Feasibility Study on Application of Impulse-UWB for Control Channel in Cognitive Radio Networks

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Outline

- Motivation
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- Problem Statement
- Evaluation of IR-UWB for Control Channel Usage
- Conclusions

Motivation

- Non-Contiguous OFDM (NC-OFDM) allows the utilization of fragmented opportunistically used spectrum in a very efficient way, but
  - Need of perfect synchronization between sender and receiver
  - Can be achieved by using a low-latency, always available Control Channel with an appropriate bitrate (a few 10kbit/s)
- Possible Control Channel solutions without dedicated resources
  - In-band
    - Outage must be avoided and QoS might be unexpected
  - Out-of-band
    - ISM Bands (theoretical unbound latencies)
    - Impulse-Radio Ultra-WideBand (IR-UWB)

Simulation Results from Nascimento et al. [1]

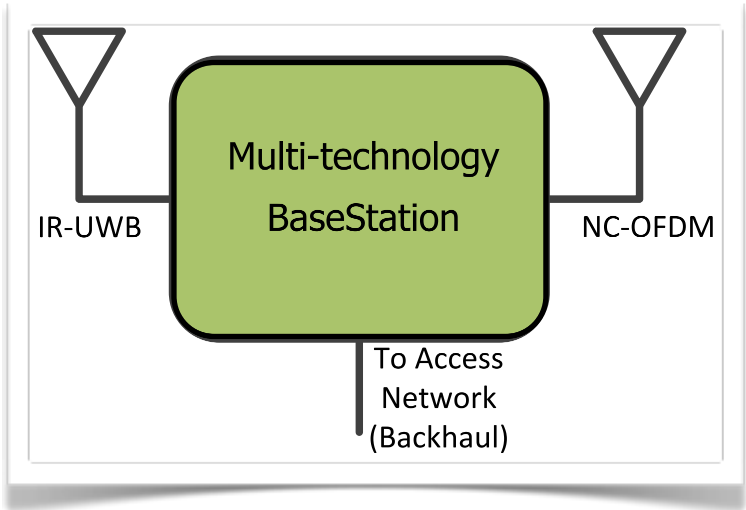
- Theoretical work shows that IR-UWB can have a communication range up to 1km, but lack of experimental studies.

Modulation	**Ranges in meter for different bitrates** 10 kbps	100 kbps	550 kbps	1000 kbps
	Free space path loss model			
2-PAM	730	231	98	73
64-PPM	1018	322	137	102
	Lognormal shadowing path loss model (outage probability of 0.01%)			
2-PAM	165	52	22	16
64-PPM	228	72	31	21
	UWB dependent two-ray path loss model			
2-PAM	850	422	133	110
64-PPM	1016	530	149	133

[1] J. Nascimento and H. Nikookar, "On the range-data rate performance of outdoor UWB communication," in *Conference on Wireless Broadband and Ultra Wideband Communications*. IEEE, 2007, pp. 72–77.

Motivation cont'd

- Intended multi-technology BaseStation (BS) with two air interfaces in simultaneous use:
  1. NC-OFDM wide-band for data transmission and
  2. IR-UWB for control signaling.



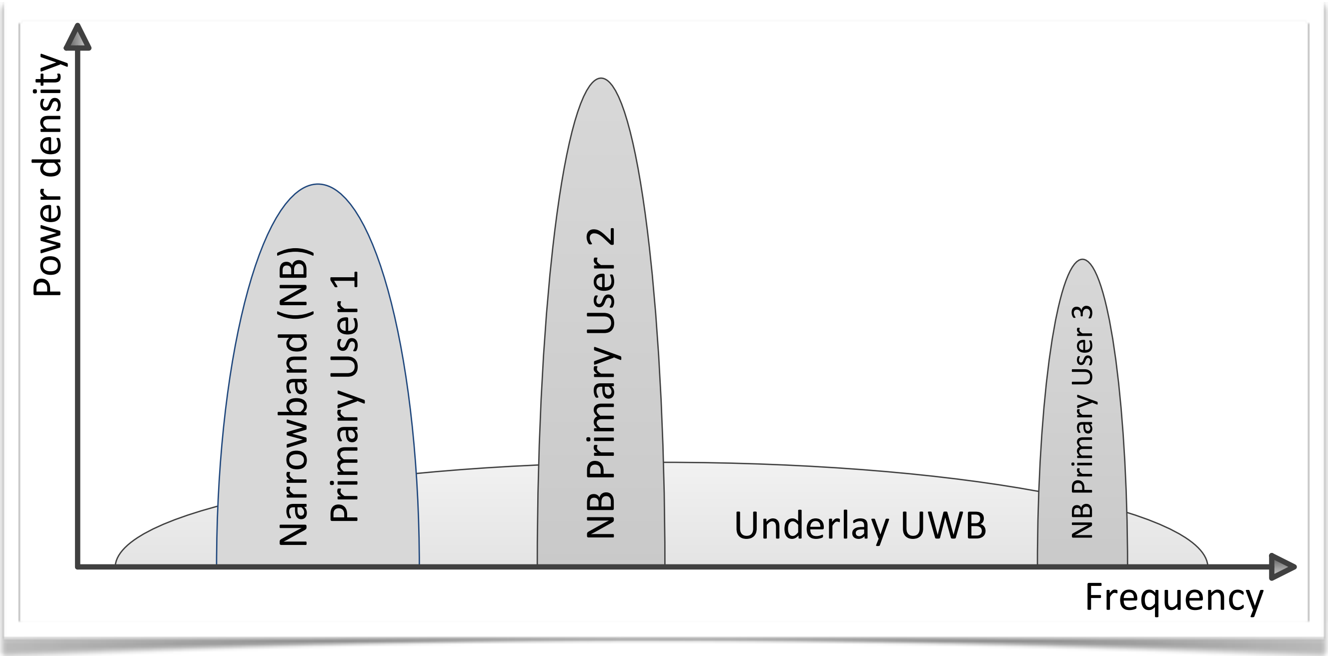
Contributions

- With the help of measurements we observed that IR-UWB can be used as CC in ranges up to several hundred of meters with Line-of-Sight, as well as with minor obstructed LOS (e.g. some leaves of trees).
- IR-UWB as wideband technology is severely affected by narrow-band interference in close proximity.
- IR-UWB is an appropriate technology for CC in small cell deployments in TV White Spaces.

Primer on IR-UWB

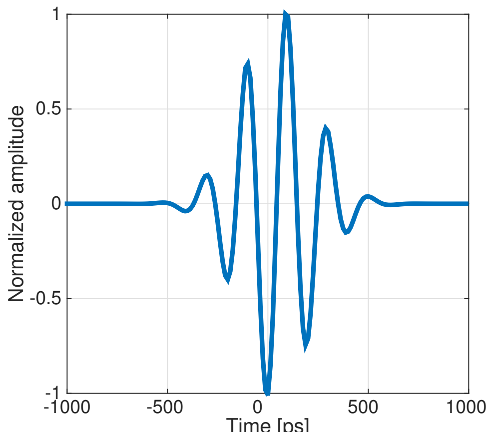
Underlay Spectrum Access Model

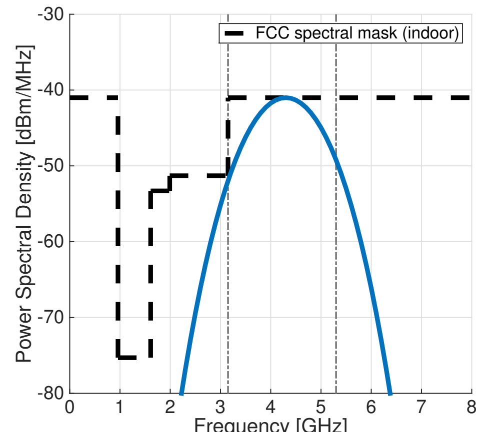
- Secondary User (SU) can transmit in parallel with a licensed user, but at a low power on each band to limit interference.
- FCC (2002): max. transmission power of -41.3dBm/MHz in the range of 3.1GHz to 10.6GHz for SU.



Impulse-UWB Primer

- Rather simple technology first introduced in 1901.
- Very short pulses in time, lead to large bandwidth in frequency
  - Signals with an instantaneous bandwidth exceeding 500MHz or with a fractional bandwidth larger than 0.2 are considered as UWB
- Robust in the face of multipath
- Communication with very low RF profiles
- Fixed pulse repetition rate, Pulse Integration Rate (PII) – increasing pulses per bit will result in SNR advantage





Problem Statement

Problem Statement

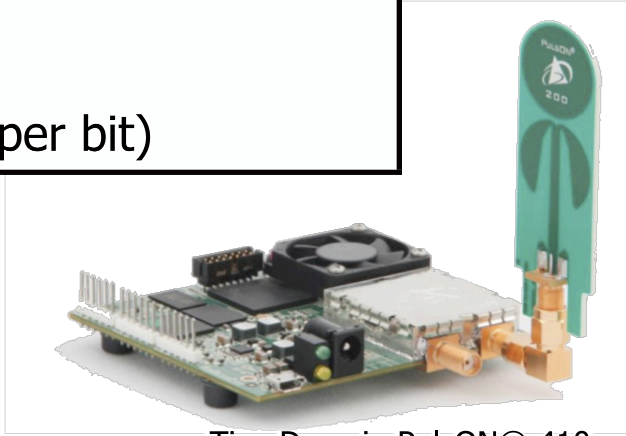
- Is IR-UWB able to provide a reliable, low latency, always available, but low bitrate (~10kbit/s) communication over a communication range of a few hundred of meters outdoors (small cells)?
- Moreover, is it possible to operate IR-UWB and NC-OFDM in parallel in an envisioned multi-technology station equipped with these two air interfaces without significant mutual disturbance between both technologies?
- Measurement study from a state-of-the-art outdoor IR-UWB testbed.

Evaluation of IR-UWB for Control Channel Usage

IR-UWB State-of-the-Art Hardware

- TimeDomain P410 testbed

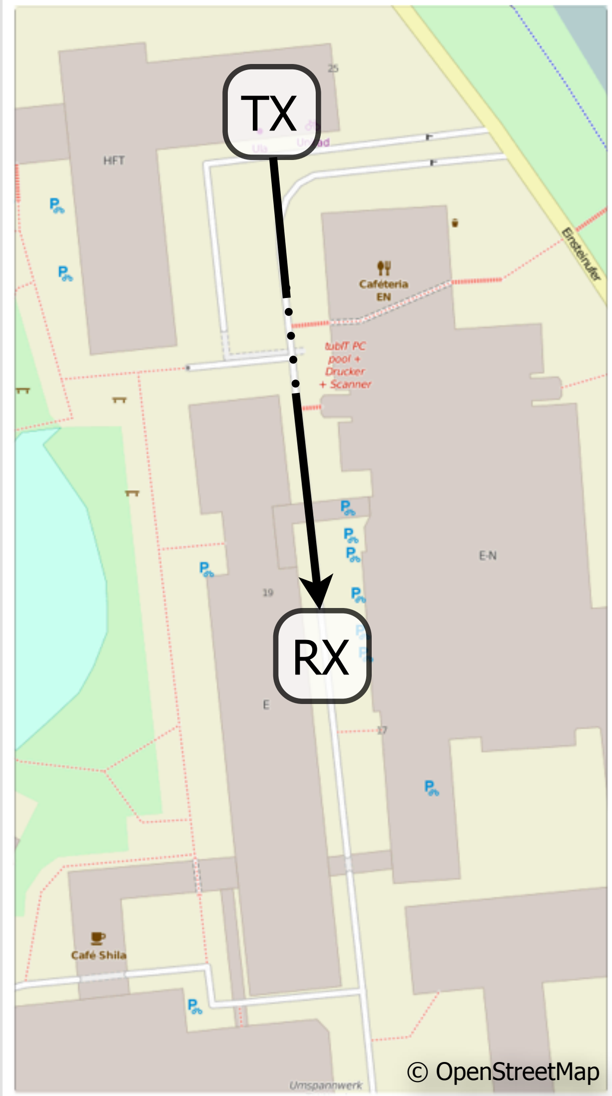
Parameter	Value
Operating band	3.1 – 5.3 GHz
Center frequency	4.3 GHz
Transmit power	-12.64 dBm
Noise figure	4.8 dB
Dynamic range (PII=10)	60 dB
Transmit pulse repetition rate	10.1 MHz
Pulse Integration Rate (PII)	10 (1024 pulses per bit)


TimeDomain PulsON® 410

Line-of-Sight Measurements

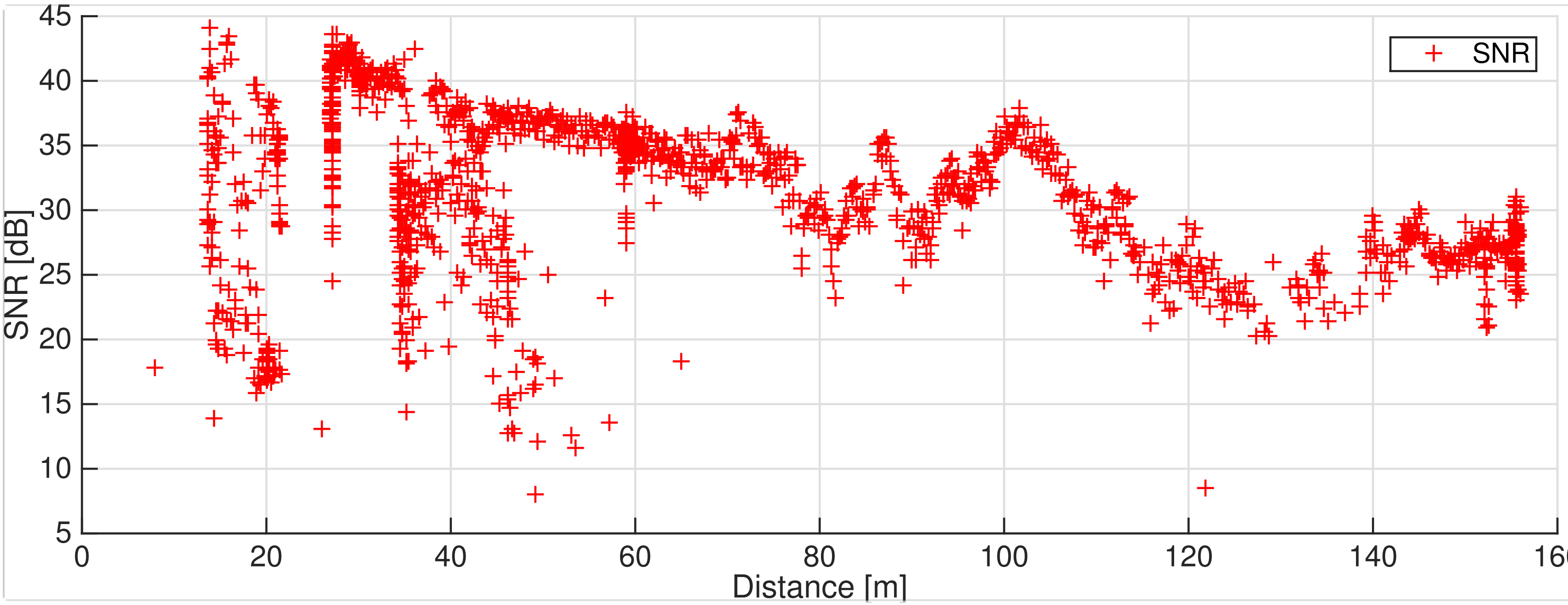
Methodology

- Transmitter (TX) on roof (25m above ground)
- Receiver (RX) on ground level with always unobstructed Line-of-Sight (LOS)
- Moved between 18 to 160m apart
- Most robust PII (1024 Pulses per bit)
- Evaluation of Signal-to-Noise Ratio (SNR), noise floor and signal strength



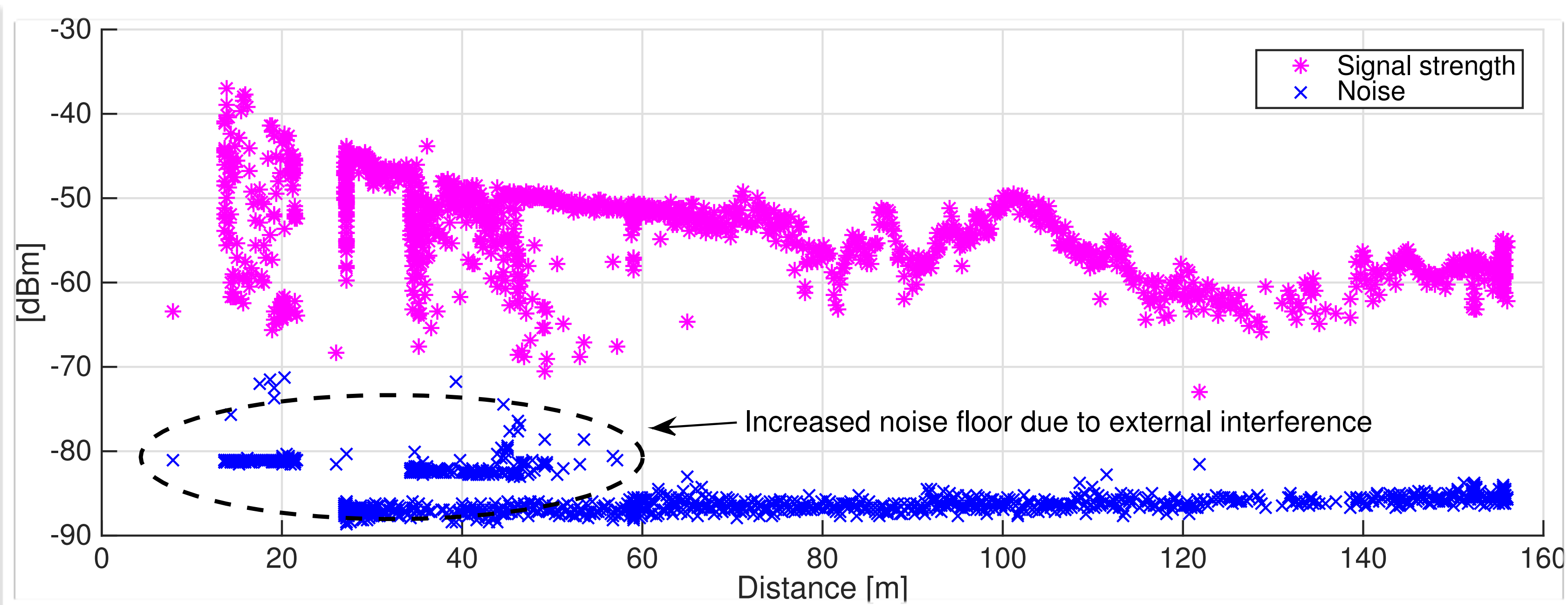
Distance vs. SNR – Results

- No clear relationship between link length and SNR. Lots of short links (<60m) have an unusual low SNR.
  - Note: Each point in the following figures represents a received packet from which SNR, noise and signal power is calculated.



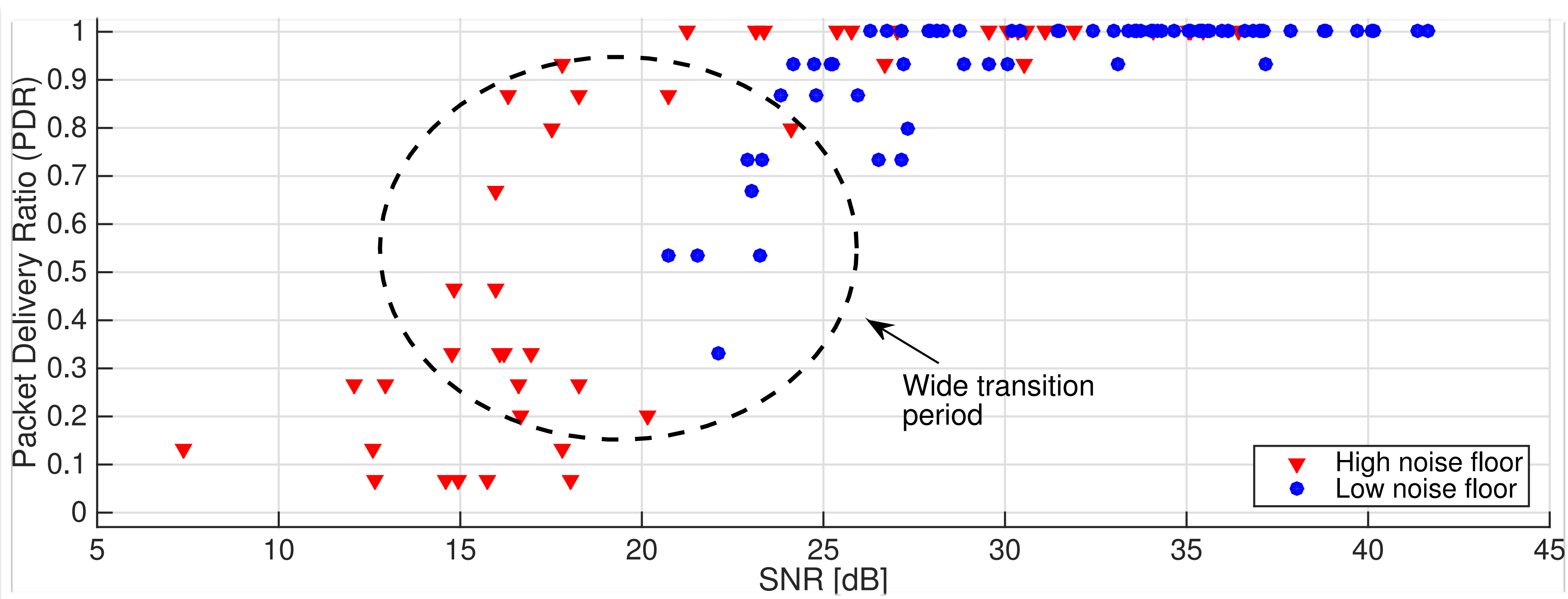
Distance vs. Noise and Signal Strength

- Unusual high noise floor which is about 8 to 17dB higher than average (about -88dBm).
- Bimodal distribution – increase of noise floor and SNR drop at low distances.
  - Influence from local sources of interference.



SNR vs. Packet Delivery Ratio (PDR)

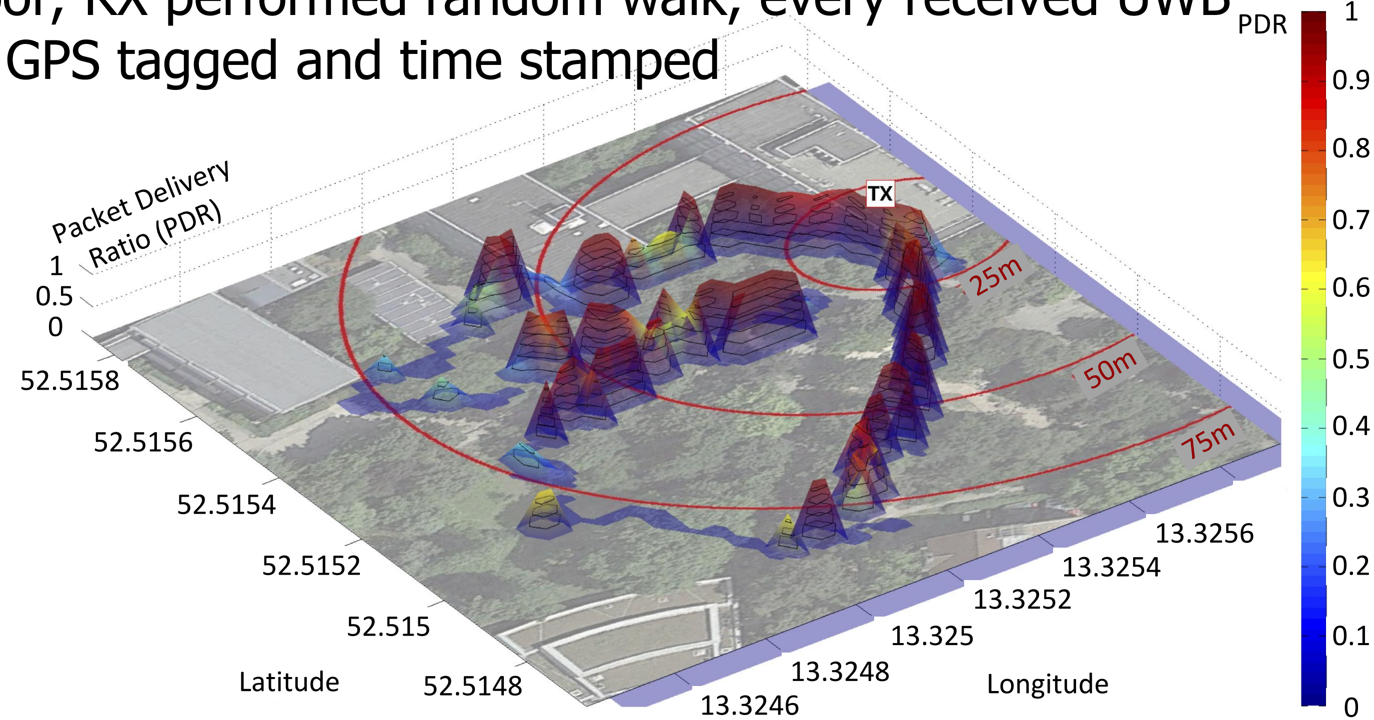
- Bi-modal distribution due to the different noise floor levels.
- Weak relationship between SNR and PDR makes SNR a poor indicator for the link quality.



Packet Delivery Ratio Measurements

PDR at Different Spatial Locations

- Investigate obstructed LOS
- Methodology:
  - TX on roof; RX performed random walk, every received UWB frame is GPS tagged and time stamped



- Results:
  - LOS and minor shadowing (a few leaves) only. Obstructed and non-LOS leads to drop in PDR.

Intermediate Summary

- At least a slightly obstructed LOS between IR-UWB transmitter and receiver is necessary to allow communication in ranges of 150m and more.
- SNR a poor indicator for the link quality.
- Under certain conditions IR-UWB fulfills the requirements as always available, low latency CC.

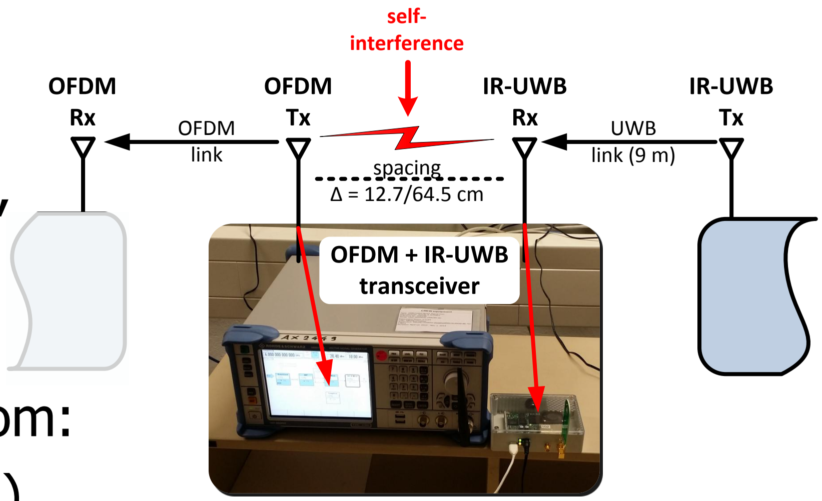
Co-existence of IR-UWB and NC-OFDM

Motivation & Research Question

- Narrowband interference problem in IR-UWB systems is well studied in theory.
- IR-UWB has a high probability to be affected by narrowband interference.
  - Ultra wide transmission leads to a large number of possible narrowband interferers in the same frequency range.
  - Restricted transmission power leads to a limited dynamic range.
  - A single strong interferer can diminish the receivers performance seriously.
- The state-of-the-art IR-UWB transceiver in our testbed has a very wide bandwidth of about 2.2GHz and a high dynamic range of about 60dB
  - To some degree the receiver is able to deal with narrowband interference.
- Study of IR-UWB transmission robustness with respect to co-located simultaneous OFDM transmissions,
  - First objective: co-existence with narrow-band OFDM transmission (WiFi 802.11a, 20MHz).

Experimental Setup

- UWB link:
  - TX: highest PII, highest allowed TX power
  - RX: capture received packets & post-processing (calculation of SNR)
- OFDM transmitter:
  - R&S signal generator (trace file),
  - 802.11a like PHY (BW=20MHz),
  - TX gain: 10dBm,
  - Center frequency was **swept** from:
    - 1GHz … 6GHz (50MHz steps)



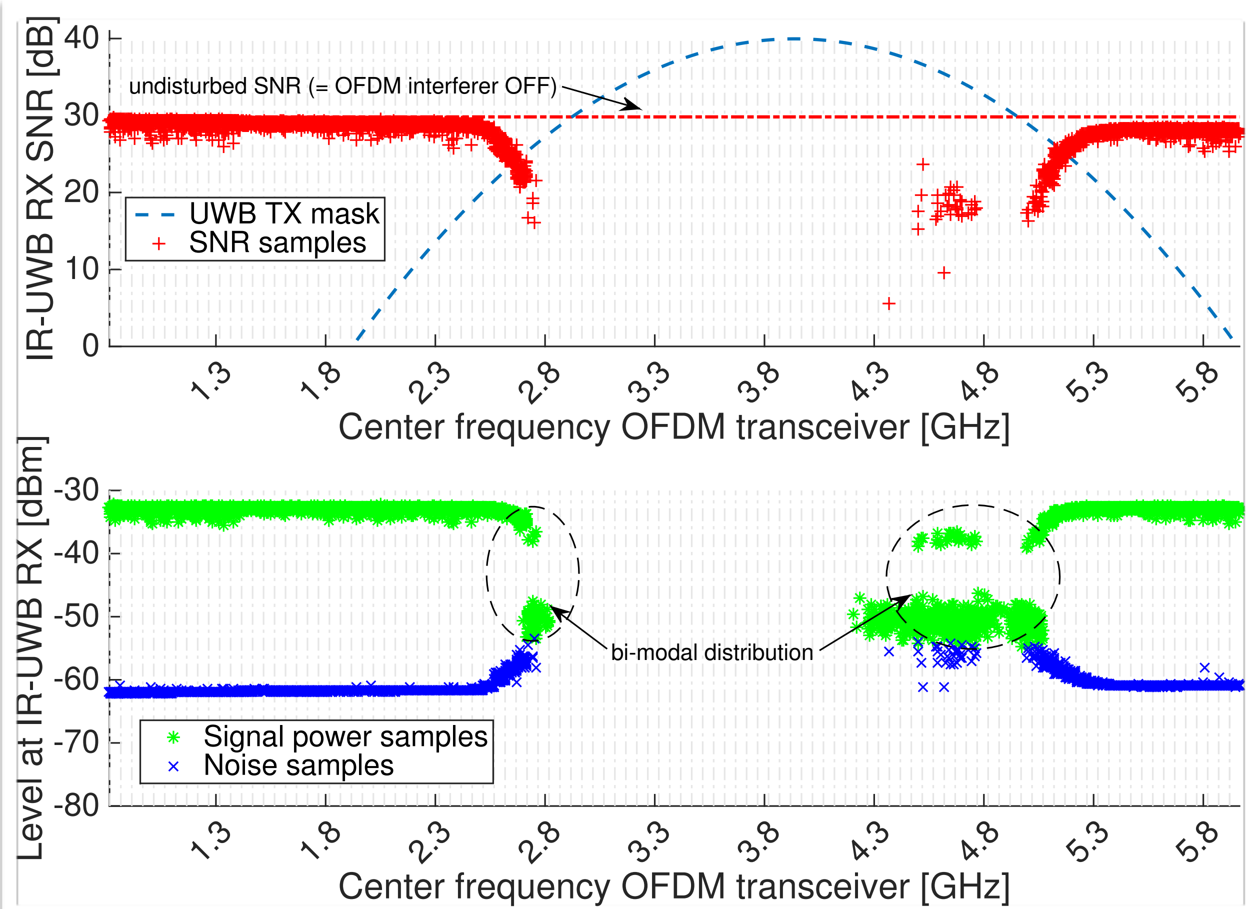
- Distance UWB-Rx to OFDM TX:

  (1) 12.7cm mockup for **multi-technology device,**

  (2) 64.5cm mockup for **outdoor setup**.

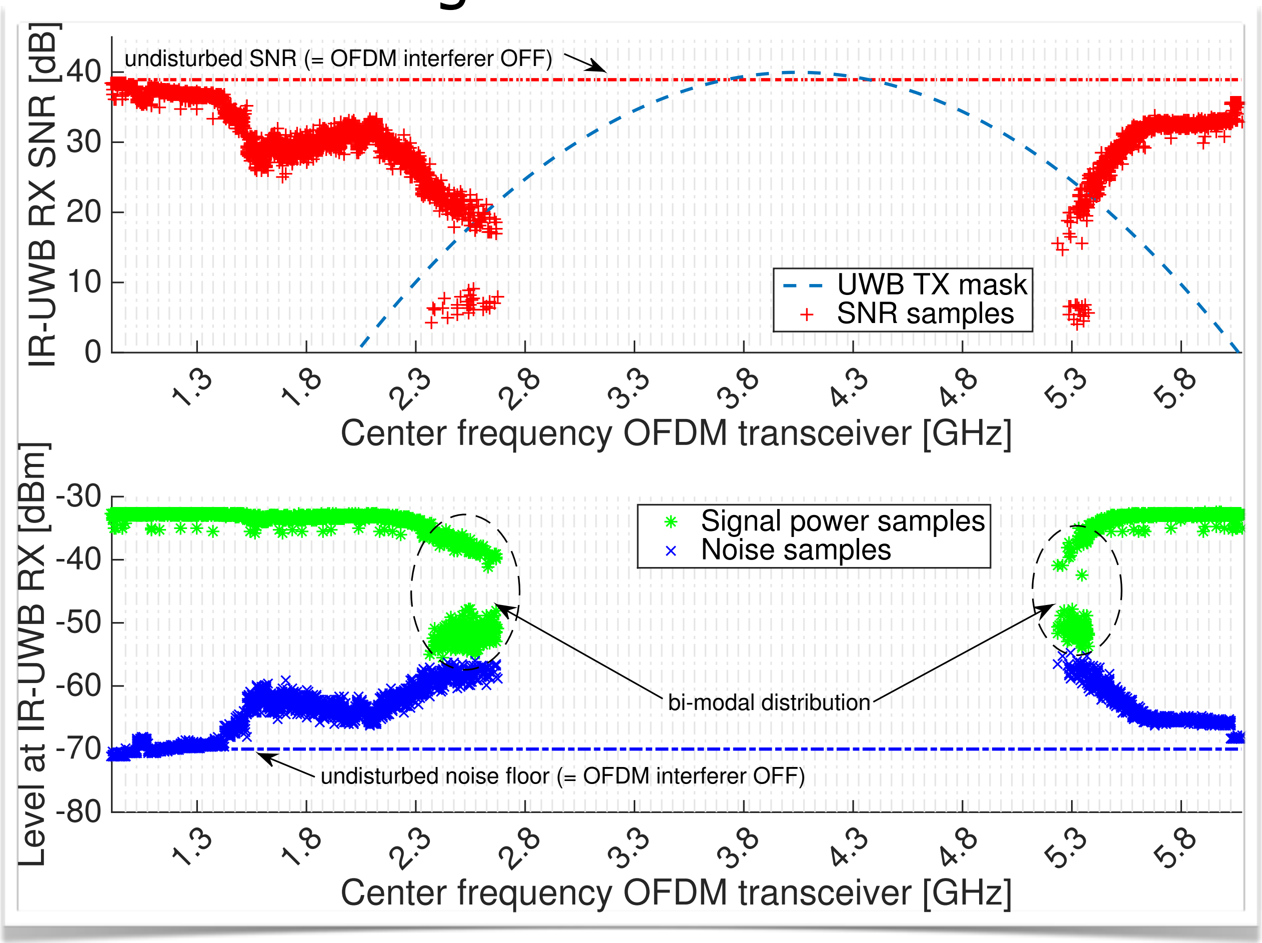
Air Interface spacing of 64.5cm

- **Results**: High distortion due to narrow-band co-channel interference



Small Spacing between Air interfaces

- **Results**: High distortion even beyond the UWB communication range



Practical Implications

- A separate CC can improve the performance of CR in TVWS significantly
  - A CC permits a very fast and reliable spectrum adaption and therefore a very high level of primary user protection.
  - The CC can further be used to coordinate spectrum allocation between secondary users.
- IR-UWB is an appropriate technology for the CC in TV White Spaces (WS)
  - First, due to the used frequency band below 1GHz we do not expect to have self-interference between IR-UWB (f_c = 4.3GHz) and NC-OFDM using TVWS.
  - Second, when using TVWS for WLAN (e.g. 802.11af) the communication ranges of the control and data channel are comparable as long as (obstructed) LOS propagation exists (e.g. WLAN Access Points mounted on roof tops outdoors).

Conclusions

- Simultaneous operation of IR-UWB and 802.11bg/a in a multi-technology BS with small spacing is not feasible.
  - Increasing the spatial separation between both air interfaces helps and 2.4GHz ISM as well as higher frequencies of the 5GHz ISM band become available.
  - Alternative is orthogonalization in time to omit self-interference.
- For small cell deployments in the 700MHz band TV White Spaces IR-UWB is an appropriate technology for CC.

Paper: Michael Döring, Anatolij Zubow and Adam Wolisz, "Feasibility Study on Application of Impulse-UWB for Control Channel in Cognitive Radio Networks", IEEE CORAL, Boston, USA, 2015

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