Technische Universität Braunschweig

Institut für Nachrichtentechnik

Path Loss Modelling for Cellular Networks

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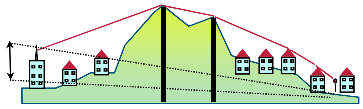
Propagation Models for Macro Cells

Propagation Models for Macro Cells

- Propagation models for macro cells normally consider topography and land use (2D model)
  - Modelling of rough terrain characteristics
  - Influence of the building development is only simplified recorded
  - Influence of single buildings is not considered explicitly



base station (BS) mobile station (MS)

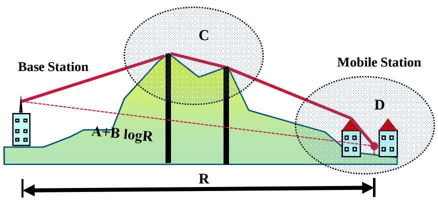
- In rural and suburban areas, the essential propagation effects are modelled with sufficient accuracy
  - Reason: Typically, the BS antenna is located distinctly above the homogeneous areas

General Model for Macro Cells

- Contributions to the attenuation regarding macro cells (general equation)

$$L(r) = A + B \log r + C + D$$

L: distance-dependent attenuation in dB
r: distance BS-MS in km
A: loss at a distance of 1 km
B: propagation coefficient
C: diffraction loss through topographical obstacles
D: correction loss for the land use (e.g. building development)



Empirical Propagation Models for Macro Cells

- Empirical models base on the evaluation of a multitude of measurements.
- In case of purely empirical models, normally no additional correction for the diffraction loss at topographical obstacles is considered, i.e. C = 0 in previous slide.
  - **Lee model**
    - The Lee model was derived from measurements at 900 MHz and is therefore only valid for this frequency range. The model is dependent on the effective antenna height of the base station h_{BS}, the antenna height of the mobile station (h_{MS}) and the environment, which is considered by n and D.

$$A = 29 - 20\log(h_{BS}/m) - 10\log(h_{MS}/m)$$

$$B = 10n$$

    - The effective antenna height corresponds to a straight line through the position of the mobile station with the slope of the terrain at this position (comp. the sphere of influence of the Fresnel zone).

Empirical Propagation Models for Macro Cells

- Regarding the Lee model, the following parameters depending on the environment have been derived from measurements:

environment	n	D
free space	2	45
open	4,35	49
suburban	3,84	61,7
urban (Philadelphia)	3,68	70
urban (Newark)	4,31	64
urban (Tokio)	3,05	84
urban (New York City)	4,8	77

Empirical Propagation Models for Macro Cells

- **Erceg model**
  - Suburban path loss model derived form measuremenst of 95 macro cells at 1.9 GHz in the following three common categories found in the United States:
    - Type A: Hilly terrain with moderate-to-heavy tree densities.
    - Type B: Hilly terrain with light tree densities or flat terrain with moderate-to-heavy tree density
    - Type C: Mostly flat terrain with light tree densities.

$$L_{Erceg} = 20\log\frac{4\pi d_0}{\lambda} - 10\gamma\log\frac{d}{d_0}$$

$$\gamma = a - bh_{BS} + \frac{c}{h_{BS}}$$

- d_0 = 100m, λ is the wave length in meters, h_{BS} is the base station height

Empirical Propagation Models for Macro Cells

- a, b. c are model parameters

Model Parameter	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4	3
b	0.0075	0.0065	0.005
c	12.6	17.1	20

- Validity range:
  - Base station height 10m…100m
  - Mobile station height around 2 m
  - Distance 100m….8000m
  - Frequency around 2 GHz

Empirical Propagation Models for Macro Cells

- **Extended Erceg model (Stanford University Interim (SUI) model)**

$$L_{Erceg,extended} = L_{Erceg} + 6\log\frac{f}{2000\,MHz} + L_h$$

$$L_h = \begin{cases} -10.8\log\frac{h_{mobile}}{2} \text{ for categories A and B} \\ -20\log\frac{h_{mobile}}{2} \text{ for category C} \end{cases}$$

  - Valid for other frequency ranges than 2 Ghz and other mobile antenna heights than 2m

- **Okumura Hata/COST231 Hata/Extended Hata model**
  - For antenna heights of the BS (h_{BS}) between 30 and 200 m, for a distance from 1 to 20 km and for antenna heights of mobile stations (h_{MS}) from 1 to 10 m, the following attenuation coefficients apply to urban areas:

Extended - Hata Model

- From 150 MHz to 1000 MHz

$$A = 69.55 + 26.26\log(f/MHz) - 13.82\log(h_{BS}/m) - a(h_{MS}/m)$$

- From 1500 to 2000 MHz

$$A = 46.3 + 33.9\log(f/MHz) - 13.82\log(h_{BS}/m) - a(h_{MS}/m)$$

- From 2000 to 3000 MHz

$$A = 46.3 + 33.9\log 2000 + 10\log(f/2000MHz) - 13.82\log h_{BS}/m - a(h_{MS}/m)$$

- For all of the above mentioned frequency ranges

$$B = 44.90 - 6.55\log(h_{BS}/m)$$

$$a(h_{MS}) = (1.1\log(f/MHz) - 0.7)h_{MS}/m - (1.56\log(f/MHz) - 0.8)$$

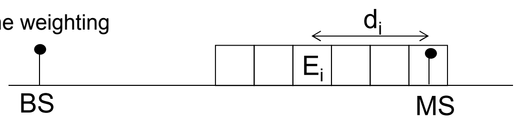
- Determination of D for different land use classes $D = -9.42\log(f/MHz) - 1.07 + E$
- The values of E are dependent on type and number of the land use classes and have to be determined by calibration

Hata Models

- Examples for E at 1800 MHz:
  - E = 19.6 dB in urban areas
  - E = 11.5 dB in open areas
  - E = 18.8 dB in forested areas
- Regarding some versions of the Okumura Hata model, the value of E does not only depend on the attenuation factor of the land use class at the position of the mobile station, but also on the values of the land use classes located between BS and MS. A possible realisation would be e.g.

$$E = \sum_{\forall i, d_i < d_{\max}} E_i e^{-w d_i}$$

  - w and d_{max} are parameters for the weighting



Semi-Empirical Propagation Models for Macro Cells

- Using empirical propagation models, it is not possible to consider explicitly the diffraction loss during propagation.
- The diffraction is included through combination of the empirical models with knife edge diffraction models.
- The combination of empirical methods with deterministic approaches results in semi-empirical methods.
- The methods mainly used in practice base on the Hata models.

Semi-Empirical Propagation Models for Macro Cells

- There are numerous types of semi-empirical models based on the Hata model. Basically, they differ in:
  - the method for the consideration of the diffraction loss (Deygout, Epstein-Petersen, Giovanelli a. o.)
  - the method for the calculation of the effective antenna height
  - the method for the consideration of the land use class

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Propagation Models for Urban Areas

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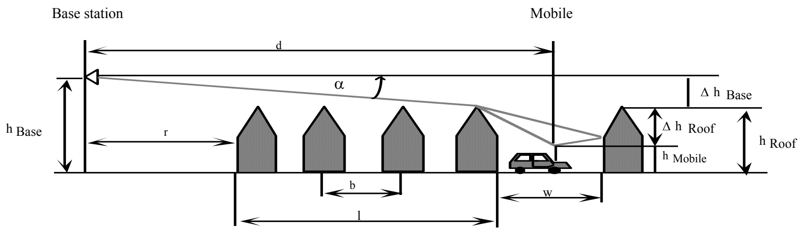
Propagation Models for Urban Areas

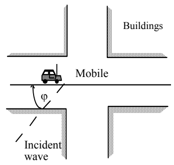
- With the models used for macro cells, only very imprecise predictions are possible especially in dense urban areas:
  - Due to the high capacity required in congested areas, the cell radii and the base station antenna heights are considerably smaller than in case of (rural) macro cells
    - propagation models for macro cells are coming up against their limiting factors
  - The propagation situation itself is much more complex
    - greater importance of multipath propagation
  - Prediction of the coverage in buildings is of greater importance
- According to the propagation models for macro cells, in this case there is also a multitude of different models with empirical, semi-empirical and ray-optical approaches:
  - In the following, several examples for the application in urban micro cells and small macro cells respectively are explained more detailed.

Propagation Models for Urban Macro Cells

- Models for the consideration of multiple diffraction effects in typical urban propagation environments



- Improvement of the modelling through consideration of more detailed data for description of the environment:
  - building height h_{Roof}
  - street width w
  - building separation b
  - street orientation φ



COST231-Walfisch-Ikegami Model

- The best-known model is the COST231 Walfisch Ikegami model
  - Developed in 1991 by COST231, based on the models by Walfisch Bertoni and Ikegami

- The model distinguishes the cases LOS (Line of Sight) and NLOS (Non Line of Sight)
- Propagation loss for LOS:

$$L_b(dB) = 42.6 + 26\log(d/km) + 20\log(f/MHz) \quad \text{für } \; d \geq 20\,\text{m}$$

- Propagation loss for NLOS:

$$L_b = \begin{cases} L_0 + L_{rts} + L_{msd} & \text{für } L_{rts} + L_{msd} > 0 \\ L_0 & \text{für } L_{rts} + L_{msd} \leq 0 \end{cases}$$

COST231-Walfisch-Ikegami Model

- L_0 is the attenuation for the free-space propagation

$$L_0(dB) = 32.4 + 20\log(d/km) + 20\log(f/MHz)$$

- L_{rts} (rooftop-to-street) considers the diffraction and reflection processes in the street canyon in which the mobile station is located:

$$L_{rts} = -16.9 - 10\log\frac{w}{m} + 10\log\frac{f}{MHz} + 20\log\frac{\Delta h_{Mobile}}{m} + L_{Ori}$$

$$L_{Ori} = \begin{cases} -10 + 0.354\dfrac{\varphi}{\deg} & \text{for } 0° \leq \varphi < 35° \\ 2.5 + 0.075(\dfrac{\varphi}{\deg} - 35) & \text{for } 35° \leq \varphi < 55° \\ 4.0 - 0.114(\dfrac{\varphi}{\deg} - 55) & \text{for} 55° \leq \varphi < 90° \end{cases}$$

$$\Delta h_{Mobile} = h_{Roof} - h_{Mobile} \quad \text{(2-61)} \quad \Delta h_{Base} = h_{Base} - h_{Roof}$$

COST231-Walfisch-Ikegami Model

- L_{msd} (multiple screen diffraction) considers the multiple diffraction over the complete row of houses touched by the wave:

$$L_{msd} = L_{bsh} + k_a + k_d \log\frac{d}{km} + k_f \log\frac{f}{MHz} - 9\log\frac{b}{m}$$

$$L_{bsh} = \begin{cases} -18\log(1+\frac{\Delta h_{Base}}{m}) & \text{for } h_{Base} > h_{Roof} \\ 0 & \text{for } h_{Base} \le h_{Roof} \end{cases}$$

$$k_a = \begin{cases} 54 & \text{for } h_{Base} > h_{Roof} \\ 54 - 0.8\frac{\Delta h_{Base}}{m} & \text{for } d \ge 0.5\text{km and } h_{Base} \le h_{Roof} \\ 54 - 0.8\frac{\Delta h_{Base}}{m}\frac{d/km}{0.5} & \text{for } d < 0.5\text{km and } h_{Base} \le h_{Roof} \end{cases}$$

COST231-Walfisch-Ikegami Model

$$k_d = \begin{cases} 18 & \text{for } h_{Base} > h_{Roof} \\ 18 - 15\frac{\Delta h_{Base}}{h_{Roof}} & \text{for } h_{Base} \le h_{Roof} \end{cases}$$

$$k_f = -4 + \begin{cases} 0.7(\frac{f/MHz}{925} - 1) & \text{for medium sized city and suburban centres with medium tree density} \\ 1.5(\frac{f/MHz}{925} - 1) & \text{for metropolitan centres} \end{cases}$$

- In case that no detailed information about buildings is available, the following parameters are recommended:

$$h_{Roof} = 3\,\text{m} \times \{\text{number of floors}\} + \text{roof - heigth}$$

- roof height: 3 m (span roof) and 0 m (flat roof)
- b = 20 ... 50 m
- w = b/2
- $\varphi = 90°$

COST231-Walfisch-Ikegami Model

- The model is valid for
  - f = 800…2000 MHz
  - h_{Base} = 4…50 m
  - h_{Mobile} = 1…3 m
  - d = 20 m...5 km
- The data used for the development of the model is the basis for this validity range.
- In practice, the model has also been applied successfully for slightly greater antenna heights and for frequencies in the UMTS band, respectively.

COST231-Walfisch-Ikegami Model

- The COST231 Walfisch Ikegami model provides inaccurate prediction results in case of grazing incidence, i.e. for l < d_s, with ds describing the „Settled Field Distance“:

$$d_s = \frac{\lambda d^2}{\Delta h_{Base}^2}$$

- Further propagation models for the consideration of multiple diffraction in urban macro cells:
  - Walfisch Bertoni model (Walfisch, Bertoni, 1988)
    - assumption that hBase > hRoof
  - Flat Edge model (Saunders, 1991)
    - closed-form solution of diffraction integrals for r >> l
  - Maciel Xia Bertoni model (Maciel, Xia, Bertoni, 1993)
    - valid for any heights of the base station antenna

A Hybrid Propagation Model for Macro Cells

- Concept of a hybrid propagation model
  - Combination of different propagation models, each with another validity range and optimal field of application, respectively
  - Strict separation of the terrain data processing and the path loss calculation
  - Path loss calculation is divided into the calculations for the basic attenuation loss and the diffraction loss
  - Example for a hybrid propagation model*
    - Basic attenuation:
      - Combination of different models for multiple diffraction in urban macro cells for the land use classes of urban areas

*Th. Kürner, R. Fauß, A. Wäsch, "A hybrid propagation modelling approach for DCS1800 macro cells," Proc. IEEE VTC'96, Atlanta, Georgia, USA, April 28-May 1, 1996, pp. 1628-1632

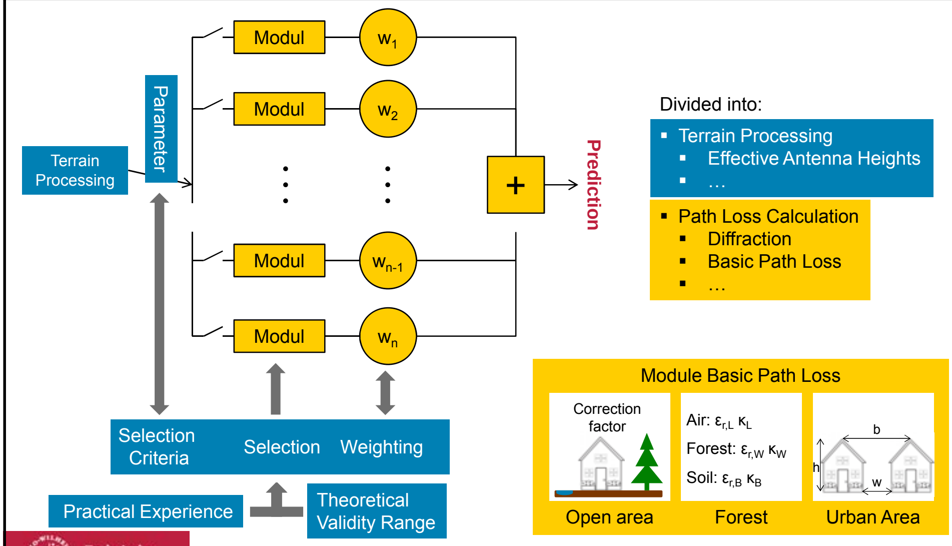
A Hybrid Propagation Model for Macro Cells

- Description of the different urban land use classes by the parameters of the COST231 WI model
- Modelling of the vegetation as a dielectric layer (lateral wave approach) for land use classes of the type forest
  - different forested classes are described by different parameters
- Okumura Hata approach for all other land use classes
  - correction factors for different land use classes

- Diffraction loss:
  - Giovanelli method
  - Consideration of the height incl. land use

- Calculation of the effective antenna height according to the combination method described in file Prop 3.1

Modular Design Principle of the Hybrid Propagation Model



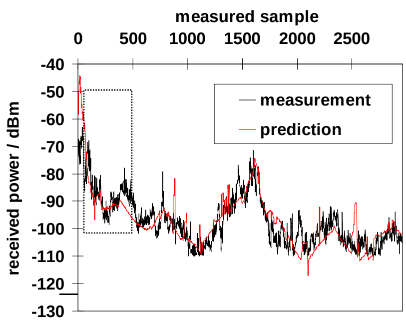
Combination of Propagation Models in Urban Areas

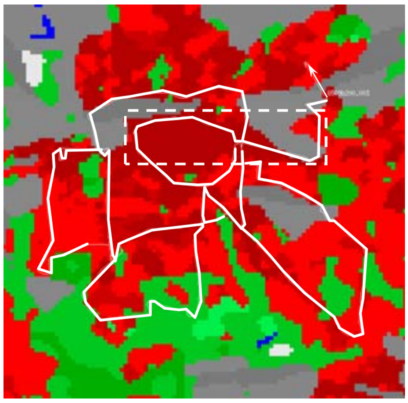
- Assumption: homogeneous building heights/separation
- Rules for the combination of submodels:

Model	**Field of application**
COST 231-Walfisch-Ikegami	$(l > d_S) \cap (h_{Base} < 70m)$
Flat Edge	$((l \leq d_S) \cup (h_{Bas} \geq 70m)) \cap (r >> l)$
Maciel-Xia-Bertoni	sonst

Combination of Propagation Models in Urban Areas

- Comparison of the prediction with a test run in Dortmund





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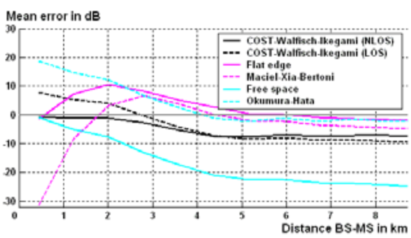
ΔE = 0.1 dB

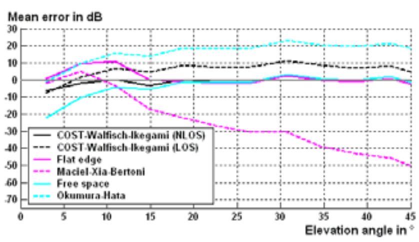
σ = 6.2 dB

area size 5 km x 5 km

Combination of Propagation Models in Urban Areas

- Investigation of propagation models for Ultra High Sites (UHS)

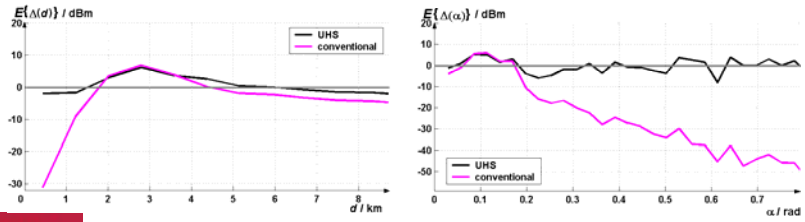




- Good results of the Maciel-Xia-Bertoni model only for α < 0.15 (8°)
- Walfisch Ikegami und Flat Edge valid for UHS (good results for antenna heights up to 273 m and α > 0)

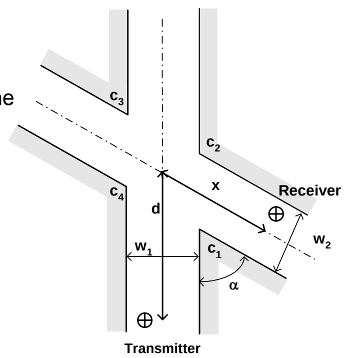
Extension of the Hybrid Propagation Model

Model	Field of application
COST 231-Walfisch-Ikegami	$(l > d_S) \cap (h_{Base} < 70\text{ m})$ $\cup ((h_{Base} > 81\text{ m}) \cap (\alpha > 0{,}15))$
Flat Edge	$((l \leq d_S) \cup (h_{Base} \geq 70\text{ m})) \cap ((r >> l)$ $\cup ((h_{Base} > 81\text{ m}) \cap (d > 4\text{ km})))$
Maciel-Xia-Bertoni	otherwise



Semi-Empirical Models for Micro Cells

- Wiart model
  - Field of application: micro cells, i.e. the height of the BS antenna is smaller than the height of the surrounding buildings
  - Consideration of propagation in a plane parallel to the surface of the earth
  - Differentiation of LOS and NLOS
    - For the LOS case, the following applies:



$$L_{LOS} = -20\log_{10}(x) + C_{LOS} + L_{fre}$$

$$L_{fre} = -20\log_{10}\left(\frac{4\pi}{\lambda}\right),$$

λ	wavelength
x	distance between transmitter and receiver
C_{LOS}	*empirical factor for the description of waveguide effects*

Semi-Empirical Models for Micro Cells

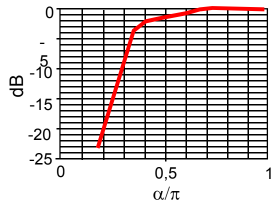
- In case of NLOS, reflected and diffracted contributions are considered separately:

$$L_{NLOS} = 20\log_{10}\left(10^{L_{REF}/20} + 10^{L_{DIFF}/20}\right)$$

- Reflected contributions

$$L_{REF} = -20\log_{10}\left(d + x\right) + S\,x + L_{fre}$$

$$S = \frac{d}{w_1 w_2} f(\alpha) \qquad [\text{dB/m}]$$



f(α)

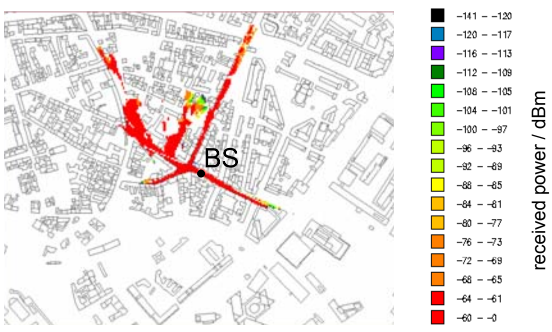
- Diffracted contributions

$$L_{DIFF} = -20\frac{1}{2}\log_{10}\left(x\left(x+d\right)d\right) + 2D_a + L_{fre}$$

$$D_a \approx -\left(\frac{45}{2\pi}\right)\text{atan}\left(\frac{x}{w_2}\right) + \frac{23}{\pi}\left(\alpha - \frac{\pi}{2}\right)$$

Application of the Wiart Model

- Calculation of the geometrical input parameters from a digital terrain model



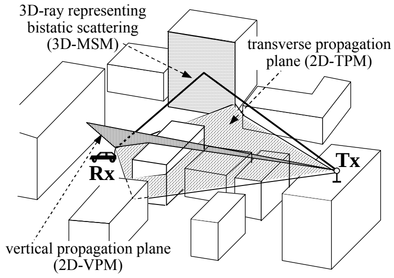
Ray-Optical Propagation Models

- Normally, with models applied to carry out planning tasks in urban areas, it must be possible to calculate micro cells (BS antenna below roof-top level of the buildings) as well as small macro cells (BS antenna above roof-top level of the buildings)
- In most cases, ray-optical methods are applied to perform these tasks. The different methods differ in terms of:
  - the type of determination (Ray Tracing or Ray Launching) including the methods for the reduction of the computation time
  - the selection of the relevant propagation paths
  - the methods for the calculation of the diffraction along the selected paths
- In the following, in order to demonstrate this method, two approaches are exemplified more detailed:

Example 1: Model by Karlsruhe University (Cichon 1994)

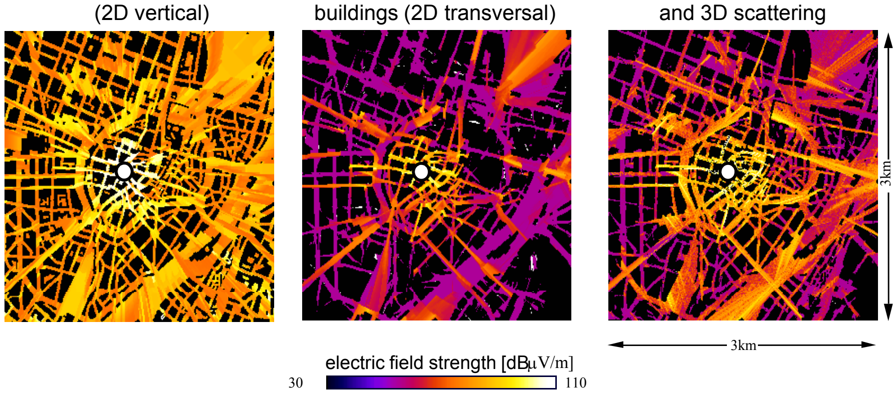
The model consists of three submodels:

- 2D vertical model (2D-VPM): Consideration of diffraction over the buildings by the UTD
- 2D transverse model (2D-TPM): Consideration of diffraction around the buildings by the UTD
- 3D multipath model (3D-MSM): Consideration of single scattering processes by applying the Kirchhoff method

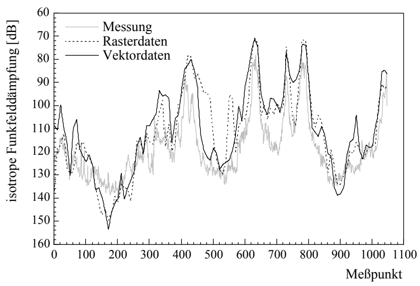


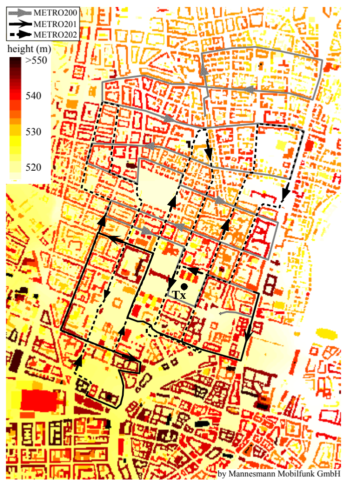
Propagation Calculations, Separate According to the 3 Submodels

propagation over buildings (2D vertical) | propagation around buildings (2D transversal) | significant 3D reflection and 3D scattering



Comparison of the Prediction with a Measurement in Munich at 947 MHz



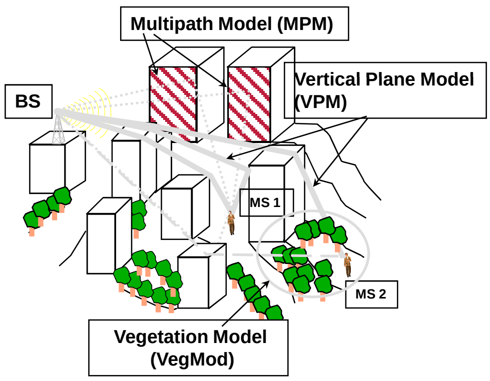


antenna height of the BS: 26 m
measurement route METRO 202

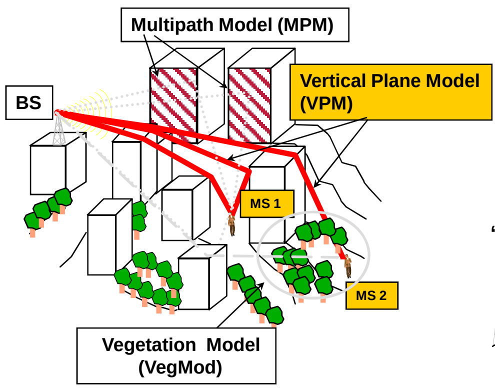
Example 2: City Model by E-Plus (Kürner, Meier 2003)

Model consists of 3 submodels:

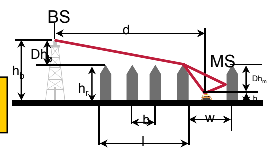
- 2D vertical plane model (VPM): consideration of diffraction over the buildings using a semi-empirical approach
- 3D multipath model (MPM): consideration of single scattering processes on the basis of Lambertian emitters
- Vegetation model (VegMod): consideration of the vegetation for all paths



Vertical Model

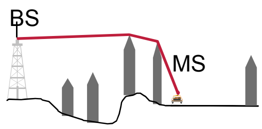


"Walfisch type" situation (WT)



Combination of 3 WT models

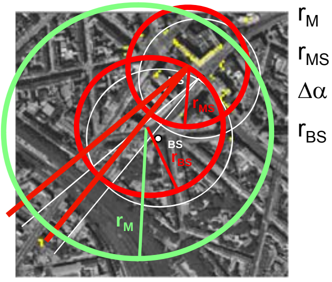
"knife-edge type" situation (KET)

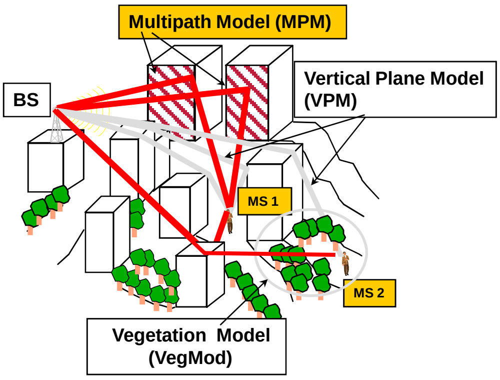


modified Deygout method

Multipath Model

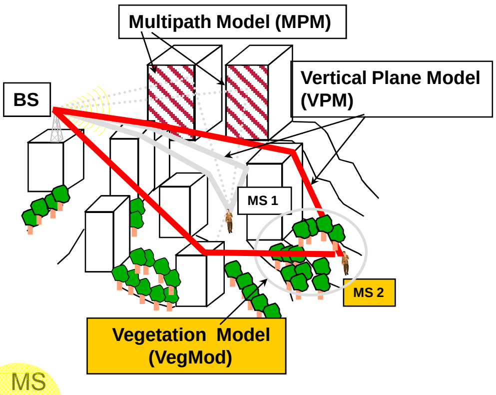
- Single scattering processes only
- Modelling as a Lambertian emitter
- Incoherent superposition of the multipath signals
- Heuristics for a fast multipath model (fast MPM)

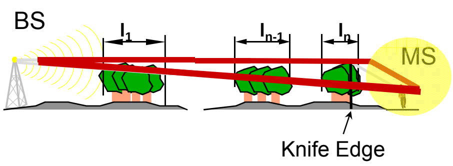




Vegetation Model

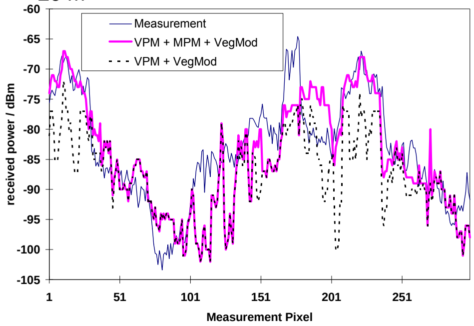
- Application to VPM and MPM
- Penetration by vegetation (empirical attenuation factor)
- Diffraction over the vegetation (knife edge diffraction)
- Full vegetation loss due to incoherent superposition of both contributions



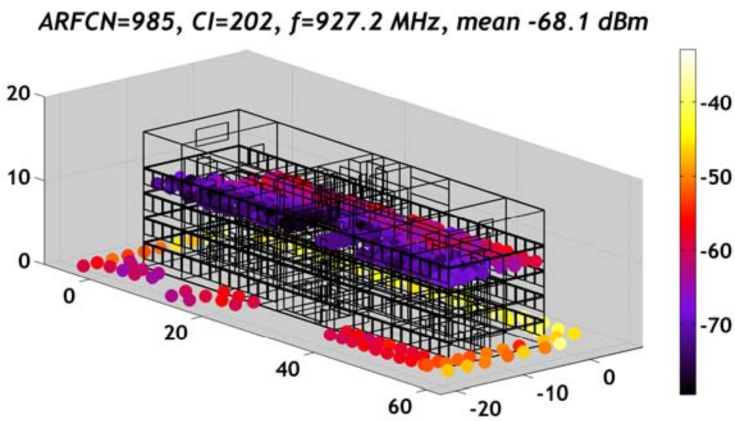


Comparison between Prediction and Measurement

height of the BS: 29 m above ground level
height of the surrounding buildings: 15 m – 25 m

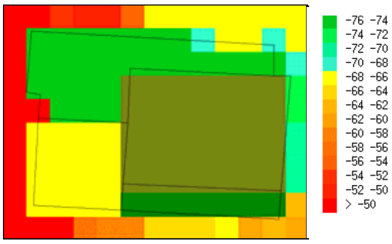


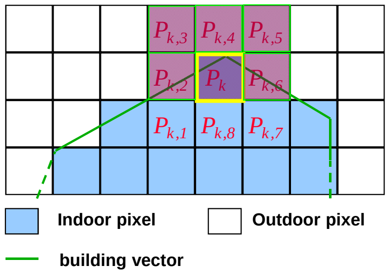
Building Penetration: Measurement of Indoor- and Outdoor Coverage of a GSM Base Station



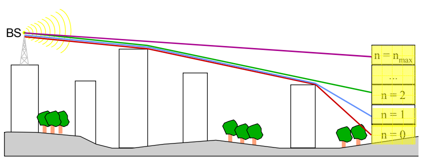
Consideration of Building Penetration

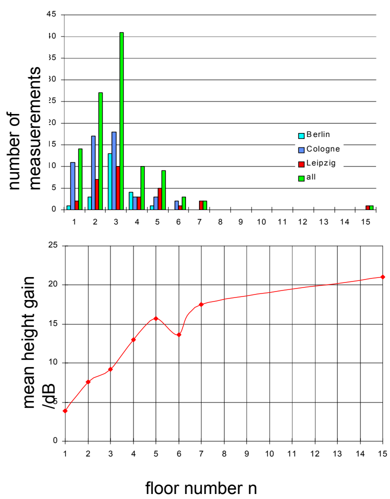
- Empirical approach: The indoor coverage on a certain floor is calculated from the „outdoor coverage“ of all pixels surrounding the building.
- For this, the following parameters are required:
  - Rules for consideration of the surrounding pixels
  - Empirical value for the penetration loss (typical values from literature: 15 to 25 dB)





Height Gain





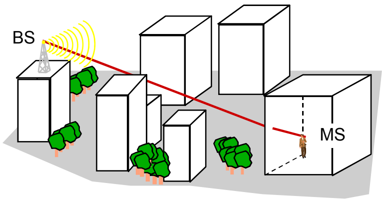
- Height gain derived from a measurement campaign:

$$G_h = 2.9n + 1.16$$

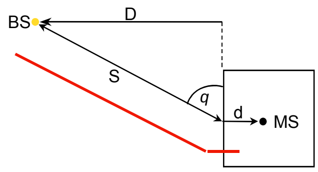
- n > 0; assumption: height of the floor of 3 m

Semi-Empirical Approach

- Considers the LOS case between the base station and the respective floor
- In case of NLOS, calculation of the building penetration using the empirical method
- Path loss calculation in case of LOS:



$$L_{in,LOS,k} = 32.4 + 20\log f + 20\log(S + d) + L_{perp} + L_{par}\left(1 - \frac{D}{S}\right)^2$$

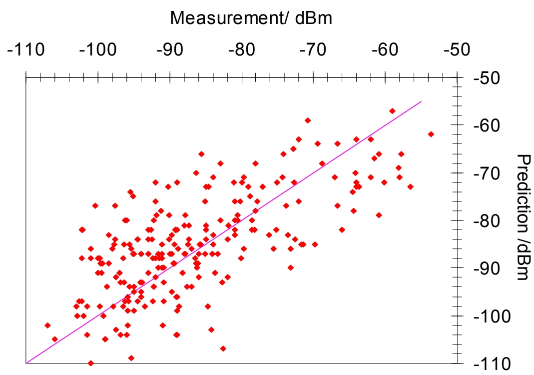


L_{perp} loss due to propagation perpendicular to the wall

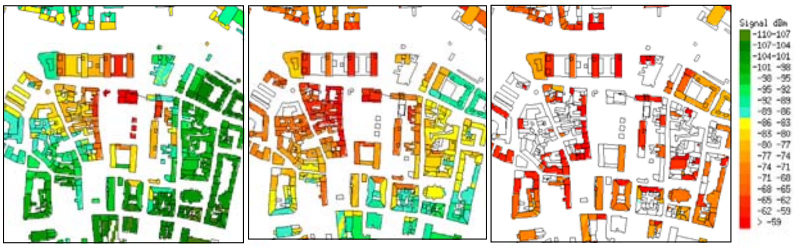
L_{par} loss due to propagation parallel to the wall

Comparison between Measurement and Prediction

- Measurement campaign in two different cities



Results of a Prediction for Various Floors



ground floor | 5th floor* | 10th floor*

* provided that the respective floor exists

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Propagation Models for Small Cells

Prof. Dr.-Ing. Thomas Kürner

Models for Small Cells

- At special „strategic“ places, e.g. at airports, train stations, exhibition centres etc., a very high network capacity has to be installed in a very small area.
- For this, the majority of base stations has to be planned inside the buildings.
- In mobile communications, the very small radio cells evolving from this are called pico cells or femto cells.
- The propagation models applied thereby can also be used in Wireless Local Area Networks (WLAN).

Empirical Models

- One-slope model
  - Only consideration of the distance dependence, with the propagation coefficient n gained from measurements:

$$L = L_0 + 10n \cdot \log(d)$$

L_0	path loss at a distance of 1 m
d	distance between transmitter and receiver in m
n	propagation coefficient

  - In literature*, values for n varying between 1.4 and 5.2 can be found. The respective values for L_0 vary between 21.9 and 44.9 dB.

*http://www.lx.it.pt/cost231

Empirical Models

- Multi-wall model (extension of the model according to Motley-Keenan)
  - Calculation of the attenuation based on an estimated number of transmissions through ceilings and walls

$$L_{[dB]} = L_{FS} + L_C + \sum_{i=1}^{I} k_{wi} L_{wi} + \sum_{j=1}^{J} k_{fj} L_{fj}$$

L_{FS}	free-space attenuation
L_C	empirical determined constant
k_{wi}	number of penetrated walls of type i
k_{fj}	number of penetrated ceilings of type j
L_{wi}	wall attenuation for wall of type i
L_{fj}	floor attenuation for floor of type j
I	number of different types of walls
J	number of different types of floors

Empirical Models

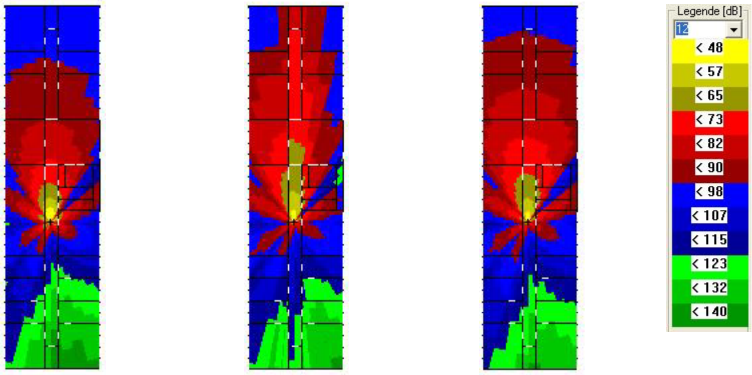
- For the consideration of the attenuation contributions due to the ceilings, several types of this model exist

- Linear attenuation model
  - A constant attenuation coefficient α in dB/m is assumed:

$$L = L_{FS} + \alpha d$$

- In literature, values for a between 0.22 and 0.62 for propagation inside a floor and α = 2.8 for propagation over several floors respectively can be found.

Comparison of the Empirical Propagation Models

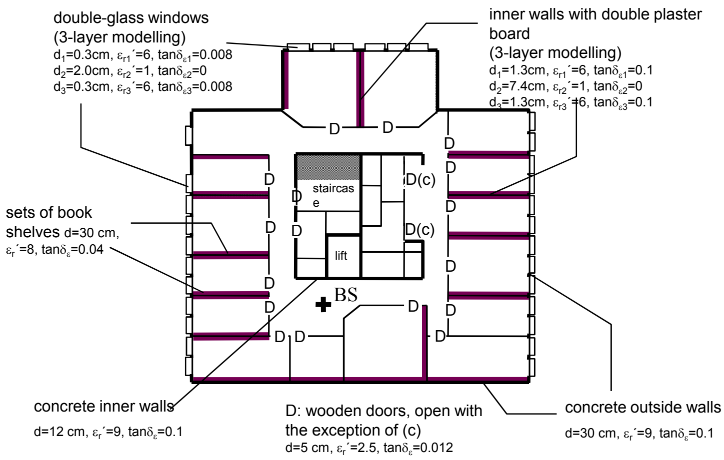


one-slope model multi-wall model linear attenuation

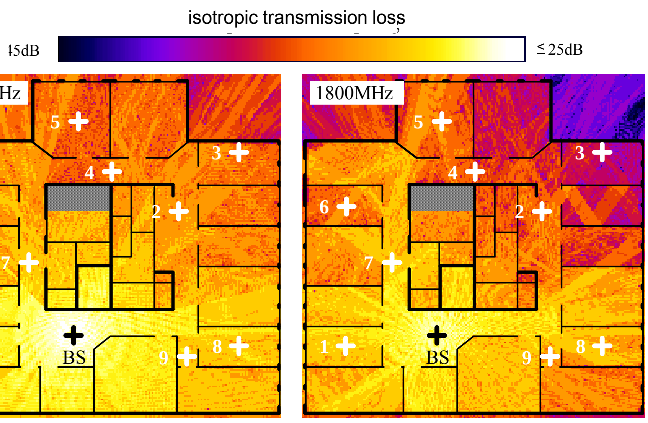
Ray-Optical Propagation Models

- Regarding pico cells, besides empirical models ray-optical methods are also applied.
- Example:
  - Ray Launching method by Cichon and Zwick (1994)
    - Modification of the Ray Launching method (ray splitting)
    - Consideration of up to 7 interactions
    - At most one edge diffraction per propagation path (LOS between Tx and diffraction edge)

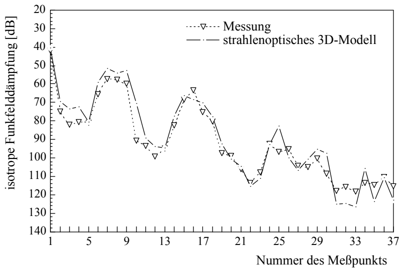
Example: Floor Plan of the 2nd Floor of an Office Building



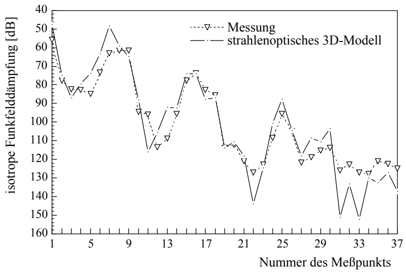
Isotropic Transmission Loss Calculated Using the Model According to Cichon/Zwick



Comparison Measurement/Prediction



856 MHz



1.8 GHz

Measuring points 1-9 on the 2nd floor, remaining measuring points on other floors

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Accuracy of Propagation Models

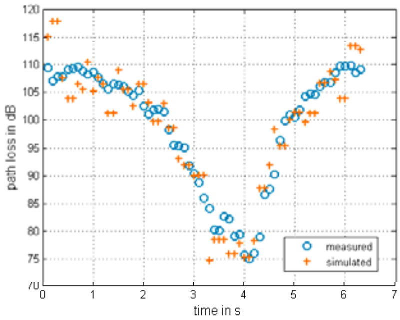
Prof. Dr.-Ing. Thomas Kürner

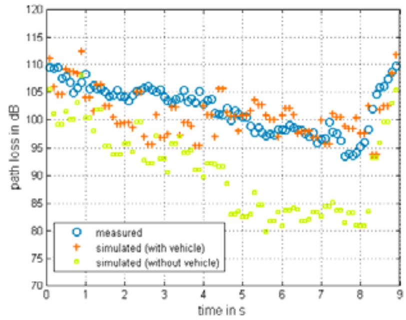
Accuracy of Propagation Models

- When the path loss and the received power, respectively, calculated by a propagation model is compared with measurements, deviations normally occur.
- Among other things, reasons for these deviations can be:
  - Propagation phenomena, which are not covered by the propagation model
    - Examples:
      - Influence of single buildings in areas for which no building data are available
      - Internal structure of buildings, characteristics of building materials
      - Sound insulating walls at motorways, in tunnels etc.
      - Road traffic

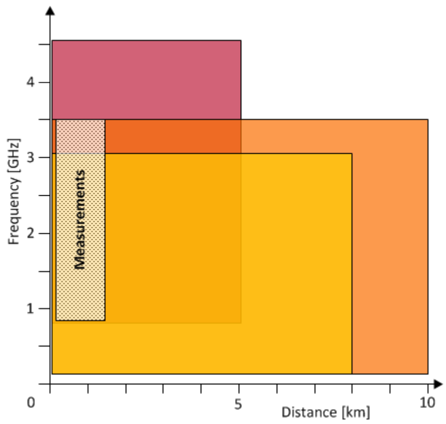
Example for the Impact of Road Traffic

- Ray-Tracing simulation and measurement at two street crossings for car-to-car communication





Exemplary Comparison of some Macro Cellular Prediction Models in Suburban Environment



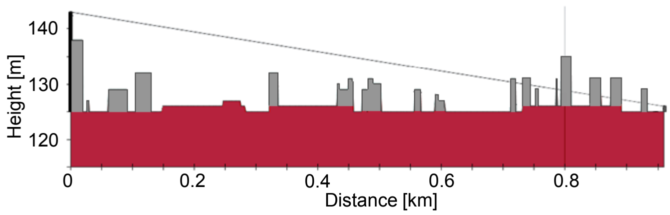
Extended Hata
Suburban

Stanford University Interim (SUI)
Category B (flat terrain, medium tree density)

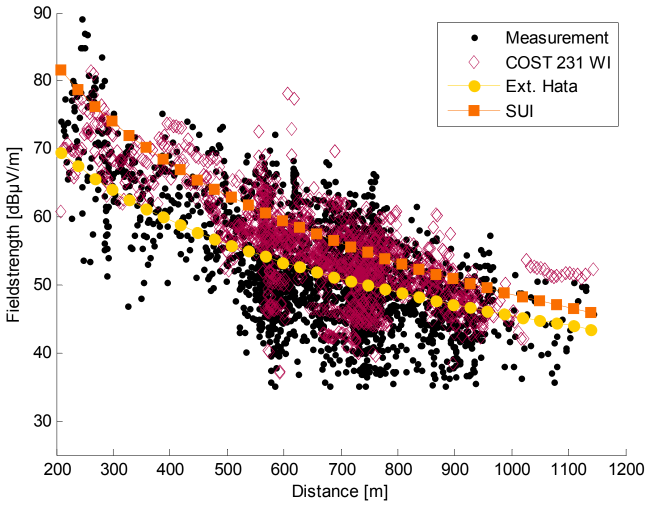
COST 231 Walfisch Ikegami
Suburban, with adjusted Lrts Har et al.

➡ Comparison in Non-LoS cases

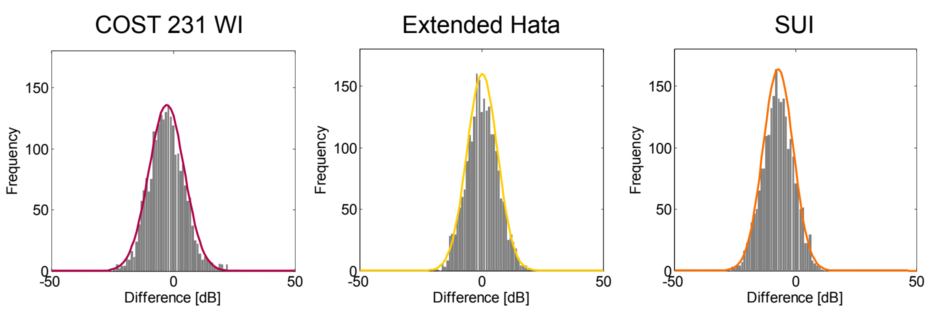
Non-LoS and parameter determination



Comparison of measurement and predictions at 860 MHz



Evaluation of prediction accuracy at 860 MHz



	COST 231 WI	Extended Hata	SUI
μ_d:	-2.87	0.21	-7.19
σ_d:	7.30	6.30	6.26
$\sqrt{\mu_d^2+\sigma_d^2}$:	7.78	6.30	9.53

Accuracy of Propagation Models

- All propagation phenomena covered by the prediction model are „modelled“ and characterised by approximation in regard to their effects.
  - No exact solution to Maxwell's Equations!
- The prediction forecasts the mean value.
  - Variation within the scope of the normal standard deviation (approx. 8 dB) does not pose a systematic error (coverage probability).
- The prediction is only as good as its input data (co-ordinates, height, antenna, tilt, orientation)!

- A good prediction model is expected to show a stable **mean value of approx. 0 dB** and a **standard deviation at the scale of 6 to 8 dB** in the complete area of an arbitrary cell.
- With this, planning results can be generated automatically by using a tool.