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19. ComNets-Workshop
Mobil- und Telekommunikation

IMTAphy – A Fully Calibrated M.2135-compliant Spatial Channel Model for openWNS

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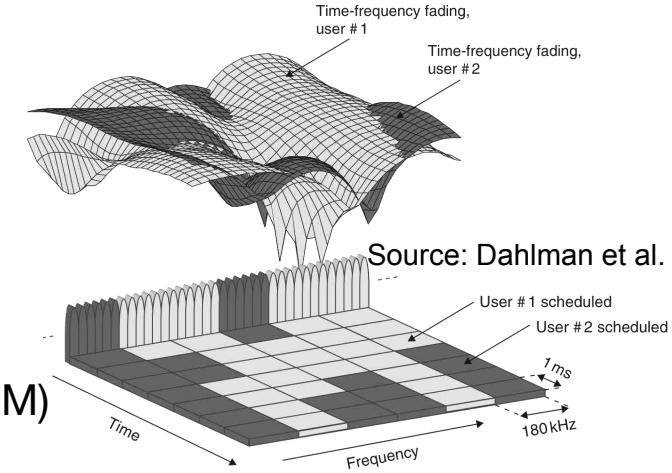
Motivation

- LTE, WiMAX, and future IMT-A cellular systems exploit
  - time/frequency selectivity of the channel by fast scheduling with link adaptation
    ➔ need multi-path / fast-fading channel model
  - MIMO transmissions
    ➔ spatial selectivity has to be modeled in addition



Source: Dahlman et al.

- Our general research topic: interference management (IM)
  - IM restricts scheduler‘s degrees of freedom (frequency reuse, usage patterns in time, available beamforming / precoding)
  - ➔ to judge tradeoff of IM schemes: fast-fading spatial channel model needed

- ITU-R M.2135 mandates system-level simulations to evaluate mean cell / cell-edge spectral efficiency of IMT-A candidate systems
  - need an efficient implementation
  - that gives accurate / reliable results

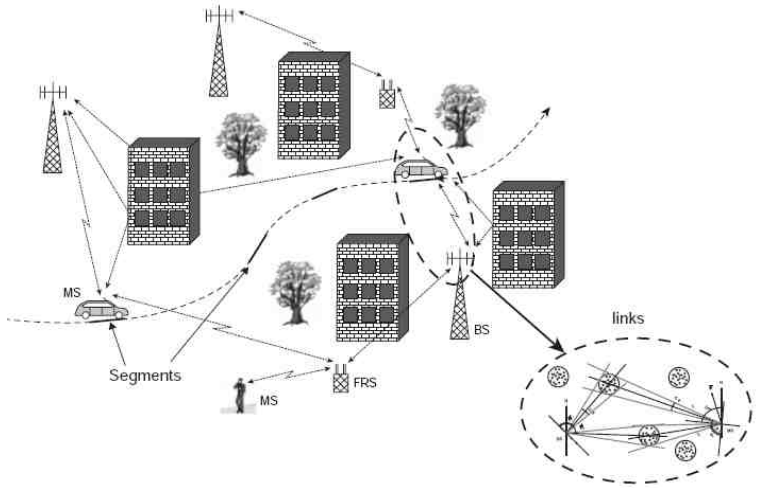
➔ We implemented and calibrated the M.2135 channel model in C++ and made it available as open source under GPLv3 license at **https://launchpad.net/imtaphy**

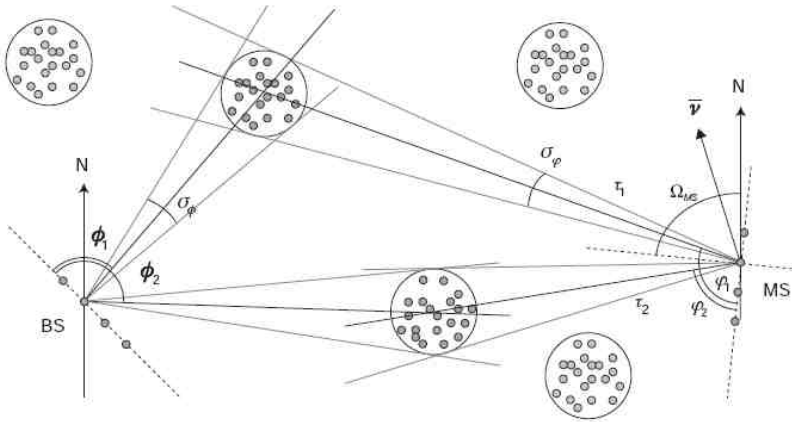
ITU-R IMT-A Channel Model (Primary Module)

- Adapted from WINNER+ channel model
- Link-level and system-level simulations possible

- Large Scale effects:
  - pathloss
  - outdoor shadowing
  - penetration shadowing
    Outdoor-to-Vehicle (O2V), Outdoor-to-Indoor (O2I)
  - antenna patterns

- Small Scale effects (due to multi-path) :
  - geometry based stochastic model
  - channel impulse response (CIR) with proper
    - angular power distribution among paths
    - power delay profile
    - phase relationships between antenna array elements
  - correlations between:
    - antenna elements
    - mobiles associated to same base station





Source: IMT-Advanced Evaluation Guidelines ITU-R M.2135

Wraparound Simulation for Hexagonal Scenarios

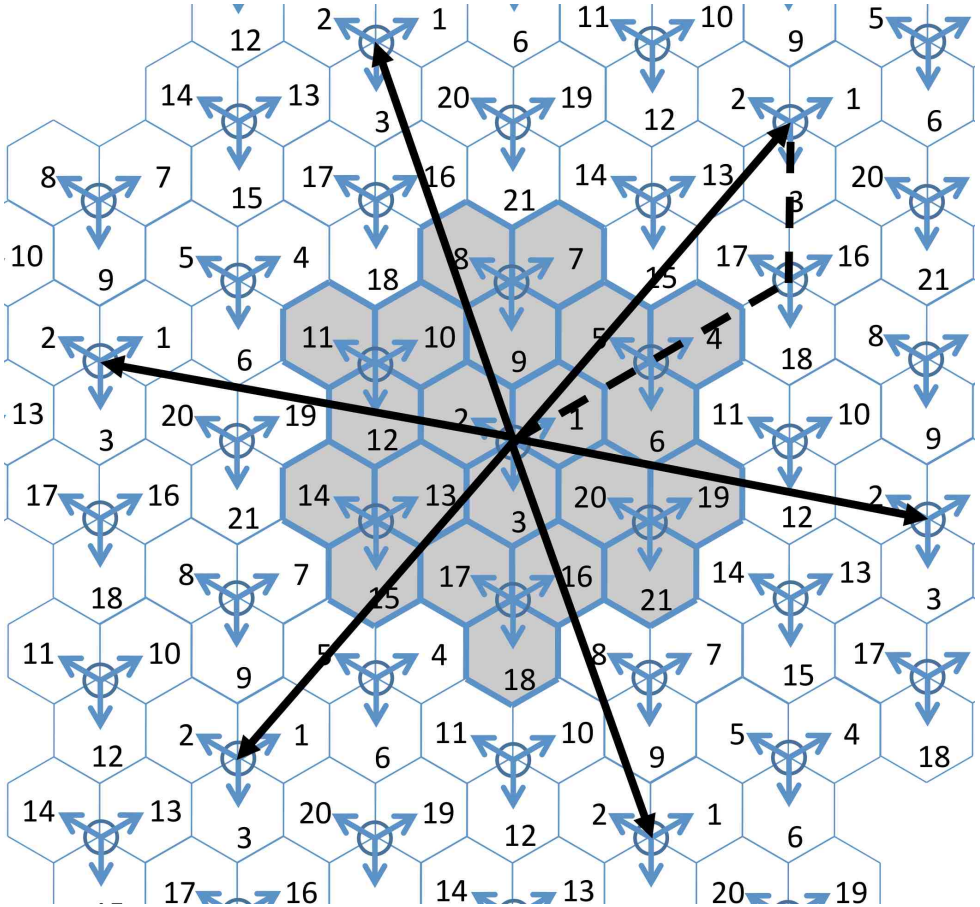
Problem:

- M2135: explicit interference modeling
- Same (full) protocol stack in all nodes for system-level simulation (complexity!)
- But realistic interference situation only in inner cells

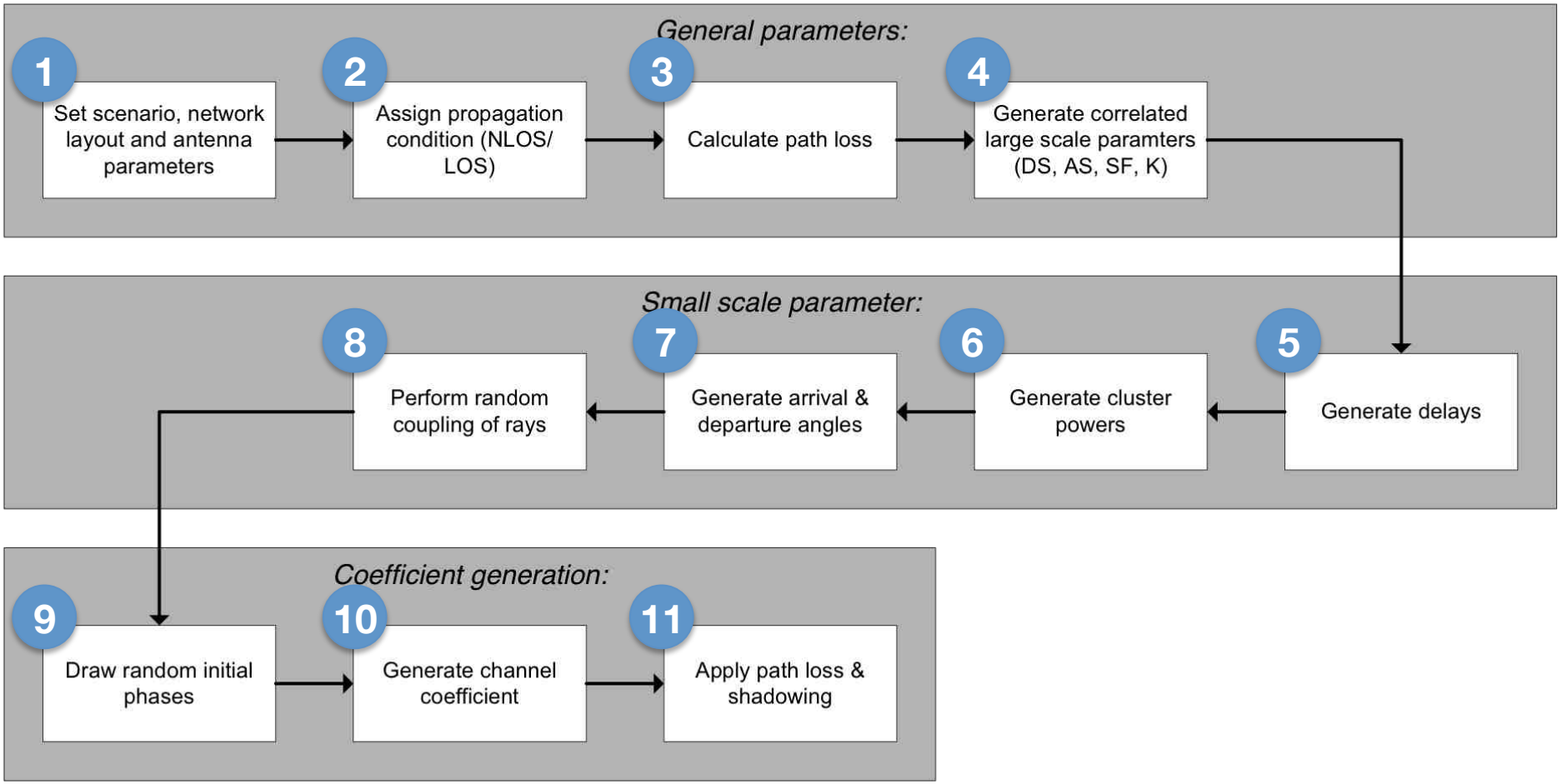
Solution: wraparound

- makes cells at opposing ends neighbors (like on a torus)
- here: per link shift mobile to all possible wraparound positions and choose closest

➔ All nodes give realistic statistics



Channel Coefficient Generation Procedure



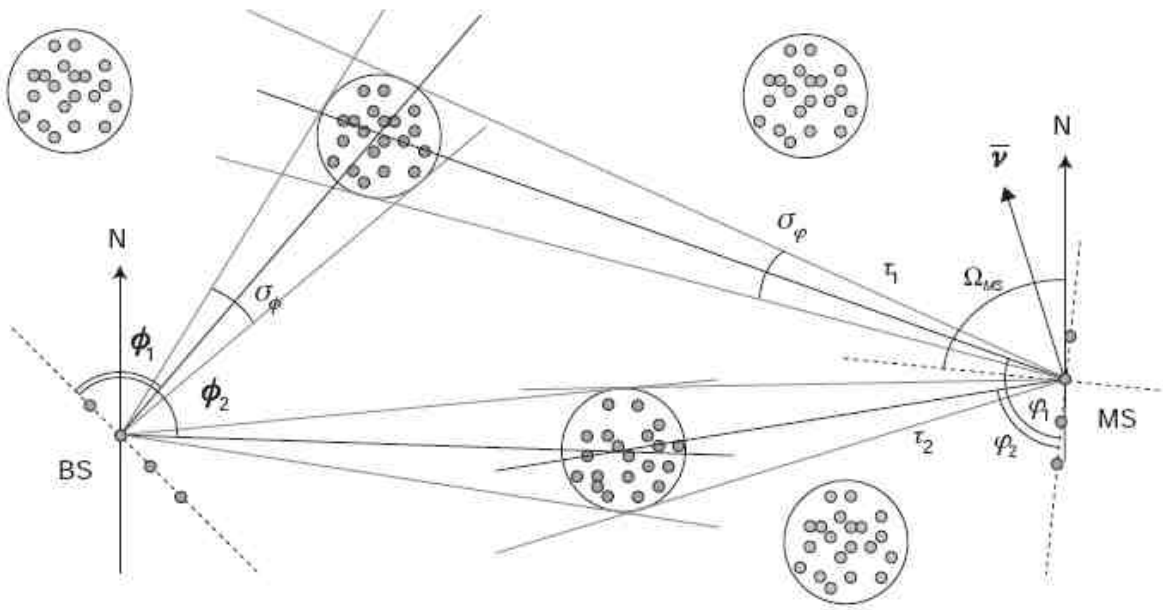
Source: Rep. ITU-R M.2135

Step 10: Generate Channel Coefficients

$$h_{u,s,n}(t) = \sqrt{P_n} \sum_{m=1}^{M} \begin{pmatrix} F_{rx,u,V}(\varphi_{n,m}) \\ F_{rx,u,H}(\varphi_{n,m}) \end{pmatrix}^T \begin{pmatrix} \exp(j\Phi_{n,m}^{vv}) & \sqrt{\kappa^{-1}}\exp(j\Phi_{n,m}^{vh}) \\ \sqrt{\kappa^{-1}}\exp(j\Phi_{n,m}^{hv}) & \exp(j\Phi_{n,m}^{hh}) \end{pmatrix} \begin{pmatrix} F_{tx,s,V}(\phi_{n,m}) \\ F_{tx,s,H}(\phi_{n,m}) \end{pmatrix}$$

$$\exp(jd_s 2\pi\lambda_o^{-1}\sin(\phi_{n,m}))\exp(jd_u 2\pi\lambda_o^{-1}\sin(\varphi_{n,m}))$$

$$\exp(j2\pi v_{n,m}t)$$



Source: Rep. ITU-R M.2135

$H_{u,s,n}(t)$	channel coefficient
u	number of Rx antennas
s	number of Tx antennas
$n = 1 \ldots 24$	cluster (path) index
$m = 1 \ldots 20$	ray index
τ_n	delay of path n
P_n	power of path n
$F_{rx,u,V}(\varphi_{n,m})$	electrical field pattern
$F_{rx,u,H}(\varphi_{n,m})$	for Rx/Tx antennas with
$F_{tx,s,V}(\phi_{n,m})$	vertical / horizontal
$F_{tx,s,H}(\phi_{n,m}$	polarization
$\Phi_{n,m}^{vv}$, $\Phi_{n,m}^{vh}$	random phases
$\Phi_{n,m}^{hv}$, $\Phi_{n,m}^{hh}$	
κ	cross polarization power ratio
d_s,	effective distance of Tx / Rx
d_u	elements s/u to reference element
$\phi_{n,m}$	angle of departure
$\varphi_{n,m}$	angle of arrival
$v_{n,m}$	Doppler frequency component
	$v_{n,m} = \|\|v\|\| \cos(\varphi_{n,m} - \theta_v)/\lambda_0$

Challenge: Complexity

Typical scenario:

- 57 cells
- 10 mobiles per cell

➔ 57 * 57 * 10 = 32.490 links

- 4 x 4 (Tx x Rx) antenna configuration

➔ 16 antenna pairs per link

- Up to n = 1..24 paths (clusters) between an antenna pair

➔ 32.490 * 16 * 24 = 12.476.160 channel coefficients to compute (for one t)

- Each path consists of m = 1..20 rays (+ LoS), so summation goes over

➔ 249.423.200 rays in total

For each time instant t, 250 million values are computed and summed up!

We need a very efficient implementation
to simulate over a significant time span

Key Observation: Most Things are time-invariant!

$$h_{u,s,n}(t) = \sqrt{P_n} \sum_{m=1}^{M} \begin{pmatrix} F_{rx,u,V}(\varphi_{n,m}) \\ F_{rx,u,H}(\varphi_{n,m}) \end{pmatrix}^T \begin{pmatrix} \exp(j\Phi_{n,m}^{vv}) & \sqrt{\kappa^{-1}}\exp(j\Phi_{n,m}^{vh}) \\ \sqrt{\kappa^{-1}}\exp(j\Phi_{n,m}^{hv}) & \exp(j\Phi_{n,m}^{hh}) \end{pmatrix} \begin{pmatrix} F_{tx,s,V}(\phi_{n,m}) \\ F_{tx,s,H}(\phi_{n,m}) \end{pmatrix}$$

$$\exp(jd_s 2\pi\lambda_o^{-1}\sin(\phi_{n,m}))\exp(jd_u 2\pi\lambda_o^{-1}\sin(\varphi_{n,m}))$$

- Between subsequent time instances, only the red term changes: $\exp(j2\pi v_{n,m}t)$
- The rest (green part) only has to be computed once

Implementation:

1. generate all input parameters with proper correlations
2. pre-compute green part and the coefficient of the red part (without *t)*
3. store for the rest of the simulation (size: e.g. 250 million values)

➔ store with single precision in large vectors to exploit vectorization/caches in CPU

To compute CIR *H* for a new time instant *t*:

1. multiply coefficient with current *t*
2. take complex exponential of (1) (specialized library functions, e.g. Intel MKL vzCIS)
3. multiply constant (green part) with result (2) and sum over all rays (dot product)

Performance Comparison

Computing the CIR for 32,490 links, 4x4 MIMO, 100 TTIs

Hardware: 8 cores Intel X5460 @ 3.16GHz (from 2008)

Implementation / IMTAphy mode	Total (real) runtime	Time for each additional TTI	Max. mem. consumption
TTA PG707 [1]	31000 sec.	310 sec.	23 GB
WINNER [2] with C-MEX	1962 sec.	18 sec.	27 GB
IMTAphy 1 thread double 8 threads	1015 sec 501 sec	7.73 sec 4.40 sec	6.4 GB
IMTAphy 1 thread single 8 threads	728 sec 275 sec	4.19 sec 2.21 sec	3.2 GB

[1] TTA PG707: C-Code for Report ITU-R M.2135 Channel Model Implementation http://www.itu.int/oth/R0A06000024/en

[2] Finland: Software Implementation of IMT.EVAL Channel Model http://www.itu.int/oth/R0A06000022/en

Channel Model and Simulator Calibration

- Different implementation assumptions (and bugs) can lead to arbitrarily wrong simulation results

➔ Need for calibration of different simulators to get comparable results

Commonly used calibration metrics (e.g., 3GPP, IMT-A evaluation process):

- "Large Scale" Calibration (no multipath effects)
  - distribution of path gain (coupling gain) between BS and associated mobiles
  - distribution of wideband downlink SINR
- "Small Scale" calibration (w.r.t. intermediate spatial channel model properties)
  - distribution of weighted RMS delay spread
  - distribution of minimum weighted RMS angular spread (for AoA and AoD)

- References:
  - 3GPP TR 36.814 "Further advancements for E-UTRA physical layer aspects", Appendix A 2.2 „System level simulator calibration"
  - WINNER+ "Calibration for IMT-Advanced Evaluations" (see WINNER website)
  - Chinese Evaluation Group: Calibration Activities in Chinese Evaluation Group (see ITU website)
  - K. Safjan et al. „Assessing 3GPP LTE-Advanced as IMT-Advanced Technology: The WINNER+ Evaluation Group Approach", IEEE Comm. Magazine, February 2011

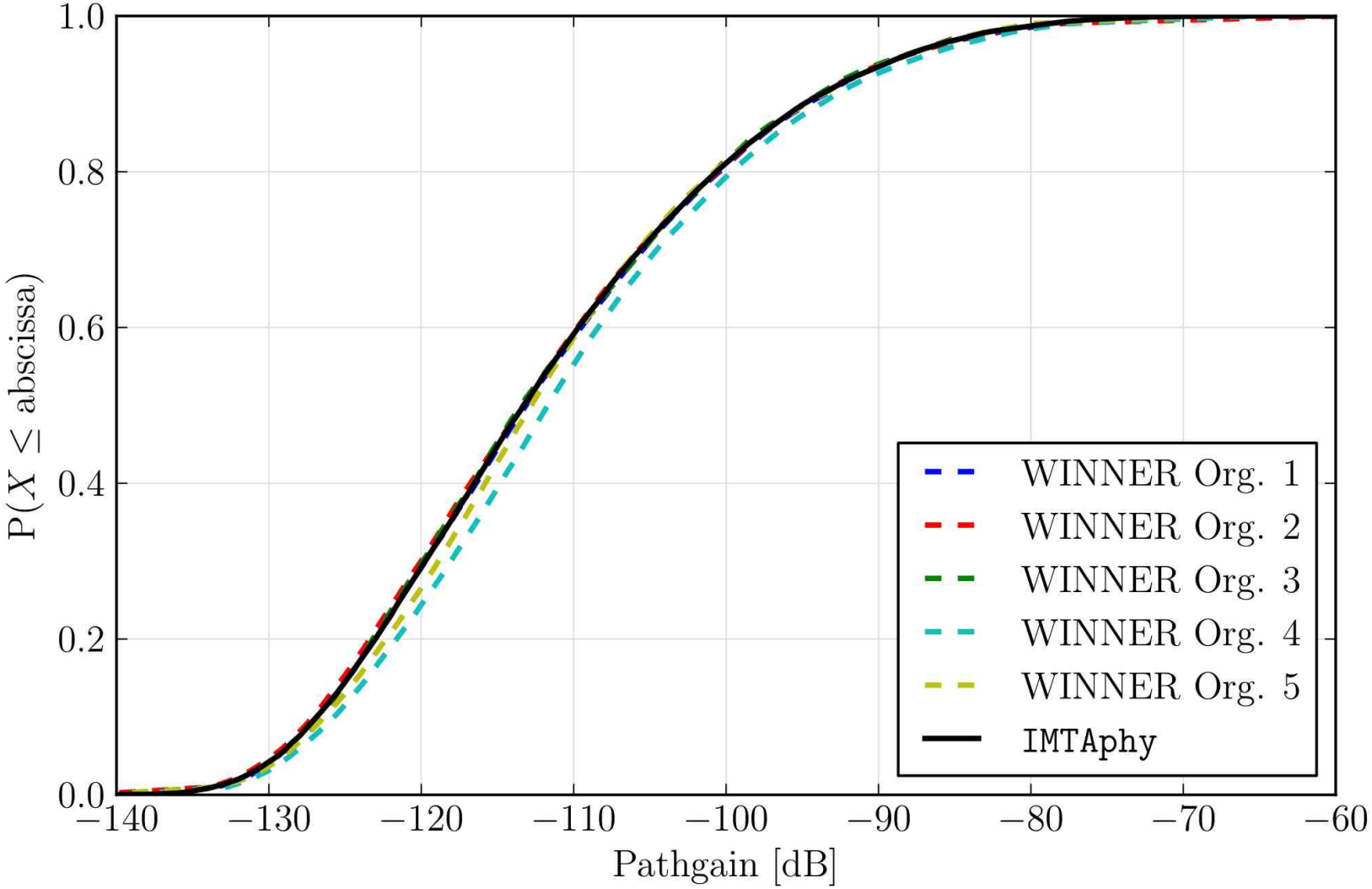
Large Scale Calibration

- Two main metrics:
  - CDF of pathgain consisting of pathloss, shadow fading, O2I or O2V shadowing (where applicable), horizontal and vertical antenna patterns; no fast fading
  - CDF of downlink reuse 1 SINR (geometry)

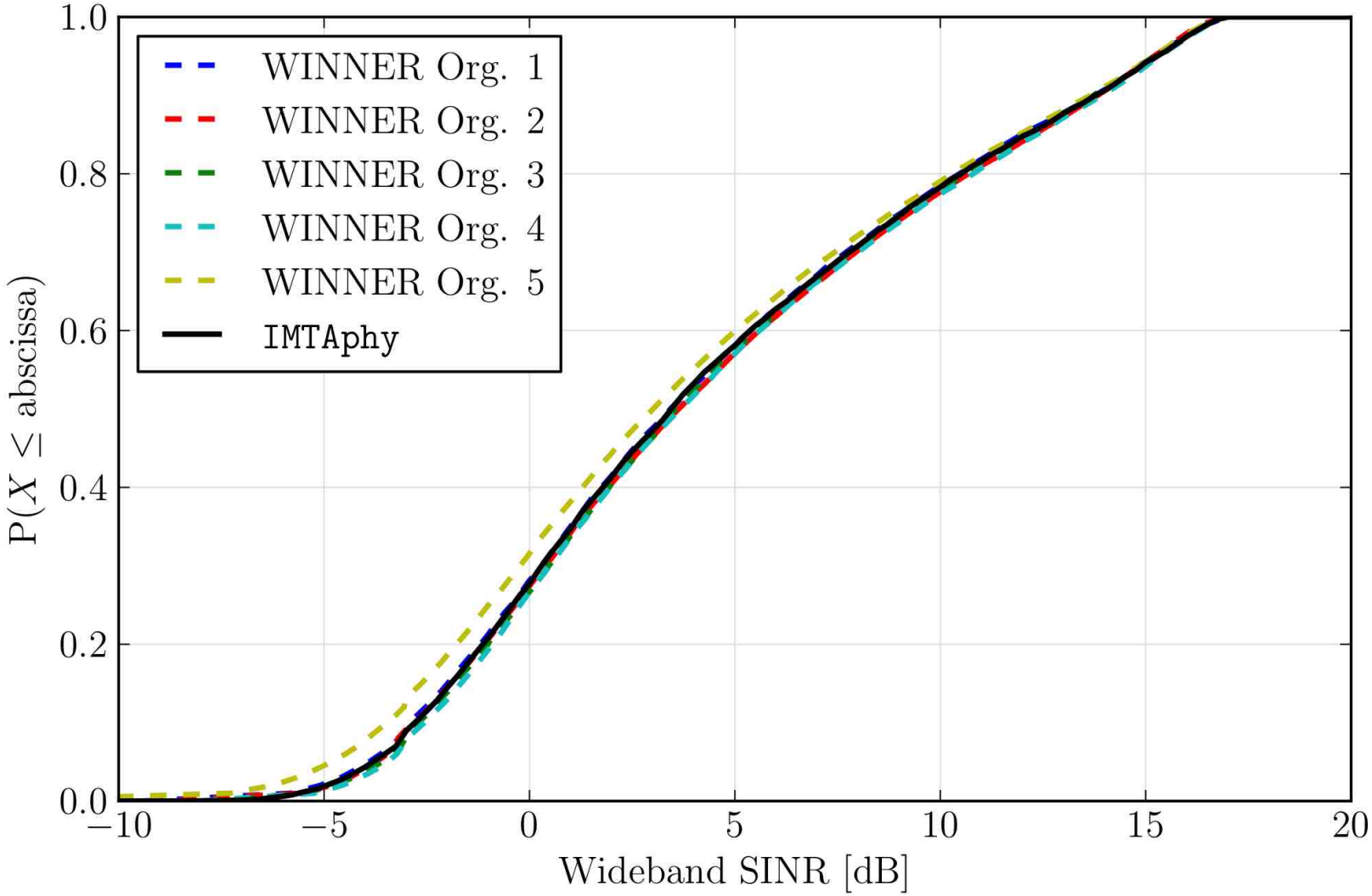
- Things to consider:
  - correct probabilistic assignment of LoS/NLoS properties on all links (fully correlated between mobile and all base stations at same site)
  - averaging over multiple scenario drops due to spatially correlated outdoor shadowing
  - consideration of log-normal distributed random O2V and O2I shadowing in some scenarios (fully correlated between mobile and multiple sites)
  - 2dB feeder loss (only implicitly stated in M2135)
  - 1dB handover margin: mobile associates randomly to one of the base stations within 1dB of strongest
  - wraparound needed if all cells are evaluated (and not only center cells)
  - minimum distances between mobile and base station

- Note: some details not yet implemented in implementations available from ITU website

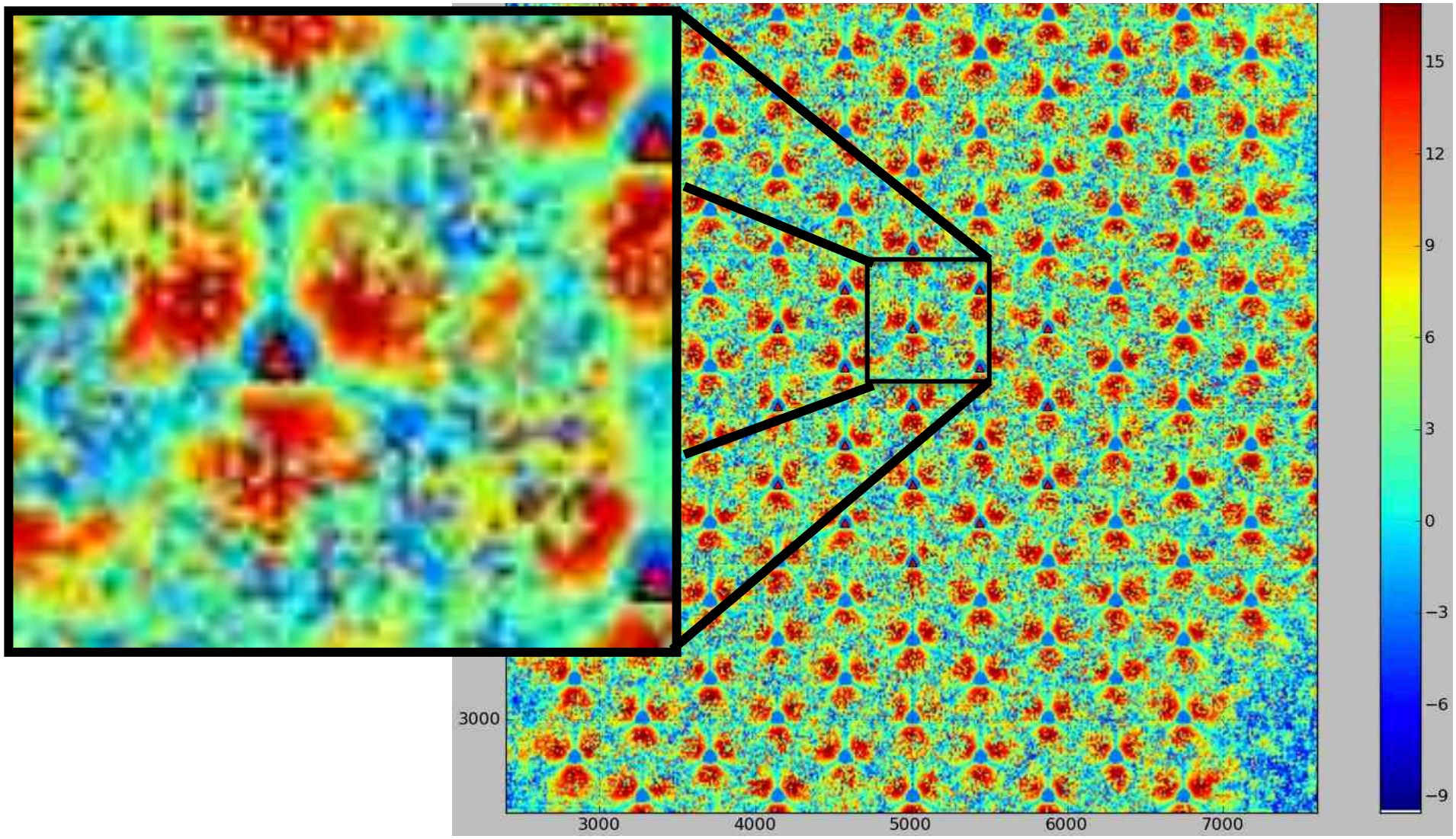
Pathgain Calibration SMa



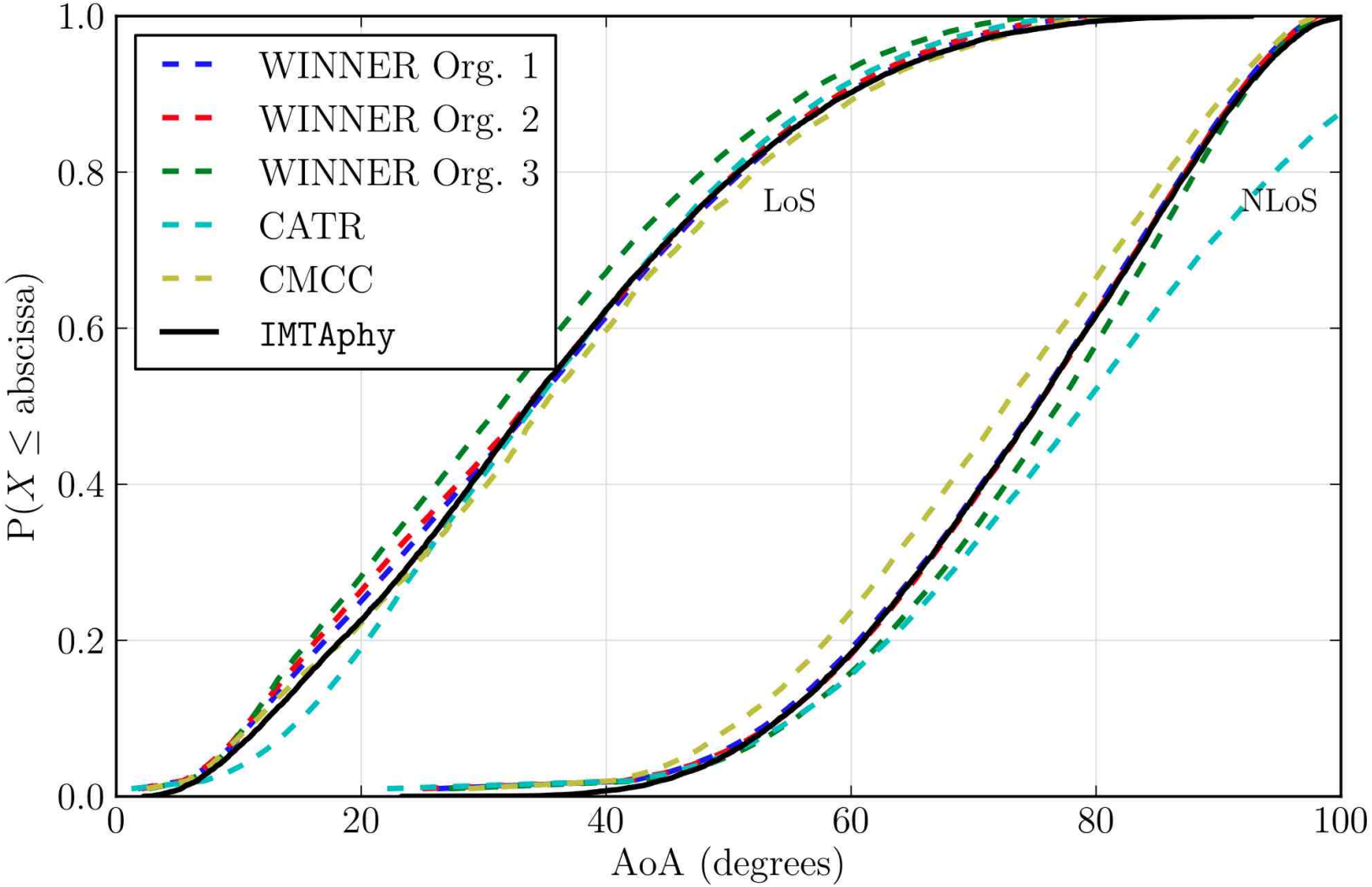
SINR Calibration SMa



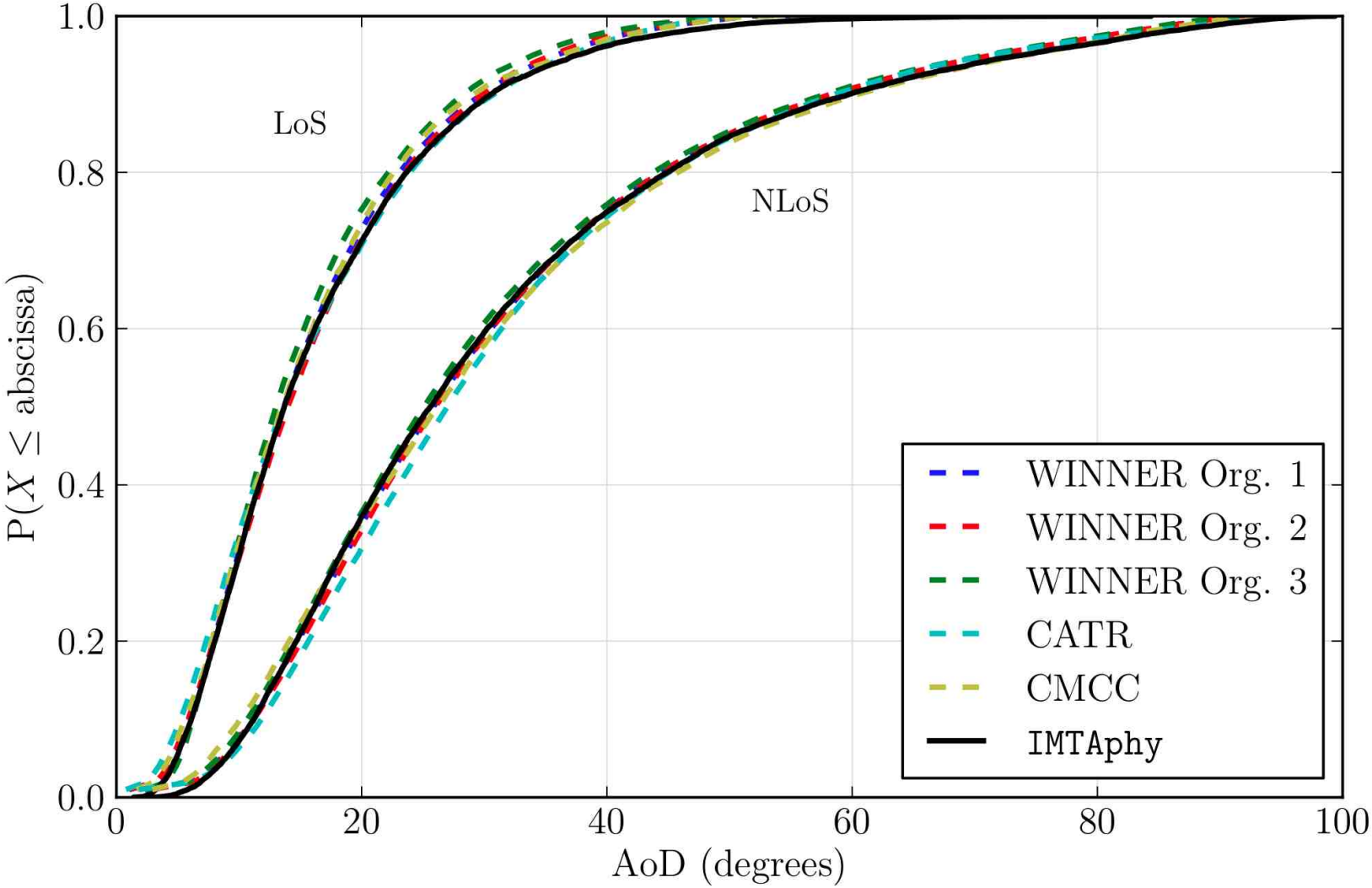
Exemplary SINR Distribution in UMa Scenario



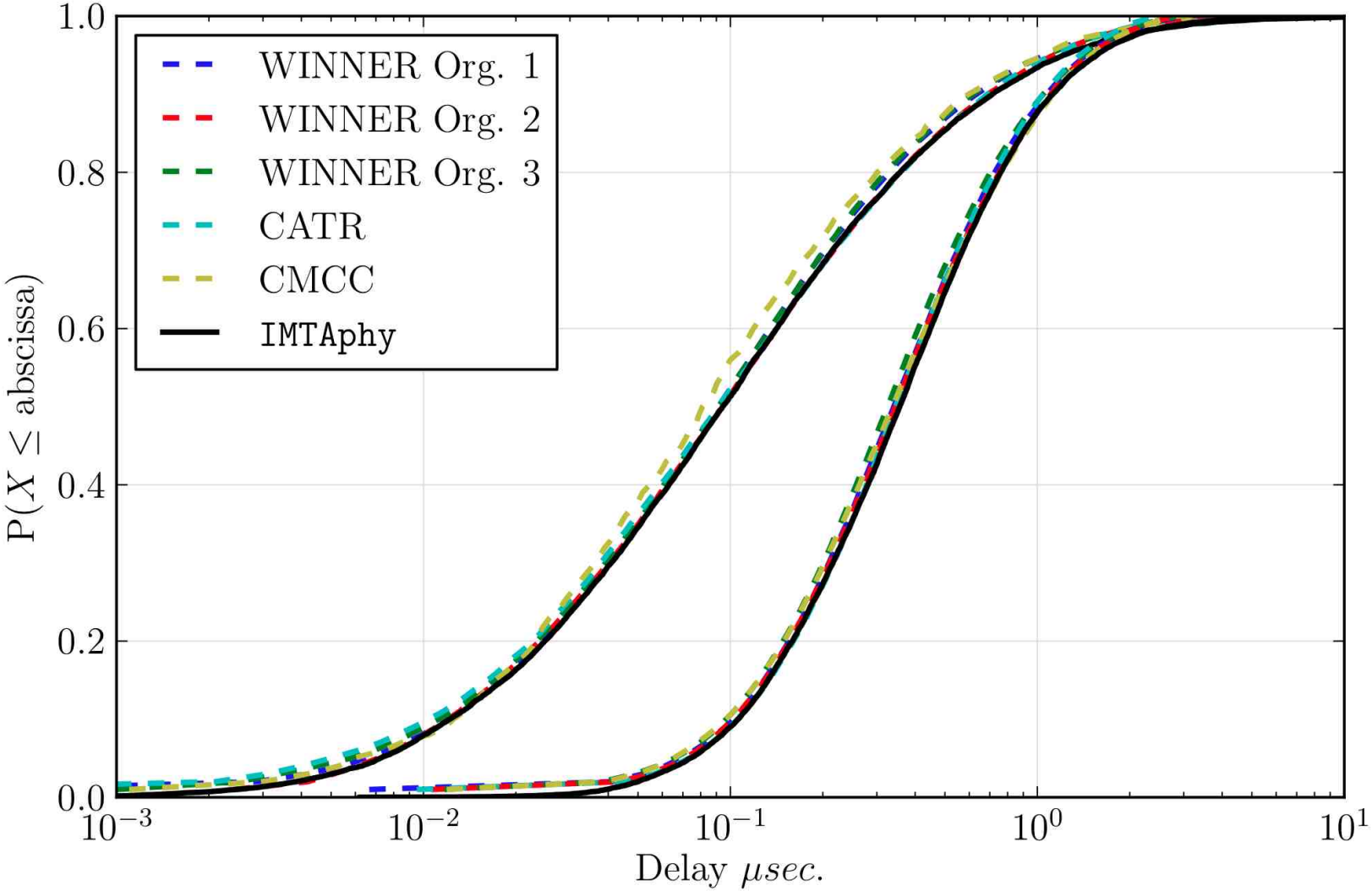
CDF of Angular Spread at Mobile (AoA, UMa)



CDF of Angular Spread at BS (AoD, UMa)



CDF of Delay Spread UMa scenario



Beyond Small Scale Calibrations

Covered by small scale calibrations:

- Distribution (RMS) of individual multi path delays
- Distribution (RMS) of arrival and departure angles
- Implicitly (serve as weights):
  - distribution of power among clusters
  - Ricean K factors for LoS links

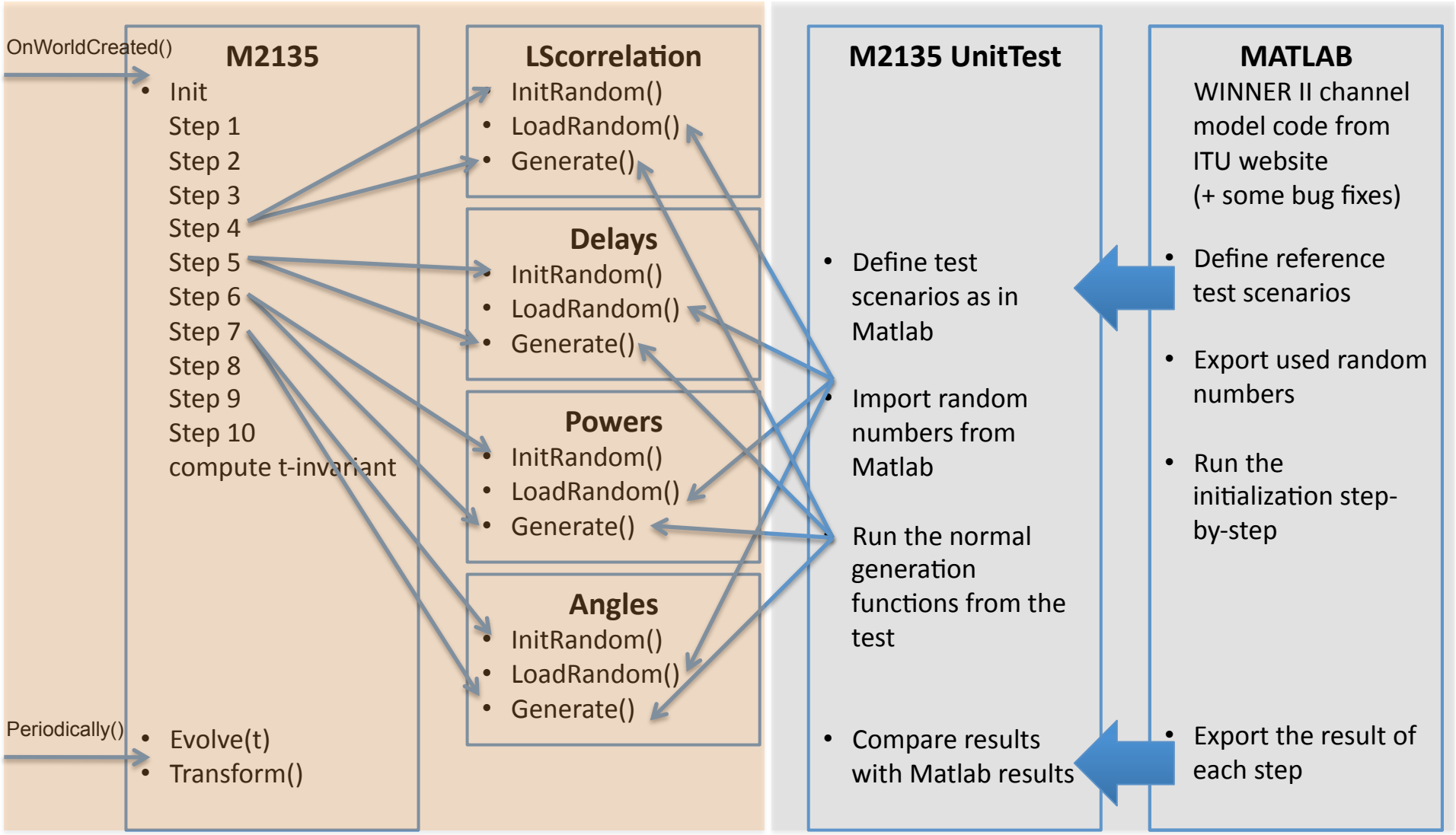
Not covered by small scale calibrations:

- Correlation properties between links or antennas
- Random coupling of rays and sub-clustering
- CIR coefficient computation (step 10) and its Fourier transform

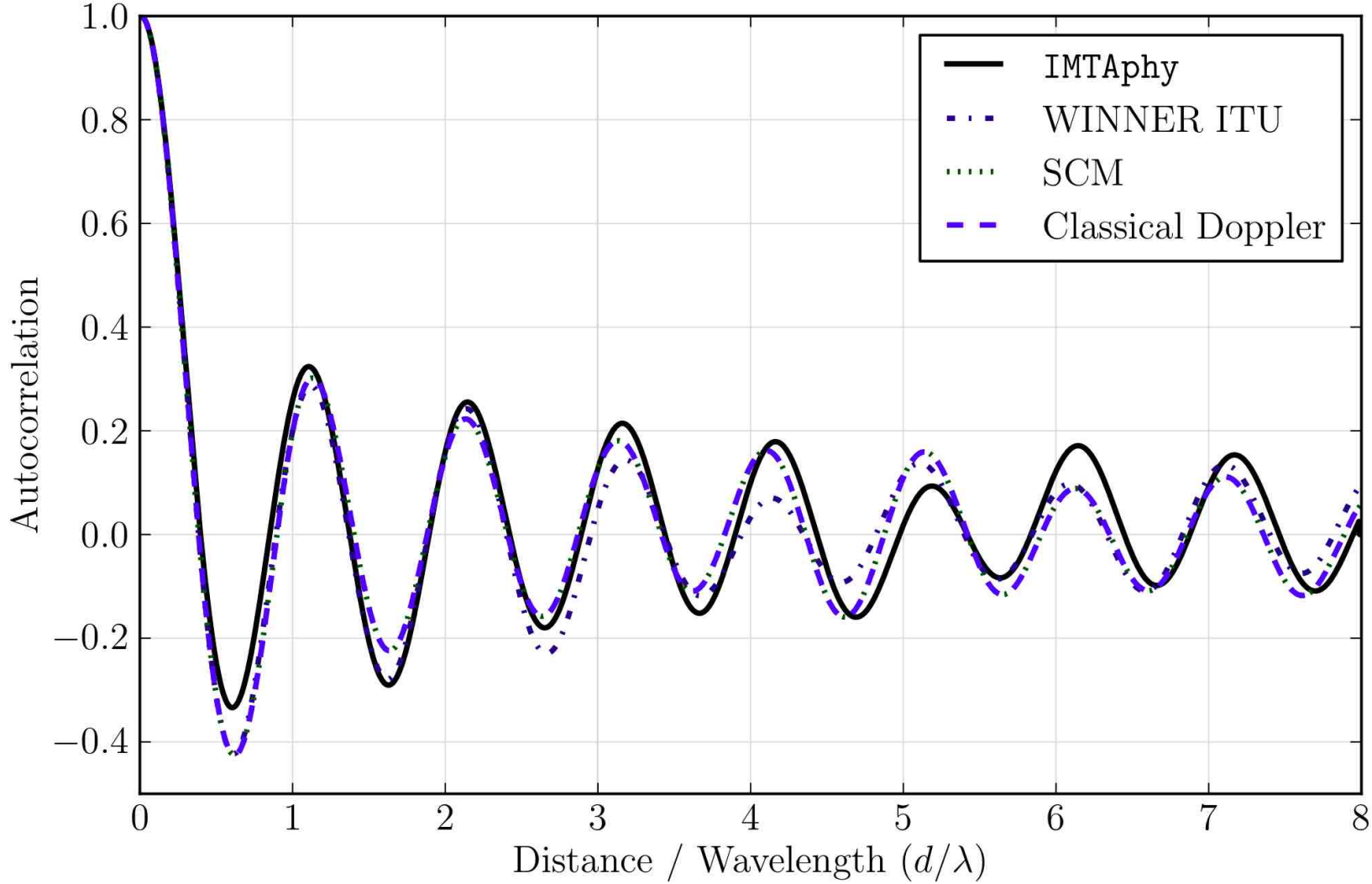
Thus, perform additional checks

- Unit tests checking against WINNER Matlab implementation
- Check Doppler influence on CIR: temporal autocorrelation
- Check properties of Fourier transform:
  - MIMO capacity CDF (checks correlations between antennas, magnitudes of coefficients)
  - Eigenvalue CDFs (same as above)

Step-wise Generation and Unit Testing

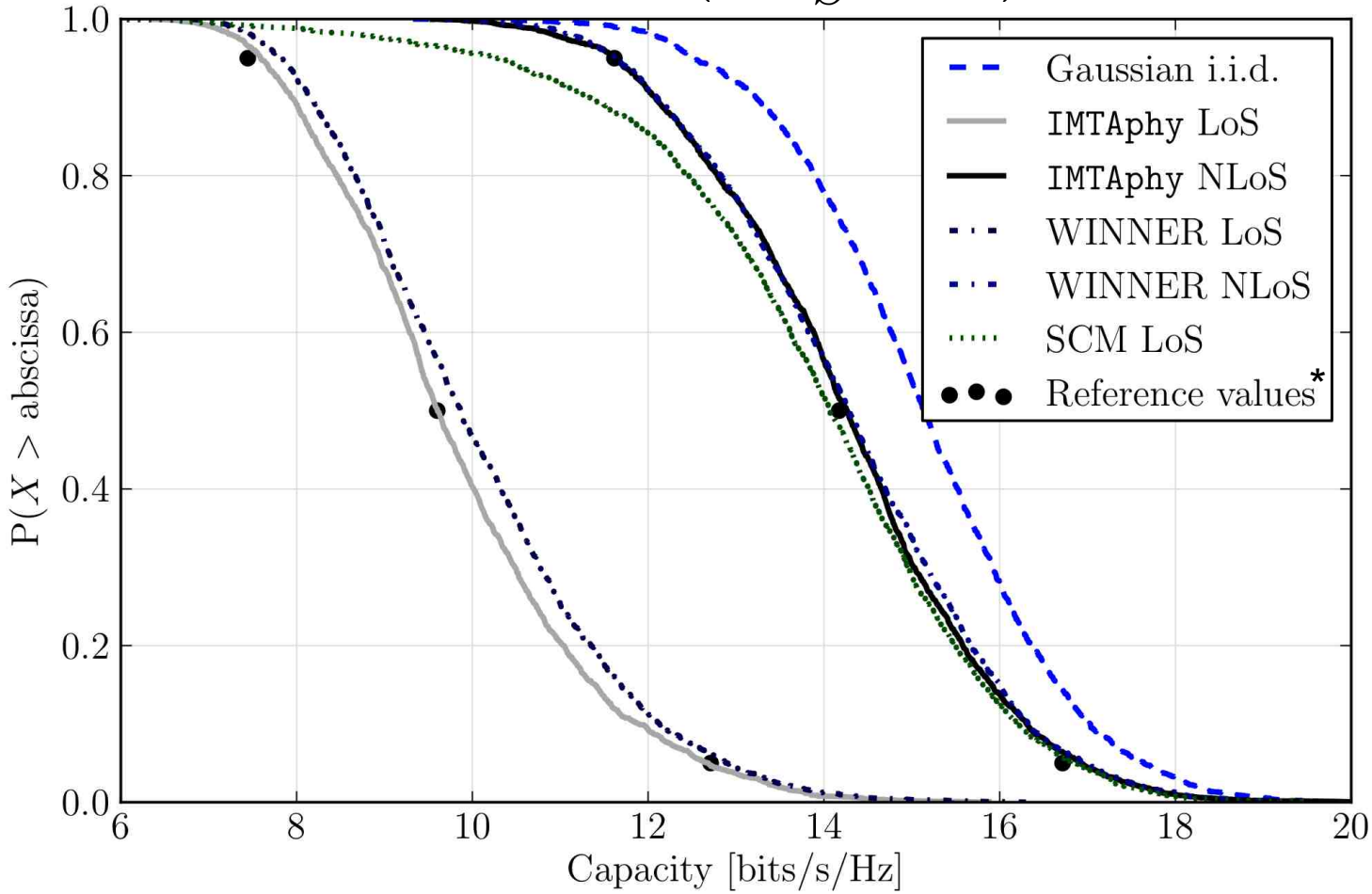


Temporal Autocorrelation (UMa scenario)



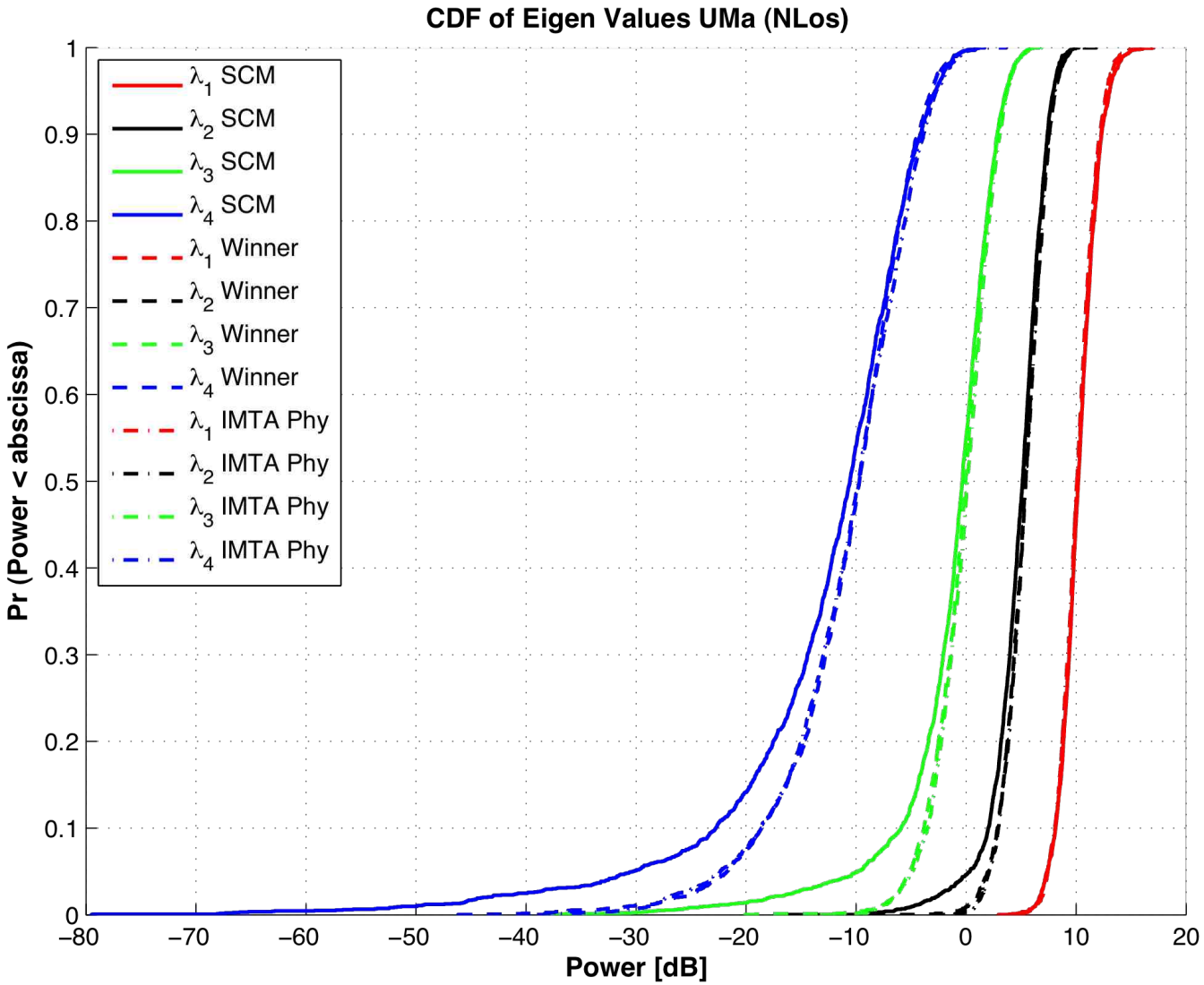
4x4 MIMO Capacity at 14 dB SINR (UMa)

$$C = \log_2 \det\left(\mathbf{I} + \frac{\rho}{S}\mathbf{H}\mathbf{H}^H\right)$$



* Chong et al. “Evolution trends of wireless MIMO channel modeling towards IMT-Advanced,” IEICE Trans. on Comm., vol. 92, no. 9, 2009.

Eigenvalue Distribution (UMa NLoS)



Conclusion

- ITU's IMT-Advanced channel model is complex to implement
- Efficient implementations needed for system-level simulation
- Simulators need to be calibrated

- Complete C++ source code together with simulation scenarios and MATLAB evaluation scripts available online under GPL license at:

https://launchpad.net/imtaphy

http://www.lkn.ei.tum.de/personen/jan/imtaphy/