Lower Network Stack redesign

José I. Álamos (@jia200x)

HAW Hamburg

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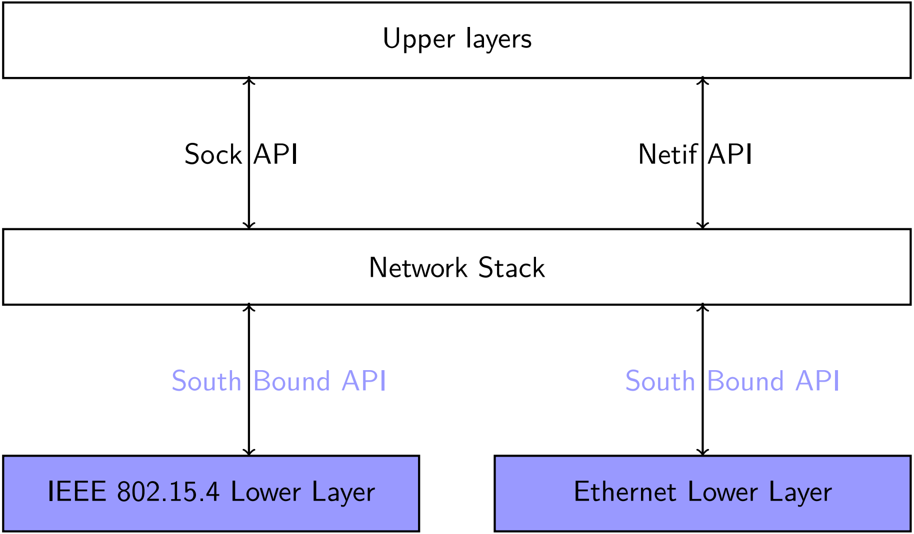
Scope


Upper layers
Sock API
Netif API
Network Stack
South Bound API
South Bound API
IEEE 802.15.4 Lower Layer
Ethernet Lower Layer

South-bound API requirements (OSI, communication)

- OpenThread: PHY (full L2 frame, PSDU)
  - IEEE 802.15.4 SubMAC (a.k.a "PHY with steroids")
- OpenWSN: RADIO (direct access to transceiver)
  - IEEE 802.15.4 Transceiver
- GNRC: LINK LAYER (full L3 frame, MSDU)
  - IEEE 802.15.4 MAC, Ethernet MAC, LoRaMAC
- LWIP: PHY (full L2 frame, PSDU)
  - Ethernet PHY, IEEE 802.15.4 SubMAC

State of IEEE 802.15.4 Link Layer

- Missing IEEE 802.15.4 MAC (only framing in `gnrc_netif_ieee802154`).
    - No Security (L2 encryption, authentication, etc)
    - Not standard with standard IEEE 802.15.4 devices
    - Missing Low Power friendly features (e.g Indirect Transmission, Slotted Mode)

State of IEEE 802.15.4 PHY

- `netdev` with one of `netdev_xxx` variants.
  - Not well defined for each network device type (who cares about retransmissions? CSMA-CA?) and PHY configurations (modulations, bands, etc).
  - It adds a generic layer where the lower layer is already known (`gnrc_netif_ieee802154`)
    - More boilerplate code, ROM usage (e.g `gnrc_netif`)
    - It rules out certain optimizations.

State of IEEE 802.15.4 RADIO

- `netdev` with one of `netdev_xxx` variants.
  - Too generic
    - Semantics of standarized IEEE 802.15.4 radios are well defined
    - NETOPTs... NETOPTs everywhere.
    - Some transceiver operations require heavy semantic overload (e.g `NETOPT_PRELOAD`)

State of IEEE 802.15.4 RADIO

- IRQ handling (Bottom Half Processing)
  - Call tree is not defined for the event callback. (See LoRaWan node ISR stack overflowed (#14962))
  - Makes strong assumptions on how the IRQ events should handled (`at86rf215`, `nrf52840`)
  - Code duplication between several network stacks (Most network stacks don't expect to do Bottom Half Processing)

State of IEEE 802.15.4 RADIO

- Pulls the whole PHY when only sub components are needed (e.g OpenWSN)
  - E.g MAC Information Base (MIB) and Physical Information Base (PIB) are usually handled by upper layers
- Not well defined for the same kind of devices (e.g `NETDEV_EVENT_TX_MEDIUM_BUSY`, `NETDEV_EVENT_CRC_ERROR`)
  - It makes network stack integration hard.

State of IEEE 802.15.4 RADIO

- “Hardware dependent” HAL: All radios are equal, but some radios are more equal than others.
  - TX with CCA, CSMA-CA or direct transmission depends on the radio
    - Poor QoS in `cc2538`, `nrf52840`, etc
  - Some radios block on send.
- Hard to test

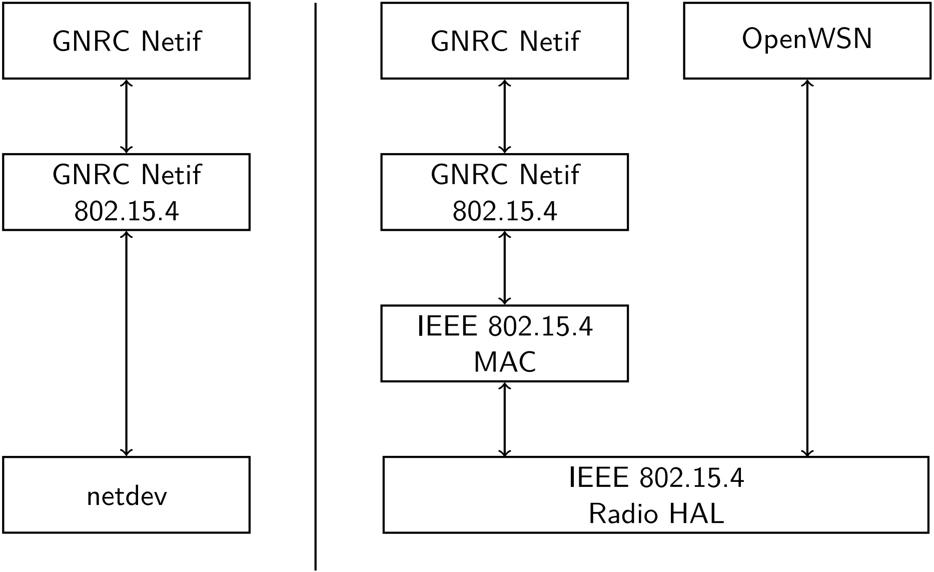
Proposals (so far!)

- RADIO: IEEE 802.15.4 Radio HAL
  - Community driven RDM: #13943
    - At least 7 members of the RIOT community contributed with the requirements, design and review.
  - Implementation: #14371
- PHY: IEEE 802.15.4 SubMAC
  - RFC: #13376
  - Implementation: #14950

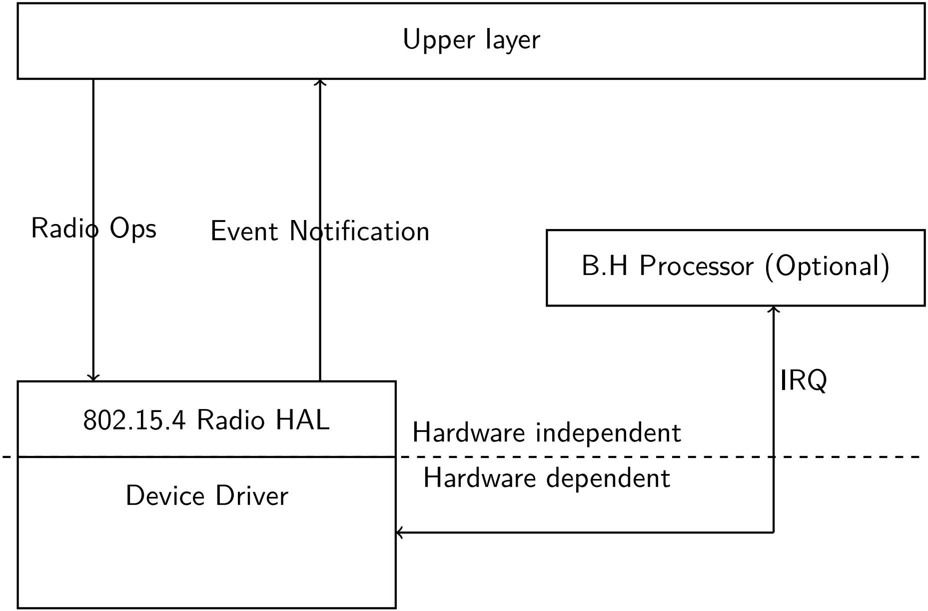
IEEE 802.15.4 Radio HAL

- Lightweight API to provide uniform access to IEEE 802.15.4 compatible radios.
- Addresses community requirements:
  - Fully asynchronous (low power friendly, low memory footprint)
  - Well defined access to optional hardware acceleration (CSMA-CA with frame retransmissions, Auto CCA, etc).
  - Compatible with the requirements of current network stacks (OpenWSN, GNRC, etc)
  - Leaves PIB and MIB to upper layers.

Radio HAL Architecture (Old vs New)



Radio HAL components



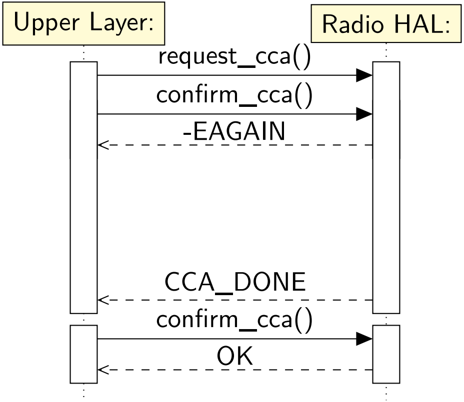
Radio Ops

- Exposes common operations to control IEEE 802.15.4 devices. Some functions are similar to those available in netdev (e.g recv mechanism).
  - Set the transceiver state
  - Set the PHY configuration (channel, tx power, etc)
  - Load and transmit a frame
  - Check if a hardware capability is supported (frame retransmissions, CSMA-CA, etc)

Request/Confirm pattern

- Blocking operations are defined by `request` and `confirm` functions.
  1. `request_xxx` requests an operation.
  2. Returns 0 if the operation was requested successfully. Otherwise, negative errno.
  3. If request was OK, `confirm_xxx` indicates the upper layer that the request finished (-EAGAIN or 0)
- The device MAY generate an event to indicate when to call the respective `confirm_xxx`

Request/Confirm pattern



Request/Confirm pattern

This allows to use the API with polling mode (e.g polling `confirm_xxx` until it returns 0) or interrupts (e.g waiting for the specific event before calling `confirm_xxx`)

Event Notification

- Informs the upper layer about a specific event (TX done, CCA done, RX done, ACK timeout, etc)
- For certain radios this can occur in ISR context.
- IRQ processing is out of the scope of the Radio HAL and it's up to the implementor of the bootstrap code (e.g `auto_init`).

Implementation status

- API was merged (#14371)
- `cc2538` and `nrf802154` in master.
- Tracker in #14792.
  - Help wanted!!

Memory footprint

	ROM			RAM		
Radio	netdev	radio_hal	Diff	netdev	radio_hal	Diff
nrf802154*	1585	1819	14%	305	318	4%
at86rf2xx**	3800	2158	-43%	72	40	-44%
cc2538	2622	2447	-8%	48	17	-64%

- *: the `netdev` version doesn't implement all CCA variants and power functions.
- **: Doesn't include SubGHz variants

Some comments: Function pointers vs Switch-Case

- It was decided to use Function Pointers instead of switch cases
  - In best case switch-cases might be implemented as a jump table (if indexes are ordered and there are only function calls)
  - For most cases, resulting code size and execution time might increase
- Easier to maintain.

See https://embeddedgurus.com/stack-overflow/2010/04/efficient-c-tip-12-be-wary-of-switch-statements/

IEEE 892.15.4 SubMAC

- Common layer that unifies common IEEE 802.15.4 lower MAC operations.
- In a nutshell, it provides "hardware independent" IEEE 802.15.4 compliant data transmission.
  - CSMA-CA Algorithm
  - Frame retransmissions
- It also stores the PIB (and some MIB attributes like CSMA-CA parameters)
- It uses the IEEE 802.15.4 Radio HAL and fill the gaps if the radio doesn't support a specific hardware acceleration (e.g frame retransmissions).

IEEE 802.15.4 SubMAC API

- Send PSDU (Full L2 frame) with CSMA-CA (and possibly retransmissions)
- Set PIB parameters (channel, page, TX power)
  - All hardware independent validations are done here, not in the radios
- Set "MAC" states
- Allocation of frames is up to the network stack (same as `netdev`).

Implementation status

- PR in #14950
- Includes a `netdev_ieeee802154_submac` transition layer to ease migration.
  - It implements a “generic IEEE 802.15.4 netdev device with CSMA-CA and frame retransmissions”
  - Fully compatible with GNRC, OpenThread, LWIP, etc.

Results

- Ping between `cc2538_rf` and `at86rf2xx`
- 1024 bytes payload
- 170 ms interval
- 1000 packets

Direct transmission

— fe80::2068:3123:fe42:2e25 PING statistics —

1000 packets transmitted, 626 packets received, 37% packet loss

round-trip min/avg/max = 129.693/140.842/155.274 ms

CSMA-CA and retransmissions

— fe80::2068:3123:fe42:2e25 PING statistics —
1000 packets transmitted, 1000 packets received, 0% packet loss
round-trip min/avg/max = 133.318/145.909/161.423 ms

Miscellaneous

- OpenThread works out of the box on CC2538! (the same is expected for the others)
- LWIP and the other stacks should work too.

Comments?

Next steps?

1. What about the other low layers? (e.g BLE)
2. IEEE 802.15.4 MAC
   - IEEE Indirect Transmission
   - IEEE 802.15.4 security (L2 encryption, Section 7.5.8 from IEEE 802.15.4 2006 standard)
   - TSCH (OpenWSN? "GNRC TSCH"?)
   - Reuse Link Layer from OpenWSN and/or OpenThread
3. Descriptors allocation + bootstrap
   - Unify allocation?
   - IRQ handling? Event handler?
   - Common auto_init for all stacks?
4. How to send L2 data?
   - Do we need an L2 interface?
5. GNRC: One stack per netif?
6. Frame buffers vs zero copy.