Experiences from developing a Wi-Fi HaLow shield for an ESP32 Board

3rd Wi-Fi HaLow in Europe Workshop, Bern

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06.02.2026

Goal

Develop the first EU-compatible Wi-Fi HaLow shield for ESP32

- Develop hardware of shield based on **Newracom WHM500A** Wi-Fi HaLow Module with **NRC7394** SoC to assess **Wi-Fi HaLow performance and energy consumption** in a realistic embedded setting

- Develop set of simple **AT-Command Wrappers** (for simple implementation of own Test-Applications on ESP32 in C running on FreeRTOS)

- Develop **test application / functions** (periodic data transmission, throughput test) based on AT-Command Wrappers

ESP32-DEVKITC-VE
(ESP32-WROVER-E)
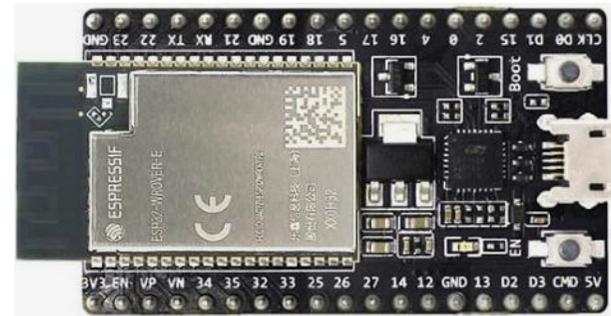
Background

- In [1] we **tested the Wi-Fi HaLow Performance** under EU/CH regulatory restrictions with the Newracom Eval-Kit (Raspberry Pi) at **1 MHz Channel-Bandwidth**

- Maximum data throughput: **2.3 Mbit/s**

- With **duty-cycle (DC) limitation of 2.8 %** for STA maximum mean data throughput: **64 kbit/s**

- Range Indoor: **3 Floors** (130 kbit/s without DC limitation)

- Range urban outdoor: **230 m** (110 kbit/s without DC limitation)

- Wi-Fi HaLow shield developed in this project uses ESP32 → No Driver available, must use AT-commands
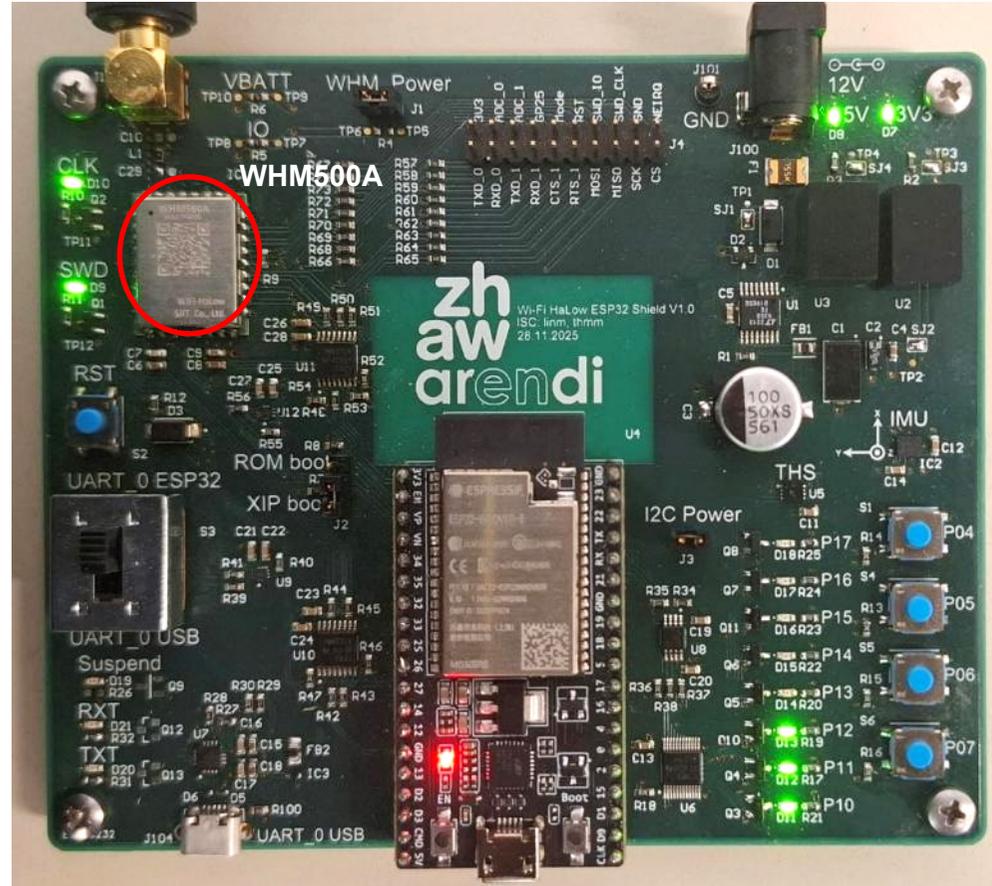

Newracom WHM500A EVK

Wi-Fi HaLow Shield for ESP32: Block Diagram
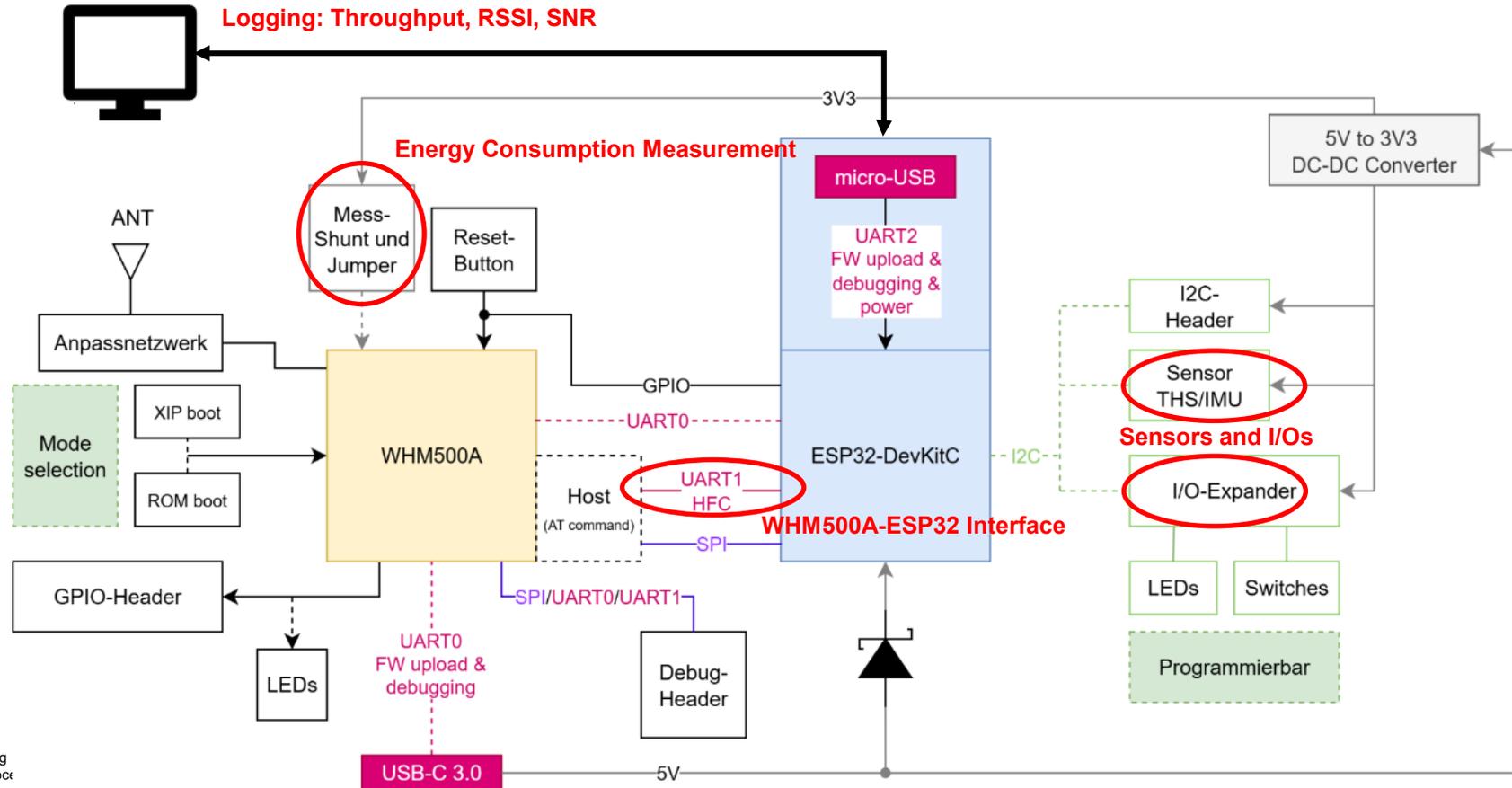
Wi-Fi HaLow Shield for ESP32: Hardware

AT-Command Wrappers

Execution of wrappers and AT commands

- The AT-Engine task handles the AT commands, there is only one task instance

- Multiple tasks may use AT-Command wrappers simultaneously. The **AT-Engine ensures** that the **AT commands** associated with the AT command wrappers **are not interrupted**
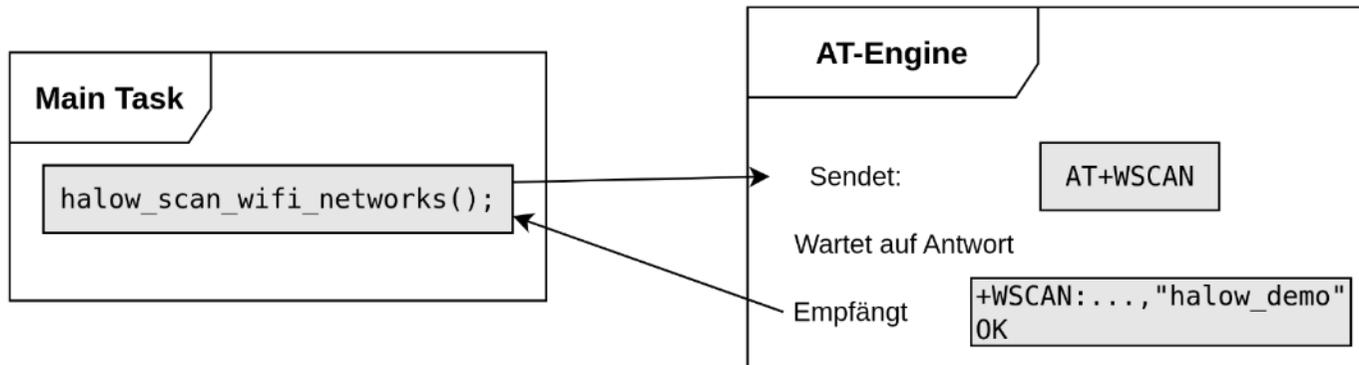
AT-Command Wrappers

Implemented AT-Command Wrappers

Read status of WHM module
halow_at_status

Set baudrate und flow control
halow_at_uart

Scan Wi-Fi networks
halow_scan_wifi

Set and read IPv4 configuration
halow_set_ipv4_config
halow_get_ipv4_config

Set, read and terminate Wi-Fi connection
halow_set_wifi_connection
halow_get_wifi_connection
halow_disconnect_wifi

Set and read country code
halow_set_country_code
halow_get_country_code

Set and read transmit power
halow_set_duty_cycle
halow_get_duty_cycle

Configure AP mode
halow_setup_soft_ap

Read RSSI and SNR
halow_get_wifi_rssi

TCP socket functions
halow_create_tcp_socket
halow_connect_to_tcp_socket
halow_close_all_sockets
halow_send_tcp_data

Timeout settings
halow_set_wifi_timeout
halow_set_socket_timeout

Test Application

Implemented high-level Test Functions (do not respect duty-cycle limits)

- TCP data transmission test: TCP Packet (32 Bytes) sent every 200 ms

- TCP throughput test: Continuous TCP Packet transmission (1024 Bytes), limited to 1 Mbit/s (see later)

Implemented Management Functions

- Automatic Wi-Fi connection setup and re-establishment

- Passthrough mode for use of AT-CMD tool from Newracom (Graphical UI for AT-Command use) via ESP32
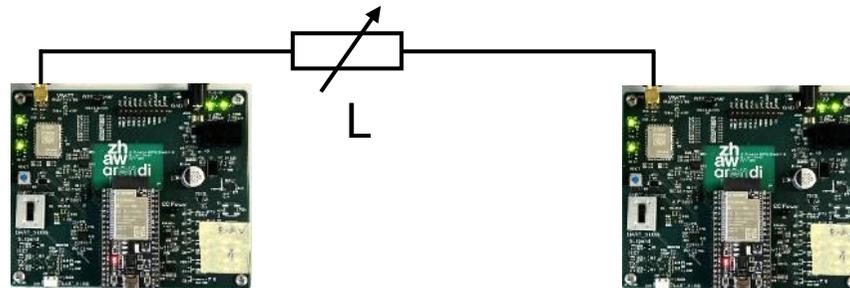
Link-Budget Test

Maximum coupling loss L$_{max}$ between TX and RX

- f_c = 863.5 MHz, BW = 1 MHz

- P_{tx_max} = 14 dBm, adaptive (auto mode)

- Transmission over Cable with attenuation, running TCP throughput test

Measured maximum coupling loss **L$_{max}$ = 112 dB** (Prx_min = -98 dBm)

Sanity check: In [1] P_{rx_min} = -101 dBm → ok

Throughput Test under 'ideal' Conditions

- ## TCP Throughput (AP and STA in close proximity)

  - $fc = 863.5$ MHz, BW = 1 MHz

  - Data transfer with 2 MBaud/s UART (transmitter and receiver)

  - Receiver determines throughput

  - Test results: Similar **throughput of 1 MBit/s as in tests with Newracom EVK** when using AT Commands over UART with 2 MBaud/s

```
[INFO AT Task] UART Throughput: 1040256.00 bits/sec
[INFO AT Task] UART Throughput: 998976.00 bits/sec
[INFO AT Task] UART Throughput: 1006528.00 bits/sec
[INFO AT Task] UART Throughput: 998592.00 bits/sec
[INFO AT Task] UART Throughput: 1019456.00 bits/sec
[INFO AT Task] UART Throughput: 993600.00 bits/sec
[INFO AT Task] UART Throughput: 1026432.00 bits/sec
[INFO AT Task] UART Throughput: 994624.00 bits/sec
[INFO AT Task] UART Throughput: 1017472.00 bits/sec
[INFO AT Task] UART Throughput: 1007808.00 bits/sec
[INFO AT Task] UART Throughput: 998976.00 bits/sec
```
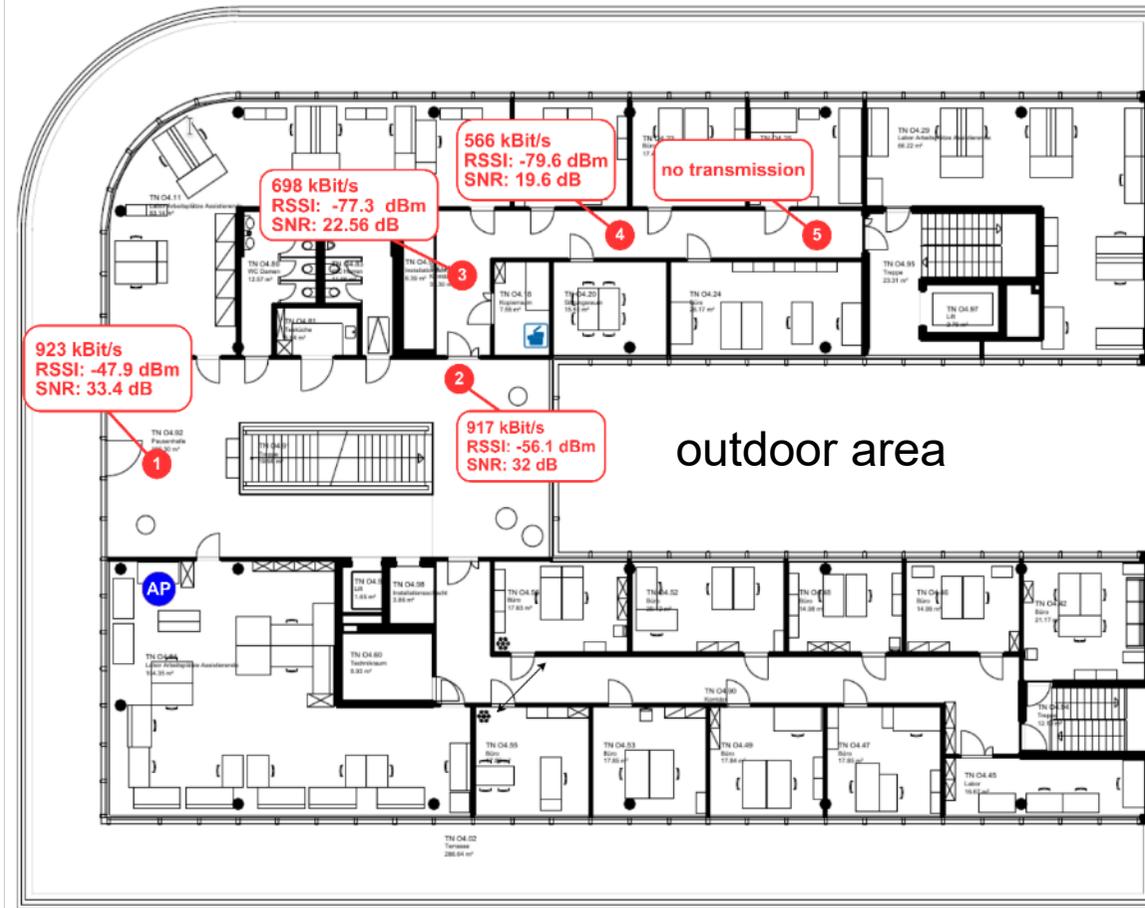
Limitations in Throughput Testing

TCP Throughput speed limitation of 1 Mbit/s due to UART at 2 MBaud/s

- Maximum UART speed of 2 MBaud/s for exchange of AT-Commands between ESP32 and WHM500A limits achievable Wi-Fi HaLow throughput

- UART Hardware Flow Control (HFC) used

- Alternative: Use of SPI for AT-Command transfer (not implemented)

Mobile STA

f_c = 863.5 MHz, BW = 1 MHz

Throughput and Range Test in Building: Across Floors

923 kBit/s
RSSI: -47.9 dBm
SNR: 33.4 dB

872 kBit/s
RSSI: -70.4 dBm
SNR: 26.6 dB

527 kBit/s
RSSI: -84.0 dBm
SNR: 14.84 dB

no transmission

no transmission

AP

TN 04

TN 03

TN 02

TN 01

TN 00

17 m

f_c = 863.5 MHz, BW = 1 MHz

References

[1] T. Barnes, V. Phimmasane, L. Sarperi, "Results from Tests with the Newracom NRC7394 Wifi HaLow SoC", 2nd Wifi HaLow in Europe Workshop, 22.01.2025, ZHAW, Winterthur, https://www.zhaw.ch/storage/engineering/institute-zentren/isc/Dateienablage_News/ZHAW_WiFi_HaLow_ISC_InEs_22.01.2025_V2.pdf