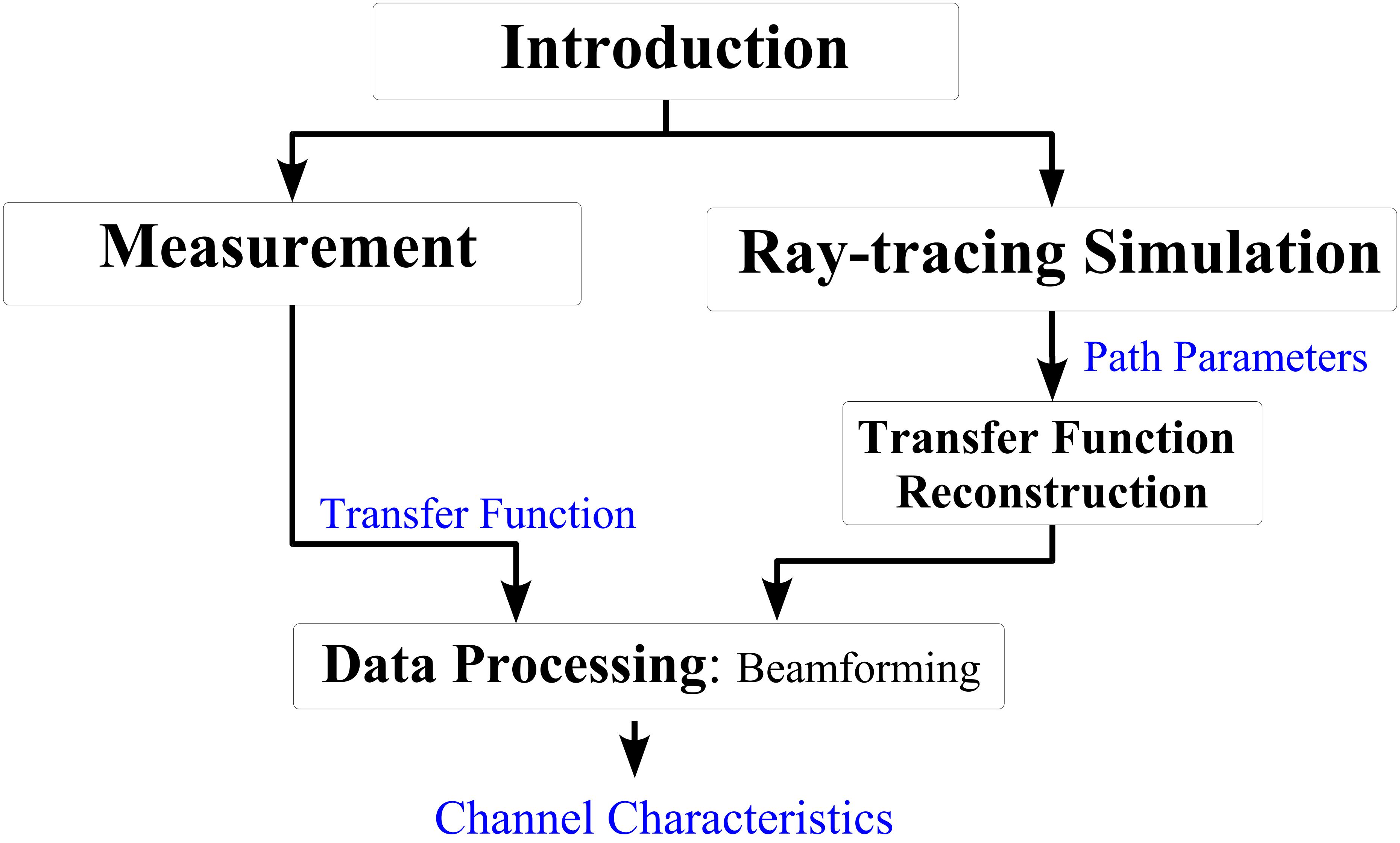
Directional Channel Characteristics from Microcell Measurement and Simulation

Navarat LERTSIRISOPON†, Gilbert SIY CHING†, Mir GHORAISHI†, Jun-ichi TAKADA†, Ichiro IDA††, and Yasuyuki OISHI††

†Department of International Development Engineering, Tokyo Institute of Technology
†† Fujitsu Ltd.

Outline



Introduction

Measurement

Ray-tracing Simulation

Path Parameters

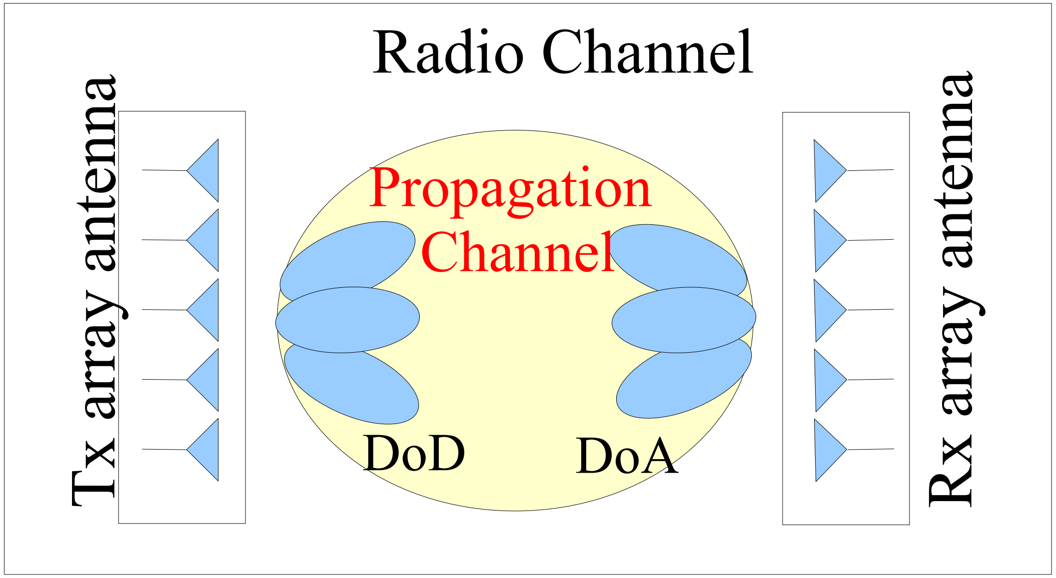
Transfer Function Reconstruction

Transfer Function

Data Processing: Beamforming

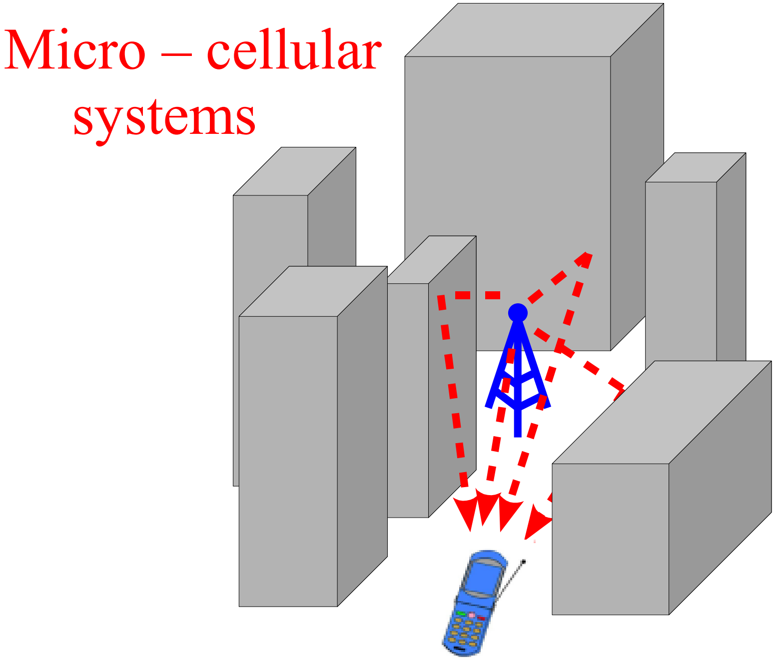
Channel Characteristics

Introduction (1)



- Multiple Input Multiple Output (MIMO) systems employing antenna arrays have recently emerged as a key technology to address the increasing demands and reliability of the systems
- By separating the influence of antennas, the concept of the **double-directional mobile radio channel** has been introduced
- Models of wireless propagation channel should include the DoA, DoD and time delay of the multipath components.

Introduction (2)

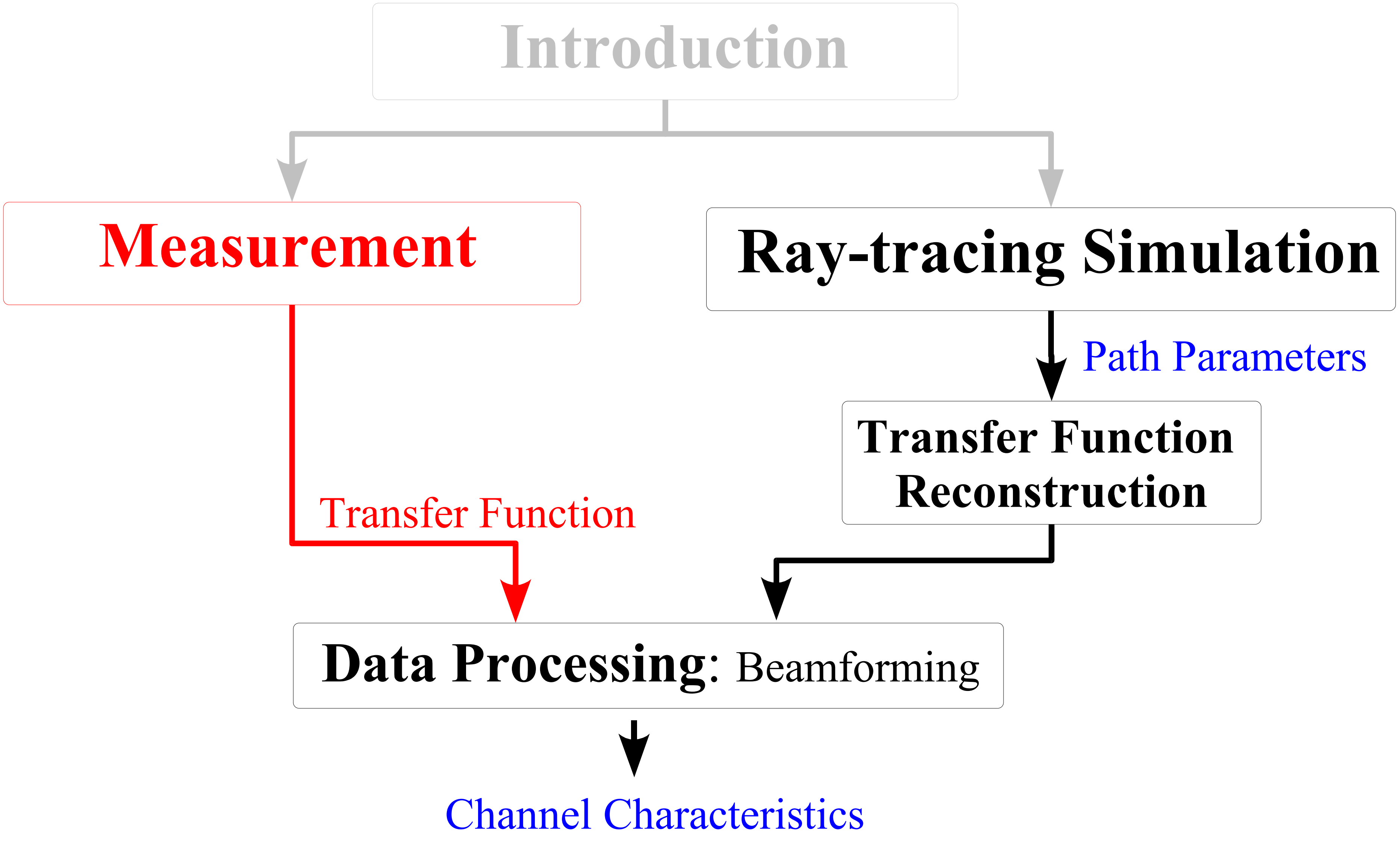


- Ray-tracing algorithms are popular approaches for propagation prediction and modeling
- Propagation mechanisms due to specular reflections from wall surfaces or diffraction from building edges can be predicted.
- Some mechanisms like non-specular scattering effects are not yet included.

Objective :

- To analyze and compare directional wideband channel characteristics from the ray-tracing results with measurements to gain insights on the significant propagation mechanisms.

Outline



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Measurement Scenario

- Location : TokyoTech
- Operating frequency : 4.5 GHz
- Bandwidth : 120 Mhz
- Delay resolution : 8.3 ns
- Excess delay : 3.2 μs

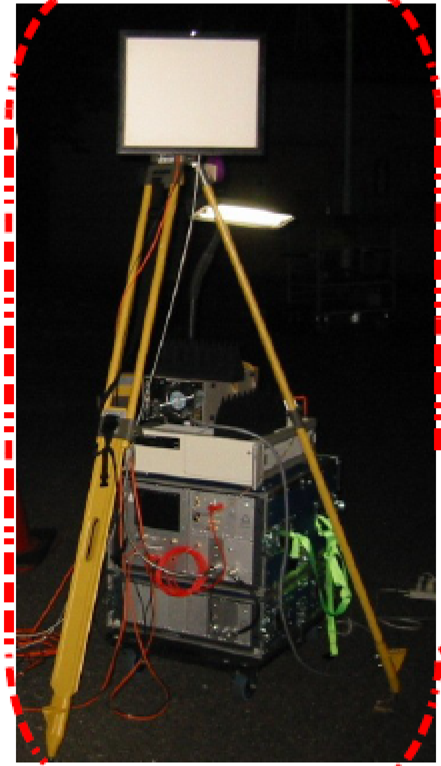
Measurement Scenario

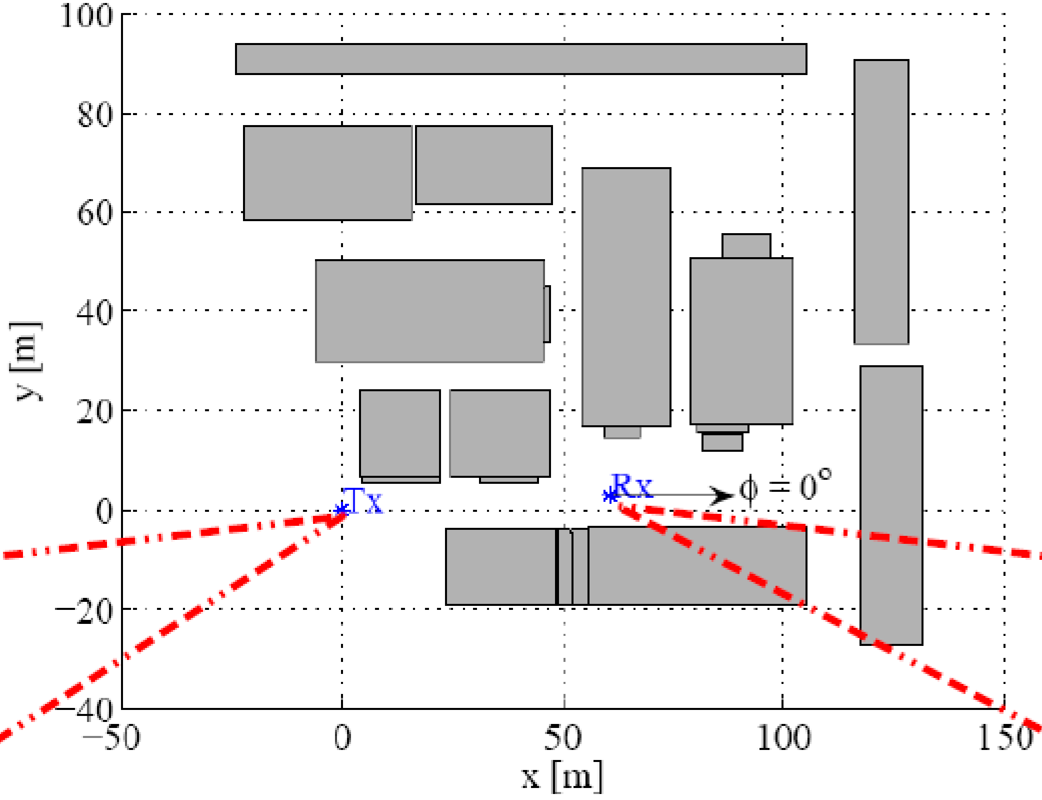
- Operating frequency : 4.5 Ghz
- Transmitted power : 40 dBm
- Distance : 60 m.

Transmitter

(Tx)

Height : 1.79 m.





Receiver

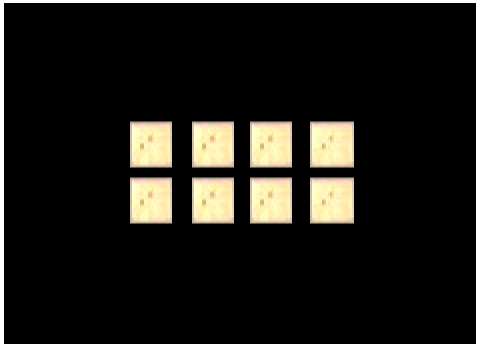
(Rx)

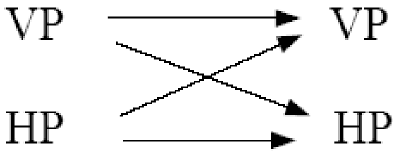
Height : 1.65 m.

Measurement Equipment

Equipment : RUSK Fujitsu channel sounder

Tx (BS)





VP → VP

HP → HP

Total = 16 * 96
= 1536 elements

Rx (MS)

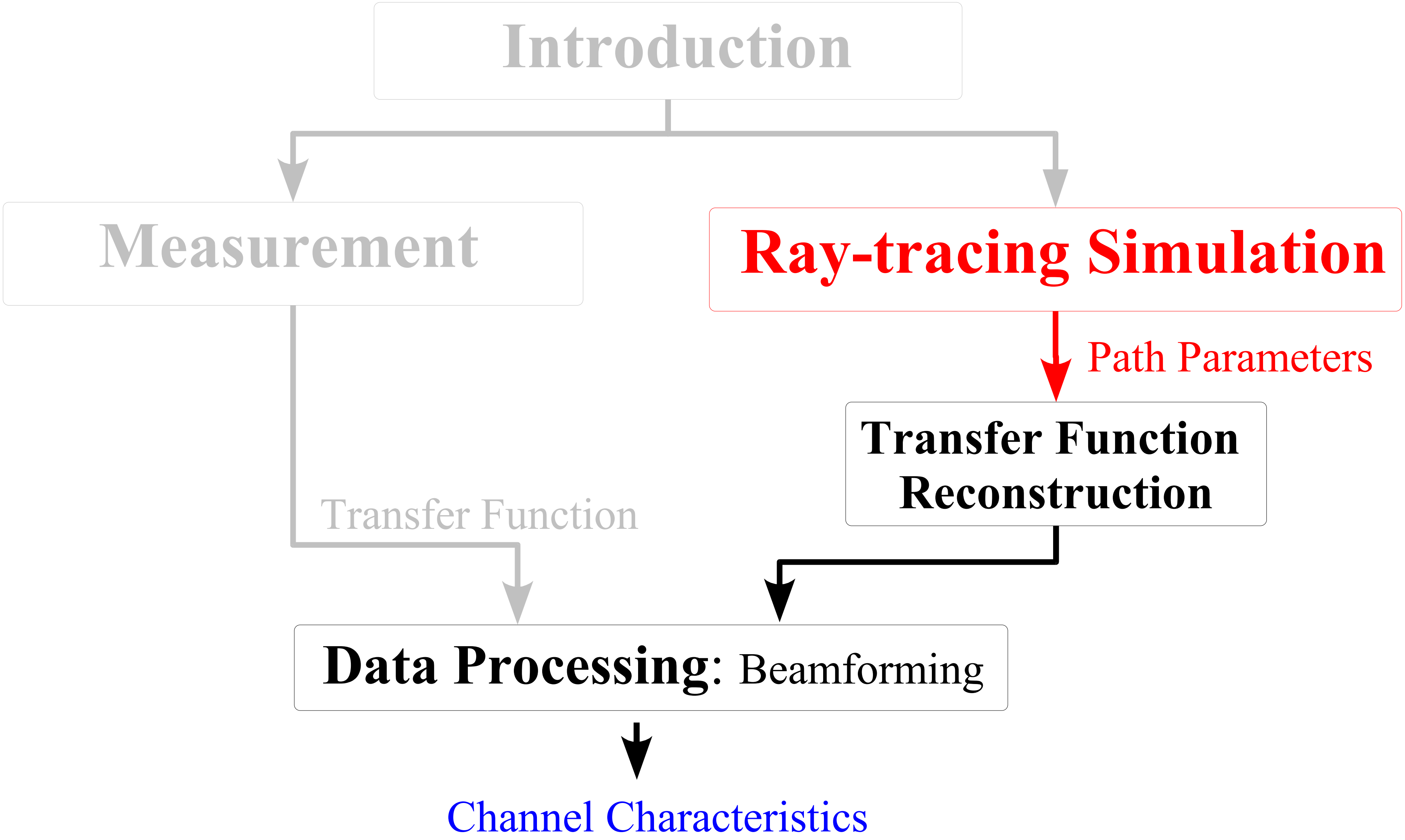
2 × 4 uniform rectangular
array antenna of dual-polarized
patch antenna elements

(VP = 8 elements, HP = 8 elements)

2 × 24 stacked uniform
circular antenna array
with dual-polarized patches

(VP = 48 elements, HP = 48 elements)

Outline



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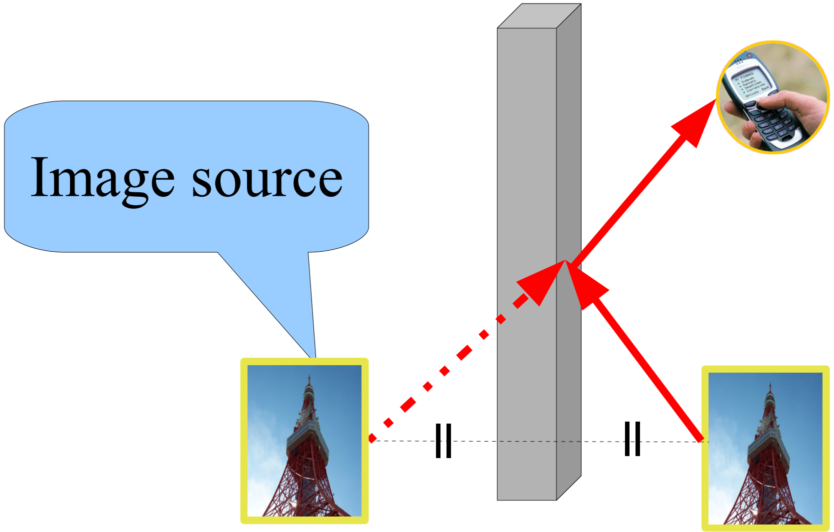
Ray-Tracing

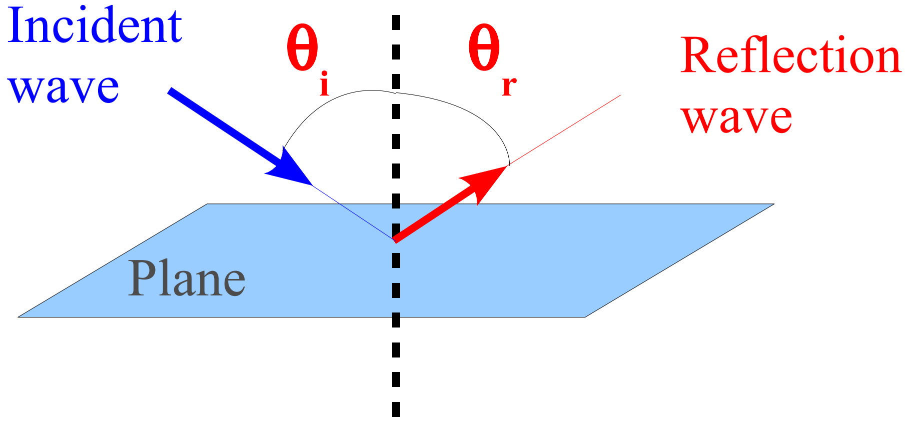
- **<u>Ray-tracing</u>**: to identify rays with reflections and diffractions by tracing rays from a source to observation points
- By incorporating 3-dimensional (3D) site-specific scenario information, the ray-tracing simulator called "Raplab" is used to predict detailed path parameters.
- The image method is utilized to trace rays from a source to the observation point .
  - Given a source point and a wall, the reflected ray from the wall can be considered as the ray radiated from a virtual source point



Calculation of Electromagnetic Wave Theory

Reflection

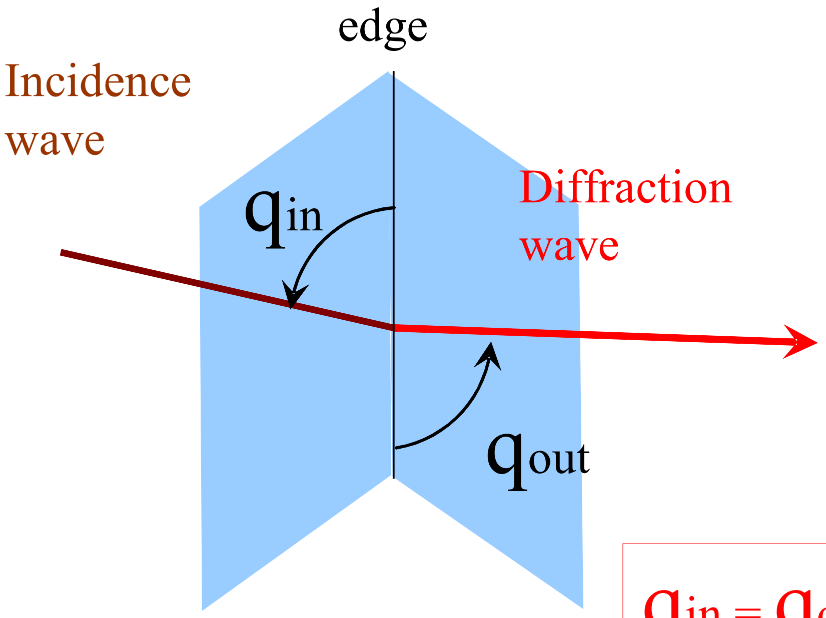
- The Fresnel reflection coefficients are used to model the reflections



$$\boxed{\theta_i = \theta_r}$$

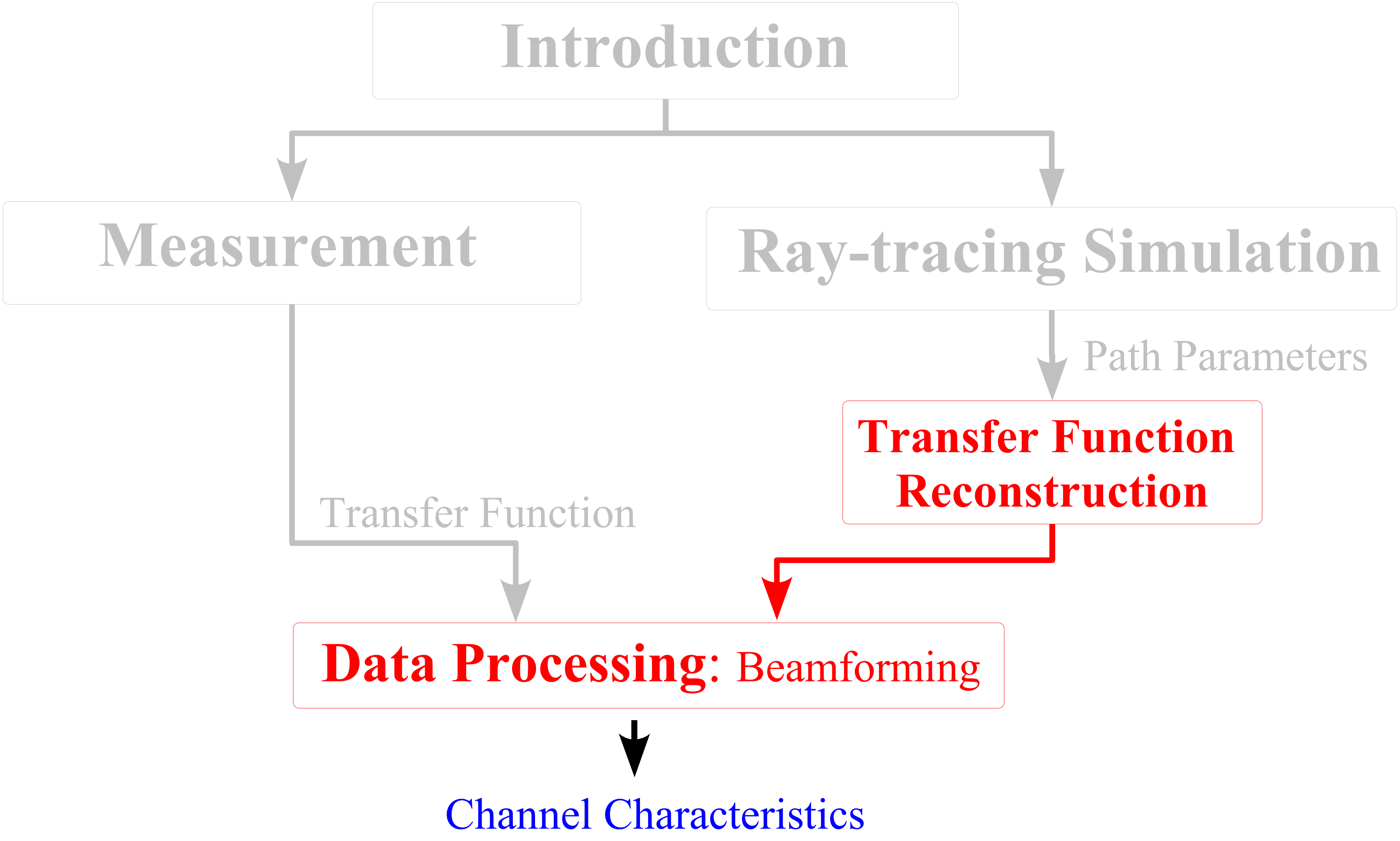
Diffraction

- Diffractions are described by the uniform geometrical theory of diffraction (UTD)



$$\boxed{q_{in} = q_{out}}$$

Outline



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Transfer Function Reconstruction (1)

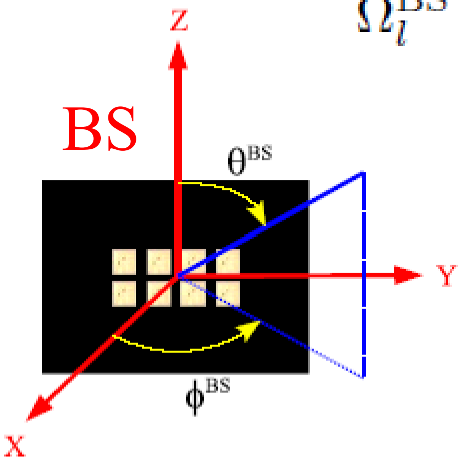
- Ray-based channel response model:

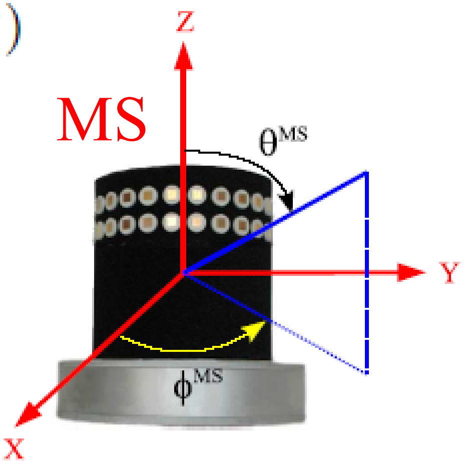
$$\bar{\bar{\mathrm{H}}}(f, \Omega^{\mathrm{BS}}, \Omega^{\mathrm{MS}}) \quad = \sum_{l=1}^{L} [\hat{\theta}_l^{\mathrm{BS}} \ \hat{\phi}_l^{\mathrm{BS}}] \begin{bmatrix} \gamma_{\mathrm{VV},l} \ \gamma_{\mathrm{VH},l} \\ \gamma_{\mathrm{HV},l} \ \gamma_{\mathrm{HH},l} \end{bmatrix} \begin{bmatrix} \hat{\theta}_l^{\mathrm{MS}} \\ \hat{\phi}_l^{\mathrm{MS}} \end{bmatrix}$$

$$\cdot \delta(\Omega^{\mathrm{BS}} - \Omega_l^{\mathrm{BS}}) \cdot \delta(\Omega^{\mathrm{MS}} - \Omega_l^{\mathrm{MS}}) \cdot e^{(-j2\pi f \tau_l)}$$

where γ_{VV} and γ_{HH} are the co-polarization components of VP and HP
γ_{VH} and γ_{HV} are those of cross polarization components

$$\Omega_l^{\mathrm{BS}} = (\theta_l^{\mathrm{BS}}, \phi_l^{\mathrm{BS}}) \quad \text{and} \quad \Omega_l^{\mathrm{MS}} = (\theta_l^{\mathrm{MS}}, \phi_l^{\mathrm{MS}})$$





Transfer Function Reconstruction (2)

- To simulate the propagation channel of measurement from ray-tracing results, the channel response is constructed as

BS antenna array response

$$\mathbf{H}_{\mathrm{RT}}(f) = \iint_{\mathrm{BS}} \iint_{\mathrm{MS}} \boxed{\bar{\mathbf{h}}_{\mathrm{MS}}(\Omega^{\mathrm{MS}})} \cdot \bar{\bar{\mathrm{H}}}(f, \Omega^{\mathrm{BS}}, \Omega^{\mathrm{MS}}) \cdot \boxed{\bar{\mathbf{h}}^{\mathrm{H}}_{\mathrm{BS}}(\Omega^{\mathrm{BS}})} d\Omega^{\mathrm{MS}} d\Omega^{\mathrm{BS}}$$

MS antenna array response

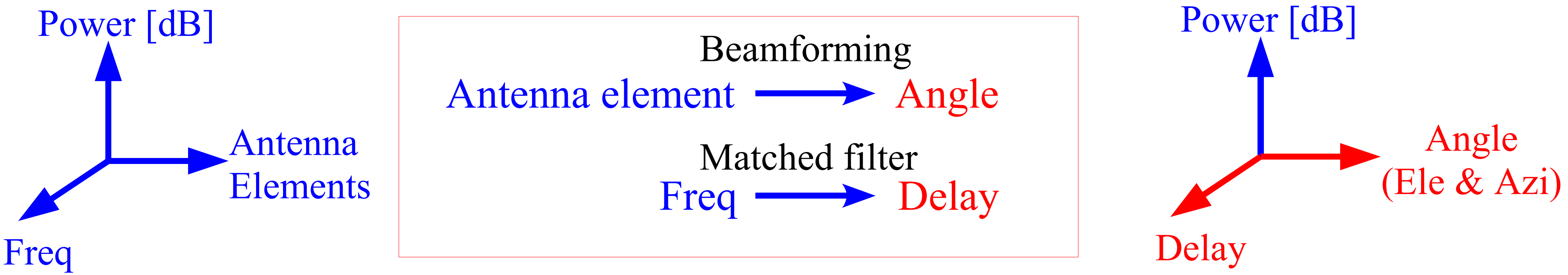
- To account for the frequency dependence of the phase delay in the exponential term, the channel response is represented in vector form for all frequency samples as

$$\mathbf{h}_{\mathrm{RT}} = \begin{bmatrix} \mathrm{vec}(\mathbf{H}_{\mathrm{RT}}(f_{-\frac{(N_f-1)}{2}})) \\ \vdots \\ \mathrm{vec}(\mathbf{H}_{\mathrm{RT}}(f_0)) \\ \vdots \\ \mathrm{vec}(\mathbf{H}_{\mathrm{RT}}(f_{\frac{(N_f-1)}{2}})) \end{bmatrix}$$

Data Processing : Beamforming

- The beamforming in the angular domain and the matched filtering in the delay domain are conducted by using the weight vector

$$\mathbf{w}(\tau,\Omega^{\mathrm{BS}},\Omega^{\mathrm{MS}}) \quad = \quad \mathbf{h}_{\mathrm{MS}}(\Omega^{\mathrm{MS}}) \otimes \mathbf{h}_{\mathrm{BS}}(\Omega^{\mathrm{BS}}) \otimes \mathbf{h}_{\mathrm{F}}(\tau)$$



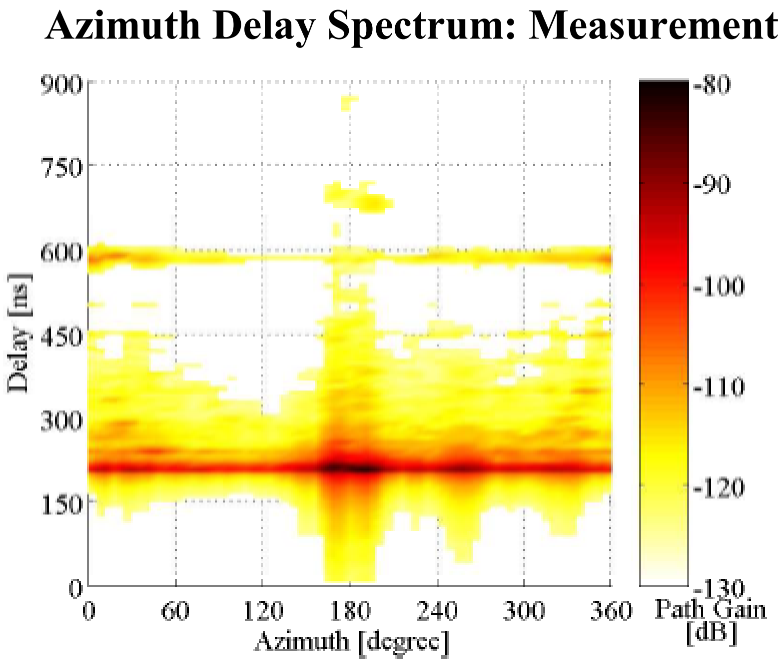
- The resultant spectrum: $P(\tau,\Omega^{\mathrm{BS}},\Omega^{\mathrm{MS}}) = \dfrac{|\mathbf{w}^{\mathrm{H}}(\tau,\Omega^{\mathrm{BS}},\Omega^{\mathrm{MS}})\mathbf{h}_{\mathrm{RT}}|^2}{\mathbf{w}^{\mathrm{H}}(\tau,\Omega^{\mathrm{BS}},\Omega^{\mathrm{MS}})\mathbf{w}(\tau,\Omega^{\mathrm{BS}},\Omega^{\mathrm{MS}})}$

- Beamforming is applied every 6° -> Azimuth Range : 0° – 360°
  Coelevation Range : 30° – 150°

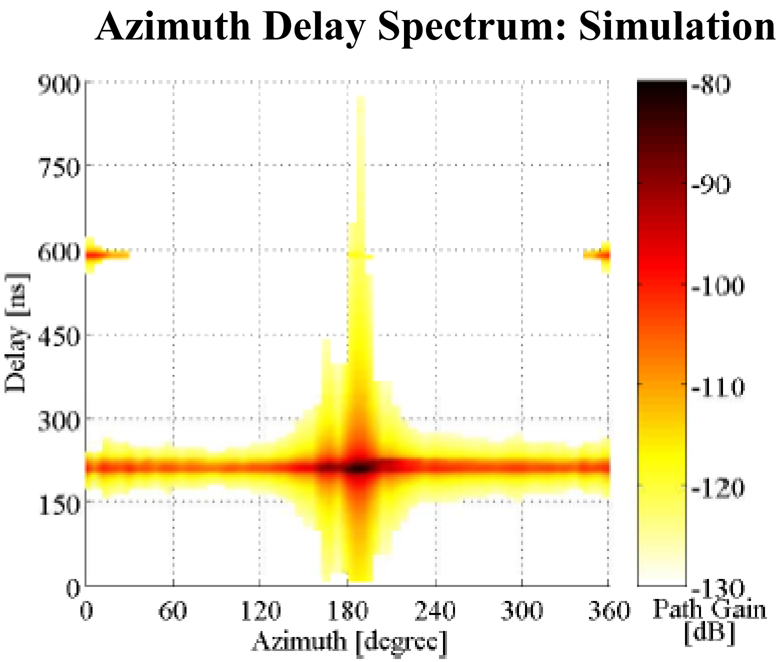
Results and discussion

- The measurement result of the azimuth-delay power spectrum after applying beamforming is

$$P_{\mathrm{ADS}} = \frac{\sum_{\theta^{\mathrm{MS}}=1}^{N_{\theta^{\mathrm{MS}}}} \sum_{\theta^{\mathrm{BS}}=1}^{N_{\theta^{\mathrm{BS}}}} \sum_{\phi^{\mathrm{BS}}=1}^{N_{\phi^{\mathrm{BS}}}} \left(P_{\mathrm{V}^{\mathrm{BS}}}(\mathbf{s}) + P_{\mathrm{H}^{\mathrm{BS}}}(\mathbf{s})\right)}{N_{\theta^{\mathrm{MS}}} \cdot N_{\theta^{\mathrm{BS}}} \cdot N_{\phi^{\mathrm{BS}}}}$$



Azimuth Delay Spectrum: Measurement



Azimuth Delay Spectrum: Simulation

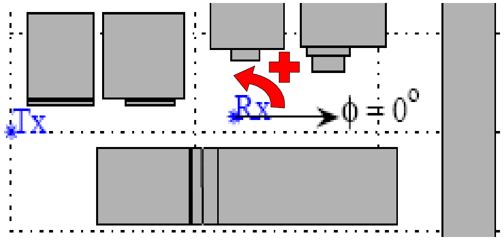
➢ Ray-tracing simulation can predict the arrival of strong signals

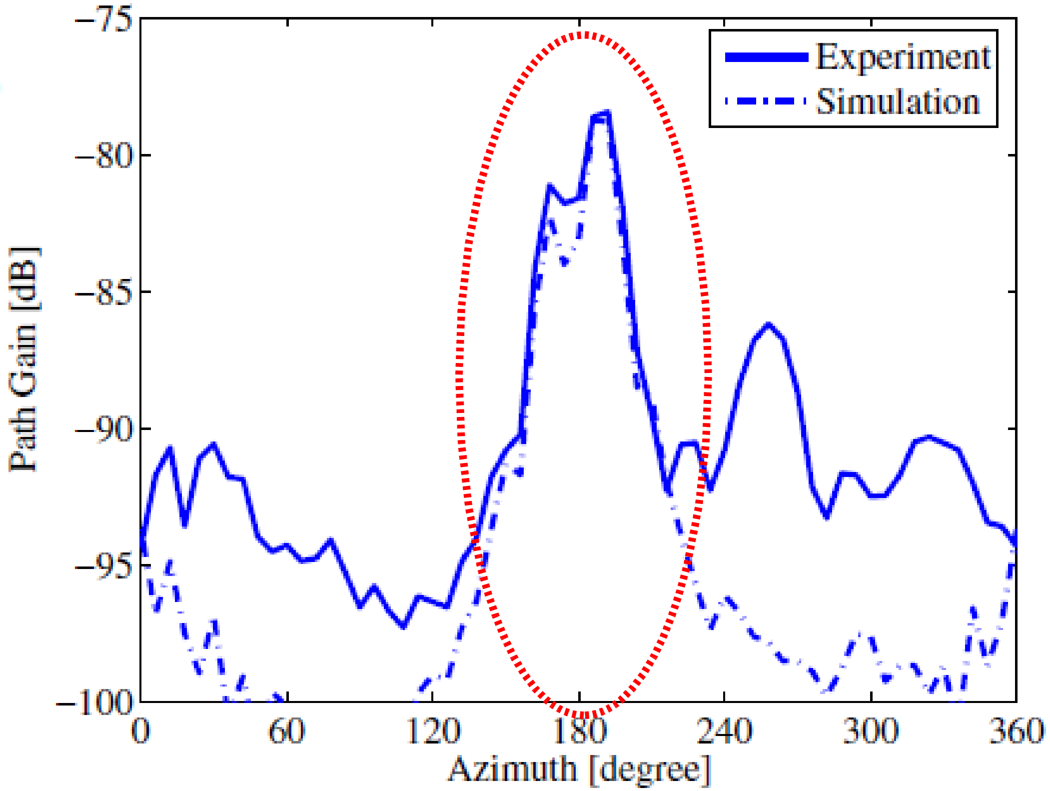
Azimuth spectrum

- Azimuth spectrum can be obtained by summing up the power of azimuth-delay spectrum with respect to delay time

$$P_{\mathrm{AS}}(\phi^{\mathrm{MS}}) = \sum_{\tau=1}^{N_\tau=385} P_{\mathrm{ADS}}(\phi^{\mathrm{MS}}, \tau)$$

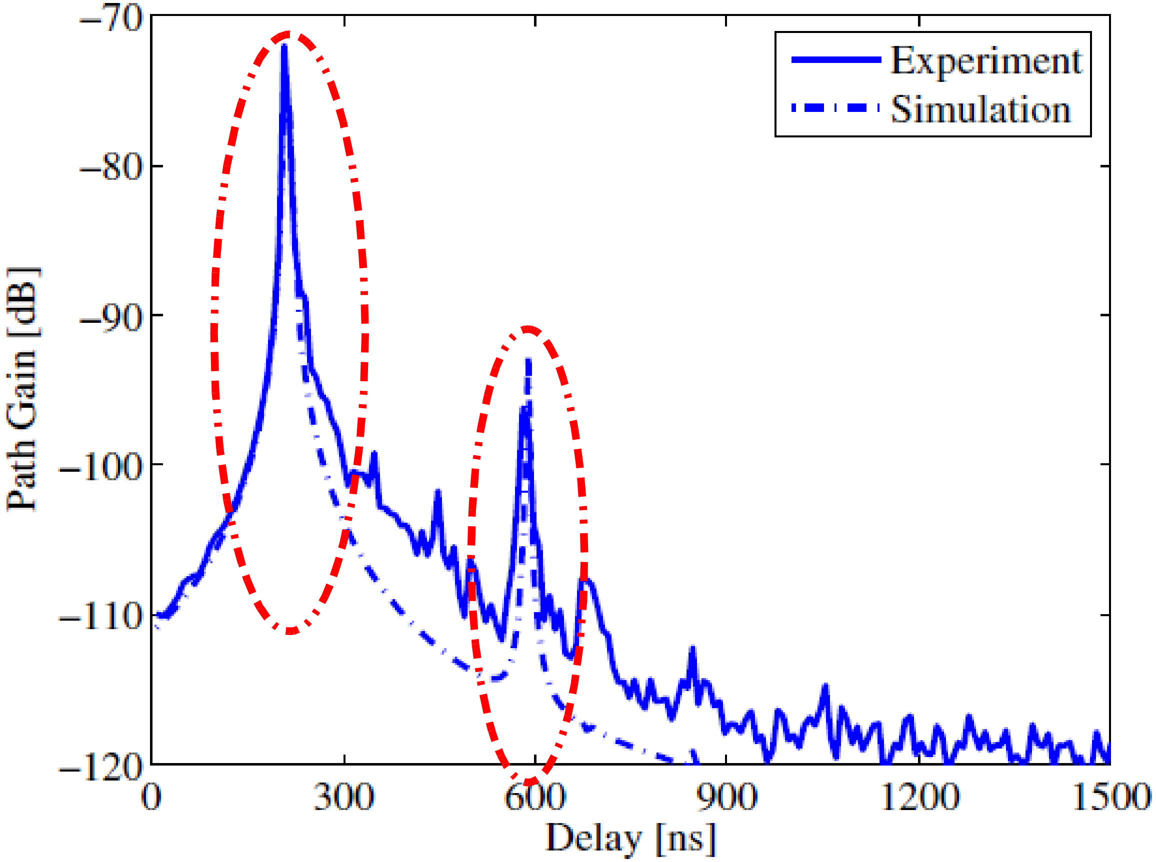
- The arrival waves within the range from 138° to 216° are in agreement with respect to the shape of the spectrum





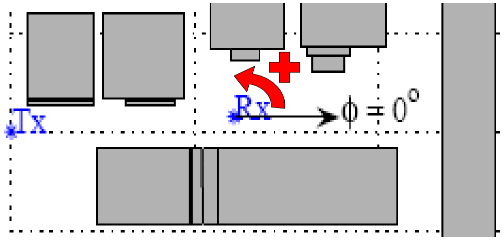
Delay spectrum

- Delay spectrum can be obtained by summing up the azimuth-delay spectrum with respect to the azimuth angle.

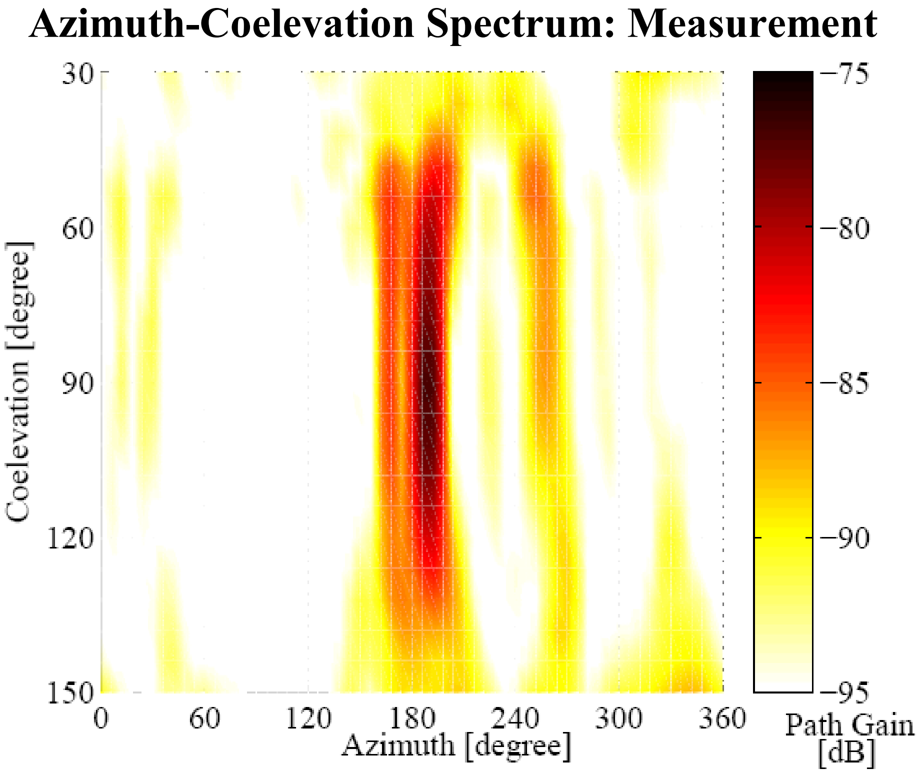


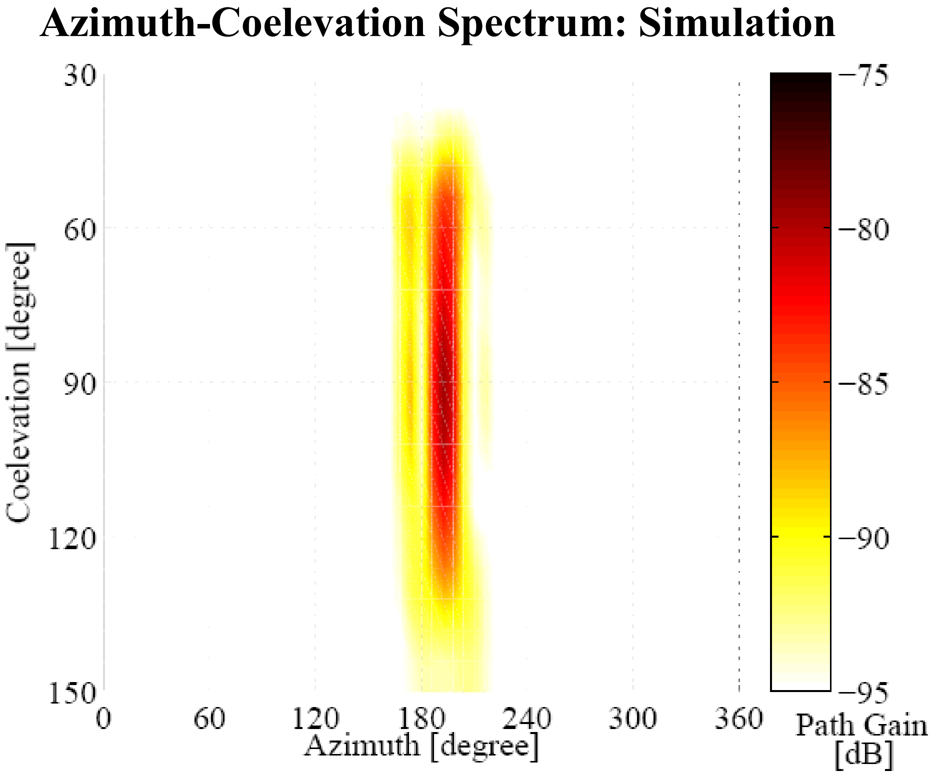
$$P_{\mathrm{DS}}(\tau) = \sum_{\phi^{\mathrm{MS}}=1}^{N_{\phi^{\mathrm{MS}}}=61} P_{\mathrm{ADS}}(\phi^{\mathrm{MS}},\tau)$$

- The 200 ns peak is composed of the LOS path and other paths close to it. (reflections from the building walls in between BS and MS)



Azimuth- Coelevation Spectrum


Azimuth-Coelevation Spectrum: Measurement


Azimuth-Coelevation Spectrum: Simulation

- By specifying the delay domain at the maximum path gain occurring at 207 [ns], azimuth-coelevation spectrum can be obtained.
- Ray-tracing simulation can estimate the coelevation within 50° to 130°

Conclusion

- A ray tracing simulator was used to predict the path parameters of a LOS microcellular environment inside a university campus
- Ray tracing results were applied to reconstruct the channel response.
- For channel data processing, the beamforming and matched filtering are utilized to extract the angular and delay channel parameters and compared to measured results.
- The results have shown that the angular and delay channel parameters extracted from the ray-tracing result can predict the major peaks with those from the measurement.

Thank you
for your attention