Embedded Devices Security
Firmware Reverse Engineering

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Administratrivia

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About – EURECOM

HIGH LEVEL RESEARCH

€11.3 m

Global budget with a project turnover of

€5.3m

283

International scientific publications

121 cosigned with foreign institutions

A 9,2% increase compared to 2011.

18

Average H-Number

EURECOM is a
Carnot Institute since 2006

INSTITUT CARNOT TELECOM-EURECOM

104

Contracts managed in 2012 including

- 31 European contracts
- 42 National contracts
- 40 Industrial contracts

About – EURECOM

Table: Eurecom Research Results – Publications

Year	Total No. of publ.	Cosigned with Ext. Labs	Cosigned with Intl. Labs	Conf.	Journals/Papers	Books/Chapters	Scientific Reports	Patents	H-number/Avg. Top 10
2012	276	152	113	173	45	3	17	1	18,00 / 26,20
2011	240	156	108	160	35	19	14	0	16,00 / 23,40
2010	267	141	100	179	39	10	15	0	15,04 / 22,60

Introduction

Introduction

Workshop Roadmap

- 1st part (14:15 – 15:15)
    - Little bit of theory
    - Overview of state of the art
- 2nd part (15:30 – 16:30)
    - Encountered formats, tools
    - Unpacking end-to-end
- 3rd part (17:00 – 18:00)
    - Emulation introduction
    - Awesome exercises – find your own 0day!

What is a Firmware? (Ascher Opler)

- Ascher Opler coined the term "firmware" in a 1967 Datamation article
- Currently, in short: it's the set of software that makes an embedded system functional

What is firmware? (IEEE)

- IEEE Standard Glossary of Software Engineering Terminology, Std 610.12-1990, defines firmware as follows:
- "The combination of a hardware device and computer instructions and data that reside as read-only software on that device.
- Notes: (1) This term is sometimes used to refer only to the hardware device or only to the computer instructions or data, but these meanings are deprecated.
- Notes: (2) The confusion surrounding this term has led some to suggest that it be avoided altogether"

Common Embedded Device Classes

- Networking – Routers, Switches, NAS, VoIP phones
- Surveillance – Alarms, Cameras, CCTV, DVRs, NVRs
- Industry Automation – PLCs, Power Plants, Industrial Process Monitoring and Automation
- Home Automation – Sensoring, Smart Homes, Z-Waves, Philips Hue
- Whiteware – Washing Machine, Fridge, Dryer
- Entertainment gear – TV, DVRs, Receiver, Stereo, Game Console, MP3 Player, Camera, Mobile Phone, Toys
- Other Devices - Hard Drives, Printers
- Cars
- Medical Devices

Common Processor Architectures

- ARM (ARM7, ARM9, Cortex)
- Intel ATOM
- MIPS
- 8051
- Atmel AVR
- Motorola 6800/68000 (68k)
- Ambarella
- Axis CRIS

Common Buses

- Serial buses - SPI, I2C, 1-Wire, UART
- PCI, PCIExpress
- AMBA

Common Communication Lines

- Ethernet - RJ45
- RS485
- CAN/FlexRay
- Bluetooth
- WIFI
- Infrared
- Zigbee
- Other radios (ISM-Band, etc/)
- GPRS/UMTS
- USB

Common Directly Addressable Memory

- DRAM
- SRAM
- ROM
- Memory-Mapped NOR Flash

Common Storage

- NAND Flash
- SD Card
- Hard Drive

Common Operating Systems

- Linux
  - Perhaps most favourite and most encoutered
- VxWorks
- Cisco IOS
- Windows CE/NT
- L4
- eCos
- DOS
- Symbian
- JunOS
- Ambarella
- etc.

Common Bootloaders

- U-Boot
  - Perhaps most favourite and most encoutered
- RedBoot
- BareBox
- Ubicom bootloader

Common Libraries and Dev Envs

- busybox + uClibc
  - Perhaps most favourite and most encoutered
- buildroot
- openembedded
- crosstool
- crossdev

What Challenges Do Firmwares Bring?

- Non-standard formats
- Encrypted chunks
- Non-standard update channels
  - Firmwares come and go, vendors quickly withdraw them from support/ftp sites
- Non-standard update procedures
  - Printer's updates via vendor-specific PJL hacks
  - Gazillion of other hacks

Updating to a New Firmware

- Firmware Update built-in functionality
  - Web-based upload
  - Socket-based upload
  - USB-based upload
- Firmware Update function in the bootloader
- USB-boot recovery
- Rescue partition, e.g.:
  - New firmware is written to a safe space and integrity-checked before it is activated
  - Old firmware is not overwritten before new one is active
- JTAG/ISP/Parallel programming

Updating to a New Firmware – Pitfalls

- TOCTOU attacks
- Non-mutual-authenticating update protocols
- Non-signed packages
- Non-verified signatures
- Incorectly/inconsistently verified signatures
- Leaking signature keys

Why Are Most Firmwares Outdated?

Vendor-view

- Profit and fast time-to-market first
  - Support and security comes (if at all!) as an after-thought
- Great platform variety raises compilation and maintenance effort
- Verification process is cumbersome, takes a lot of time and effort
  - E.g. for medical devices depends on national standards which require strict verification procedure, sometimes even by the state.

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Why Are Most Firmwares Outdated?

Customer-view

- *"If it works, don't touch it!"*
- High effort for customers to install firmwares
- High probability something goes wrong during firmware upgrades
- "Where do I put this upgrade CD into a printer – it has no keyboard nor a monitor nor an optical drive?!"

Firmware Formats

Firmware Formats

Firmware Formats – Typical Objects Inside

- Bootloader (1st/2nd stage)
- Kernel
- File-system images
- User-land binaries
- Resources and support files
- Web-server/web-interface

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Firmware Formats – Components Category View

- Full-blown (full-OS/kernel + bootloader + libs + apps)
- Integrated (apps + OS-as-a-lib)
- Partial updates (apps or libs or resources or support)

Firmware Formats – Packing Category View

- Pure archives (CPIO/Ar/Tar/GZip/BZip/LZxxx/RPM)
- Pure filesystems (YAFFS, JFFS2, extNfs)
- Pure binary formats (SREC, iHEX, ELF)
- Hybrids (any breed of above)

Firmware Formats – Flavors

- Ar
- YAFFS
- JFFS2
- SquashFS
- CramFS
- ROMFS
- UbiFS
- xFAT
- NTFS
- extNfs
- iHEX
- SREC/S19
- PJL
- CPIO/Ar/Tar/GZip/BZip/LZxxx/RPM

Firmware Analysis

Firmware Analysis

Firmware Analysis – Overview

- Get the firmware
- Reconnaissance
- Unpacking
- Reuse engineering (check code.google.com and sourceforge.net)
- Localize point of interest
- Decompile/compile/tweak/fuzz/pentest/fun!

Firmware Analysis – Getting the Firmware

Many times not as easy as it sounds! In order of increasing complexity of getting the firmware image

- Present on the product CD/DVD
- Download from manufacturer FTP/HTTP site
- Many times need to register for manufacturer spam :(
- Google Dorks
- FTP index sites (mmnt.net, ftpfiles.net)
- Wireshark traces (manufacturer firmware download tool or device communication itself)
- Device memory dump

Firmware Analysis – Reconnaissance

- strings on the firmware image/blob
  - Fuzzy string matching on a wide embedded product DB
- Find and read the specs and datasheets of device

Firmware Analysis – Unpacking

- Did anyone pay attention to the previous section?!

Unpacking firmware from SREC/iHEX files

SREC and iHEX are much simpler binary file formats than elf - in a nutshell, they just store memory addresses and data (Altough it is possible to specify more information, it is optional and in most cases missing).
Those files can be transformed to elf with the command

```
objcopy -I ihex -O elf32-little <input> <output>
objcopy -I srec -O elf32-little <input> <output>
```

Of course information like processor architecture, entry point and symbols are still missing, as they are not part of the original files. You will later see some tricks how to guess that information.

Firmware Emulation

Firmware Emulation

Firmware Emulation – Prerequisites

- Kernel image with a superset of kernel modules
- QEMU compiled with embedded device CPU support (e.g. ARM, MIPS)
- Firmware – most usually split into smaller parts/FS-images which do not break QEMU

Debugging Embedded Systems

- JTAG
- Software debugger (e.g. GNU stub or ARM Angel Debug monitor)
- OS debug capabilities (e.g. KDB/KGDB)

Developing for Embedded Systems

- GCC/Binutils toolchain
- Cross-compilers
- Proprietary compiler
- Building the image

Firmware Exercise

Firmware Exercise

Reversing a Seagate HDD's firmware file format

Task:

- Assuming you already have a memory dump of a similar firmware available
- Reverse-engineer the firmware file format
- Get help from the assembler code from the firmware update routine contained in the firmware

Obtaining a memory dump

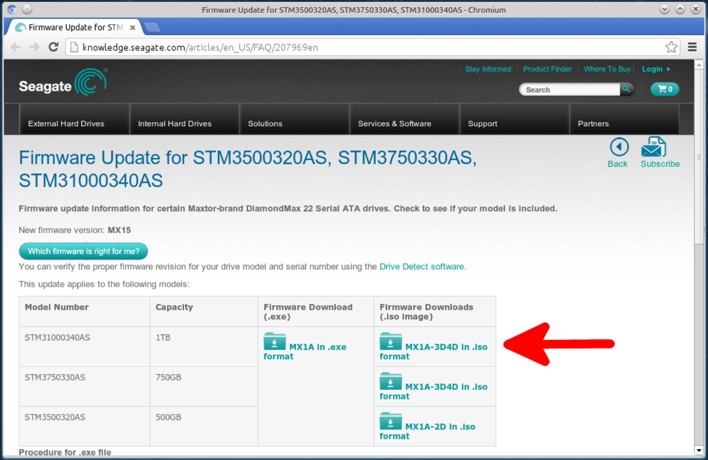
- Seagate's hard drives have a serial test console
- Can be accessed with a TTL (1.8V) → to UART converter cable
- The console menu (reachable via ˆZ) has an online help:

```
All Levels CR: Rev 0011.0000, Flash,   Abort
All Levels '/': Rev 0001.0000, Flash,   Change Diagnostic Command Level, /[Level]
All Levels '+': Rev 0012.0000, Flash,   Peek Memory Byte, +[AddrHi],[AddrLo],[NotUsed],[NumByt
All Levels '-': Rev 0012.0000, Flash,   Peek Memory Word, -[AddrHi],[AddrLo],[NotUsed],[NumByt
All Levels '=': Rev 0011.0002, Flash,   Poke Memory Byte, =[AddrHi],[AddrLo],[Data],[Opts]
All Levels '@': Rev 0001.0000, Overlay, Batch File Label, @[LabelNum]
All Levels '|': Rev 0001.0000, Overlay, Batch File Terminator, |
```

Obtaining a memory dump

- The Peek commands provide exactly what is needed
- One small BUT – the HDD crashes when an invalid address is specified :(
- After probing the address ranges, a python script easily dumps the memory ranges

Obtaining the firmware



Unpacking the firmware

A quite stupid and boring mechanic task:

```
$ 7z x MooseDT-MX1A-3D4D-DMax22.iso -oimage
$ cd image
$ ls
[BOOT]  DriveDetect.exe  FreeDOS  README.txt
$ cd \[BOOT\]/
$ ls
Bootable_1.44M.img
$ file Bootable_1.44M.img
Bootable_1.44M.img: DOS floppy 1440k,
x86 hard disk boot sector
```

Unpacking the firmware

```
$ mount -o loop Bootable_1.44M.img /mnt
$ mkdir disk
$ cp -r /mnt/* disk/
$ cd disk
$ ls
AUTOEXEC.BAT  COMMAND.COM  CONFIG.SYS  HIMEM.EXE
KERNEL.SYS  MX1A3D4D.ZIP  RDISK.EXE  TDSK.EXE
unzip.exe
$ mkdir archive
$ cd archive
$ unzip ../MX1A3D4D.ZIP
$ ls
6_8hmx1a.txs  CHOICE.EXE  FDAPM.COM  fdl464.exe
flash.bat  LIST.COM  MX1A4d.lod  README.TXT
seaenum.exe
```

Unpacking the firmware

```
$ file *
6_8hmx1a.txs: ASCII text, with CRLF line terminators
CHOICE.EXE:   MS-DOS executable, MZ for MS-DOS
FDAPM.COM:    FREE-DOS executable (COM), UPX compressed
fdl464.exe:   MS-DOS executable, COFF for MS-DOS,
              DJGPP go32 DOS extender, UPX compressed
flash.bat:    DOS batch file, ASCII text, with CRLF
              line terminators
LIST.COM:     DOS executable (COM)
MX1A4d.lod:   data
README.TXT:   ASCII English text, with CRLF line
              terminators
seaenum.exe:  MS-DOS executable, COFF for MS-DOS,
              DJGPP go32 DOS extender, UPX compressed
```

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Unpacking the firmware

```
$ less flash.bat
set exe=fdl464.exe
set family=Moose
set model1=MAXTOR STM3750330AS
set model2=MAXTOR STM31000340AS
rem set model3=
rem set firmware=MX1A4d.lodd
set cfgfile=6_8hmx1a.txs
set options=-s -x -b -v -a 20
...
:SEAFLASH1
%exe% -m %family% %options% -h %cfgfile%
if errorlevel 2 goto WRONGMODEL1
if errorlevel 1 goto ERROR
goto DONE
```

Unpacking the firmware (Summary)

- We have unpacked the various wrappers, layers, archives and filesystems of the firmware
  - ISO $\rightarrow$ DOS IMG $\rightarrow$ ZIP $\rightarrow$ LOD
- The firmware is flashed on the HDD in a DOS environment (FreeDOS)
- The update is run by executing a DOS batch file (flash.bat)
- There are
  - a firmware flash tool (fdl464.exe)
  - a configuration for that tool (6_8hmx1a.txs, encrypted or obfuscated/encoded)
  - the actual firmware (MX1A4d.lod)
- The firmware file is not in a binary format known to file and magic tools

$\rightarrow$ Let's have a look at the firmware file!

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Inspecting the firmware file: hexdump

```
$ hexdump -C MX1A4d.lod
00000000  00 00 00 00 00 00 00 00  00 00 00 00 00 00 07 00  |................|
00000010  80 01 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
00000020  00 00 00 00 00 22 00 00  00 00 00 00 00 00 00 00  |....."..........|
00000030  00 00 00 00 00 00 00 00  00 00 00 00 00 00 79 dc  |..............y.|
00000040  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
*
000001c0  0e 10 14 13 02 00 03 10  00 00 00 00 ff 10 41 00  |..............A.|
000001d0  00 20 00 00 ad 03 2d 00  13 11 15 16 11 13 07 20  |. ....-........ |
000001e0  00 00 00 00 40 20 00 00  00 00 00 00 00 00 00 00  |....@ ..........|
000001f0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 3f 1d  |..............?.|
00000200  00 c0 49 00 00 00 2d 00  10 b5 27 48 40 68 41 42  |..I...-...'H@hAB|
00000210  26 48 00 f0 78 ee 10 bd  10 b5 04 1c ff f7 f4 ff  |&H..x...........|
00000220  a0 42 03 d2 22 49 40 18  00 1b 10 bd 00 1b 10 bd  |.B.."I@.........|
00000230  1d 48 40 68 40 42 70 47  10 b5 01 1c ff f7 f8 ff  |.H@h@BpG........|
00000240  41 1a 0f 20 00 f0 5e ee  10 bd 7c b5 04 1c 20 1c  |A.. ..^...|... .|
00000250  00 21 00 90 17 a0 01 91  0c c8 00 98 00 f0 f2 ed  |.!..............|
00000260  01 da 00 f0 ed ff ff f7  cf ff 05 1c 28 1c ff f7  |............(...|
00000270  d3 ff a0 42 fa d3 7c bd  7c b5 04 1c 20 01 00 1b  |...B..|.|... ...|
00000280  00 21 00 90 0b a0 01 91  0c c8 00 98 00 f0 da ed  |.!..............|
...
```

→ The header did not look familiar to me :(

Inspecting the firmware file: strings

```
$ strings MX1A4d.lod
...
XlatePhySec, h[Sec],[NumSecs]
XlatePhySec, p[Sec],[NumSecs]
XlatePlpChs, d[Cyl],[Hd],[Sec],[NumSecs]
XlatePlpChw, f[Cyl],[Hd],[Wdg],[NumWdgs]
XlateSfi, D[PhyCyl],[Hd],[Sfi],[NumSfis]
XlateWedge, t[Wdg],[NumWdgs]
ChannelTemperatureAdj, U[TweakTemperature],[Partition],[Hd],[Zone],[Opts]
WrChs, W[Sec],[NumSecs],,[PhyOpt],[Opts]
EnableDisableWrFault, u[Op]
WrLba, W[Lba],[NumLbas],,[Opts]
WrLongOrSystemChs, w[LongSec],[LongSecsOrSysSec],[SysSecs],[LongPhySecOpt],,[SysOpts]
RwPowerAsicReg, V[RegAddr],[RegValue],[WrOpt]
WrPeripheralReg, s[OpType],[RegAddr],[RegValue],[RegMask],[RegPagAddr]
WrPeripheralReg, t[OpType],[RegAddr],[RegValue],[RegMask],[RegPagAddr]
...
```

→ Strings are visible, meaning the program is neither encrypted nor compressed

→ We actually know these strings ... they are from the diagnostic menu's help!

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Inspecting the firmware file: binwalk

```
$ binwalk MX1A4d.lod

DECIMAL         HEX             DESCRIPTION
-------------------------------------------------------------------------
499792          0x7A050         Zip archive data, compressed size: 48028,
                                uncompressed size: 785886, name: ""

$ dd if=MX1A4d.lod of=/tmp/bla.bin bs=1 skip=499792
$ unzip -l /tmp/bla.bin
Archive:  /tmp/bla.bin
  End-of-central-directory signature not found.  Either this file is not
  a zipfile, or it constitutes one disk of a multi-part archive.  In the
  latter case the central directory and zipfile comment will be found on
  the last disk(s) of this archive.
unzip:  cannot find zipfile directory in one of /tmp/bla.bin or
        /tmp/bla.bin.zip, and cannot find /tmp/bla.bin.ZIP, period.
```

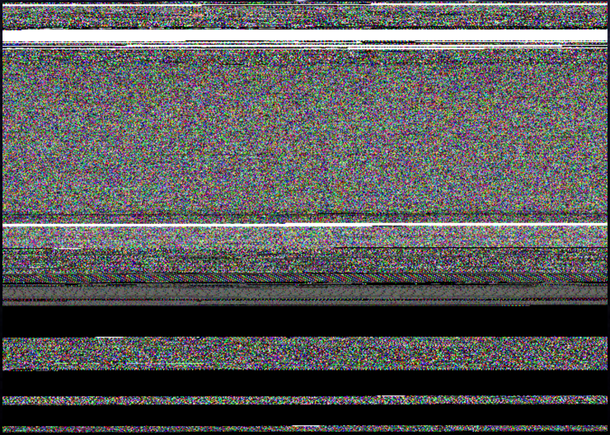
$\rightarrow$ binwalk does not know this firmware, the contained archive was apparently a false positive.

Inspecting the firmware file: Visualization

To spot different sections in a binary file, a visual representation can be helpful.

- HexWorkshop is a commercial program for Windows. Most complete featureset (Hex editor, visualisation, ...) http://www.hexworkshop.com/
- Binvis is a project on google code for different binary visualisation methods. Visualisation is ok, but the program seems unfinished. http://code.google.com/p/binvis/
- Bin2bmp is a very simple python script that computes a bitmap from your binary http://sourceforge.net/projects/bin2bmp/

Inspecting the firmware file: Visualization with bin2bmp



Identifying the CPU instruction set

- **ARM:** Look out for bytes in the form of 0xeX that occur every 4th byte. The highest nibble of the instruction word in ARM is the condition field, whose value 0xe means AL, execute this instruction unconditionally. The instruction space is populated sparsely, so a disassembly will quickly end in an invalid instruction or lots of conditional instructions.
- **Thumb:** Look out for words with the pattern 0xF000F000 (bl/blx), 0xB500BD00 ("pop XXX, pc" followed by "push XXX, lr"), 0x4770 (bx lr). The Thumb instruction set is much denser than the ARM instruction set, so a disassembly will go for a long time before hitting an invalid instruction.

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Identifying the CPU instruction set

- i386
- x86_64
- MIPS

In general, you should either know the processor already from the reconnaissance phase, or you try to disassemble parts of the file with a disassembler for the processor you suspect the code was compiled for. In the visual representation, executable code should be mostly colorful (dense instruction sets) or display patterns (sparse instruction sets).

Identifying the CPU instruction set

In our firmware, searching for ”e?” in the hexdump leads us to:

```
00002420  04 e0 4e e2 00 40 2d e9  00 e0 4f e1 00 50 2d e9  |..N..@-...O..P-.|
00002430  db f0 21 e3 8f 5f 2d e9  18 10 9f e5 00 00 91 e5  |..!.._-.........|
00002440  30 ff 2f e1 8f 5f bd e8  d1 f0 21 e3 00 50 bd e8  |0./.._....!..P..|
00002450  0e f0 69 e1 00 80 fd e8  44 00 00 00 08 20 fe 01  |..i.....D.... ..|
00002460  94 00 00 00 00 30 a0 e1  0c ce 9f e5 01 00 a0 e1  |.....0..........|
00002470  10 40 2d e9 14 10 93 e5  be c3 dc e1 d0 10 d1 e1  |.@-.............|
00002480  08 e0 93 e5 02 20 8c e0  92 01 01 e0 20 c0 e0 e3  |..... ...... ....|
00002490  81 22 61 e0 01 25 62 e0  42 29 a0 e1 82 0c 62 e1  |."a..%b.B)....b.|
000024a0  d8 cd 9f e5 82 11 81 e0  c6 20 51 e2 42 20 81 42  |......... Q.B .B|
000024b0  81 10 8c e0 f0 10 d1 e1  82 20 8c e0 04 c0 93 e5  |......... ......|
000024c0  f0 20 d2 e1 ac 01 2c e1  8e c2 2c e1 00 c0 83 e5  |. ....,...,.....|
000024d0  ac cd 9f e5 fc c9 dc e1  00 00 5c e3 10 40 bd a8  |..........\..@..|
000024e0  8e 1a 04 aa 10 80 bd e8  f0 41 2d e9 94 7d 9f e5  |.........A-..}..|
000024f0  80 40 a0 e1 07 00 54 e3  00 50 a0 e1 f7 6f 47 e2  |.@....T..P...oG.|
```

Let’s verify that this is indeed ARM code ...

Finding the CPU instruction set

```
$ dd if=MX1A4d.lod bs=1 skip=$(( 0x2420 )) > /tmp/bla.bin
$ arm-none-eabi-objdump -b binary -m arm -D /tmp/bla.bin

/tmp/bla.bin:     file format binary


Disassembly of section .data:

00000000 <.data>:
       0:       e24ee004        sub     lr, lr, #4
       4:       e92d4000        stmfd   sp!, lr
       8:       e14fe000        mrs     lr, SPSR
       c:       e92d5000        push    ip, lr
      10:       e321f0db        msr     CPSR_c, #219    ; 0xdb
      14:       e92d5f8f        push    r0, r1, r2, r3, r7, r8, r9, sl, fp, ip, lr
      18:       e59f1018        ldr     r1, [pc, #24]   ; 0x38
      1c:       e5910000        ldr     r0, [r1]
      20:       e12fff30        blx     r0
      24:       e8bd5f8f        pop     r0, r1, r2, r3, r7, r8, r9, sl, fp, ip, lr
      28:       e321f0d1        msr     CPSR_c, #209    ; 0xd1
      2c:       e8bd5000        pop     ip, lr
      30:       e169f00e        msr     SPSR_fc, lr
      34:       e8fd8000        ldm     sp!, pc^
      38:       00000044        andeq   r0, r0, r4, asr #32
      3c:       01fe2008        mvnseq  r2, r8
      40:       00000094        muleq   r0, r4, r0
      44:       e1a03000        mov     r3, r0
      48:       e59fce0c        ldr     ip, [pc, #3596] ; 0xe5c
```

→ Looks good!

Navigating the firmware

At the very beginning of a firmware, the stack needs to be set up for each CPU mode. This typically happens in a sequence of "msr CPSR_c, XXX" instructions, which switch the CPU mode, and assignments to the stack pointer. The msr instruction exists only in ARM mode (not true for Thumb2 any more ... :( ) Very close you should also find some coprocessor initializations (mrc/mcr).

```
18a2c:      e3a000d7      mov     r0, #215        ; 0xd7
18a30:      e121f000      msr     CPSR_c, r0
18a34:      e59fd0cc      ldr     sp, [pc, #204]  ; 0x18b08
18a38:      e3a000d3      mov     r0, #211        ; 0xd3
18a3c:      e121f000      msr     CPSR_c, r0
18a40:      e59fd0c4      ldr     sp, [pc, #196]  ; 0x18b0c
18a44:      ee071f9a      mcr     15, 0, r1, cr7, cr10, 4
18a48:      e3a00806      mov     r0, #393216     ; 0x60000
18a4c:      ee3f1f11      mrc     15, 1, r1, cr15, cr1, 0
18a50:      e1801001      orr     r1, r0, r1
18a54:      ee2f1f11      mcr     15, 1, r1, cr15, cr1, 0
```

Navigating the firmware

In the ARMv5 architecture, exceptions are handled by ARM instructions in a table at address 0. Normally these have the form "ldr pc, XXX" and load the program counter with a value stored relative to the current program counter (i.e. in a table from address 0x20 on).
$\rightarrow$ The exception vectors give an idea of which addresses are used by the firmware.

```
arm-none-eabi-objdump -b binary -m arm -D MX1A4d.lod \
  | grep -E 'ldr\s+pc' | less
```

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Navigating the firmware

→ We get the following output from arm-none-eabi-objdump

```
220e4:      e59ff018    ldr     pc, [pc, #24]   ; 0x22104
220e8:      e59ff018    ldr     pc, [pc, #24]   ; 0x22108
220ec:      e59ff018    ldr     pc, [pc, #24]   ; 0x2210c
220f0:      e59ff018    ldr     pc, [pc, #24]   ; 0x22110
220f4:      e59ff018    ldr     pc, [pc, #24]   ; 0x22114
220f8:      e1a00000    nop                     ; (mov r0, r0)
220fc:      e59ff018    ldr     pc, [pc, #24]   ; 0x2211c
22100:      e59ff018    ldr     pc, [pc, #24]   ; 0x22120
22104:      0000a824    andeq   sl, r0, r4, lsr #16
22108:      0000a8a4    andeq   sl, r0, r4, lsr #17
2210c:      0000a828    andeq   sl, r0, r8, lsr #16
22110:      0000a7ec    andeq   sl, r0, ip, ror #15
22114:      0000a44c    andeq   sl, r0, ip, asr #8
22118:      00000000    andeq   r0, r0, r0
2211c:      0000a6ac    andeq   sl, r0, ip, lsr #13
22120:      00000058    andeq   r0, r0, r8, asr r0
```

Emulating a Linux-based firmware

The goal is to run a firmware with as much functionality as possible in a system emulator (Qemu)

Emulating a Linux-based firmware

- We need a new Linux kernel. Why?
- Because the existing one is not compiled for the peripherals emulated by Qemu.

Compiling a Linux kernel for Qemu

Following this tutorial to build the kernel:

http://xecdesign.com/compiling-a-kernel/

```
sudo apt-get install git libncurses5-dev gcc-arm-linux-gnueabihf ia32-libs
git clone https://github.com/raspberrypi/linux.git
wget http://xecdesign.com/downloads/linux-qemu/linux-arm.patch
patch -p1 -d linux/ < linux-arm.patch
cd linux
make ARCH=arm versatile_defconfig
make ARCH=arm menuconfig
```

Compiling a Linux kernel for Qemu

Change the following kernel options:

```
General Setup --->  Cross-compiler tool prefix = (arm-linux-gnueabihf-)
System Type ---> [*] Support ARM V6 processor
System Type ---> [*] ARM errata: Invalidation of the Instruction Cache operation can fail
Floating point emulation  ---> [*] VFP-format floating point maths
Kernel Features ---> [*] Use ARM EABI to compile the kernel
Kernel Features ---> [*] Allow old ABI binaries to run with this kernel
Bus Support ---> [*] PCI Support
Device Drivers ---> SCSI Device Support ---> [*] SCSI Device Support
Device Drivers ---> SCSI Device Support ---> [*] SCSI Disk Support
Device Drivers ---> SCSI Device Support ---> [*] SCSI CDROM support
Device Drivers ---> SCSI Device Support ---> [*] SCSI low-lever drivers --->
          [*] SYM53C8XX  Version 2 SCSI support
Device Drivers ---> Generic Driver Options--->
          [*] Maintain a devtmpfs filesystem to mount at /dev
Device Drivers ---> Generic Driver Options--->
          [*] Automount devtmpfs at /dev, after the kernel mounted the root
File systems ---> Pseudo filesystems--->
          [*] Virtual memory file system support (former shm fs)
Device Drivers ---> Input device support---> [*] Event interface
General Setup ---> [*] Kernel .config support
General Setup ---> [*] Enable access to .config through /proc/config.gz
Device Drivers ---> Graphics Support ---> Console display driver support --->
          [ ] Select compiled-in fonts
File systems ---> Select all file systems
```

Compiling a Linux kernel for Qemu

```
make ARCH=arm -j8
cp arch/arm/boot/zImage ../
```

... or just download the kernel that we prepared for you here

Get or compile Qemu

```
wget http://wiki.qemu-project.org/download/qemu-1.5.1.ta
tar xf qemu-1.5.1.tar.bz2
cd qemu-1.5.1
./configure --target-list=arm-softmmu
make -j8
```

or install the package of your distribution, if it is recent (qemu-kvm-extras in Ubuntu 12.04)

Exercise – DIR655_FW200RUB13Beta06.bin

- DLink DIR-655
- Wireless N Gigabit Router

Exercise – DIR655_FW200RUB13Beta06.bin

- Getting DIR655_FW200RUB13Beta06.bin
- Unpacking DIR655_FW200RUB13Beta06.bin
  - Classic way
  - Firmware.RE way
- Exploring DIR655_FW200RUB13Beta06.bin

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Exercise – 51110.2.1800.96.bin

- Vicon IPCAM 960 series
- IP/Network based cameras for CCTV surveillance

Exercise – 51110.2.1800.96.bin

- Getting 51110.2.1800.96.bin
- Unpacking 51110.2.1800.96.bin
  - $VICON_JFFS2 is the unpacked JFFS2 image inside 51110.2.1800.96.bin
- Exploring 51110.2.1800.96.bin web-interface
  - $VICON_JFFS2/etc/lighttpd/lighttpd.conf
  - $VICON_JFFS2/mnt/www.nf

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Exercise – 51110.2.1800.96.bin

Web-interface of 51110.2.1800.96.bin

- first, quick-explore the web-interface
- lighttpd-based
  - sudo apt-get install lighttpd php5-cgi
  - sudo lighty-enable-mod fastcgi
  - sudo lighty-enable-mod fastcgi-php
  - sudo service lighttpd force-reload
- then, we want to emulate the web-interface on a PC
  - requires tweaking $VICON_JFFS2/etc/lighttpd/lighttpd.conf
  - requires some minor development and fixes

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Exercise – 51110.2.1800.96.bin

Tweaking $VICON_JFFS2/etc/lighttpd/lighttpd.conf

- correct document-root
- replace /mnt/www.nf with $VICON_JFFS2/mnt/www.nf
- set port to 1337
- set errorlog and accesslog
- create plain basic-auth password file
- set auth.backend.plain.userfile
- replace all .fcgi files with a generic action.bottle.fcgi.py
- enable .py as FastCGI in $VICON_JFFS2/etc/lighttpd/lighttpd.conf

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Exercise – 51110.2.1800.96.bin

Writing a stub action.bottle.fcgi.py

- sudo apt-get install python-pip python-setuptools
- sudo pip install bottle

Exercise – 51110.2.1800.96.bin

Running and debugging web-interface of 51110.2.1800.96.bin

- iterative-fixing approach
- sudo lighttpd -D -f $VICON_JFFS2/etc/lighttpd/lighttpd.conf
- check lighttpd logs for startup errors
- check Firefox web-developer console for client/server errors
  - console shows we need to define INFO_SWVER inside info.js
  - start from above by restarting lighttpd

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Summary and Take-aways

- Embedded devices and firmware security is an awesome topic :)
- Nevertheless, security is totally missing :(
- Reversing firmwares used to be hard
- Now it is much cheaper, easier, faster
- Virtually any component of a firmware is vulnerable
- This includes web-interface, crypto PKI/IPSEC, unpatched/outdated dependencies/kernels
- Backdooring is still there and is a real problem

Questions?

- Ask right here right now
-
- Visit, share and support (by uploading firmwares) our project:
- FIRMWARE.RE
-
- Contact us at:
- contact@firmware.re
- jonas@firmware.re
- andrei@firmware.re

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