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August 24-28, 2020

ieee802154 and rpld

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IoT Microconference

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Who am I

- FOSS developer since 2006
- EFL developer and release manager
- Linux kernel ieee802154 subsystem maintainer

Agenda

- IPv6 over LoWPAN
- Linux-wpan
- rpld

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IPv6 over LoWPAN (6LoWPAN)

Products

- Products with IEEE 802.15.4 transceivers (using 6LoWPAN, newer ZigBee profiles or OpenThread):
- Nest devices (e.g. thermostat, protect, etc)
- Google WiFi / OnHub router
- IKEA Tradfri system
- Philips Hue light system
- And many, many more

Motivation 6LoWPAN

- “Things” might have restricted wireless connectivity
- Using IPv6 instead of something proprietary allows the **usage of existing and proven protocols** driving the Internet
- **But** unmodified TCP/IP protocol headers can clash with MTU limitations
- Things often only need to transfer small amounts of data

IEEE 802.15.4

- IEEE specifications for Low-Rate Wireless ~~Personal Area~~ Networks (LoWPAN)
- Not only low-rate, but also low-power
- PHY and MAC layer with star and peer-to-peer topologies
- Addressing but no routing defined
- Mesh routing possible with layers on top
- Designed for small sensors to run months/years on battery with the right duty cycle
- **127 bytes MTU** and 250 kbit/s
- Often mixed-up with ZigBee as it is used as PHY and MAC layer
- Compared to Bluetooth it is older than BTLE and less complex

6LoWPAN

- Physical and MAC layer defined by IEEE 802.15.4
- Series of IETF specifications from 2007 onwards (RFCs 4944, 6282, etc)
- Goal was to use IPv6 in sensor networks based on IEEE 802.15.4
- Direct IP addressing of nodes

- Adaptation layer between data-link and network layer
- **Address auto-configuration**
- **Frame encapsulation and fragmentation**
- **Header compression**

L5 Application Layer	Application	Application
L4 Transport Layer	TCP | UDP | ICMP	UDP | ICMPv6
L3 Network Layer	IP	IPv6
		6LoWPAN
L2 Data Link Layer	Ethernet MAC	IEEE 802.15.4 MAC
L1 Physical Layer	Ethernet PHY	IEEE 802.15.4 PHY

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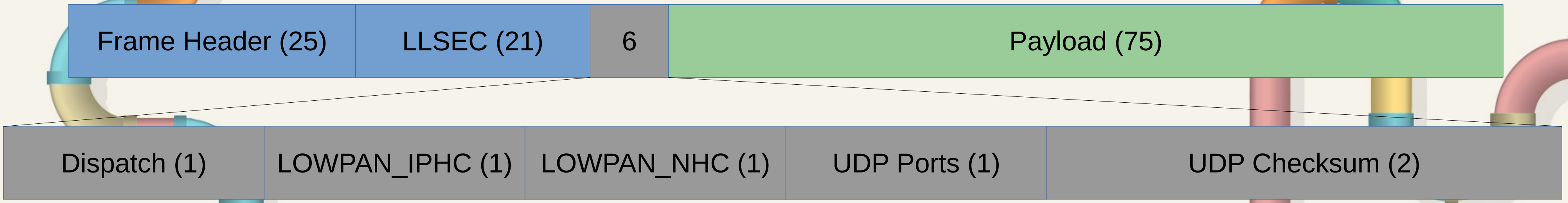
The Header Size Problem

- Worst-case scenario calculations
- Maximum frame size in IEEE 802.15.4: 127 bytes
- Reduced by the max. frame header (25 bytes): 102 bytes
- Reduced by highest link-layer security (21 bytes): 81 bytes
- Reduced by standard IPv6 header (40 bytes): 41 bytes
- Reduced by standard UDP header (8 bytes): 33 bytes
- This leaves only **33 bytes** for actual payload
- The rest of the space is used by headers (~ 3:1 ratio)

The Header Size Solution

- IPv6 with link-local and UDP on top
- IPHC with NHC for UDP
- The 48 bytes IPv6 + UDP header could in the best cases be reduced to 6 bytes
- That allows for a payload of **75 bytes** (~ 2:3 ratio)



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Linux-wpan

Why linux-wpan?

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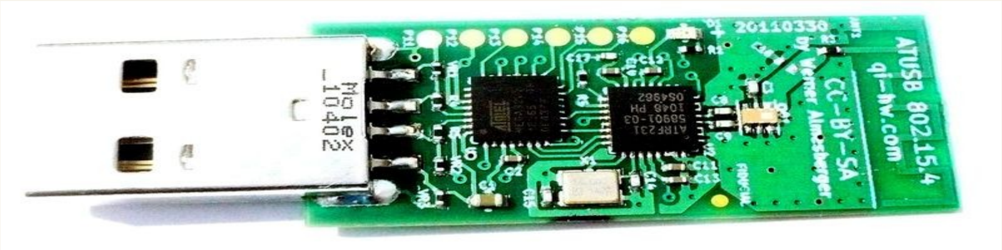
- Goal: IEEE 802.15.4 and 6LoWPAN support in mainline
- Platforms already running Linux would benefit from native IEEE 802.15.4 and 6LoWPAN subsystems
- IEEE 802.15.4 transceivers can easily be added to existing hardware designs (SPI + few GPIOs)
- Battery powered sensors are more likely to run a RTOS like RIOT, Contiki or Zephyr, but they need a border router
- Started in 2008 as linux-zigbee project, from 2012 mainline (renamed to linux-wpan)

Development Boards

- Raspberry Pi’s with Openlabs shield (AT86RF233)
- Ci40 Creator (CA-8210)
- Transceivers can be hooked up via SPI
  (drivers have devicetree bindings)
- ATUSB USB dongle



Network Interfaces

- The wpan0 interface shows up automatically
- Ieee802154 specific configuration over netlink, e.g. with wpan-tools
- Setting up the basic parameters:

  $ ip link set lowpan0 down

  $ ip link set wpan0 down

  $ iwpan dev wpan0 set pan_id 0xabcd

  $ iwpan phy phy0 set channel 0 26

  $ ip link add link wpan0 name lowpan0 type lowpan

  $ ip link set wpan0 up

  $ ip link set lowpan0 up

Setting up the interface in promiscuous mode:

$ iwpan dev wpan0 del

$ iwpan phy phy0 interface add monitor%d type monitor

$ iwpan phy phy0 set channel 0 26

$ ip link set monitor0 up

$ wireshark -i monitor0

- No automatic channel hopping (changing the channel manually in the background is possible)

Socket Interfaces

- AF_INET6 Socket
- Can be used like a normal IPv6 socket
- Transparently handled

```
sd = socket(PF_INET6,
SOCK_DGRAM, 0);

dst.sin6_family = AF_INET6;

sendto(sd, ...);
```

- AF_IEEE802154 Socket
- Direct IEEE 802.15.4 communication
- Short and extended addressing schemes as well as network PAN ID handling

```
sd = socket(PF_IEEE802154, SOCK_DGRAM, 0);
dst.family = AF_IEEE802154;
dst.addr.pan_id = 0x0023;
dst.addr.addr_type = IEEE802154_ADDR_LONG;
memcpy(&dst.addr.hwaddr, long_addr,
IEEE802154_ADDR_LEN);
or
dst.addr.addr_type =
IEEE802154_ADDR_SHORT;
dst.addr.short_addr = 0x0002;
sendto(sd, ...);
```

Current Status

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- 6LoWPAN with fragmentation and reassembly (RFC 4944)
- Header compression with IP header compression (IPHC) and next header compression (NHC) for UDP (RFC 6282), shared with Bluetooth subsystem
- ieee802154 layer with softMAC drivers for at86rf2xx, mrf24j40, cc2520, atusb, adf7242, ca8210 and mcr20a
- Hwsim virtual driver module for testing
- USB dongle to be used on your workstation
- Link Layer Security

New Webpage launched

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- Recent effort to move project page
  wpan.cakelab.org → https://linux-wpan.org
- Old one was to difficult to maintain and access
- New one is with GitHub pages, well known, easy edits
- Existing content has been moved and a redirect is in place
- More content (e.g. rpld) is needed and
  better integration with the kernel docs

Wpanusb - past

- Generic USB device driver (like btusb)
- Originally developed by Andrei Emeltchenko @intel
- ieee802154 does not specify an HCI
- Own USB interface spec based on atusb
- Developed together with Zephyr firmware
- Project stalled in 2018 as Andrei has no time

Wpanusb – future

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- Taken over by Koen, Eric and Stefan now
- Extend USB interface spec to be more flexible e.g. capabilities provided by firmware, different frequency bands, power levels, permanent address, etc
- CAN subsystem maintainers expressed interest for a similar generic USB driver
- RIOT OS firmware to be developed in parallel
- Zephyr firmware needs to be updated to new spec
- Bare metal or Contiki implementations?

Kselftest support

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- Hwsim will be hooked in kselftest to give an easy way of regression testing
- Will be used in review process
- Useful during network stack re-work’s
- Basic suite of tests to start with (ieee802154 frames in different sizes, 6lowpan packets in different sizes, header compression on and off)

Linux-wpan Future

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- Implement missing parts of the IEEE 802.15.4 specification
  - Beacon and MAC command frame support
  - Coordinator support in MAC layer and wpan-tools
  - Scanning
- Add better support for HardMAC transceivers
- Configuration interface for various header compression modules
- Expose information for routing protocols (started with LQI already)

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RTOS Systems

RTOS Systems

- Various real time operating systems support IEEE 802.15.4 and 6lowpan
- RIOT
- Contiki
- Zephyr
- OpenThread
- MbedOS (nanostack finally open source from mbed-os-5.7 onwards)

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Comparison

Feature	Linux	RIOT	Contiki	Zephyr	OpenThread
IEEE 802.15.4: data and ACK frames	✔	✔	✔	✔	✔
IEEE 802.15.4: beacon and MAC command frames	✘	✘	✘	✔	✔
IEEE 802.15.4: scanning, joining, PAN coordinator	✘	✘	✘	✔	✔
IEEE 802.15.4: link layer security	✔	✘	✔	✔	✔
6LoWPAN: frame encapsulation, fragmentation, addressing	✔	✔	✔	✔	✔
6LoWPAN: IP header compression (RFC 6282)	✔	✔	✔	✔	✔
6LoWPAN: next header compression, UDP only (RFC 6282)	✔	✔	✔	✔	✔
6LoWPAN: generic header compression (RFC 7400)	✘	✘	✘	✘	✘
6LoWPAN: neighbor discovery optimizations (RFC 6775)	Partial	✔	✘	✘	✘
RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks	✔	✔	✔	✔	✘
Mesh link establishment draft	✘	✔	✘	✔	✔

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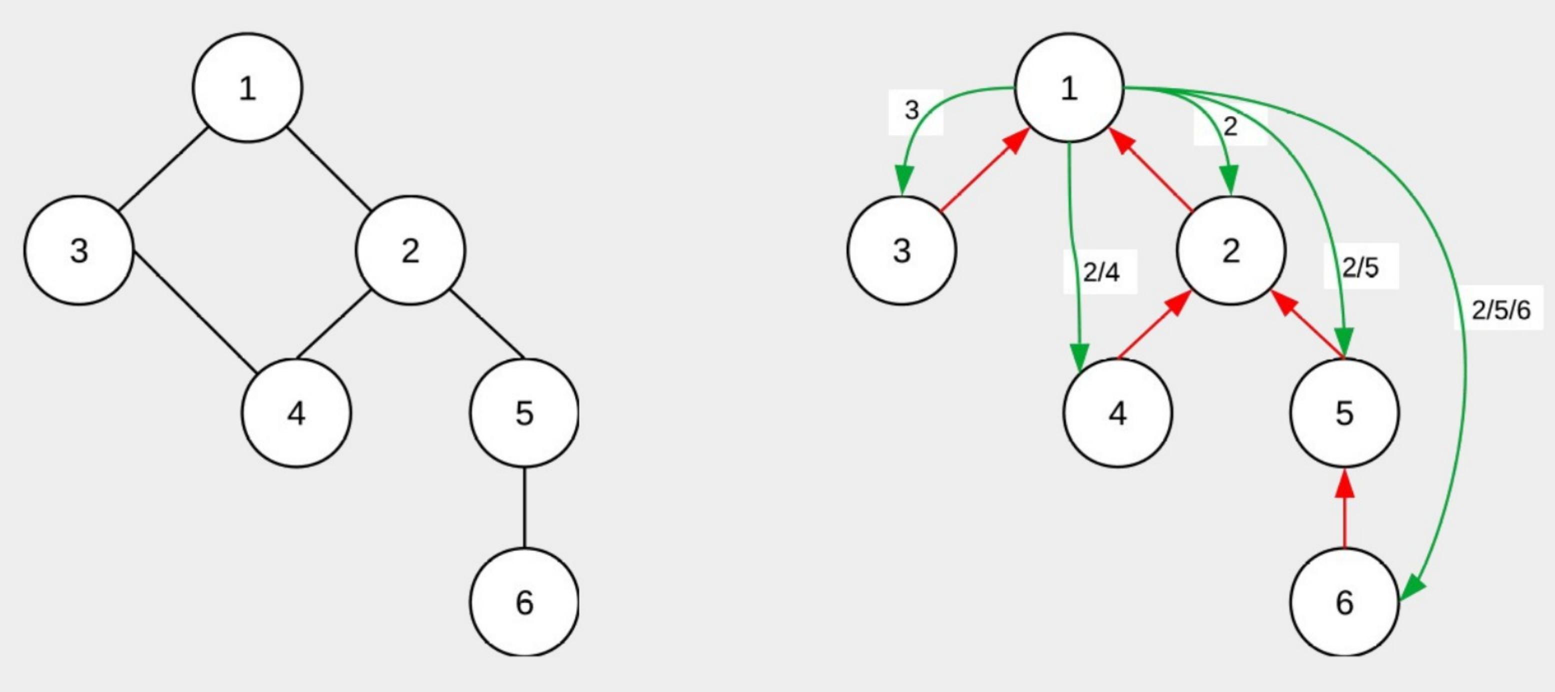
rpld

RPL

- Routing protocol for low power and lossy networks
- IETF approach, route over protocol
- IPv6 Routing Protocol for Low-Power and Lossy Networks (RFC6550, RFC6553)
- Tree like topology in a mesh, one parent, n childs
- Constructs a directed acyclic graph in an attempt to minimize the routing costs

RPL- up and down routes



rpld

- Unstrung was the Linux user-space reference
- rpld as new alternative https://github.com/linux-wpan/rpld
- Part of linux-wpan and only around for a year
- Developed by Alexander Aring
- Netdev Conf 0x14 talk RPL: IPv6 Routing Protocol for LLNs

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rpld – non-storing mode

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- In a nutshell RPL has two modes of operation:

  Storing: routes are propagated via ICMPv6 messages into the routing table

  Non-storing: source routing with routing header
- First implementation with non-storing mode on Linux by extending the existing Kernel segment routing
- https://netdevconf.info/0x14/session.html?talk-extend-segment-routing-for-RPL

rpld – non-storing mode

- Source routing extention header only inserted by root node
- IPv6 only
- Forwarding with address swapping and loop detection
- Compression of addresses in headers
- Details on kernel implementation in the mentioned talk

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Thank you!

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Bonus

Address Auto-configuration & Fragmentation

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Stateless address auto-configuration:

- Used for IPv6 networks without DHCP
- Based on layer 2 address
- Extended address uses EUI-64 as is
- Short address uses EUI-48 to EUI-64 mapping

(16 Bit PAN+16 Bit zero+16 Bit short address)

Fragmentation:

- IPv6 requires the link to allow for a MTU of at least 1280 bytes
- Impossible to handle in the 127 bytes MTU of IEEE 802.15.4
- 6LoWPAN adds a 11 bit fragmentation header allows for 2048 bytes
- Fragmentation should still be avoided for best performance

IPv6 Header Compression (IPHC)

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IPHC (RFC6282)

- Deprecates HC1 & HC2 compressions from RFC4944
- Better compression for global and multicast address, not only link-local
- Compress header fields with common values: version, traffic class, flow label, hop limit
- NHC IPv6 Extension Header compression (RFC6282)
  - Hop-by-Hop, Routing Header, Fragment Header, Destination Options Header, Mobility Header
- NHC UDP Header compression (RFC6282)
  - Compressing ports range to 4 bits
  - Allows to omit the UDP checksum for cases where upper layers handle message integrity checks

Generic Header Compression

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- Generic approach instead of defining a scheme for each header
- Plugging into NHC
- Useful for header like payload e.g. DTLS or RPL (addresses elided from dictionary)
- 6CIO option in neighbour discovery messages to indicate support
- LZ-77 style compression with byte codes (RFC7400)
  - Appending zeroes, back referencing to a static dictionary and copy

Mesh-under

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- Allow for fast packet forwarding without travelling the IP stack
- IEEE 802.15.4 does not include mesh routing in the MAC specification, mesh implementations is an extra layer above the MAC but below the network layer
- Various (proprietary) implementations (e.g. WirelessHART, ZigBee mesh, RF mesh, etc)
- IEEE 802.15.5 can also to be used for mesh on top of 15.4
- 6LoWPAN specification has a field for mesh headers
- Lost fragments of bigger packets will cause troubles

Thread

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- Mesh network specification from Thread Group
- OpenThread implementation from NestLabs
- Routing Information Protocol (RIP) algorithms are used, but not RIP itself
- Distribution of route information is handled by mesh link establishment (MLE, IETF drafts dropped)
- MLE allows router to update the tables of routing costs periodically in a compressed form
- Due to MLE no on-demand route discovery is needed

References

- IEEE 802.15.4 specification (PHY and MAC layer)

  http://standards.ieee.org/about/get/802/802.15.html

- RFC 4944: Transmission of IPv6 Packets over IEEE 802.15.4 Networks

  https://tools.ietf.org/html/rfc4944

- RFC 6282: Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks

  https://tools.ietf.org/html/rfc6282

- RFC 7400: 6LoWPAN-GHC: Generic Header Compression for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)

  https://tools.ietf.org/html/rfc7400Lossy Networks

- Linux-wpan source (wpan-tools & rpld) and project pages

  https://github.com/linux-wpan