Introduction To IoT Reverse Engineering

with an example on a home router

Valerio Di Giampietro

Linux enthusiast since 1993

http://va.ler.io

v@ler.io

@valerio

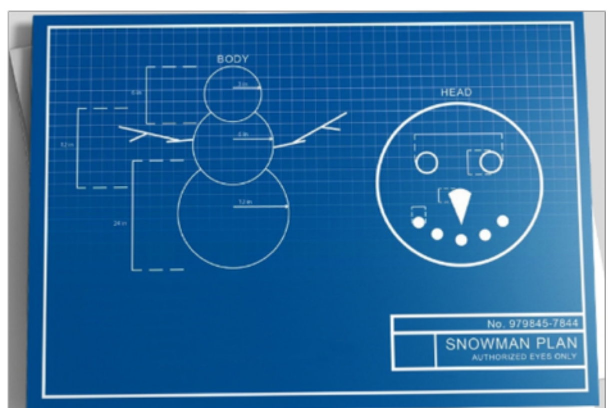
- Introduction
- Information gathering
- Emulation environment using QEMU
- Analyze how the device works
- Modify the firmware

What is *"engineering"*? *"the science of making things"*

- Define *"product requirements"*
- Design the product
- Build or manufacture the product

Requirements

Design Blueprint



Product

Reverse Engineering

What is ”*reverse engineering*”?

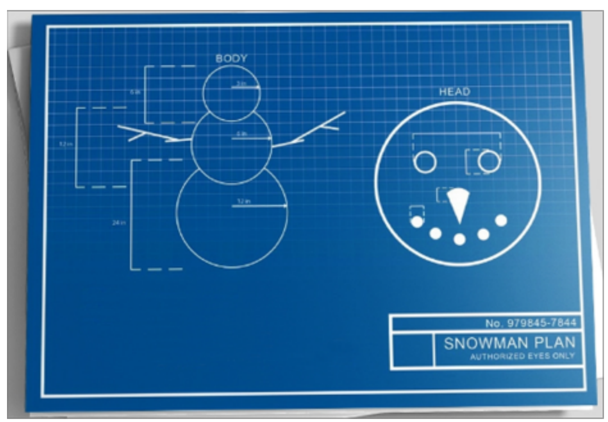
- It is the ”*engineering*” process done in reverse order and, usually, with limited scope

What is this example project “*limited scope*”?

- Understand how to modify the router firmware to add features and additional programs

Product

Design Blueprint



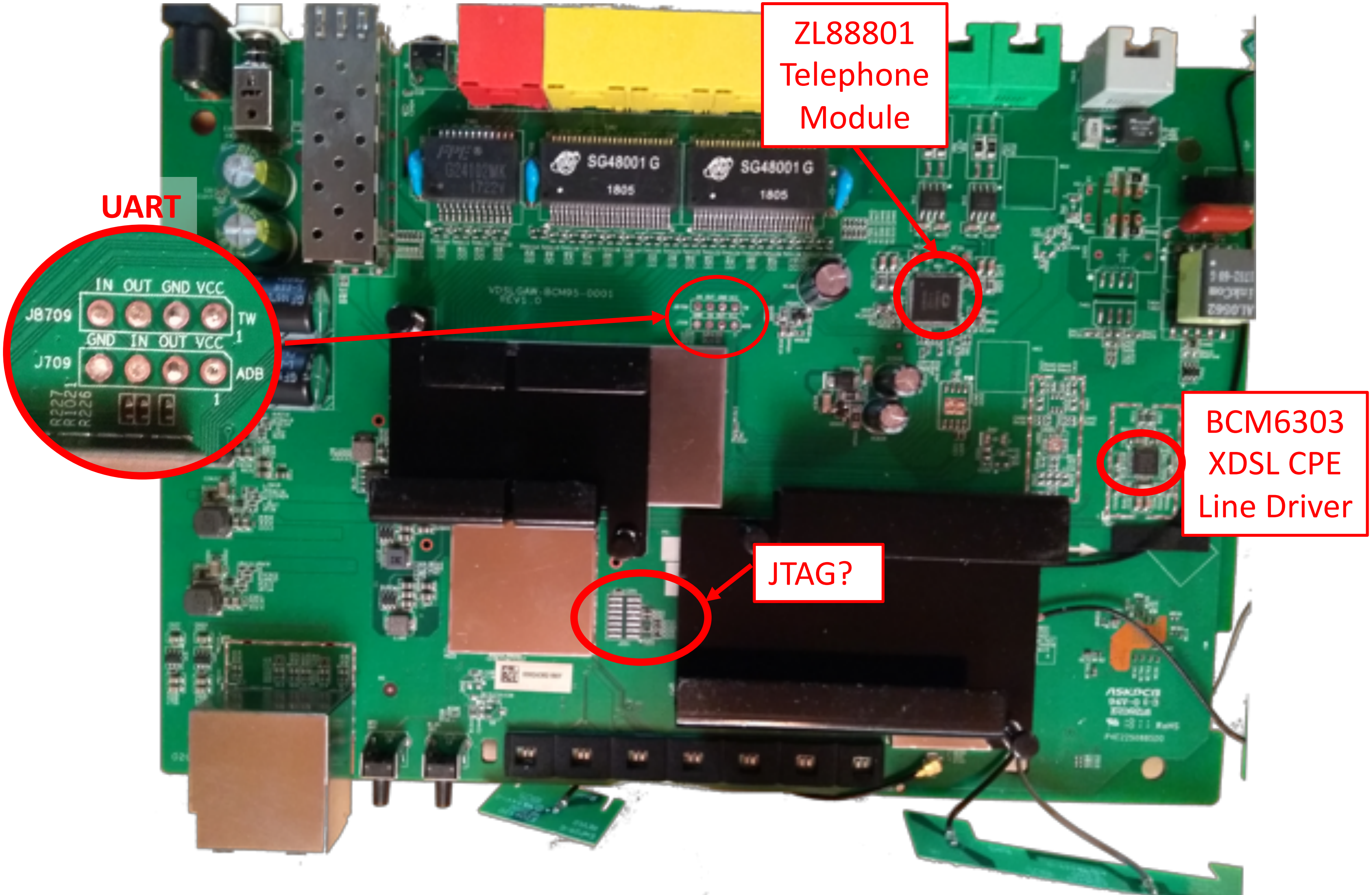
Requirements

Information Gathering

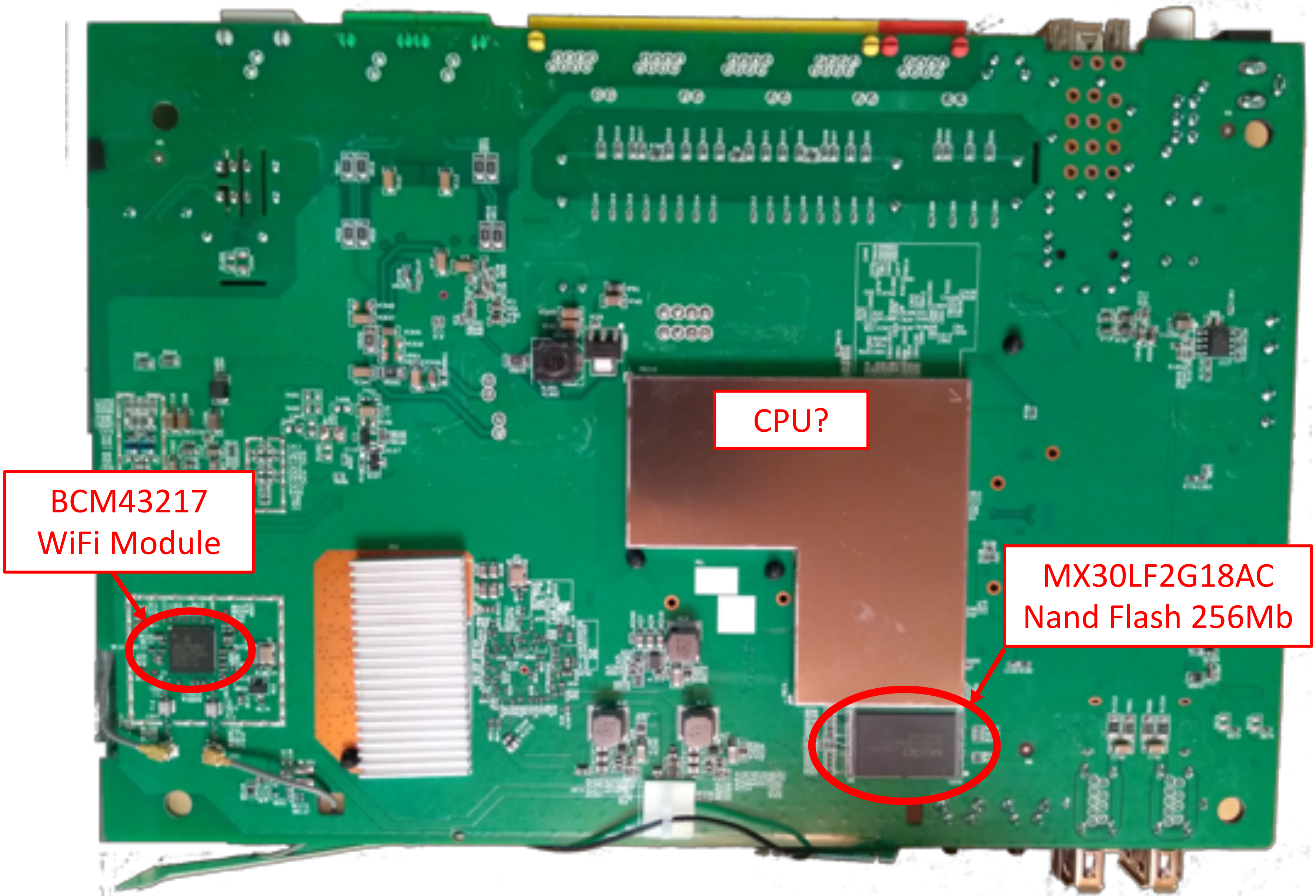
- Who makes the device?
- Is there an ODM (*Original Design Manufacturer*)?
- Open the case
- Identify main device components
- Locate UART and possibly JTAG Interfaces
- Get the firmware and the root file system

D-Link DVA 5592
example home router

Mainboard Top



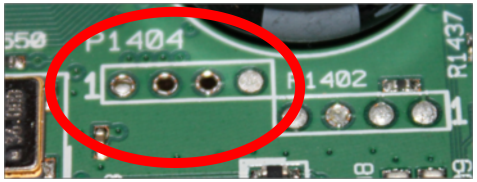
Mainboard Bottom

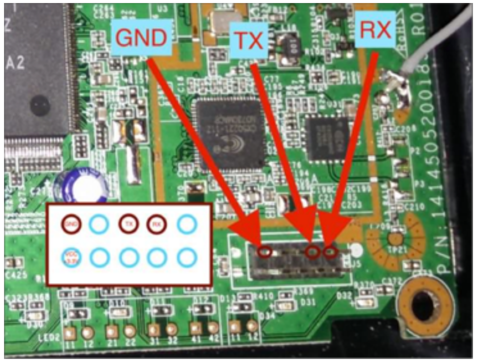


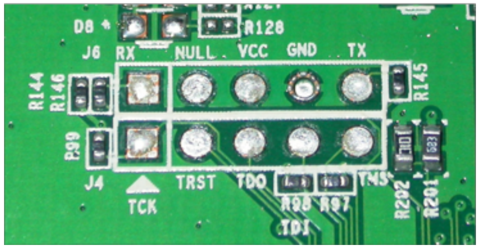
Locate the UART interface

- Search on Internet
- Identify potential serial headers candidates
- Sometimes marked in the PCB's silkscreen
- Usually 4 pins: Vcc, Gnd, Tx, Rx
- Use a multimeter to find potential candidates
- Locate pins on SOC and follow PCB traces
- Use tools like Jtagulator
- Oscilloscope or Logic Analyzer to locate Tx (a little overkill)

UART on various boards

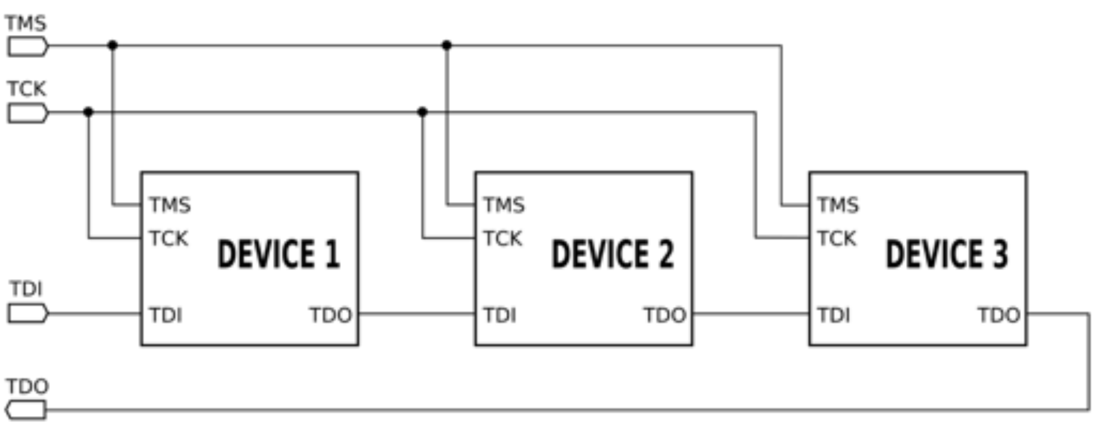






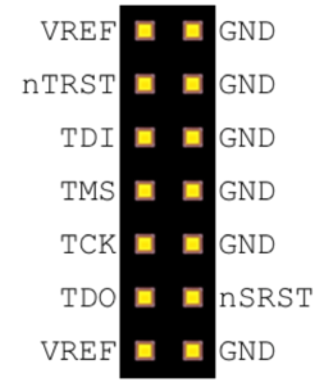
The JTAG interface

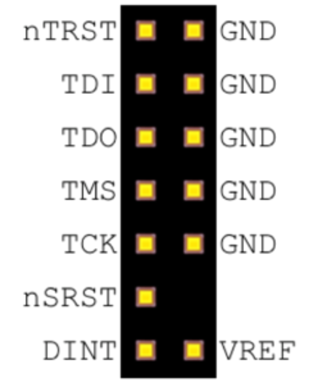
- JTAG is an industry standard for testing printed circuit boards after manufacture
- Allows access to read/write flash memory contents and can be used as a primary means for an in-circuit emulator
- Multiple devices are daisy-chained together
- Pins:
  TCK *test clock*
  TDI *test data in*
  TDO *test data out*
  TMS *test mode sel.*
  TRST *test reset (opt.)*

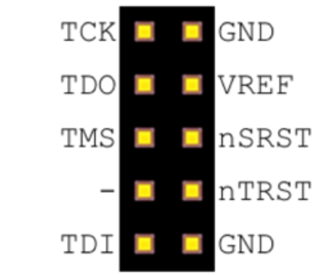


Locate the JTAG interface

- No standard pinout, but few popular pinouts: http://www.jtagtest.com/pinouts/
- Search on Internet
- Look for headers labeled TCK, TDI, TDO, TMS
- Look for 1x5/6, 2x5, 2x7, 2x10 pin headers
  - Look for GND and VCC with a multimeter and compare to popular pinouts
  - Often there are pullups (1-100k) for TMS, TDI and TRST, TRST can also be pulled low
  - TDO should be high impedance
- Locate pins on SOC and follow PCB traces
- Use tools like Jtagulator







Repopulate the interfaces

Connect the serial cable

Why repopulate the interfaces?

- UART (Serial Interface)
  - Watch what is printed on the serial console during the boot cycle and find bootloader and OS version
  - Watch the firmware upgrade cycle
  - Use a USB TTL serial adapter and a terminal emulator on the PC
- JTAG
  - Be able to read the firmware out of the flash eeprom
  - Be able to break into the boot cycle and use JTAG as a means to do ”*in circuit debugging*”
  - Attach an interface board, like *Bus Pirate*, to the JTAG interface
  - Use software, as *OpenOCD*, to dump flash eeprom and to do ”*in circuit debugging*”

Getting the firmware file

- Follow the easiest path first
- If the supplier has a website with firmware updates go and download the firmware file
- If the firmware update can be downloaded directly only by the device, sniff the communication with *wireshark* and get the firmware file
- If the above steps are not available, download the eeprom image through the JTAG connector using Bus Pirate and OpenOCD

Get info from the firmware

- Get basic info from the firmware file

```
$ file DVA-5592_A1_WI_20180405.sig
DVA-5592_A1_WI_20180405.sig: data

$ binwalk DVA-5592_A1_WI_20180405.sig
DECIMAL HEXADECIMAL DESCRIPTION
---------------------------------------------------
512       0x200      JFFS2 filesystem, little endian
24379992  0x1740258  gzip compressed data, from
                     Unix, last modified:
                     2018-04-11 10:40:16
```

Extract content from firmware

LINUXLAB BUILDING SMARTER DEVICES

- Install Jefferson to extract files from JFFS2 file system
- Use binwalk to extract content from firmware

```
$ binwalk -e DVA-5592_A1_WI_20180405.sig

$ ls -lh _DVA-5592_A1_WI_20180405.sig.extracted
-rw-rw-r-- 1 val val  30K ott 21 13:28 1740258
-rw-rw-r-- 1 val val  24M ott 21 13:27 200.jffs2
drwxrwxr-x 5 val val 4,0K ott 21 13:28 jffs2-root

$ file 1740258
1740258: POSIX tar archive (GNU)

$ tar -tvf 1740258
drwxr-xr-x l.fornalczyk/adb  boards/
drwxr-xr-x l.fornalczyk/adb  boards/963138_VD5….ipk
```

Looking at the extracted files

- Looking at the extracted files

```
$ ls jffs2-root/
fs_1  fs_2  fs_3
```

- It seems we have 3 file systems here: “/boot” and “/” splitted in two parts

```
$ ls -lh fs_1
-rw-r--r-- 1 val val    0 ott 21 13:28 a
-rw-r--r-- 1 val val 260K ott 21 13:28 cferam.000
-rw-r--r-- 1 val val 1,2M ott 21 13:28 vmlinux.lz
```

- cferam.000 is the boot loader image based on Broadcom CFE (Common Firmware Environment)
- vmlinux.lz is the kernel, in an unusual CFE compressed format

Looking at other files

- /sbin/init is missing (but it’s not true), busybox is there

```
$ ls -lh fs_2/bin/busybox
-rwsr-sr-x 1 val val 382K fs_2/bin/busybox
$ strings fs_2/bin/busybox
…
BusyBox v1.17.3 (2018-04-11 12:29:54 CEST)
…

$ arm-linux-readelf -a fs_2/bin/busybox
…
… program interpreter: /lib/ld-uClibc.so.0]

$ ls -lh fs_2/lib/ld-uClibc*
-rwxr-xr-x ld-uClibc-0.9.33.2.so
lrwxrwxrwx ld-uClibc.so.0 -> ld-uClibc-0.9.33.2.so

$ ls -l fs_3/lib/libgcrypt.so.11*
lrwxrwxrwx libgcrypt.so.11 -> libgcrypt.so.11.5.3
-rwxr-xr-x libgcrypt.so.11.5.3
```

Boot output on serial console

- Output on serial console during boot

```
...
CFE version 1.0.38-118.3-S for BCM963138 (32bit,SP,LE)
generic
...
Chip ID: BCM63136B0, ARM Cortex A9 Dual Core: 1000MHz
Total Memory: 268435456 bytes (256MB)
NAND ECC BCH-4, page size 0x800 bytes, spare size 64 bytes
NAND flash device: , id 0xc2da block 128KB size 262144KB
...
Linux version 3.4.11-rt19 (l.fornalczyk@quelo) (gcc version
4.5.4 20120306 (prerelease) (Linaro GCC 4.5-2012.03) )
...
CPU: ARMv7 Processor [414fc091] revision 1 (ARMv7)
...
jffs2: version 2.2 (NAND) (SUMMARY) (ZLIB) (LZMA) (RTIME)
...
```

Boot output on serial console

- Output on serial console during boot (part 2)

```
...
[2.502000] Found YAPS PartitionSplit Marker at 0x080FFF00
[2.503000] Creating 8 MTD partitions on "brcmnand.0":
[2.504000] 0x000000000000-0x000000020000 : "CFE"
[2.506000] 0x000007f00000-0x000008100000 : "bootfs_1"
[2.508000] 0x000008100000-0x00000fbc0000 : "rootfs_1"
[2.510000] 0x000000200000-0x000007ce0000 : "upgrade"
[2.512000] 0x00000fbc0000-0x00000fdc0000 : "conf_fs"
[2.513000] 0x00000fdc0000-0x00000fe00000 : "conf_factory"
[2.515000] 0x00000fe00000-0x000010000000 : "bbt"
[2.517000] 0x000000000000-0x000010000000 : "flash"
...
Init started: BusyBox v1.17.3 (2018-04-11 12:29:54 CEST)
starting pid 235, tty '': '/etc/init.d/rcS S boot'
Starting boot.sh ...
Restore passwd ....
Restore group ....
Starting /etc/rc.d/S11services.sh ...
Starting Configuration Manager (B)
```

/etc/inittab

```
::sysinit:/etc/init.d/rcS S boot
::shutdown:/etc/init.d/rcS K shutdown
tts/0::askfirst:/bin/login
ttyS0::askfirst:/bin/login
```

- Output on serial console during boot (part 3)

```
...
CM TR-181 ready
CM TR-98 ready
Epicentro Software Version: DVA-5592_A1_WI_20180405
Epicentro Platform Version: 6.0.0.0028
...
Starting /etc/rc.d/S13acsd.sh ...
Starting /etc/rc.d/S20voip.sh ...
Starting /etc/rc.d/S60ipsec.sh ...
Starting /etc/rc.d/S70vpn.sh ...
Starting /etc/rc.d/S94printkd.sh ...
```

Searching «Epicentro Software» on Internet gives the ODM (Original Design Manufacturer): ADB www.adbglobal.com

What was found

- Processor ARMv7 Cortex-A9 Multicore
- 256Mb NAND Flash
- Linux version 3.4.11-rt19 (September 2012)
- uClibc version 0.9.33.2 (May 2012)
- BusyBox version 1.17.3 (October 2010)
- Libgcrypt version 1.4.5 (December 2009)
- Epicentro software by ADB (adbglobal.com)

QEMU Emulation

- Choosing Board and CPU emulation in QEMU

```
$ qemu-system-arm -M help|egrep Cortex-A9
realview-pbx-a9 ARM RealView Platform for Cortex-A9
vexpress-a9     ARM Versatile Express for Cortex-A9
xilinx-zynq-a9  Xilinx Zynq Platform  for Cortex-A9

$ qemu-system-arm -M vexpress-a9 -cpu help
...
cortex-a9
...
```

Choosing a Build System

- **The Yocto Project**
  very powerful, builds a root file system and create a custom Linux distribution. It's main drawback is that it has a steep learning curve

- **Buildroot**
  builds the root file system and the kernel, easy and fast to learn, very good user manual

- **Openwrt/LEDE Build System**
  tailored to build a replacement router firmware, documentation scattered in the web site, requires more time to learn compared to Buildroot

Choosing a Buildroot version

- Based on uClibc 0.9.33.2
- Gnu libgcrypt crypto library compatible with version 1.5 (with library file: libgcrypt.so.11)
- With custom kernel version 3.4.1-rt19
- Other libraries with compatible versions
- The version to use is: buildroot-2014.02
- This version doesn't run on Ubuntu 16.04 or Ubuntu 18.04
- Use Debian Wheezy (released in 2013) in a docker Container

The Dockerfile

- The Dockerfile builds a minimal Debian Wheezy container to run Buildroot

```
FROM debian:wheezy
...
RUN apt-get update
RUN apt-get upgrade
RUN apt-get install -y -q \
    bash \
...
RUN mkdir -p         /src/misc
ADD startup.sh       /src/misc/startup.sh
RUN chmod a+x        /src/misc/startup.sh
ENTRYPOINT cd        /src/misc ; ./startup.sh
```

- Available at: https://github.com/digiampietro/buildroot-armv7

The Docker run command

- The *Docker run* maps user and user's home directory in the Docker Container

```
docker run      -h BRHOST                          \
                --rm                               \
                -v /tmp/.X11-unix:/tmp/.X11-unix   \
                -v $HOME:$HOME                     \
                -e DISPLAY=$GDISPLAY               \
                -e GUSERNAME=$GUSERNAME            \
                -e GUID=$GUID                      \
                -e GGROUP=$GGROUP                  \
                -e GGID=$GGID                      \
                -e GHOME=$GHOME                    \
                -e GSHELL=$SHELL                   \
                -e GRUNXTERM=$GRUNXTERM            \
                -e GPWD=$GPWD                      \
                -it digiampietro/buildroot-armv7
```

Docker run in action

```
valerio@ubuntu-hp:~$ ls -ld br
drwxrwxr-x 6 valerio valerio 4096 ott 26 22:30 br

valerio@ubuntu-hp:~$ grep VERSION /etc/os-release
VERSION="18.04.1 LTS (Bionic Beaver)"
VERSION_ID="18.04"
VERSION_CODENAME=bionic
valerio@ubuntu-hp:~$ br/..../docker/dockrun.sh
```

```
valerio@BRHOST:~$ ls -ld br
drwxrwxr-x 6 valerio valerio 4096 Oct 26 20:30 br

valerio@BRHOST:~$ grep VERSION /etc/os-release
VERSION_ID="7"
VERSION="7 (wheezy)"
```

Buildroot configuration

- Based on "*qemu_arm_vexpress_defconfig*"
- With the following main modifications
  - Build packages and libraries with debugging symbols, don't strip binaries, no gcc optimization
  - Build gdb, gdbserver, ltrace, strace and cross gdb for the host
  - Include mtd and jffs2 file system and tools also for the host
  - Include main libraries used in the router (libgcrypt, expat, roxml, libxml2, Mini-XML)

Linux kernel configuration

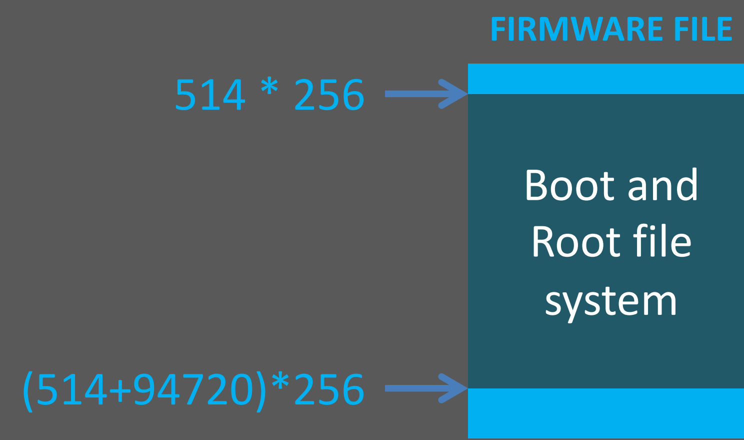
- With the following additional settings
  - Versatile Express platform type with Device Tree support
  - Preemptible Kernel
  - NAND Device Support and Support for NAND Flash Simulator
  - JFFS2 file system with LZMA compression

uClibc configuration

- Minor modifications to be compatible with the router's binaries (like native POSIX threading etc.)
- To include debugging symbols, uClibc don't obey to the general option included in the Buildroot configuration, has his own flag for this purpose; the problem is that enabling his own flag the compilation gives impossible to fix errors
- in Compiler Warnings add the string "-ggdb", this is the work around to compile the uClibc with debugging symbols

- Analyzing the upgrade process on the UART output (1 of 2)

```
Start pid 4 /usr/sbin/upgrade-prepare.sh cwmp
...
/usr/sbin/upgrade.sh
Signature OK
...
/usr/sbin/flash_eraseall \
    -j -p 0 -l 8 /dev/mtd3
...
Writing boot & root filesystems...
dd if=/tmp/upgrade/fw.bin bs=256 skip=514 count=94720
| /usr/sbin/nandwrite -s 524288 /dev/mtd3 -
...
[…] Found YAPS PartitionSplit Marker at 0x080FFF00
[…] Creating 2 MTD partitions on "brcmnand.0":
[…] 0x000007f00000-0x000008100000 : "bootfs_2”
[…] 0x000008100000-0x00000fcc0000 : "rootfs_2"
```



The upgrade process

- Analyzing the upgrade process on the UART output (2 of 2)

```
Installing packages...
opkg … -f /tmp/new_rootfs/etc/opkg.conf -o
/tmp/new_rootfs install …
Umount /tmp/new_rootfs
...
Writing first block of cferam...
dd if=/tmp/upgrade/fw.bin bs=256 skip=2 count=512 |
/usr/sbin/nandwrite /dev/mtd8 -
...
rebooting...
```

The upgrade process - summary

- The upgrade script to analyze is `/usr/sbin/upgrade.sh`
- The firmware is signed, signature is checked with `sig_verify $file 2> /dev/null`
- Boot and root file systems are written in a single nandwrite operation
- A JFFS2 partition splitter proprietary kernel module is used to create the two partitions on the fly
- A JFFS2 end marker open source kernel module is used to delimit the end of the root file system partition
- Some additional packages are added, based on board type
- The cferam boot loader is written with another nandwrite operation

Reverse engineering sig_verify

sig_verify is a stripped binary, but calls library functions. We put breakpoints on these calls in the emulation environment

```
$ arm-linux-readelf --sym -D sig_verify
Symbol table for image:
  Num Buc: Value    Size Type Bind    Vis      Ndx Name
   16   0: 00008928    0 FUNC GLOBAL DEFAULT UND fseek
   29   1: 00008994    0 FUNC GLOBAL DEFAULT UND strcmp
   40   3: 000089dc    0 FUNC GLOBAL DEFAULT UND gcry_md_ctl
   38  11: 000089d0    0 FUNC GLOBAL DEFAULT UND fputs
   23  14: 00008964    0 FUNC GLOBAL DEFAULT UND fread
    1  15: 00008898    0 FUNC GLOBAL DEFAULT UND printf
   44  16: 00008a0c    0 FUNC GLOBAL DEFAULT UND gcry_md_get_algo…
   41  16: 000089e8    0 FUNC GLOBAL DEFAULT UND close
    9  17: 000088e0    0 FUNC GLOBAL DEFAULT UND lseek
    7  19: 000088c8    0 FUNC GLOBAL DEFAULT UND gcry_md_open
    6  19: 000088bc    0 FUNC GLOBAL DEFAULT UND gcry_md_write
    3  20: 000088a4    0 FUNC GLOBAL DEFAULT UND gcry_check_version
...
```

Running sig_verify in GDB

Start gdb server in the emulation environment

```
# gdbserver :9000 sig_verify --readonly \
    DVA-5592_A1_WI_20180405.sig
```

Start gdb in the host machine

```
$ arm-linux-gdb --ex="target remote :9000" \
                --ex="set sysroot $SYSROOT"\
                --ex="directory $MYDIR"    \
                --ex="directory $TOOLBIN"  \
                     -x  sv.gdb
```

Running sig_verify in GDB

- Reads the last 256 bytes from the file (signature)
- Calls *gcry_md_open*, *gcry_md_write*, `gcry_md_ctl` to calculate SHA1 checksum
- Calls `gcry_sexp_build` 3 times to build the 3 s-expressions and then `gcry_pk_verify` to verify the signature with the following parameters
  - **SHA1 message digest**
  - **Signature** (the firmware file last 256 bytes)
  - **The public key** (embedded in the file)

Running sig_verify in GDB

- The public key (MPI modulus and exponent) can be dumped from memory to recover the public key in the standard .pem format
- Unfortunately the private key remains unknown, it is not included in router's certificates files in the folder /etc/certs

Restricted shell

- Firmware modification through the upgrade process seems impossible
- The router allows telnet/ssh but present a Cisco-like restricted shell

```
$ telnet 192.168.1.1
Connected to 192.168.1.1.
Escape character is '^]'.
Login: admin
Password:
********************************************
*                  D-Link                  *
*       WARNING: Authorised Access Only    *
********************************************
Welcome
DLINK#
```

Escaping the restricted shell

- */etc/shells* suggests that the restricted shell is a Clish (or Klish), open source, shell
- /bin/clish is a script:

```
#!/bin/sh
...
exec /bin/clish.elf -l -x /tmp/clish
```

- In */etc/init.d/services.sh:*

```
#in factory mode
ln -s /etc/clish/prod /tmp/clish
#in normal mode
ln -s /etc/clish /tmp/clash
```

- clish xml startup files are:
  /etc/clish/prod/startup.xml
  /etc/clish/startup.xml

Escaping the restricted shell

- In */etc/clish/startup.xml:*

```
<COMMAND name="factory-mode" help="hidden">
  <ACTION>cmclient DUMPDM FactoryData
         /tmp/cfg/FactoryData.xml > /dev/null
          nvramUpdate Feature 0x2 > /dev/null
          cmclient REBOOT > /dev/null
  </ACTION>
</COMMAND>
```

- ”factory-mode” is an hidden, not auto-completed command: it is a command to try:

```
DLINK# factory
DLINK(factory)# factory-mode
DLINK(factory)#
DLINK(factory)# Connection closed by foreign
host.
```

Escaping the restricted shell

- Factory mode is special mode: no normal WiFi, no Internet connection, no DHCP server, but it allows a non privileged shell login:

```
Login: admin
Password:
*************************************
*                 D-Link            *
*                                   *
*      WARNING: Authorised Access Only    *
*************************************
Welcome
DLINK# system shell
BusyBox v1.17.3 built-in shell (ash)
Enter 'help' for a list of built-in commands.
/root $
```

The Quest for Root

- Looking for processes running with root privileges

```
/root $ ps -ef
PID USER       VSZ STAT COMMAND
   1 0          1184 S    init
 261 0           724 S <  /sbin/udevd --daemon
 274 1001       1328 S    /bin/clish.elf -l -x /tmp/clish
 326 0          2332 S    cm
 365 0          1800 S    logd
 368 0           704 S    ec
2383 0           820 S    dns
2630 0          2480 S    cwmp
2631 0          1204 S    inetd -f
2633 0           736 S    yamp -c /tmp/yamp.conf -p /tmp/…
2658 0           664 S    wpspbc
3089 0          2316 S    hostapd -B /tmp/wlan/config/ho…
3090 65534      3560 S    httpd -u nobody
3647 0          1068 S    chronyd -n -f /tmp/chrony.conf
4191 0           696 S    /sbin/rngd -r /dev/urandom -W 4000
4211 0          7136 S    voip
4404 1001       1176 S    /bin/ash
```

The Quest for Root - 1

- Identify each process and executable version using “strings” and/or running the executable with parameters
  “`-v -V -version -h -h -help`”
- Identify open source executables
- Search the internet for known vulnerabilities for the specific executable version
- Check if the vulnerability is exploitable in the specific IoT device configuration

The Quest for Root - 2

- If no exploitable vulnerability has found select a process candidate to reverse engineer to find vulnerabilities
- Operating system binaries with no known vulnerabilities are hard to crack
- Lower level binaries (dns, voip …) are more difficult to crack
- Higher level executables with bigger configuration files are less difficult to crack

The Quest for Root - 3

- The most interesting process is “cm”: router configuration with root privileges is done by the “cm” process (add users, configure dhcp server, set ip address etc.)
- “cm” uses shell scripts to carry out his duties
- The “cmclient” command, running as normal user, is used by restricted shell and web interface to talk to the “cm” process to configure the router
- “cmclient” is used, in startup scripts, to configure the “cm” process

The Quest for Root - 4

– In a startup script there is:

```
cmclient DOM Device /etc/cm/tr181/dom/
```

– This loads all the xml file in that directory to configure the cm process, including

```
/etc/cm/tr181/dom/Management.xml
```

– That has the following snippet

```
<object name="Users.User.{i}."
         access="readOnly"
         minEntries="0"
         maxEntries="unbounded"
         numEntriesParameter="UserNumberOfEntries"
         enableParameter="Enable"
         set="Users.sh"
         add="Users.sh"
         del="Users.sh"
   >
```

The Quest for Root - 5

- To trigger an execution of our script:

```
cmclient DOM Device /tmp/fakeManagement.xml
```

- It has the following snippet

```
<object name="Users.User.{i}."
        access="readOnly"
        minEntries="0"
        maxEntries="unbounded"
        numEntriesParameter="UserNumberOfEntries"
        enableParameter="Enable"
        set="../../tmp/fakeUsers.sh"
        add="../../tmp/fakeUsers.sh"
        del="../../tmp/fakeUsers.sh"
>
```

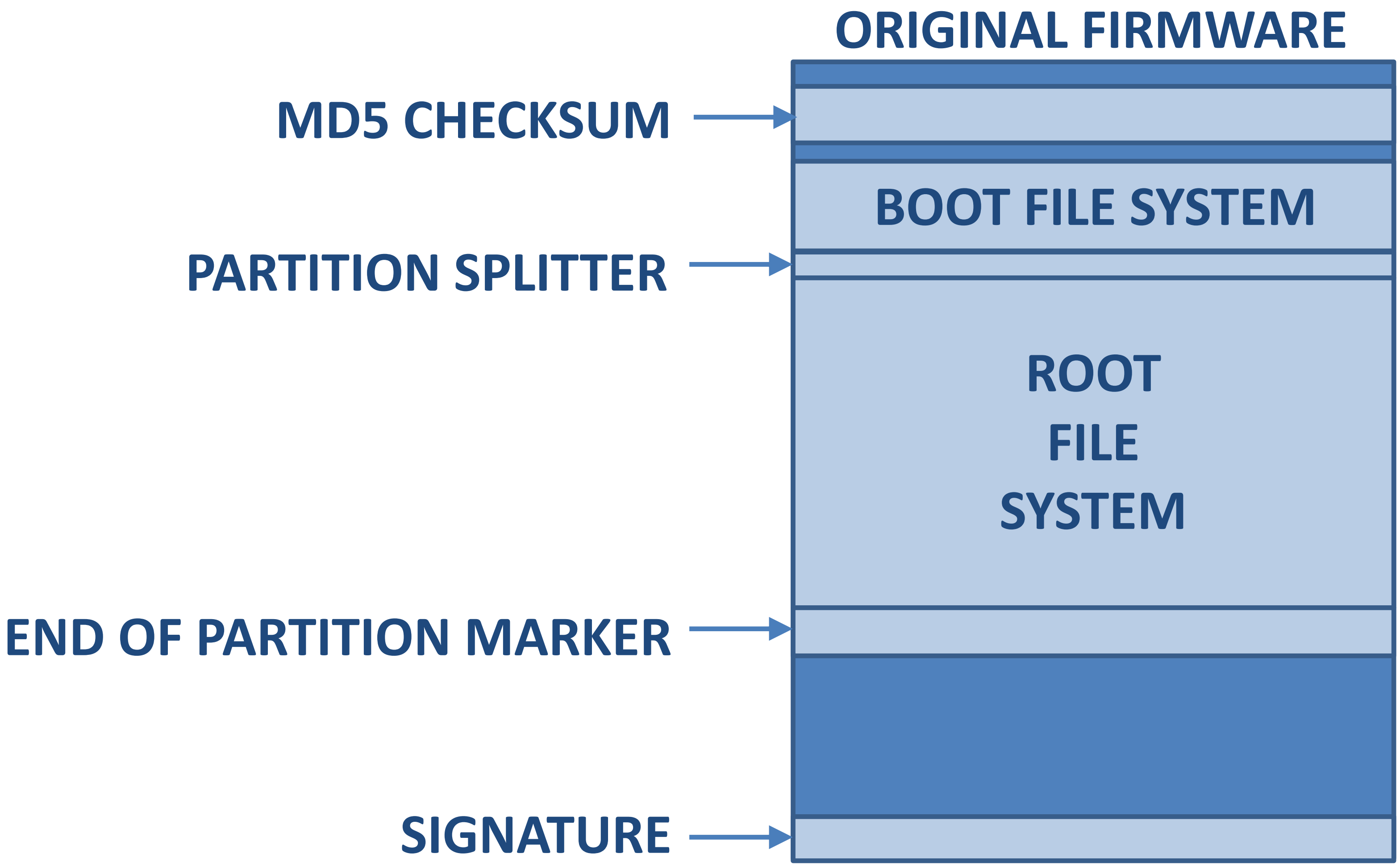
- Trigger the execution of the «fakeUsers.sh» script with

```
cmclient ADD Device.Users.User
```

The Quest for Root - 7

```
/root $ cat > /tmp/hack-script.sh
   do a copy and paste of the script
   press CTRL-D to terminate the copy
/root $ chmod a+x /tmp/hack-script.sh
/root $ /tmp/hack-script.sh
...
/root $ su -
BusyBox v1.17.3 (2018-04-11) built-in shell (ash)
Enter 'help' for a list of built-in commands.
r41358.07b1b3a7
...........................................................
yet another solution by  Advanced Digital Broadcast SA
...........................................................
root@localhost:~# id
uid=0(root) gid=0(root)
groups=0(root),19(remoteaccess),20(localaccess)
```

- Based on firmware upgrade script analysis the firmware file has the following structure:



Firmware Modification Kit - 2

- Extract the root file system, modify it
- Create the new root file system image
- Pad the file system image to the same size as the original root file system image (the USB key will be used for additional software)
- Reassemble the firmware file putting together all the pieces, excluding the signature, using the ”dd” command
- The unsigned firmware file is ready

Loading the unsigned firmware

- The upgrade script checks the firmware signature:

```
sig_verify $file 2> /dev/null
ret_code=$?
```

- As root copy the upgrade script in /tmp
- Modify it:

```
sig_verify $file 2> /dev/null
ret_code=0
```

- Temporary replace it with mount:

```
mount --bind /tmp/upgrade.sh \
             /usr/sbin/upgrade.sh
```

- Do the upgrade through the web interface

Summary

- Reverse engineering can be really challenging
- Clearly define the limited scope of your reverse engineering project
- Start gathering information following the easiest path first
- If some information is missing or difficult to get move forward, go back only if absolutely needed
- Search on Internet for known vulnerabilities
- Select to hack processes running as root and with a large attack surface

Useful Links & Documentation

GitHub repositories related to the Home Router Example

- **Adbtools2**, Tools for hacking ADB Epicentro routers, including firmware modification: *https://github.com/digiampietro/adbtools2*
- **Buildroot-armv7**: a set of scripts, configuration files and Buildroot external tree to setup a Qemu emulation environment to run and reverse engineer the Netgear DVA 5592 executables: *https://github.com/digiampietro/buildroot-armv7*

Reverse engineering and physical disassembly

- Introduction to reverse engineering, Mike Anderson, Embedded Linux Conference 2018, slides and videos: *https://elinux.org/images/c/c5/IntroductionToReverseEngineering_Anderson.pdf* *https://www.youtube.com/watch?v=7v7UaMsgg_c*

Recommended Books

- *Chris Simmonds* - Mastering Embedded Linux Programming - Second Edition - *Packt Publishing 2017*
- *Norman Matloff , Peter Jay Salzman* - The Art of Debugging with GDB , DDD and Eclipse - *NO STARCH PRESS 2008*

Useful Links & Documentation

Hardware tools
- Bus Pirate: *http://dangerousprototypes.com/docs/Bus_Pirate*
- Jtagulator: *http://www.grandideastudio.com/jtagulator/*
- J-Link debug probes: *https://www.segger.com/products/debug-probes/j-link/*

JTAG and UART interfaces
- Popular pinouts: *http://www.jtagtest.com/pinouts/*

Software
- Buildroot: https://buildroot.org/
- Putty terminal emulator: *https://www.putty.org/*
- OpenOCD (Open On-Chip Debugger) provides debugging, in-system programming and boundary-scan testing for embedded target devices: *http://openocd.org/*
- Wireshark, network protocol analyzer: *https://www.wireshark.org/*
- Binwalk, firmware analysis tool: *https://github.com/ReFirmLabs/binwalk*
- Jefferson, JFFS2 filesystem extraction tool: *https://github.com/sviehb/jefferson*

?

Question Time

Thank You