Stochastic and Deterministic Broadband UHF RFID Channel Models for Indoor Localization

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Lehrstuhl für Informationstechnik
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Agenda

- Motivation: Indoor Localization
- Status of Broadband UHF RFID Channel Models
- Indoor Channel Models (determ., stoch.)
- Results
- Conclusion & Outline

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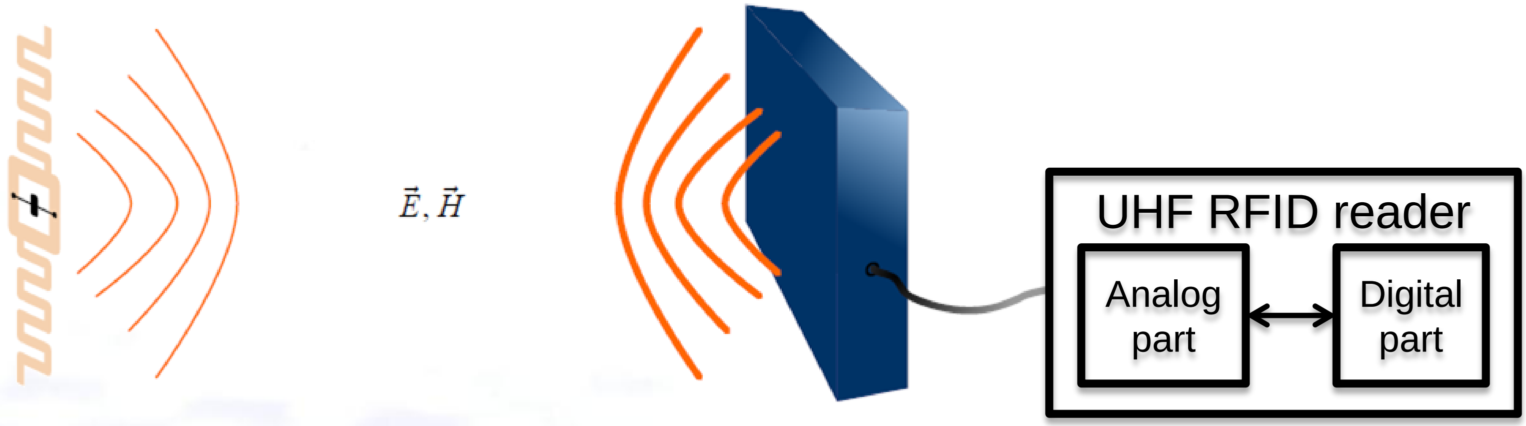
Motivation – Indoor Localization

Distance estimation between RFID reader and RFID tag

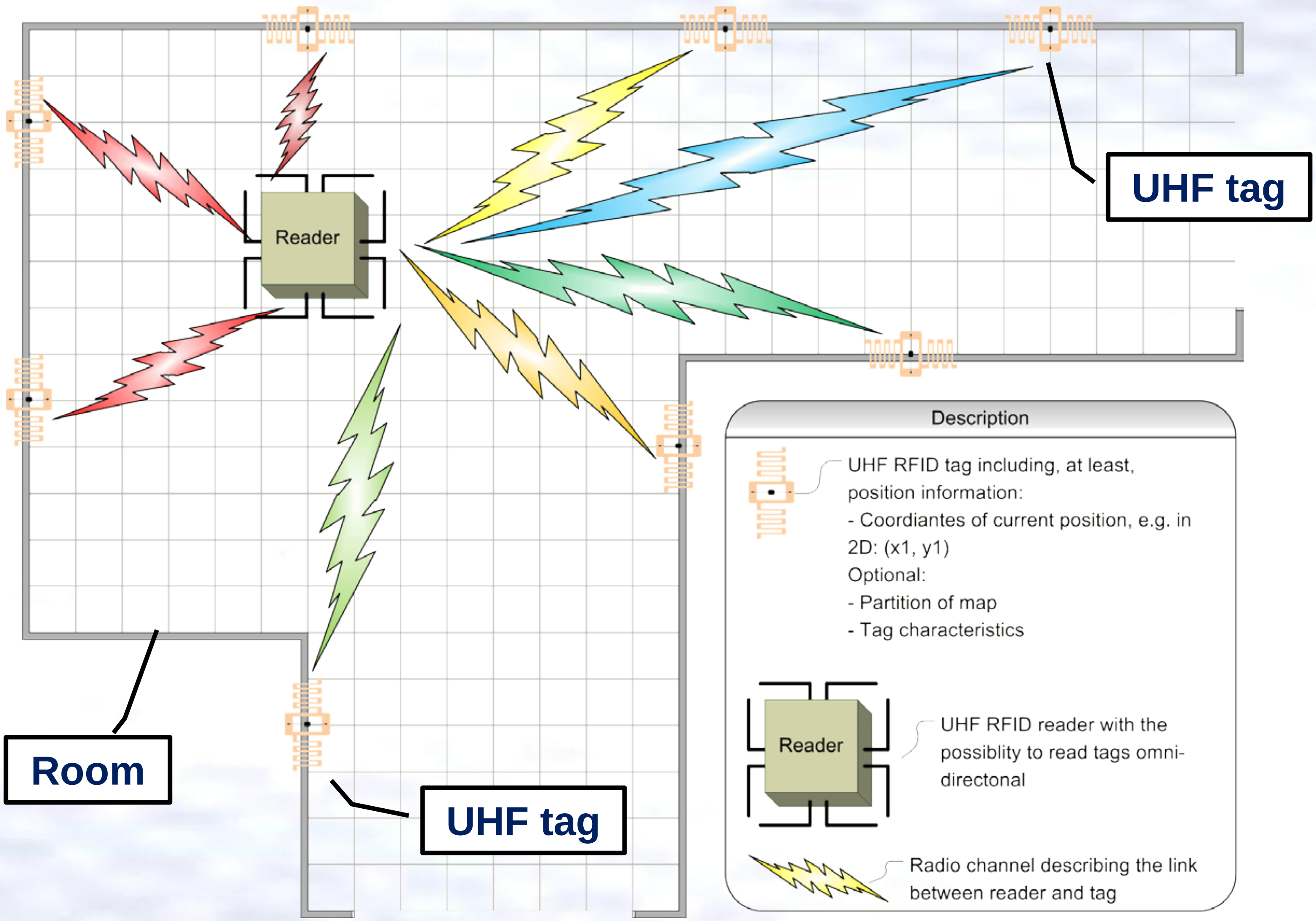
- Tag localization (e.g., logistic processes): External bearing
- Reader localization (e.g., Indoor positioning): Self-localization



RFID tag

RFID reader

Motivation – Indoor Localization – Scenario



Motivation – Indoor Localization – Requirements

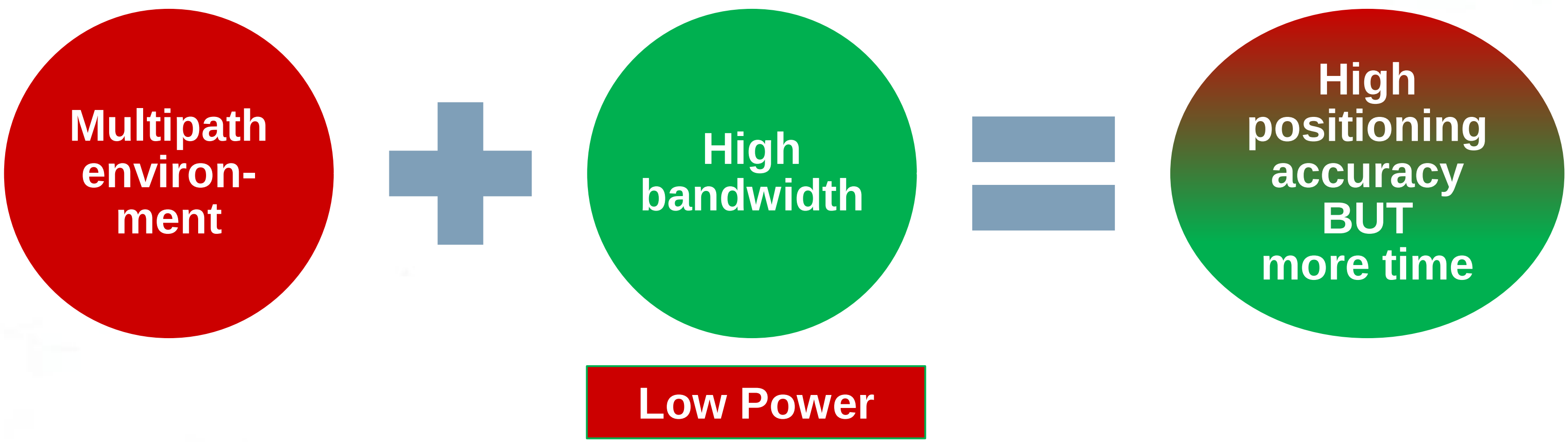
Multipath environ-ment

Small bandwidth

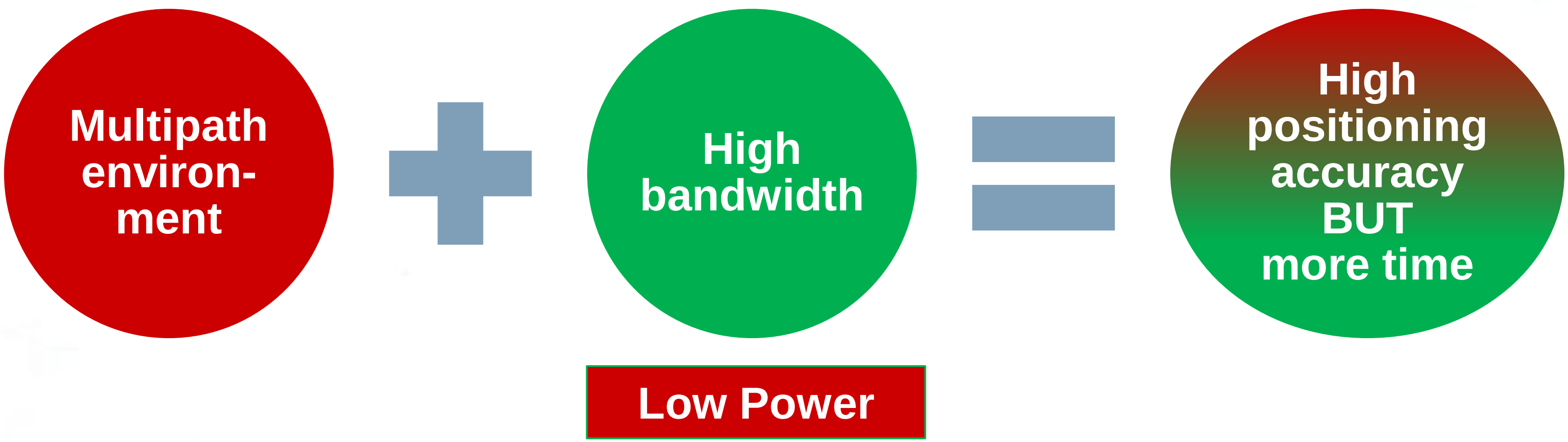
Low positioning accuracy

High Power

Motivation – Indoor Localization – Requirements



Motivation – Indoor Localization – Requirements



→ Need for broadband UHF RFID channel models in Indoor environments

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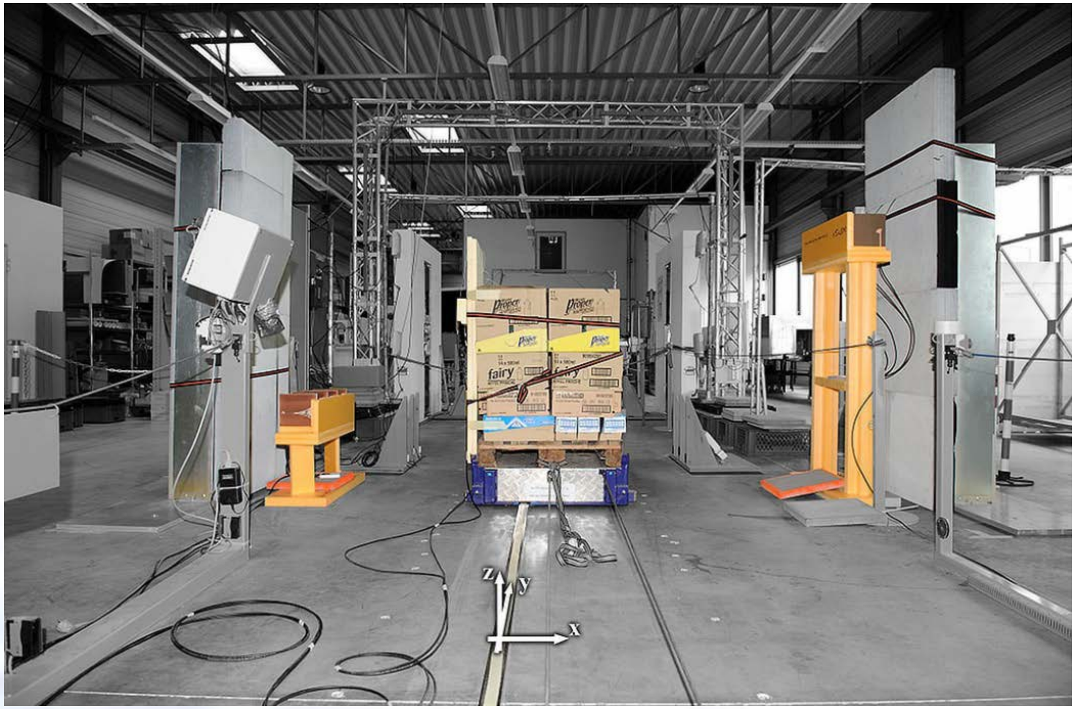
Status of Broadband UHF RFID Channel Models

- Due to the small bandwidth of RFID nearly no effort has been put in modeling broadband RFID channels
- One approach covers the 500 MHz to 1.5 GHz band for RFID gates in a warehouse environment



UWB Channel Sounding for Ranging and Positioning in Passive UHF RFID
Daniel Arnitz, Grzegorz Adamiuk, Ulrich Muehlmann, Klaus Witrisal

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Indoor Channel Models

Distinguish between

- Deterministic models (e.g., from raytracing)
  - \+ Very good model for the specific scenario
  - \- Only one channel model for each scenario
- Stochastic models (e.g., from measurements)
  - \+ Lots of channel models
  - \- Only applicable for general assumptions
- Hybrid models combine deterministic & stochastic channel models

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Indoor Channel Models

- Channel models are based on the Saleh-Valenzuela model:

$$h_{\text{S-V}}[t] = \sum_{l=1}^{L} \sum_{k=1}^{K} a_{k,l} e^{j\varphi_{k,l}} \delta[t - T_l - \tau_{k,l}]$$

- *K* = number of multipath components (MPCs) per cluster
- *L* = number of clusters
- T_l = arrival time of cluster *l*
- $T_{k,l}$ = relative arrival time of MPC *k*
- RFID channel model comprises up- and downlink channel
- LOS factor describes power of LOS path: $K_{\text{LOS}} = \frac{P_{\text{LOS}}}{P_{\text{channel}}}$

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Deterministic Channel Model

- Based on Raytracing model from KIT
- Scenario:
- Frequency:

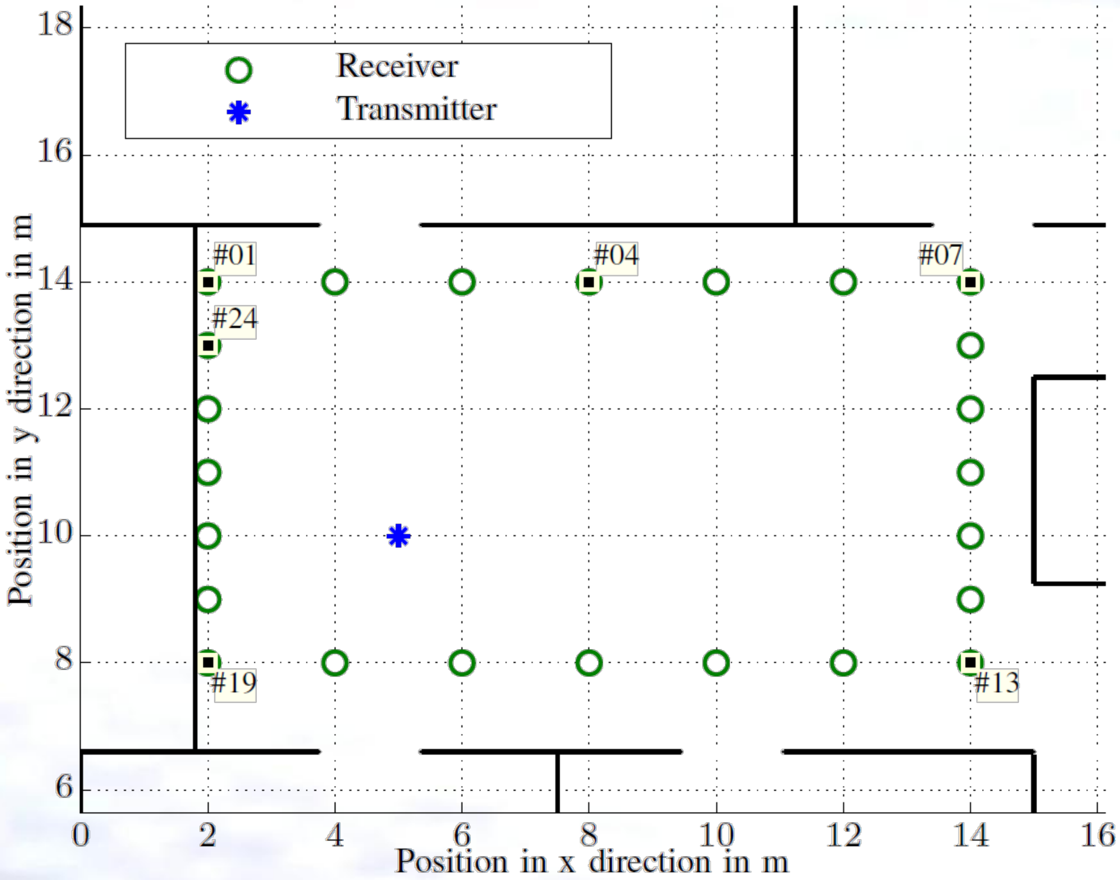
  850-950 MHz

  in steps of 1 MHz
- Results:

  Electrical field

  strength E(t) for

  all traces



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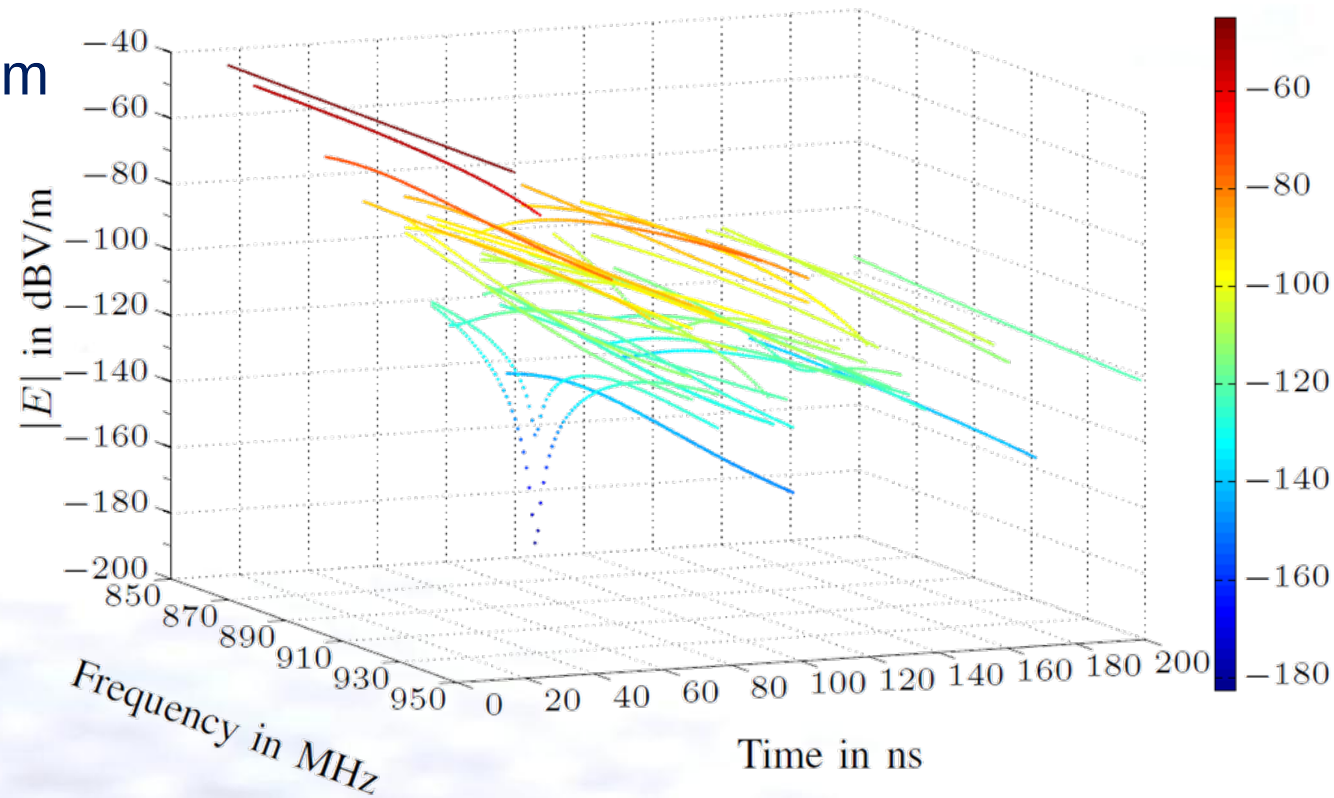
Deterministic Channel Model – Channel Example

- Absolute value of electrical field strength for channel #01
- Distance

  T→R: 5 m



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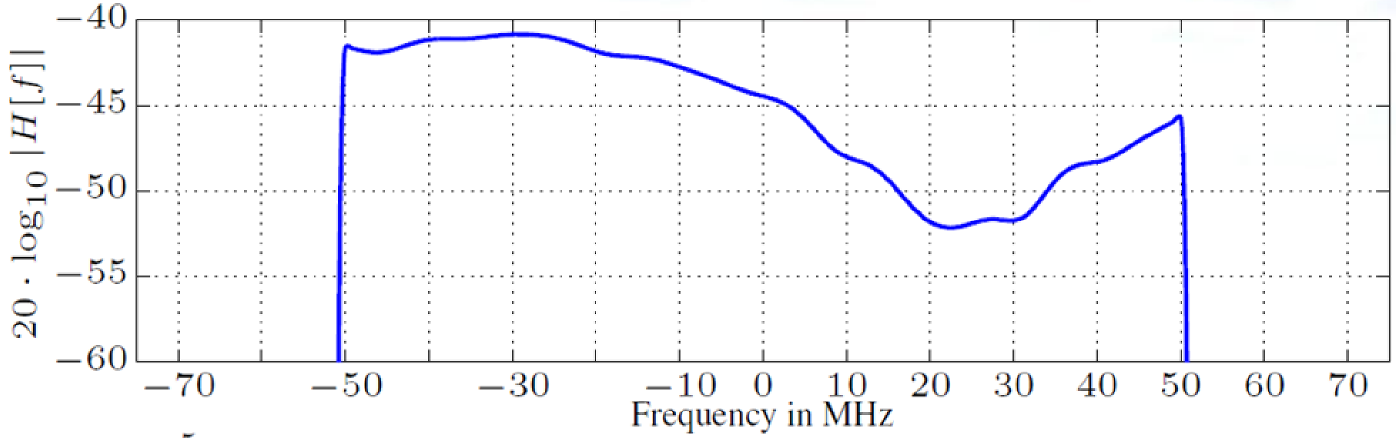
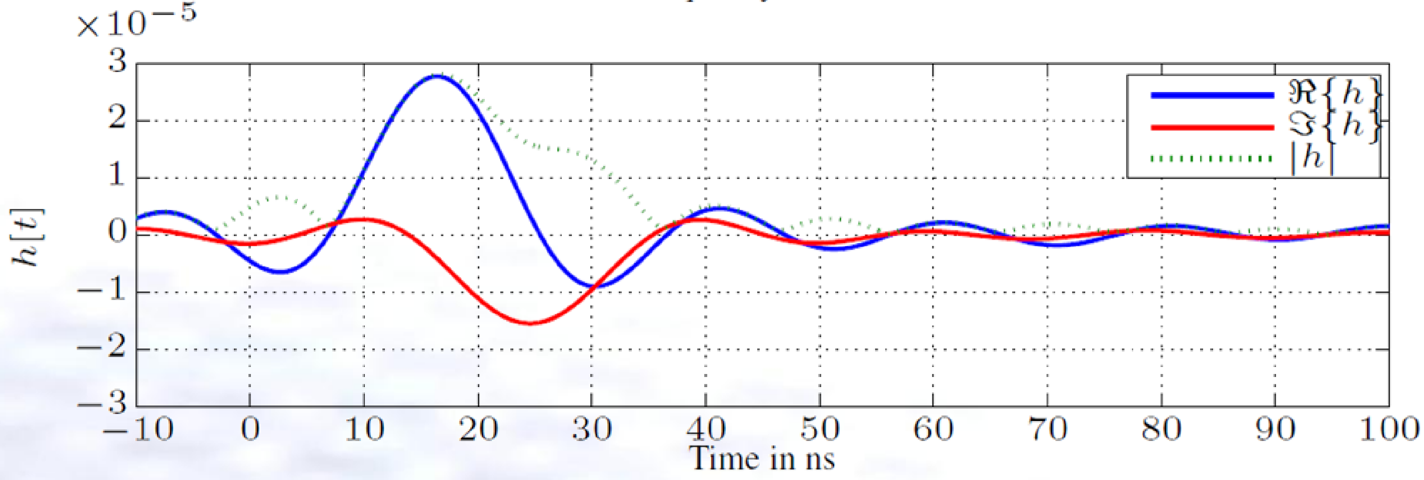
Deterministic Channel Model – Channel Example

- Calculation of CTF and CIR for channel #01:





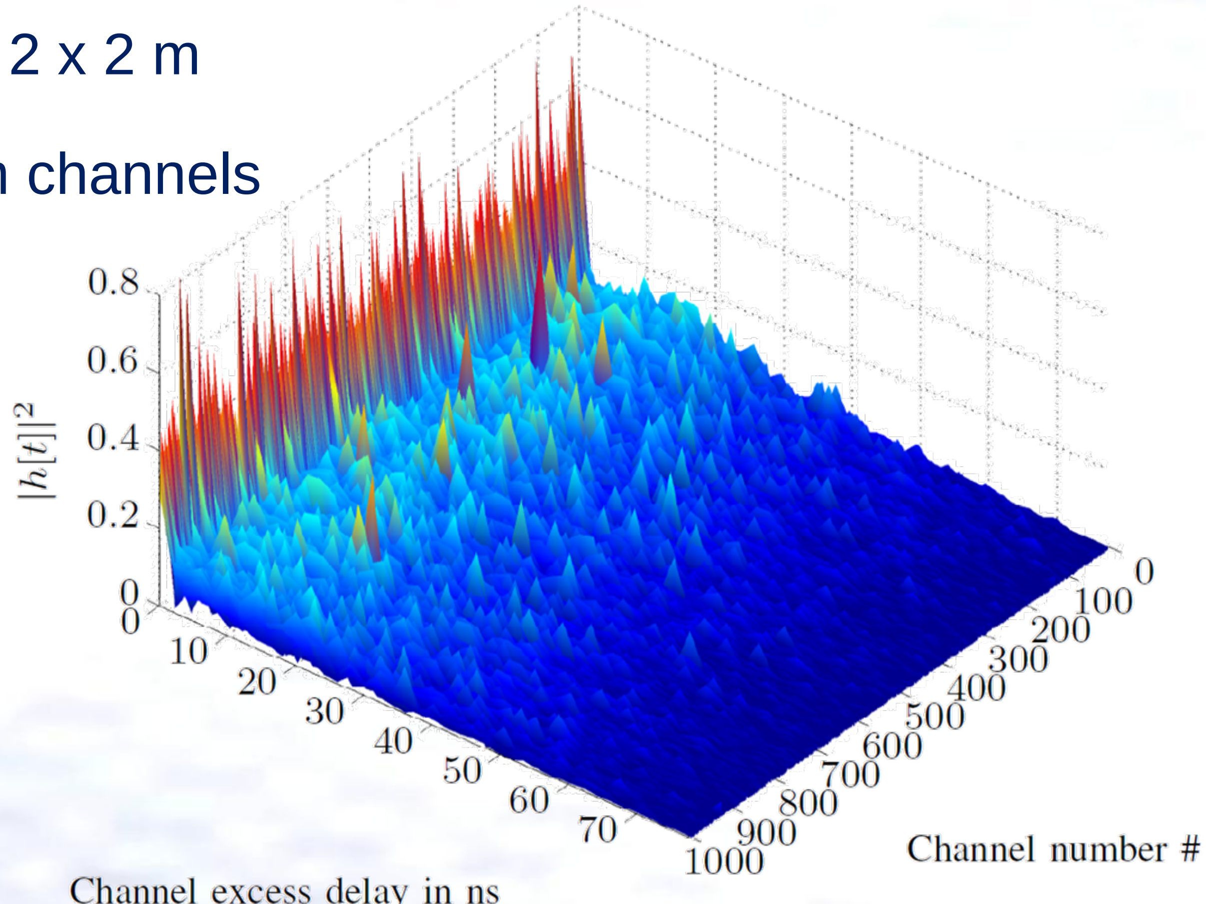
Stochastic Channel Model

- Based on UWB channel model sub-1GHz (IEEE 802.15.4a)
- Only LOS links ($P_{LOS} \geq P_{NLOS}$ or LOS path is strongest path)
- 1-cluster model, i.e., $h[t] = \sum_{k=1}^{K} a_k e^{j\varphi_k} \delta[t - \tau_k]$

  with *K* multipaths (MPCs)

Stochastic Channel Model - Example

- Bidirectional RFID channel considering up- and downlink
- Distance d = 2 x 2 m
- 1000 random channels



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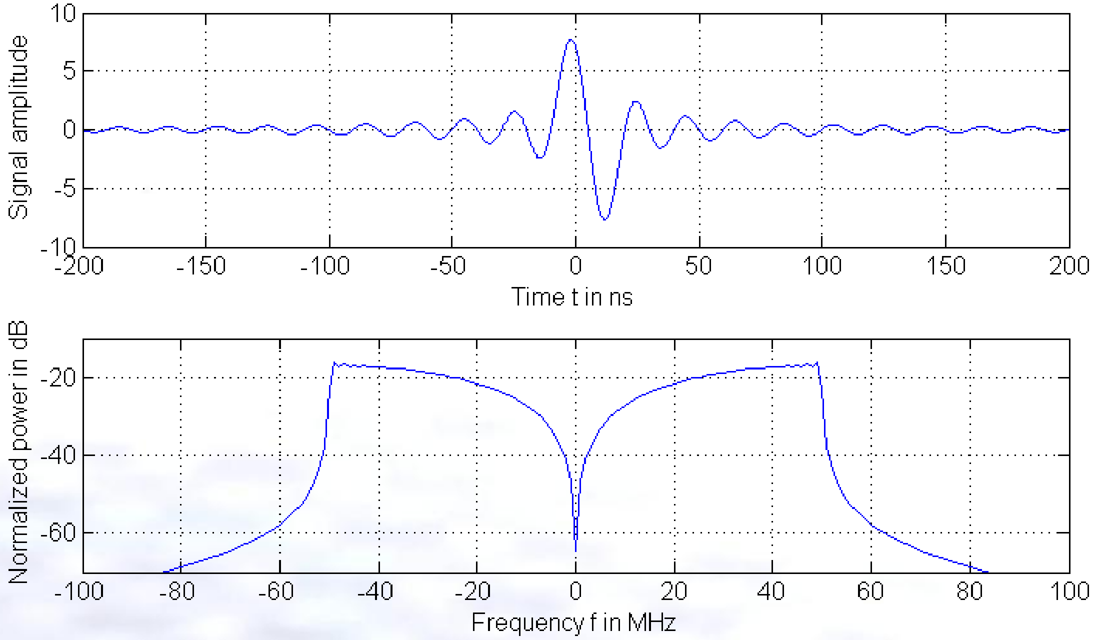
Results

Results (= distance errors) are based on a TOA range approach

- Signal bandwidth: 100 MHz
- Barker code
- RC pulses (ISI free pulse shaping):

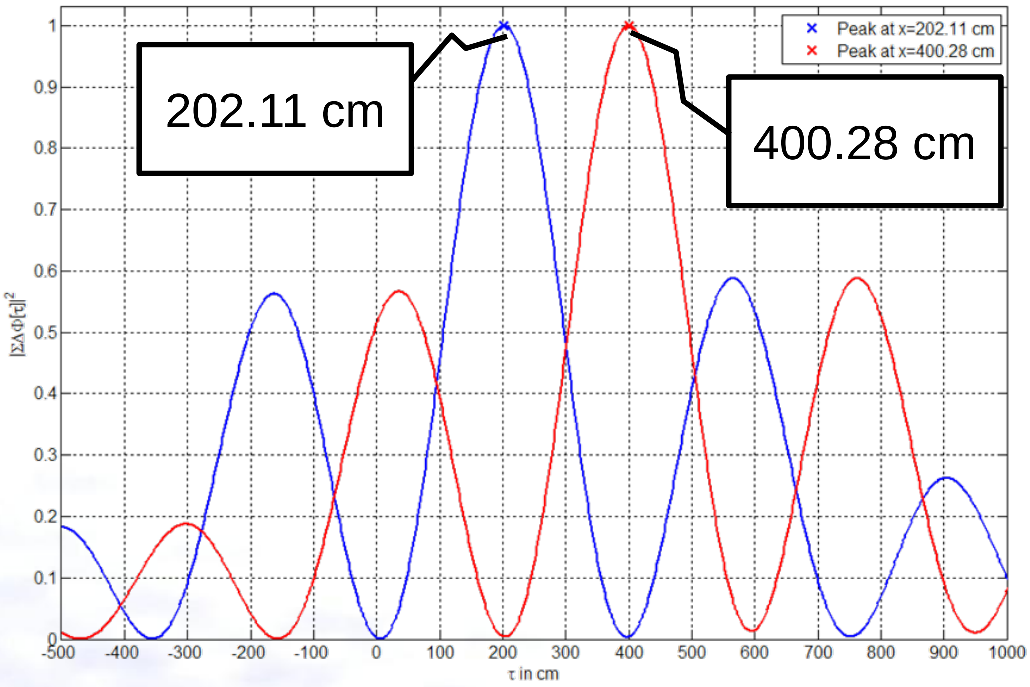


Results

Results (= distance errors) are based on a TOA range approach

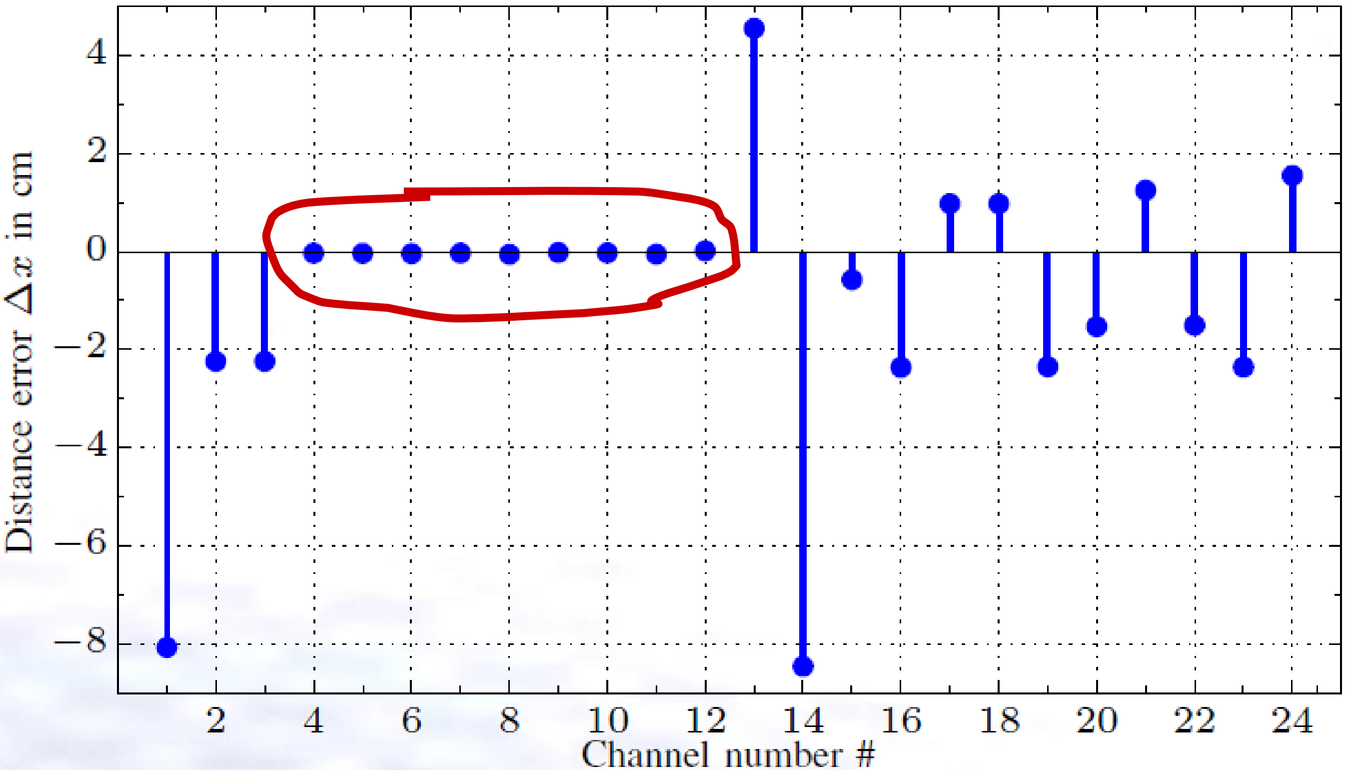
- Principle of correlation is used to determine range:

- 1. Measurement @ 100 cm
- 2. Measurement @ 200 cm
- Round-trip distance of signal ≈ 200 cm
- Equals twice the signal propagation time



Results – Deterministic Channel Model

- Create RFID channels from standard TX→RX channel
- Distance errors for all 24 RFID channels:



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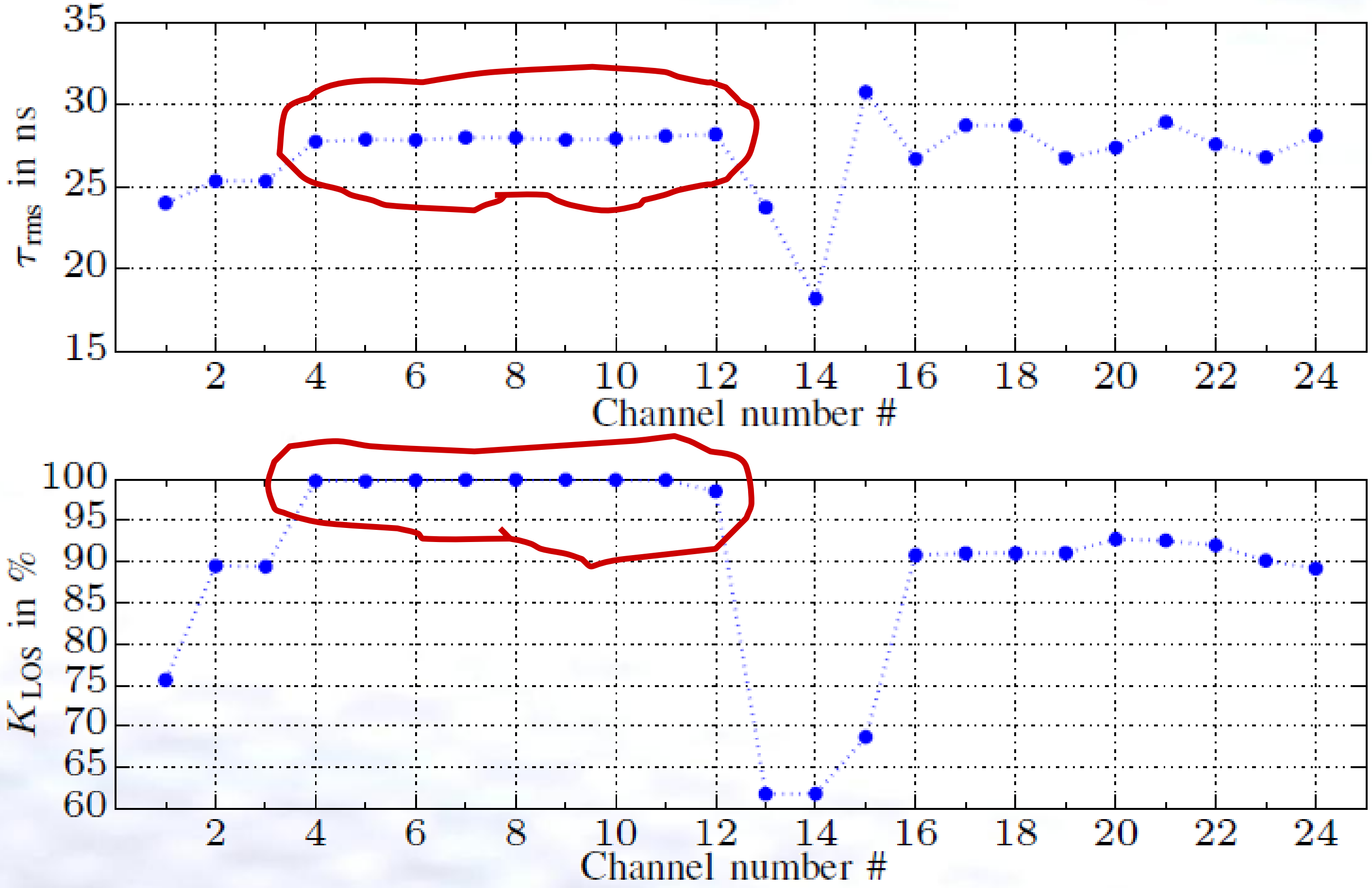
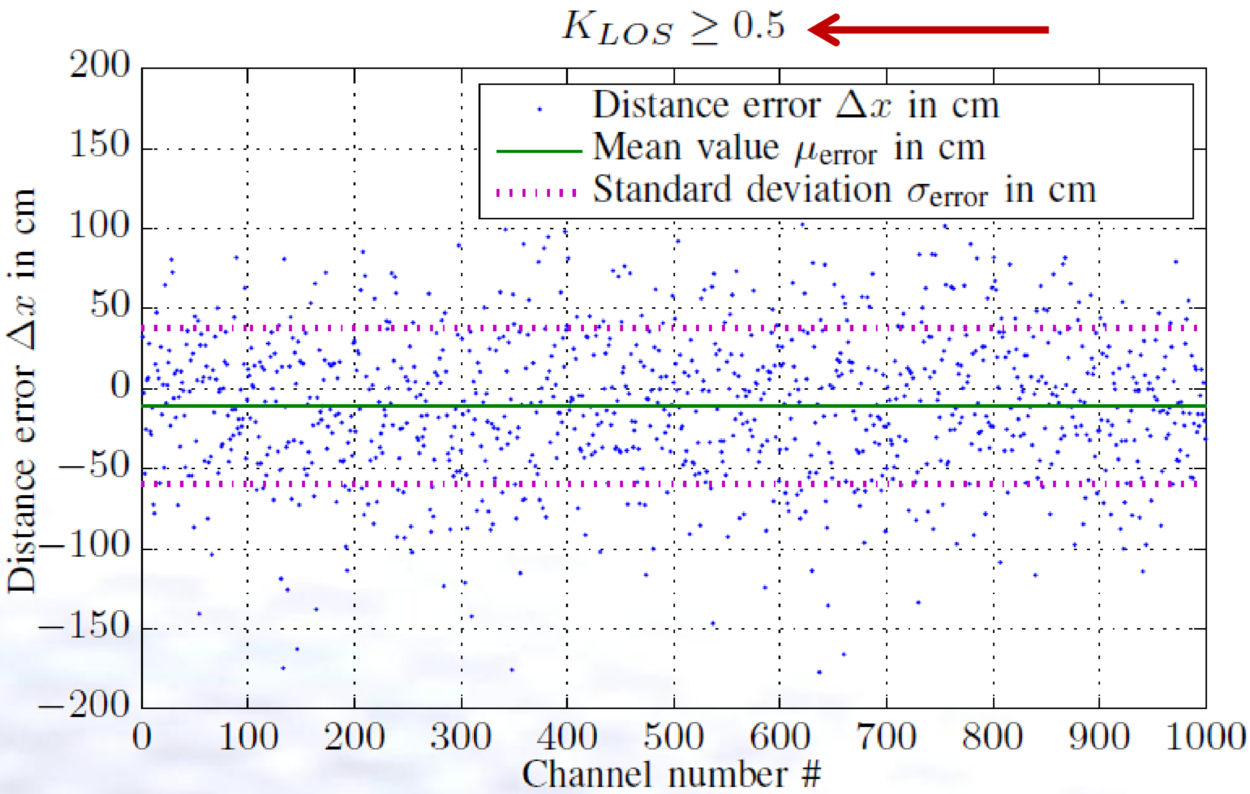
Results – Deterministic Channel Model

- RMS delay spread and LOS factor for the 24 RFID channels



Results – Stochastic Channel Model

- Create RFID channels from standard TX→RX channel
- Distance errors for 1000 random RFID channels:



Results – Stochastic Channel Model

- Distance errors (mean and standard deviation in cm) and RMS delay spread for 1000 random RFID channels with varying K_{LOS} factor from .5 to .9

$K_{\mathrm{LOS}} >$	median of τ_{rms} in ns	μ_{error} in cm	σ_{error} in cm
0.5	20.0	−10.8	48.7
0.6	19.1	−7.6	43.8
0.7	17.8	−2.9	30.2
0.8	15.7	−1.6	21.9
0.9	12.1	−0.6	13.9
1st path is largest	22.6	−53.2	112.7

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Results – Stochastic Channel Model

- Distance errors (mean and standard deviation in cm) and RMS delay spread for 1000 random RFID channels with varying K_{LOS} factor from .5 to .9

Accuracy = 49.9 cm

$K_{LOS} >$	median of τ_{rms} in ns	μ_{error} in cm	σ_{error} in cm
0.5	20.0	−10.8	48.7
0.6	19.1	−7.6	43.8
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0.8	15.7	−1.6	21.9
0.9	12.1	−0.6	13.9
1^{st} path is largest	22.6	−53.2	112.7

Accuracy = 13.9 cm

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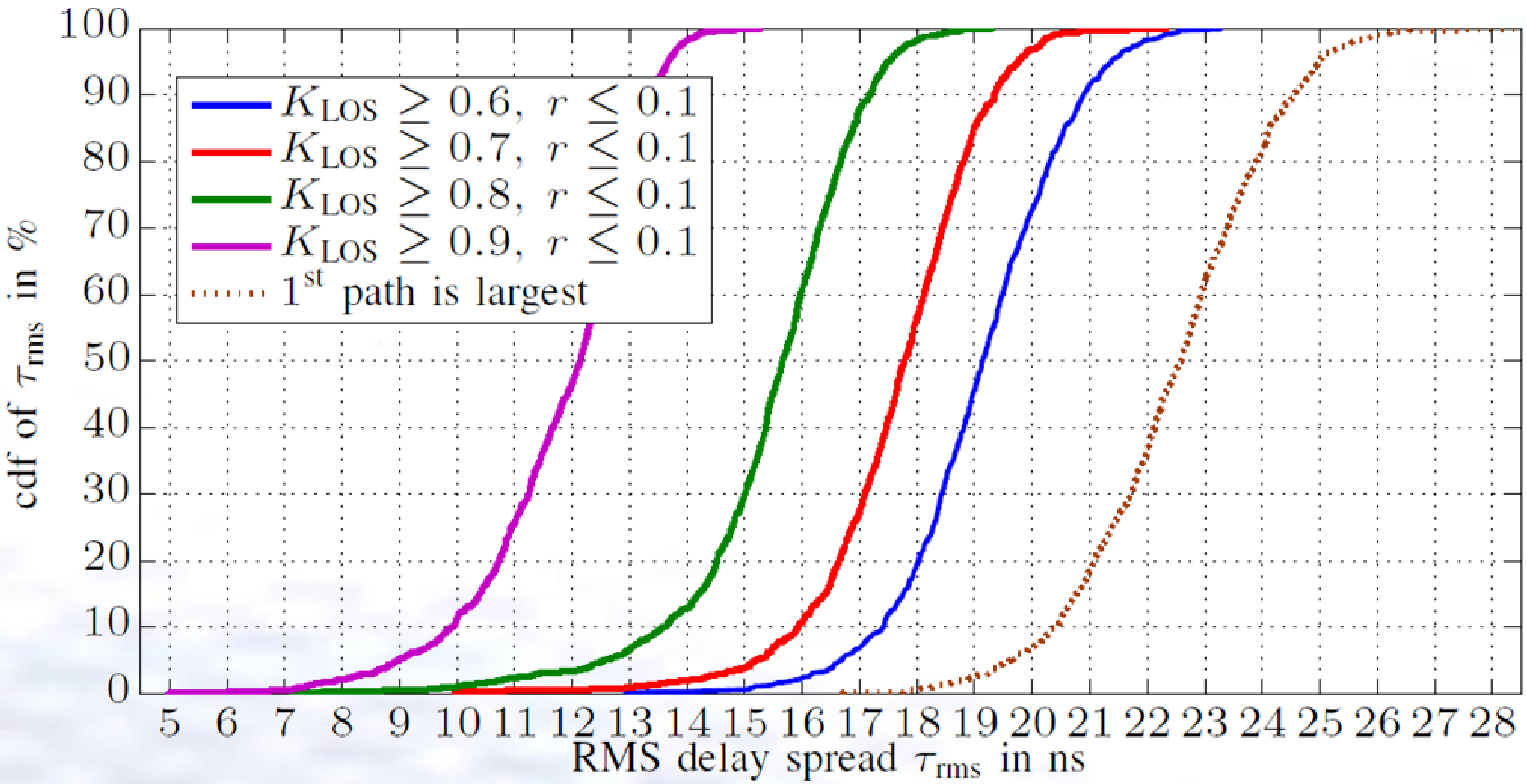
Results – Stochastic Channel Model

- RMS delay spread for 1000 random RFID channels w/ varying K_{LOS} factor from .6 to .9



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Conclusion

- The distance error highly depends on the K_{LOS} factor describing the power in the LOS path
- Results are based on omnidirectional links
- Using one or two directional antennas lead to a lower RMS delay spread and higher K_{LOS} factors
- 2 directional antennas: 55% of RMS delay spread
- 1 directional antenna: 33% "—"

- 1st path is strongest model

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Conclusion

- 2 directional antennas: RMS delay spread = 10 ns
- 1 directional antenna: RMS delay spread = 15 ns
- This will lead to accuracies of around
  10 cm resp. **20 cm**

- Deterministic Channel Model can be used as lower bound for distance errors
- Stochastic Channel Model may be used as higher bound for distance errors

Outline

- Perform further real measurements
- Indoor measurements particularly for RFID channels (bidirectional) in the whole UHF frequency band
- Develop UHF RFID stochastic channel model for indoor environments
- Examine behavior of different antennas and the effects on the ranging system

Thank you for your attention!
Questions?

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