

# Dominant Path Prediction Model for Indoor Scenarios

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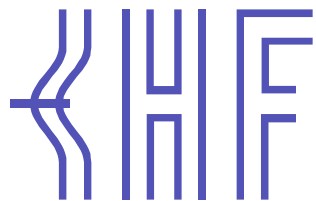
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Böblingen

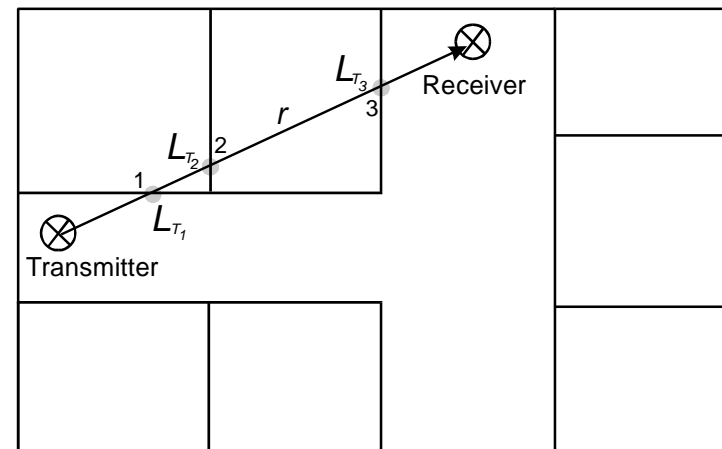


- Introduction: Wave Propagation Models for Indoor scenarios
- Indoor Dominant Path Model
- Comparison to Measurements
- Conclusions

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## Empirical Propagation Models for indoor scenarios

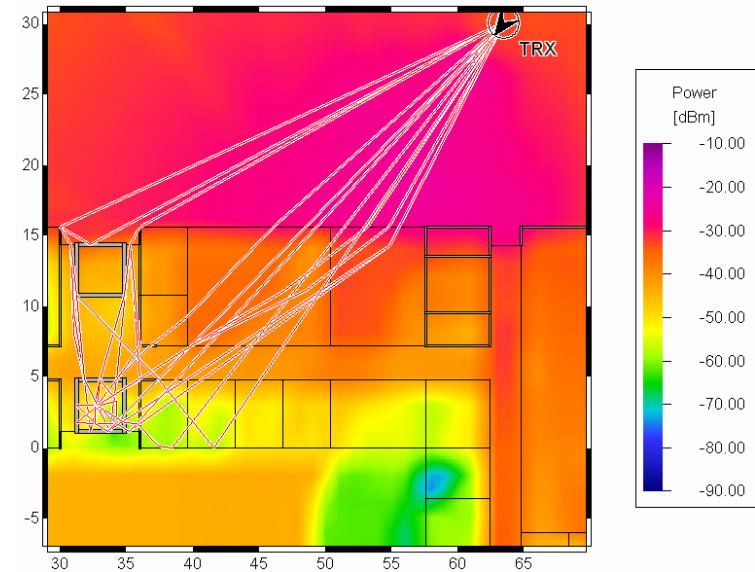
- Based on direct ray
- Consider only objects intersecting direct ray
- Simple calibration options
- Moderate dependency on accuracy of database
- Not very accurate
- Not including waveguiding effects



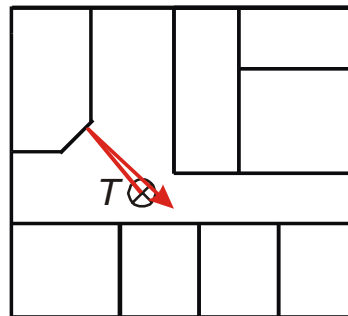
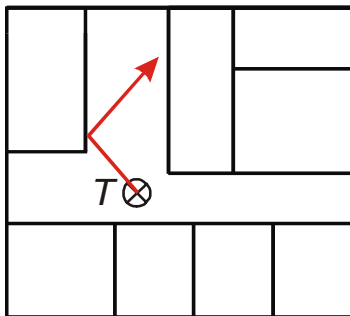
Indoor COST 231 Multi Wall Model

## Ray Optical Propagation Models for indoor scenarios

- Diffractions and reflections
- Multiple rays for each pixel
- Superposition of contributions
- Prediction of impulse response
- High accuracy, but strongly depending on accuracy of the database
- Waveguiding effects only partly considered
- Very high computational demand



Indoor Ray Tracing

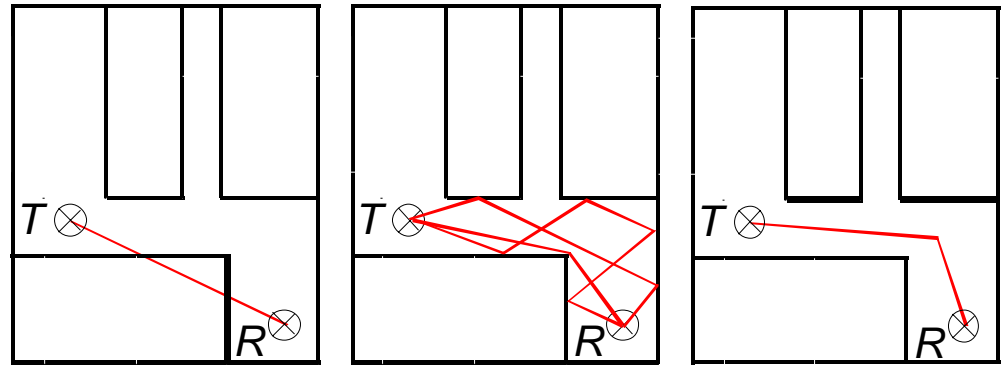


Problem of database accuracy

- Introduction: Wave Propagation Models for Indoor scenarios
- **Indoor Dominant Path Model**
- Comparison to Measurements
- Conclusions

## Principle of Dominant Path Propagation Model

- Known from Ray Tracing results:  
In most cases 95% of the energy is carried by 2 or 3 rays (from many hundred)  
→ Determination of the dominant paths for each pixel
- Diffractions, transmissions and reflections included
- Waveguiding and multiple reflections considered with waveguiding factor
- Auto calibration possible with measurements
- Moderate dependency on accuracy of database
- Very high accuracy
- Short computation times
- 3D multi floor buildings possible



Empirical model (left), Ray Tracing model (center)  
and Indoor Dominant Path Model (right)



## Path Loss Determination

The following parameters are taken into account for path loss determination:

- Path length  $d$
- Path loss exponent  $p$
- Transmission loss  $t_j$  for all  $m$  transmissions through walls
- Number  $n$  of interactions with individual angle-dependent attenuation  $f(\varphi, i)$  for each interaction  $i$
- Gain by waveguiding  $w_k$  for all considered  $c$  pixels along the current propagation path
- Directional gain of transmitter  $g_t$
- Power of transmitter  $p_t$
- Wavelength  $\lambda$

$$L = 20 \cdot \log\left(\frac{4\pi}{\lambda}\right) + 10 \cdot p \cdot \log_{10}(d) + \sum_{i=0}^n f(\varphi, i) + \sum_{j=0}^m t_j - \frac{1}{c} \sum_{k=0}^c w_k - g_t - p_t$$

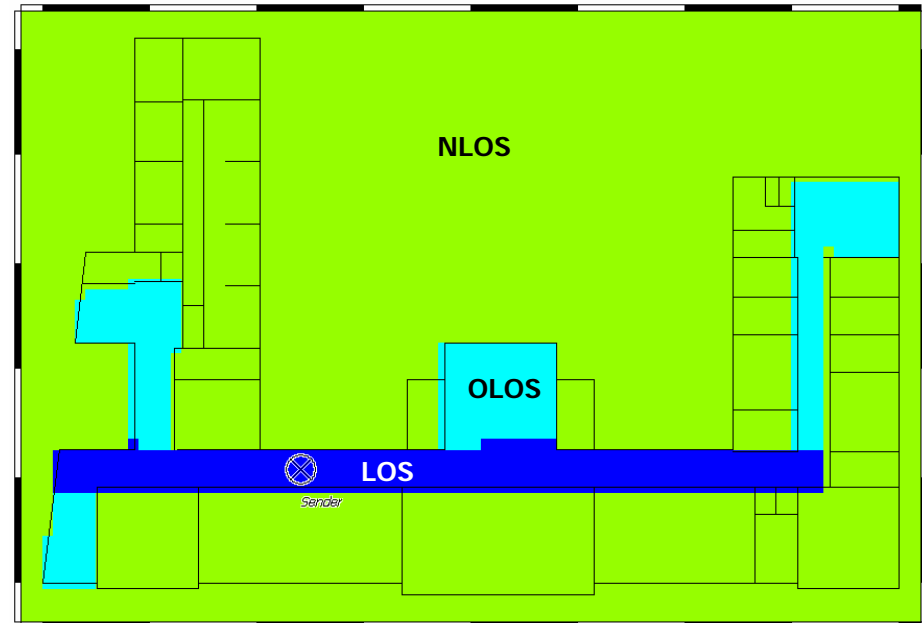


## Special Features for Indoor Needs (1/3)

Special needs in indoor scenarios lead to new features

- The path loss exponent is automatically adapted depending on the current situation  
→ LoS, OLoS and NLoS areas possible

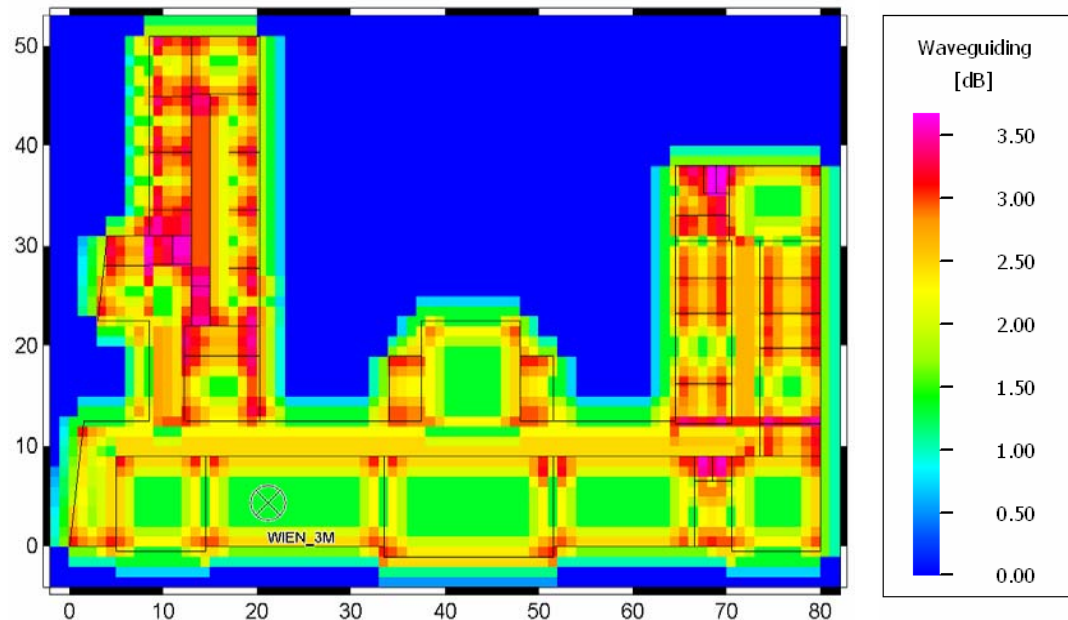
Typical Path Loss exponents					
LoS		OLoS		NLoS	
<i>min.</i>	<i>max.</i>	<i>min.</i>	<i>max.</i>	<i>min.</i>	<i>max.</i>
2.0	2.2	2.1	2.3	2.2	2.5



## Special Features for Indoor Needs (2/3)

Waveguiding factor is introduced to improve the accuracy in long corridors

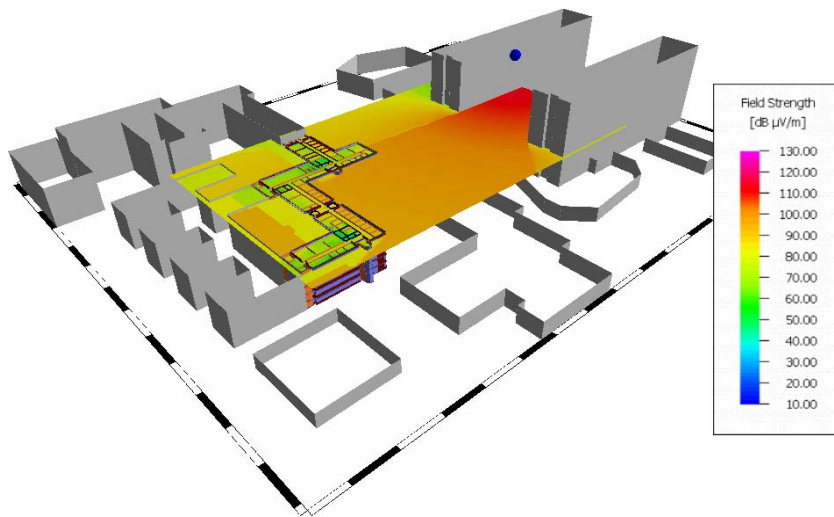
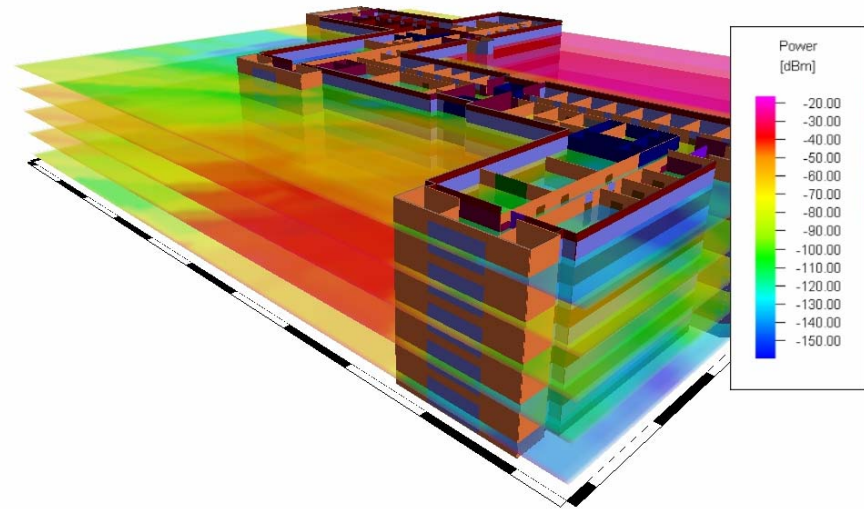
- The waveguiding factor is determined under consideration of the following parameters:
  - Material properties of walls
  - Distance to reflecting walls
  - Orientation of walls



## Special Features for Indoor Needs (3/3)

- **3D Mode**

- Only needed if horizontal objects are located between prediction plane and transmitter plane
- Multiple prediction layers analyzed
- Path finding over multiple floors
- Highly accurate



- **Combined Network Planning (CNP) Mode**

- Combination of urban and indoor prediction
- Different set of parameters for indoor and urban case
- Adaptive resolution between indoor and urban areas

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## Measurement Campaigns

Measurement campaigns were used for three different scenarios:

1. Modern office building:
  - One floor of an office building at the University of Stuttgart
2. Old office building:
  - One floor of an office building at the University of Vienna
3. Modern office building with multiple floors:
  - A scenario with two adjacent buildings at the University of Lisbon

The measurements were compared to the results of the following prediction models:

- COST 231 Multi-Wall (MW)
- 3D Ray Tracing (IRT; transmissions: 7, reflections: 4, diffractions: 5, total: 7)
- Indoor Dominant Path (IDP)

**Differences to results in paper due to more accurate definition of the material properties (1<sup>st</sup> and 2<sup>nd</sup> scenario) and choice of a different measurement route (3<sup>rd</sup> scenario).**

## Preprocessing of databases

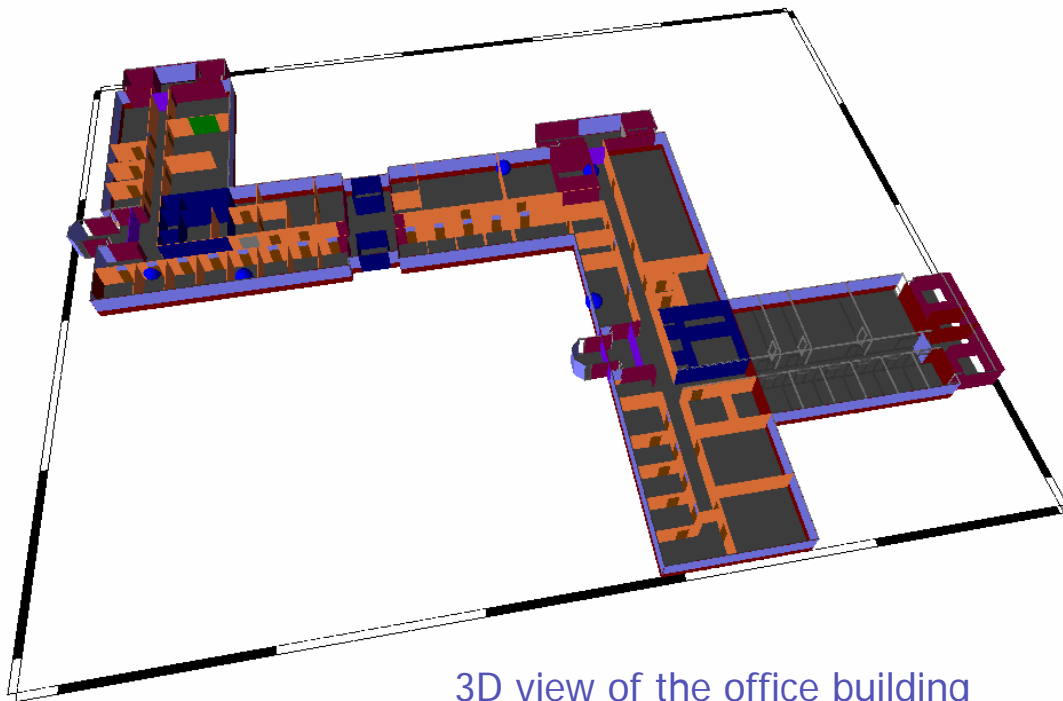
A single time preprocessing is needed before starting a computation of a prediction

Scenario	Preprocessing times		
	COST 231 Multi Wall	3D Ray Tracing	Indoor Dominant Path
Stuttgart	< 1 s	11 min 51 s	< 1 s
Vienna	< 1 s	1 min 50 s	< 1 s
Lisbon	< 1 s	30 min 54 s	< 1 s

A standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM was used to determine the preprocessing times

## Modern Office Building (1/5)

'Institute for Radio Frequency Technology' at the University of Stuttgart



Scenario Information	
Material	concrete and glass
Total number of objects	242
Number of walls	108
Resolution	0.50 m
Transmitter height	0.90 m
Prediction height	0.90 m

Challenge for computation:

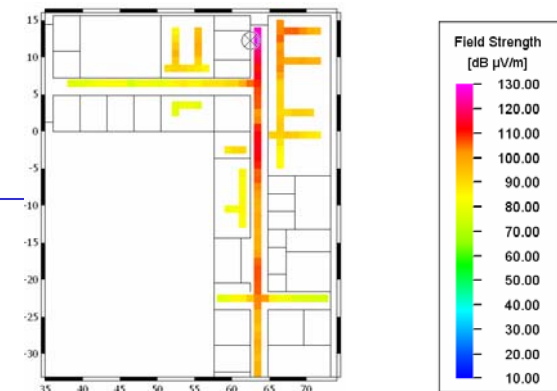
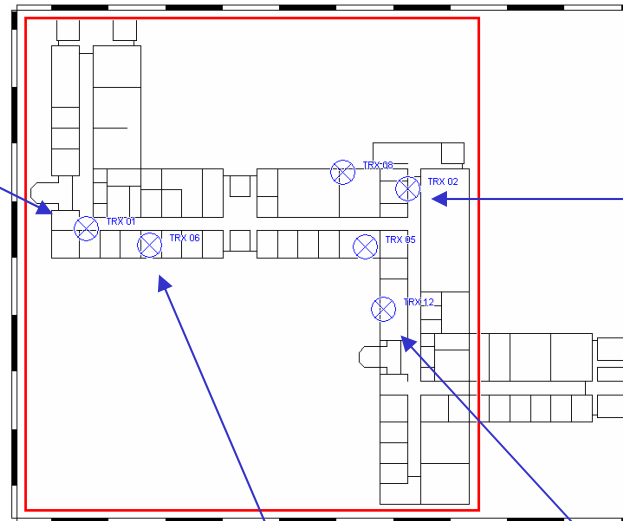
Many small rooms with numerous walls cause many diffractions and penetrations

## Modern Office Building (2/5)

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Transmitter location 1



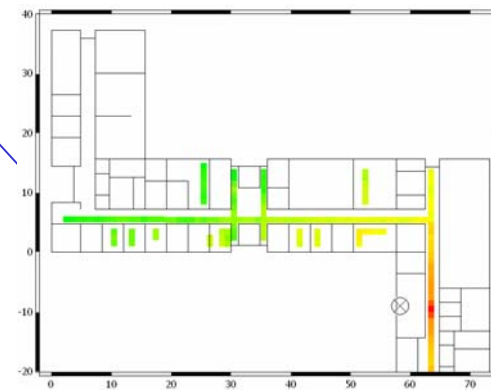
Transmitter location 2



Peissler's wheel



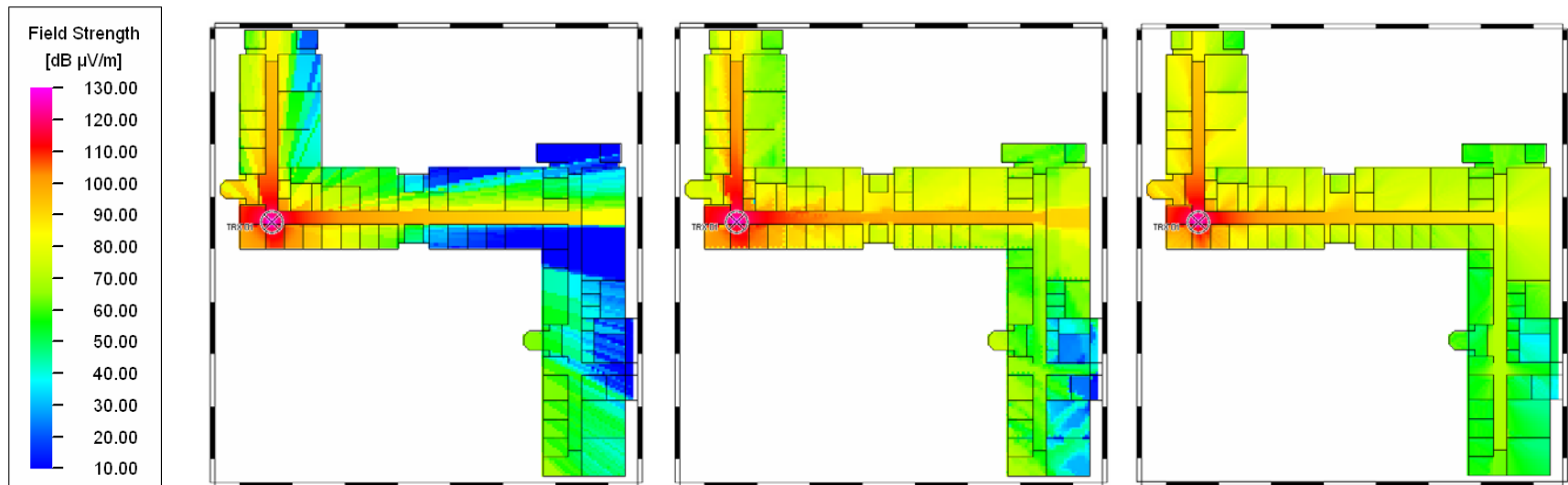
Transmitter location 6



Transmitter location 12

## Modern Office Building (3/5)

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Prediction with Multi-Wall Model for transmitter 1

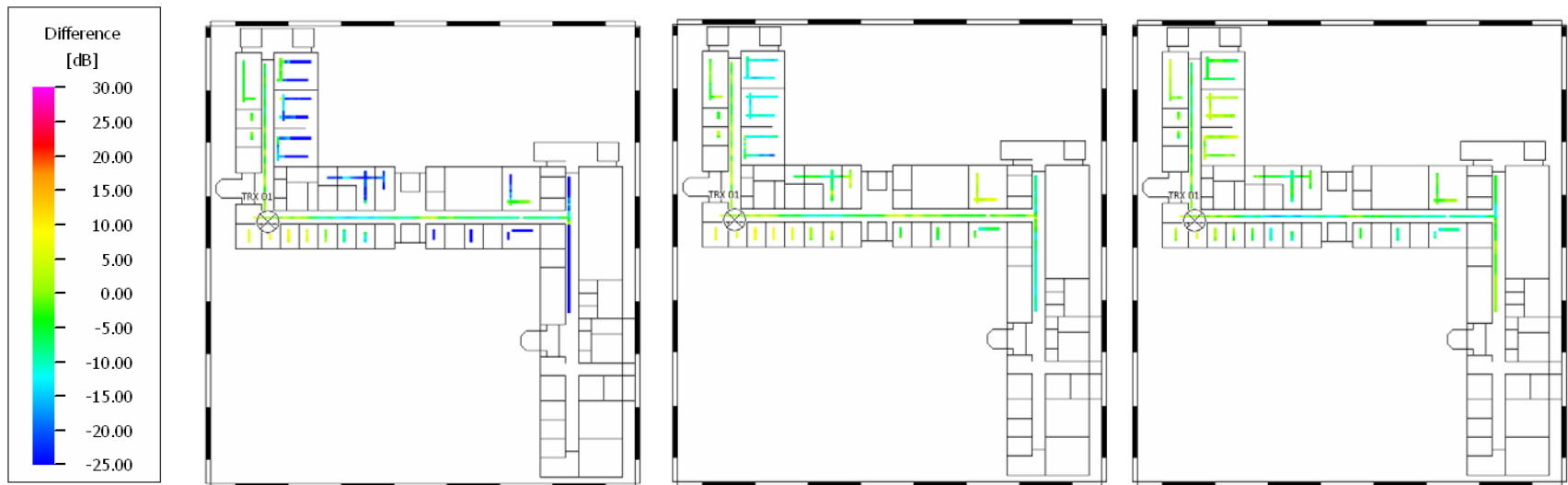
Prediction with 3D Ray Tracing Model for transmitter 1

Prediction with Indoor Dominant Path Model for transmitter 1

Result: Limited accuracy of Ray Tracing model due to the number of considered interactions

## Modern Office Building (4/5)

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Difference of prediction for Multi-Wall Model and measurement for transmitter 1

Difference of prediction with 3D Ray Tracing and measurement for transmitter 1

Difference of prediction with Indoor Dominant and measurement Path for transmitter 1

Result: Multi-Wall Model is far too pessimistic if numerous diffractions occur (see left image). Ray Tracing performs similarly to Dominant Path model.

## Modern Office Building (5/5)

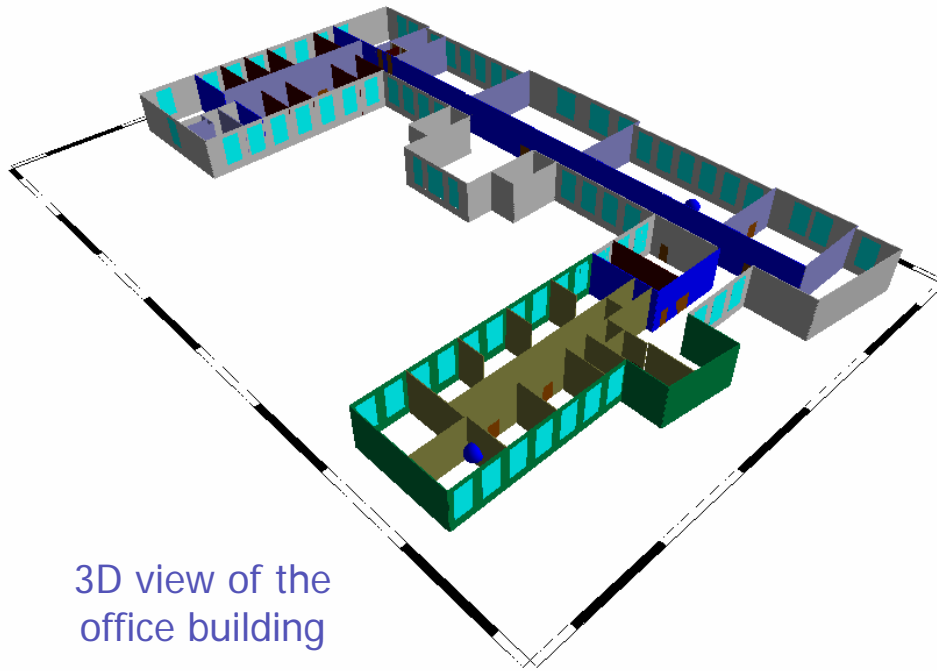
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Site	Statistical Results								
	COST 231 Multi Wall			3D Ray Tracing			Indoor Dominant Path		
	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>
1	-17.08	20.42	< 1	-4.05	6.26	388	-3.88	4.86	8
2	-4.59	13.28	< 1	1.75	5.54	132	-2.67	5.24	7
5	2.54	4.22	< 1	3.78	4.66	10	-0.50	3.95	6
6	-12.84	16.44	< 1	-1.64	10.13	6	-0.61	5.04	9
8	-2.56	18.03	< 1	5.48	5.83	16	1.56	5.49	8
12	-2.61	9.27	< 1	3.27	4.64	13	-2.36	3.59	9
<b>Average</b>	<b>-6.19</b>	<b>13.61</b>	<b>&lt; 1</b>	<b>1.43</b>	<b>6.18</b>	<b>94</b>	<b>-1.41</b>	<b>4.70</b>	<b>7.8</b>

A standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM was used to determine the computation times

## Old Office Building (1/4)

'Institute for Radio Frequency Technology' at the University of Vienna



3D view of the office building

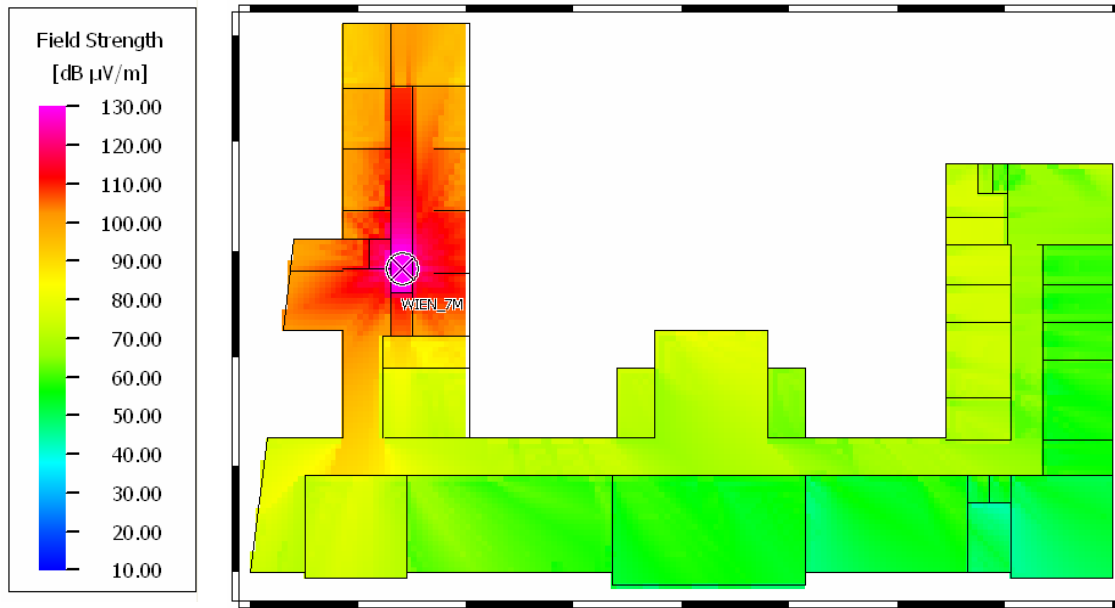
Scenario Information	
Material	brick and wood
Total number of objects	209
Number of walls	107
Resolution	0.50 m
Transmitter height	1.60 m
Prediction height	1.30 m

Challenge for computation: Many different materials and numerous walls

## Old Office Building (2/4)

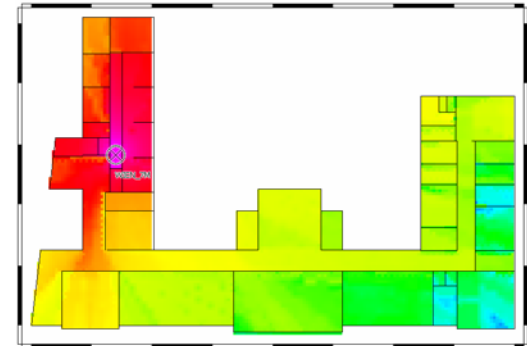
'Institute for Radio Frequency Technology' at the University of Vienna

Transmitter location 7 displayed

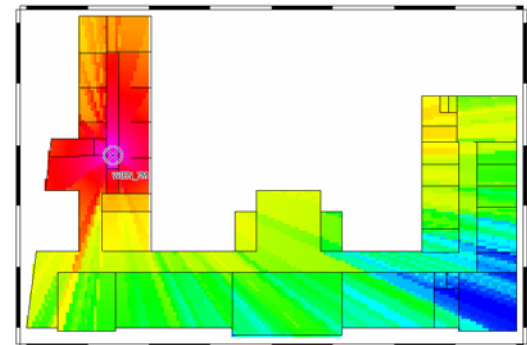


Prediction with Indoor Dominant Path Model

Prediction with 3D Ray Tracing Model

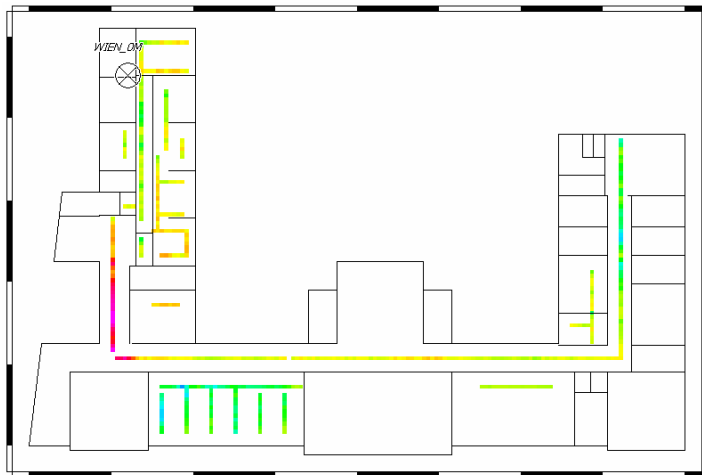


Prediction with COST 231 Multi-Wall Model

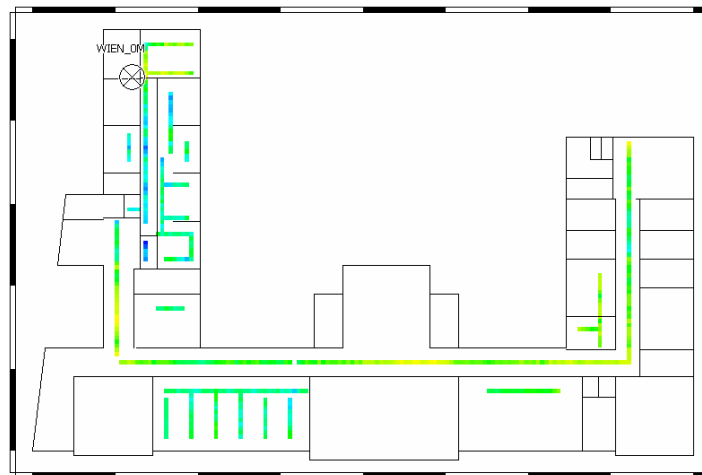


## Old Office Building (3/4)

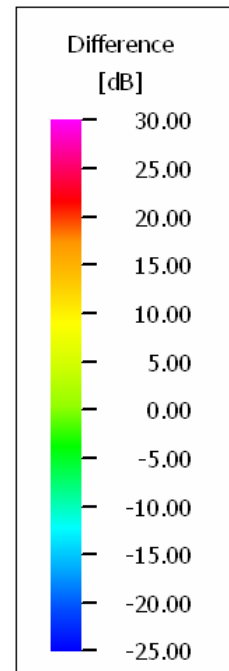
'Institute for Radio Frequency Technology' at the University of Vienna



Difference of prediction with 3D Ray Tracing and measurement for transmitter 0



Difference of prediction with Indoor Dominant Path Model and measurement for transmitter 0



## Old Office Building (4/4)

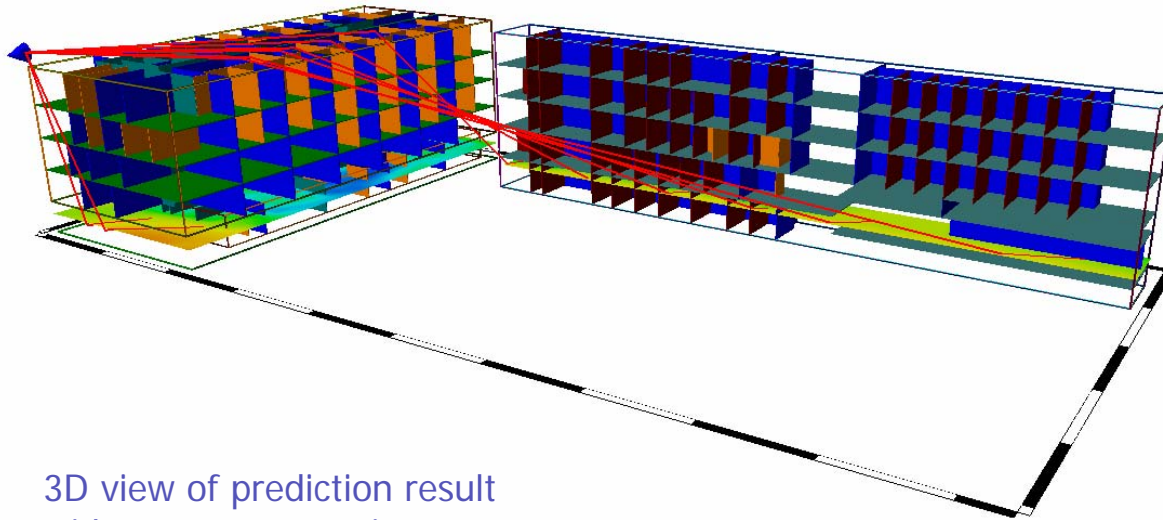
'Institute for Radio Frequency Technology' at the University of Vienna

Site	Statistical Results								
	COST 231 Multi Wall			3D Ray Tracing			Indoor Dominant Path		
	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>	<i>Mean Value [dB]</i>	<i>Std. Dev. [dB]</i>	<i>Comp. Time [s]</i>
0	-2.54	11.74	< 1	4.23	8.44	4	-4.74	5.76	1
3	-4.62	10.76	< 1	2.73	6.84	105	-0.59	6.43	2
7	0.16	5.74	< 1	3.02	6.31	49	-3.34	5.54	2
<b>Average</b>	<b>-2.33</b>	<b>9.41</b>	<b>&lt; 1</b>	<b>3.33</b>	<b>7.20</b>	<b>53</b>	<b>-2.89</b>	<b>5.91</b>	<b>2</b>

An AMD Athlon64 2800+ with 1024 MB was used to determine the computation times

## Modern Multi-Floor Building (1/3)

'Instituto de Telecomunicacoes' near Lisbon



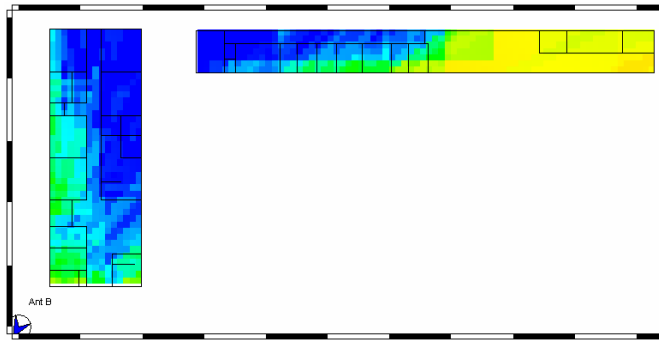
3D view of prediction result with some propagation paths

Scenario Information	
Material	concrete and glass
Total number of objects	356
Resolution	1.00 m
Transmitter height	19.50 m
Prediction height	2.10 m

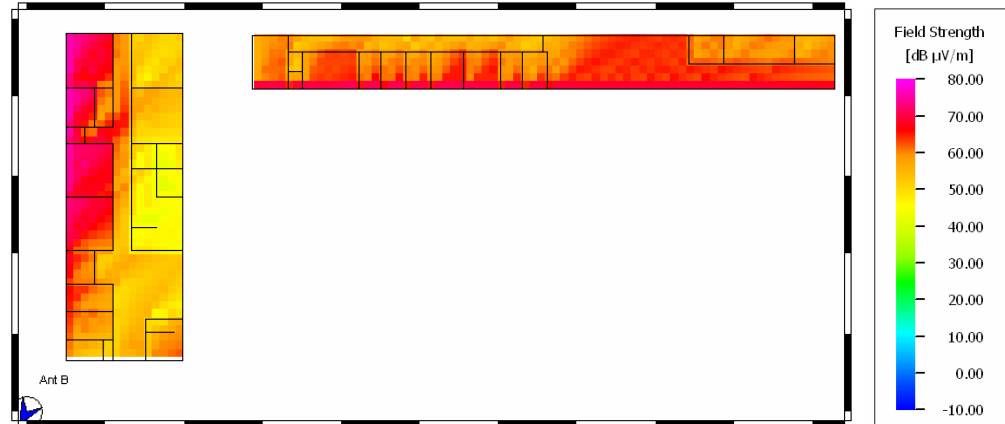
Challenge for computation: Transmitter and receiver are located in different buildings on different heights. Because of this, the 3D mode of the Indoor Dominant Path Model is used for computation.

## Modern Multi-Floor Building (2/3)

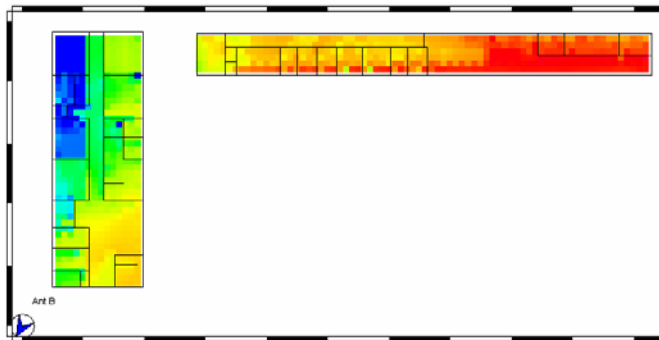
'Instituto de Telecomunicacoes' near Lisbon



Prediction with Multi-Wall Model  
for transmitter A



Prediction with Indoor Dominant Path Model for  
transmitter A



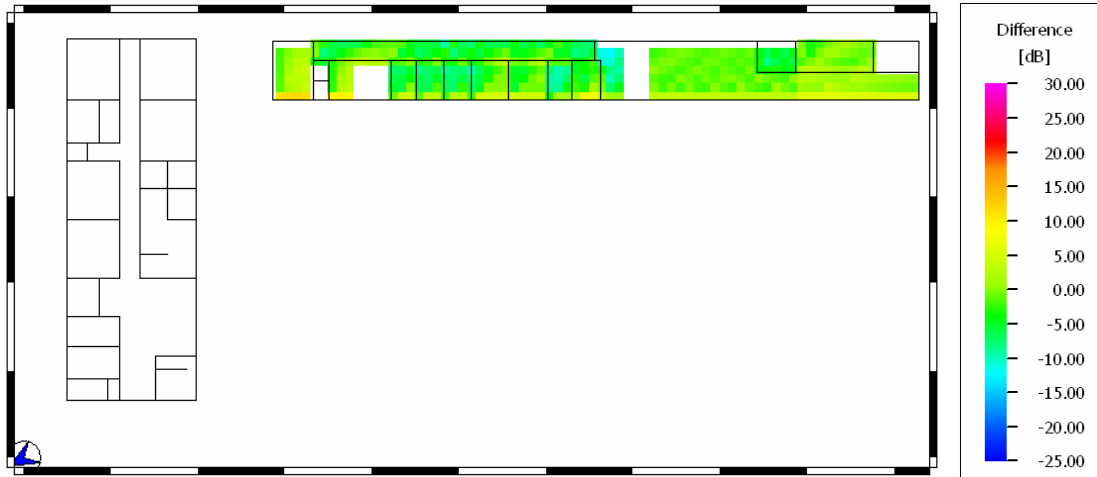
Prediction with 3D Ray Tracing  
for transmitter A

The transmitter is located on the rooftop (19.5 m) and the prediction is on the ground floor (2.1 m)

→ Worst case scenario

## Modern Multi-Floor Building (3/3)

'Instituto de Telecomunicacoes' near Lisbon



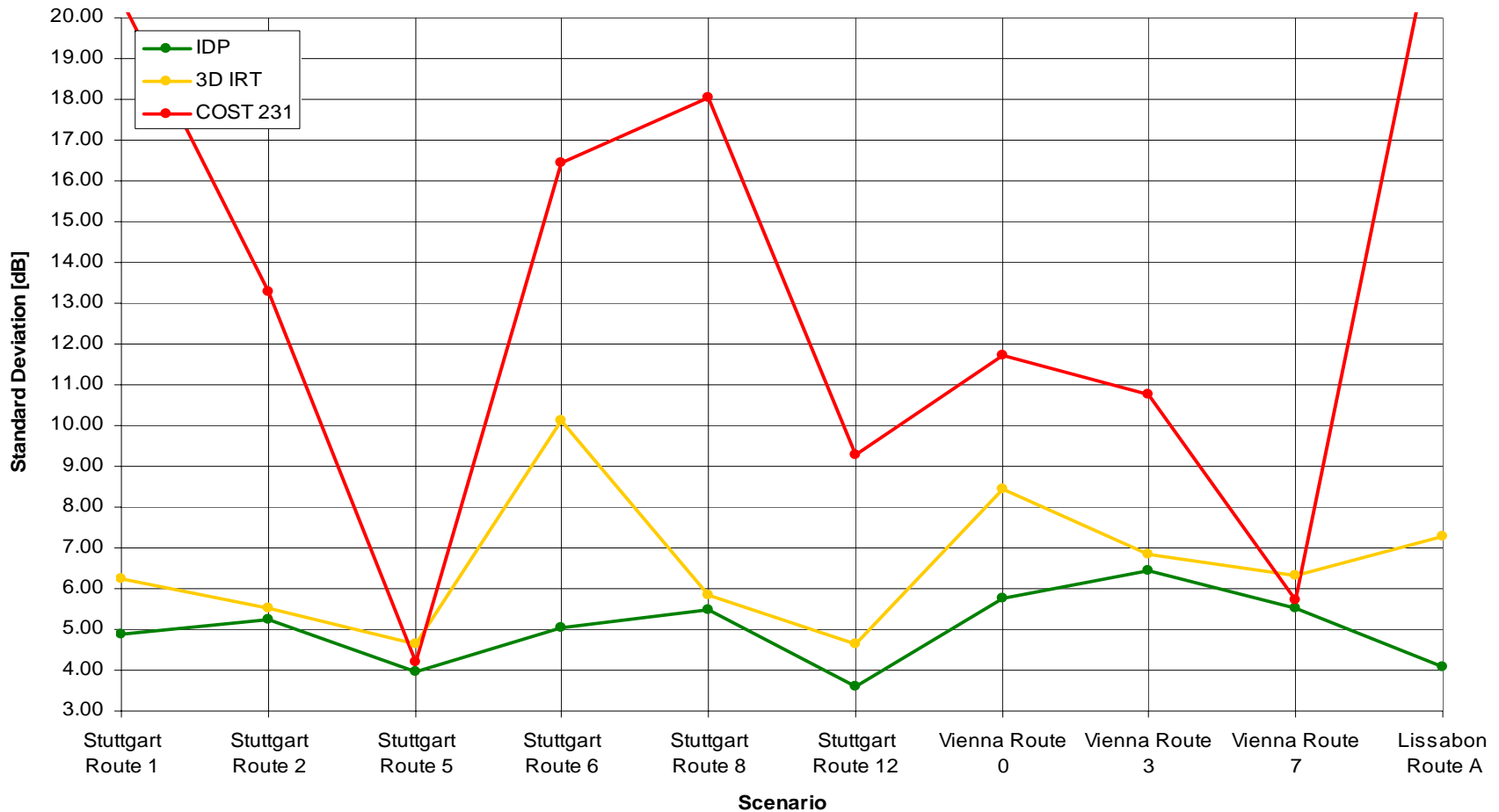
Difference of prediction with Indoor Dominant Path Model and measurement for transmitter A

Site	Statistical Results								
	COST 231 Multi Wall			3D Ray Tracing			Indoor Dominant Path		
	Mean Value [dB]	Std. Dev. [dB]	Comp. Time [s]	Mean Value [dB]	Std. Dev. [dB]	Comp. Time [s]	Mean Value [dB]	Std. Dev. [dB]	Comp. Time [s]
A	-43.98	23.34	1	-5.78	7.28	7	-1.36	4.10	28

An AMD Athlon64 2800+ with 1024 MB was used to determine the computation times

## Comparison of the results

Comparison of the Std. Dev. for all investigated scenarios and measurement routes



- Introduction: Wave Propagation Models for Indoor scenarios
- Indoor Dominant Path Model
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- Determination of dominant ray paths leads to short computation time and less sensitivity to database errors
- Accuracy of Dominant Path Model exceeds the accuracy of ray tracing models
- No preprocessing necessary
- Wideband properties can also be determined