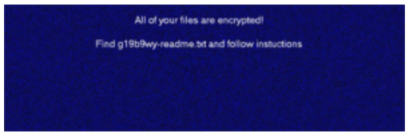
Before encrypting a file or directory, REvil determines whether its name matches any entry in the whitelist configuration entries. The whitelisted folders, files and extensions are lists stored in the **wht** JSON configuration field as **fld**, **fls** and **ext**.

REvil ransomware also avoids encrypting a file more than once by determining if it previously was encrypted. This is achieved by examining whether the metadata it stores at the end of encrypted files exists.

To encrypt the files, REvil relies on multithreading and input/output (I/O) completion ports, allowing it to perform asynchronous I/O and process multiple files simultaneously.

Each file is encrypted with a different key derived from a single public key linked to the victim. See the Encryption section below for details on how REvil implements file encryption.

After the encryption is complete, REvil generates a bitmap image and sets it as the desktop background.


All of your files are encrypted!

Find g19b9wy-readme.txt and follow instuctions

Afterward, REvil ransomware reads the Boolean configuration field **net** to determine whether it should communicate with its controllers. See the Communications section below for more details.

Finally, REvil ransomware marks its binary code for deletion during the next reboot and terminates execution.

Configuration

The table below describes each field of the REvil JSON configuration:

Argument	Description
pk	The attacker's public key encoded in base64.
pid	The affiliate ID. In v2.0 and earlier, this was an integer. From 2.1 it became a Bcrypt hash.
sub	An integer value. The campaign identifier.
dbg	Boolean value that determines if REvil should run in debug mode.
et	An integer value specifying the encryption type.- 0: Fast encryption. - 1: Full encryption. - 2: Encrypt 1 MB then skip the number of MBs specified by the **spsize** field.
spsize	Specifies the number of MBs to skip when the encryption type is 2.
wipe	A Boolean value that indicates whether REvil should wipe folders specified in the **wfld** element. We have not seen this option implemented in the analyzed samples.
wfld	The folders to be wiped by REvil.
wht	Contains three lists of elements that REvil will not encrypt: - fld: Whitelisted folders. - fls: Whitelisted files. - ext: Whitelisted extensions.
prc	A list of regular expressions that REvil matches against processes to terminate them.
net	If this Boolean value is set to **true**, REvil communicates with its controllers.
dmn	A string of controllers separated by a semicolon.
svc	A list of regular expressions to match against running services to stop and delete them.
nbody	The template of the ransom note encoded in base64.
nname	The file name of the ransom note to be dropped inside encrypted directories.
exp	Indicates if REvil should exploit the CVE-2018-8453 vulnerability to escalate privileges.
img	The text to be written in the background image encoded in base64.
arn	When set to **true**, REvil persists in the system.

The registry values that REvil creates are described below:

Value name	Description
1TfXk	Victim's secret key encrypted with the attacker's public key present in the configuration.
2YEdLY	Victim's secret key encrypted with a master public key hard coded in the binary code.
aah	The attacker's public key.
fdle	The victim's public key.
AaZW1s3	The extension appended to files after encryption.
QaUXNv2P	The victim's key encrypted with a second hard-coded public key in the binary code.

Encryption

REvil ransomware implements encryption schemes involving an elliptic curve called Curve25519, Salsa20, SHA-3, CRC32 and Advanced Encryption Standard (AES). We identified the specific open-source implementations utilized by REvil:

- Curve25519: https://github.com/vstakhov/opt-cryptobox/tree/master/curve25519 .
- Salsa20: https://cr.yp.to/snuffle/salsa20/merged/salsa20.c .

This subsection delves into the details of how these algorithms are used to encrypt data and files.

Encryption keys

REvil ransomware relies on Curve25519 to generate public and secret key pairs and to create shared keys for encryption. What follows defines the Curve25519 keys referred to throughout this subsection:

Key-pair name	Description
crypt (crypt_public/crypt_secret)	The victim's main key pair used for file encryption.
file (file_public / file_secret)	A random key pair generated for each encrypted file.

attacker (attacker_public / attacker_secret)	The attacker's key pair. attacker_public is present under the **pk** configuration field.
master (master_public / master_secret)	The master key pair. master_public is hard coded inside the binary code and is the same across all REvil samples.
user_config (user_config_public / user_config_secret)	The user configuration key pair. user_config_public is hard coded in the binary code and is used to encrypt the user key we find encrypted in the ransom note.

Data encryption

REvil ransomware encrypts all important data it stores in the registry. For instance, the user key present in the ransom note and in the registry is a JSON dictionary encrypted using the method we describe in the paragraphs that follow.

To encrypt a buffer, REvil invokes the following function:

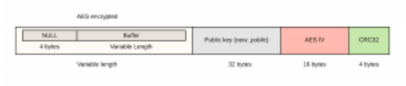
```
BYTE* rvl_encrypt_data(BYTE *hispublic, BYTE *buffer, int buffer_length, BYTE *out_buffer_length)
```

This function requires a 32-byte Curve25519 public key, a buffer to encrypt and its length. The end result is a pointer to the buffer in the return value and its length in the output parameter **out_buffer_length**.

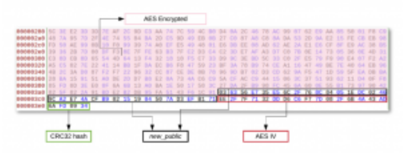
Internally, this function performs the following actions:

- Allocate buffer_length bytes plus an extra 56 bytes to hold the final data.
- Zero out the first 4 bytes of the allocated buffer.
- Copy the buffer to encrypt after the zeroed double word.
- Generate a new Curve25519 key pair we call new_public and new_secret.
- Calculate a Curve25519 shared key between the hispublic key supplied in the arguments and the new_secret. The recipient of the message can use the secret key and new_public to obtain the same shared key.
- Hash the shared key using the SHA-3 algorithm.
- Clear the shared key from memory.
- Clear new_secret from memory.
- Generate a random 128-bit AES initialization vector.
- Encrypt the buffer using AES with the SHA-3 hash as a key. The buffer to encrypt includes the prepended 32-bit NULL value.
- Clear the SHA-3 hash from memory.
- Calculate the CRC32 of the encrypted buffer.
- Append the following elements to the encrypted buffer in this order:
    - The generated new_public key (32 bytes).
    - The initialization vector (16 bytes).
    - CRC32 of the encrypted buffer (4 bytes).

The end result looks like:



As an example, after decoding the user key present in the ransom note using base64, we see it respects this same format:



In order for the attackers to decrypt this data and retrieve the JSON dictionary and as a result the encrypted victim's crypt_secret key, they must do the following:

- Verify the CRC32 hash of the encrypted data.
- Calculate a Curve25519 shared key using the new_public key in the data and the attacker's secret user_config_secret.
- Hash the shared key using SHA-3.
- Retrieve the AES initialization vector and decrypt the buffer using AES.
- Remove the NULL double word at the start of the buffer.

It is important to mention the victim's *crypt_secret* key is encrypted the same way using the attacker's *attacker_public* key (registry value "1TfXk") and the *master_public* key (registry value "2YEdLY").

File encryption

REvil ransomware encryption works by encrypting the files in 1 MB increments unless the file size is smaller, the remaining bytes to encrypt are less than 1 MB or when the encryption type specified is not full encryption. Contents of the file are read, encrypted and written back to the file overwriting the original content. After the encryption is complete, metadata is written to the end of file and the file is renamed to include the generated file extension (registry value **AaZW1s3**).

For each given file, REvil ransomware starts encryption by initializing a structure used throughout the process. Its first part includes the Windows **OVERLAPPED** structure used for asynchronous I/O followed by custom fields REvil uses. The most interesting part of this structure was reverse engineered to the following:

```
<strong>typedef</strong> <strong>struct</strong> _rvl_filecrypt_struct { OVERLAPPED Overlapped; <em>/*..SNIP..*/</em> <strong>struct</strong> _rvl_metadata { BYTE crypt_secret_w_attacker_pub[88]; <em>// same as registry value "1TfXk".</em> BYTE crypt_secret_w_master_pub[88]; <em>// same as registry value "2YEdLY".</em> BYTE file_public[32]; <em>// The file_public key.</em> BYTE salsa20_iv[8]; <em>// salsa20 initialization vector.</em> DWORD crc32_file_public; <em>// CRC32 hash of file_public.</em> DWORD et; <em>// The encryption type.</em> DWORD spsize; <em>// spsize field if applicable.</em> DWORD encrypted_null; <em>// A NULL value encrypted with salsa20.</em> } metadata; <em>/*..SNIP..*/</em> } rvl_filecrypt_struct, *prvl_filecrypt_struct;
```

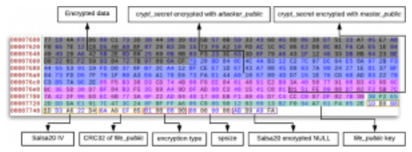
This metadata substructure is appended to the end of every encrypted file, is used by the decrypter and by REvil to verify a file previously was encrypted.

The Salsa20 symmetric encryption key is the SHA-3 hash of a shared key derived from the victim's *crypt_public* key and the secret of a generated key pair: *file_secret*.

To decrypt a file, both the victim's *crypt_secret* key and the *file_public* key must be known:

- It is possible to decrypt the *crypt_secret* knowing either the operators' *attacker_secret* or *master_secret* keys and by applying the same logic described in the Data encryption subsection.
- It is possible to retrieve the per file *file_public* key from the end of an encrypted file after validating its CRC32 hash.
- Having attained both a public and a secret key from previous steps, generate a shared Curve25519 key and hash it using SHA-3.
- Copy the value of the Salsa20 initialization vector from the metadata structure at the end of the file.
- Test decrypting the encrypted NULL double word with the SHA-3 hash as a key.
- Determine the encryption type used to perform correct decryption of the file, then start decrypting accordingly.

By following this scheme, the attackers are sure not to divulge their secret keys when sending decrypters to victims. On their side, attackers only have to decrypt the victim's *crypt_secret* key and send back a decrypter embedding this key.



Persistence mechanism

Prior to version 2.1, REvil ransomware persists on the machine if the **arn** configuration field is set to **true**. It writes its path to the registry key **SOFTWARE** for persistence. The value name of the entry for the analyzed sample is **k51299BQXH**.

Before terminating execution, REvil marks its executable file for deletion during the next reboot. As a result, the persistence path will become invalid.

The persistence mechanism was removed from REvil version 2.1.

Protections

REvil ransomware does not implement any protections.

Communications

REvil ransomware only initiates communication with its controllers when the configuration field **net** is set to **true**. In that case, REvil extracts the controller list from the **dmn** configuration string and proceeds to build a custom URL in a loop for each controller before initiating communications.

Each controller is preceded by the string **https://**, followed by a random path chosen from hard-coded values and then terminated by a random file name. The regular expression below matches all random URL paths generated by REvil ransomware:

```
\/(wp-content|static|content|include|uploads|news|data|admin)\/(images|pictures|image|temp|tmp|graphic|assets|pics|game)\/([a-z]{2}){1,10}\.(jpg|png|gif)
```

REvil then proceeds to send a POST request containing the victim's key stored in the registry value **QaUXNv2P** to the controllers. Afterward, the controller response is read into a buffer that subsequently is ignored and freed.

Appendix

Appendix 1: REvil configuration

Example of a REvil configuration. We redacted most of the controllers for readability:

```
{ "pk":"YO9E7ouT83RseZgGnLR2DxiFRbXiteYQirOJcZOjplo=", "pid":"$2a$10$7qQ70syLvX5aslSuSa9AWurg843zRR.433XEtfk2rGURjN9e.xNz6", "sub":"3195", "dbg":<strong>false</strong>, "et":1, "wipe":<strong>false</strong>, "wht":{ "fld":[ "programdata", "perflogs", "application data", "appdata", "$windows.~bt", "system volume information", "windows", "tor browser", "google", "msocache", "boot", "windows.old",
"$windows.~ws", "mozilla", "intel" ], "fls":[ "boot.ini", "ntuser.dat", "iconcache.db", "autorun.inf",
"bootsect.bak", "desktop.ini", "thumbs.db", "ntuser.ini", "ntuser.dat.log", "ntldr", "bootfont.bin" ], "ext":[ "msp",
"rom", "rtp", "shs", "mod", "cur", "msc", "nomedia", "deskthemepack", "diagcab", "diagcfg", "msstyles", "scr", "hta",
"idx", "ics", "lock", "diagpkg", "icns", "msi", "themepack", "key", "bin", "theme", "bat", "cab", "nls", "spl",
"icl", "sys", "drv", "lnk", "cmd", "adv", "cpl", "ico", "com", "exe", "ocx", "dll", "hlp", "mpa", "prf", "wpx",
"ani", "msu", "ps1", "386" ] }, "wfld":[ "backup" ], "prc":[ "w3wp", "thunderbird", "mydesktopqos", "powerpnt",
"outlook", "srv", "infopath", "msaccess", "ocautoupds", "qb", "core", "mspub", "store", "ssms", "dbeng50", "ax32",
"sql", "exchange", "onenote", "ocssd", "sage", "pos", "word", "java", "sophos", "xfssvccon", "visio", "synctime",
"oracle", "crm", "excel", "dbs", "ocomm", "svc$" ],
"dmn":"sweering[.]fr;shiresresidential[.]com;bogdanpeptine[.]ro;ruralarcoiris[.]com;echtveilig[.]nl", "net":
<strong>false</strong>, "svc":[ "memtas", "crm", "quickbooks", "svc$", "veeam", "oracle", "mepocs", "exchange",
"pos", "vss", "sql", "backup", "qb", "sophos", "sage" ],
"nbody":"LQAtAC0APQA9AD0AIABXAGUAbABjAG8AbQBlAC4AIABBAGcAYQBpAG4ALgAgAD0APQA9AC0ALQAtAA0ACgANAAoAWwArAF0AIABXAGgAYQB0AHM
"nname":"{EXT}-readme.txt", "exp":<strong>false</strong>,
"img":"QQBsAGwAIABvAGYAIAB5AG8AdQByACAAZgBpAGwAZQBzACAAYQByAGUAIABlAG4AYwByAHkAcAB0AGUAZAAhAA0ACgANAAoARgBpAG4AZAAgAHsAR
"arn":<strong>false</strong> }
```

Anti-virus (AV) classifications

AV	Alias
ALYac	Trojan.Ransom.Sodinokibi
Ikarus	Trojan-Ransom.Sodinokibi
ClamAV	Win.Ransomware.Sodinokibi
ESET-NOD32	Win32/Filecoder.Sodinokibi
Fortinet	W32/Sodinokibi.B!tr.ransom
Malwarebytes	Ransom.Sodinokibi
Microsoft	Ransom:Win32/Sodinokibi
Rising	Ransom.Sodin
TrendMicro HouseCall	Win32.SODINOKIB.SMTH
ViRobot	Trojan.Win32.Z.Sodinokibi
Webroot	W32.Ransom.Sodinokibi