EURECOM Sophia Antipolis

Quarkslab

ESPwn32: Hacking with ESP32 System-on-Chips

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Who are we ?

Romain Cayre, EURECOM

- maintainer of *Mirage*, a popular BLE swiss-army tool
- loves *cross-protocol attacks* (*Wazabee*)

Damien Cauquil, Quarkslab

- maintainer of *Btlejack*, another BLE swiss-army tool
- loves reversing stuff, including *embedded systems*

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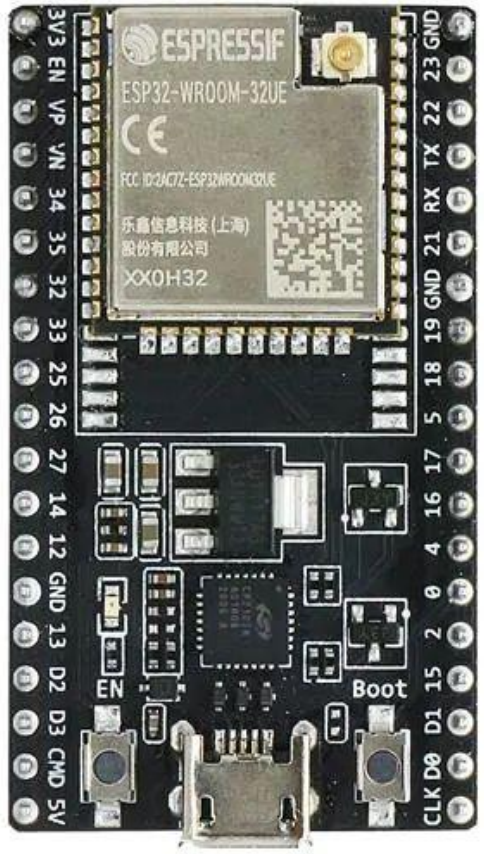
Introduction

Enter the ESP32 world !

- **Cheap** and **lightweight** SoCs
- Commonly used for **IoT devices**
- Provides **WiFi**, **Bluetooth Low Energy** / **Bluetooth BR/EDR**
- **Tensilica Xtensa** (ESP32, ESP32-S3) and **RISC-V** (ESP-C3)



Lots of questions ...

Is it possible to:

- **sniff** BLE communications ?
- **inject** an arbitrary BLE PDU ?
- **divert the radio PHY** to do *nasty* things ?
- support **other wireless protocols** ?
- turn any ESP32 into a **wireless hacking tool** ?

BLE controller hacking

ESP32 Internal ROMs

- 2 **specific ROM** regions
- These regions contain some **code and data**
- **Low-level API functions** to drive the BLE core
- **Problem**: how to hook these functions?

Hooking ROM functions

- ROM functions are called through `r_ip_funcs_p`
- `r_ip_funcs_p` is a **table of function pointers in RAM**

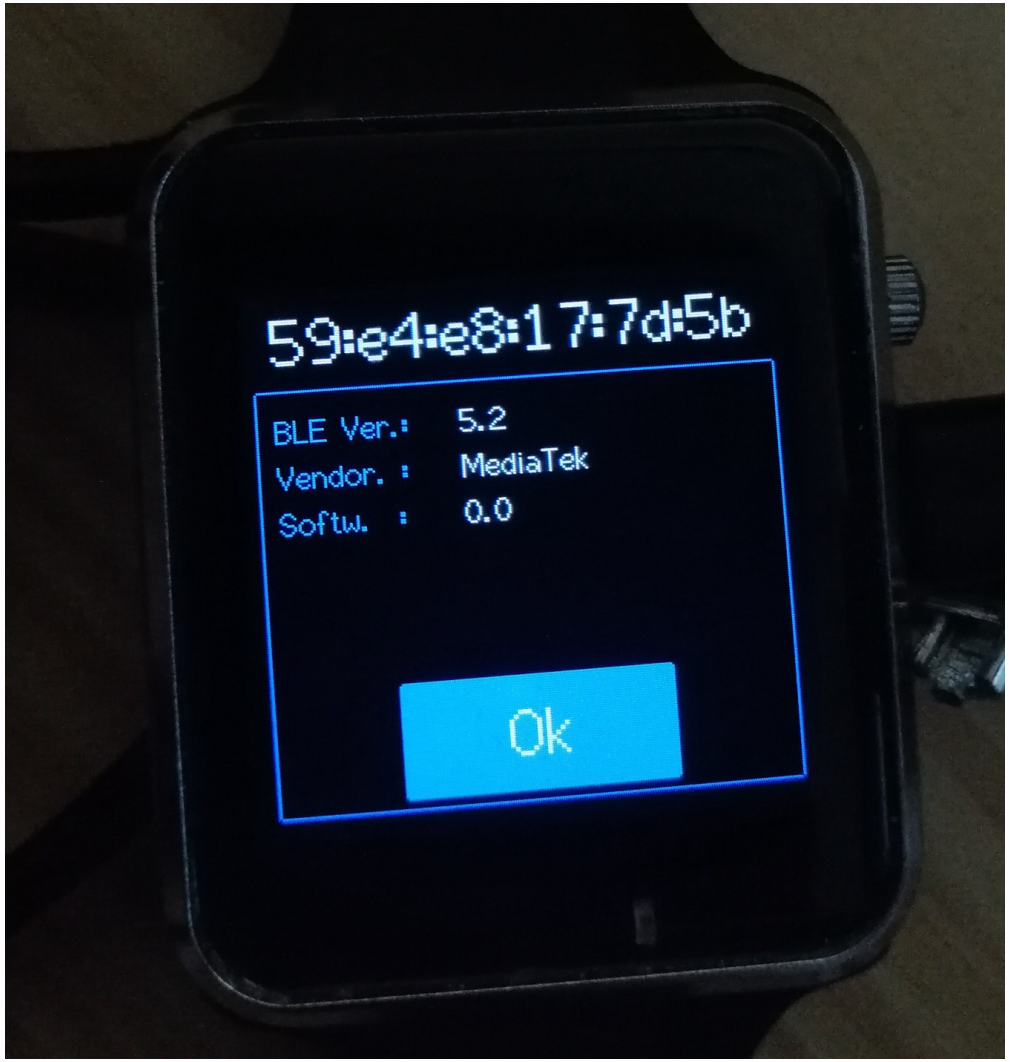
```
400ea86a 41 df e8      l32r      a4,->r_ip_funcs_p
400ea86d 48 04         l32i.n    a4=>r_ip_funcs_p,a4,0x0
400ea86f 42 d4 0a      addmi     a4,a4,0xa00
400ea872 42 24 2f      l32i      a4,a4,0xbc
400ea875 e0 04 00      callx8    a4
```

PDU sniffing & injection

- `r_lld_pdu_rx_handler()` : called whenever a **PDU is received**
- `r_lld_pdu_data_tx_push()` : used to **send a PDU**

LL_VERSION_IND injection

Remote BLE stack fingerprinting !



Hacking the physical layer

Cross-protocol attacks

Can ESP32 radio be diverted to interact with other protocols ?

- BLE uses **Gaussian Frequency Shift Keying** (GFSK) modulation…
- … like dozens of weak proprietary protocols !
  (**ANT** / ANT+ / ANT-FS, Riitek, MosArt, Logitech Unifying, Microsoft…)
- **WazaBee:** equivalence between O-QPSK (802.15.4) and 2Mbps GFSK (BLE 2M) → **ESP32-S3 / ESP32-C3 only**

Cross-protocol attacks

We **control** the following **low level radio parameters**:

- CRC verification
- frequency
- datarate
- synchronization word
- whitening / dewhitening
- input and output bitstreams

Arbitrary reception primitive

Hook `r_llm_start_scan_en()` and **modify RF parameters**

- force channel 39, disable channel hopping, configure synchronization word, datarate and test format
- disable whitening and CRC

Reuse `r_lld_pdu_rx_handler()` hook to **extract packets**

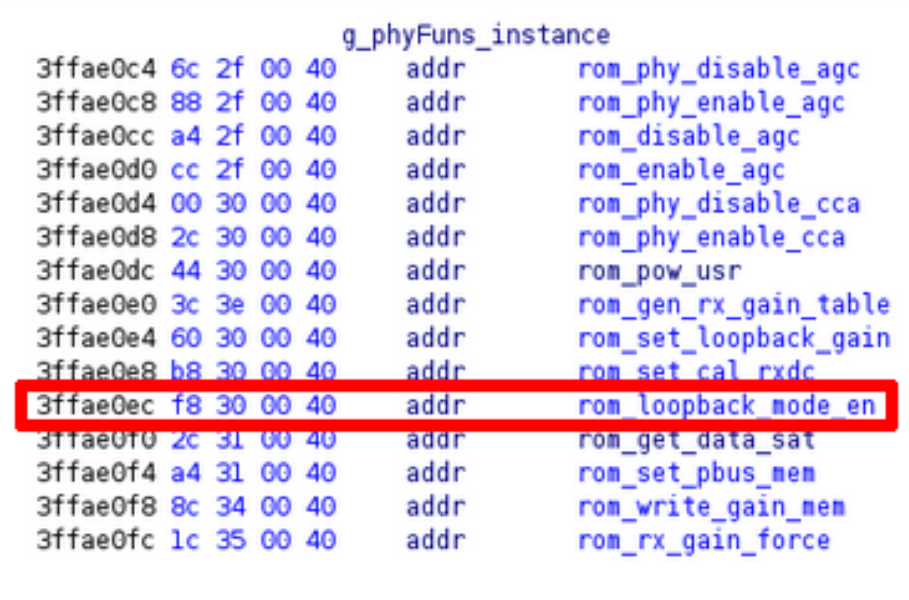
Arbitrary transmission primitive

- **Hook** `r_lld_pdu_tx_push` and **modify RF parameters**
- **Find the TX buffer** in memory and write a packet (PIP attack)
- Start radio in **TX test mode**

Demo time !

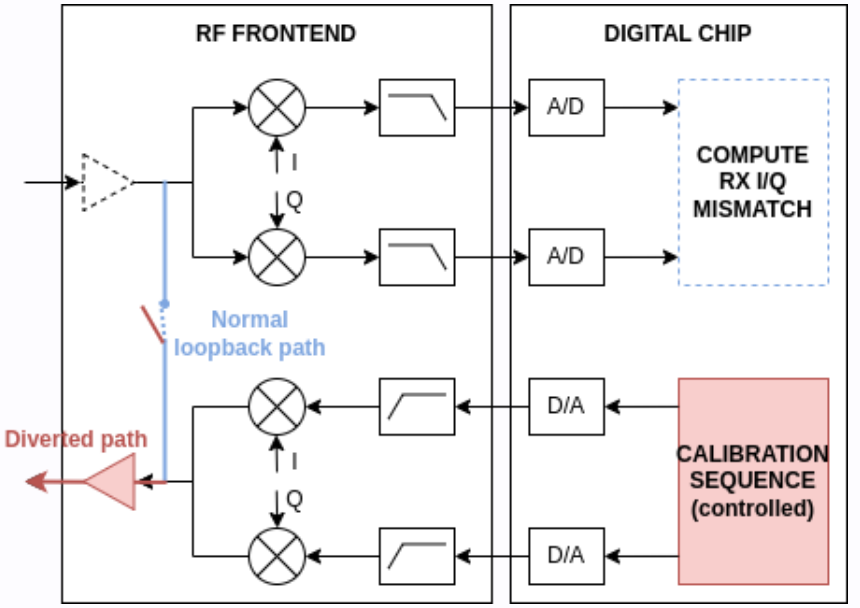
Can we go *deeper* ?

Hooking PHY functions



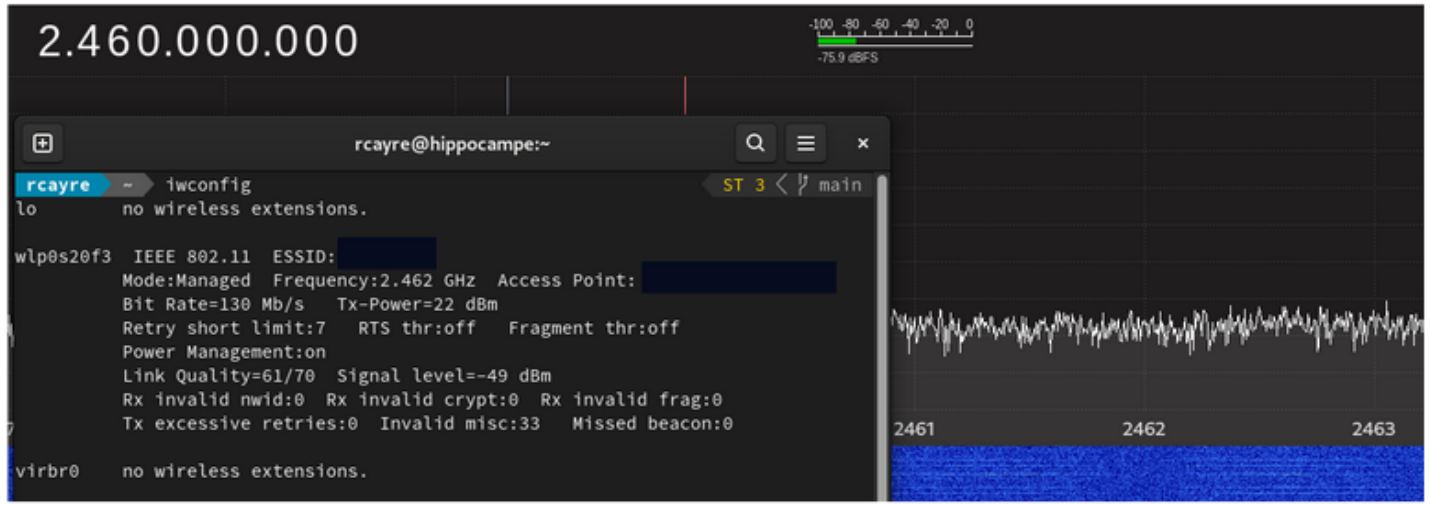
PHY functions stored in a specific function pointers array: `g_phyFuns` (pointer returned by `phy_get_romfuncs()`)

Diverting calibration process

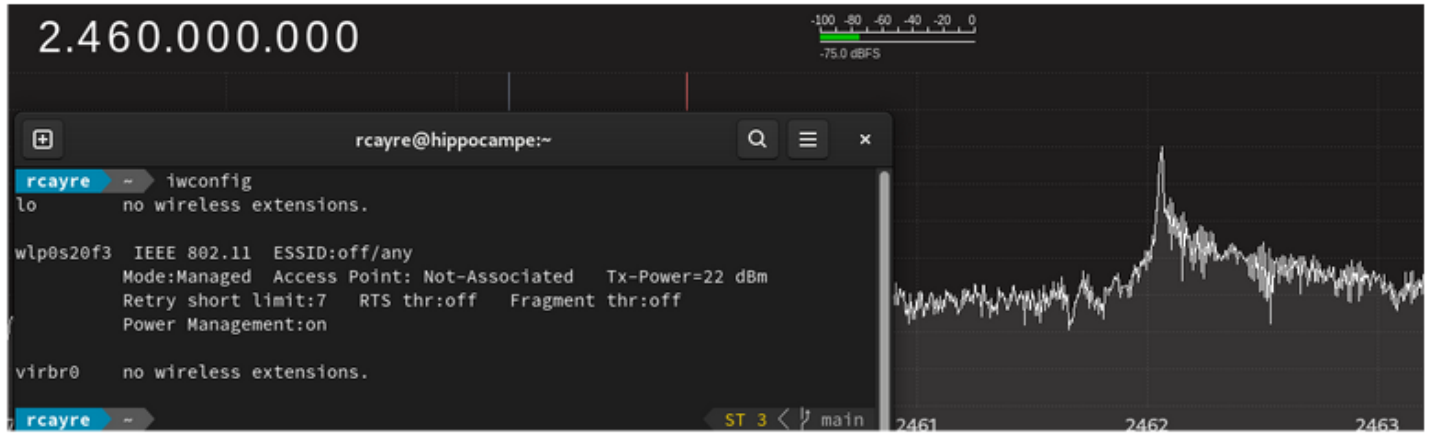


1. Disable HW frequency control (`phy_dis_hw_set_freq`)
2. Infinite loop when `rom_loopback_mode_en` is called
3. Have fun with signal control functions (frequency, gain) !

WiFi Jamming

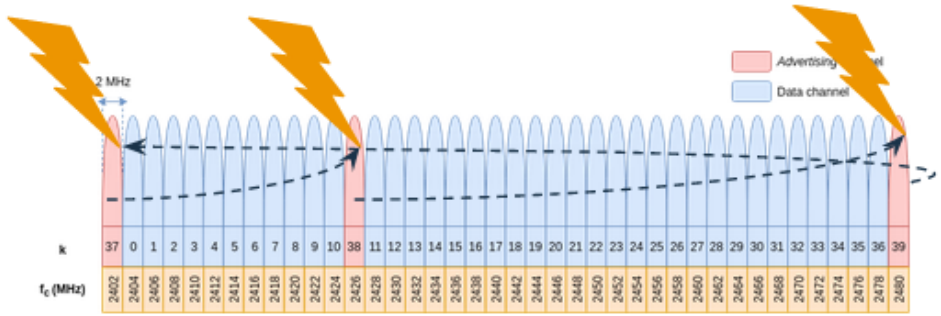


Jamming disabled

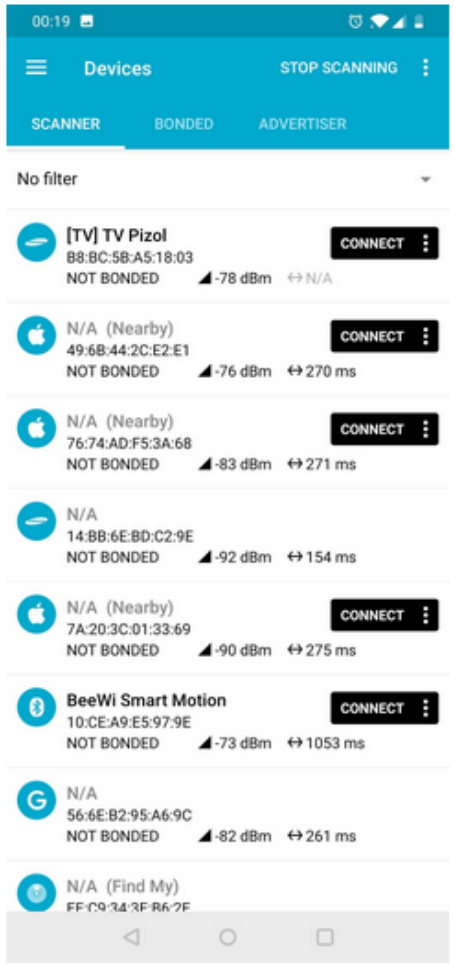


Jamming enabled

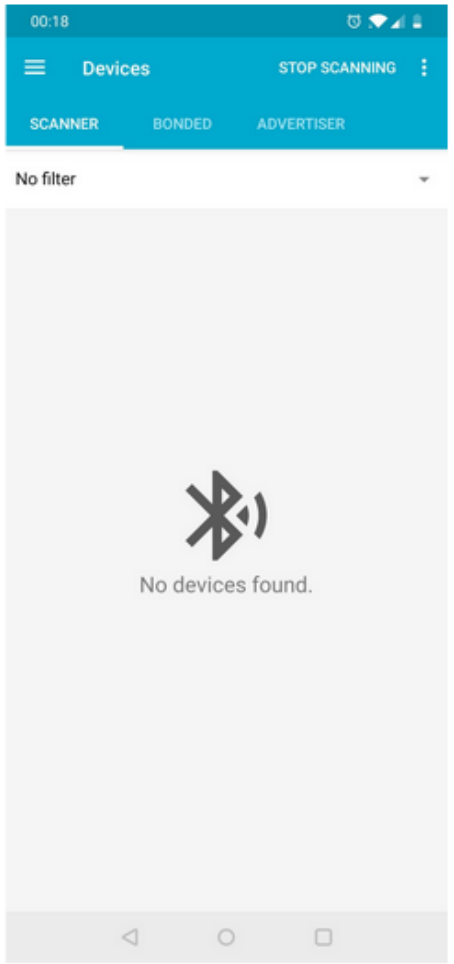
BLE Jamming




```
while (jammer) {
        // Set frequency to 2402 MHz (channel 37)
         set_chan_freq_sw_start(2,0,0);
        // Alter the parameters
        ram_start_tx_tone(1,0,10,0,0,0);

        // Set frequency to 2426 MHz (channel 38)
        set_chan_freq_sw_start(26,0,0);
        ram_start_tx_tone(1,0,10,0,0,0)

        // Set frequency to 2480 MHz (channel 39)
        set_chan_freq_sw_start(80,0,0);
        ram_start_tx_tone(1,0,10,0,0,0);

}
```



Jamming disabled



Jamming enabled

BLE Jamming - demo

Conclusion

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Takeaways

- on the fly BLE PDU monitoring, modification & injection
- cross-protocol reception and transmission
- multi channel jamming / covert channel

What's next ?

- Direct control over RF: raw IQ reception / transmission ?

Q/A time

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Thank you !