Breaking Down Binaries

Navigating the Labyrinth of IoT Firmware Analysis

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whoami

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  - ~6 years of startup life
- Chicago based
- Indoor boulderer
- Latest hyperfixation: Leatherworking

Outline

Why does any of this matter

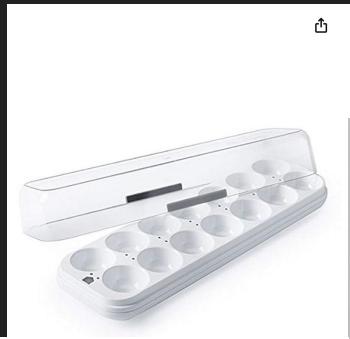
The Flavors of Firmware

Firmware Acquisition

Unpacking

Analysis

Motivation

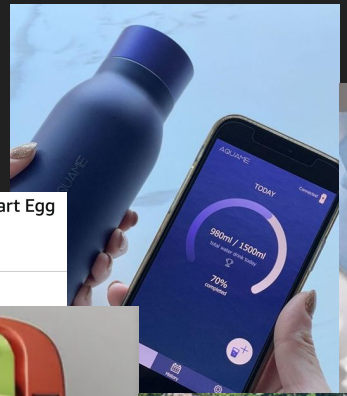


Quirky Egg Minder Wink App Enabled Smart Egg Tray, PEGGM-WH01

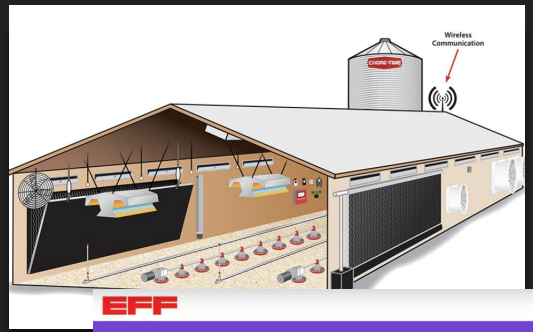
Visit the Quirky Store

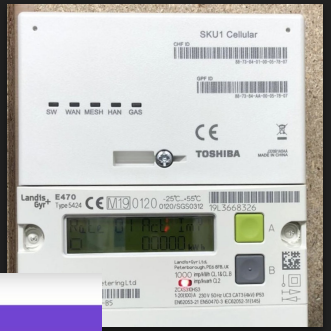
2.2 ★★☆☆☆ 603 ratings | Search this page

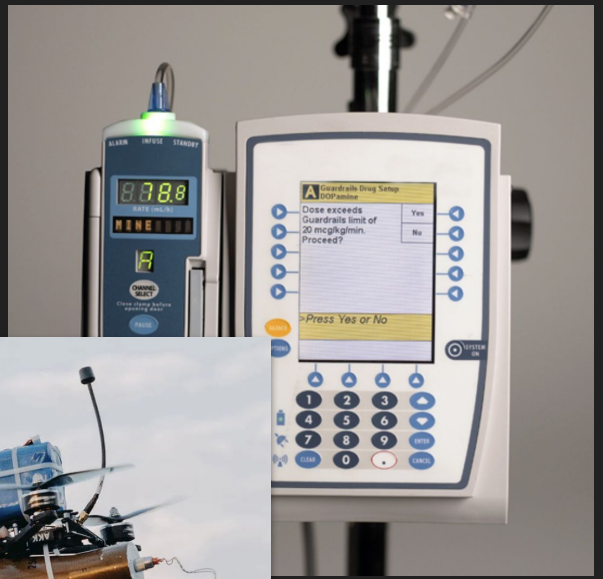
-8% $9.17 ($9.17 / count)



You can’t opt out of IoT

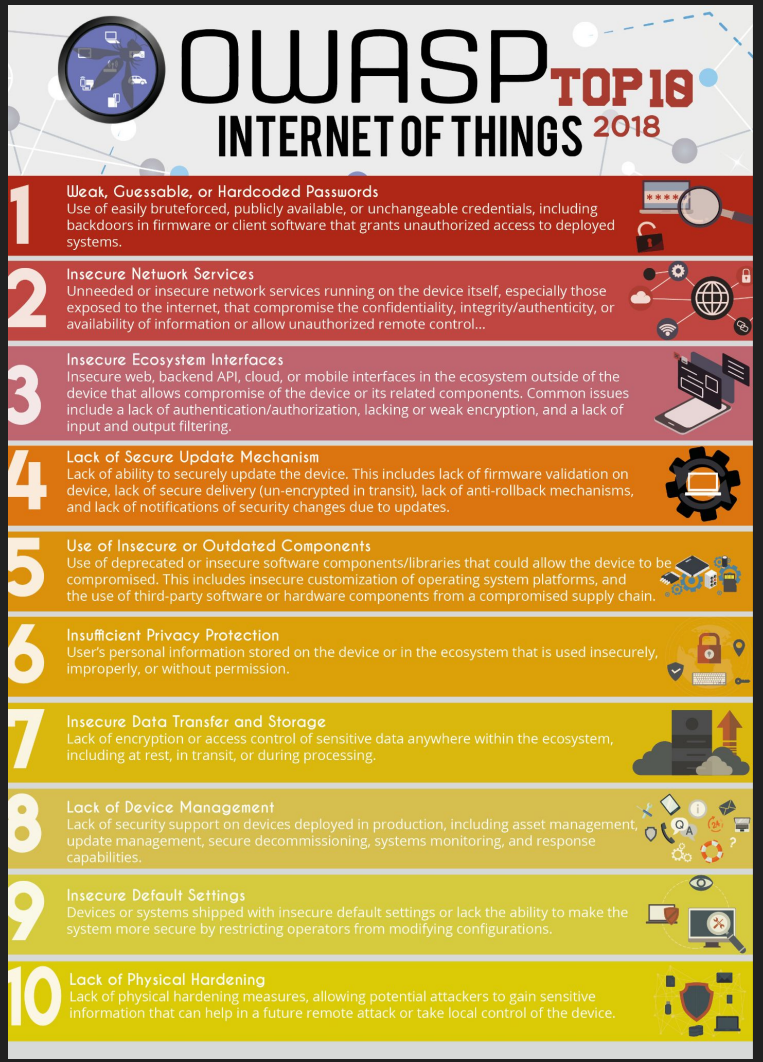






Threat Surface

- Long update cycles
  - Even for FOTA, updates usually need to be tested to a greater extent
- Generally very behind compared to the desktop
  - Parker Wiksell - Vulnerability Trends in the Supply Chain DEF CON 28 IoT Village
  - Really rough OWASP Top 10



Types of Firmware

Linux-y Firmware

- Linux (and Android) is well understood and documented
- Most complicated relative to RTOS or bare metal
  - Full featured operating system
- Costs way less than you might expect
  - Sub $3 Linux-on-a-business card (pre-covid)

Component	Price
F1C100s	$1.42
PCB	$0.80
8MB flash	$0.17
All other components	$0.49
Total	**$2.88**

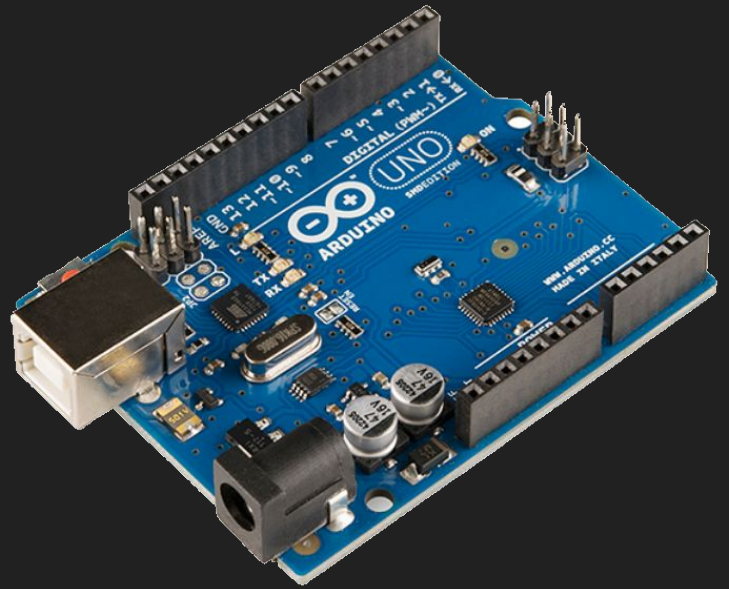
RTOS (Real Time OS) based firmware

- Single monolithic binaries
- May be closed source
- Highly configurable so existing research may or may not apply


```
## Starting application at 0x4010100000 ...

 _____                  _____
 \77777777\            /77777777/
  \77777777\          /77777777/
   \77777777\        /77777777/
    \77777777\      /77777777/
     \77777777\    /7777777/
      \77777777\  /77777/                VxWorks 7 SMP 64-bit
       \77777777\/777/
        \77777777\7/      Core Kernel version: 1.0.0.0
         \7777777\-       Build date: May 30 2014 10:51:05
          \77777777\
           \777777/       Copyright Wind River Systems, Inc.
            \77777/-                    1984-2014
             \777/ /7\
              \7/ /777\
               - -------

          Board: Wind River Dev Kit MP8
      CPU Count: 8
 OS Memory Size: 1899MB
ED&R Policy Mode: Deployed

Adding 5290 symbols for standalone.

[vxWorks]# i
  NAME          TID        PRI   STATUS       PC          ERRNO  CPU #
---------- ---------------- --- ---------- ---------------- ------- -----
tJobTask    40104cdbc0        0 PEND       401020c83c           0     -
tExcTask    40102a073c        0 PEND       401020c83c           0     -
tLogTask    40104d01d8        0 PEND       401020b0f0           0     -
tShell0     40105c1d30        1 READY      4010215e08           0     0
ipcom_tick> 401057a990       20 PEND       401020c83c           0     -
tVxdbgTask  401057dc20       25 PEND       401020c83c           0     -
tNet0       40104d3b78       50 PEND       401020c2b4           0     -
ipcom_sysl> 40104c9810       50 PEND       401020d3d4           0     -
tNetConf    40105a6e40       50 PEND       401020c83c           0     -
miiBusMoni> 40104d5e08      252 DELAY      4010215640           0     -
ipcom_egd   4010583c20      255 DELAY      4010215640           0     -
tIdleTask0  40102a2fb0      287 READY      401020c004           0     -
tIdleTask1  40102a7220      287 READY      401020c00c           0     1
tIdleTask2  40102ab490      287 READY      401020c004           0     2
tIdleTask3  40102afb20      287 READY      401020c004           0     3
tIdleTask4  40102b1700      287 READY      401020c004           0     4
tIdleTask5  40102b2440      287 READY      401020c004           0     5
tIdleTask6  40102a4620      287 READY      401020c004           0     6
tIdleTask7  40102a4860      287 READY      401020c004           0     7
[vxWorks]#
```

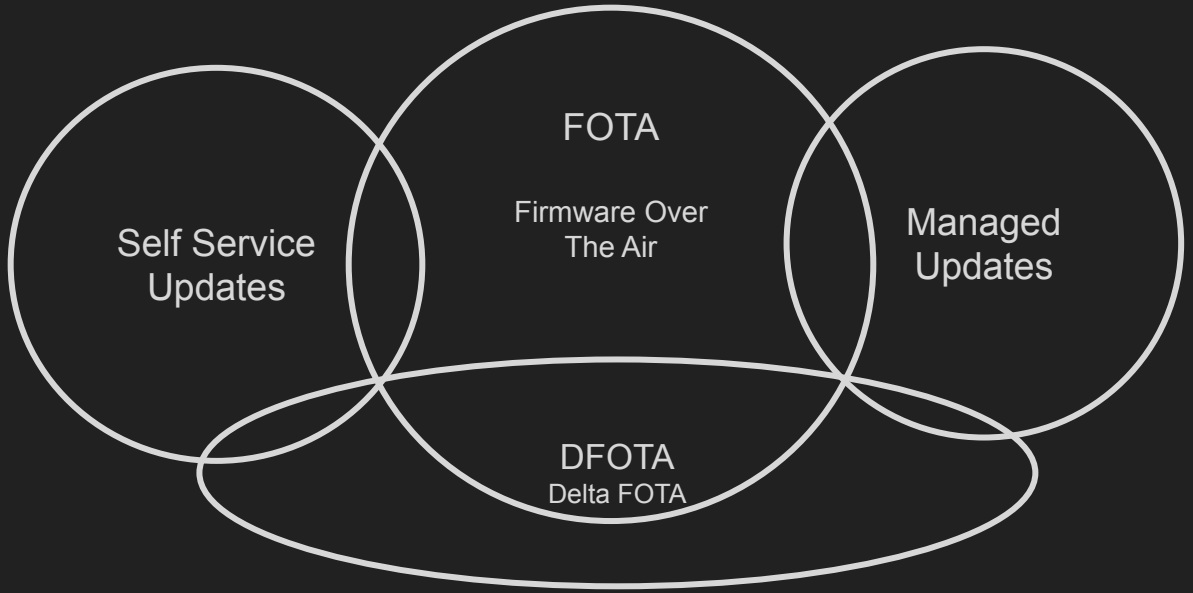
Bespoke Bare Metal Firmware

- You'll have to RE everything yourself
- Least complicated overall
  - No threads, no tasks, basically one big c file
- Very cheap → very prevalent
- Low power has security implications
  - Impacts on encryption and random number generation

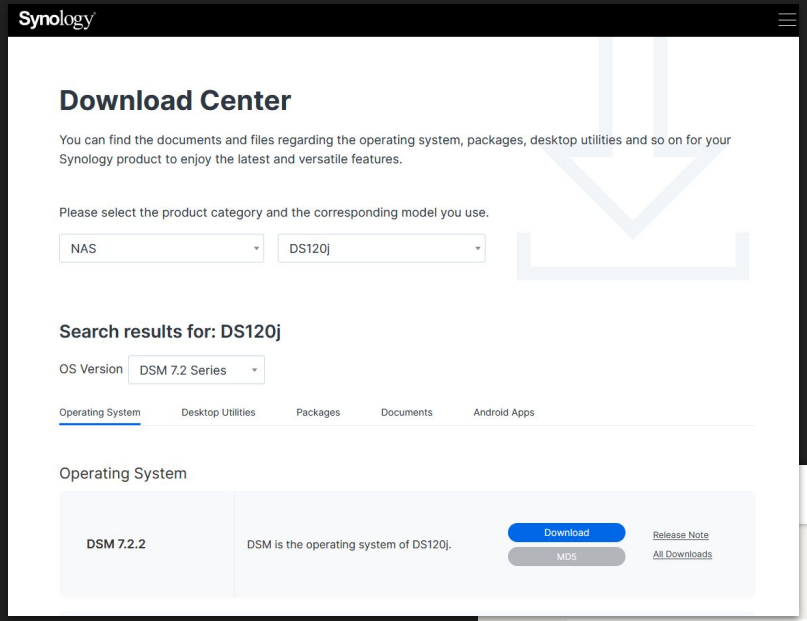


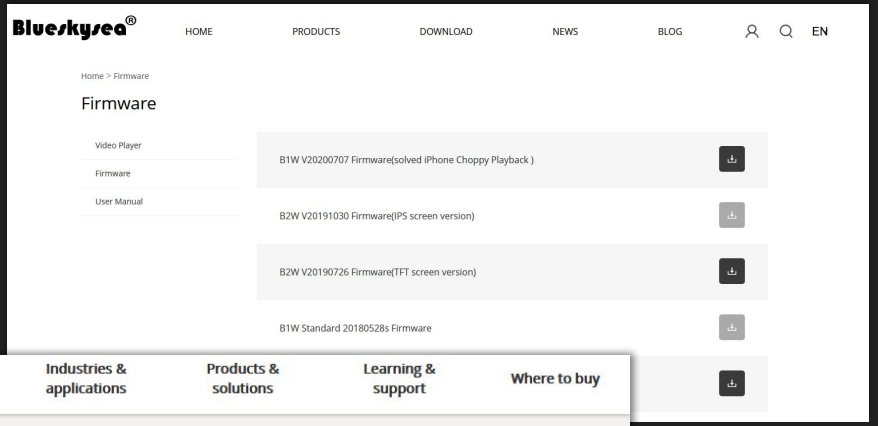
How to get firmware 101

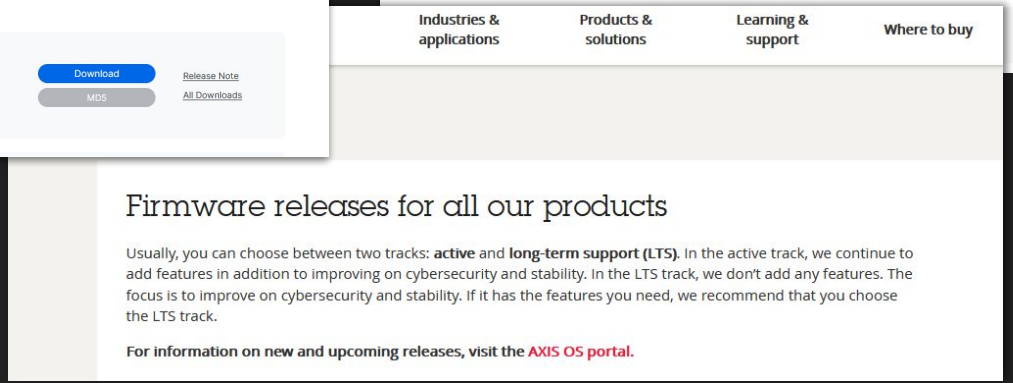
How do updates happen anyways



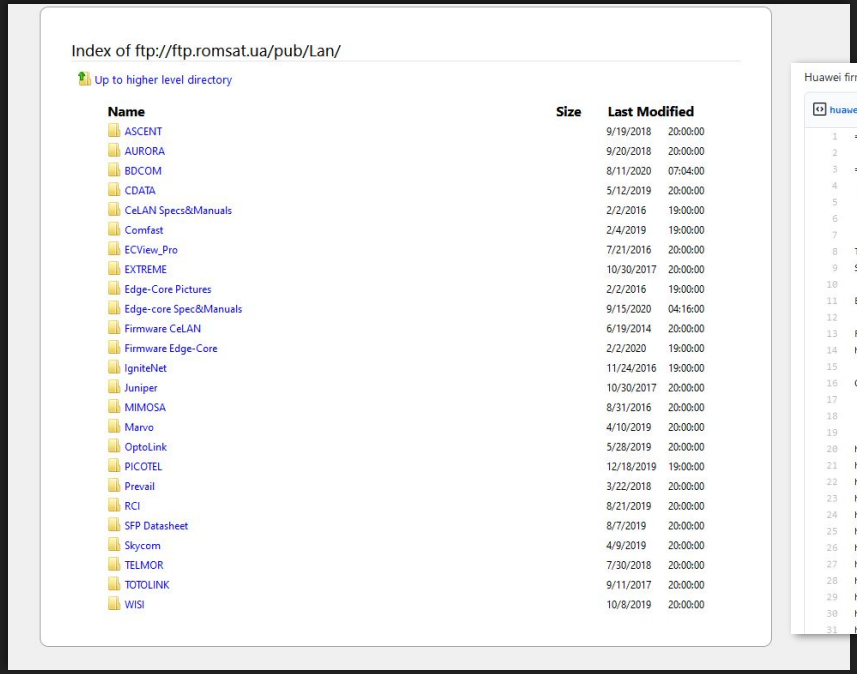
Download pages







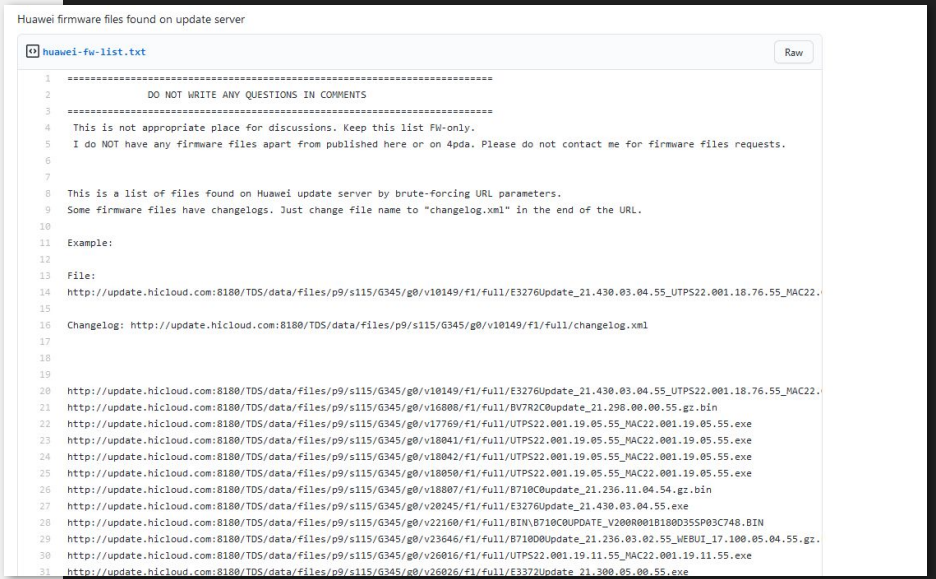
Other Online Exposure



Index of ftp://ftp.romsat.ua/pub/Lan/

Up to higher level directory

Name	Size	Last Modified
ASCENT		9/19/2018 20:00:00
AURORA		9/20/2018 20:00:00
BDCOM		8/11/2020 07:04:00
CDATA		5/12/2019 20:00:00
CeLAN Specs&Manuals		2/2/2016 19:00:00
Comfast		2/4/2019 19:00:00
ECView_Pro		7/21/2016 20:00:00
EXTREME		10/30/2017 20:00:00
Edge-Core Pictures		2/2/2016 19:00:00
Edge-core Spec&Manuals		9/15/2020 04:16:00
Firmware CeLAN		6/19/2014 20:00:00
Firmware Edge-Core		2/2/2020 19:00:00
IgniteNet		11/24/2016 19:00:00
Juniper		10/30/2017 20:00:00
MIMOSA		8/31/2016 20:00:00
Marvo		4/10/2019 20:00:00
OptoLink		5/28/2019 20:00:00
PICOTEL		12/18/2019 19:00:00
Prevail		3/22/2018 20:00:00
RCI		8/21/2019 20:00:00
SFP Datasheet		8/7/2019 20:00:00
Skycom		4/9/2019 20:00:00
TELMOR		7/30/2018 20:00:00
TOTOLINK		9/11/2017 20:00:00
WISI		10/8/2019 20:00:00



Huawei firmware files found on update server

huawei-fw-list.txt

Raw

```
================================================================================
              DO NOT WRITE ANY QUESTIONS IN COMMENTS
================================================================================
 This is not appropriate place for discussions. Keep this list FW-only.
 I do NOT have any firmware files apart from published here or on 4pda. Please do not contact me for firmware files requests.


This is a list of files found on Huawei update server by brute-forcing URL parameters.
Some firmware files have changelogs. Just change file name to "changelog.xml" in the end of the URL.

Example:

File:
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v10149/f1/full/E3276Update_21.430.03.04.55_UTPS22.001.18.76.55_MAC22.

Changelog: http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v10149/f1/full/changelog.xml



http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v10149/f1/full/E3276Update_21.430.03.04.55_UTPS22.001.18.76.55_MAC22.
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v16808/f1/full/BV7R2C0update_21.298.00.00.55.gz.bin
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v17769/f1/full/UTPS22.001.19.05.55_MAC22.001.19.05.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v18041/f1/full/UTPS22.001.19.05.55_MAC22.001.19.05.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v18042/f1/full/UTPS22.001.19.05.55_MAC22.001.19.05.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v18050/f1/full/UTPS22.001.19.05.55_MAC22.001.19.05.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v18807/f1/full/B710C0update_21.236.11.04.54.gz.bin
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v20245/f1/full/E3276Update_21.430.03.04.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v22160/f1/full/BIN\B710C0UPDATE_V200R001B180D35SP03C748.BIN
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v23646/f1/full/B710D0Update_21.236.03.02.55_WEBUI_17.100.05.04.55.gz.
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v26016/f1/full/UTPS22.001.19.11.55_MAC22.001.19.11.55.exe
http://update.hicloud.com:8180/TDS/data/files/p9/s115/G345/g0/v26026/f1/full/E3372Update_21.300.05.00.55.exe
```

Academic Datasets

- Scrapers for large academic datasets:
  - https://github.com/firmadyne/scraper/
  - https://github.com/WUSTL-CSPL/Firmware-Dataset

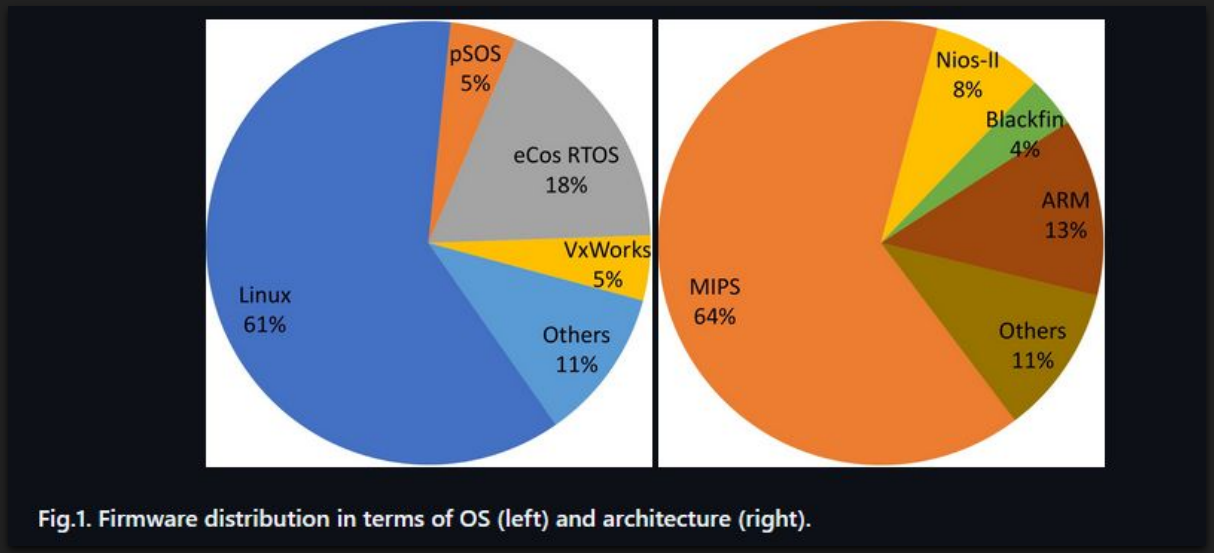


Fig.1. Firmware distribution in terms of OS (left) and architecture (right).

Graphs from https://github.com/WUSTL-CSPL/Firmware-Dataset

Dig Deeper with App Reverse Engineering

- Packaged with apps
- Update API/URL exposed via app
- Sometimes also exposes decryption keys and/or default passwords 👀

```
 Directory of [redacted]\assets\fota

09/20/2024  12:38 PM    <DIR>          .
09/20/2024  12:36 PM    <DIR>          ..
09/20/2024  12:36 PM            79,461 app__[redacted]ref_dfu_package.zip
06/25/2019  08:49 AM            78,824 BLE-nRF52832.bin
06/25/2019  08:49 AM               141 BLE-nRF52832.dat
09/20/2024  12:36 PM           106,564 DMS_L152.sim
06/25/2019  08:49 AM               156 manifest.json
```

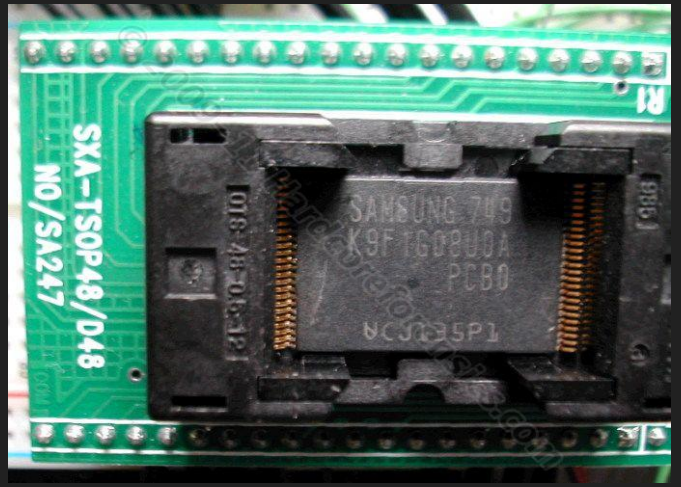
Example of Firmware Embedded in Android App

```
    private VerticalRangeSeekBar verticalBar;
    private int width;
    private String downLoadURL = "https://drive.google.com/file/d[redacted]iew?usp=sharing";
    private boolean sendShutter = true;
    private int HD_Mode_Style = 2;
}

/* JADX INFO: Access modifiers changed from: private */
public void stringRequestWithGet() {
    Volley.newRequestQueue(getApplicationContext()).add(new StringRequest(1, [redacted], new Response.Listener<String>(this
        final MainActivity this$0;

        {
            this.this$0 = this;
```

Examples of APIs and URLs in App Code

Other Methods

- Capture off the wire
- Pull it off a running device
- Read off the flash



Unpacking

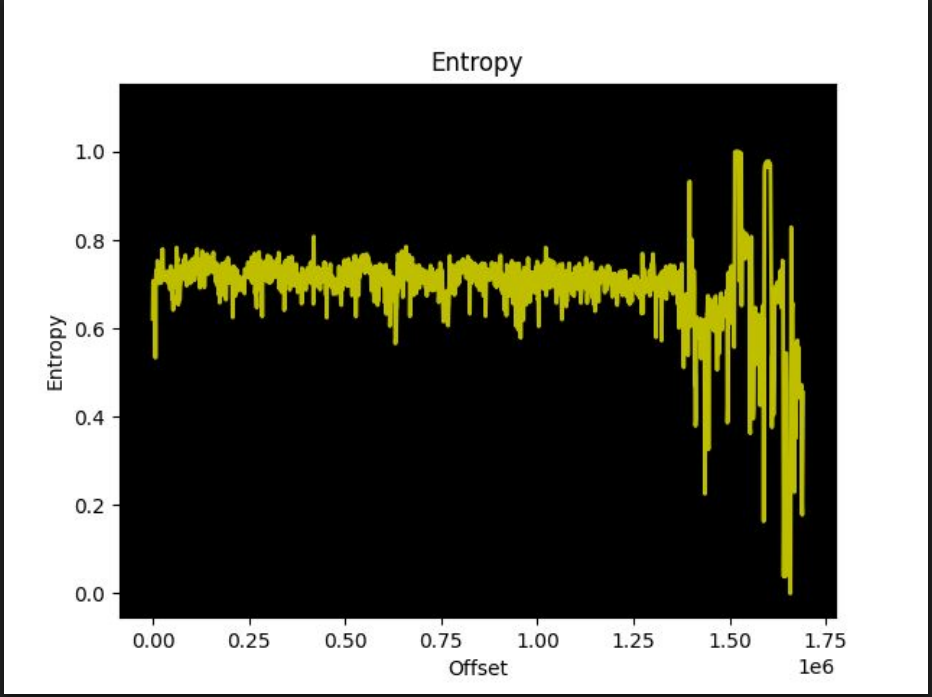
Known Formats

- File systems
  - UBIFS, SquashFS, Ext*, JFFS2, YAFFS, etc
  - Usually you can either mount them (best case) or extract them with FOSS (less good)
- Container formats
  - tar, zip, etc
- Flashing formats
  - Intel Hex, Motorola SREC
- Esoterica
  - Many proprietary formats have unpackers written by the community
  - If you write something, you should post it, even if it’s not perfect (I need to follow this advice)

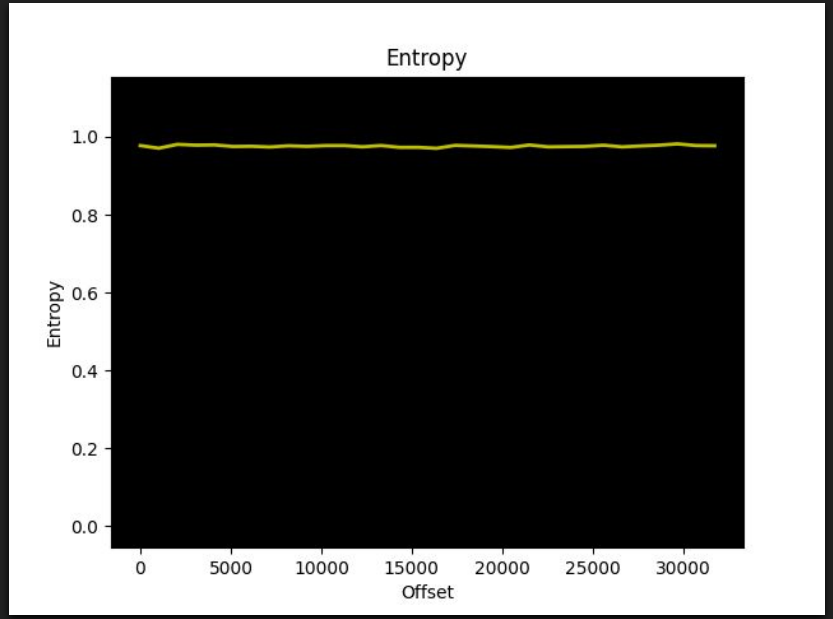
Unknown Formats

- Generic unpackers
  - ~~Binwalk: https://github.com/ReFirmLabs/binwalk/~~
    - ~~Currently maintained fork: https://github.com/OSPG/binwalk~~
    - Binwalk V3 in development!!! https://github.com/ReFirmLabs/binwalk/tree/binwalkv3
  - Unblob: https://github.com/onekey-sec/unblob
- Get Google'in for magic numbers
- Check entropy
  - ent
  - binwalk -E
  - unblob can do it too

A Moment on Entropy



Entropy graph of an uncompressed, unencrypted file



Entropy graph of a compressed file

Really Unknown Formats

- Make an unpacker
  - Kaitai.io is cool
  - Stare at it in a hex editor
- Think like an embedded systems engineer
  - Header?
  - File/Object Table?
  - List of Files/Objects?

```
/*
 * Legacy format image header,
 * all data in network byte order (aka natural aka bigendian).
 */
typedef struct image_header {
        uint32_t        ih_magic;       /* Image Header Magic Number    */
        uint32_t        ih_hcrc;        /* Image Header CRC Checksum    */
        uint32_t        ih_time;        /* Image Creation Timestamp     */
        uint32_t        ih_size;        /* Image Data Size              */
        uint32_t        ih_load;        /* Data  Load  Address          */
        uint32_t        ih_ep;          /* Entry Point Address          */
        uint32_t        ih_dcrc;        /* Image Data CRC Checksum      */
        uint8_t         ih_os;          /* Operating System             */
        uint8_t         ih_arch;        /* CPU architecture             */
        uint8_t         ih_type;        /* Image Type                   */
        uint8_t         ih_comp;        /* Compression Type             */
        uint8_t         ih_name[IH_NMLEN];      /* Image Name           */
} image_header_t;
```

Analysis

Tips for Embedded Linux

- Network testing
  - Open ports and services?
  - shodan.io & censys can be used to get an idea of typical configurations
- Existing credentials, documented and… less documented
  - RTFM; RTWFM
- Software components
  - N-day CVEs
- Update mechanisms
  - CRCs, hashes, signing
  - Safe parsing of invalid formats

Some rad tools

- Emulation
  - QEMU: https://gitlab.com/qemu-project/qemu
  - Unicorn: https://github.com/unicorn-engine/unicorn
  - Firmadyne (2016): https://github.com/firmadyne/firmadyne
  - FirmAE (2020): https://github.com/pr0v3rbs/FirmAE
- End to end analysis with EMBA
  - Repo: https://github.com/e-m-b-a/emba
  - Unpacking, OS detection, Arch detection
  - Static and emulated dynamic analysis
  - Configuration analysis
  - Surface level SBOM + CVEs

The Conspiracy Board

Sandia Labs:
Reverse Engineering ICS Field Devices

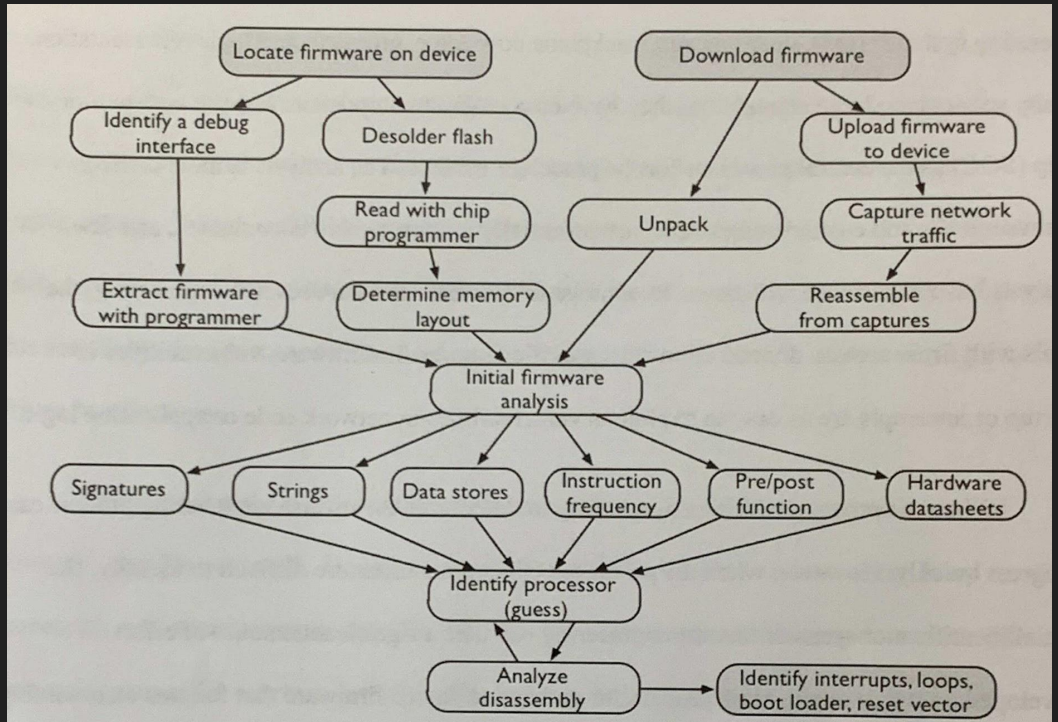


Figure 6. Process for reverse engineering embedded device firmware.

Getting the Firmware

We explored four methods of obtaining firmware—

RTOS and Bare Metal

- Identify architecture
  - Identify the chip it’s running on (fccid.io may help)
  - binwalk -A
- Identify base addresses
  - Use the datasheet for the chip to start off
  - Intel Hex and SREC include addresses, you can import them right to Ghidra
  - Generic algorithm outlined in POC||GTFO 21:13 by EVM
- Identify entry/vector table
- Start looking for symbol tables/logging strings
- CMSIS System View Description (SVD)
  - Peripheral mapping for ARM Cortex-M

Questions?

Thank you!

Special thanks to Larry Pesce and Stephanie Pirman