An adaptive channel quality metric for ultra-narrowband systems

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presented at EuCNC 2018, Ljubljana, 20 June 2018

Introduction

- An important part of the Internet of Things are small, battery powered sensors.
  - e.g. a water meter that sends out a meter reading and ID once per day.

- Low power WANs (LP-WANs)
  - high density of devices,
  - uplink traffic, small payloads,
  - QoS requirement,
  - relaxed latency requirements.

Ultra-narrowband

- A radio technology used by some LP-WANs
  - Sub 1-GHz frequencies (e.g. 868 MHz SRD band)
  - low bit-rate transmissions (100-1000 bits/s)
  - low channel bandwidth (100-1000 Hz)
  - Opportunistic media access.
- Many UNB LP-WANs operate in unlicensed bands
  - With increasing number of devices QoS is harder to achieve due to radio interference.

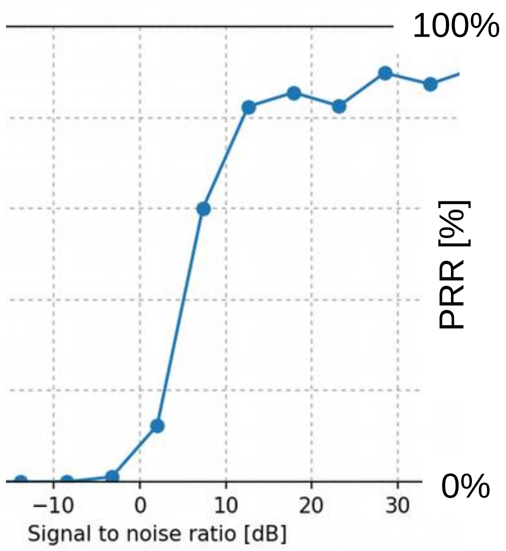
Motivation

- Uplink radio channel selection
  - One of the interference avoidance strategies.
  - What metric to base the selection on?
- Packed-based link quality metric are less suitable.
  - UNB system can have 1000s of channels ("links")
  - low number of packets/link/day,

    → takes too long to collect a meaningful statistic.
- Channel quality from power spectral density (PSD)
  - PSD measurements are readily available from base station hardware.

Simple channel quality metrics

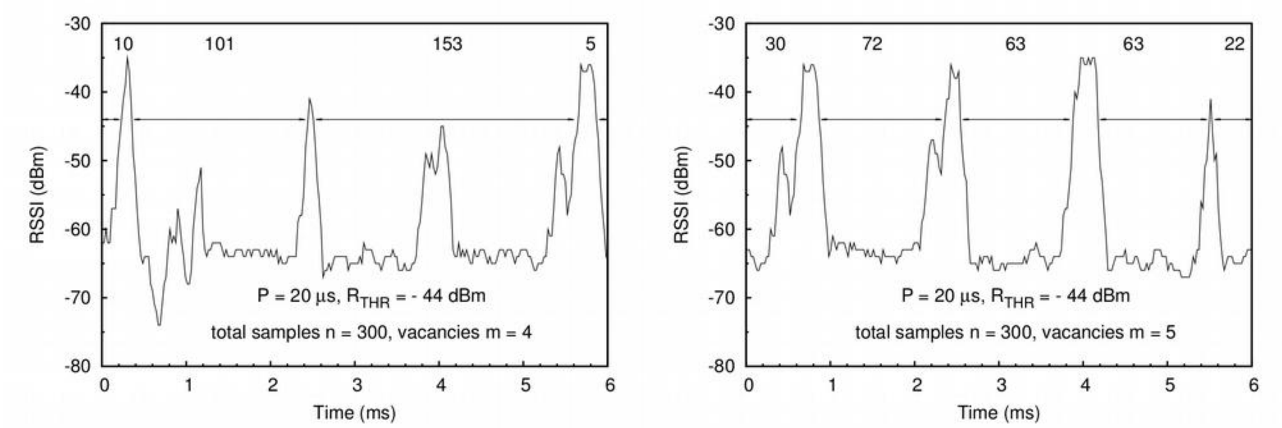
- Mean power in a channel over time window
  - Problem: Ignores time distribution of interference. infrequent, strong inteference results in identical quality to frequent, weak interference.
- Mean Channel Availability
  - Percentage of time where interference power in a channel is below a threshold.
  - Problem: Assumes a sharp threshold between 0 and 100 % packet loss.



Time-aware channel quality

- *CQ(τ)* metric[1]

$$CQ(\tau) = \frac{1}{n-1} \sum_{j|(j-1)P>\tau} j^{1+\beta} m_j$$



  - <u>Problem</u>: How to choose β *(bias towards longer vacancies)*
  - <u>Problem</u>: Assumes a sharp threshold in packet loss.

[1] *NODA, Claro, et al. Quantifying the channel quality for interference-aware wireless sensor networks. ACM SIGBED Review, 2011, 8.4: 43-48.*

Our simplified metric based on *CQ(τ)*

$$CQ^*(\tau) = \frac{1}{n - \tau/P} \sum_{j|(j-1)P>\tau} (j - \tau/P) m_j$$

# of all possible transmission start times

# of transmission start times where transmission is not interfered with power higher than $\mathbf{R}_{\mathrm{THR}}$.

CQ(τ)* is a MLE for the probability of successful transmission of a packet with length *τ*, assuming any interference more powerful than $\mathbf{R}_{\mathrm{THR}}$ results in a lost packet.

Accounting for realistic PRR(SINR)

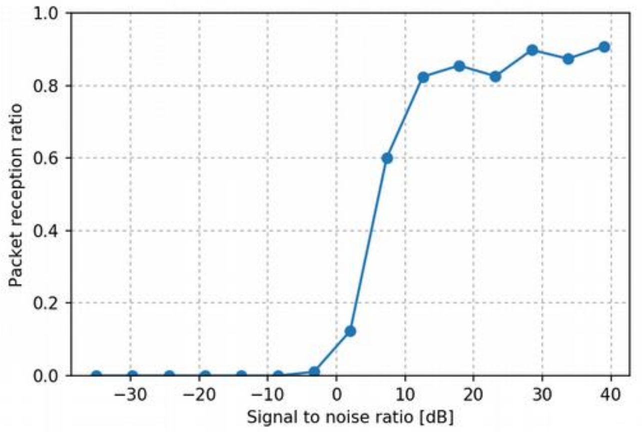
For each possible transmission time i_0:

1) <u>estimate SINR,</u>

$$\overline{P_{IN}}(i_0) = \frac{1}{\tau/P} \sum_{i=i_0}^{i_0+\tau/P} P_i \qquad SINR(i_0) = \frac{R_{rx}}{\overline{P_{IN}}(i_0)}$$

2) <u>calculate predicted PRR</u>

$$PRR(SINR(i_0))$$

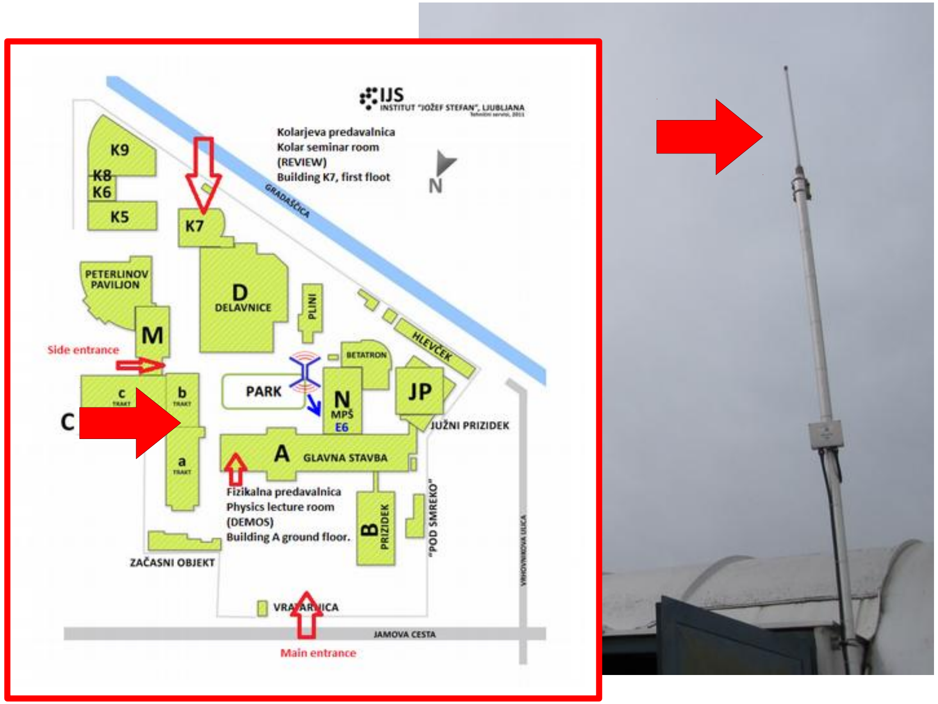


Calculate mean predicted PRR over all i_0:

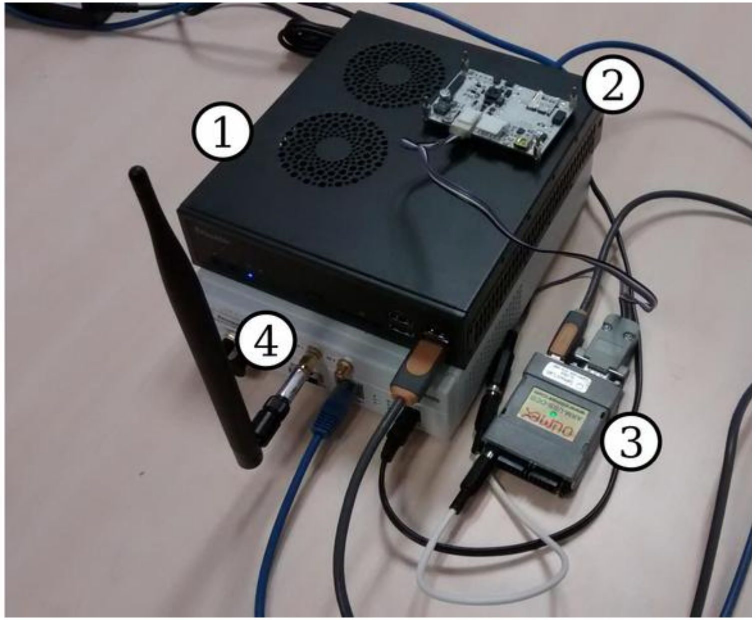
$$\overline{PRR} = \frac{1}{n-\tau/P} \sum_{i_0=0}^{n-\tau/P} PRR(SINR(i_0))$$

Experimental evaluation

- Commercial UNB base station



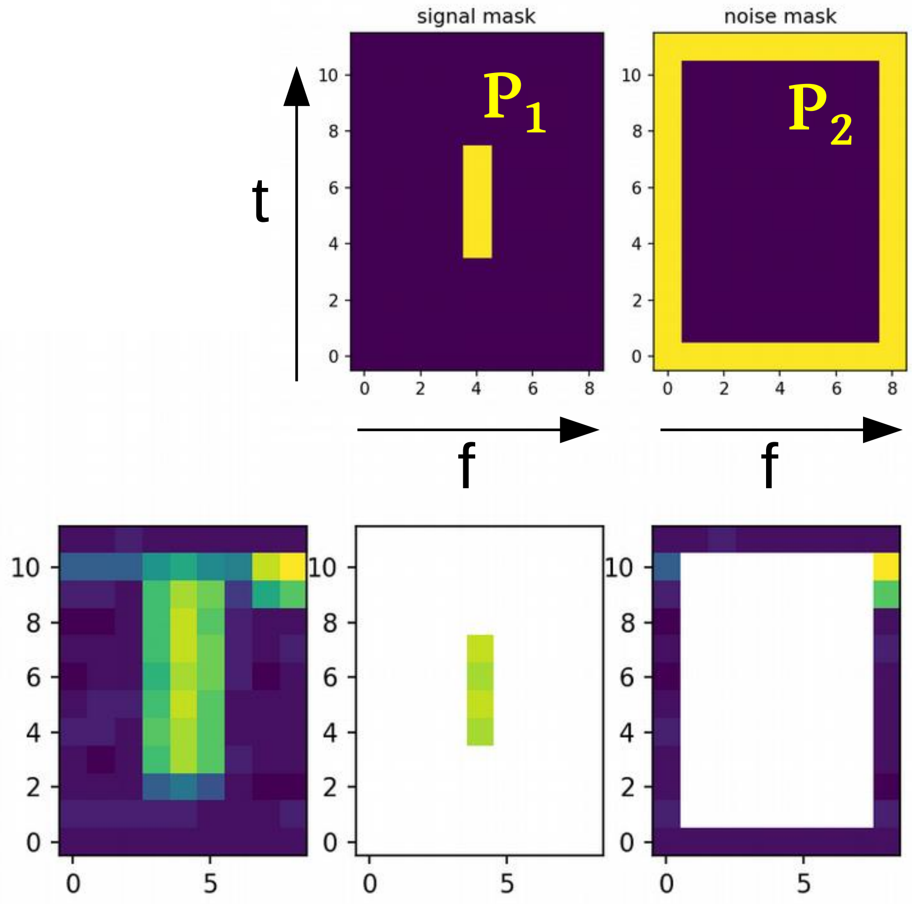
- Custom SDR-based UNB transmitter



Empirically estimating SINR

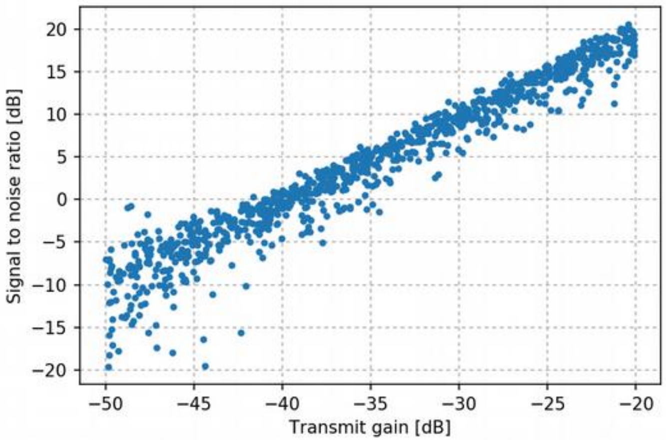
- We had to calculate SINR from PSD measurements.
- For each packet, mask two regions in PSD(t, f):
  - Central region: $\mathbf{P_1 = S + I + N}$
  - Outer region: $\mathbf{P_2 = I + N}$

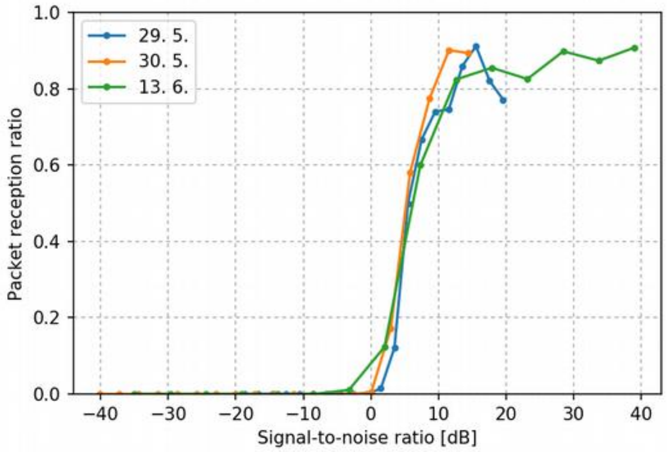
$\mathbf{SINR=(P_1 - P_2)/P_2}$



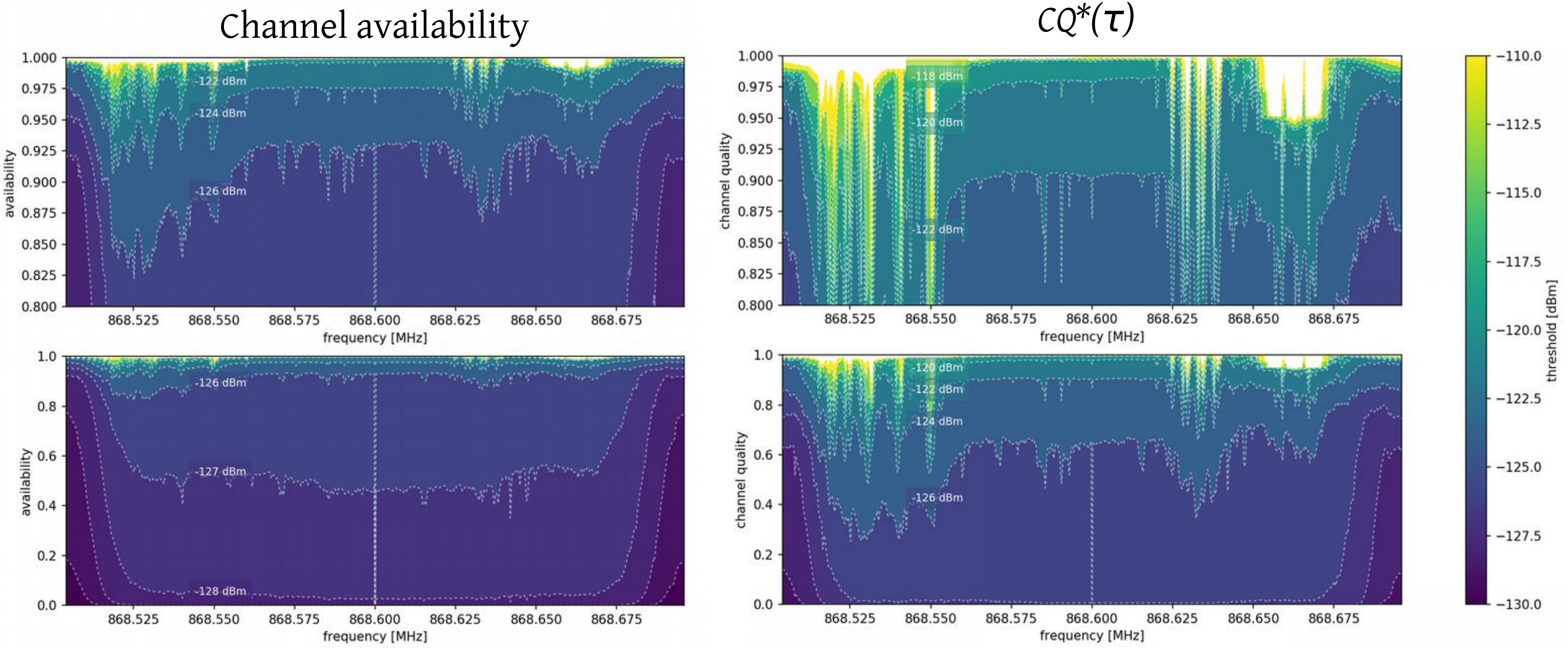
Our PRR(SINR) estimates

- Calculated SINR falls linearly with TX gain
  - as expected ✓
- PRR(SINR) approximately constant over multiple measurement campaigns.
  - Measured PRR(SINR) is similar to the theoretical for BPSK





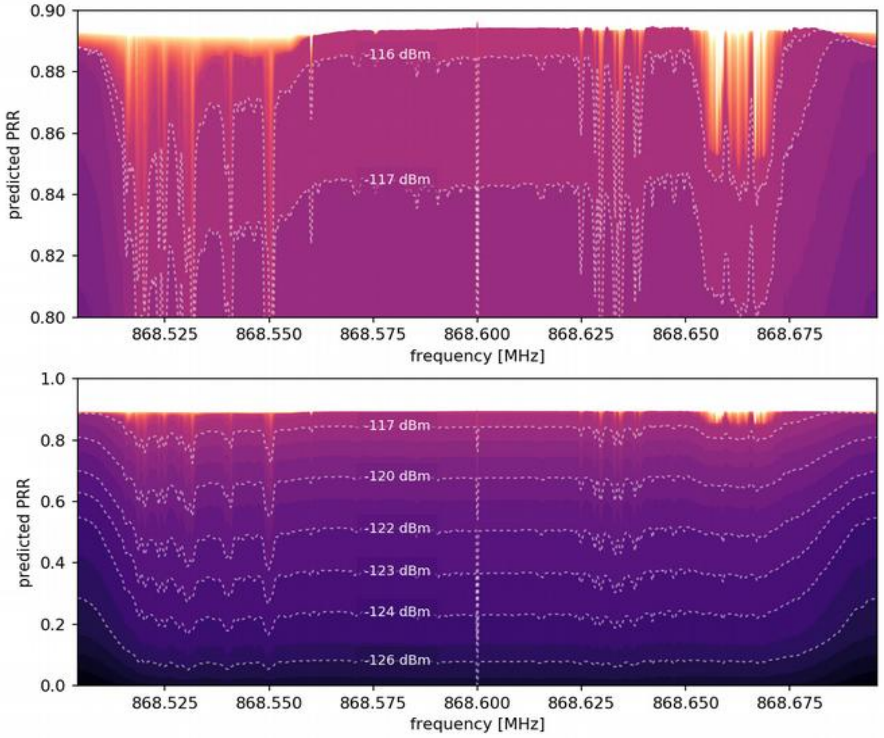
Results



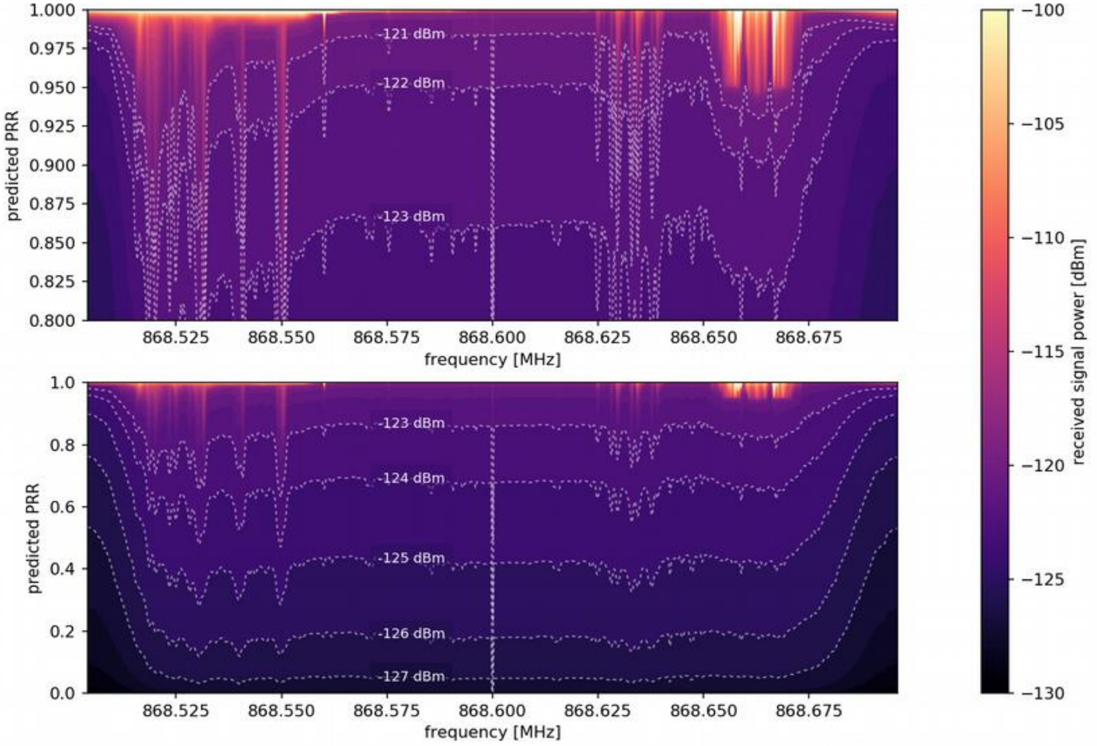
868 MHz SRD band. Measured in Ljubljana, between 29 May and 14 June 2017.

Results: predicted PRR

Using empirically estimated PRR(SINR)



Using theoretical PRR(SINR) for BPSK



868 MHz SRD band. Measured in Ljubljana, between 29 May and 14 June 2017.

Conclusions

- We have: presented some existing channel quality metrics and how they can be applied to UNB,
- proposed a <u>new channel quality metric</u> based on maximum likelihood estimation of PRR,
- shown how this metric can be estimated using only PSD measurements, and
- performed a preliminary experimental evaluation of the proposed metric.

Acknowledgements

- The research leading to these results has received funding from the European Horizon 2020 Programme project eWINE under grant agreement n°688116.
- The authors acknowledge the financial support from the Slovenian Research Agency (P2-0016).

Questions?