SDR-Based Radio Channel Measurements in sub-GHz Unlicensed Frequency Bands

Hendrik Lieske, Thomas Lauterbach, Jörg Robert,
Gerd Kilian, Albert Heuberger

2015 Wireless Innovation Forum, 06.10.2015
European Conference on Communication Technologies and Software Defined Radio

TECHNISCHE HOCHSCHULE NÜRNBERG
GEORG SIMON OHM

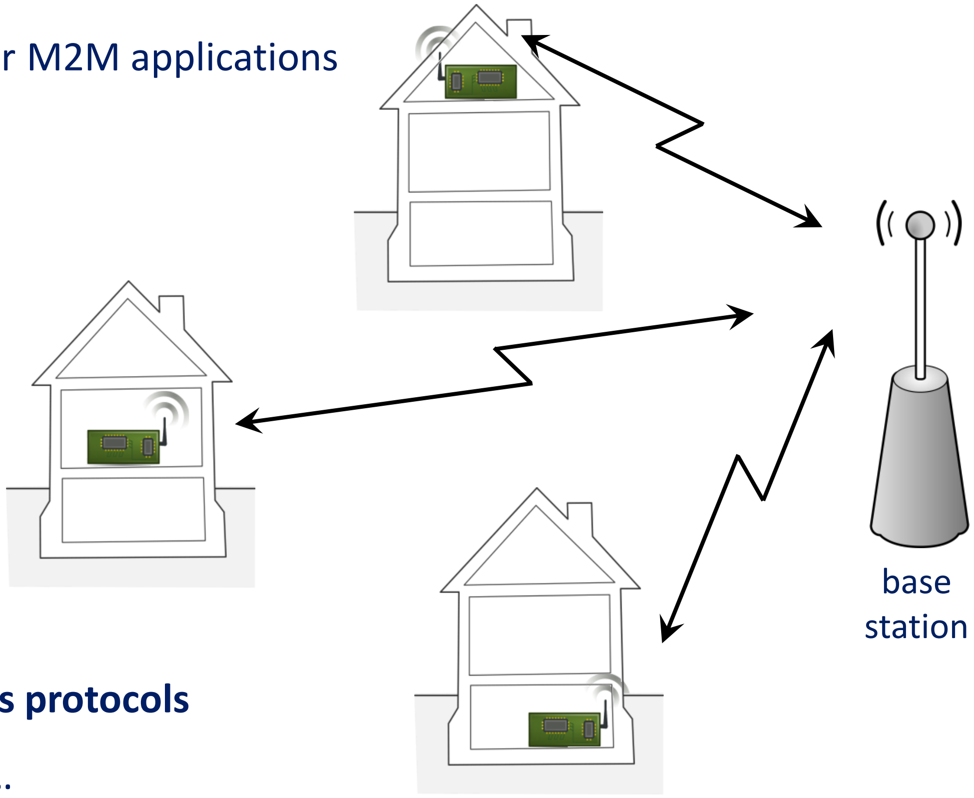
Fraunhofer
IIS

LIKE
LEHRSTUHL FÜR INFORMATIONSTECHNIK
Schwerpunkt Kommunikationselektronik

FAU
FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

Motivation

- Indoor-to-outdoor radio links for low-power M2M applications
  - Smart metering
  - Infrastructure monitoring
  - IoT, Smart Cities, …



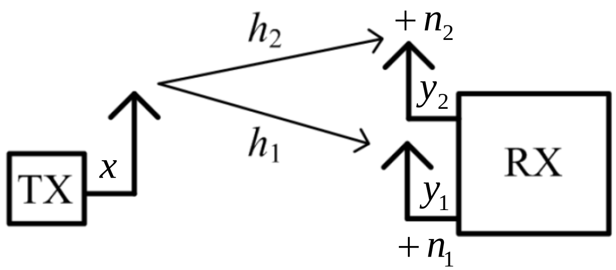
- Design and optimisation of **reliable wireless protocols** requires **detailed channel knowledge**, but…
  - ➔ How do typical radio links look like?
  - ➔ What is their long-term behaviour?

Agenda

- Introduction
- Transmit Signal Design
- Experimental Setup
- Field Trial and Initial Results
- Conclusion

Introduction

- Objective: Characterization of…
  - … linear distortions in **indoor-to-outdoor radio links** at 169, 434 and 868 MHz
  - … its long-term behaviour
  - … potential gain for SIMO/MIMO techniques



- Scenario:
  - Transmitter emits signal $x(t)$
  - Time-variant channel $h(t, \tau)$
  - Multi-antenna base station receives:

$$y_i(t) = x(t) * h_i(t, \tau) + n_i(t)$$

$i\ldots$ antenna index

$n_i\ldots$ interference plus noise

- Approach:
  - **Narrowband** channel sounding (regulation & costs!)
  - Flat fading ➔ single coefficient $h_i \in \mathbb{C}$
  - $\hat{x}(t)$ … local copy of successfully decoded packet
  - **Estimation**:

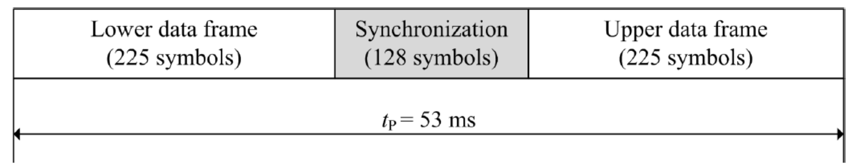
$$\begin{aligned}\hat{h}_i(\tau) &= \hat{x}^*(-t) * y_i(t) = \ldots \\ &= c \cdot h_i(t, \tau) + \tilde{n}_i(t)\end{aligned}$$

➔ Observation of time and frequency dependencies requires sampling in both domains

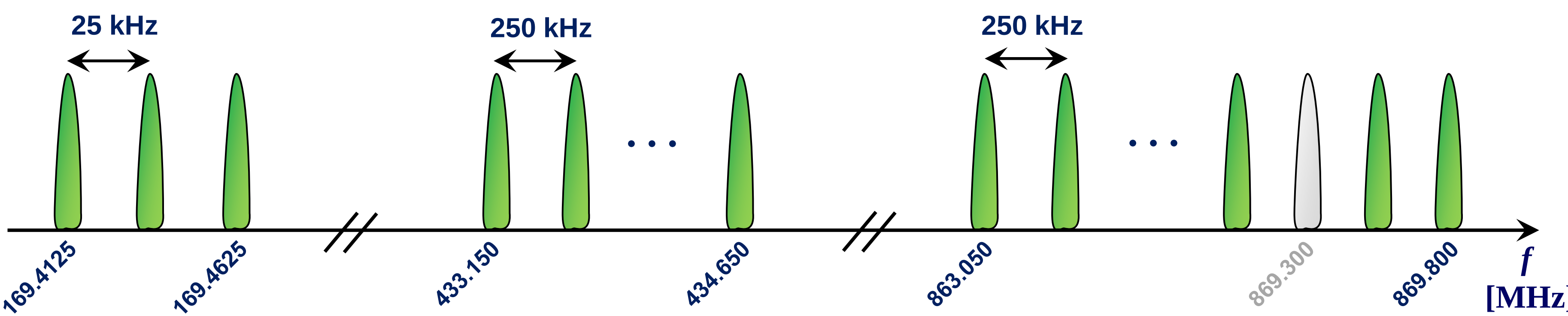
➔ Comprehensive channel models require measurements of **many $h_i(t, \tau)$**

Transmit Signal Design

- Channel sounding waveform:
  - Narrowband MSK with 10.92 kSps
  - 14 byte payload, 32 bit CRC, rate 1/3 conv. code
  - Error free decoding down to 0 dB SNR



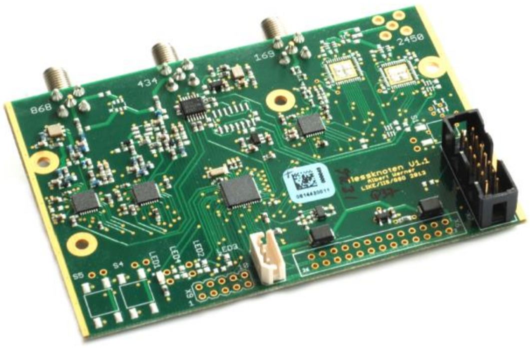
- Time and frequency domain sampling: **Every 5 minutes**



➔ How to design an experimental setup?

Experimental Setup I

- Transmitter
  - Cost efficiency and high accuracy for large-scale deployment
  - Support for 169, 434 and 868 MHz (optionally 2.4 GHz)
  - Three TI CC1125 transceiver chipsets (max. ≈ 20 mW)
  - Low-power micro-controller TI MSP430
  - Powered by 3 AA batteries (≈ two months)



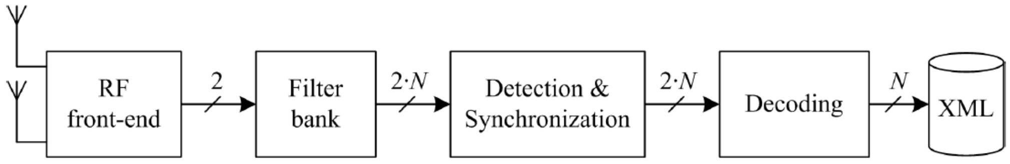
- Optional connector to Raspberry Pi for high-level operation and increased flexibility

- Closed antenna mounting influences antenna pattern

➔ Up to **50 transmitters** assembled

Experimental Setup II

- Multi-antenna software-defined radio receiver
  - RF front-end: 3x USRP B210
  - Block diagram for one receive path with N channels:

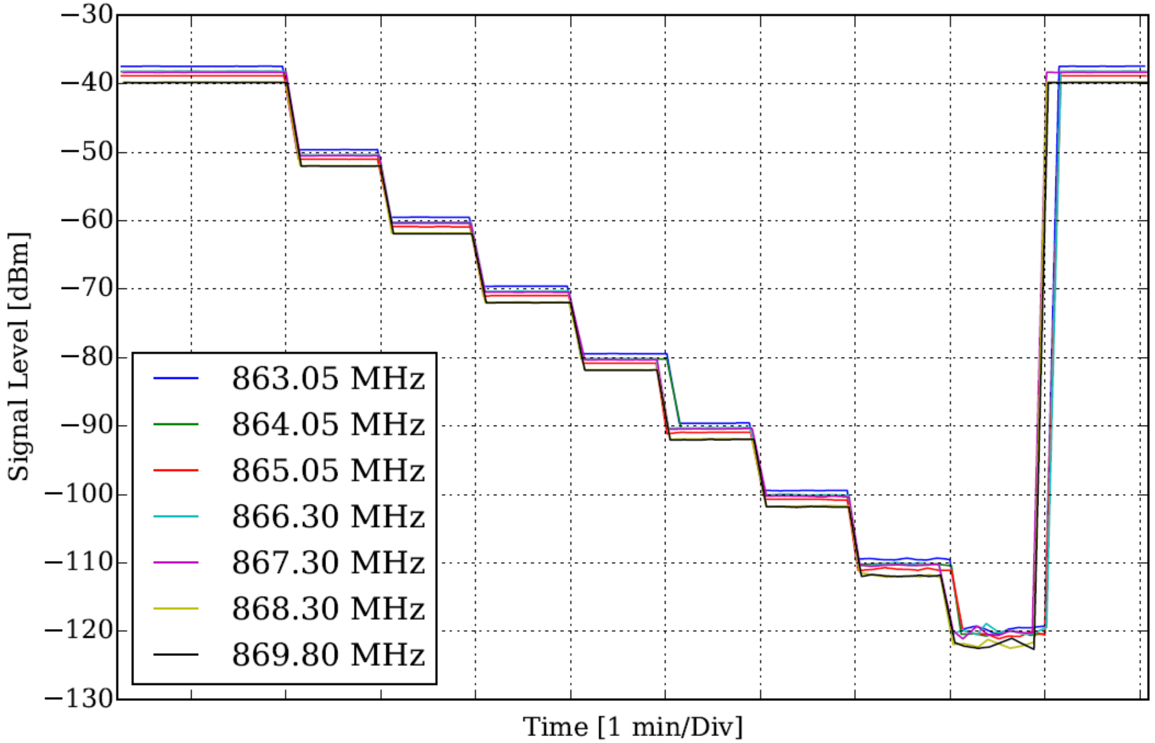


  - Signal processing in high-speed C++ framework (up to 160 MB/s)
  - Coherent MSK demodulation; estimation of amplitude, SNR and bit errors for each antenna
  - Parameters and payload stored in XML file for statistical post processing

➔ Framework implementation details:
"DFC++ - A novel framework approach for flexible signal processing on embedded systems"
Session SDR, CR and DSA Architectures 1

Experimental Setup III

- SDR power calibration results:



→ Maximum deviation of 2 dB for different channels and RF ports

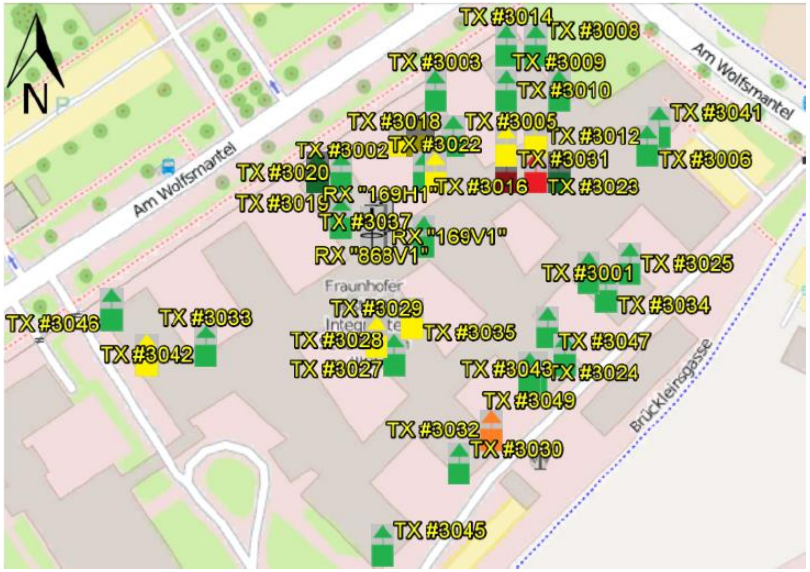
Agenda

- Introduction
- Transmit Signal Design
- Experimental Setup
- **Field Trial and Initial Results**
- **Conclusion**

Field Trial

- Building of Fraunhofer Institute for Integrated Circuits (IIS) in Erlangen-Tennenlohe
- Almost 40 transmitters deployed
- Receive antennas placed on roof
- Continuous operation from mid-August to mid-October 2014

Image source: Fraunhofer IIS / Kurt Fuchs

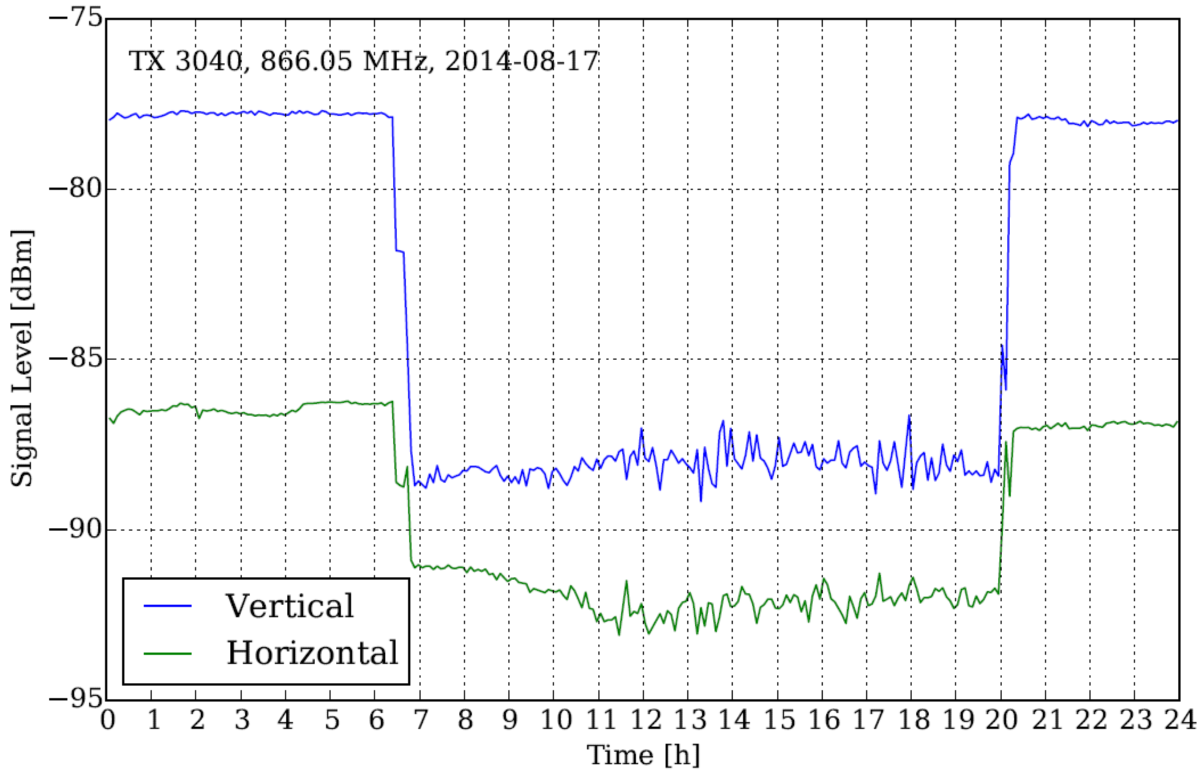


© OpenStreetMap contributors

➔ KML file provides quick overview and supports transmitter maintenance

Initial Results I

- Signal level on one channel for TX 3040



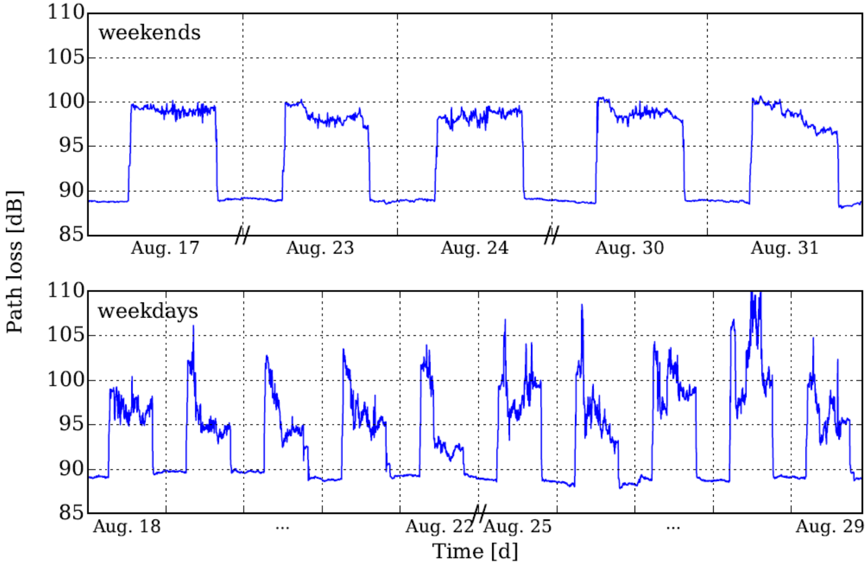
➔ In *most* situations, receive level on horizontal antenna is lower

- What might be the reason for this signal level drop?

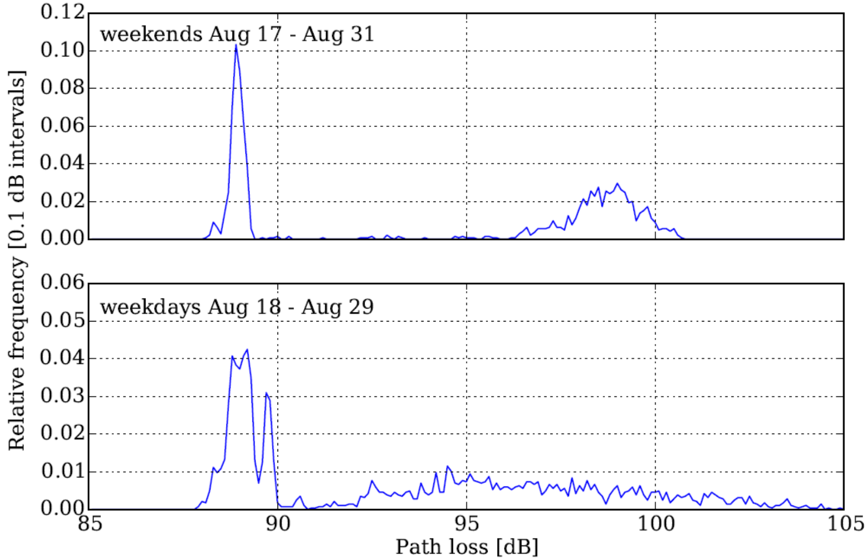
Initial Results II

- Path loss of TX 3040 at 866.05 MHz

  - Over weekends and working days:



  - Histogram:

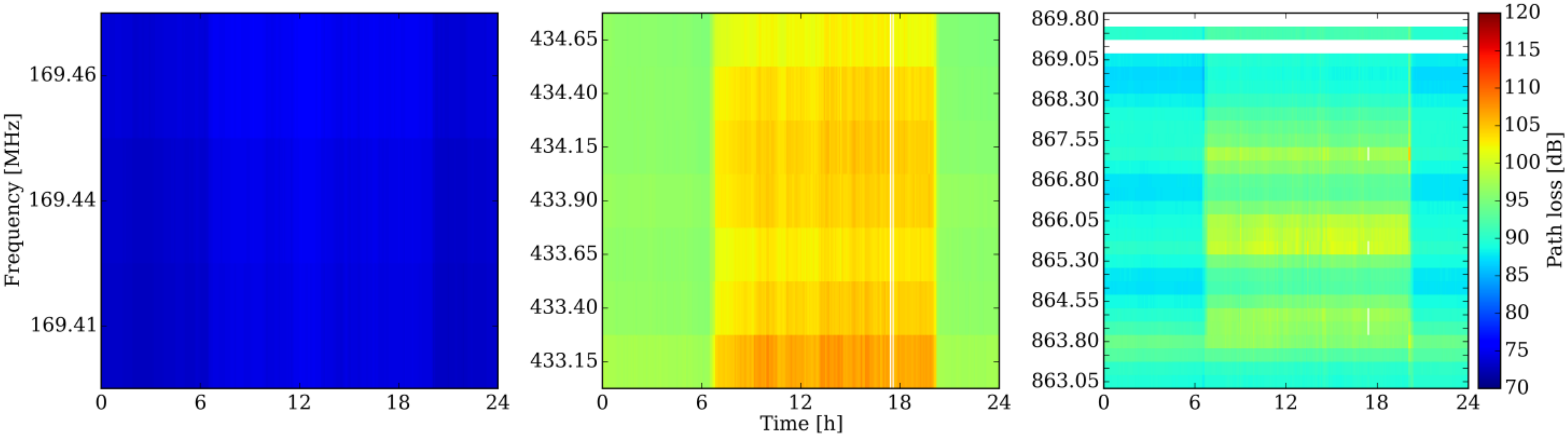


→ Automatic sun-blinds significantly influence propagation channel

→ Effect can be destructive, constructive or not be present

Initial Results III

- Waterfall diagram from TX 3040 for all frequency bands (24th August, 2014):



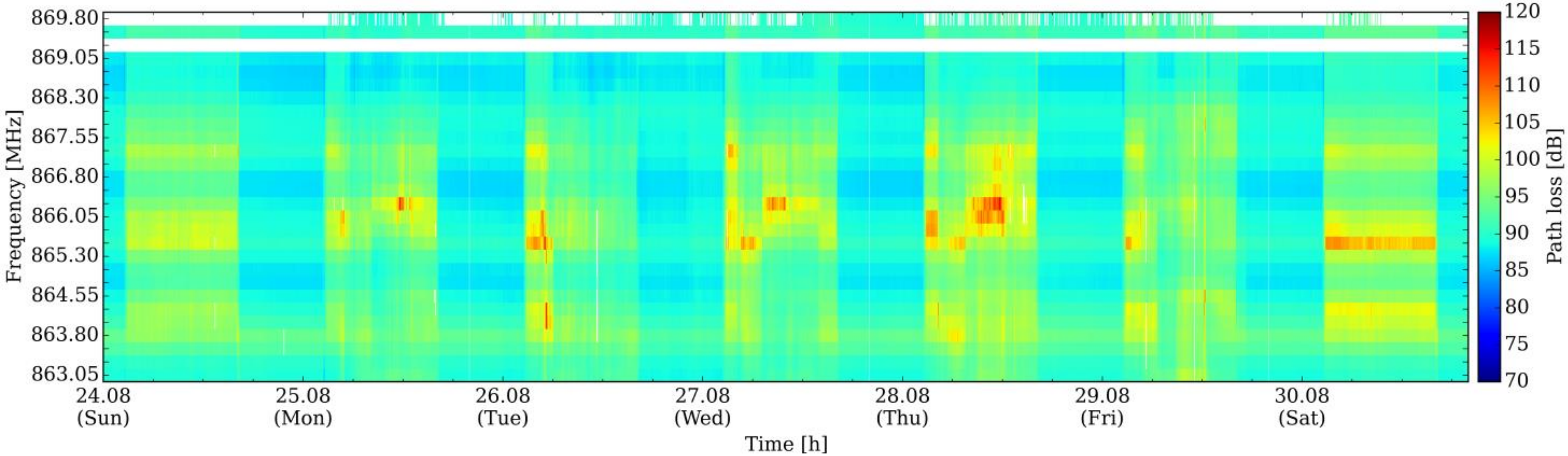
➔ Stationary channel conditions in 169 MHz band

➔ Sun-blinds affect 434 and 868 MHz bands

➔ Distinctive frequency selectivity in 868 MHz band

Initial Results IV

- Waterfall diagram from TX 3040 for seven days:



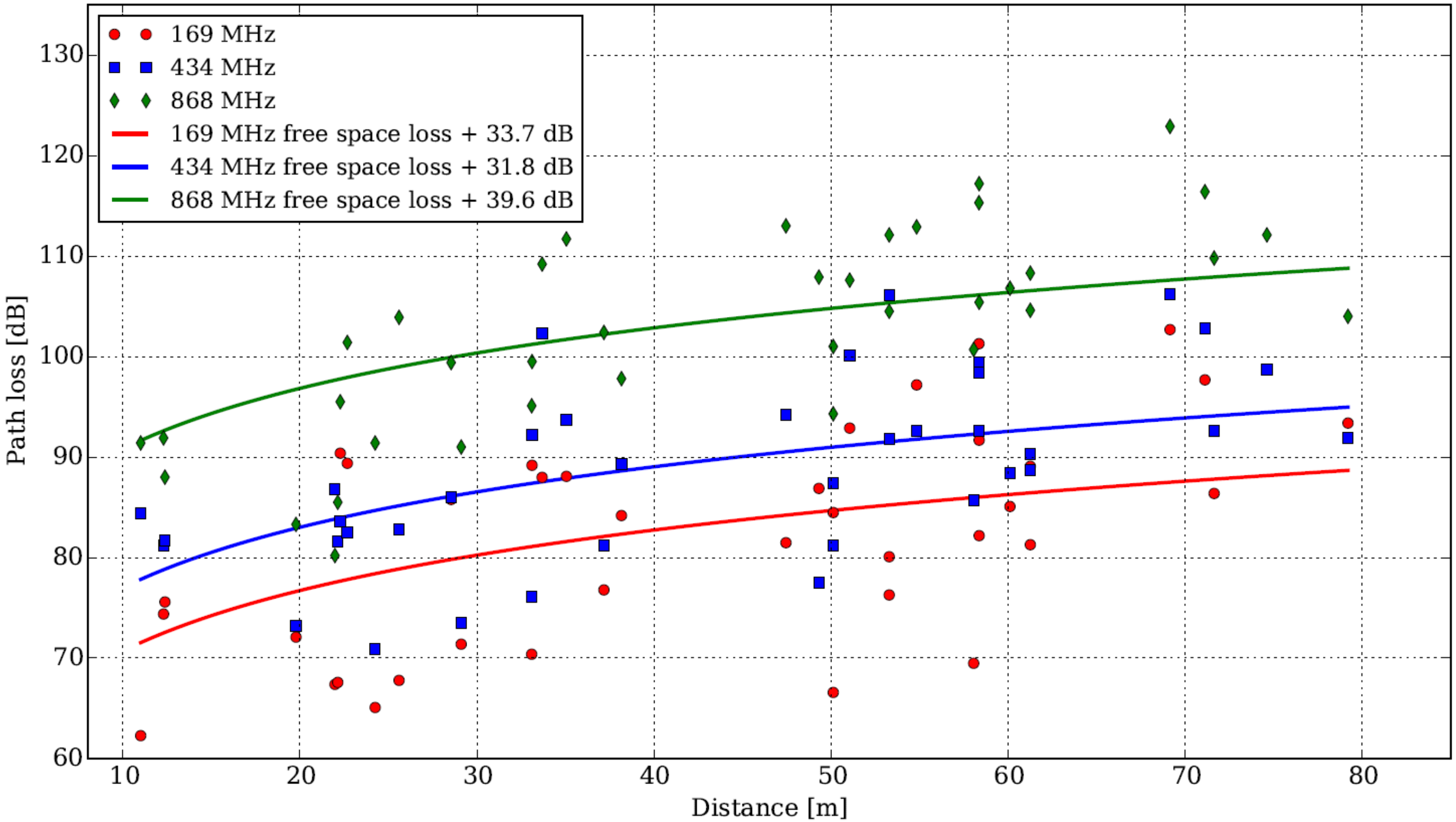
→ Time invariant channel conditions at night times

→ Fluctuations during working times

→ Other transmitters show *different* channel characteristics

Initial Results V

➔ Mean path loss during night time over transmitter distance (38 transmitters considered):



Conclusion

- Large-scale experimental setup for long-term channel propagation studies
- SDR receiver platform provides flexibility and sufficient accuracy
- Both time and frequency selectivity observed ➔ affects wireless system design
- Enormous amount of data during first field trial
- Careful evaluation and channel modelling in progress

- Future work:
  - Diversity combining of receive antennas
  - Scenarios urban, rural and industrial production sites

Thanks for your kind attention!

TECHNISCHE HOCHSCHULE NÜRNBERG
GEORG SIMON OHM

Fraunhofer
IIS

ANWENDUNGSZENTRUM
esi

FAU
FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
FACULTY OF ENGINEERING

Dipl.-Ing. Hendrik Lieske

hendrik.lieske@fau.de