Karlsruhe Institute of Technology

Implementation and Performance Evaluation of IEEE 802.15.4k LECIM DSSS PHY at 2.4 GHz

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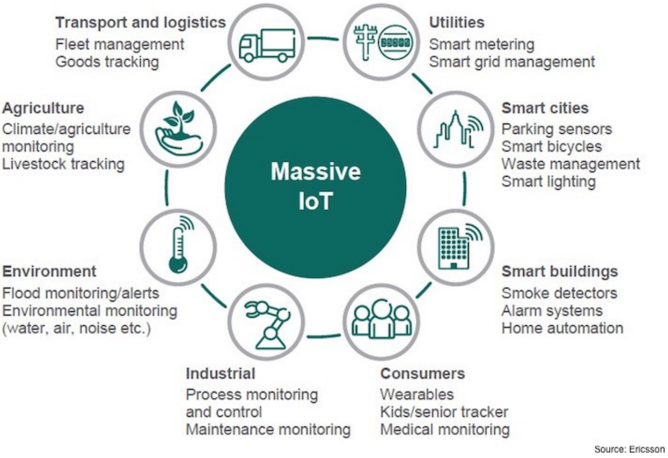
Agenda

1. Low Power Wide Area Networks
2. A new GNU Radio module: `gr-lpwan`
3. IEEE 802.15.4k LECIM DSSS PHY
4. Measurements
5. Conclusion

Low Power Wide Area Networks

Some possible business cases for IoT applications:



Low Power Wide Area Networks

Common characteristics of many potential applications:

- (Very) low data rates
- Relaxed requirements for latency and reliability
- Strict power and size constraints
- Expected to run on a single battery for up to 15 years without maintenance

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Those can not be served efficiently by existing wireless technologies!

New paradigm: **L**ow **P**ower **W**ide **A**rea **N**etworks (**LPWAN**)

- Usually star topology
- Cell radius of up to 15 km
- Tens of thousands of devices per cell

Low Power Wide Area Networks

Many players with different approaches competing for market shares

- Standardized vs. proprietary technology
- Licensed vs. unlicensed bands
- Spread spectrum vs. (Ultra) Narrow Band

A new GNU Radio module: `gr-lpwan`

Motivation:

- LPWAN technology is evolving rapidly
- Many open questions, e.g., regarding interference, performance and scalability
- No quantitative comparison between competing technologies available

Goal: Create an open-source testbed to facilitate field tests

First project: IEEE 802.15.4k LECIM DSSS PHY

- Only LPWAN technology using the 2.4 GHz ISM band
- Spreading factor of up to $2^{15} \rightarrow$ 45 dB processing gain!
- Compatible to Ingenu's Random Phase Multiple Access (RPMA)
- Implemented at CEL (KIT) by Kristian Maier (GitHub: @krmaier)

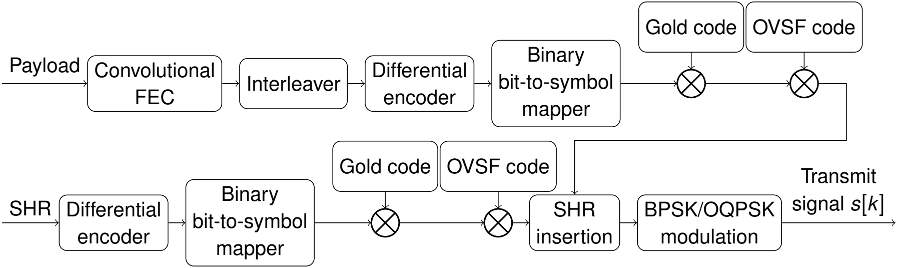
IEEE 802.15.4k LECIM DSSS PHY

Modulator: Standard

- Frame format

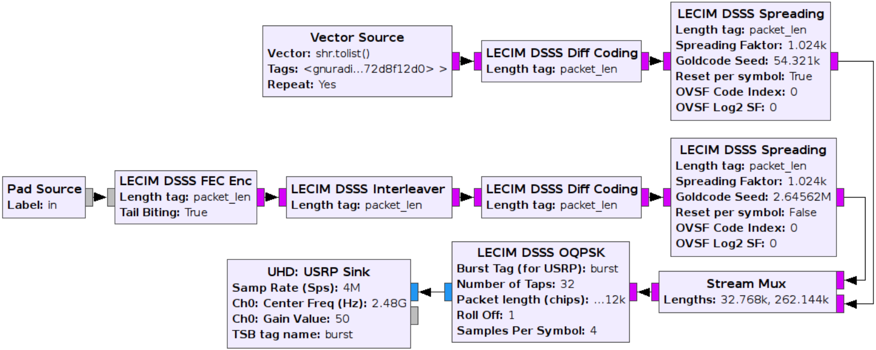
Bytes: 0/2/4	0/1	16/24/32
Preamble	SFD	PHY payload

- Block diagram



IEEE 802.15.4k LECIM DSSS PHY

Modulator: GNU Radio / GRC hierarchical block



IEEE 802.15.4k LECIM DSSS PHY

Synchronization:

1. Correlate with spreading sequence
   - 2-D search required due to frequency offset

$$\varphi_k[l] = \sum_{n=0}^{\mathrm{SF}-1} r[n+l] \cdot c^*[n] e^{-j2\pi f_\Delta / f_s \cdot k \cdot n}$$

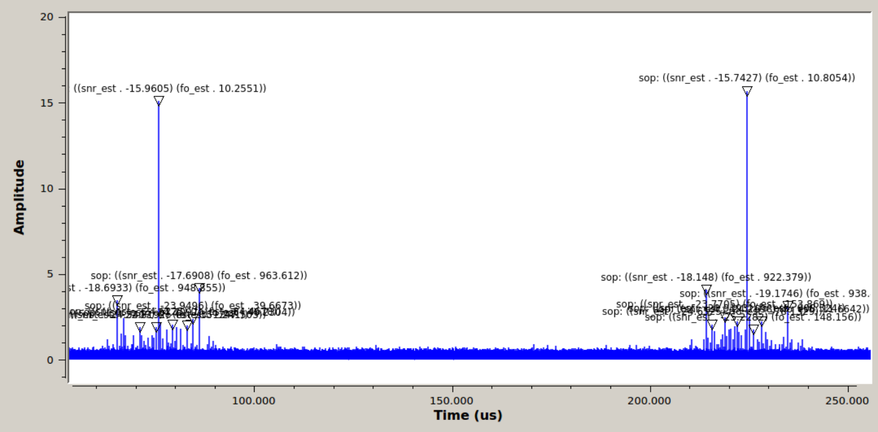
2. Differential decoding: $\varphi_{\mathrm{dec},k}[l] = \varphi_k[l] \cdot \varphi_k^*[l + M \cdot \mathrm{SF}]$
3. Correlate with preamble symbols

$$\psi_k[l] = \sum_{n=0}^{L_{\mathrm{SHR}}-1} \varphi_{\mathrm{dec}}[l + n \cdot M \cdot \mathrm{SF}] \cdot p^*[n]$$

4. Find frame start: $\hat{l}, \hat{k} = \arg \max_{k,l} |\psi_k[l]|$
5. Find frequency offset: $\hat{f}_o = \hat{k} \cdot f_\Delta + \frac{\angle \psi_{\hat{k}}[\hat{l}]}{2\pi \cdot \mathrm{SF}}$

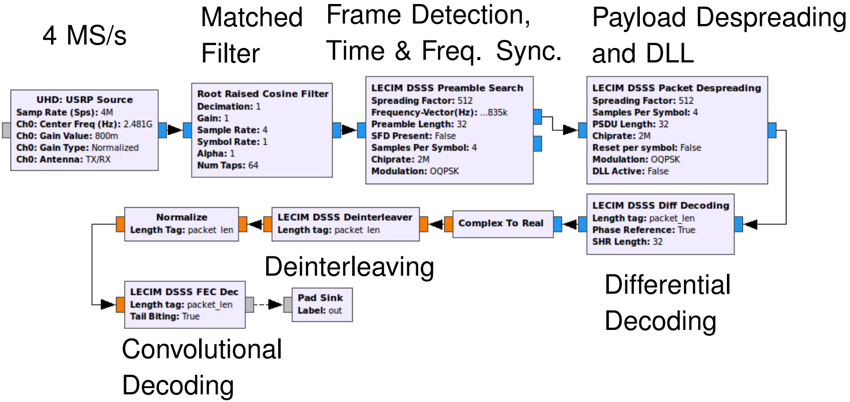
IEEE 802.15.4k LECIM DSSS PHY

Preamble correlation example: SNR = -16 dB, SF = 1024



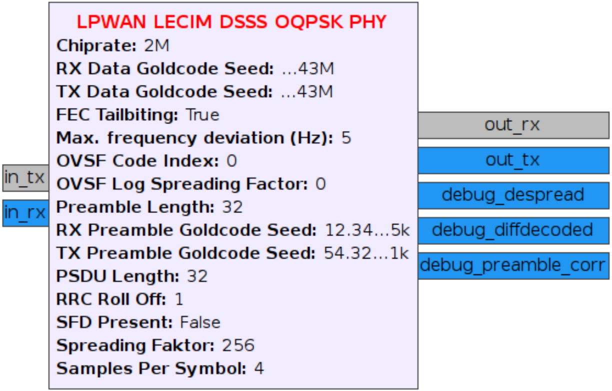
IEEE 802.15.4k LECIM DSSS PHY

Receiver: GRC hierarchical block



IEEE 802.15.4k LECIM DSSS PHY

Transceiver:



Measurements

- Transmitter set up on a high building on KIT campus
- Four different receive locations
  1. 350m distance, Campus, near-LOS, many co-located WiFi APs
  2. 450m distance, Campus, NLOS, many co-located WiFi APs
  3. 2100m distance, Commercial area, NLOS, few WiFi APs
  4. 3800m distance, apartment building, LOS, many uncoordinated WiFi APs

Measurements

Transmitter

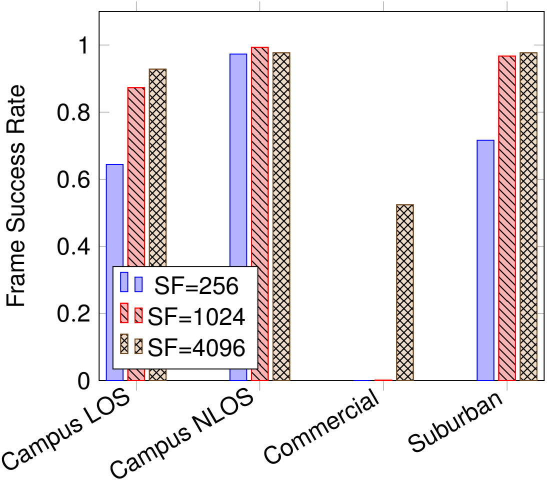
Receiver

Measurements

Results for the different receive locations at 2.45 GHz

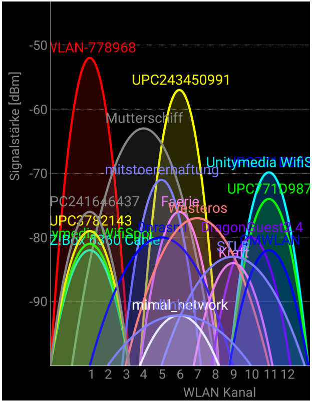
Configuration:

- 1 MHz bandwidth
- 16 byte payload
- OQPSK modulation
- 5 dBm transmit power
- omnidirectional antennas



Measurements

Impact of WiFi interference



(a) Neighboring WiFi APs
(Image: Wifi Analyzer)

Measurements

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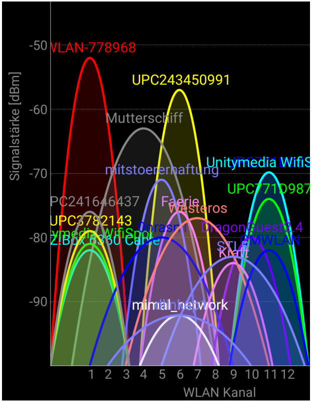
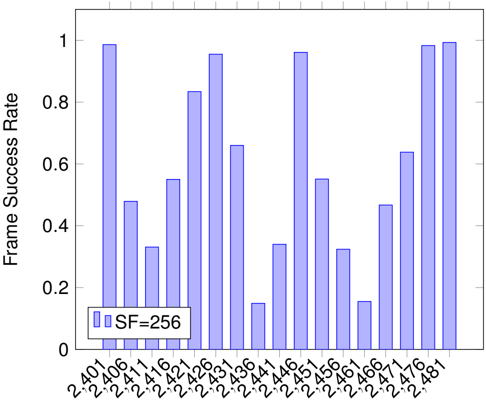


(c) Neighboring WiFi APs (Image: Wifi Analyzer)



(d) FSRs at the suburban apartment house. WiFi channels 1, 6, 11 at 2412, 2436, and 2462 MHz show severe degradation.

Conclusion

Summary

- New OOT module: `gr-lpwan`
  - Implements IEEE 802.15.4k LECIM PHYs
    - Complete DSSS PHY including fragmentation sublayer
    - First standards-compliant and open source implementation
    - FSK PHY is WIP
  - Available on GitHub: `https://github.com/kit-cel/gr-lpwan`
- DSSS PHY field tests in 2.4 GHz ISM band
  - Cross-technology interference can be challenging
  - Large spreading factors needed to overcome shadowing
  - LOS links over many km possible

Outlook

- Investigation and characterization of cross-technology interference
- Investigation of self-interference / MAI effects on the scalability

Thank you for your attention!
Questions?