Optimization of Ultra-Narrowband Wireless Communication: an Experimental Case Study

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Introduction

LP-WANs

- Low Power Wide Area Networks
  - provide connectivity to small, battery powered devices (e.g. smart meters, sensors - Internet of Things)
  - >1 km cell coverage, >1 year on battery life, ~100 byte payloads, mostly uplink, high latency
- Current mobile networks are not well fitted for MTC
- Many competing technologies and networks
  - LoRaWAN, SIGFOX, Weightless, 802.11ah
  - LTE-M, NB-LTE release 13, ...
- Some of these networks use **ultra-narrowband**.

Motivation for our work

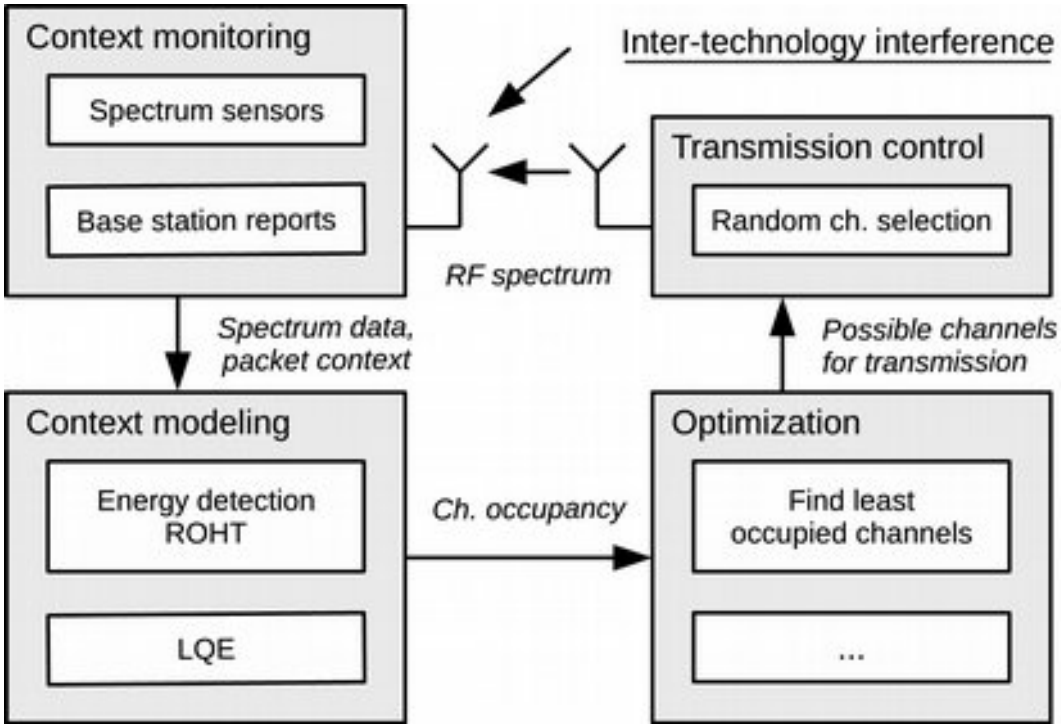
- Devices in LP-WANs face an interference problem in dense environments.
  - Inter-technology: Unlicensed band are shared
  - Intra-technology: Packet collisions in a network
- Can we design a testbed architecture for **rapid experimentation** with UNB technology?
- Case study: **the SIGFOX network**
  - can we optimize the **spectrum** use and
  - improve the device **battery life?**

Proposed generic architecture

- Each entity covers a specific functionality
  - separation of concerns allows for rapid optimization

1) collecting both intra- and inter-technology context information

2) creating a model of the operating environment

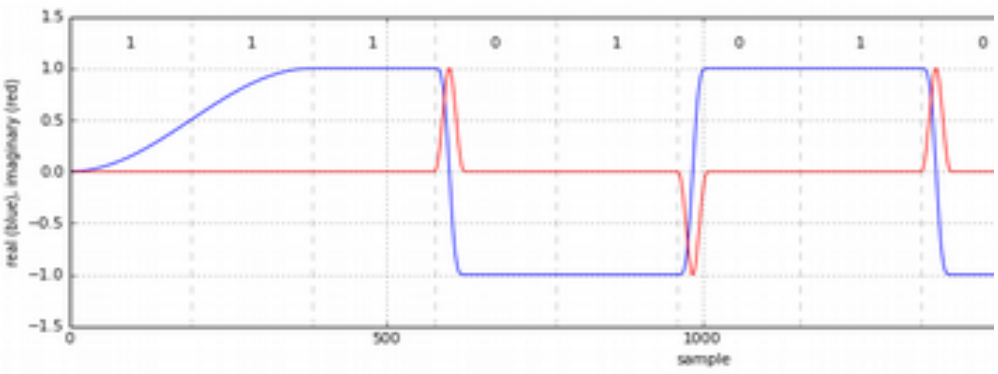


4) acting upon the optimization instructions

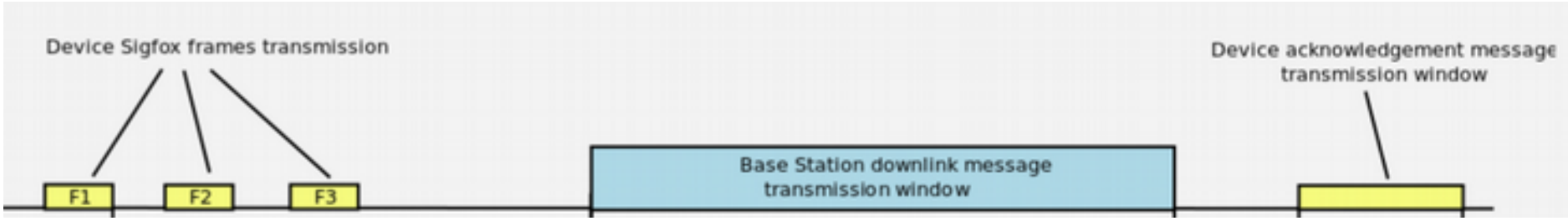
3) deciding on actions to meet specific goals

Case study: SIGFOX network

- Ultra-narrowband physical layer
  - Using unlicensed bands (868 MHz SRD in Europe)
  - 100 bits/s, DBPSK, 1500 microchannels



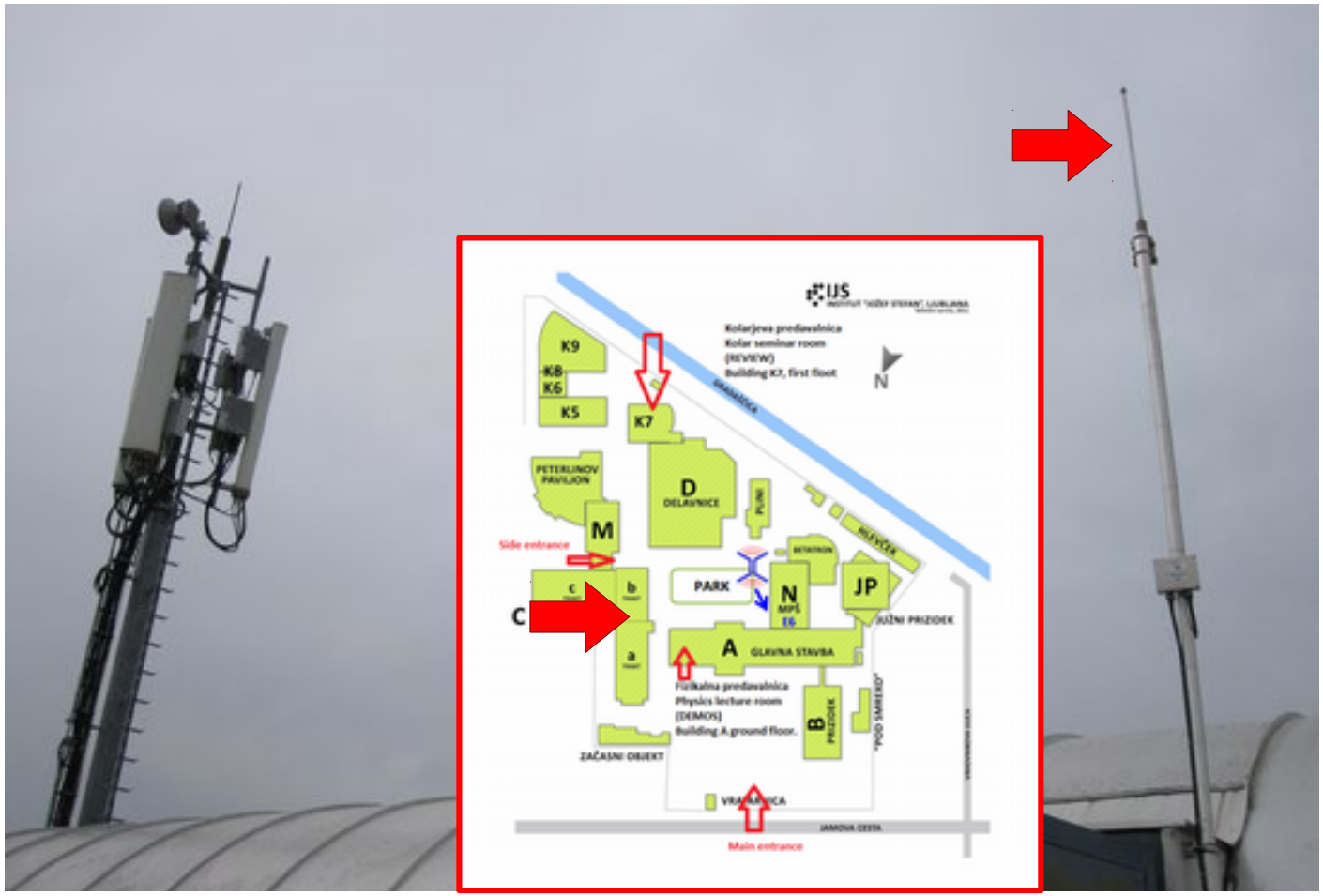
- Opportunistic media access
  - ALOHA protocol: on uplink device (pseudo-) randomly chooses time and frequency of transmission.
  - QoS: 3 frame retransmissions (on different channels).



Setup in the LOG-a-TEC Testbed

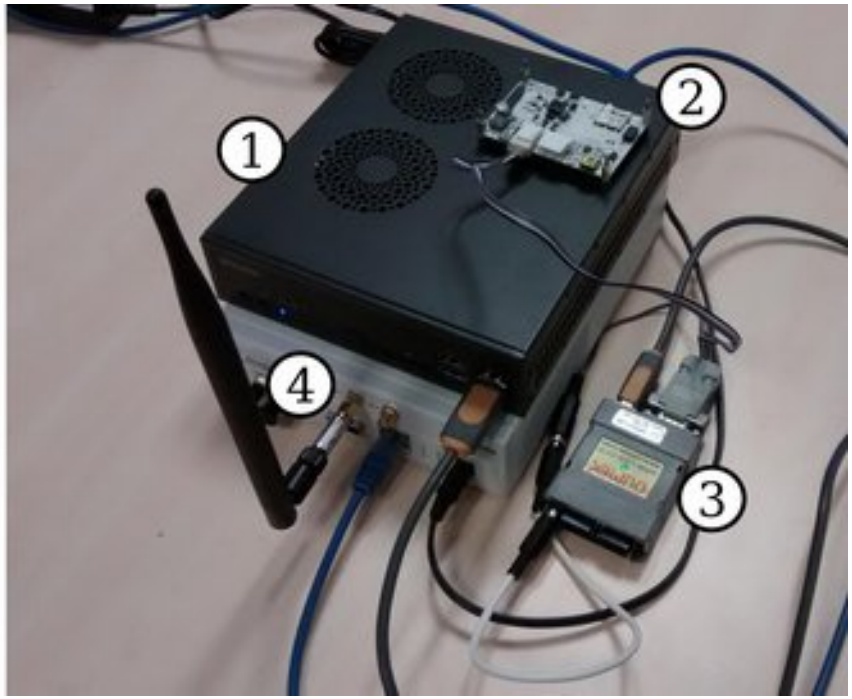
SIGFOX base station @ JSI

- On loan from SIGFOX, mounted in May 2016.
  - Did not require modifications for our work.



Experimental SIGFOX device

- We built our own device for rapid experimentation
  - Firmware in production modems is hard to modify.
  - We used a software-defined radio approach.
- To avoid re-implementing the MAC layer, we run part of the original modem firmware on an ARM CPU.



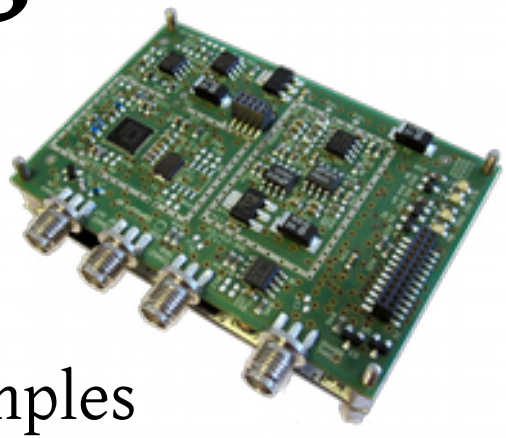
1) Compact PC running GNU/Linux OS and our SIGFOX PHY implementation using Python, numpy, GNU Radio framework.

2) ARM board running SIGFOX MAC layer.

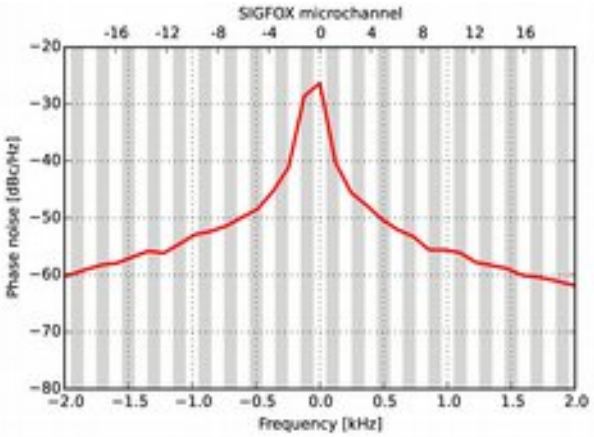
3) serial interface between ARM and PC

4) SDR front-end (NI USRP N210)

Spectrum sensing

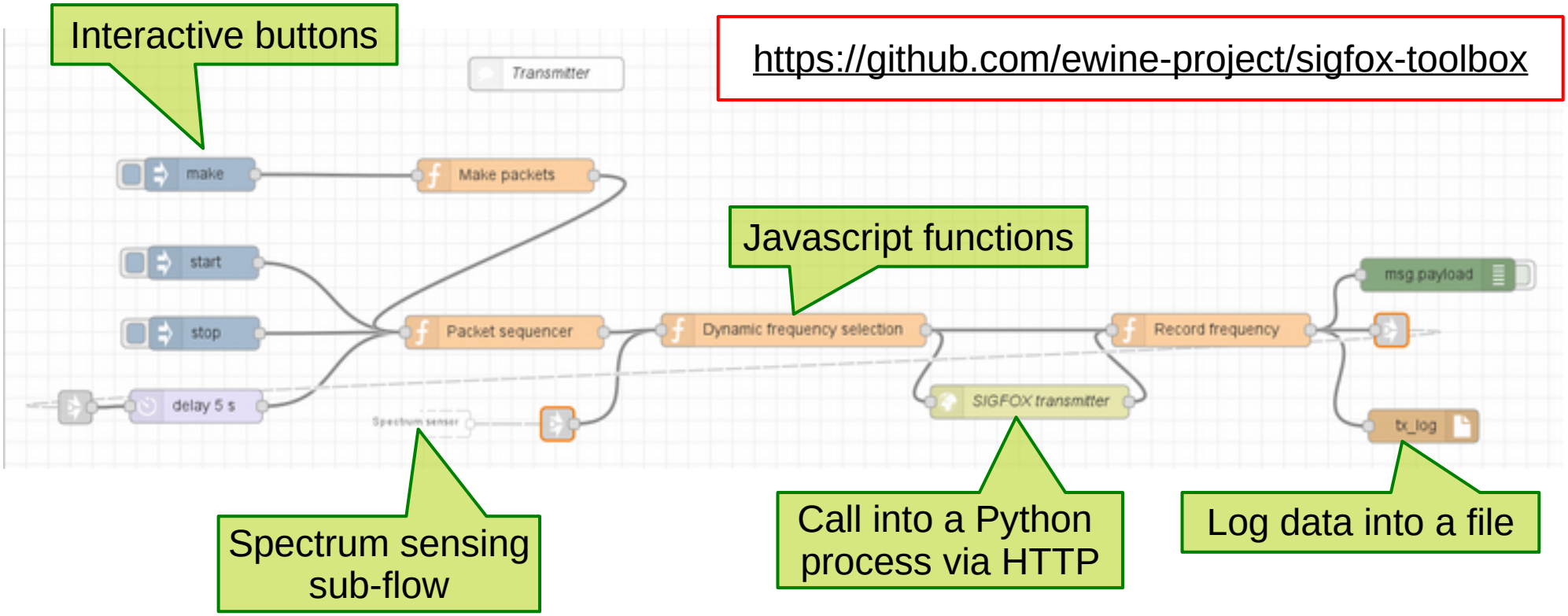


- VESNA SNE-ESHTER spectrum sensor
  - custom designed compact receiver
  - UHF reception, up to 2 Msamples/s, 25k samples
  - one receiver mounted on roof nearby SIGFOX basestation
- Energy detection based on FFT of signal samples
  - 200 Hz resolution (one bin = 2 SIGFOX microchannels)
- Challenges
  - high phase noise (-58 dBc/Hz @ 1 kHz)
  - low sensitivity (868 MHz is on the edge of the antenna and receiver pass band)



Experiment controller

- Node-RED used as glue between components
  - Flow-based visual programming tool from IBM
  - Browser-based (experiments can be done remotely)



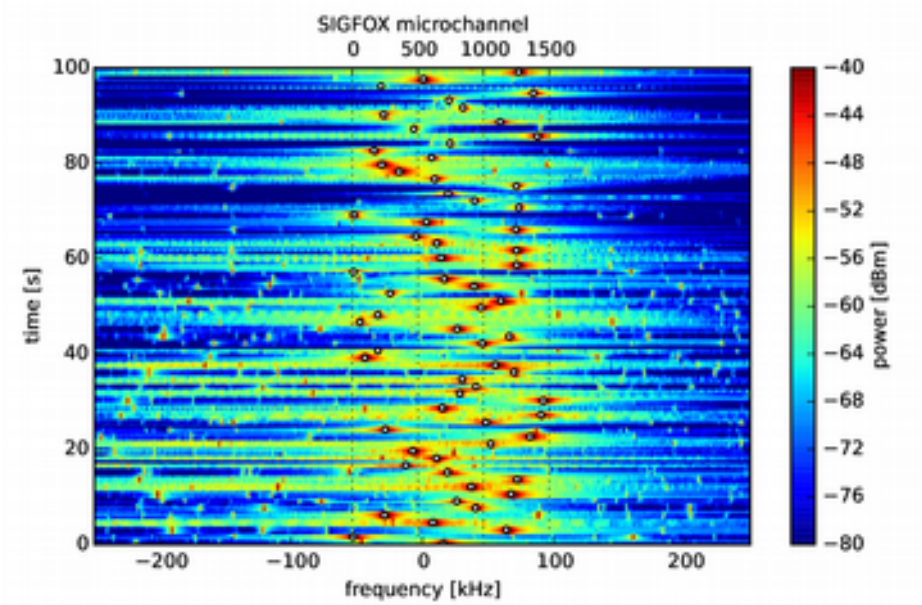
Experiments & results

Dataset collection

- Packet based data
  - RSSI, SNR as reported by the base station,
  - packet loss calculated from sequence num.


```
{
    "seqNumber": "675",
    "avgSnr": "10.06",
    "station": "0BF2",
    "snr": "11.99",
    "time": "1473675863",
    "device": "1CF14C",
    "rssi": "-129.00",
    "data": "0001"
},
```

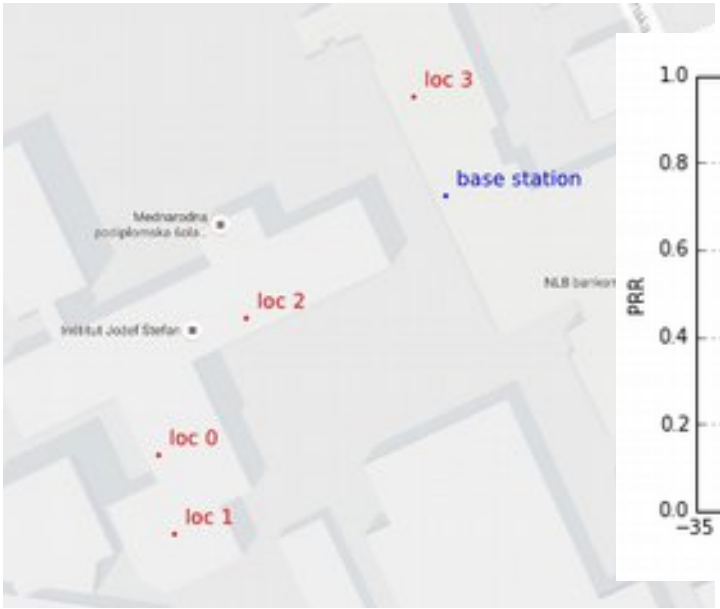

- Spectrum data
  - Power spectral density,
  - time synchronized with packet data timestamps using correlation.

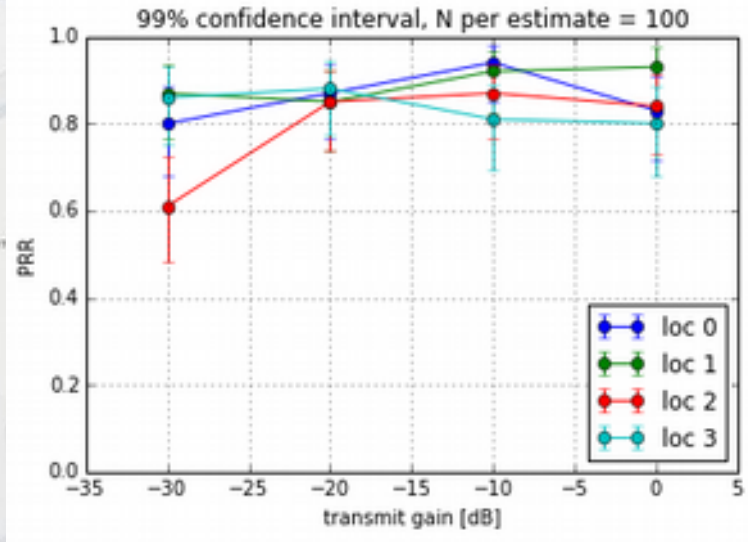


Dataset collection

- Currently collected data contains ~30k packets
  - various device locations, transmit powers
  - frame repetition patterns, ch. selection algorithms, ...
- Some datasets already published on GitHub

https://github.com/ewine-project/sigfox-packet-datasets



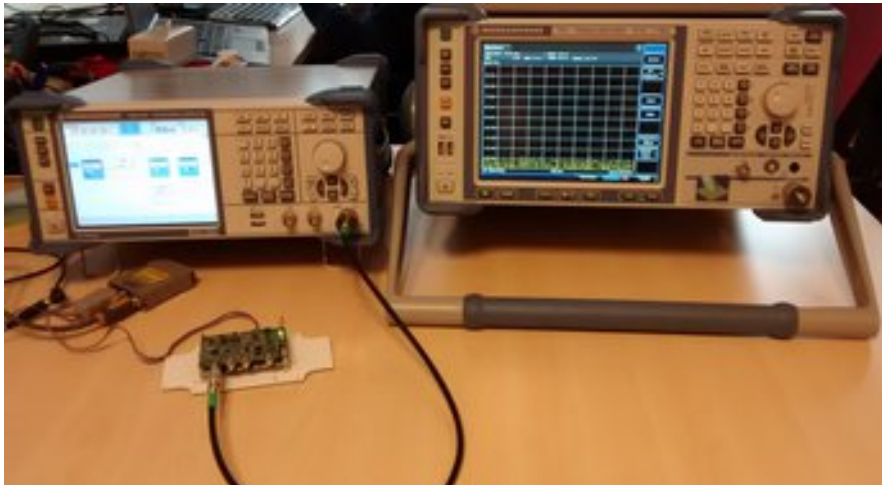


Case study: uplink optimization

- Increase **packet reception ratio** by intelligently choosing the transmit channel.
  - Can we get same QoS with fewer frame retransmissions?
- How to find most vacant channels?
  - **physical layer**: channel occupancy table
  - **MAC layer**: link quality estimation and prediction
- Time frame for optimization?
  - **fast loop**: do channel assessment on device, transmit immediately when channel is vacant (e.g. LBT)
  - **slow loop**: do channel assessment on network, occasionally transmit statistics to devices.

PHY: Finding least occupied ch.

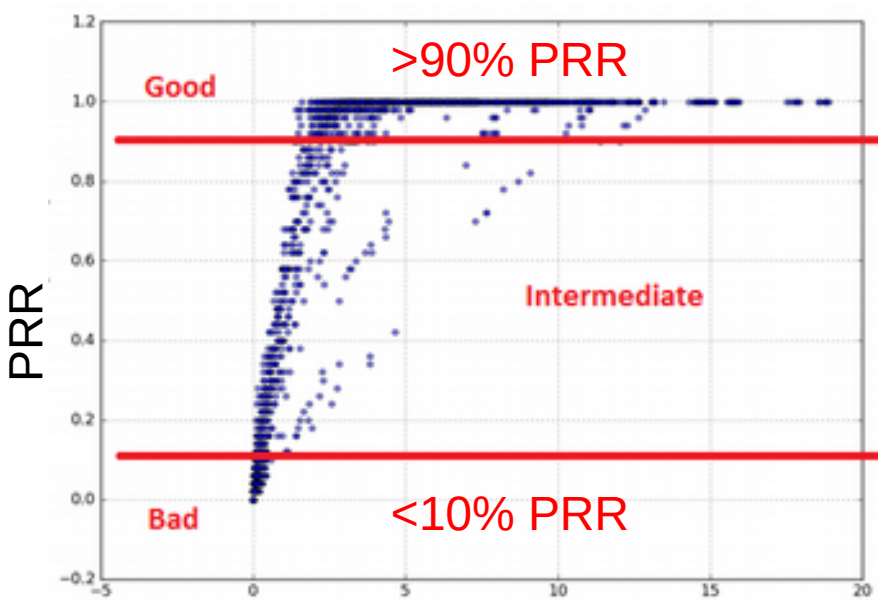
- Evaluated covariance detection with SNE-ESHTER
  - ~3 dB better sensitivity than ED @ Pfa = 5%, Pd = 99%
  - very long sensing time required for 100 Hz resolution
- Energy detection with ROHT algorithm.
  - Occupied/vacant decision based on dynamically adjusted thresholds.
  - Doesn't seem to work well with UNB signals.

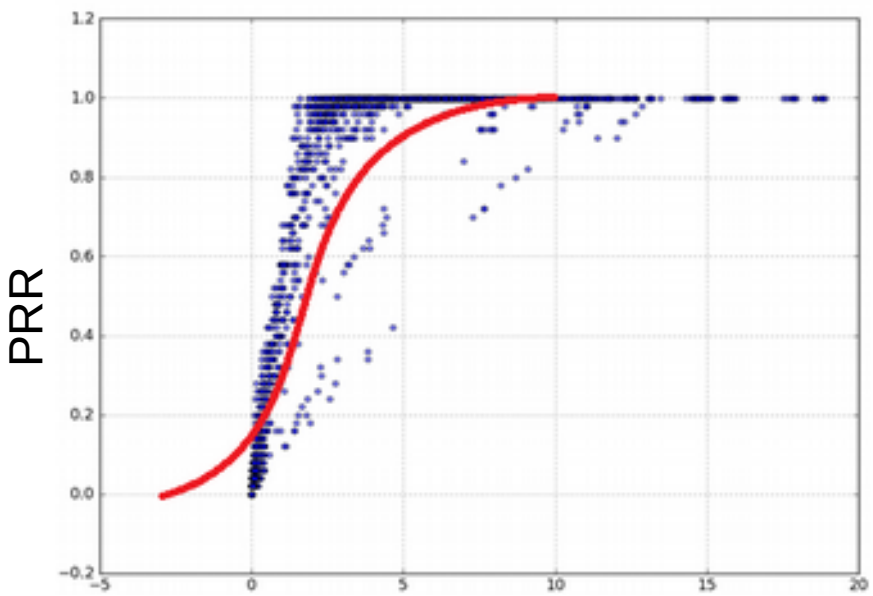


- Mean PSD over time window got best results.

MAC: Link quality estimation

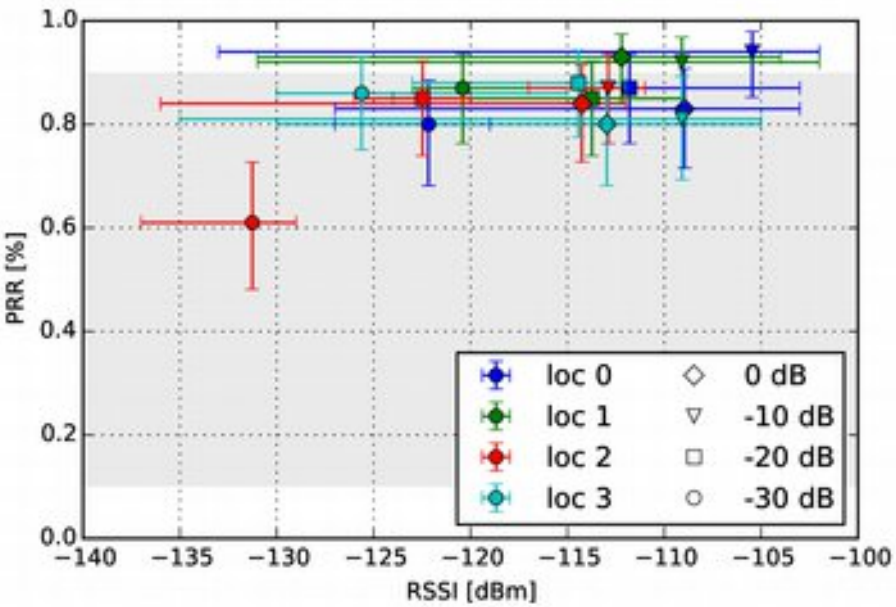
- Can we **predict** which the best link in the future?
  - Mean, variance of **RSSI, SNR, PRR** over time window.
- Classification or regression?
  - The usefulness and accuracy of LQE is a debated topic.





Good/bad link classification

- Training data
  - 4 locations, 4 TX powers
  - 16 x 100 = 1600 packets
  - 37% good links,
    63% intermediate links



- Classification results
  - WEKA machine learning
  - J48 decision tree

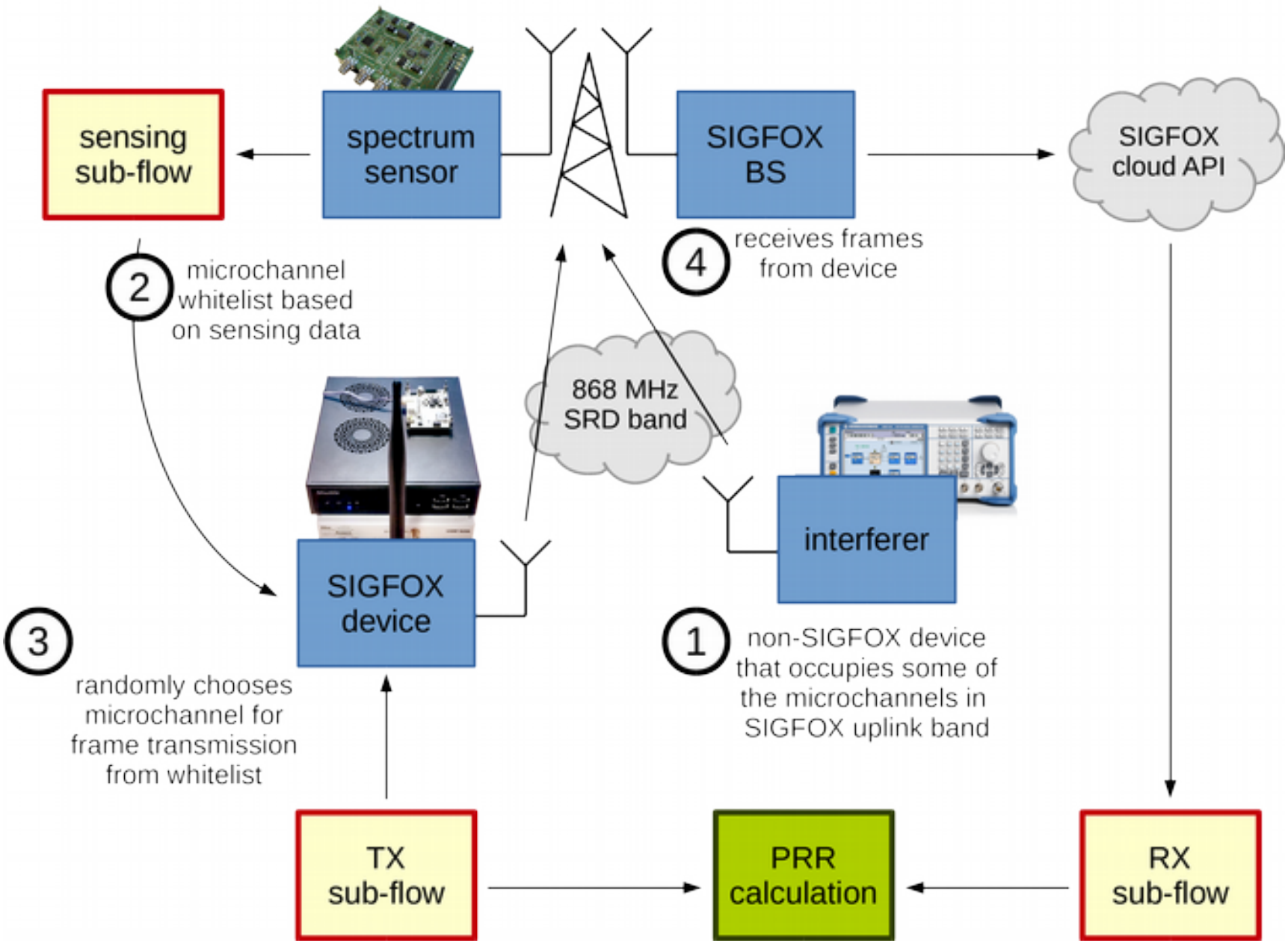
TABLE I. LQE CLASSIFICATION FOR THE BEST PERFORMING FEATURE VECTORS.

Feature vector	Correct	Incorrect
rssi, avg(rssi), std(rssi), avg(snr), std(snr), avgSnr	78.82%	21.17 %
avg(rssi), std(rssi), std(snr), avgSnr	78.01 %	21.98%
avg(rssi), avg(snr), std(snr), avgSnr	77.42%	22.57 %

https://github.com/ewine-project/link-quality-estimation

Demonstration: Interference avoidance

Experiment setup



Summary and Future Work

Address LTE interference

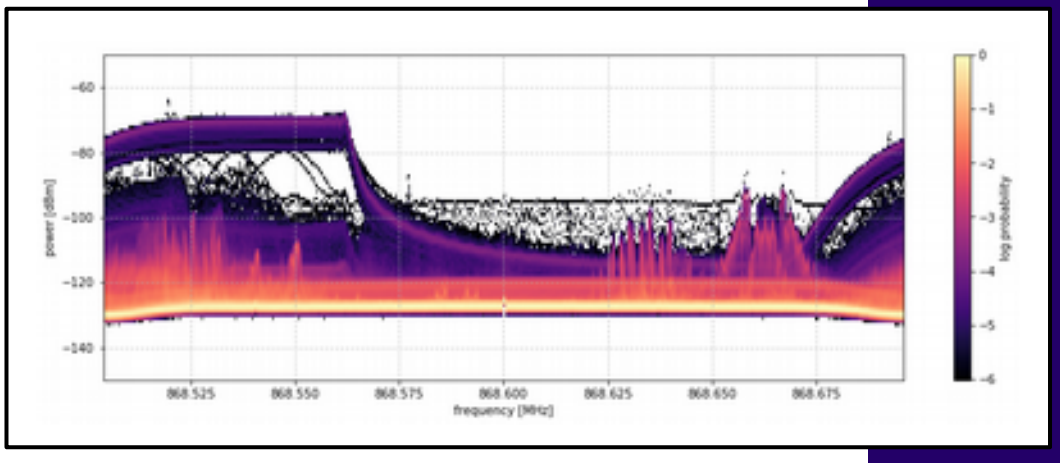
- LTE band 20 station (800 MHz) mounted nearby
- We observed decreased sensitivity of our spectrum sensor and SIGFOX BS
  - LNA saturation in SNE-ESHTER causes spurious signals
  - SIGFOX reports in-band and out-of-band interference
- SIGFOX moved the uplink band in our testbed from 868.130 MHz to 868.600 MHz.
  - preliminary tests show improved sensitivity
  - possibly install a cavity band-pass filter in the future

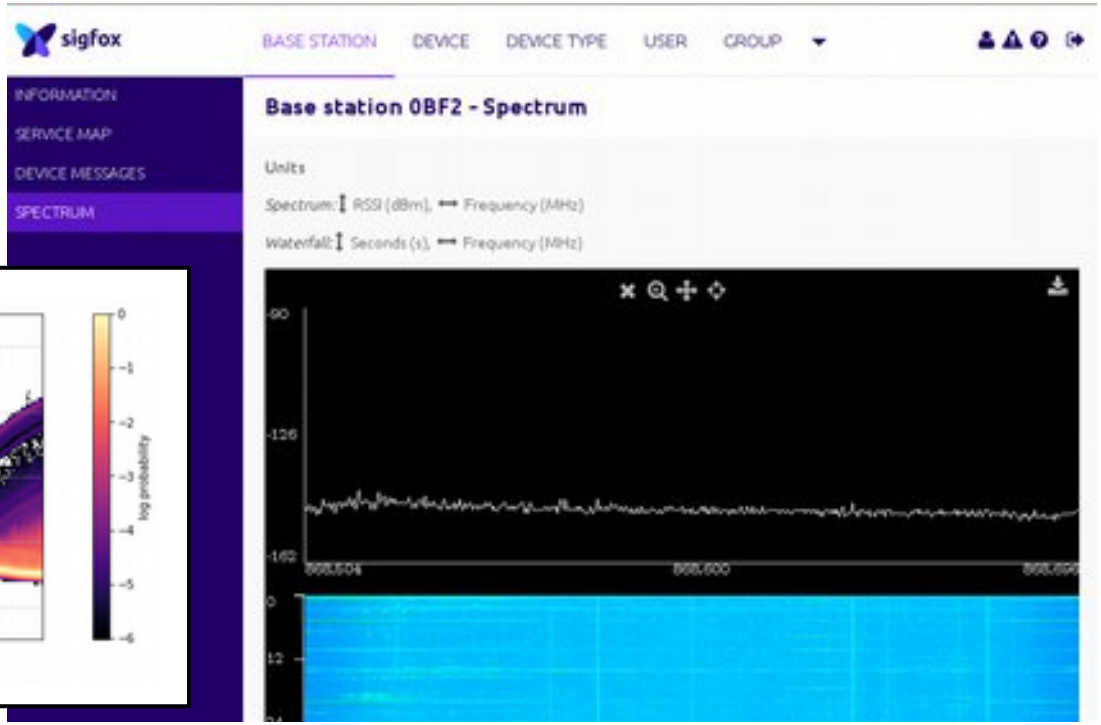
Improve packet datasets

- Collect more data:
  - Longer term, more packets, more locations, longer distance links
- Correct problem with low PRR
  - Devices with low PRR are automatically blocked from network by some mechanism in the SIGFOX backend.
- Integrate MAC layer with physical layer sensing
  - Can LQE improve upon the results from spectrum sensing only?

Spectrum from the base station

- We are exploring a possibility of obtaining high-quality baseband data from the SIGFOX backend
  - same antenna, receiver as used by the base station
  - much better sensitivity and lower phase noise than our sensor.





Summary

- We proposed a generic, four-part architecture for optimization of ultra-narrowband networks.
- We implemented the architecture by extending an existing LOG-a-TEC testbed.
- We performed a case study of the SIGFOX network
  - we collected several datasets
  - we investigated network optimization approaches at PHY and MAC network layers
- We have shown a demonstration of interference avoidance using channel whitelisting.

Acknowledgements

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eWINE
Elastic Wireless Networking Experimentation