Industroyer2: Industroyer reloaded

blog.eset.ie/2022/04/12/industroyer2-industroyer-reloaded

ESET Ireland April 12, 2022

This ICS-capable malware targets a Ukrainian energy company.

Executive summary

The blogpost presents the analysis of a cyberattack against a Ukrainian energy provider.

Key points:

- ESET researchers collaborated with CERT-UA to analyze the attack against the Ukrainian energy company
- The destructive actions were scheduled for 2022-04-08 but artefacts suggest that the attack had been planned for at least two weeks
- The attack used an ICS-capable malware and regular disk wipers for Windows, Linux and Solaris operating systems
- We assess with high confidence that the attackers used a new version of the Industroyer malware, which was used in 2016 to cut power in Ukraine
- We assess with high confidence that the APT group Sandworm is responsible for this new attack

ESET researchers responded to a cyber-incident affecting an energy provider in Ukraine. We worked closely with CERT-UA in order to remediate and protect their network.

The collaboration resulted in the discovery of a new variant of Industroyer malware, which we together with CERT-UA named Industroyer2 – see CERT-UA publication here. Industroyer is an infamous piece of malware that was used in 2016 by the Sandworm APT group to cut power in Ukraine.

The Sandworm attackers made an attempt to deploy the Industroyer2 malware against high-voltage electrical substations in Ukraine.

In addition to Industroyer2, Sandworm used several destructive malware families including CaddyWiper, ORCSHRED, SOLOSHRED and AWFULSHRED. We first discovered CaddyWiper on 2022-03-14 when it was used against a Ukrainian bank – see our Twitter thread about CaddyWiper. A variant of CaddyWiper was used again on 2022-04-08 14:58 against the Ukrainian energy provider previously mentioned.

At this point, we don't know how attackers compromised the victim nor how they moved from the IT network to the Industrial Control System (ICS) network. Figure 1 shows an overview of the different wipers used in this attack.

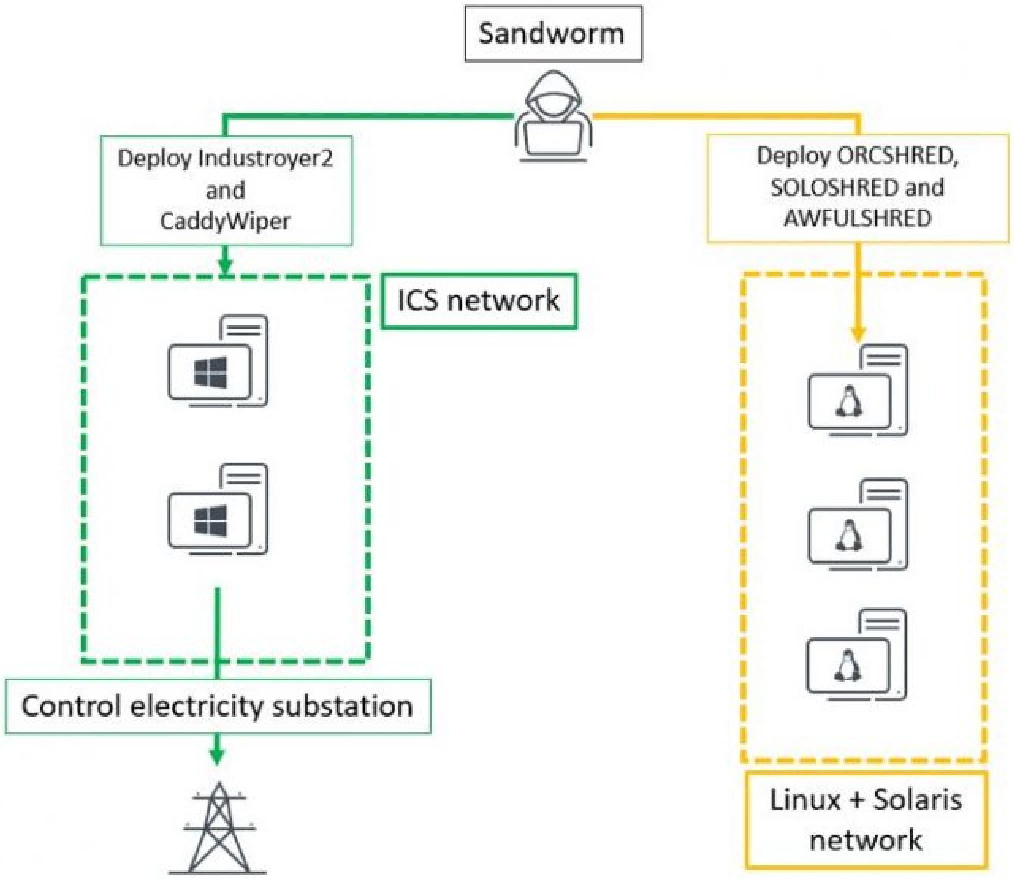

Sandworm
Deploy Industroyer2 and CaddyWiper
Deploy ORCSHRED, SOLOSHRED and AWFULSHRED
ICS network
Control electricity substation
Linux + Solaris network

Figure 1. Overview of the wiping components.

Figure 2 summarizes the chain of events.

> 2022-02-24: Beginning of the current Russian invasion in Ukraine
>
> 2022-03-14: Deployment of CaddyWiper against a Ukrainian bank
>
> 2022-04-01: Deployment of CaddyWiper against a Ukrainian governmental entity
>
> 2022-04-08 14:58 UTC: Deployment of CaddyWiper on some Windows machines and of Linux and Solaris destructive malware at the energy provider
>
> 2022-04-08 15:02:22 UTC: Sandworm operator creates the scheduled task to launch Industroyer2
>
> 2022-04-08 16:10 UTC: Execution of Industroyer2 to cut power in an Ukrainian region
>
> 2022-04-08 16:20 UTC: Execution of CaddyWiper on the same machine to erase Industroyer2 traces

Figure 2. Timeline of events.

In 2017, ESET researchers revealed that a piece of malware called Industroyer was responsible for the power blackout that impacted Ukraine's capital Kiev in December 2016.

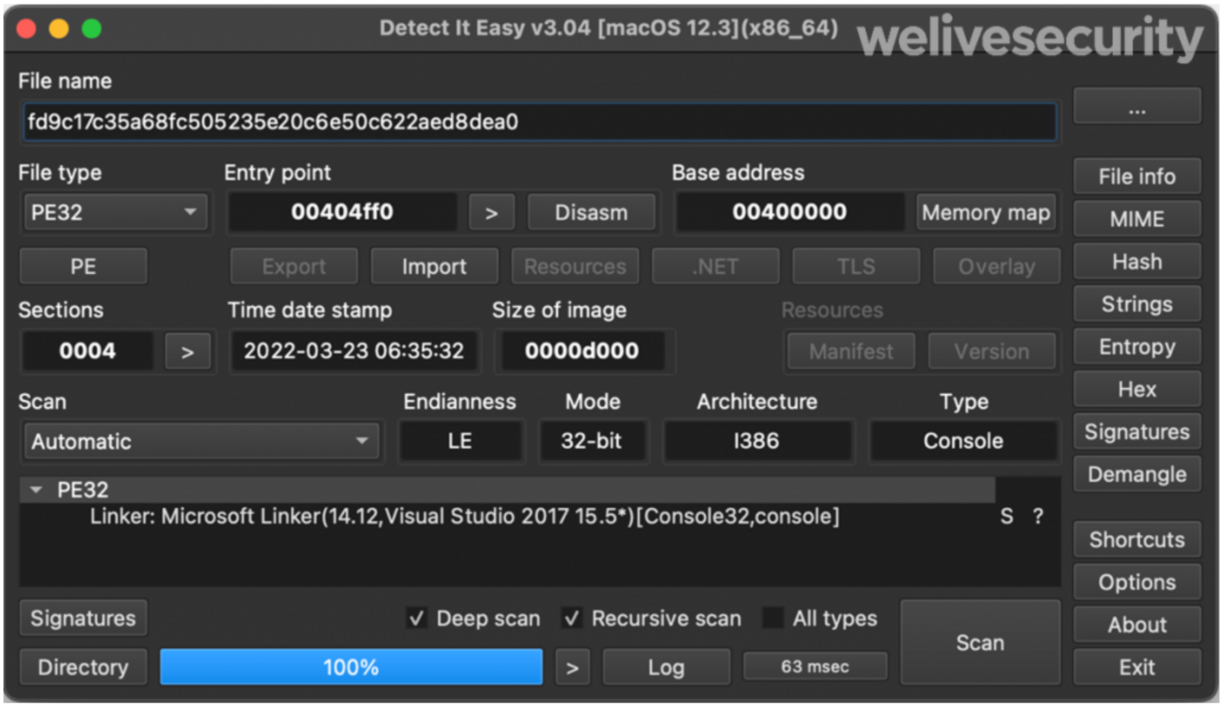
As detailed in our detailed white paper Win32/Industroyer: A new threat for industrial control systems, it is capable of interacting with industrial control systems typically found in electric power systems. This includes IEC-101, IEC-104, IEC 61850 and OPC DA.

At that time, we said that "it seems very unlikely anyone could write and test such malware without access to the specialized equipment used in the specific, targeted industrial environment". This was confirmed in 2020 by the United States government when six officers of the Russian Military Unit 74455 of the Main Intelligence Directorate (GRU), were indicted for their role in multiple cyberattacks including Industroyer and NotPetya – see the indictment on justice.gov and our historical overview of Sandworm's operations.

The recently discovered malware is a new variant of Industroyer, hence the name Industroyer2.

Industroyer2

Industroyer2 was deployed as a single Windows executable named 108_100.exe and executed using a scheduled task on 2022-04-08 at 16:10:00 UTC. It was compiled on 2022-03-23, according to the PE timestamp, suggesting that attackers had planned their attack for more than two weeks.



Detect It Easy v3.04 [macOS 12.3](x86_64)

File name: fd9c17c35a68fc505235e20c6e50c622aed8dea0

File type: PE32
Entry point: 00404ff0
Base address: 00400000

Sections: 0004
Time date stamp: 2022-03-23 06:35:32
Size of image: 0000d000

Scan: Automatic
Endianness: LE
Mode: 32-bit
Architecture: I386
Type: Console

PE32
Linker: Microsoft Linker(14.12,Visual Studio 2017 15.5*)[Console32,console] S ?

✓ Deep scan ✓ Recursive scan □ All types

100%
63 msec

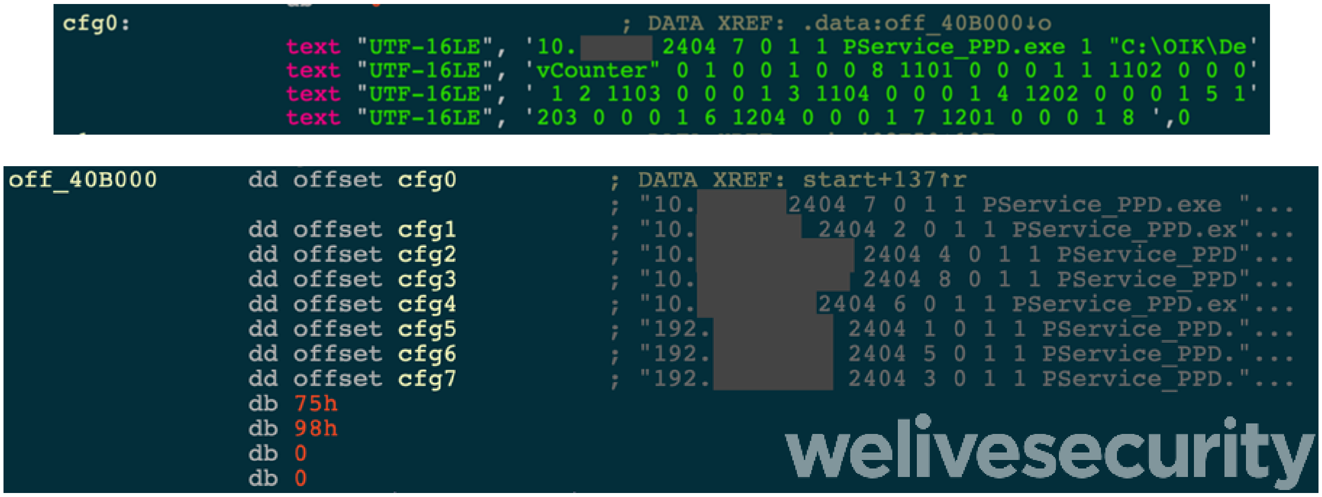
Figure 3. Timestamp and compiler information.

Industroyer2 only implements the IEC-104 (aka IEC 60870-5-104) protocol to communicate with industrial equipment. This includes protection relays, used in electrical substations. This is a slight change from the 2016 Industroyer that is a fully-modular platform with payloads for multiple ICS protocols.

Industroyer2 shares number of code similarities with the payload 104.dll of Industroyer. We assess with high confidence that the new variant was built using the same source code.

Industroyer2 is highly configurable. It contains a detailed configuration hardcoded in its body, driving the malware actions. This is different from Industroyer that stores configuration in a separate .INI file. Thus, attackers need to recompile Industroyer2 for each new victim or environment. However, given that the Industroyer* malware family was only deployed twice, with a five year gap between each version, this is probably not a limitation for Sandworm operators.

The new configuration format is stored as a string which is then supplied to the IEC-104 communication routine of the malware. Industroyer2 is able to communicate with multiple devices at once. Specifically, the analyzed sample contains 8 different IP addresses of devices – see Figure 4.



```
cfg0:                                ; DATA XREF: .data:off_40B000↓o
                 text "UTF-16LE", '10.[redacted] 2404 7 0 1 1 PService_PPD.exe 1 "C:\OIK\De'
                 text "UTF-16LE", 'vCounter" 0 1 0 0 1 0 0 8 1101 0 0 0 1 1 1102 0 0 0'
                 text "UTF-16LE", ' 1 2 1103 0 0 0 1 3 1104 0 0 0 1 4 1202 0 0 0 1 5 1'
                 text "UTF-16LE", '203 0 0 0 1 6 1204 0 0 0 1 7 1201 0 0 0 1 8 ',0
```

```
off_40B000      dd offset cfg0           ; DATA XREF: start+137↑r
                                         ; "10.[redacted]2404 7 0 1 1 PService_PPD.exe "...
                dd offset cfg1           ; "10.[redacted] 2404 2 0 1 1 PService_PPD.ex"...
                dd offset cfg2           ; "10.[redacted] 2404 4 0 1 1 PService_PPD"...
                dd offset cfg3           ; "10.[redacted] 2404 8 0 1 1 PService_PPD"...
                dd offset cfg4           ; "10.[redacted]2404 6 0 1 1 PService_PPD.ex"...
                dd offset cfg5           ; "192.[redacted] 2404 1 0 1 1 PService_PPD."...
                dd offset cfg6           ; "192.[redacted] 2404 5 0 1 1 PService_PPD."...
                dd offset cfg7           ; "192.[redacted] 2404 3 0 1 1 PService_PPD."...
                db 75h
                db 98h
                db 0
                db 0
```

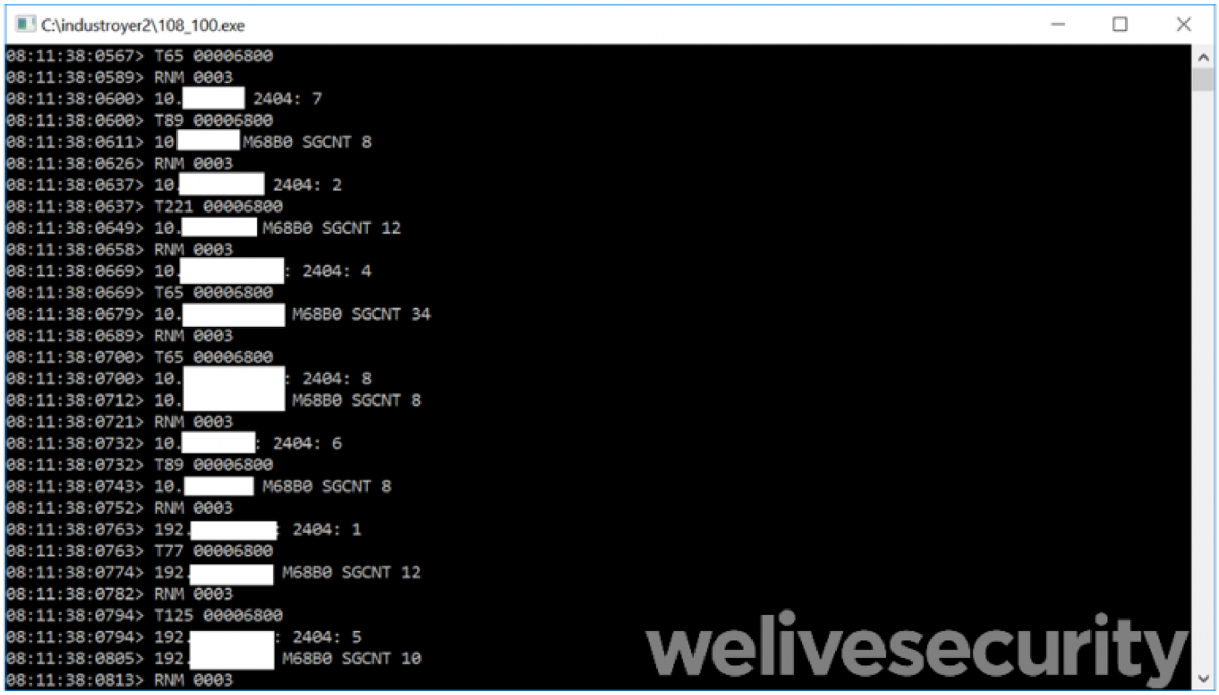
Figure 4 – Hardcoded configuration found in Industroyer2 sample

The configuration contains values that are used during communication via IEC-104 protocol, such as ASDU (Application Service Data Unit) address, Information Object Addresses (IOA), timeouts, etc.

Before connecting to the targeted devices, the malware terminates a legitimate process that is used in for standard daily operations. In addition to that, it renames this application by adding .MZ to the filename. It does so in order to prevent automatic re-start of this legitimate process.

The analysis is still on-going in order to determine what are the exact actions taken for each device. We believe that this component is able to control specific ICS systems in order to cut power.

Industroyer2 can produce a log file or output its progress to the console window. However, instead of meaningful text messages as in previous version the malware writes various error codes – see Figure 5. We believe it is an obfuscation attempt by Sandworm developers to thwart analysis.



```
08:11:38:0567> T65 00006800
08:11:38:0589> RNM 0003
08:11:38:0600> 10.[redacted] 2404: 7
08:11:38:0600> T89 00006800
08:11:38:0611> 10[redacted]M68B0 SGCNT 8
08:11:38:0626> RNM 0003
08:11:38:0637> 10.[redacted] 2404: 2
08:11:38:0637> T221 00006800
08:11:38:0649> 10.[redacted] M68B0 SGCNT 12
08:11:38:0658> RNM 0003
08:11:38:0669> 10.[redacted]: 2404: 4
08:11:38:0669> T65 00006800
08:11:38:0679> 10.[redacted] M68B0 SGCNT 34
08:11:38:0689> RNM 0003
08:11:38:0700> T65 00006800
08:11:38:0700> 10.[redacted]: 2404: 8
08:11:38:0712> 10.  M68B0 SGCNT 8
08:11:38:0721> RNM 0003
08:11:38:0732> 10.[redacted]: 2404: 6
08:11:38:0732> T89 00006800
08:11:38:0743> 10.[redacted] M68B0 SGCNT 8
08:11:38:0752> RNM 0003
08:11:38:0763> 192.[redacted]: 2404: 1
08:11:38:0763> T77 00006800
08:11:38:0774> 192.[redacted] M68B0 SGCNT 12
08:11:38:0782> RNM 0003
08:11:38:0794> T125 00006800
08:11:38:0794> 192.[redacted]: 2404: 5
08:11:38:0805> 192.  M68B0 SGCNT 10
08:11:38:0813> RNM 0003
```

Figure 5. Output produced by Industroyer2 malware

CaddyWiper

In coordination with the deployment of Industroyer2 in the ICS network, the attackers deployed a new version of the CaddyWiper destructive malware. We believe it was intended to slow down the recovery process and prevent operators of the energy company from regaining control of the ICS consoles. It was also deployed on the machine where Industroyer2 was executed, likely to cover their traces.

The first version of CaddyWiper was discovered by ESET researchers in Ukraine on 2022-03-14 when it was deployed in the network of a bank. It was deployed via Group Policy Object (GPO), indicating the attackers had prior control of the target's network beforehand. The wiper erases user data and partition information from attached drives, making the system inoperable and unrecoverable.

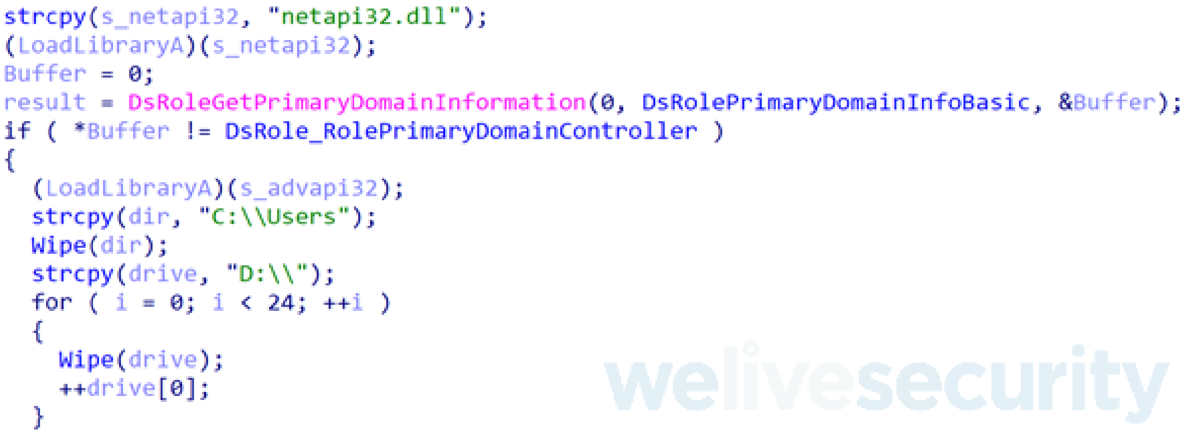
New CaddyWiper loading chain

In the network of the energy provider, attackers deployed a new version of CaddyWiper that uses a new loader, named ARGUEPATCH by CERT-UA. ARGUEPATCH is a patched version of a legitimate component of Hex-Rays IDA Pro software, specifically the remote IDA debugger server win32_remote.exe. IDA Pro is not supposed to be used in an ICS environment as its main purpose is for software reverse-engineering including malware analysis. We don't know why attackers choose to trojanized this piece of software, it might be a troll towards defenders.

ARGUEPATCH was executed by a scheduled task that was intended to be launched once on 2022-04-08 14:58 UTC on one machine and at 16:20 UTC on the machine where Industroyer2 was deployed.

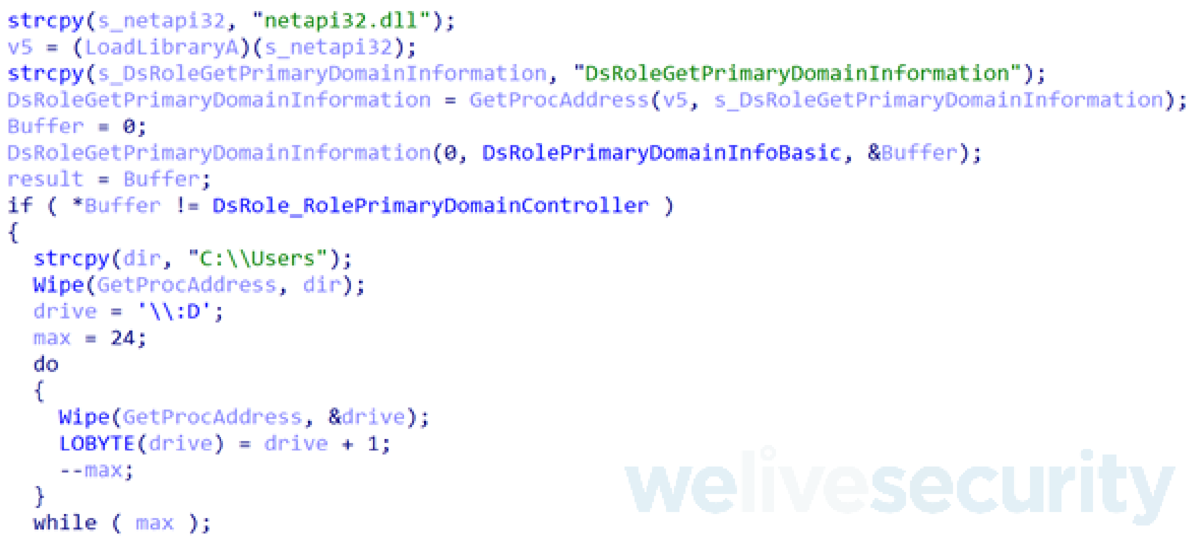
The patched binary loads an encrypted shellcode from a file and decrypts it with a key, both are provided in command line. A single-byte XOR key is derived from the input key and used to decrypt the shellcode.

The decrypted shellcode is a slightly modified version of CaddyWiper. A comparison of their main routines is provided in Figure 6 and Figure 7. Note that they do not wipe the domain controller, and they wipe C:\Users\ and disks from D:\ to [:\. The wiping routine is also almost identical: it fills all files with 0.



```
strcpy(s_netapi32, "netapi32.dll");
(LoadLibraryA)(s_netapi32);
Buffer = 0;
result = DsRoleGetPrimaryDomainInformation(0, DsRolePrimaryDomainInfoBasic, &Buffer);
if ( *Buffer != DsRole_RolePrimaryDomainController )
{
  (LoadLibraryA)(s_advapi32);
  strcpy(dir, "C:\\Users");
  Wipe(dir);
  strcpy(drive, "D:\\");
  for ( i = 0; i < 24; ++i )
  {
    Wipe(drive);
    ++drive[0];
  }
```

Figure 6. Main routine of the first sample of CaddyWiper.



```
strcpy(s_netapi32, "netapi32.dll");
v5 = (LoadLibraryA)(s_netapi32);
strcpy(s_DsRoleGetPrimaryDomainInformation, "DsRoleGetPrimaryDomainInformation");
DsRoleGetPrimaryDomainInformation = GetProcAddress(v5, s_DsRoleGetPrimaryDomainInformation);
Buffer = 0;
DsRoleGetPrimaryDomainInformation(0, DsRolePrimaryDomainInfoBasic, &Buffer);
result = Buffer;
if ( *Buffer != DsRole_RolePrimaryDomainController )
{
  strcpy(dir, "C:\\Users");
  Wipe(GetProcAddress, dir);
  drive = '\\:D';
  max = 24;
  do
  {
    Wipe(GetProcAddress, &drive);
    LOBYTE(drive) = drive + 1;
    --max;
  }
  while ( max );
```

Figure 7. Main routine of the CaddyWiper sample deployed at the energy provider

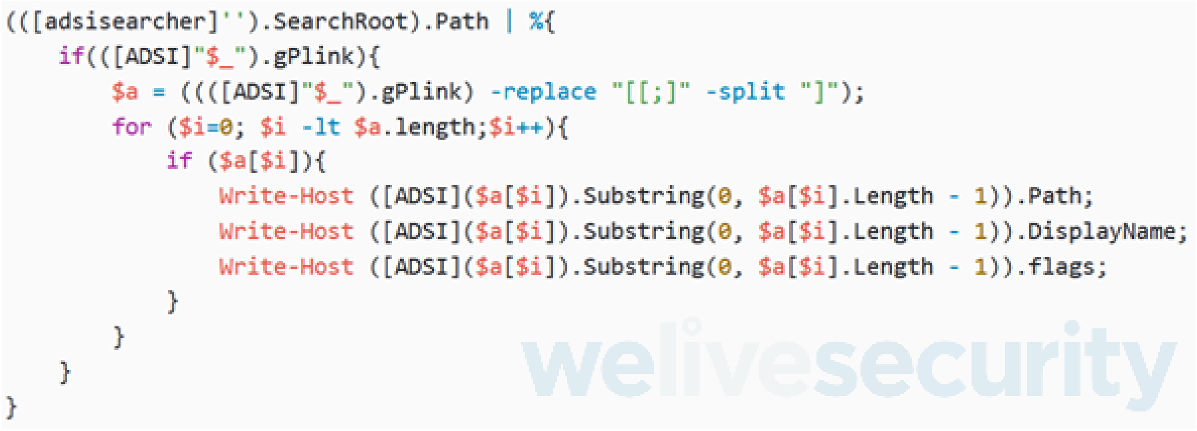
Finally, CaddyWiper calls DeviceIoControl with IOCTL_DISK_SET_DRIVE_LAYOUT_EX and a zeroed InputBuffer for all disks from \\PHYSICALDRIVE9 to \\PHYSICALDRIVE0. This erases extended information of drive's partitions: the Master boot record (MBR) or the GUID Partition Table (GPT). The machine won't be able to boot again.

Active directory enumeration

Alongside CaddyWiper, a PowerShell script was found both in the energy provider network and in the bank that was compromised earlier.

This script enumerates Group Policies Objects (GPO) using the Active Directory Service Interface (ADSI). The script, shown in Figure 8, is almost identical to a snippet provided in a medium blogpost.

We believe that attackers deployed CaddyWiper via a GPO and used the script to check the existence of this GPO.



```
(([adsisearcher]'').SearchRoot).Path | %{
    if(([ADSI]"$_").gPlink){
        $a = ((([ADSI]"$_").gPlink) -replace "[[;]" -split "]");
        for ($i=0; $i -lt $a.length;$i++){
            if ($a[$i]){
                Write-Host ([ADSI]($a[$i]).Substring(0, $a[$i].Length - 1)).Path;
                Write-Host ([ADSI]($a[$i]).Substring(0, $a[$i].Length - 1)).DisplayName;
                Write-Host ([ADSI]($a[$i]).Substring(0, $a[$i].Length - 1)).flags;
            }
        }
    }
}
```

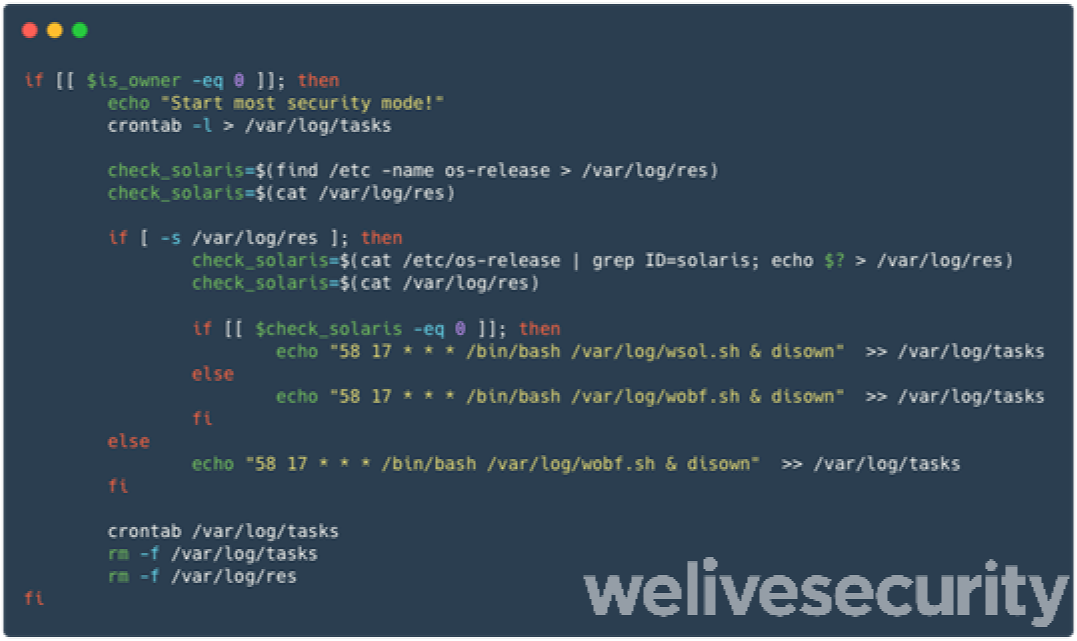
Figure 8. PowerShell script to enumerate GPO (beautified)

Linux and Solaris destructive malware (ORCSHRED, SOLOSHRED, AWFULSHRED)

On the network of the targeted energy company was found additional destructive malware for systems running Linux and Solaris. There are two main components to this attack: a worm and a wiper. The latter was found in two variants, one for each of the targeted operating system. All malware was implemented in Bash.

The worm

The first component launched by the attacker was a worm, having its file named sc.sh. This Bash script starts by adding a scheduled task (cron job) to launch the wiper component at 2:58pm UTC (assuming the system is in the local time zone, UTC+3), unless it was launched with the “owner” argument. This is likely a way to avoid autodestructing the initial system used to launch the worm.



```
if [[ $is_owner -eq 0 ]]; then
        echo "Start most security mode!"
        crontab -l > /var/log/tasks

        check_solaris=$(find /etc -name os-release > /var/log/res)
        check_solaris=$(cat /var/log/res)

        if [ -s /var/log/res ]; then
                check_solaris=$(cat /etc/os-release | grep ID=solaris; echo $? > /var/log/res)
                check_solaris=$(cat /var/log/res)

                if [[ $check_solaris -eq 0 ]]; then
                        echo "58 17 * * * /bin/bash /var/log/wsol.sh & disown"  >> /var/log/tasks
                else
                        echo "58 17 * * * /bin/bash /var/log/wobf.sh & disown"  >> /var/log/tasks
                fi
        else
                echo "58 17 * * * /bin/bash /var/log/wobf.sh & disown"  >> /var/log/tasks
        fi

        crontab /var/log/tasks
        rm -f /var/log/tasks
        rm -f /var/log/res
fi
```

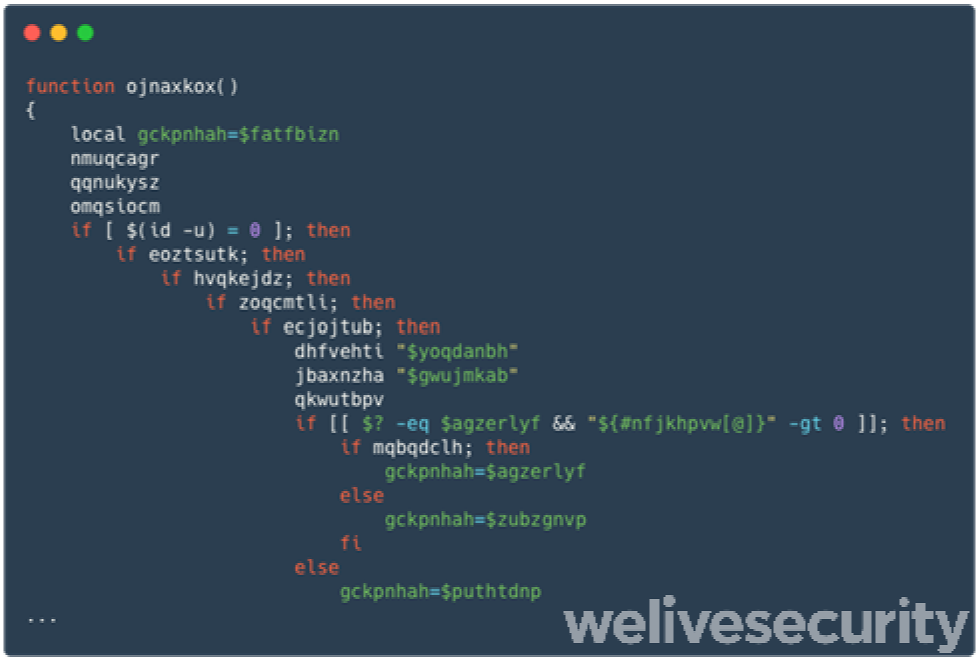
Figure 9 Setting up the crob job to launch the wiper at 5:58pm. The correct wiper is picked depending on the installed operating system.

The script then iterates over the networks accessible by the system by looking at the result of ip route or ifconfig -a. It always assumes a class C network (/24) is reachable for each IP address it collects. It will try to connect to all hosts in those networks using SSH to TCP port 22, 2468, 24687 and 522. Once it finds a reachable SSH server, it tries credentials from a list provided with the malicious script. We believe the attacker had credentials prior to the attack to enable the spread of the wiper.

If the system is not already compromised, malware is copied to the new target, and the worm is launched. The worm is *not* launched with the “owner” argument, so the wiper is scheduled to launch at 2:58pm UTC and destroy all data. If those systems were set to the local time zone, the destruction must’ve started at the same time as the system compromised with CaddyWiper.

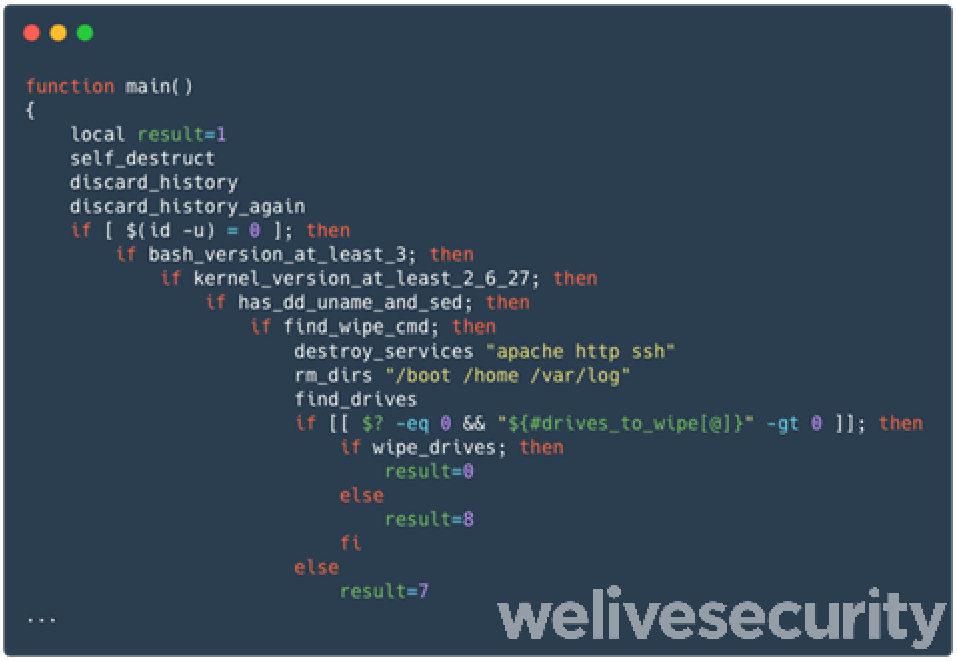
The Linux wiper

The Linux variant of the wiper is lightly obfuscated variables and function names were replaced with meaningless 8-letter word. Most literal values were also replaced with variables at the beginning of the file.



```
function ojnaxkox()
{
    local gckpnhah=$fatfbizn
    nmuqcagr
    qqnukysz
    omqsiocm
    if [ $(id -u) = 0 ]; then
        if eoztsutk; then
            if hvqkejdz; then
                if zoqcmtli; then
                    if ecjojtub; then
                        dhfvehti "$yoqdanbh"
                        jbaxnzha "$gwujmkab"
                        qkwutbpv
                        if [[ $? -eq $agzerlyf && "${#nfjkhpvw[@]}" -gt 0 ]]; then
                            if mqbqdclh; then
                                gckpnhah=$agzerlyf
                            else
                                gckpnhah=$zubzgnvp
                            fi
                        else
                            gckpnhah=$puthtdnp
...
```

Figure 10 – Except from the obfuscated script (whitespace optimised).



```
function main()
{
    local result=1
    self_destruct
    discard_history
    discard_history_again
    if [ $(id -u) = 0 ]; then
        if bash_version_at_least_3; then
            if kernel_version_at_least_2_6_27; then
                if has_dd_uname_and_sed; then
                    if find_wipe_cmd; then
                        destroy_services "apache http ssh"
                        rm_dirs "/boot /home /var/log"
                        find_drives
                        if [[ $? -eq 0 && "${#drives_to_wipe[@]}" -gt 0 ]]; then
                            if wipe_drives; then
                                result=0
                            else
                                result=8
                            fi
                        else
                            result=7
...
```

Figure 11 – Deobfuscation of the above obtained by renaming functions and variables and using literals

Ultimately, the Linux wiper destroy the whole content of the disks attached to the system by using shred if available or simply dd (with if=/dev/random) otherwise. If multiple disks are attached, data removal is done in parallel to speed up the process.

Depending on the size, it may take hours for the full disk to be completely erased. To render the system inoperable faster, it first tries to stop and disable HTTP and SSH services. Services are disabled both by using systemctl disable. To ensure service isn't reenabled, the systemd unit file responsible for loading the service is deleted from the disk.

Files from /boot, /home and /var/log are also removed before destroying the full drives. This makes the system inoperable faster, deletes user data and perhaps removes incriminating logs.

The malicious script's last action is to forcibly initiate a reboot using SysRq. Since all drives are filled with random, no operating system will boot.

The Solaris wiper

Unlike the Linux wiper, the Solaris variant is not obfuscated.

Like the Linux variant, the malicious script iterates over all services to stop and disable them if they contain the keyword ssh, http, apache and additionally ora_ or oracle. Those services are very likely used by applications used to control ICS systems. Wiping them would prevent the energy company's operators from retaking control of the substations and roll back Industroyer2 actions.

It uses either systemctl or svcadm depending on what's available. The latter is most likely since Solaris is not running systemd.

File destruction begins by deleting databases. It removes, using shred then rm, all files and directories contained in environment variables starting with ORA. Oracle Database uses the following variables to define location of database files and software: ORACLE_BASE, ORACLE_HOME and ORACLE_PATH. Note that shred makes sure data recevery (without a backup) isn't possible.

Like the Linux variant, files in /boot, /home and /var/log are deleted in priority.

Then the script iterates over disks connected to the system, found in /dev/dsk/. It ignores slices (partitions) and work only on full disks. For each of them, the malicious script overwrites the full content using shred. To minimize the time required to perform the wipe, all disks are erased in parallel.

Lastly, the script self-destructs.

Conclusion

Ukraine is once again at the center of cyberattacks targeting their critical infrastructure. This new Industroyer campaign follows multiple waves of wipers that have been targeting various sectors in Ukraine. ESET researchers will continue to monitor the threat landscape in order to better protect organizations from these types of destructive attacks.