Eight ou two eleven

Dynamic inspection of Broadcom Wi-Fi cards on mobile devices

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Agenda

- Overview of Broadcom Wi-Fi NiC mobile devices
  - Architecture
  - Attack surface & possibilities
- Tool:
  - Dynamic inspection.
  - Why not just make a debugger?
  - Our objective
  - Explore findings along the way.
- Usage of the tool to inspect firmware

Previous works

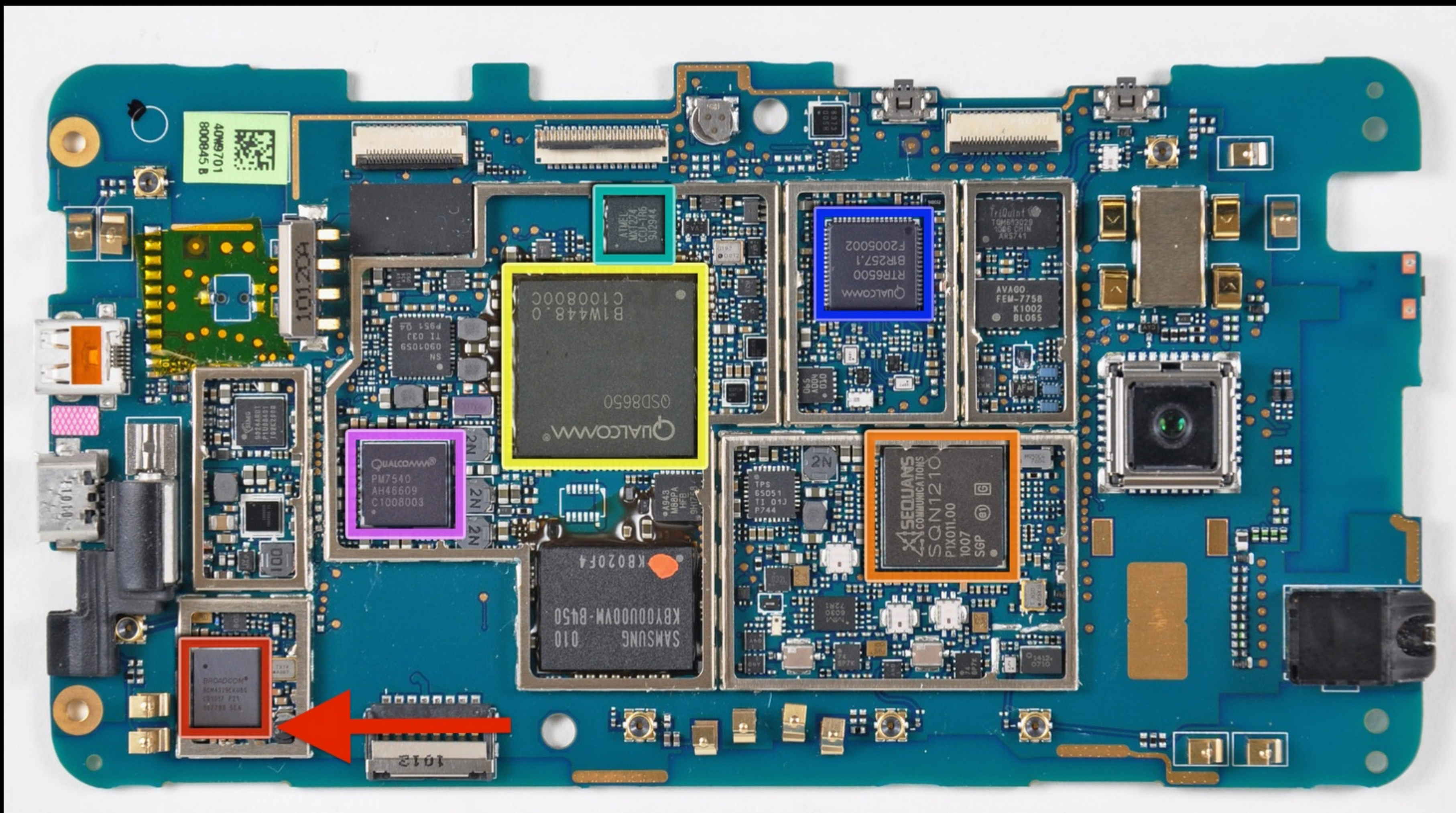
- Much has been done on network card firmware. See Triulzi[1], Delugré[2], others [3]
- Mobile devices
  - Firmware modified for monitor mode and raw injection on iOS & Android by two different teams (Andres Blanco, bcmon team)
  - Vulnerabilities discovered: CVE-2012-2619
  - Not much (*public*) research after that.

Broadcom huge WI-FI player

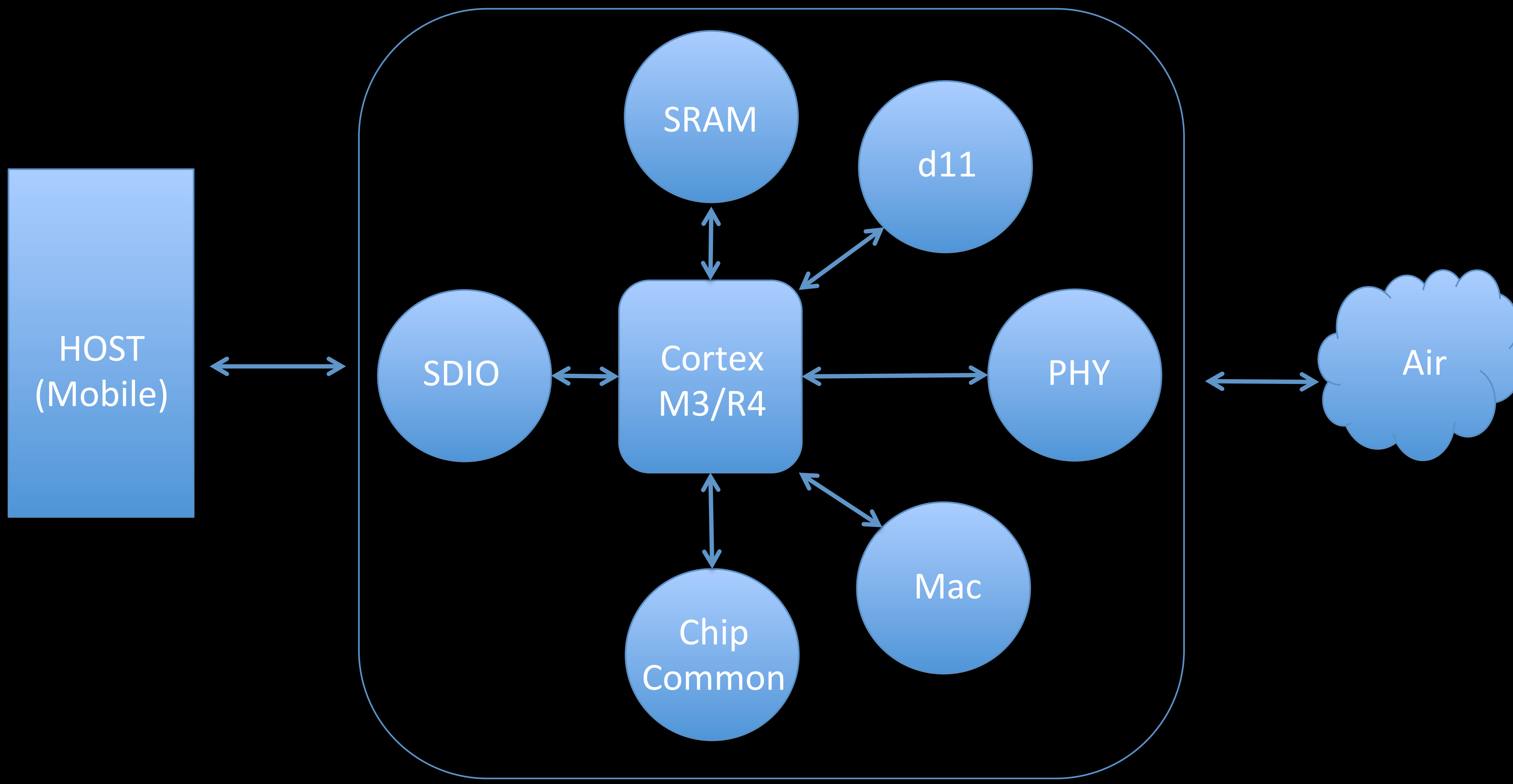
BROADCOM

Wi Fi

What do the cards look like?

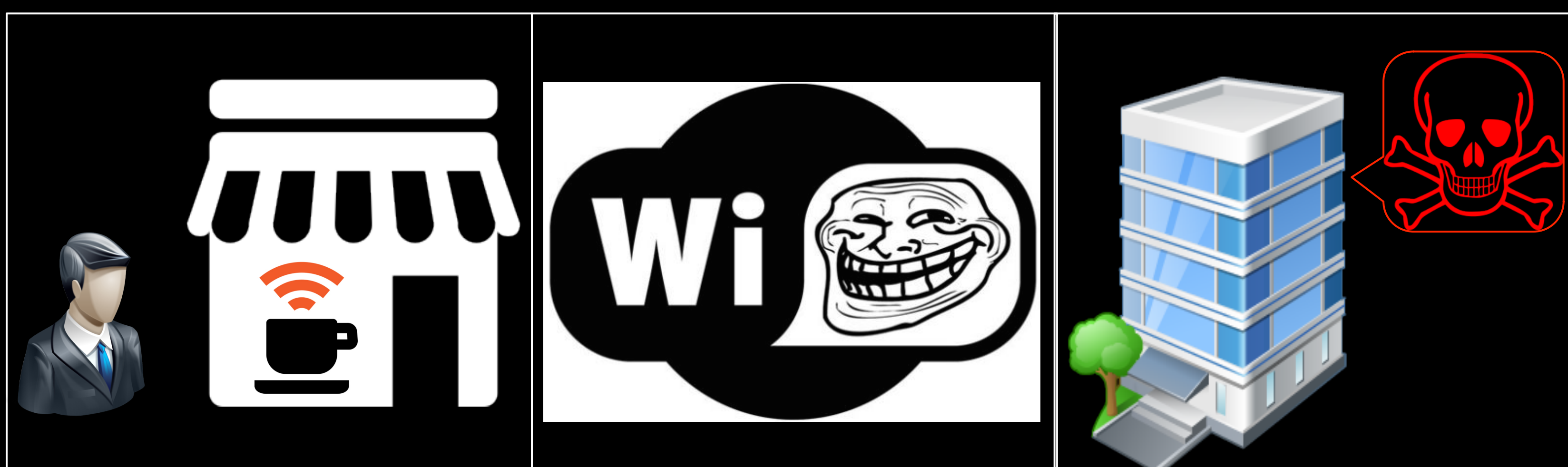


What's inside?
CPU, memory and *cores*



Attack surface & possibilities

- 802.11 implementation bug -> RCE Firmware
  - Pivot Firmware -> Driver
  - Man-in-the-middle to inject browser/app exploits
  - At least pivot to a target LAN:

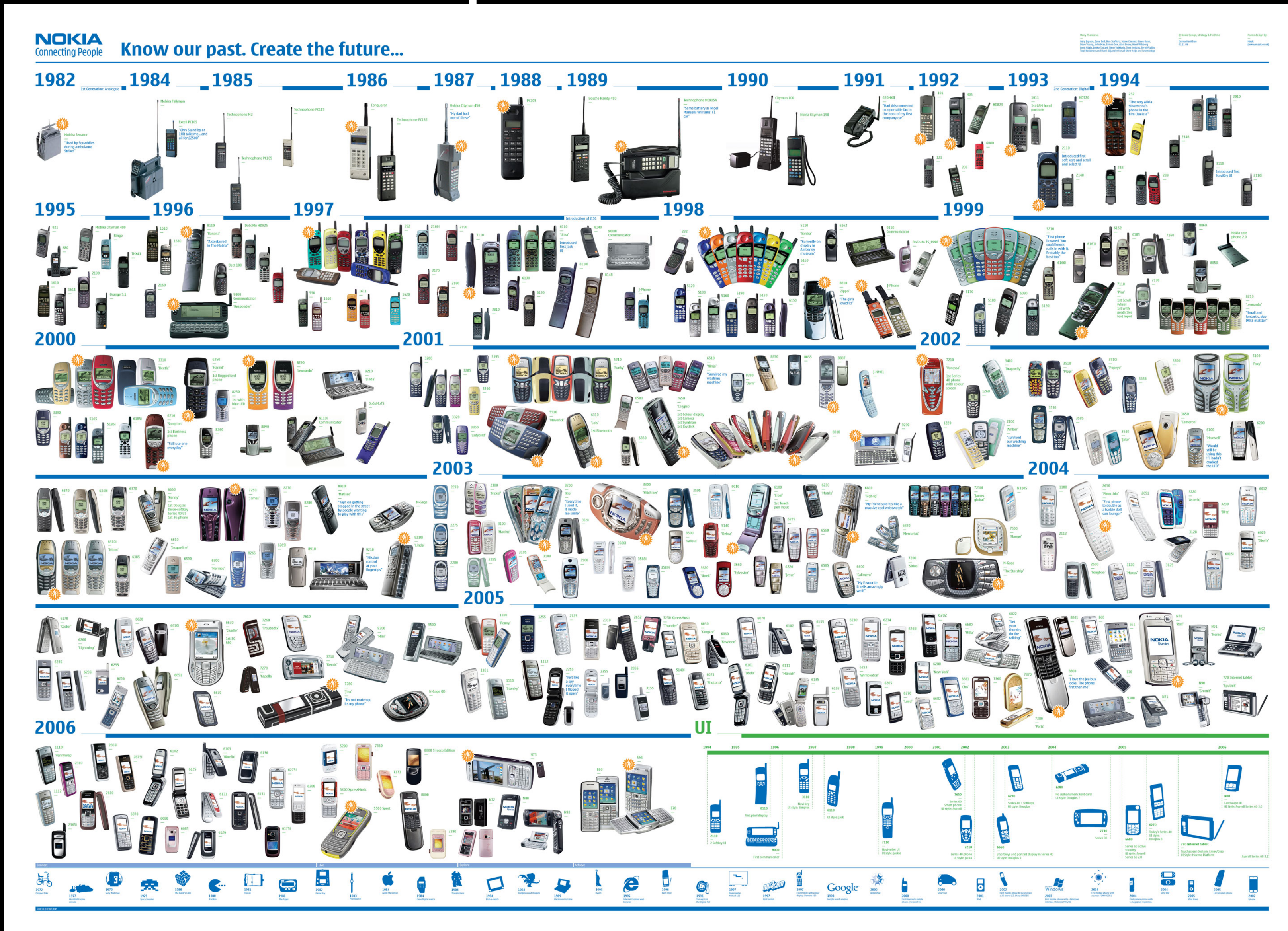


Even more surface

- Firmware supports wide range of features:
  - TCP
  - ICMP & ARP offloading
  - Firewall implementation
  - Mobile hotspot, Wi-Fi Direct, AirDrop
  - Proprietary 802.11 extensions (Broadcom/Cisco)
- We need to play more with these firmwares!

Mobile products timeline

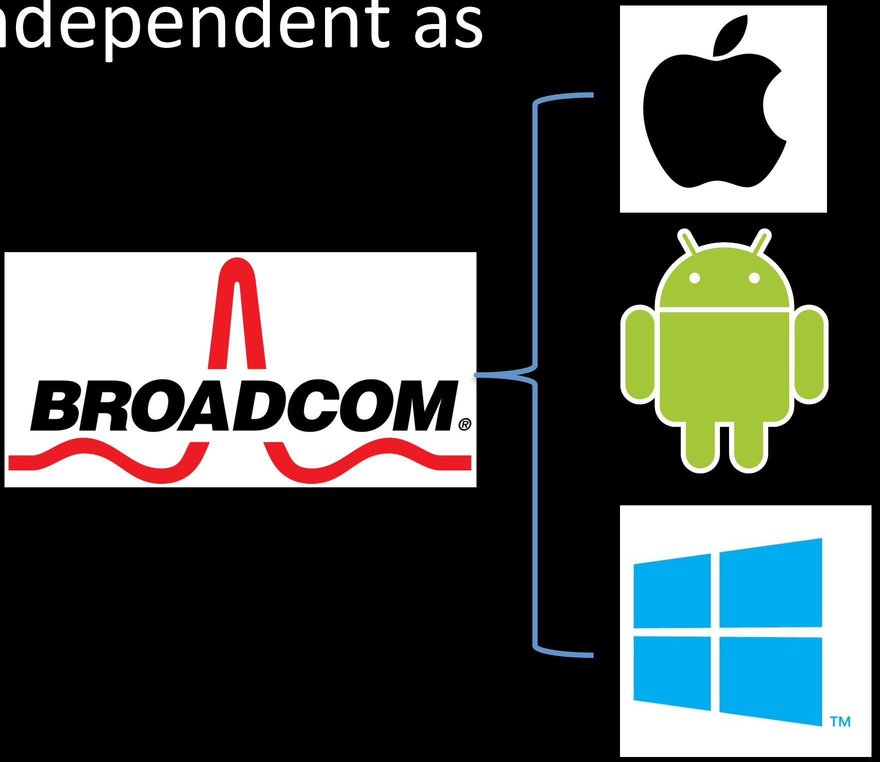
Mobile products timeline



Very soon you end up buried in a sea of devices

Objectives

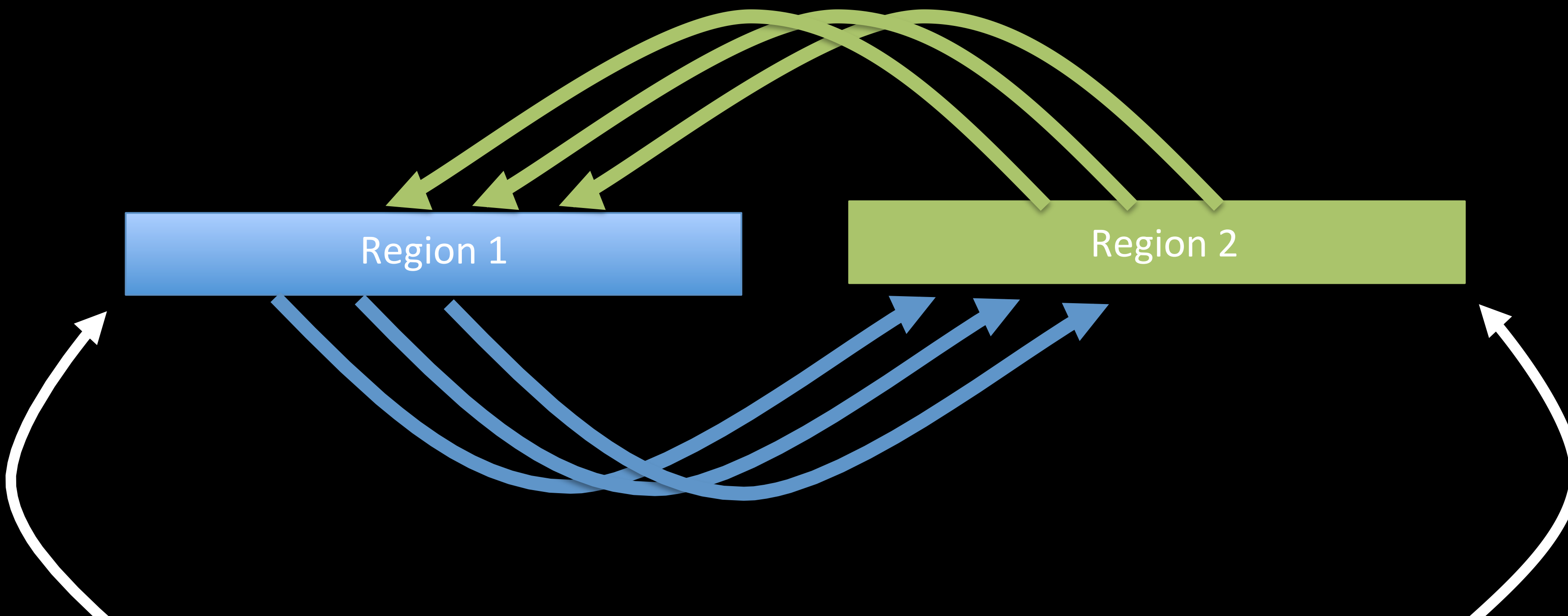
- Dynamically inspect firmware
- Be as OS/Device independent as possible



Why dynamic?

- Static inspection only gets you that far.
- Once you have all memory dumped, understanding everything from a static perspective is limited. E.g. indirect calls.
- If you manage to get a crash it is hard to understand what happened.

Firmware is Separated in two regions



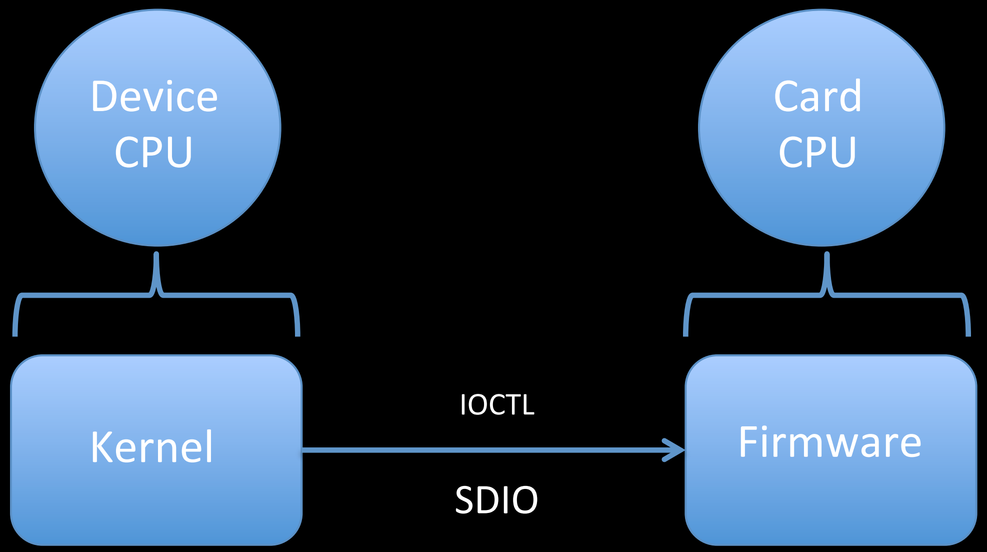
Loaded from filesystem:

Only protected by CRC
/etc/wifi/firmware
/usr/share/firmware/wifi

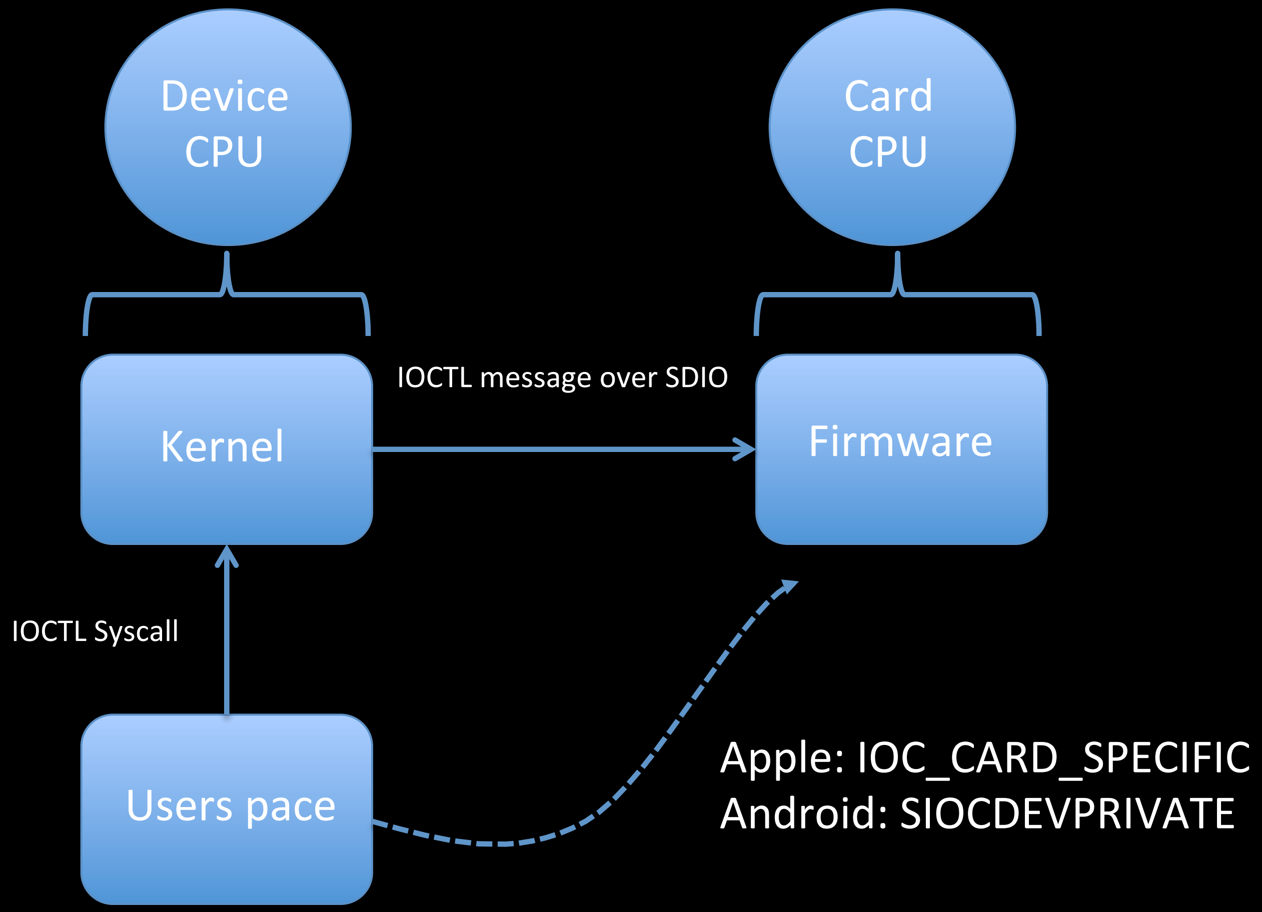
Burned into ROM:

Not initially accesible to us

Communication



Communication

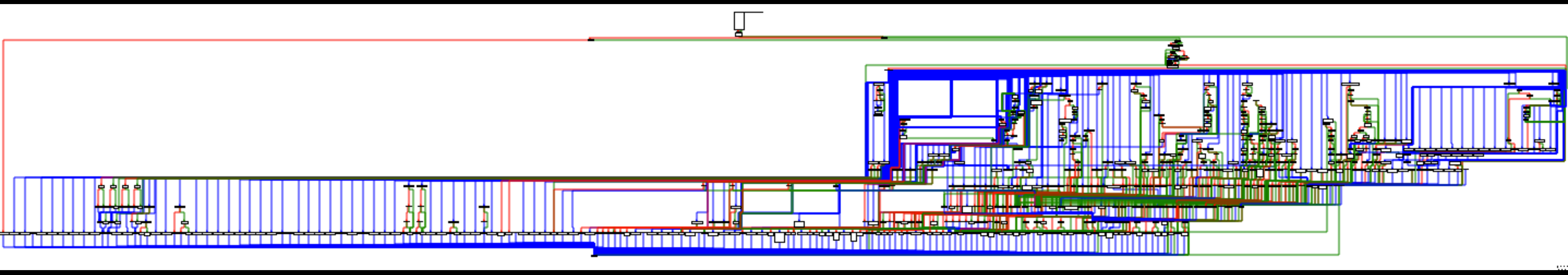


Proposed solution

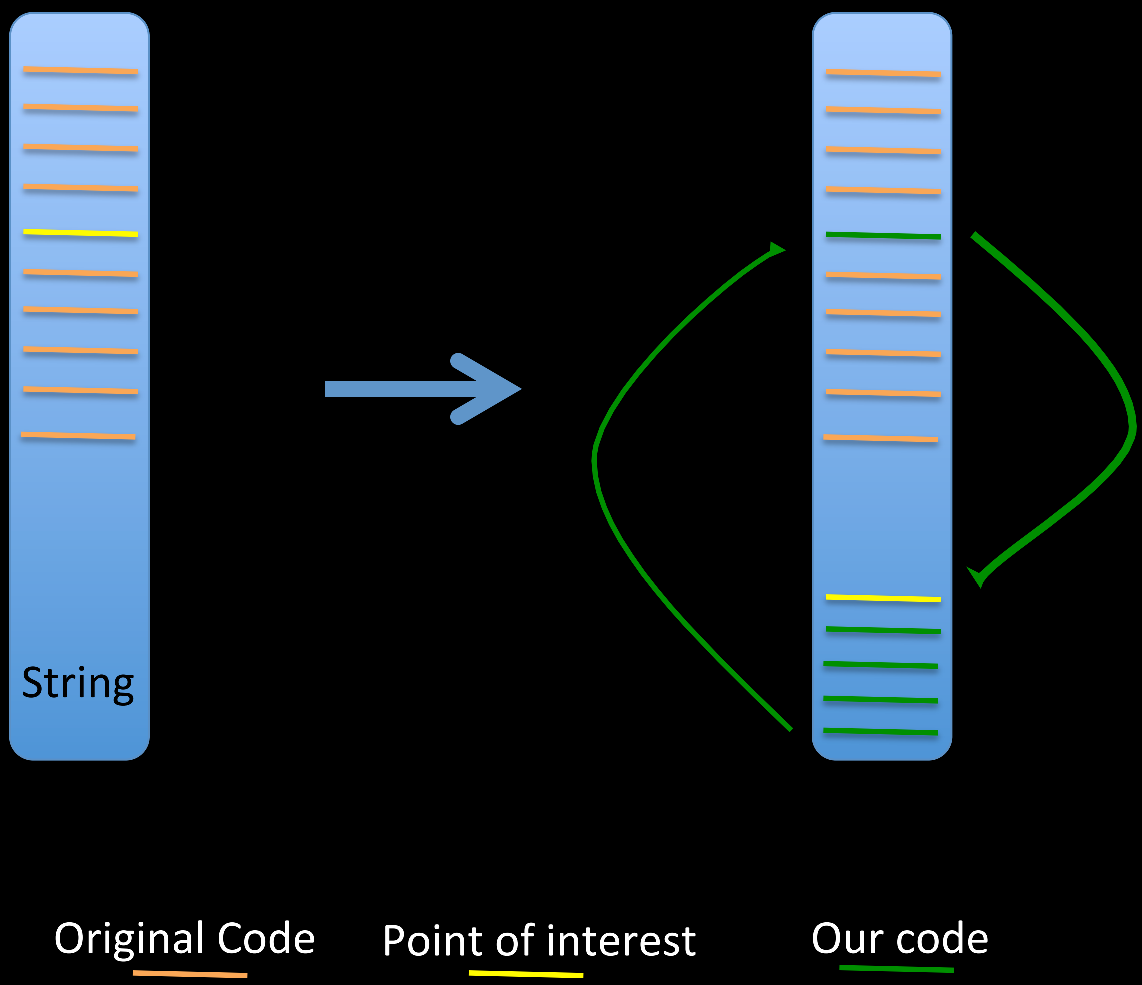
- If we modify the firmware to support to new IOCTL msgs: Read & Write.
- Send a user -> kernel IOCTL, that encapsulates a Kernel -> firmware IOCTL
- If we can do this, then we can even write python code, from userspace, that will read and write memory from the firmware!

Identifying IOCTL Handler

- Search for switch with lots of cases.
- Or search for WLC_MAGIC IOCTL=0x14e46c77
- Sometimes the handler is on Region 2… BUT if we have an earlier or different firmware we can find the caller.
- If all else fails, follow interrupt handler path



Typical hooking



Code

```
B1 F5 7A 4F                 CMP.W   R1, #0xFA00
05 D0                       BEQ     read
B1 F5 7B 4F                 CMP.W   R1, #0xFB00
06 D0                       BEQ     write
07 46                       MOV     R7, R0
0E 46                       MOV     R6, R1
70 47                       BX      LR
            ; ---------------------------------------

            read
10 46                       MOV     R0, R2
11 68                       LDR     R1, [R2]
52 68                       LDR     R2, [R2,#4]
03 E0                       B       done
            ; ---------------------------------------

            write
10 68                       LDR     R0, [R2]
12 F1 08 01                 ADDS.W  R1, R2, #8
52 68                       LDR     R2, [R2,#4]

            done
02 4B                       LDR     R3, =(memcpy+1)
98 47                       BLX     R3 ; memcpy
00 20                       MOVS    R0, #0
BD E8 FC 81                 POP.W   {R2-R8,PC}
```

R&W Little Demo

R&W Little Demo

Read & Write. Now what?

- Dump Region 2.
- At this point we can read & write to memory mapped registers
- All sort of counters, stats, even packets.
- Most importantly we can modify the code.
  - And we can do that without having to create new firmwares each time!

Handler code

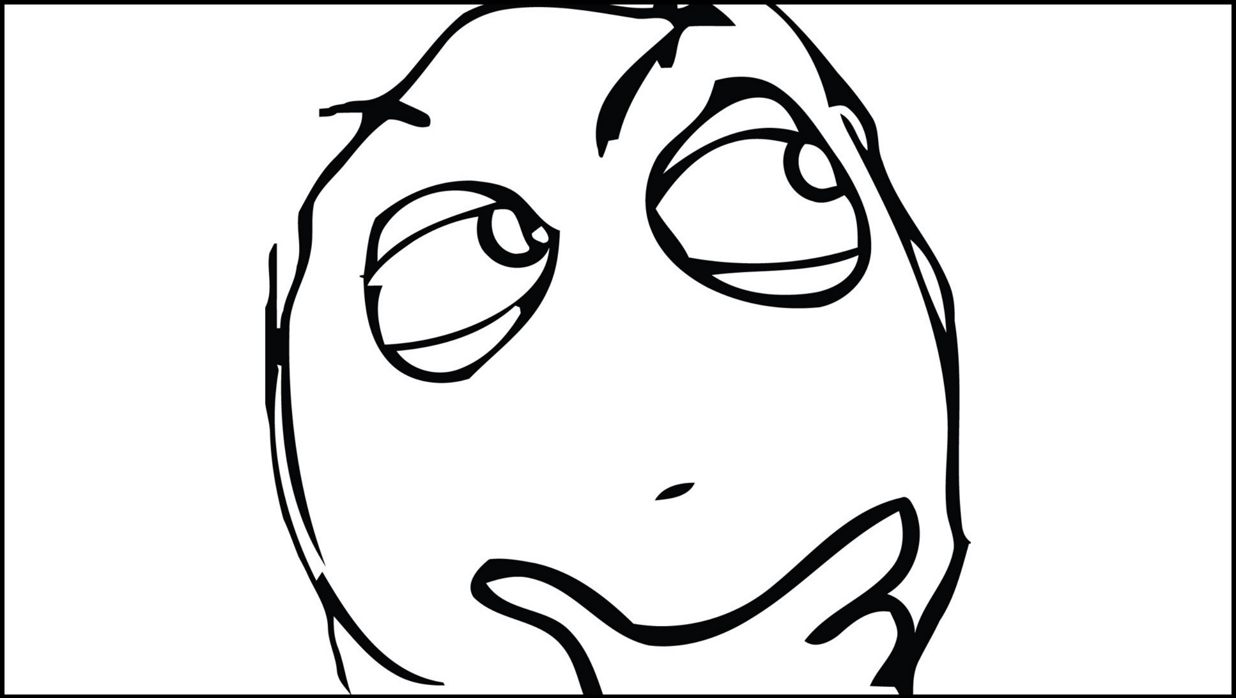
```
def createHook(self, pointCode):
    code = (
    "00BF"    #   NOP     ; placeholder to place the instructions smashed by the jmp
    "00BF"    #   NOP     ; that the tracer injected.
    "07B4"    #   PUSH    {R0-R2}
    "00BF"    #   NOP     ; placeholder to place a mov instruction with the desired register.
    "0449"    #   LDR     R1, =sub_22CA0
    "0A68"    #   LDR     R2, [R1]
    "102A"    #   CMP     R2, #0x10
    "02D0"    #   BEQ     done
    "0432"    #   ADDS    R2, #4
    "0A60"    #   STR     R2, [R1]
    "8850"    #   STR     R0, [R1,R2]
              #   done
    "07BC"    #   POP     {R0-R2}
    "7047"    #   BX      LR
    "0000"    #   align
    # "A02C0200"
    ).decode('hex')
    code += struct.pack("<L", self.DataAddr)

    code = code.replace('\x00\xbf\x00\xbf', pointCode)
    code = code.replace('\x00\xbf', self.assembleMov())
    return code
```

First Tracer

- Given an address and a register:
  - Create hook & hook handler code.
  - Clear a storage area
  - The read from storage
  - Usage as simple as:

```
t = Tracer(0x026CB4, 'R3')
t.hook()
try:
    while True:
        print t.traces()
        time.sleep(1)
except:
    t.unhook()
```

What about region 2?

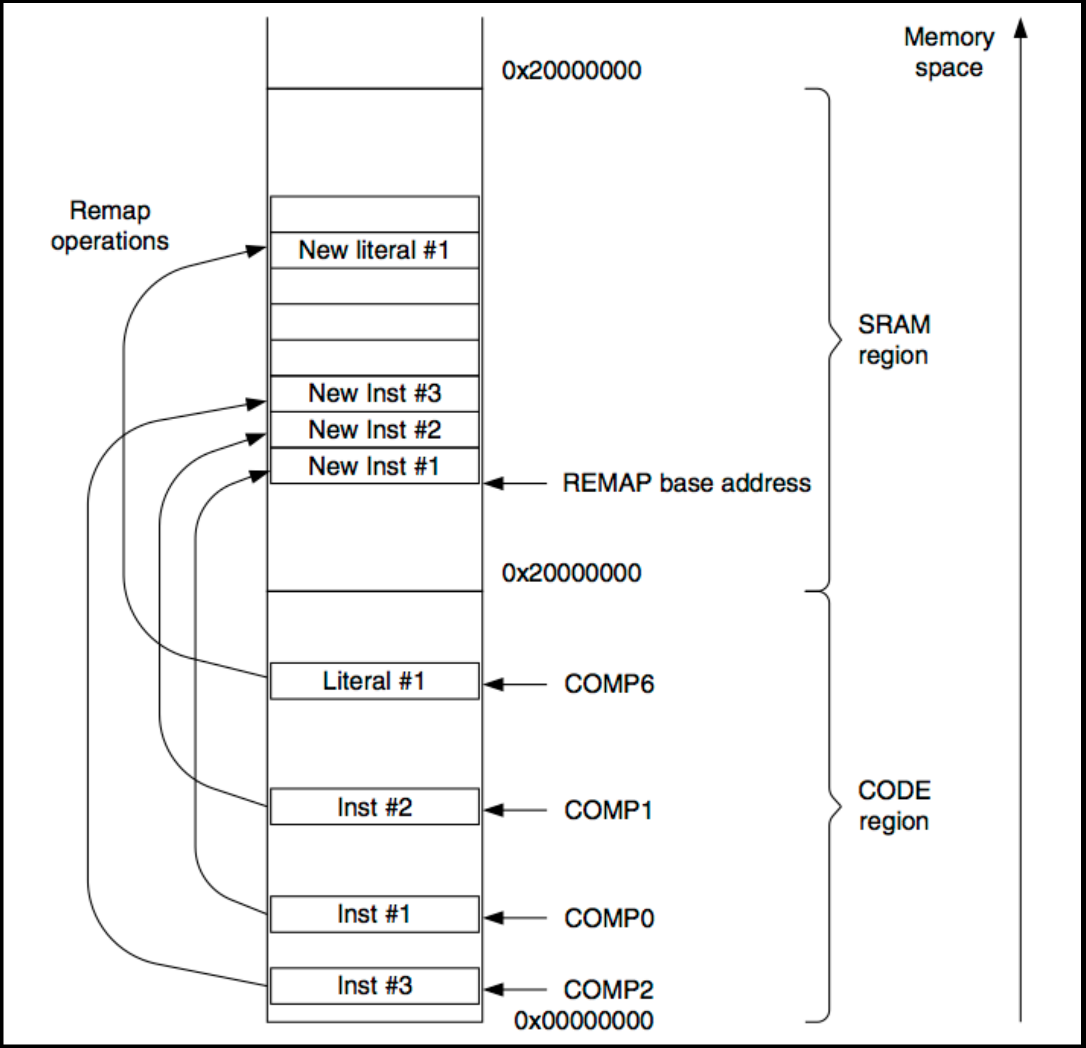


What about region 2?

- Enter flash patch
  - Set up a remap table
  - Comparators
  - Enable FPB through a control register.

- Basically, it is like we are setting up the MMU to modify instructions on fetch.

Flash patch operation diagram



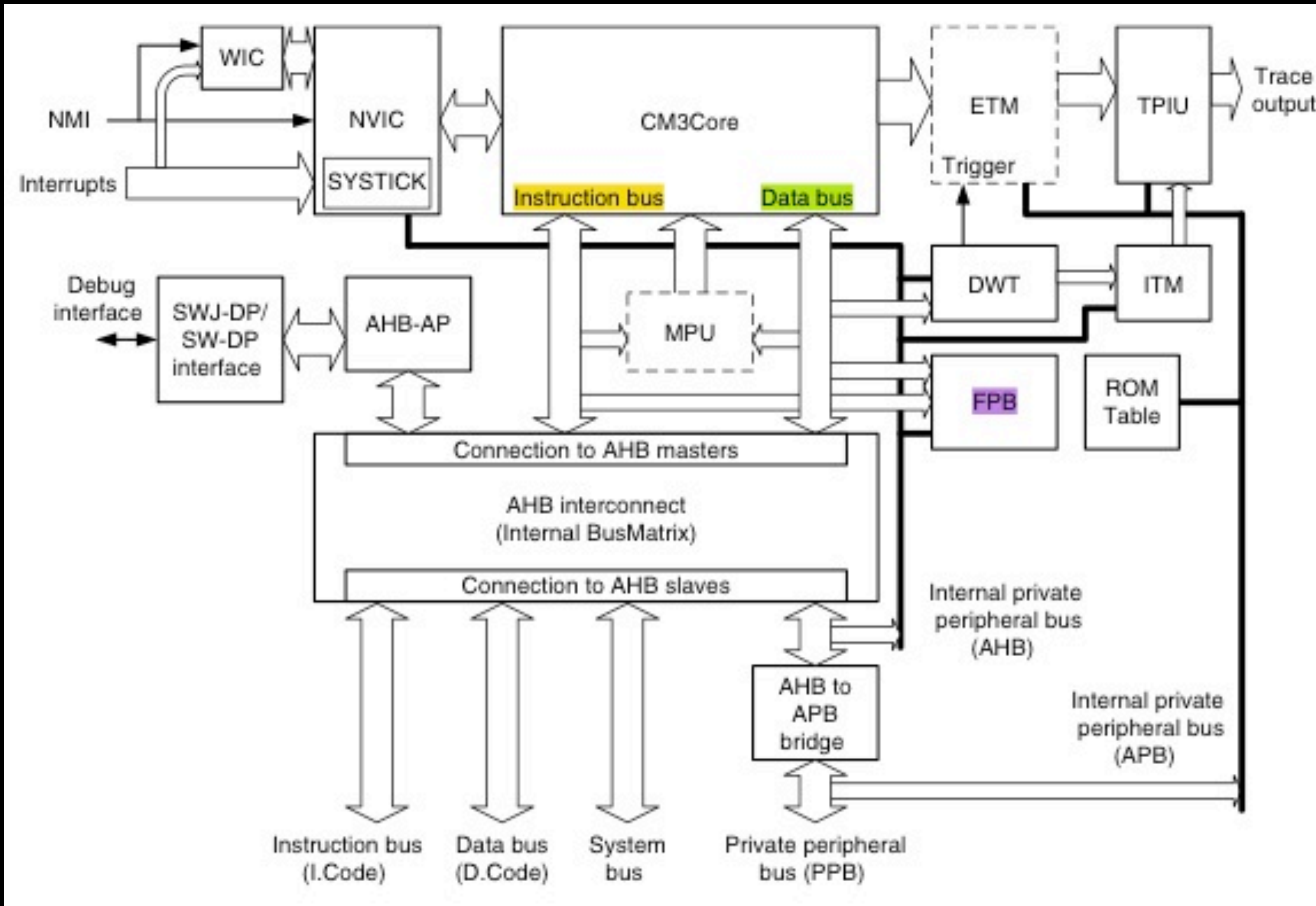
Tracer again

- Setup Hook handler as before and then:
  - Write remap table in memory
  - Setup comparators
  - Enable FPB
  - Houston: we have tracepoints (kindda).

Wait a minute!

- Basically, it is like we are setting up the MMU to modify instructions on fetch.

How does it work?



Non-persistent rootkit?

- Scenario:
  - Compromised device.
  - Modifies Region 1 file on disk.
  - Loads into the card.
  - Restores Region 1 file.
  - Exfiltrate traffic or pivot through another network, side-channel, etc.

Want even more stealth?

- Make it so that even if someone can read the firmware live from the card memory. It cant!
- Setup remap table so that malicious code is hidden.
- What about the remap table? No problem! Remapping the remap table works!

100% Stealth?

- Answer is no:
  - Can't remap control or comparator registers.
  - Have a limited number of comparator and remap entries.
  - If remap control register is disabled the whole deception falls.

- Still more work to discover hidden code.

Back to our tool

- Brief 802.11 review:
  - 3 Types of frames:
    - Data
    - Management
    - Control
  - Mgmt frames contain Information Elements

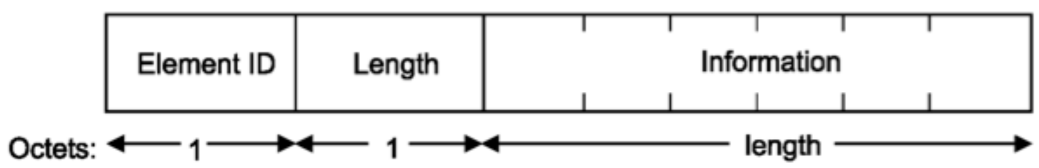
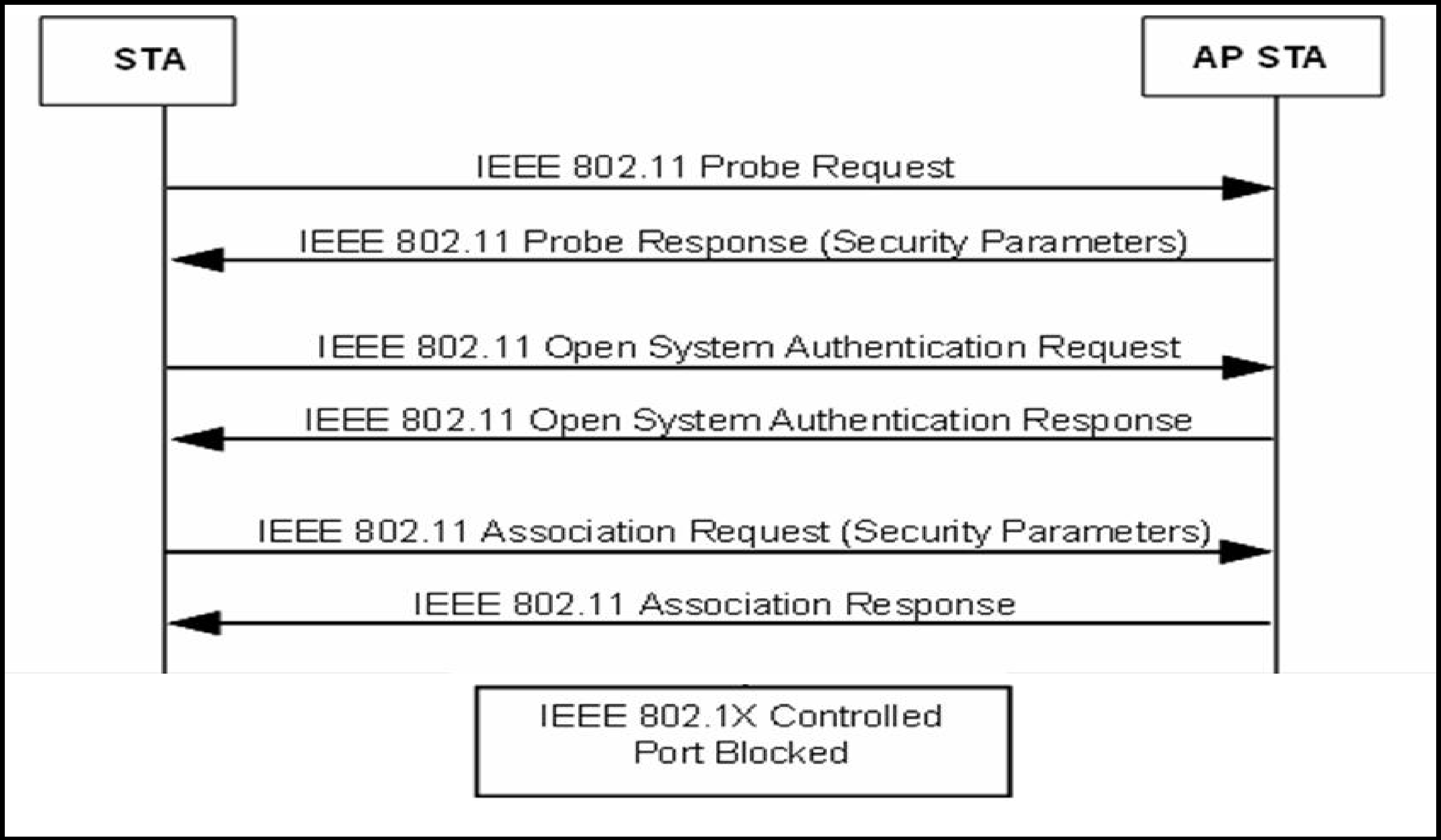


Figure 7-37—Element format

Usual association process (management frames)



Association response

```
▷ IEEE 802.11 Association Response, Flags: ........C
▽ IEEE 802.11 wireless LAN management frame
  ▷ Fixed parameters (6 bytes)
  ▽ Tagged parameters (151 bytes)
    ▷ Tag: Supported Rates 1(B), 2(B), 5.5(B), 11(B), 9, 18, 36, 54, [Mbit/sec]
    ▽ Tag: Vendor Specific: Microsof: WMM/WME: Parameter Element
        Tag Number: Vendor Specific (221)
        Tag length: 24
        OUI: 00-50-f2 (Microsof)
        Vendor Specific OUI Type: 2
        Type: WMM/WME (0x02)
        WME Subtype: Parameter Element (1)
        WME Version: 1
      ▷ WME QoS Info: 0x00
        Reserved: 00
      ▷ Ac Parameters ACI 0 (Best Effort), ACM no , AIFSN 3, ECWmin 4 ,ECWmax 10, TXOP 0
      ▷ Ac Parameters ACI 1 (Background), ACM no , AIFSN 7, ECWmin 4 ,ECWmax 10, TXOP 0
      ▷ Ac Parameters ACI 2 (Video), ACM no , AIFSN 2, ECWmin 3 ,ECWmax 4, TXOP 94
      ▷ Ac Parameters ACI 3 (Voice), ACM no , AIFSN 2, ECWmin 2 ,ECWmax 3, TXOP 47
```

Code processing association response

```
00026C9E D5 F8 18 33          LDR.W    R3, [R5,#0x318]
00026CA2 72 68                LDR      R2, [R6,#4]
00026CA4 D5 F8 7C C5          LDR.W    R12, [R5,#0x57C]
00026CA8 06 93                STR      R3, [SP,#0x58+var_40]
00026CAA 42 F0 40 02          ORR.W    R2, R2, #0x40
00026CAE 0A 9B                LDR      R3, [SP,#0x58+var_30]
00026CB0 72 60                STR      R2, [R6,#4]
00026CB2 5A 78                LDRB     R2, [R3,#1]
00026CB4 0C F1 0E 00          ADD.W    R0, R12, #0xE
00026CB8 99 1C                ADDS     R1, R3, #2
00026CBA CD F8 20 C0          STR.W    R12, [SP,#0x58+var_38]
00026CBE E5 F3 AD F3          BL.W     memcpy
00026CC2 DD F8 20 C0          LDR.W    R12, [SP,#0x58+var_38]
00026CC6 9C F9 14 20          LDRSB.W  R2, [R12,#0x14]
00026CCA 00 2A                CMP      R2, #0
00026CCC 07 DA                BGE      loc_26CDE
```

Hook trace demo

THANKS!