Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Stochastic Modeling of Scattered Multipath Clusters in THz Indoor Communication Channels

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Re: doc.: IEEE 802.15-15-11-0146-00-0thz_diffuse-rough-surface-scattering-analysis

Abstract: Ray tracing in combination with analytical rough surface scattering models is well suited to determine broadband channel characteristics at THz frequencies. Due to the high computational complexity, however, ray tracing cannot be applied reasonably to generate channel realizations for communication system simulations. Hence, a stochastic abstract model is introduced to randomize angle of arrival/ departure, time of arrival and amplitude of scattered multipath clusters in indoor environments.

Purpose: Input for THz channel modeling

Stochastic Modeling of Scattered Multipath Clusters in THz Indoor Communication Channels

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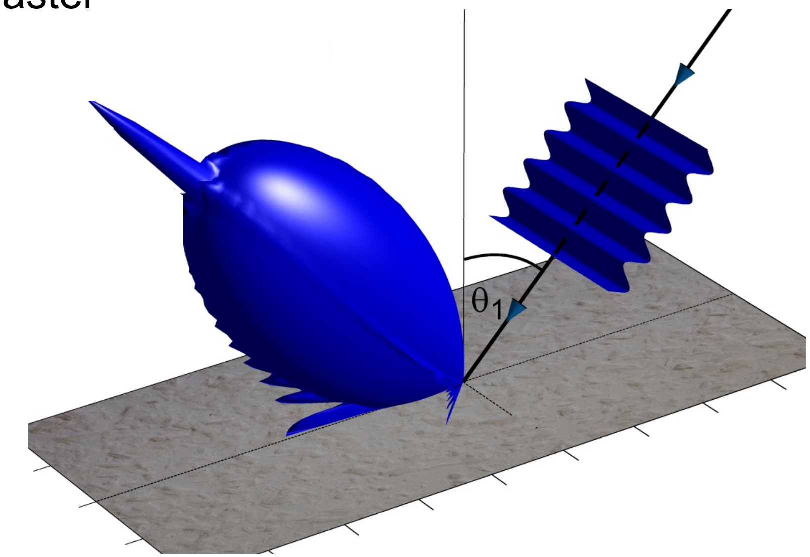
Outline

1. **Introduction**
2. The Investigated Scenario
3. Modeling of Multipath Clusters
4. Summary/Outlook

Introduction (1)

- Rough surface scattering:
  - has a high impact on THz indoor communication channels
  - can be modeled with the Kirchhoff scattering theory for typical building materials like plaster

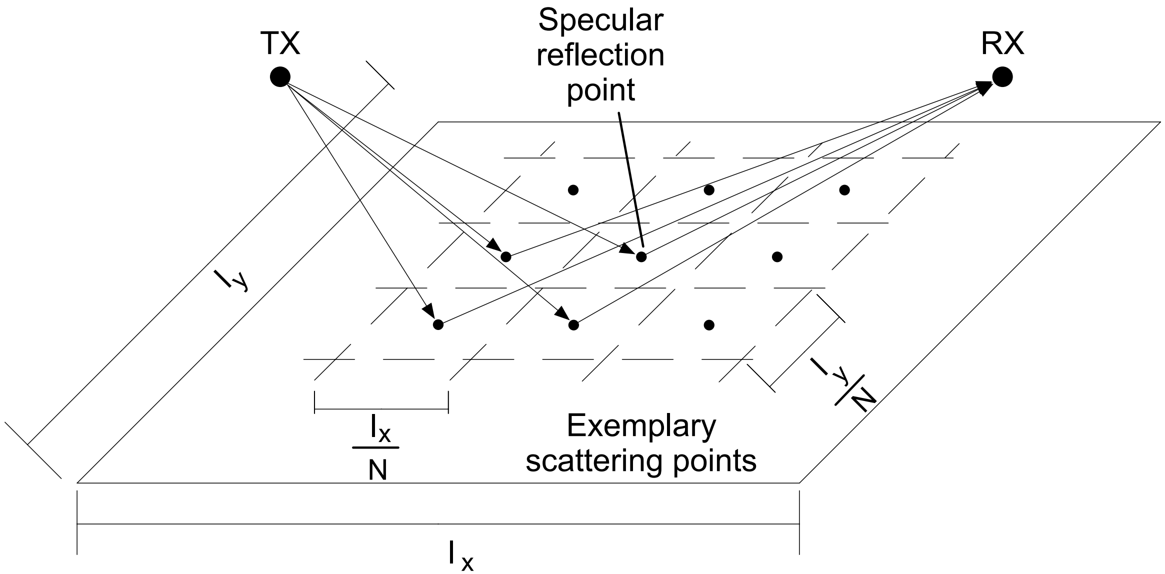


IEEE document 802.15-15-11-0146-00-0thz_diffuse-rough-surface-scattering-analysis.

→ Characteristics of scattered rays like angle of arrival (AoA)/ departure (AoD) and time of arrival (ToA) must be known for channel modeling

Introduction (2)

- Scattering has been implemented into ray tracing
- All ray characteristics can be determined



- Drawback: Very high computational time, unsuitable for fast system simulations

→ Solution: Abstract stochastic model for the generation of channel realizations including AoA, AoD, amplitudes, ToA, phase

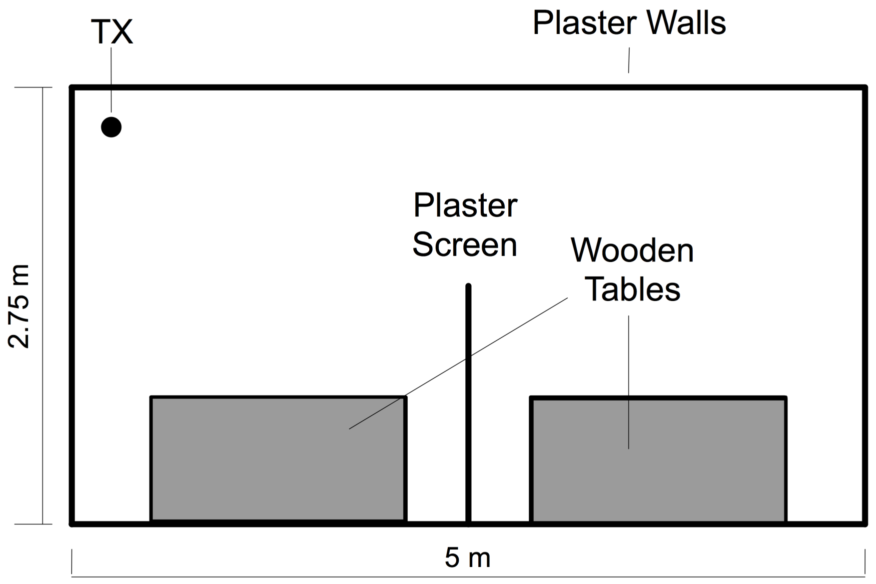
Outline

1. Introduction
2. **The Investigated Scenario**
   - **Office Room Setup**
   - **Exemplary Angular Power Profiles**
3. Modeling of Multipath Clusters
4. Summary/Outlook

Office Room Setup

- Connection of a nomadic device to an access point
- TX at a height of 2.3 m, RX at 0.75 m, room height of 2.5 m
- Ray tracing simulations: 220 equidistant receiver positions distributed in the whole room with ≈ 11000 simulated rays each
- Omnidirectional antennas, horizontal polarization
- Frequency: f = 300 GHz

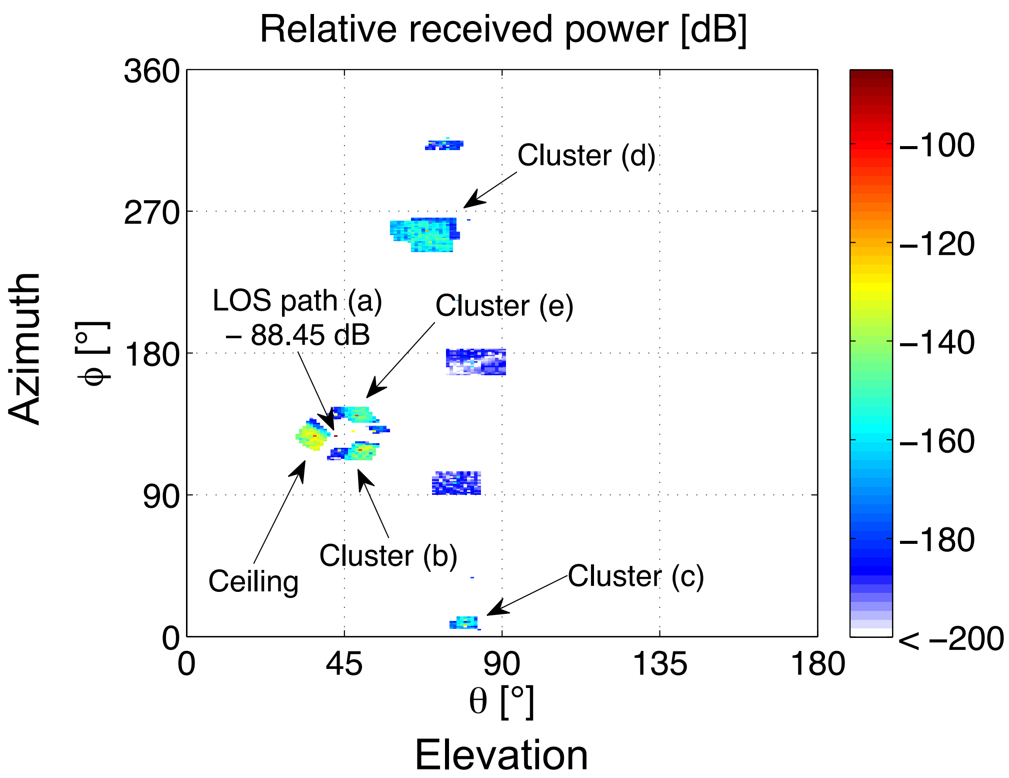
Top view

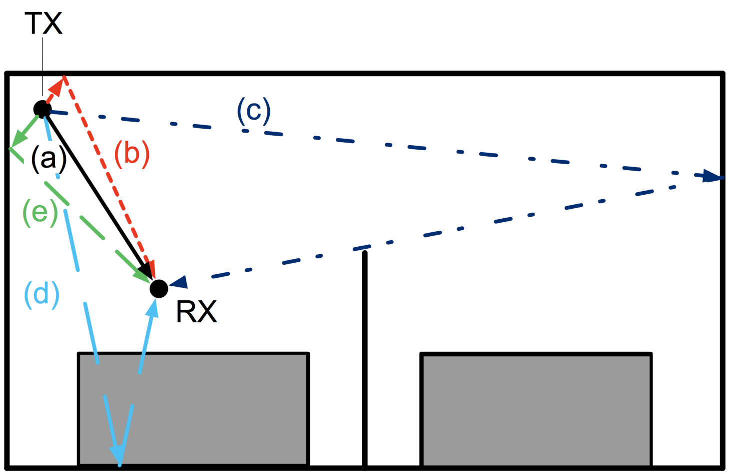


cf. IEEE document 802.15-15-11-0146-00-0thz

Exemplary Angular Power Profiles (1)

- Exemplary simulated power profile in the AoA domain:

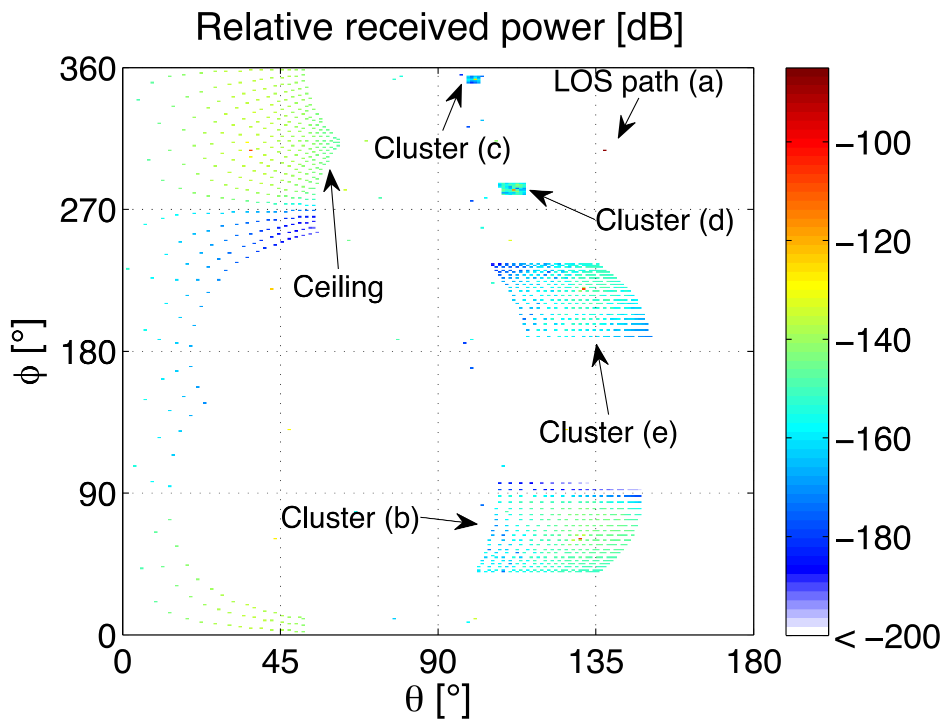


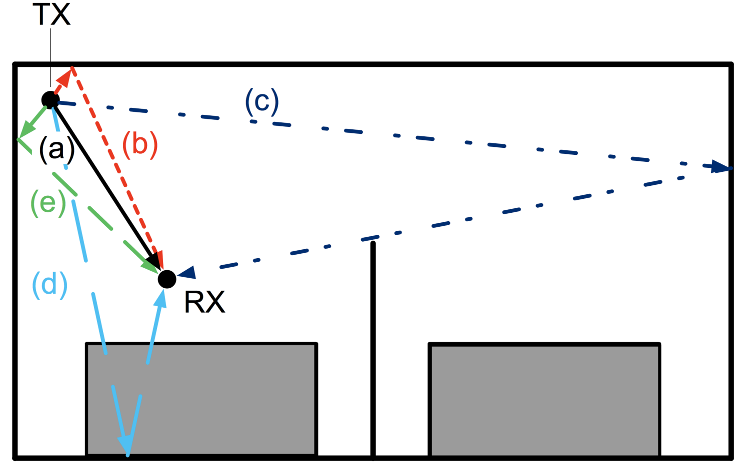


→ Multipath components (MPCs) show a clustered behavior

Exemplary Angular Power Profiles (2)

- AoD domain:





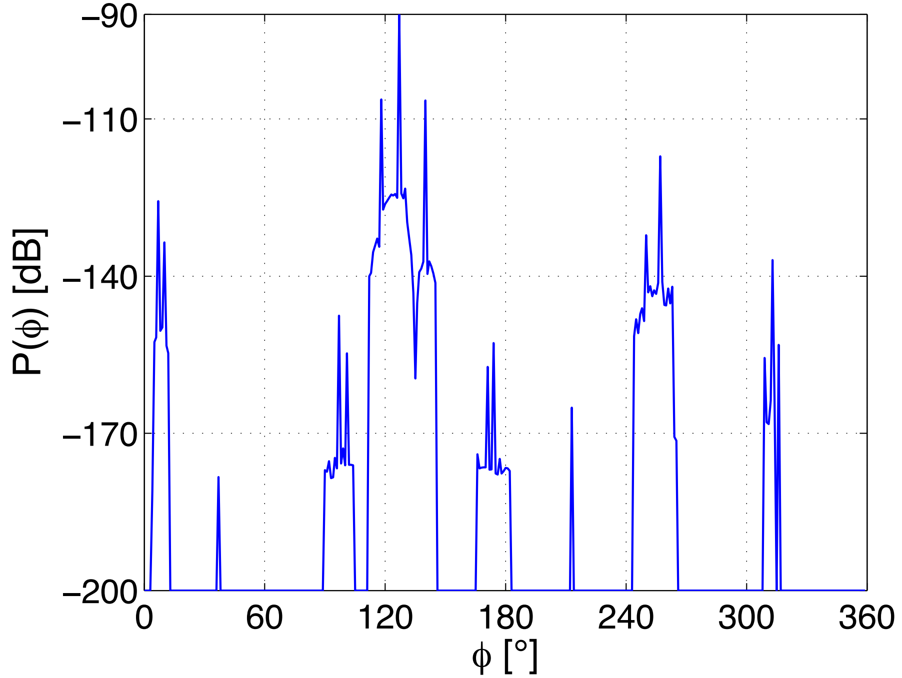
→ Clustered behavior also for the AoD

→ Surface discretization visible

→ Problem: Very high computational time

Exemplary Angular Power Profiles (3)

- Azimuth angular power profile, AoA:



- Power summed up in the elevation for each azimuth angle
- Sharp spikes due to specular reflections in every cluster

→ Modeling of cluster behavior with reference to the specular reflection

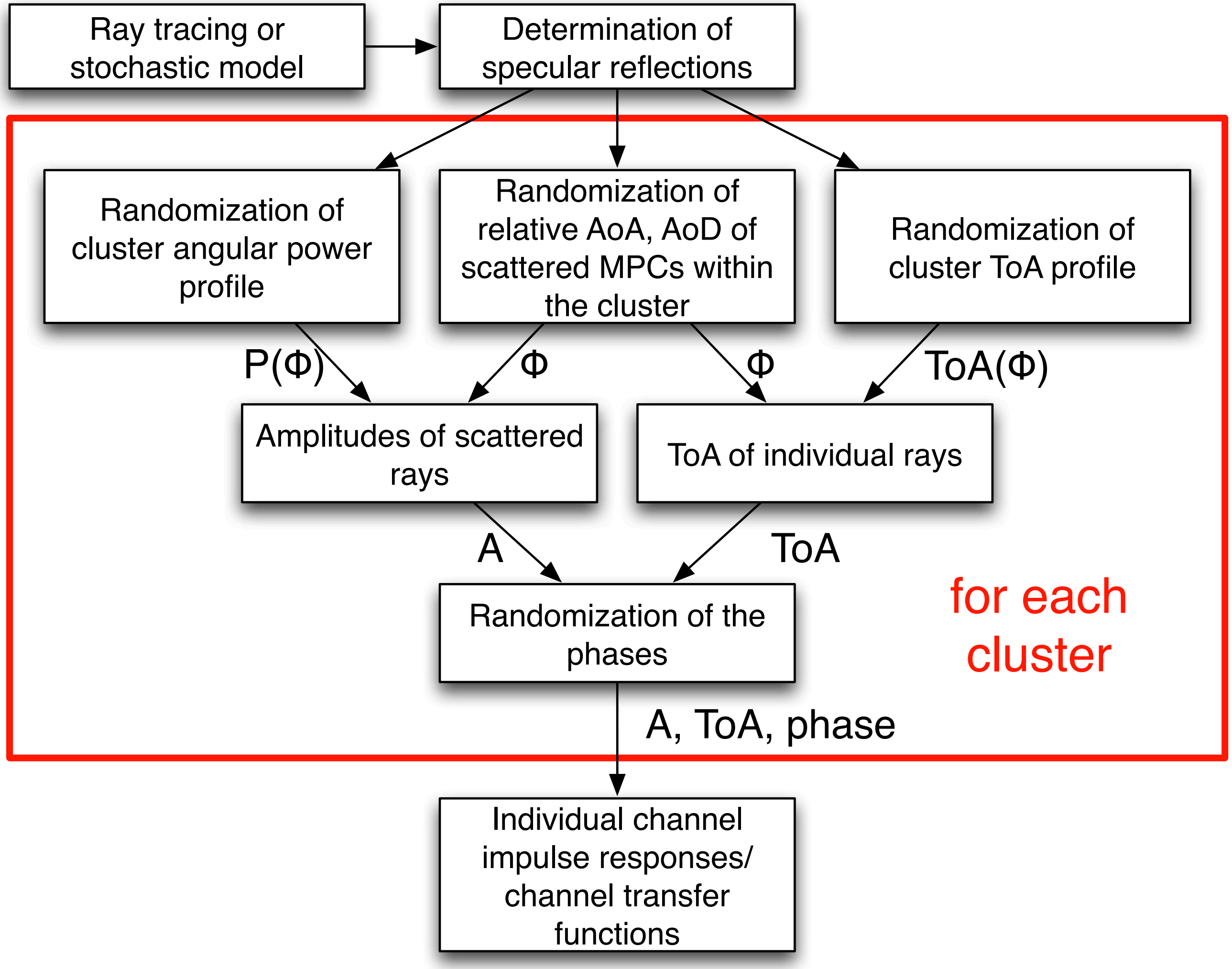
Outline

1. Introduction
2. The Investigated Scenario
3. **Modeling of Multipath Clusters**
   - **Modeling Approach**
   - **Angle of Arrival/Departure**
   - **Angular Power Profiles**
   - **Time of Arrival**
   - **Phase**
   - **Generated Impulse Response/Transfer Function**
4. Summary/Outlook

Modeling Approach (1)

- Idea:
  - Modeling of relative characteristics of scattered multipath components with respect to specular reflections for each cluster
  - Determination of statistics from ray tracing
    - Angles of arrival/departure
    - Amplitude
    - Time of arrival
    - Phase
  - Randomization of channel realizations based on known specular components

Modeling Approach (2)

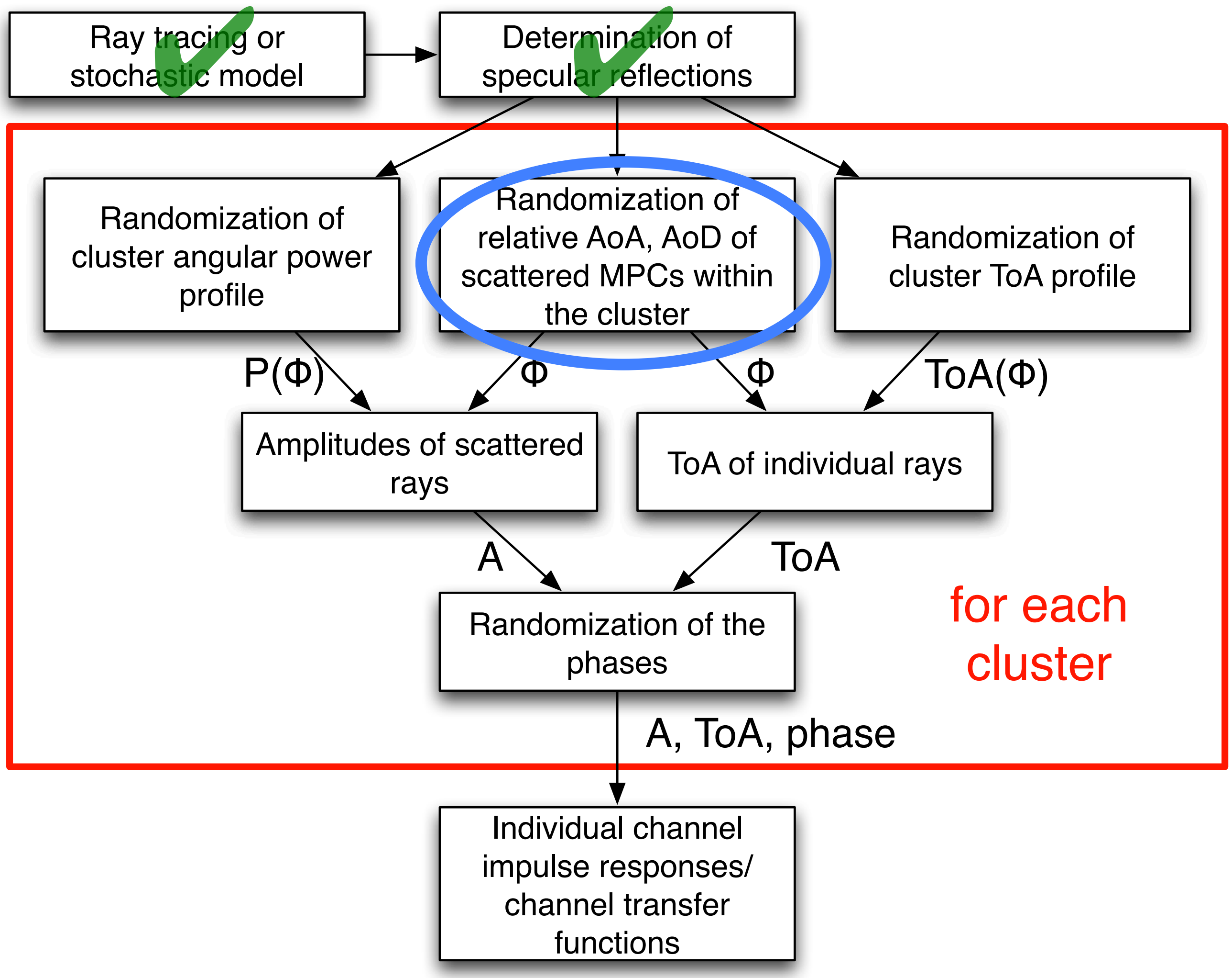


Modeling Approach (3)

- Main advantages:

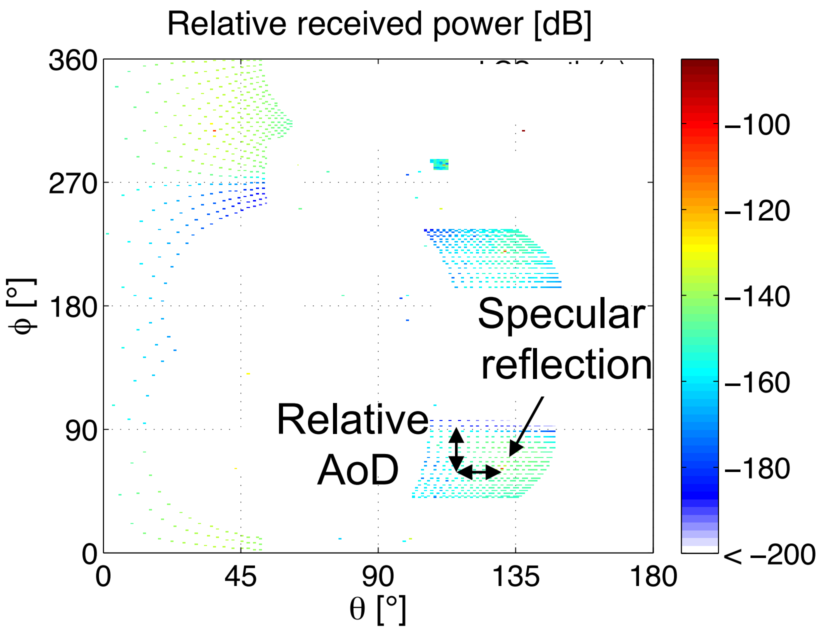
1. Only computationally inextensive determination of specular reflections must be performed
2. Physically motivated model: angular dependence of scattering is used as the basis to determine amplitude and ToA of MPCs
3. All information necessary for broadband channel generations is included
4. A fast generation of channel realizations can be achieved
5. Consideration of realistic antenna diagrams can be done during post processing

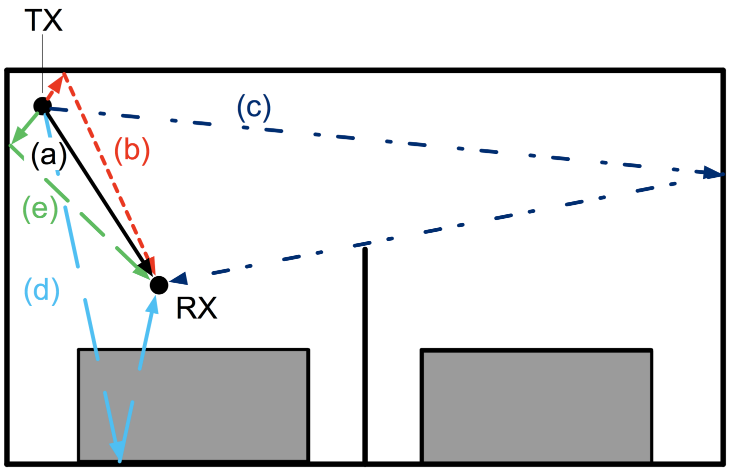
Angle of Arrival/Departure (1)



Angle of Arrival/Departure (2)

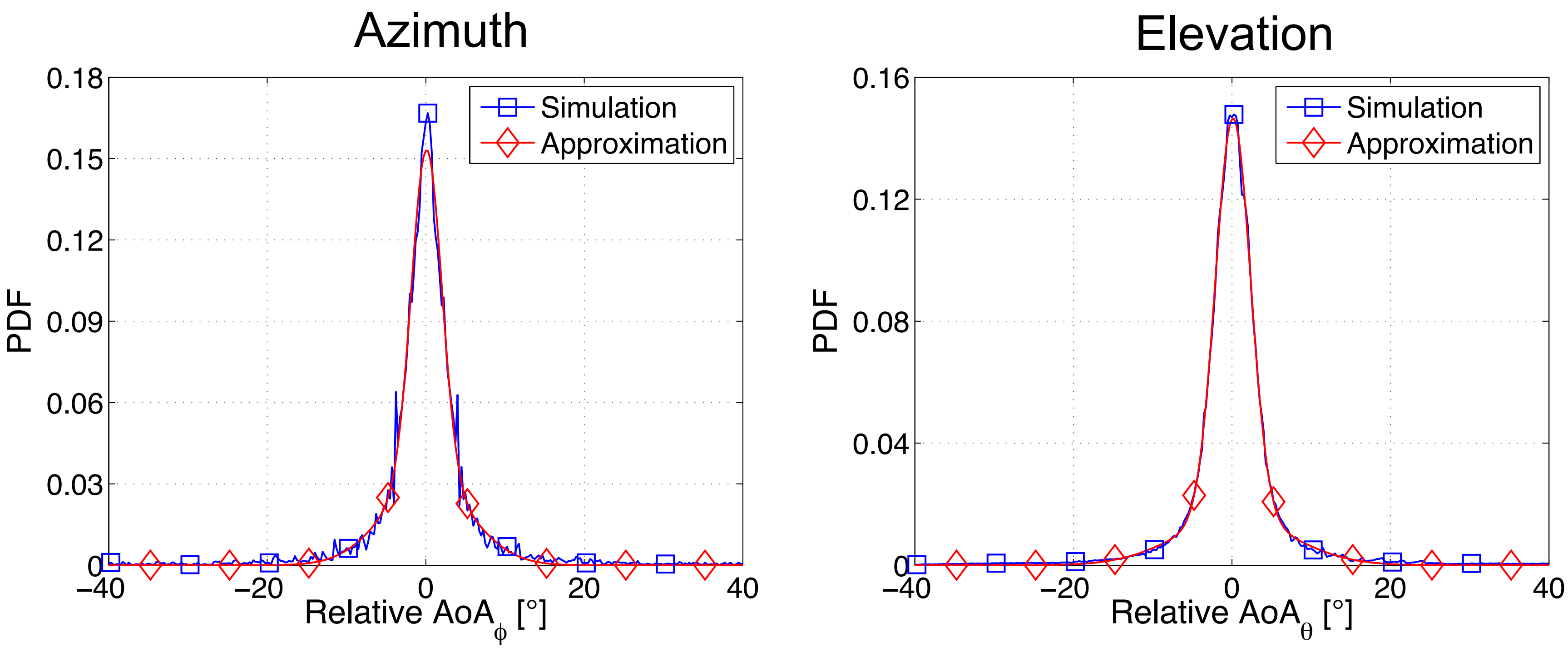
- Derivation of probability density functions (PDFs) for the relative AoAs/AoDs of scattered MPCs
- Consideration of each cluster at each of the 220 RX position in the room
- Measured with respect to the specular direction of the cluster:





Angle of Arrival/Departure (3)

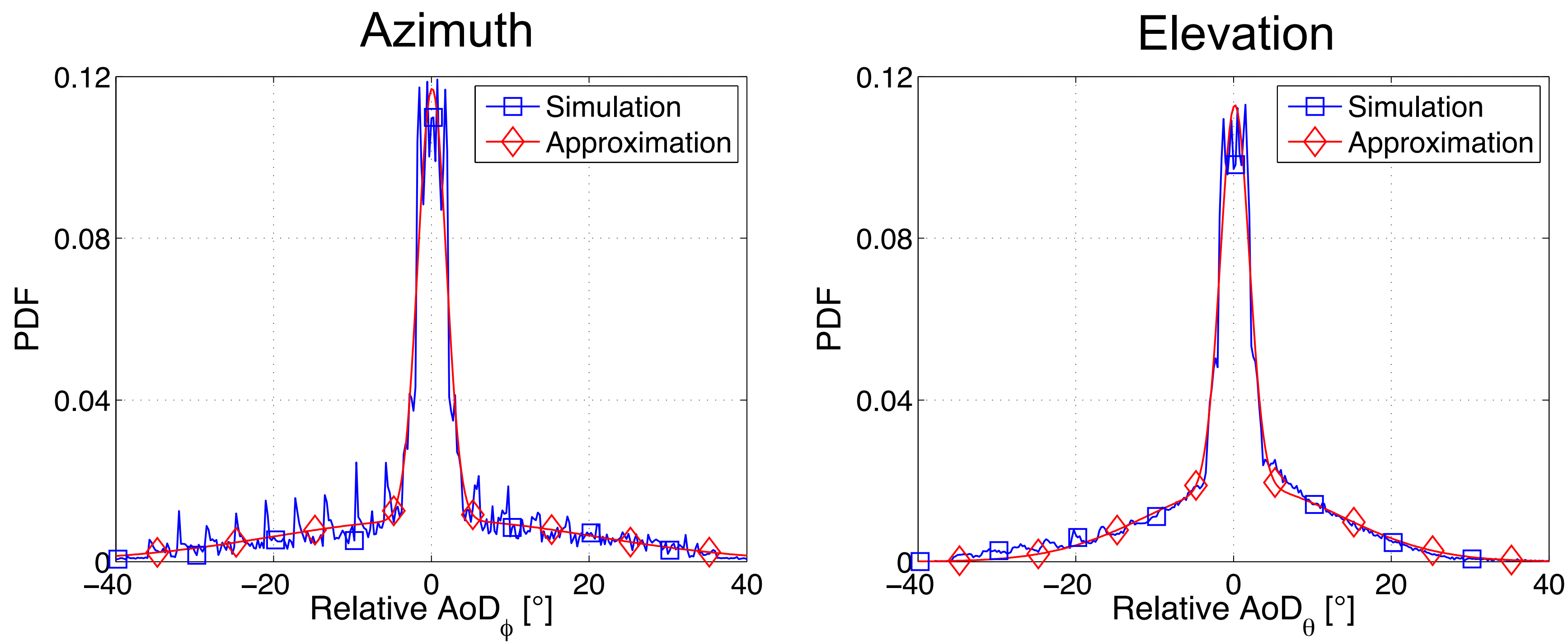
- PDFs for the relative AoA:



→ Very good approximation with a zero mean second order Gaussian mixture model (GMM); GMM parameters given in [1]

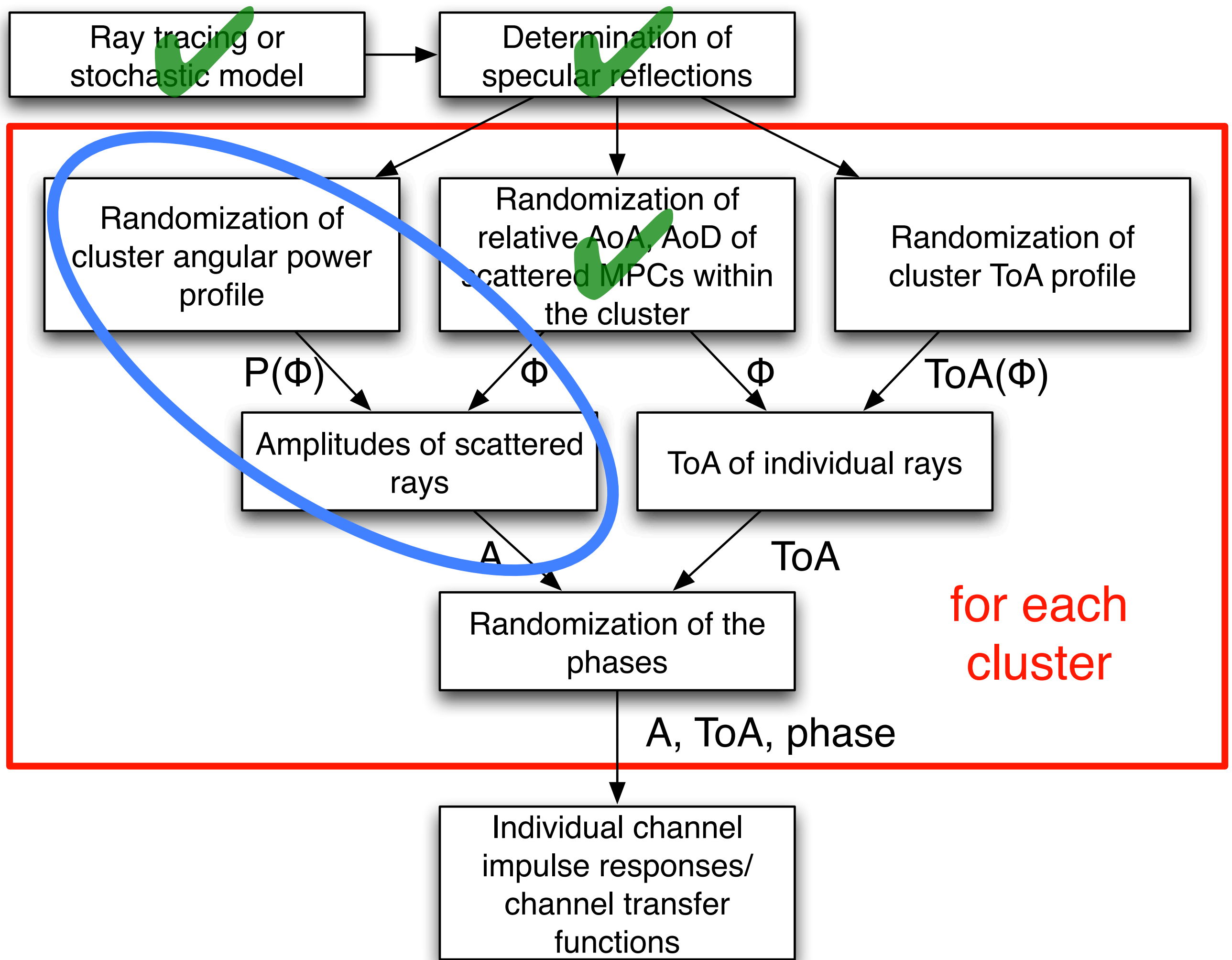
Angle of Arrival/Departure (4)

- The relative AoD:



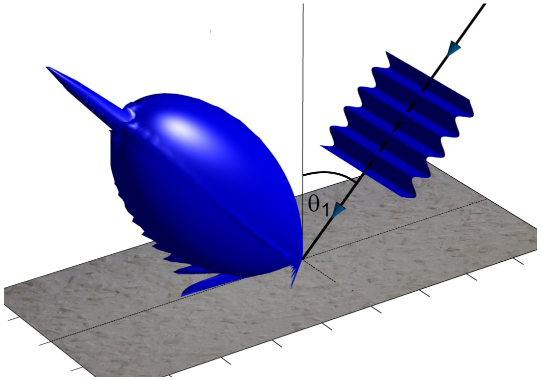
→ Angular characteristics of scattered MPCs can be randomized

Angular Power Profiles (1)



Angular Power Profiles (2)

- Strong angular dependence of the scattered power



- Aim: Determination of cluster angular power profiles (APP)

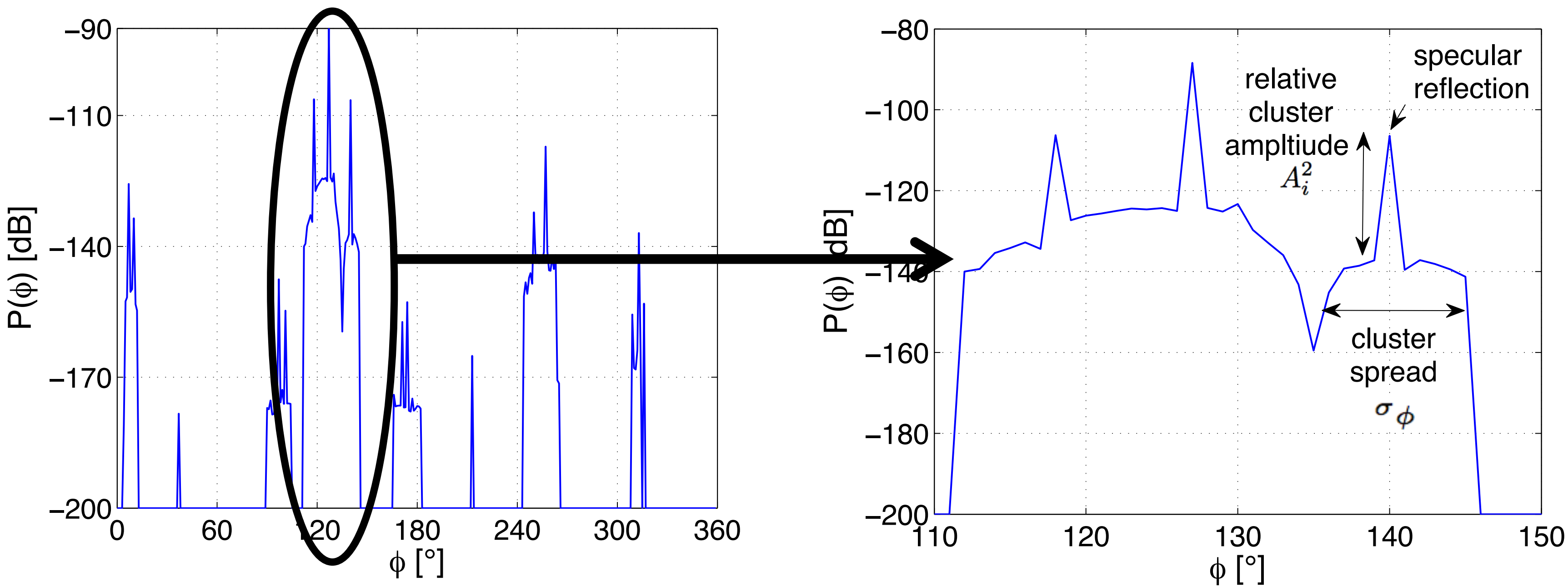
→ Amplitude of scattered rays can be determined from the APP based on the AoA/AoD

→ Complete channel angular power profile can be composed of all cluster profiles

→ Shape of the cluster APP varies based on the position of the RX relative to the reflection/scattering point and hence can be randomized

Angular Power Profiles (3)

- Cut-out of the exemplary simulated APP:



→ Cluster power profile shape characterized with the specular reflection, the relative amplitude and the cluster spread

- <u>Idea</u>: Approximation of the cluster shape with a Gaussian function

Angular Power Profiles (4)

- Cluster power profile shape is assumed independent in azimuth and elevation:

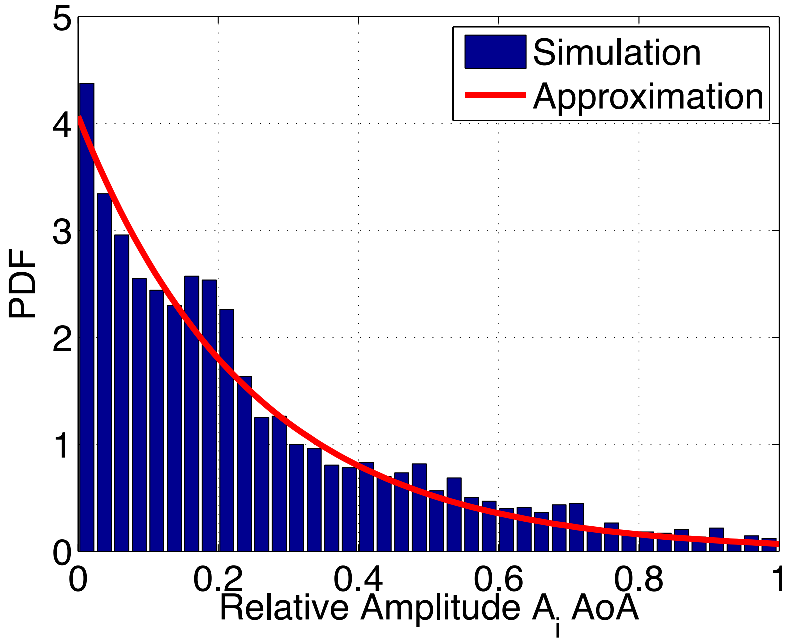
$$P_i(\phi,\theta)_{cluster} = P_{i,spec} \cdot A_i^2 \cdot P_i(\phi)_{cluster} \cdot P_i(\theta)_{cluster}$$
$$= P_{i,spec} \cdot A_i^2 \cdot e^{-\frac{1}{2}\left(\frac{\phi}{\sigma_\phi}\right)^2} \cdot e^{-\frac{1}{2}\left(\frac{\theta}{\sigma_\theta}\right)^2}$$

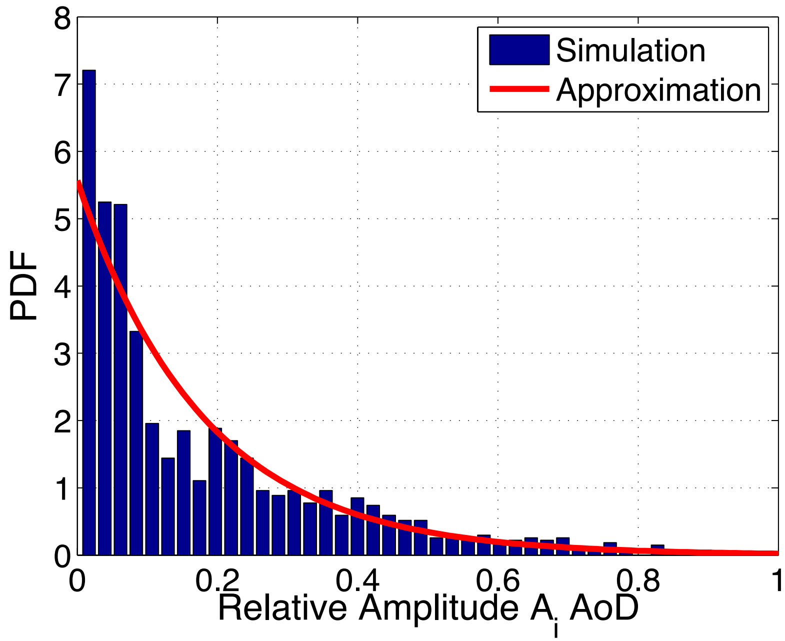
$P_{i,spec}$	Power of the specular reflection within the i^{th} cluster	A_i	Relative amplitude of the scattered MPCs with reference to the specular power
Φ	Azimuth AoA with respect to the specular AoA_Φ	σ_Φ	Cluster spread in the azimuth
Θ	Elevation AoA with respect to the specular AoA_Θ	σ_Θ	Cluster spread in the elevation

→ Statistics for A_i, σ_Φ, σ_Θ must be derived to randomize the cluster power profile

Angular Power Profiles (5)

- Gaussian functions are fitted to each cluster APP at each of the 220 RX positions for both AoA and AoD
- Relative amplitude PDFs:

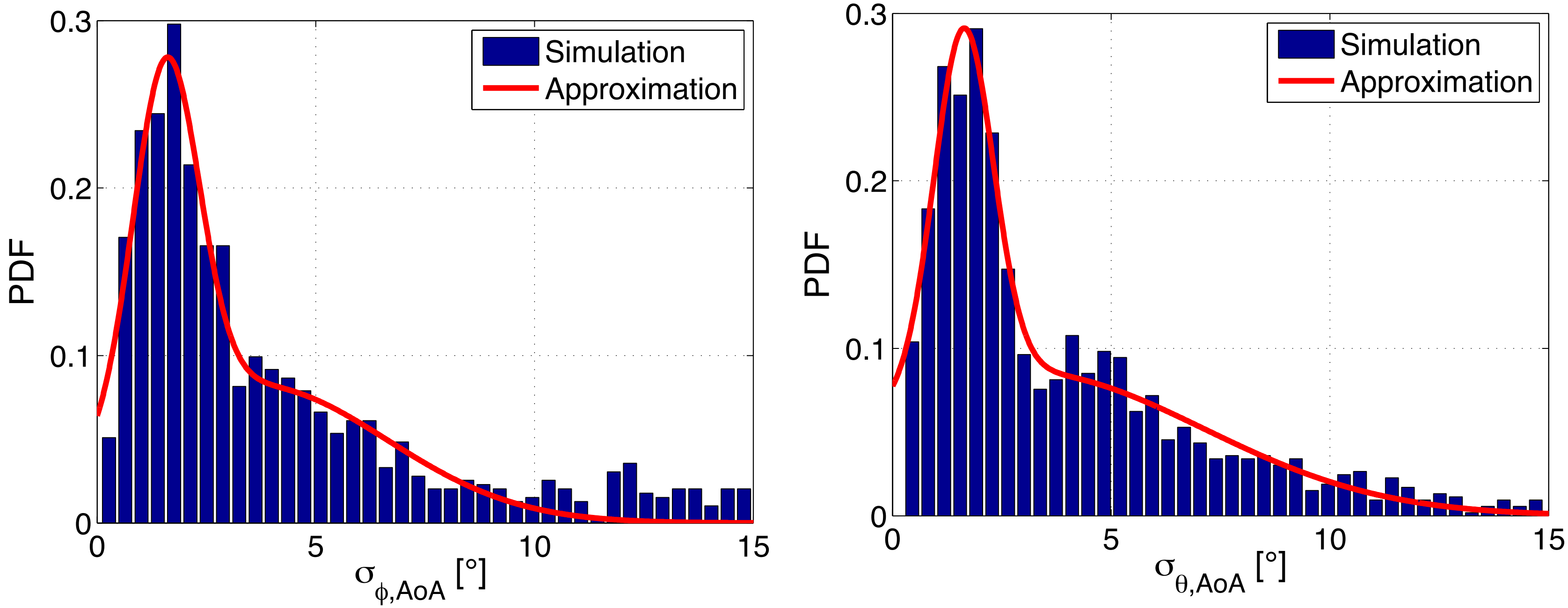




→ Approximation with negative exponential distributions; parameters can be found in [1]

Angular Power Profiles (6)

- Cluster spread PDFs for the AoA:

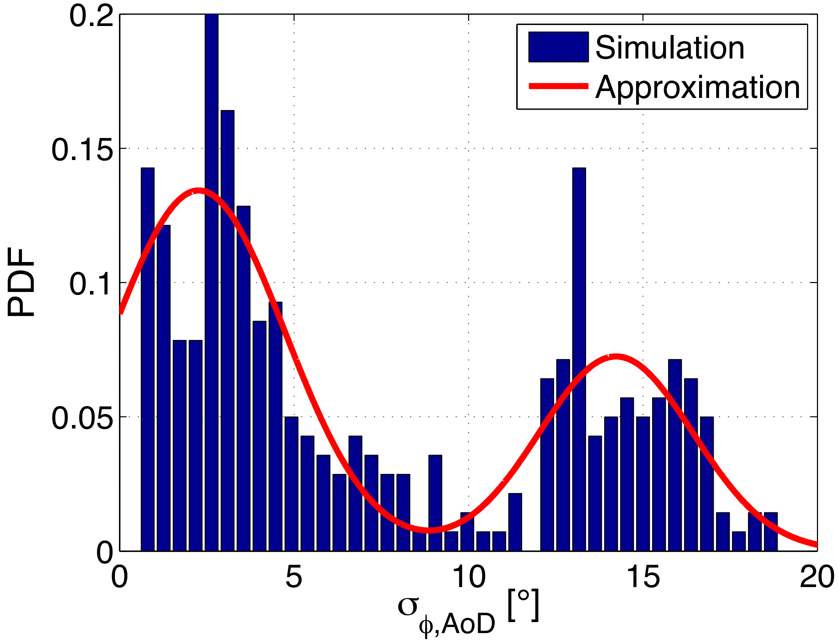


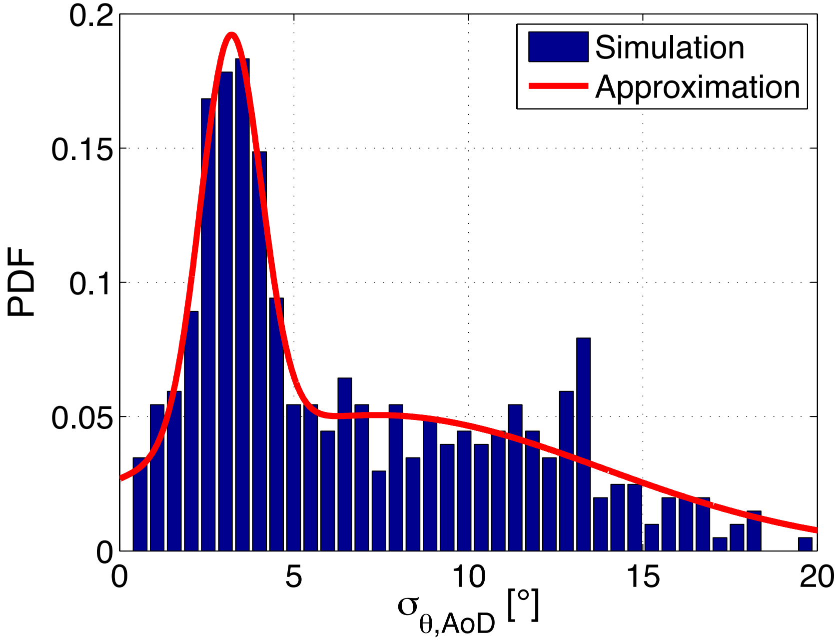
→ Very similar behavior in azimuth and elevation

→ Approximation with second order Gaussian mixture models; parameters can be found in [1]

Angular Power Profiles (7)

- Cluster spread PDFs for the AoD:

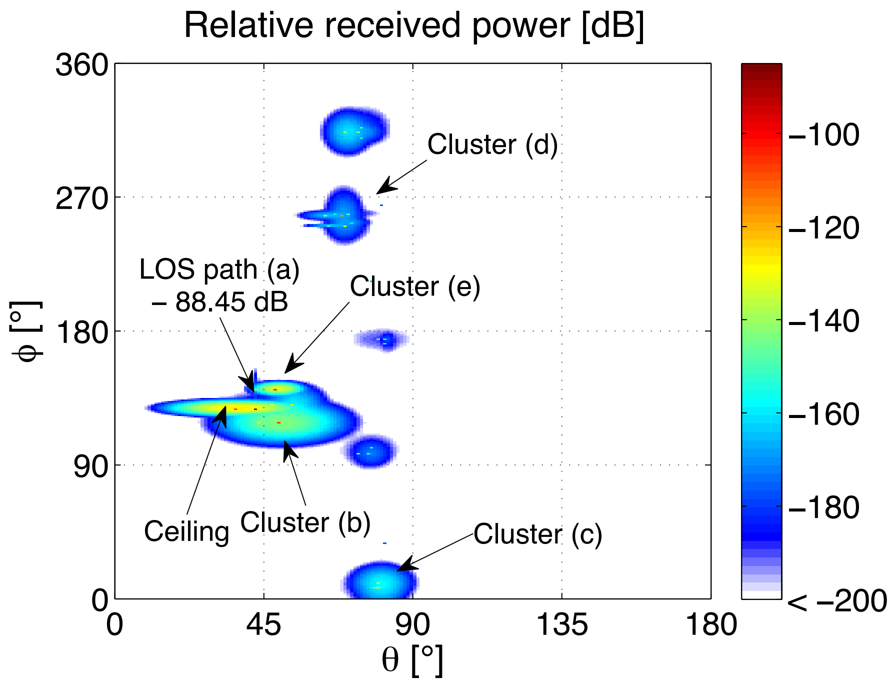




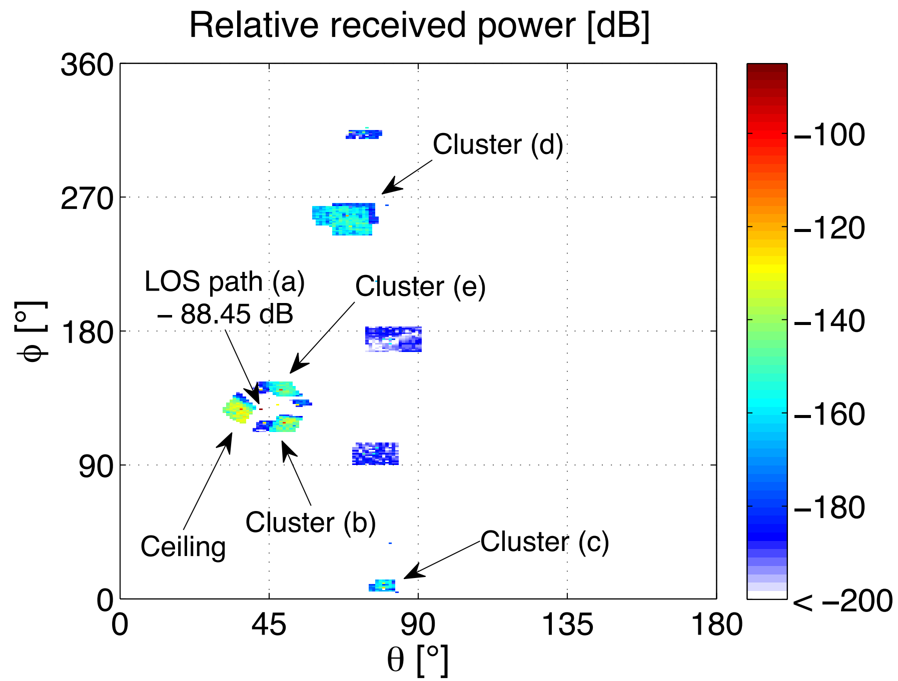
→ All necessary statistics known to randomize the APPs

Angular Power Profiles (8)

- Validation: Exemplarily generated vs. simulated APP (AoA):



Randomized



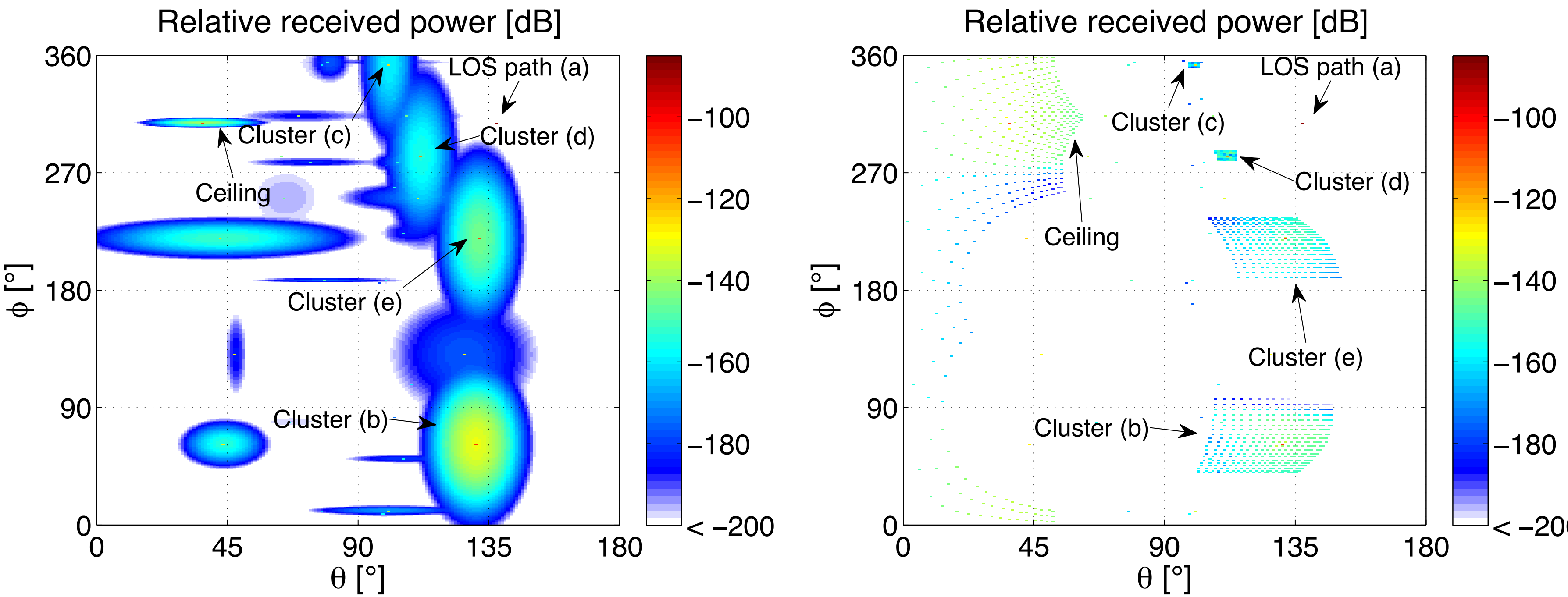
Ray tracing

→ Realistic randomized power profile

→ No need for complex computation of the scattered MPCs

Angular Power Profiles (9)

- Exemplarily generated vs. simulated APP for the AoD:



Randomized

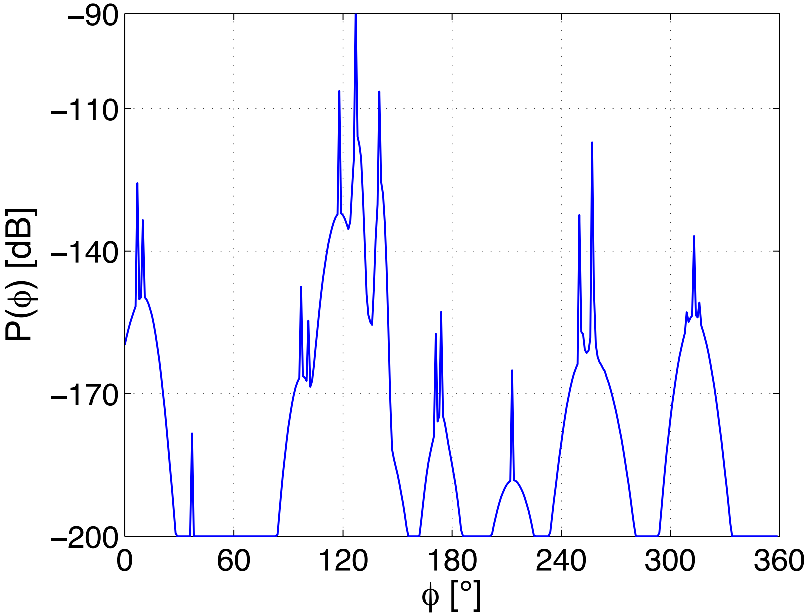
Ray tracing

→ Continuous randomized profile compared to surface discretization

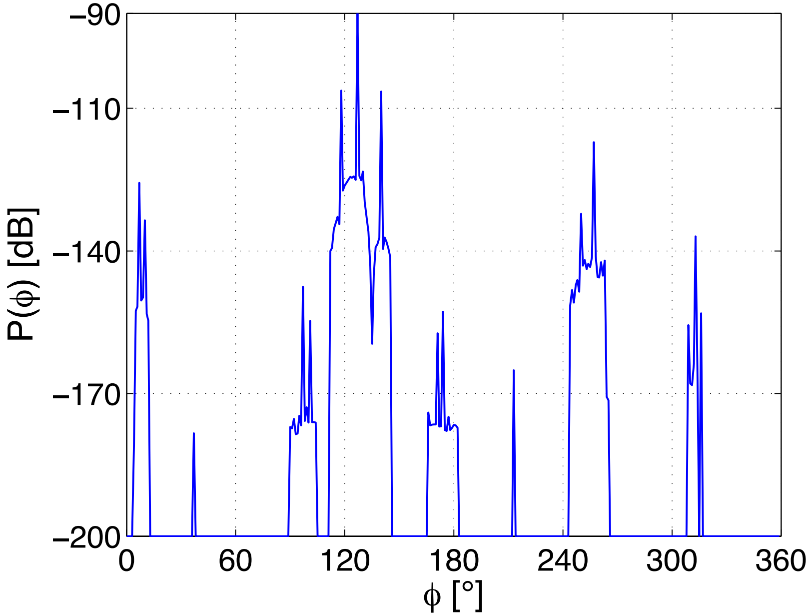
→ Appropriate realizations also for the AoD

Angular Power Profiles (10)

- Exemplarily generated vs. simulated APP for the AoA in the azimuth:



Randomized



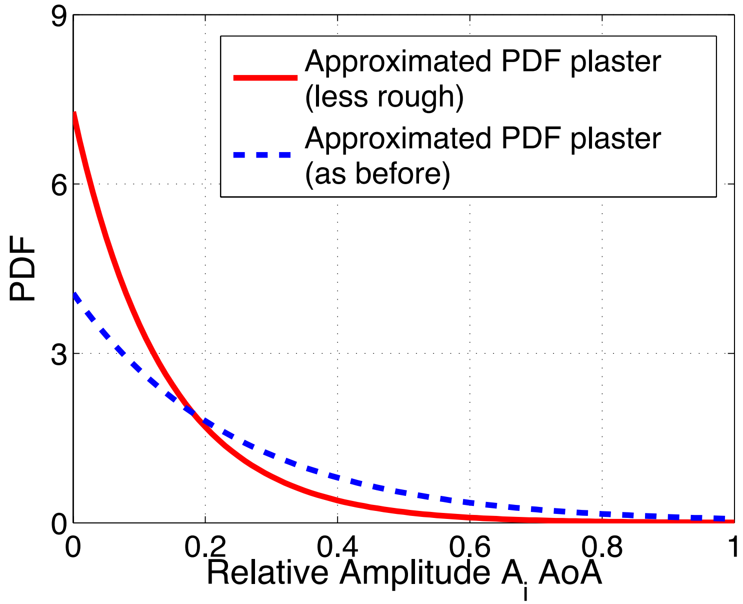
Ray tracing

→ Sharp cluster boundaries due to limited number of respected surface elements in ray tracing

→ General cluster behavior well approximated with Gaussian functions

Angular Power Profiles (11)

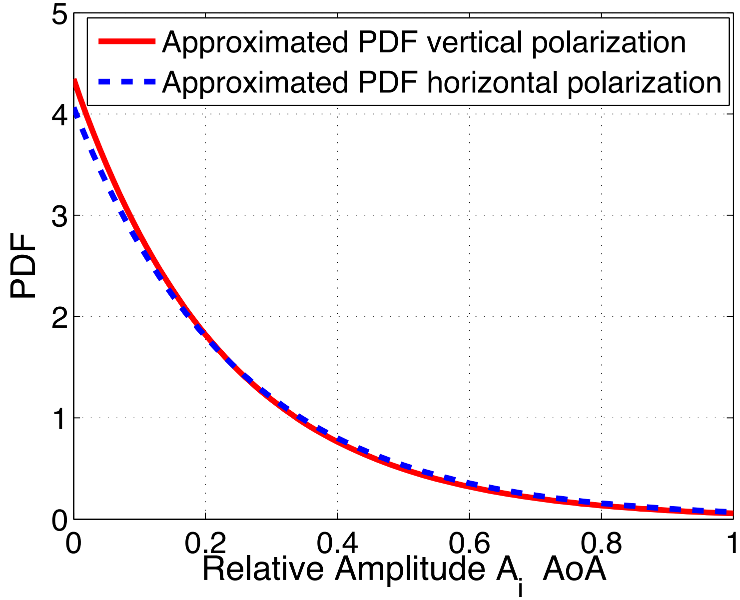
- Roughness dependence?
  - AoA/AoD statistics remain unaffected
  - Higher roughness → more power is scattered out of the specular direction
  - New statistics for cluster amplitudes and cluster spreads are required (complete statistics for two roughnesses can be found in [1])



→ Lower roughness leads to lower relative cluster amplitudes

Angular Power Profiles (12)

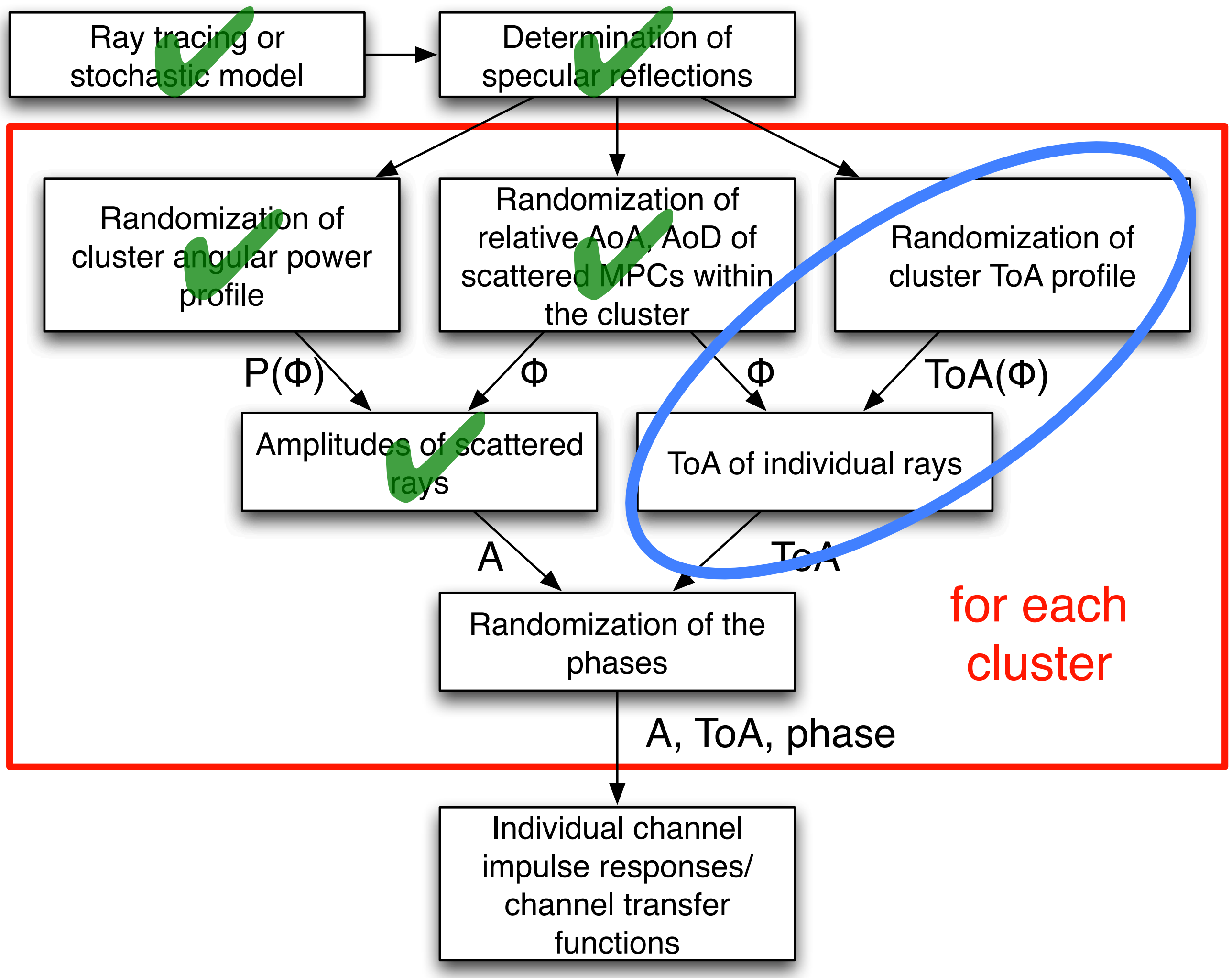
- Polarization dependence?
  - Polarization affects both the specular reflection and the scattered MPCs in the same way
  - Polarization has hardly any impact on the cluster spread



→ Relative amplitude statistics remain almost unaffected

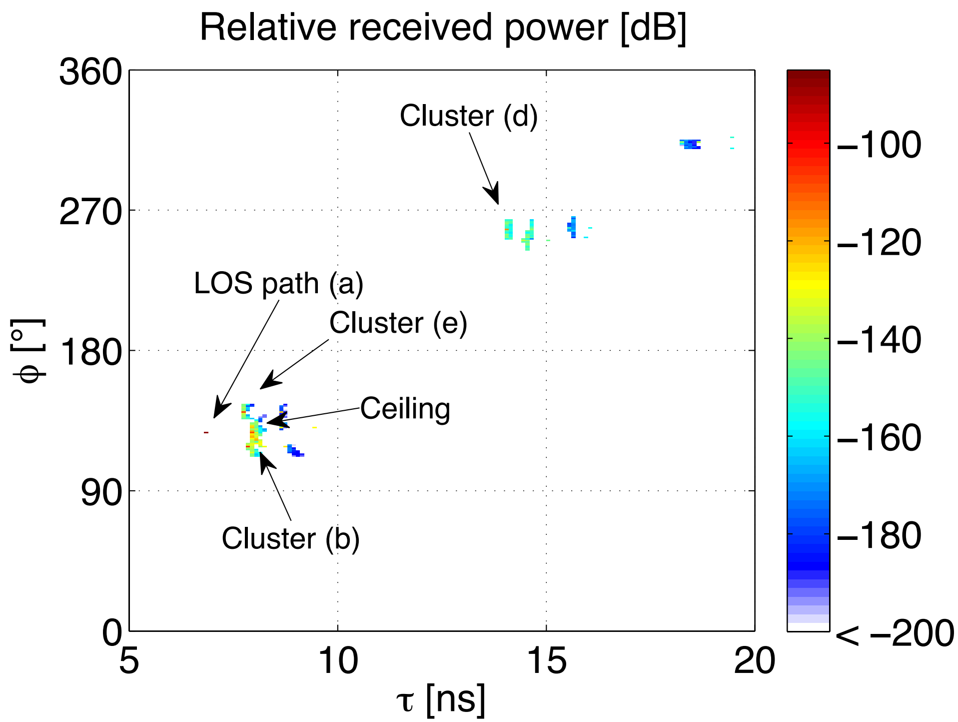
→ Slight differences occur due to geometrical depolarization

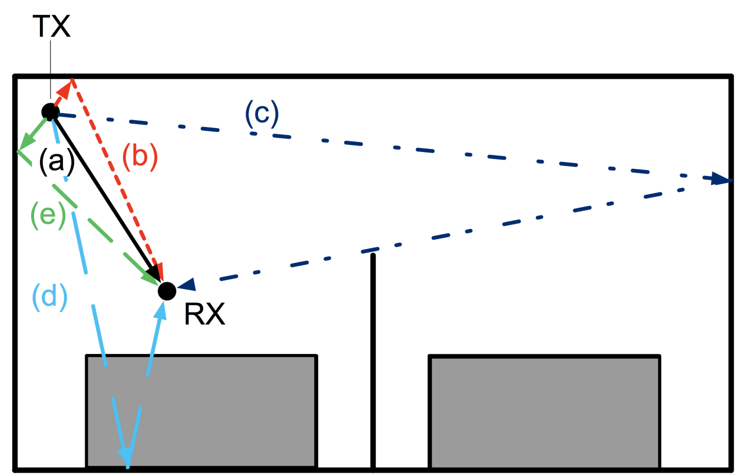
Time of Arrival (1)



Time of Arrival (2)

- Exemplarily simulated AoA/ToA profile:



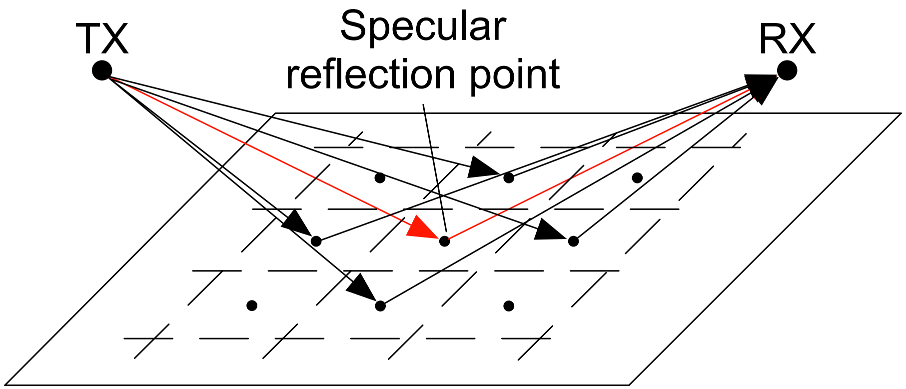


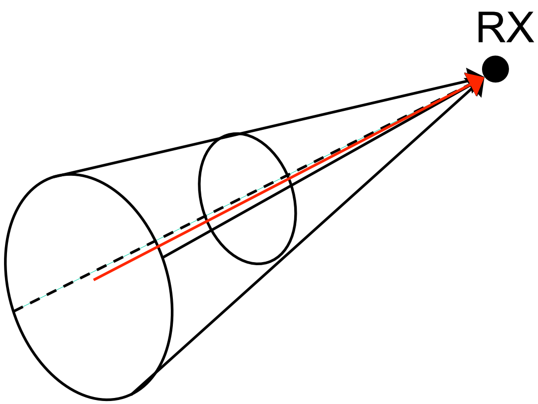
→ Clustered behavior also occurs in time domain

→ <u>Question</u>: Is there any interdependence between AoA and ToA?

Time of Arrival (3)

- Scattered rays propagate on shells of cones around the specularly reflected ray:





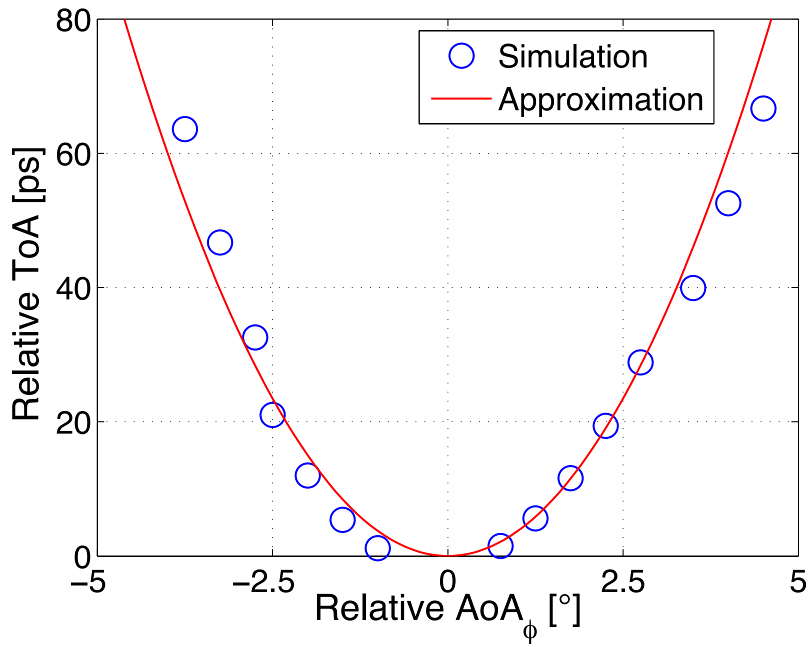
→ Their relative path length with respect to the specular reflection and hence also the AoA-dependent ToA of the i^th cluster can be approximated with a second order polynomial

$$ToA_i(\phi,\theta) = \tau_i + \left(c_\phi \cdot \phi^2\right) + \left(c_\theta \cdot \theta^2\right)$$

τ_i	Delay of the specular path	$c_{\Phi,\Theta}$	Cluster-specific constants; to be randomized

Time of Arrival (4)

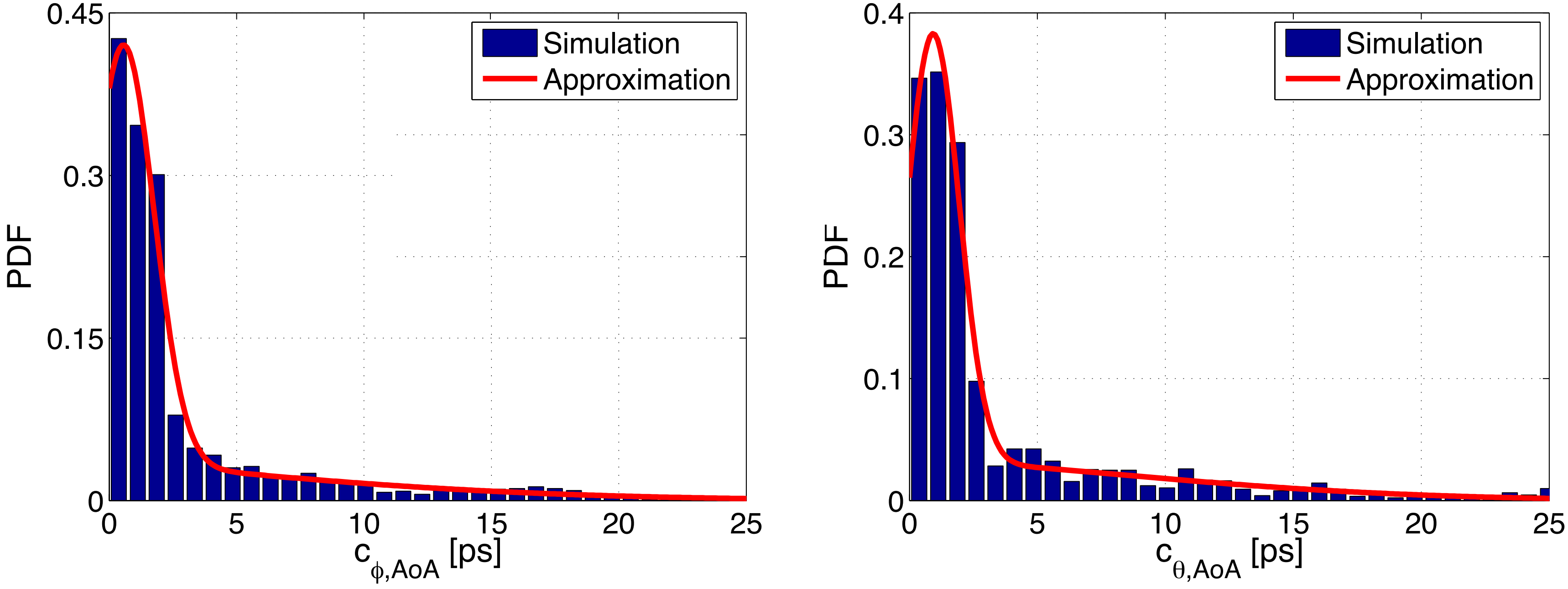
- Quadratic functions are fitted to each cluster separately for Φ and Θ in order to obtain statistics of $c_{\Phi,\Theta}$
- Exemplary fitting for one cluster:



→ Approach proves suitable

Time of Arrival (5)

- Histograms:



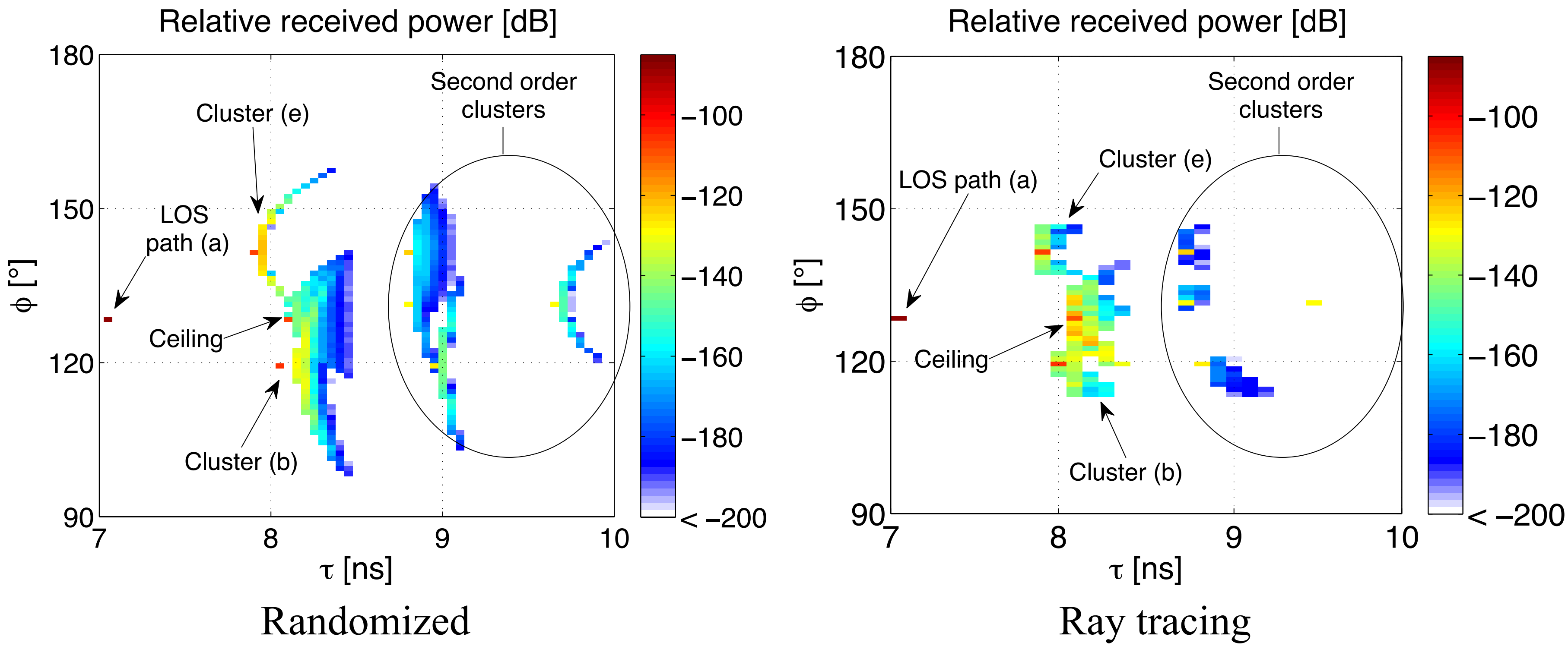
→ Again good approximation with second order GMM

→ Similar statistics for the AoD (omitted here, cf. [1])

→ All information known to randomize the ToA profile

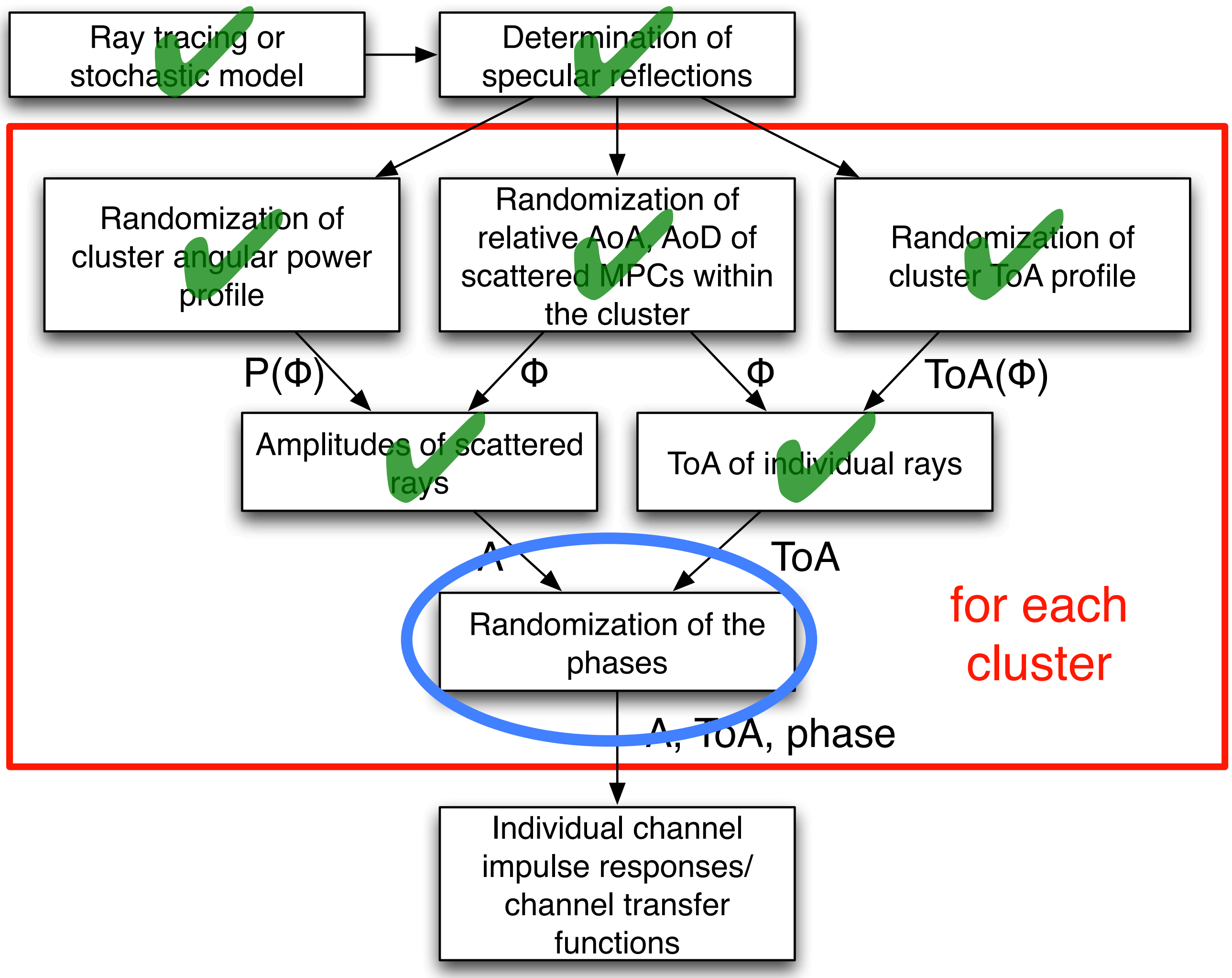
Time of Arrival (6)

- Cut-out of an exemplarily generated vs. simulated AoA/ToA profile:



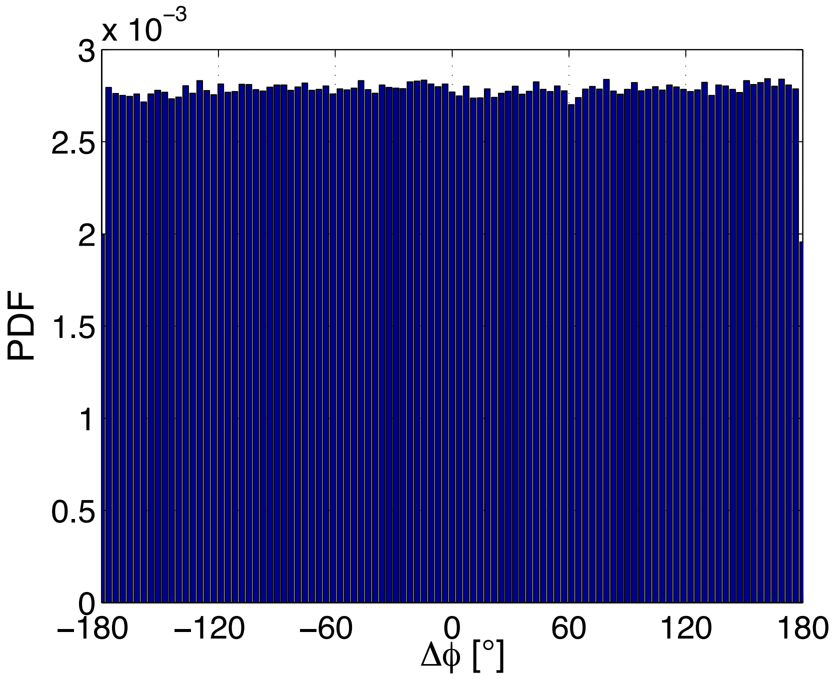
→ Slightly different shapes due to the stochastic generation, but realistic behavior

Phase (1)


Ray tracing or stochastic model
Determination of specular reflections
Randomization of cluster angular power profile
Randomization of relative AoA, AoD of scattered MPCs within the cluster
Randomization of cluster ToA profile
P(Φ)
Φ
Φ
ToA(Φ)
Amplitudes of scattered rays
ToA of individual rays
A
ToA
Randomization of the phases
for each cluster
A, ToA, phase
Individual channel impulse responses/ channel transfer functions

Phase (2)

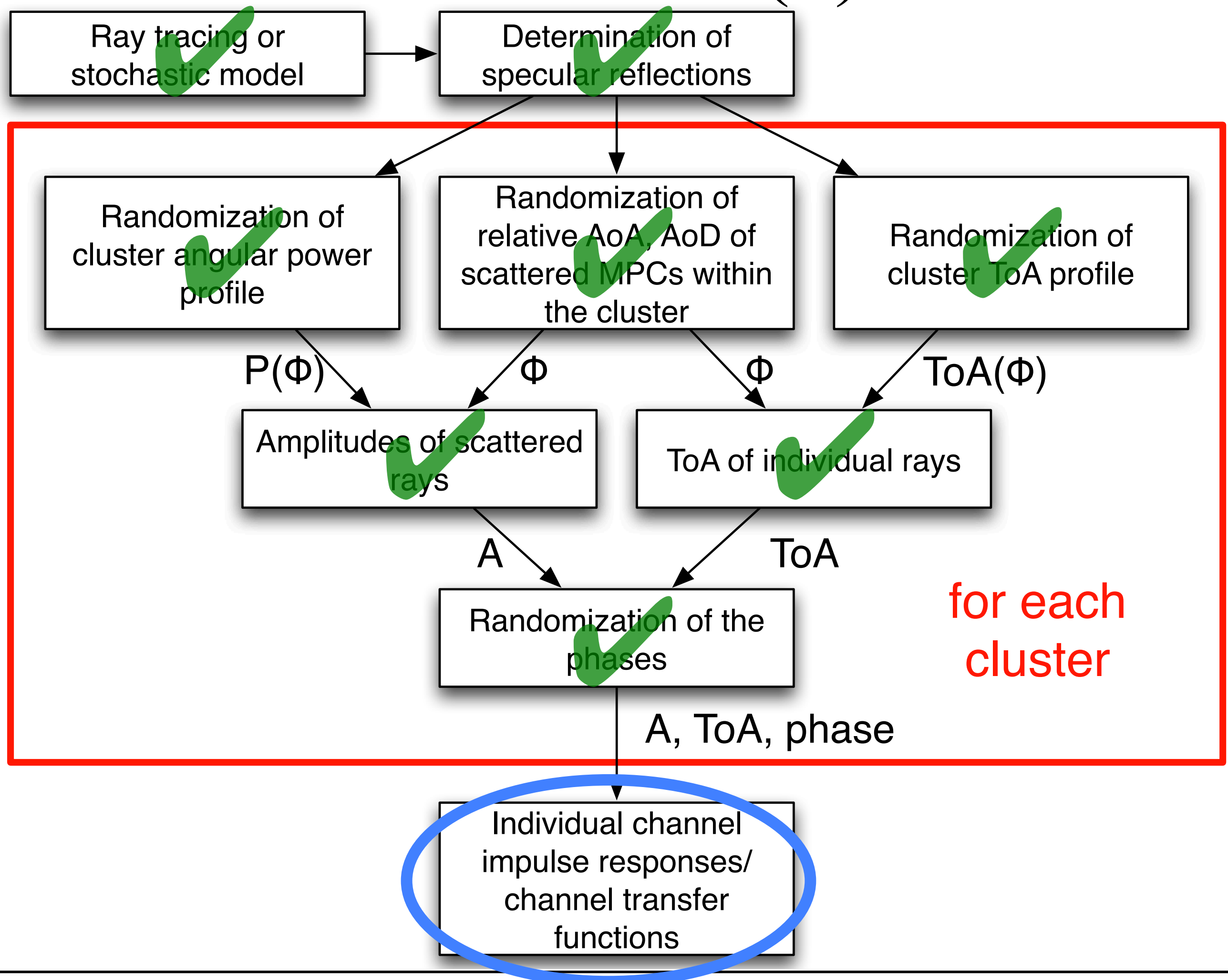
- Phase required for complete complex channel realiziations
- PDF of the relative phase with respect to the specular phase:



→ Almost perfect uniform distribution

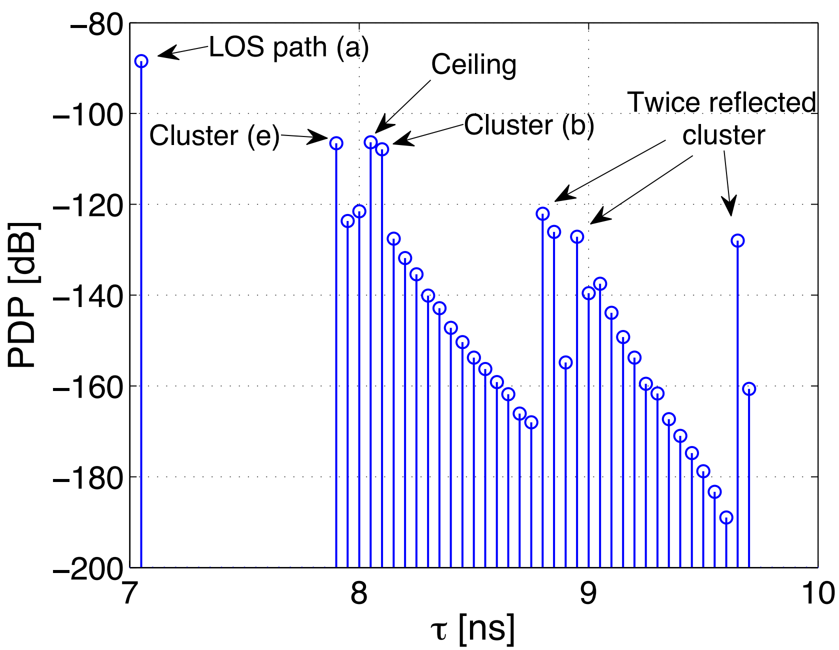
→ Random phase between -π and +π for scattered MPCs

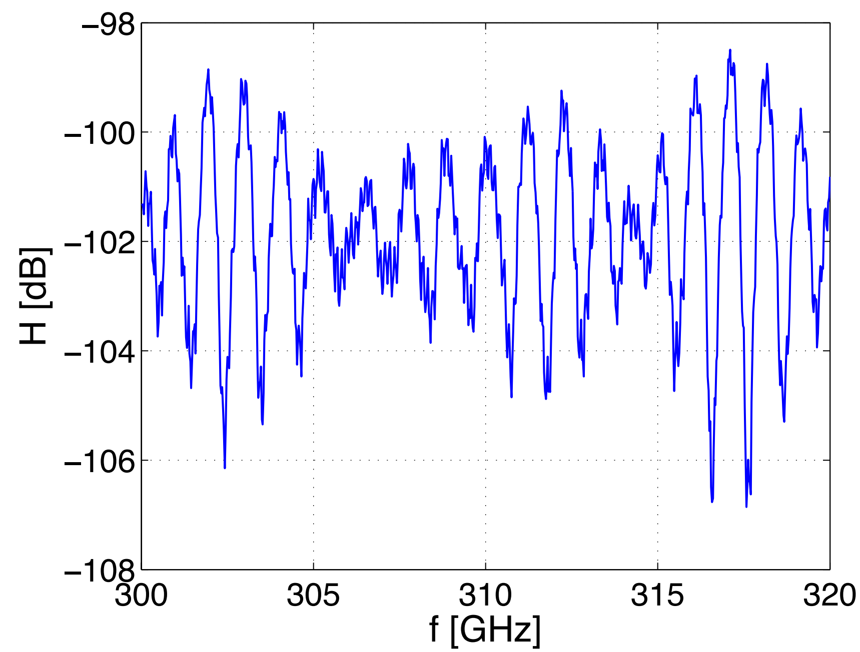
Generated Impulse Response/Transfer Function (1)



Generated Impulse Response/Transfer Function (2)

- Cut-out of a generated power delay profile and the corresponding transfer function (omnidirectional antenna) with 20 GHz bandwidth:





→ Model also suitable to provide realistic channel transfer functions

→ Channel transfer functions as input for system simulations

Outline

1. Introduction
2. The Investigated Scenario
3. Modeling of Multipath Clusters
4. **Summary/Outlook**

Summary

- A physically motivated stochastic channel model for scattered MPCs has been introduced
- Realistic channel realizations can be generated very fast for system simulations
- Necessary steps:

1. Specular reflections from ray tracing or a stochastic model
2. AoAs/AoDs of scattered MPCs within the clusters from PDFs
3. Cluster angular power profiles from statistics
4. Amplitudes from the APPs
5. Cluster ToA functions from statistics
6. ToAs from the ToA functions
7. Random phases between $-\pi$ and π

→ Complete channel realization

Outlook

- Specular reflections will also be modeled statistically
- Further statistics must be derived in other representative scenarios like e.g. a living or a conference room

→ Meaningful system simulations can be performed under realistic channel conditions for plenty of channel realizations

→ System specifications and design guidelines can be developed

References

More information on the topic including parameters for the approximated analytical PDFs can be found in:

[1] Priebe, S.; Jacob, M.; Kürner, T.: *AoA, AoD and ToA Characteristics of Scattered Multipath Clusters for THz Indoor Channel Modeling.* 17th European Wireless Conference (EW), 9 pages, Vienna, April 2011

Thank you for paying attention.

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