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  Pixel or vector databases

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  - Diffraction
  - Scattering
  - Antenna pattern

• **Propagation Modeling**
  Propagation models and prediction of path loss (ProMan)

• **Network Planning**
  Planning of indoor wireless networks (ProMan)

• **Comparison to Measurements**
  Comparison to measurements in different types of buildings
Building Databases

Databases: Pixel or Vector?

Pixel Databases

• Formats: jpg, bmp, gif, tiff,…
• 2D approach (propagation in horizontal plane only)
• Colors represent materials
• Multiple floors (bitmaps) possible

3D Vector Databases

• Formats: dxf, dwg, stl, nas,…
• Rigorous 3D approach
• Single or multiple floors
• Different materials
• Subdivisions (doors, windows)

⇒ Powerful graphical editor for building databases: WallMan
Building Databases

Databases: 3D Vector Building Databases

- 3D vector oriented database
- Walls as planar objects with polygonal shape
- Arbitrary location and orientation in space
- Individual material properties
- Subdivisions with different material properties to model doors and windows
Special features

- Subdivisions with different material properties to model doors (e.g. Wood) and windows (e.g. Glass).
- Subdivision defined as Hole to model openings in walls
- Arbitrary number of subdivisions per wall
- Subdivisions cannot intersect each other
Databases: Material Properties

Global material catalogue for different frequency bands

(In WallMan via menu Edit → Materials used in Database → Import)

⇒ User can select and add materials
Databases: Material Properties

Local material database (in building database)

- only relevant for objects in this database
- independent of global material catalogue
  (modification of global catalogue does not affect material properties of objects in database)
- can be updated with materials from global material catalogue

Settings of local material database

- individual material properties for different frequency bands
  (always the properties of the frequency band closest to TX frequency is used)
- Material (incl. all properties) is assigned to objects (walls/buildings)
- Always all material properties must be defined even if they are not required for the selected propagation model
- Individual colors can be assigned to the materials for better visualization
Databases: Material Properties

Properties of a material for individual frequency bands

- Properties affecting **all propagation models** (except One Slope and Motley)
  - Transmission Loss (in dB)

- Properties affecting **Dominant Path Model**
  - Reflection Loss (in dB)

- Properties affecting **Ray Tracing**
  - GTD/UTD related properties
    - Relative Dielectricity
    - Relative Permeability
    - Conductance (in S/m)
  - Empirical reflection/diffraction model
    - Reflection Loss (in dB)
    - Diffraction Loss Incident Min (in dB)
    - Diffraction Loss Incident Max (in dB)
    - Diffraction Loss Diffracted (in dB)
Databases: Non-deterministic Objects/ Furniture

- Possibility to define areas with non-deterministic objects (polygonal cylinders)
- Propagation paths inside these areas get higher attenuation depending on the length of the path inside the object
- Mobile stations located inside these objects will also get a higher path loss assigned
Definition of (multiple) Floors in WallMan

- Definition of floors in WallMan by user (heights of each floor and ceiling)
- For each floor different bitmap (i.e. floor layout) can be used
- Fast access to floors by mouse
- Drawing of (vertical) objects can be optionally restricted to floor height
Selection of Floor in ProMan

- Floors read from database (as defined in WallMan)
- Fast access to floors by selection from drop-down list
- Predictions either on all floors or on selected floor only (prediction height is defined relative to floor/s)
- Antennas can be hidden on display if not mounted on the selected floor

Display of prediction results either in 2D or 3D
Concept of RF Components

- Definition of several properties per component. Currently supported:
  - Signal Transmitter/Receiver/Transceiver
  - Antenna
  - Radiating Cable
  - Cable
  - Amplifier/Attenuator
  - Splitter/Combiner

- Collection of all components in a global catalogue

- Easy-to-use editor for global catalogue (CompoMan)

- Global catalogue available for all network planning projects

- Changes in global catalogue are always directly considered during the network planning
CompoMan: Editor for RF Components - Overview

- Powerful and easy-to-use editor for the management of RF components
- Components can be added, edited and removed
- Combination of two component databases possible
- Individual component properties depending on type
- Currently supported components:
  - Transmitter/Receiver/Transceiver
  - Antenna
  - Radiating Cable
  - Cable
  - Amplifier/Attenuator
  - Splitter/Combiner
CompoMan: RF Component Editor - User Interface

- List with components
- Add new component
- Selection filter
CompoMan: Editor for RF Components

- General parameters of all components
  - Model
  - Manufacturer
  - Type
  - Description
  - Price
  - Mechanical dimensions: Width, height, depth
  - Weight
  - Connectors
  - Max. power at each input
  - Frequency range (min./max.)
**CompoMan: RF Component Editor – Antenna**

- Parameters considered during the wave propagation prediction
  - Antenna pattern
    - 2x2D (vertical and horizontal plane)
  - 3D
  - Gain
- Further parameters
  - 3 dB beam width
  - Polarization
  - Electrical downtilt
CompoMan: RF Component Editor - Radiating Cable

- Parameters considered during the wave propagation prediction
  - Attenuation in dB per meter (depending on actual cable length in installation)
  - Coupling loss in dB
  - Distance coupling loss in meter
  - All frequency dependent

- Further parameters
  - Connector (e.g. coaxial)
CompoMan: RF Component Editor - Cable

- Parameters considered during the wave propagation prediction
  - Attenuation in dB per meter (depending on actual cable length in installation)
  - Frequency dependent
- Further parameters
  - Connector (e.g. coaxial)
CompoMan: RF Component Editor - Amplifier

- Parameters considered during the wave propagation prediction
  - Frequency independent amplification in dB
  - Frequency dependent amplification in dB
CompoMan: RF Component Editor - Attenuator

- Parameters considered during the wave propagation prediction
  - Frequency independent attenuation in dB
  - Frequency dependent attenuation in dB
CompoMan: RF Component Editor – Splitter/Combiner

- Parameters considered during the wave propagation prediction
  - Number outputs/inputs
  - Frequency independent attenuation in dB (for each input/output)
  - Frequency dependent attenuation in dB
  - Phase shift
Global RF Components Catalogue

- Global catalogue with components can be selected in the RNP tool
- Components are identified by their unique name
- Modification of components in global catalogue affects optionally the components in the network installation
Adding RF Components to the Network (Project)

- Graphical tools
- Components can be added, edited, and removed with mouse
- Different buttons for add, edit, move, and delete components
- Currently supported components:
  - Transmitter/Receiver
  - Antenna
  - Radiating Cable
  - Cable
  - Amplifier/Attenuator
  - Splitter/Combiner
Connecting RF Components with Cables

- Graphical tool (cables are drawn with mouse on bitmaps or vector databases)
- Cable coordinates in 3D (i.e. cables on multiple floors are possible)
- Length of cable is determined and used to compute its attenuation
- If components - connected to the cable - are moved, the cable is automatically elongated
- Currently supported types of cables:
  - Cable
  - Radiating Cable
Signal Handling in the Network Installation

- Downlink signal always generated in transmitter component or transceiver component
- Uplink signal ends always at receiver component or transceiver component
- Definition of the following properties at transmitter/receiver/transceiver:
  - Carrier ID / MIMO Stream ID
  - Signal power (DL)
  - Noise Figure (UL)
- Radiation/reception of signals possible for following components:
  - Antenna
  - Radiating Cable
Network Installations with RF Components

Reporting

- Generation of the following reports possible:
  - List of installed parts
  - List of deployed antennas with details
  - List of deployed cables with details
  - Costs (separate prices for hardware and installation)

- Format of the reports:
  - csv (Excel)
  - PDF
  - ASCII

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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</thead>
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<td>Amount</td>
<td>Price (unit)</td>
<td>Price (Installation Costs)</td>
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<td>K741984</td>
<td></td>
<td>7.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>5</td>
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<td>SPL-217</td>
<td></td>
<td>5.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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Propagation Models

- **One Slope Model**
  - Only distance dependency
  - Path loss exponent is dominant parameter

- **Motley Keenan Model**
  - All walls have identical attenuation

- **COST 231 Multi-Wall-Model**
  - Only direct ray between Tx and Rx
  - Individual attenuation of each wall
    (transmission loss of wall)

- **Ray Tracing**
  - 3D Ray Tracing (IRT, with preprocessing)
  - 3D Ray Tracing (SRT, without preprocessing)

- **Dominant Path Model**
  - 3D (Multiple floors)
Propagation Models: COST 231 Multi Wall Model

Principle of model:

- Based on direct ray between transmitter and receiver
- Free space loss (one slope) with additional loss due to transmission of walls
- Individual material properties of each wall considered

Computation of field strength:
Multipath propagation considered

- Dominant effects: diffraction, reflection and transmission (penetration)

- Ray with up to 6 reflections and 2 diffractions (and arbitrary number of transmissions / penetrations) are determined in different combinations

- Full 3D approach

- Uncorrelated or correlated superposition of contributions (rays)

- Supports only vector databases

- Two sub-modes:
  - 3D IRT: Incl. single pre-processing of building data and accelerated predictions
  - 3D SRT: Without any pre-processing
Considerations to accelerate the time consuming process of path finding:

- Deterministic modelling generates a large number of rays, but only few of them deliver most of the energy
- Visibility relations between walls and edges are independent of transmitter location
- Adjacent receiver pixels are reached by rays with only slightly different paths

➔ Single pre-processing of the building database with determination of the visibility relations between buildings reduces computation time
Propagation Models: Intelligent Ray Tracing (IRT)

Pre-processing of the Building Database

- Subdivision of the walls into tiles
- Subdivision of the vertical and horizontal edges into segments
- Subdivision of the prediction area into receiving points (grid)

-stored information for each visibility relation:
  - angle between the elements
  - distance between centres
- example: visibility between a tile and a receiver pixel
- projection of connecting straight lines into xy-plane and perpendicular plane
- 4 angles for each visibility relation
Propagation Models: Intelligent Ray Tracing (IRT)

Prediction with Pre-processed Data

- Determination of all tiles, segments and receiving points, which are visible from the transmitter
- Computation of the angles of incidence belonging to these visibility relations
- Recursively processing of all visible elements incl. consideration of the angular conditions
- Tree structure is very fast and efficient
Propagation Models: Dominant Path Model

- Dominant Path (single path or group of paths)
- Unlimited number of interactions (changes of orientation) along the path
- Parameters of path determined (e.g. length, number of interactions, angles, ...) and used to compute path loss with semi-deterministic equations
- Optional consideration of wave guiding possible (wave guiding factor, based on reflection loss of walls)
- No pre-processing required
- Accurate and fast
- Auto-calibration available
- Robust against errors in vector building database
Propagation Models: Dominant Path Model

Determination of Paths

- Analysis of types of walls in scenario
- Generation of tree with walls
- Searching best path through walls
- Computation of path loss

Propagation Modeling
Propagation Models: Dominant Path Model

Computation of Path Loss

- Path length $l$
- Wavelength $\lambda$
- Path loss exponent $p$
- Individual interaction losses $f(\phi,i)$ for each interaction $i$ of all $n$ interactions
- Penetration loss $t_j$ for all $m$ transmissions through walls
- Gain due to waveguiding $\Omega$

$$L = 20 \log\left(\frac{4\pi}{\lambda}\right) + 10 p \log(l) + \sum_{i=1}^{n} f(\phi,i) + \sum_{j=1}^{m} t_j - \Omega$$
Propagation Models: Dominant Path Model

Parameters for prediction (2/2)

- Definition of different path loss exponents $p$ for
  - LOS (line of sight)
  - OLOS (obstructed line of sight => no transmission through a wall)
  - NLOS (non line of sight => at least one transmission through a wall)

- Interaction losses (effective attenuation depends on angle of incident and diffracted ray)

- Wave guiding effect
Propagation Models: Comparison

<table>
<thead>
<tr>
<th>Model</th>
<th>Computation time</th>
<th>Preprocessing time</th>
<th>Accuracy Near Tx</th>
<th>Accuracy Far Away</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST 231</td>
<td>&lt; 1 min</td>
<td>none</td>
<td>High accuracy in region of Tx</td>
<td>Limited accuracy far away</td>
</tr>
<tr>
<td>Ray Tracing (3D IRT)</td>
<td>&lt; 1 min</td>
<td>10 min</td>
<td>High accuracy in region of Tx</td>
<td>High accuracy also far away from Tx</td>
</tr>
<tr>
<td>Dominant Path (3D)</td>
<td>&lt; 1 min</td>
<td>none</td>
<td>High accuracy in region of Tx</td>
<td>High accuracy also far away from Tx</td>
</tr>
</tbody>
</table>
Leaky Feeder Models: Comparison

**Shortest Distance Model**
- Shortest distance between cable and receiver
- Loss due to transmission of intersected walls (optional with angle of incidence)
- Additional distance loss due to propagation (path loss exponents)

**Smallest Transmission Loss**
- Based on transmission loss evaluation for discrete Tx points along the cable (definable discretization)
- Selection of path with smallest transmission loss
- Loss due to transmission of intersected walls (optional with angle of incidence) and distance depending loss

**Smallest Path Loss Model**
- Based on path loss evaluation for discrete Tx points along the cable (definable discretization)
- Selection of path with smallest path loss
- Loss due to transmission of intersected walls (optional with angle of incidence) and distance depending loss
Prediction on multiple floors are possible with all indoor prediction models in WinProp.
Buildings: Arbitrary Prediction Planes

Prediction planes not only horizontal, but arbitrarily located
Example: Prediction in staircases inside a building
Buildings: Prediction on Surfaces

Coverage computed on the surfaces of buildings in an urban scenario
Tunnels: Prediction inside Tunnel Scenarios

- Separate tool for defining tunnel databases based on cross sections and track
- Tunnel database can be modified in WallMan
- Coverage prediction and network planning in ProMan
Indoor: Sample Predictions

Stadium: Computed with Indoor Ray Tracing

Prediction of the coverage on upper and lower tiers inside a stadium
Indoor: Sample Predictions

Airport: Computed with Indoor Ray Tracing

Prediction of the radio link between an airplane and the tower
Indoor: Sample Predictions

Metro Station: Computed with Dominant Path Model

Prediction of the W-LAN coverage in a METRO station (two trains arriving)
Indoor: Sample Predictions

Metro Station: Computed with Dominant Path Model

Prediction of the W-LAN coverage in a METRO station (two trains arriving)
Indoor: Sample Predictions

Highway (VANET): Computed with Ray Tracing

Car2Car communications:
Prediction of the mobile radio channel for VANETs
Indoor: Sample Predictions

Vehicles: Computed with Ray Tracing

Radio links to transmit sensors data inside vehicles

Coverage of a wireless sensor inside a vehicle
Indoor: Sample Predictions

Keyless Entry: Computed with Ray Tracing

Analysis of the radio channel for keyless go systems
Indoor: Sample Predictions

Keyless Entry: Computed with Ray Tracing

Analysis of the coverage area for keyless go systems

Number of received sub-carriers in an UWB radio system for keyless go
Evaluation with Measurements

Investigated Scenarios:

I. Institute for Radio Frequency Technology, University of Stuttgart

II. University of Vienna, Vienna, Austria

III. Institute of Telecommunications, Lisbon

IV. Institute of Radio Frequency Engineering, University of Vienna, Austria

V. Whittemore Hall of the Virginia State University

VI. Villa of Guglielmo Marconi, Bologna
**Scenario I**: Institute for Radio Frequency Technology, University of Stuttgart, Germany

**Scenario Information**

<table>
<thead>
<tr>
<th>Material</th>
<th>concrete and glass</th>
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</thead>
<tbody>
<tr>
<td><strong>Total number of objects</strong></td>
<td>353</td>
</tr>
<tr>
<td><strong>Number of walls</strong></td>
<td>170</td>
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<tr>
<td><strong>Resolution</strong></td>
<td>0.50 m</td>
</tr>
<tr>
<td><strong>Transmitter</strong></td>
<td>0.90 m, 20 dBm, 1800 MHz</td>
</tr>
<tr>
<td><strong>Prediction height</strong></td>
<td>0.90 m</td>
</tr>
</tbody>
</table>

3D view of the modern office building
Scenario I: Institute of Radio Frequency Technology, University of Stuttgart, Germany
**Scenario I**: Institute of Radio Frequency Technology, University of Stuttgart, Germany

- **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**
Scenario I: Institute of Radio Frequency Technology, University of Stuttgart, Germany

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 Path and measurement for transmitter 1
Scenario I: Institute of Radio Frequency Technology, University of Stuttgart, Germany

All predictions on this slide were computed with the Indoor Dominant Path Model.
## Indoor Evaluation

**Scenario I**: Institute of Radio Frequency Technology, University of Stuttgart, Germany

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean Value [dB]</th>
<th>Std. Dev. [dB]</th>
<th>Comp. Time [s]</th>
<th>Empirical Model (e.g. COST 231 Multi Wall)</th>
<th>Mean Value [dB]</th>
<th>Std. Dev. [dB]</th>
<th>Comp. Time [s]</th>
<th>Deterministic Model (e.g. 3D Ray Tracing or Indoor Dominant Path)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-17.08</td>
<td>20.42</td>
<td>&lt; 1</td>
<td>-4.05...-3.88</td>
<td>4.86...6.26</td>
<td>4.7...6.18</td>
<td>3.2...94</td>
<td>Average</td>
</tr>
<tr>
<td>2</td>
<td>-4.59</td>
<td>13.28</td>
<td>&lt; 1</td>
<td>-2.67...1.75</td>
<td>5.24...5.54</td>
<td>4.64</td>
<td>3...132</td>
<td>2...6</td>
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<td>5</td>
<td>2.54</td>
<td>4.22</td>
<td>&lt; 1</td>
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<td>3.95...4.66</td>
<td>3..10</td>
<td>2...6</td>
<td>4...16</td>
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<tr>
<td>6</td>
<td>-12.84</td>
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<td>&lt; 1</td>
<td>-1.64...5.04</td>
<td>5.6...10.13</td>
<td>3...6</td>
<td>3...13</td>
<td>3...10</td>
</tr>
<tr>
<td>8</td>
<td>-2.56</td>
<td>18.03</td>
<td>&lt; 1</td>
<td>5.49...5.48</td>
<td>5.83</td>
<td>4...16</td>
<td>3...13</td>
<td>3...16</td>
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<tr>
<td>12</td>
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<td>9.27</td>
<td>&lt; 1</td>
<td>3.27...3.59</td>
<td>4.64</td>
<td>3...13</td>
<td>3...13</td>
<td>3...13</td>
</tr>
<tr>
<td>Average</td>
<td>-6.19</td>
<td>13.61</td>
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<td>4.7...6.18</td>
<td>3.2...94</td>
<td>3...13</td>
<td>3...13</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
**Scenario II**: University of Vienna, Austria

**Scenario Information**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
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<tr>
<td><strong>Material</strong></td>
<td>brick and wood</td>
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<tr>
<td><strong>Total number of objects</strong></td>
<td>209</td>
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<tr>
<td><strong>Number of walls</strong></td>
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<tr>
<td><strong>Resolution</strong></td>
<td>0.5 m</td>
</tr>
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<td><strong>Transmitter</strong></td>
<td>1.6 m, 30 dBm, 1800 MHz</td>
</tr>
<tr>
<td><strong>Prediction height</strong></td>
<td>1.3 m</td>
</tr>
</tbody>
</table>

3D view of the historical building

Typical historical urban building!
**Scenario II**: University of Vienna, Austria

- **Prediction with Indoor Dominant Path Model**
- **Prediction with COST 231 Multi-Wall Model**
- **Prediction with 3D Ray Tracing Model**
Scenario II: University of Vienna, Austria

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
### Scenario II: University of Vienna, Austria

<table>
<thead>
<tr>
<th>Site</th>
<th>Empirical Model (e.g. COST 231 Multi Wall)</th>
<th>Deterministic Model (e.g. 3D Ray Tracing or Indoor Dominant Path)</th>
<th>Statistical Results</th>
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<tbody>
<tr>
<td>0</td>
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<td>11.74</td>
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<tr>
<td>3</td>
<td>-4.62</td>
<td>10.76</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Average</td>
<td>-3.58</td>
<td>11.25</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
Scenario III: Institute of Telecommunication, Lisbon, Portugal

3D view of two multi floor office buildings

3D view of the database with a prediction result in the first floor and some propagation paths

3 sector GSM base station on top of a building!

EMC aspects in this building and adjacent building especially important!

<table>
<thead>
<tr>
<th>Scenario Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Total number of objects</td>
</tr>
<tr>
<td>Number of walls</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td>Transmitter</td>
</tr>
<tr>
<td>Prediction height</td>
</tr>
</tbody>
</table>
Scenario III: Institute of Telecommunication, Lisbon, Portugal

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

⇒ Worst case scenario
Scenario III: Institute of Telecommunication, Lisbon, Portugal

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

<table>
<thead>
<tr>
<th>Site</th>
<th><strong>Empirical Model</strong> (e.g. COST 231 Multi Wall)</th>
<th><strong>Statistical Results</strong></th>
<th><strong>Deterministic Model</strong> (e.g. 3D Ray Tracing or Indoor Dominant Path)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-43.98</td>
<td>23.34</td>
<td>1</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
Scenario IV: Institute of Communications and Radio Frequency Engineering, University of Vienna, Austria

3D view of one floor of the database

<table>
<thead>
<tr>
<th>Scenario Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Total number of objects</td>
</tr>
<tr>
<td>Number of walls</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td>Transmitter</td>
</tr>
<tr>
<td>Prediction height</td>
</tr>
</tbody>
</table>
Scenario IV: Institute of Communications and Radio Frequency Engineering, University of Vienna, Austria

Indoor Evaluation

Prediction with Multi-Wall Model for transmitter 6
Prediction with 3D Ray Tracing Model for transmitter 6
Prediction with Indoor Dominant Path Model for transmitter 6
Scenario IV: Institute of Communications and Radio Frequency Engineering, University of Vienna, Austria

Difference of prediction for Multi-Wall Model and measurement for transmitter 6

Difference of prediction with 3D Ray Tracing and measurement for transmitter 6

Difference of prediction with Indoor Dominant Path and measurement for transmitter 6
## Scenario IV: Institute of Communications and Radio Frequency Engineering, University of Vienna, Austria

<table>
<thead>
<tr>
<th>Site</th>
<th>Empirical Model (e.g. COST 231 Multi Wall)</th>
<th>Statistical Results</th>
<th>Deterministic Model (e.g. 3D Ray Tracing or Indoor Dominant Path)</th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td>-0.94</td>
<td>5.84</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>7</td>
<td>-0.29</td>
<td>4.95</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Average</td>
<td>-0.62</td>
<td>5.40</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
Scenario V: Whittemore Hall of the Virginia State University, Virginia, USA

Typical modern office building!

3D view of one floor of the modern office block
Scenario V: Whittemore Hall of the Virginia State University, Virginia, USA

Prediction with Indoor Dominant Path Model

Prediction with Multi-Wall Model

Prediction with 3D Ray Tracing
Scenario V: Whittemore Hall of the Virginia State University, Virginia, USA

Difference of prediction with Indoor Dominant Path Model and measurement

<table>
<thead>
<tr>
<th>Site</th>
<th>Empirical Model (e.g. COST 231 Multi Wall)</th>
<th>Statistical Results</th>
<th>Deterministic Model (e.g. 3D Ray Tracing or Indoor Dominant Path)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx</td>
<td>-11.86</td>
<td>11.23</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
**Scenario VI:** Villa of Guglielmo Marconi, Bologna, Italy

**Scenario Information**

<table>
<thead>
<tr>
<th>Material</th>
<th>brick and wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of objects</td>
<td>28</td>
</tr>
<tr>
<td>Number of walls</td>
<td>10</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Transmitter</td>
<td>1.1 m, 11 dBm, 900 MHz</td>
</tr>
<tr>
<td>Prediction height</td>
<td>1.6 m</td>
</tr>
</tbody>
</table>

Typical historical building in rural areas!

3D view of the historical villa
Scenario VI: Villa of Guglielmo Marconi, Bologna, Italy

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

Field Strength [dB µV/m]
- 120.00
- 118.00
- 116.00
- 114.00
- 112.00
- 110.00
- 108.00
- 106.00
- 104.00
- 102.00
- 100.00
- 98.00
- 96.00
- 94.00
- 92.00
- 90.00
### Indoor Evaluation

**Scenario VI:** Villa of Guglielmo Marconi, Bologna, Italy

- Difference for COST 231 Multi Wall Model
- Difference for 3D Ray Tracing Model
- Difference for Indoor Dominant Path Model

<table>
<thead>
<tr>
<th>Site</th>
<th><strong>Empirical Model (e.g. COST 231 Multi Wall)</strong></th>
<th><strong>Statistical Results</strong></th>
<th><strong>Deterministic Model (e.g. 3D Ray Tracing or Indoor Dominant Path)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>TRX 1</td>
<td>-3.87</td>
<td>2.96</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Remark: Standard PC with an AMD Athlon64 2800+ processor and 1024 MB of RAM
Summary

Features of WinProp Indoor Module

• **Highly accurate propagation models**
  
  Empirical: One Slope, Motley-Keenan, Multi Wall,….
  
  Deterministic (ray optical): 3D Ray Tracing, 3D Dominant Path

  Optionally calibration of 3D Dominant Path Model with measurements possible – but not required as the model is pre-calibrated

• **Building data**
  
  Models are based on 3D vector (CAD) data of indoor buildings

  Consideration of material properties (also subdivisions like windows or doors)

• **Antenna patterns**
  
  Either 2x2D patterns or 3D patterns

• **Outputs**
  
  Predictions on multiple heights simultaneously

  Signal level (path loss, power, field strength)

  Delays (delay window, delay spread,…)

  Channel impulse response

  Angular profile (direction of arrival)
Further Information

WinProp Software Package

Product News
- Components for Indoor Networks incl. new Editor Computer
- Scattering for Indoor Ray-Optical Models
- Bridges in urban scenarios supported
- New Traffic Simulators: Monte-Carlo and Fractional-User
- Read more...

Traffic Modeling
- Monte Carlo Simulator and Fractional User Simulator for sophisticated consideration of heterogeneous traffic defined by the user (based on vector or cluster databases).
- Prediction of blocking, capacity, throughput, and cell loads.

Company related News and Events
- GIS/IT purchases new indoor components module
- AWE purchases WinProp licenses for all scenarios
- New customers: ASO, ETSC, PPS, ...
- EIT Project: Validation with measurements started
- Read more...

New WinProp Release
- V13

Download the free WinProp trial version

WTP2014
- Wave Technology 2014
- Jobikeello will present Winprop at Wireless Technology Park in Tokyo in May 2014

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