Broken, Abandoned, and Forgotten Code, Part 9

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In the previous part, we switched gears back to the Netgear R6200 `upnpd` after spending some time analyzing `httpd`. The HTTP daemon provided an understanding of how the firmware header is *supposed* to be constructed. We found a header parsing function in `upnpd` that was similar to its `httpd` counterpart. So similar that it has the same `memcpy()` buffer overflow. This overflow was more interesting this time around, as it did not require authentication. Additionally, we discovered a reference to the "Ambit image" via an error message string. Presumably an ambit image is a firmware format analogous to TRX. In this case, however, the ambit image encapsulates a TRX image.

In this part we will identify more fields of the Ambit header, as well as run up against a limitation of QEMU: attempts to open and write to the flash memory device will fail since, in emulation, there is no actual flash memory. We'll need to patch the `upnpd` binary in order to work around this. I previously covered binary patching for emulation here.

Updated Exploit Code

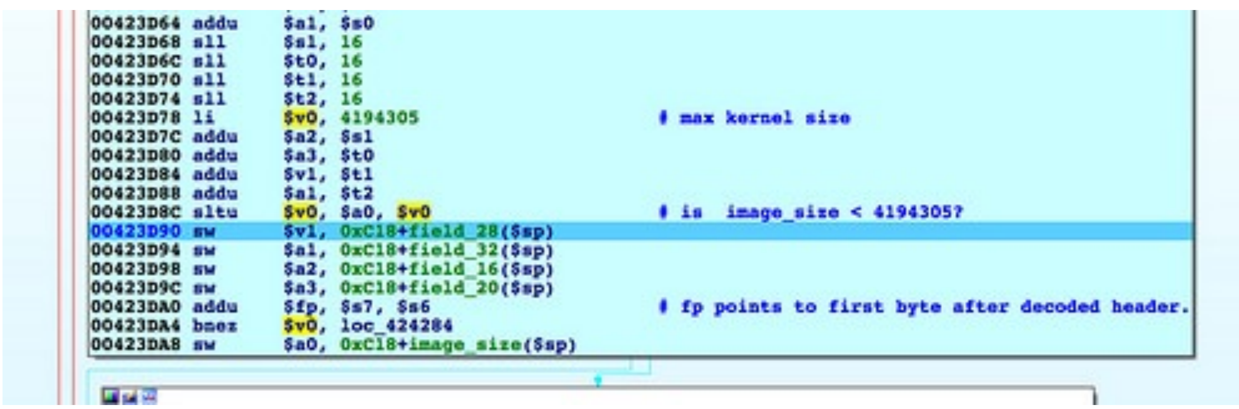
The `janky_ambit_header.py` module has been updated to reflect the additional fields we add to the header in this part. You can find the updated code and README in the part_9 directory. Now is a good time to do a pull or to clone the repository from:
https://github.com/zcutlip/broken_abandoned

We Should Have Checked the Firmware Size Before Now

The `sa_CheckBoardID()` function, analogous to `abCheckBoardID()` from `httpd`, returns success if the following is true:

- The ambit magic number is found at offset 0.
- The header size field doesn't overflow during the `memcpy()` operation
- The checksum in the ambit header matches the header's actual checksum,
- The proper board ID string is found and the end of the ambit header.

After `sa_CheckBoardID()`, at 0x00423CAC, we see several 32-bit fields parsed out. It remains to be seen how these values get used; presumably they are the same fields and get used the same way as in the `httpd` firmware validation. Then the size field from offset 24 is checked. It must be less than 0x400001, or 4194305, or firmware validation fails.



Somewhat ironically, this check can never fail, assuming the size field is truthful. If the firmware image is larger than this size, then `upnpd` will crash, having overflowed the 4MB buffer allocated for base64 decoding. In our proof-of-concept code, the size field contains a bogus value, and execution skips down to an error message.

```
00423DAC li      $a0, 0x440000
00423DB0 la      $t9, unk_2AC7C140
00423DB4 nop
00423DB8 jalr    $t9 ; puts
00423DBC addiu   $a0, (aTheKernelImage - 0x440000)  # "The kernel image is over 512Kbytes!!"
00423DC0 lw      $gp, 0xC18+var_C08($sp)
00423DC4 beqz    $fp, loc_423DE4
00423DC8 nop
```

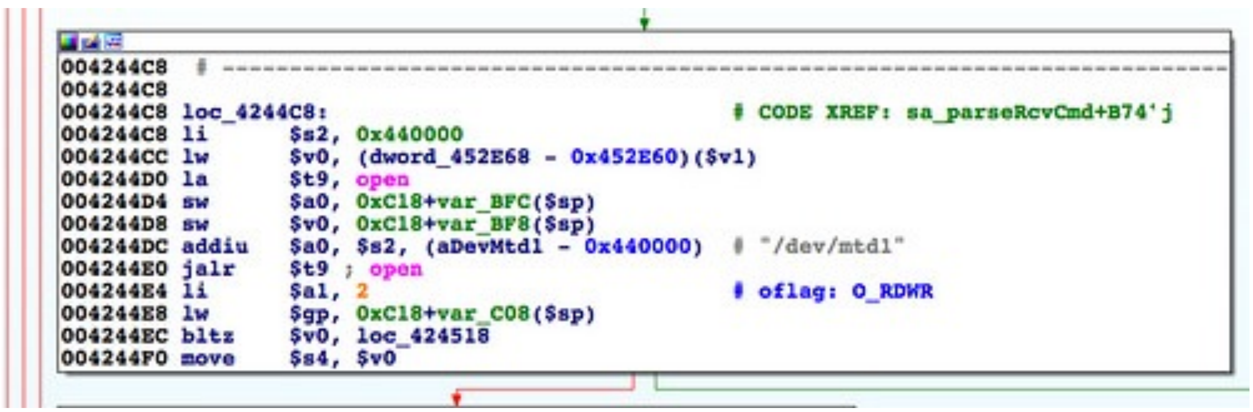
The error message belies someone's continued confusion over exactly how this capability is supposed to work. If the size validation fails, the error message is "The kernel image is over 512Kbytes!", although the test was against a 4MB upper limit.

Inserting the proper TRX image size (or "kernel size" as the error message indicates) at offset 24 gets past this step. After the check, a function is called at 0x0042428C, `sa_upgrade_setImageInfo()`, that parses out several more values from the header. Again, no validation is performed on these values at this point. It remains to be seen if they are the same fields and will be used in the same way as in `httpd`.

```
00421F34
00421F34
00421F34
00421F34                 .globl sa_upgrade_setImageInfo
00421F34 sa_upgrade_setImageInfo:                # CODE XREF: sa_parseRcvCmd+B18 p
00421F34                                         # DATA XREF: sa_parseRcvCmd:loc_424284 o ...
00421F34                 li      $gp, 0x3878C
00421F3C                 addu    $gp, $t9
00421F40                 li      $a1, 0x450000
00421F44                 lw      $t0, 0xC($a0)
00421F48                 lw      $t1, 0x10($a0)
00421F4C                 lw      $a2, 4($a0)
00421F50                 lw      $a3, 8($a0)
00421F54                 addiu   $v0, $a1, (dword_452E60 - 0x450000)
00421F58                 lw      $v1, 0($a0)
00421F5C                 sw      $t0, (dword_452E6C - 0x452E60)($v0)
00421F60                 sw      $t1, (dword_452E70 - 0x452E60)($v0)
00421F64                 sw      $a2, (dword_452E64 - 0x452E60)($v0)
00421F68                 sw      $a3, (dword_452E68 - 0x452E60)($v0)
00421F6C                 move    $v0, $zero
00421F70                 jr      $ra
00421F74                 sw      $v1, (dword_452E60 - 0x450000)($a1)
00421F74  # End of function sa_upgrade_setImageInfo
00421F74
```

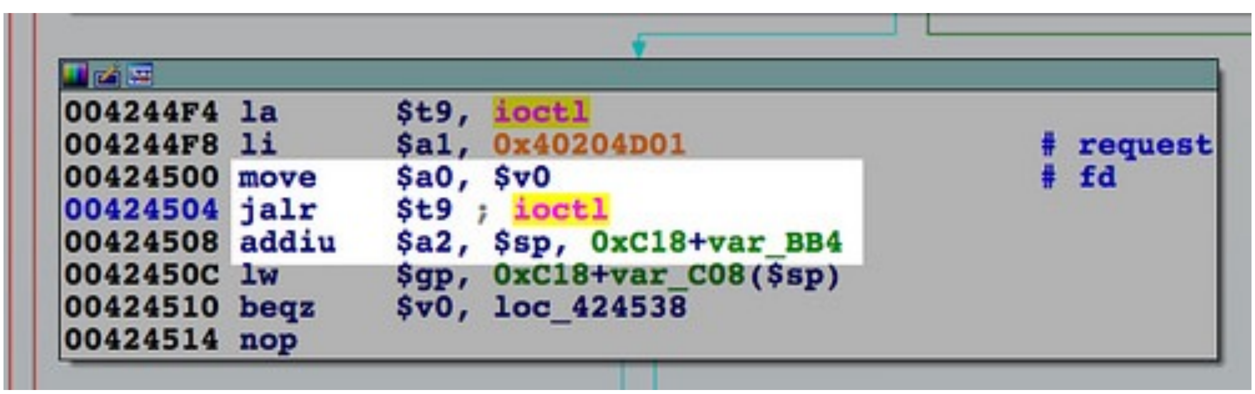
After this function is called, things begin to get interesting in a few ways. After a temporary "upgrade" file is created (but never used; wtf), `/dev/mtd1` device is opened. You'll need to work around the fact that QEMU doesn't provide this device. The following following things will fail if not addressed.

First, opening mtd1 will fail if it doesn't already exist. Create an empty file to ensure the `open()` operation is successful.

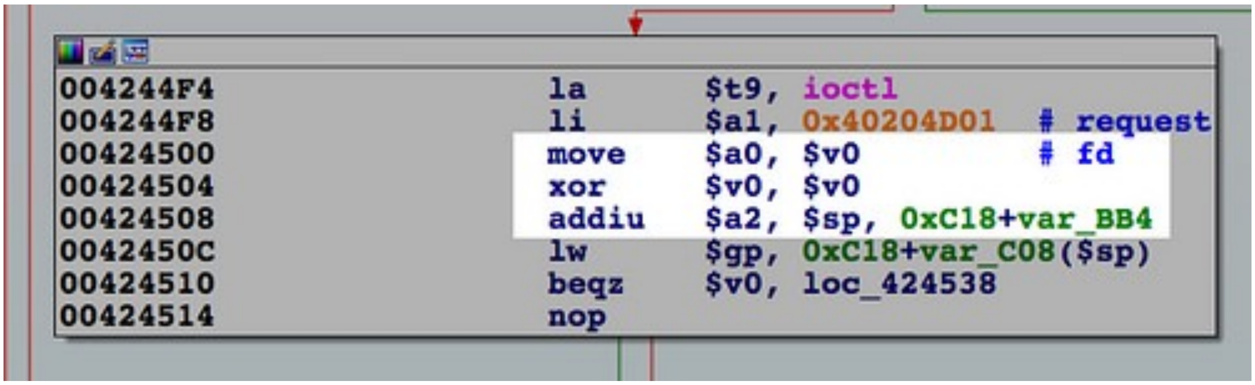


Opening /dev/mtd1 with O_RDWR.

Next, a series of `ioctl()`s is performed on the open file descriptor. To understand what these operations do, it's helpful to refer to [mtd.c](mtd.c) from the OpenWRT source code as a guide.

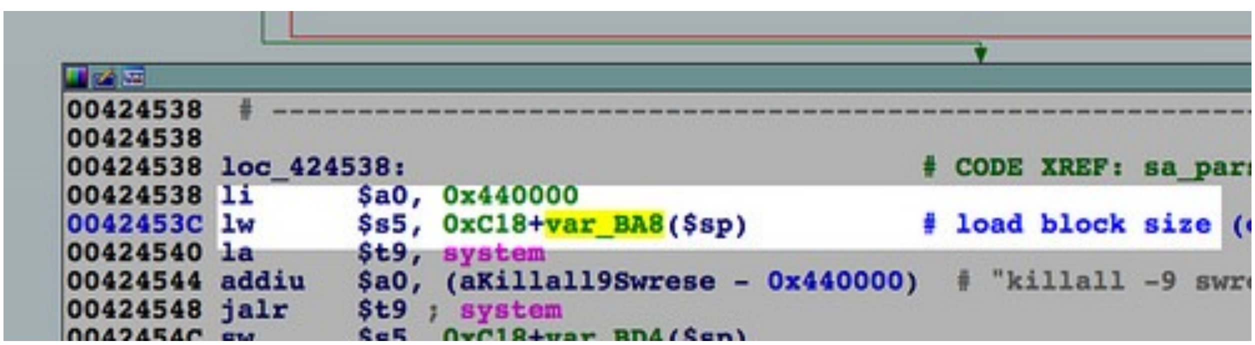


The first `ioctl()` will fail in emulation since we're just providing a regular file, not a device node. Patch out this operation with something that puts 0 in $v0, such as xor $v0,$v0.



ioctl is patched out.

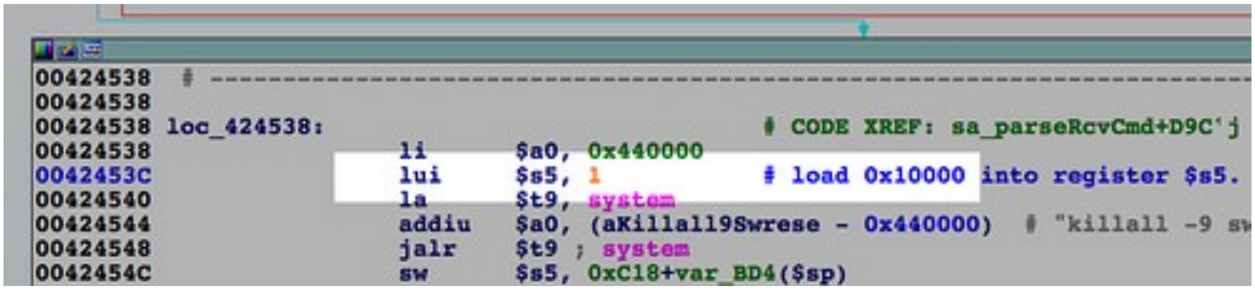
This `ioctl()` we just patched out obtains, among other things, the erase size (i.e., block size) for the mtd device. We can simulate that result by patching at 0x0042453C where the the erase size is loaded into register $s5.



It doesn't matter a great deal what you use for the erase size in emulation. The write loop will write the firmware in blocks of that size, then it will write any remaining fractional block at the end. An actual R6200 device reports a block size of 65536, or 0x10000, so that's a good number to use. Patching this instruction with:

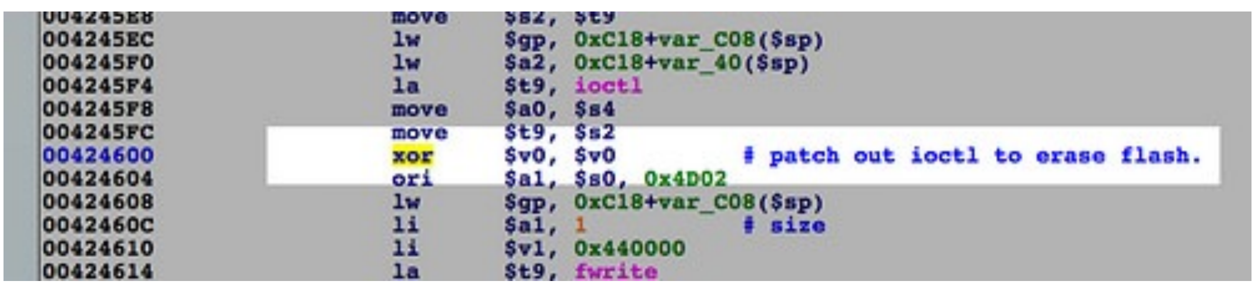
```
lui $s5, 1
```

loads 1 into the upper half of register $s5 and 0x0 into the lower half, resulting in a value of 0x10000.



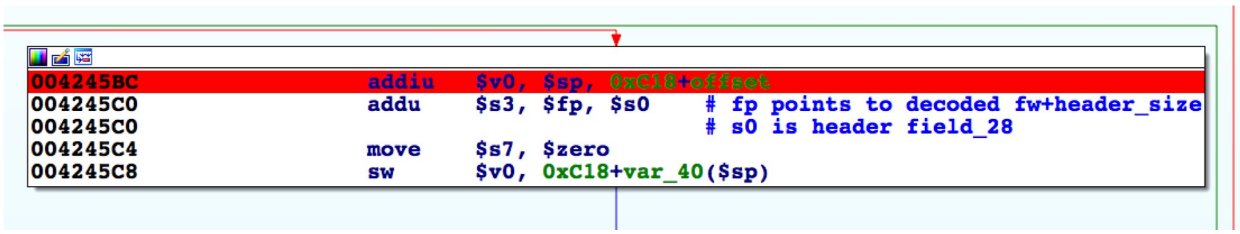
Patch in a constant 0x10000 for mtd1 block size.

Next, in the basic block starting at 0x004245D0, there are two more `ioctl()`s. The first one most likely unlocks the current portion of flash for writing. The return value from it isn't checked, end execution immediately proceeds to the second. Based on the error message, the second one erases the block of flash so it can be rewritten. With our fake `/dev/mtd1` there's no need to erase, so we can patch out this operation as before.



Patch out the `ioctl()` to erase flash memory.

Now, having patched out the `ioctl()`s that fail in emulation, writing to a regular file should work as normal. There is one more field that, while not validated directly, does affect what data gets written. When analyzing `httpd`, we discovered the field at offset 28 that contains the size of a theoretical second partition. In stock firmware this field is zeroed out. In `upnpd`, at 0x004245C0, this value is added to the address of the TRX image, and the result is the start of data that gets written to flash.



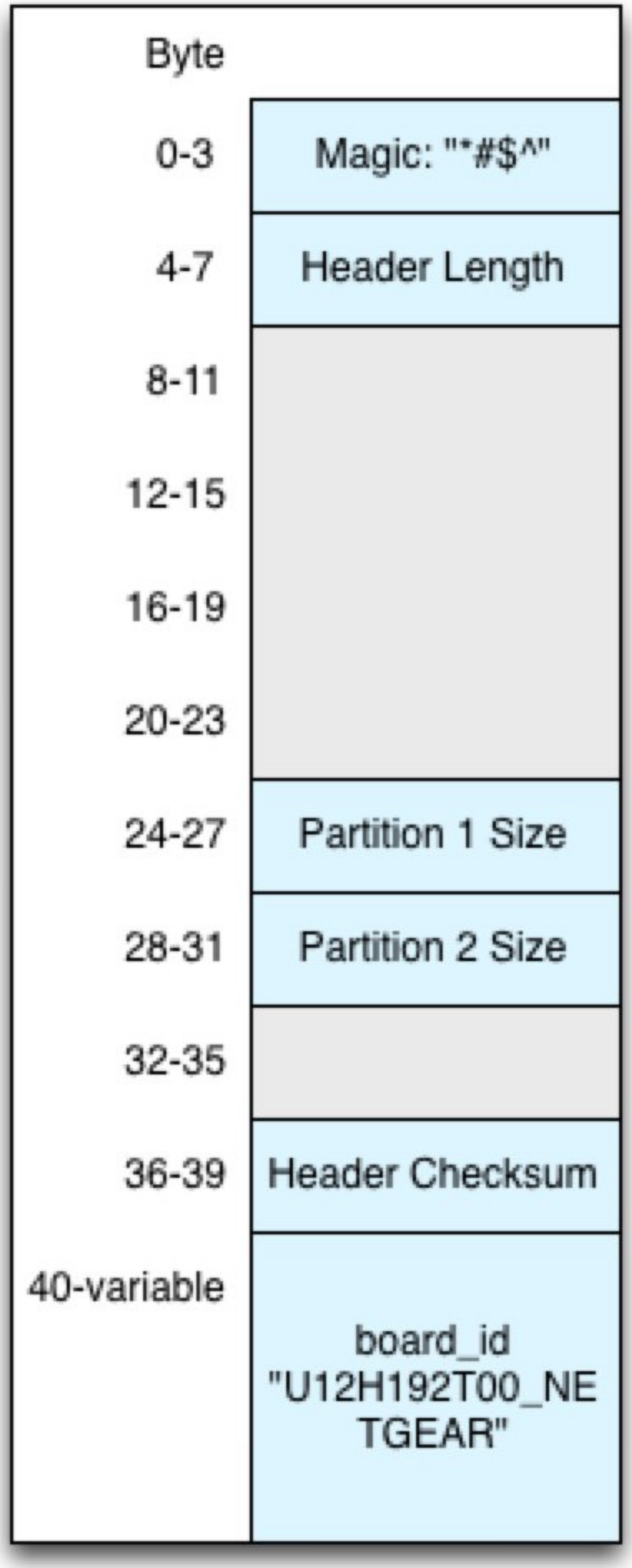
The start of firmware data is calculated.

In other words, the pointer to data that gets written is calculated as:

<Address of firmware image> + <ambit header size> + <partition 2 size> = <start of data to write>

This doesn't make sense and further belies the programmer's confusion over how this algorithm should work and how the firmware should be formatted. At any rate, if we zero out the field at byte 28, everything works fine. The address of the TRX image will be the start of data written to flash.

At this stage `upnpd` is ready to write our firmware to `/dev/mtd1`. Let's have a review of what portions of the ambit header had to be verified before getting here.


Byte
0-3
Magic: "*#$^"
4-7
Header Length
8-11
12-15
16-19
20-23
24-27
Partition 1 Size
28-31
Partition 2 Size
32-35
36-39
Header Checksum
40-variable
board_id
"U12H192T00_NE
TGEAR"

There's our familiar ambit header. It looks similar to the header diagram from our `httpd` analysis, except there's still lot of gray in there. Only six fields have been validated by `upnpd` up to this point:

- Ambit magic number
- Header length
- Header checksum
- TRX image size (partition 1, aka "kernel")
- Partition 2 size (not validated, but affects what gets written to flash)
- Board ID string

That was easier than expected. When I sent the "firmware image" generated from random data to `upnpd`, my QEMU machine rebooted. This is because after the write loop, `upnpd` triggers a reboot so the new firmware will take effect. Our fake "/dev/mtd1" has even grown to 3.9MB as a result of the firmware writing.

```
zach@devaron $ ls -l mtd1
-rw-r--r-- 1 root 80 3900028 Mar 20 14:30 mtd1
```

At this point we've successfully exploited the `SetFirmware` UPnP SOAP action. We've gone as far as we can go with emulation. From here we'll move to physical hardware to test and develop the deployment of our firmware. In the next post, I'll describe connecting to the R6200 router's debug interface over its UART connection, so get your soldering iron ready.

Spoiler: I'll go ahead and say we're not quite home free yet. Don't attempt to generate an image and flash it to your router yet. At best, the write will still fail. At worst, you'll brick it. Besides not having generated a valid squashfs filesystem and TRX image, there at least two more header fields that will trip you up before you're done. Once we get access over UART figured out, it will be possible to recover a bricked device.