Technische Universität Braunschweig

Institut für Nachrichtentechnik

Coverage Planning and Planning Tools

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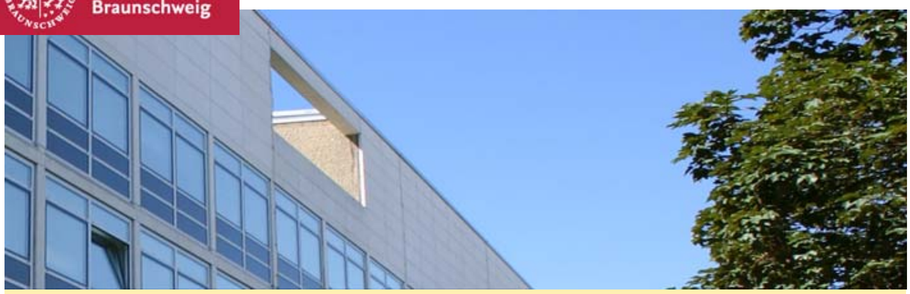


Coverage Planning

Coverage Planning

In order to carry out the tasks within the scope of the strategic radio network planning and the radio coverage planning, respectively, the following is required:

- Radio propagation models
  Prediction of the mean path loss between BS and MS (see previous files)
- Models for the description of the fading effects
  Calculation of the coverage probability
- Information about system technology regarding BS and MS
  set-up of the link budget

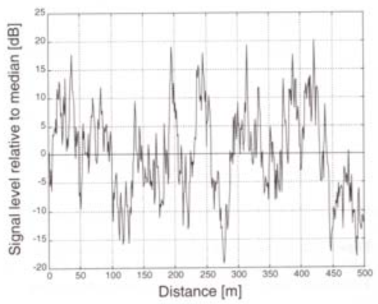
With this information, it is possible

- to estimate the number of required base stations from a given coverage probability for an area to be planned and from the information about the system technology and
- to calculate the radio coverage for a given base station and for a full network or a subnetwork, respectively.

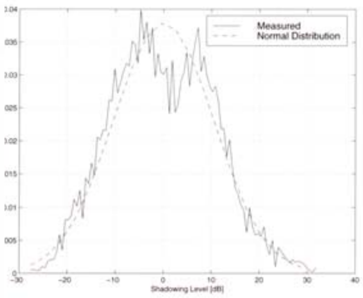
Coverage Probability

- Using a radio propagation model, only the mean path loss can be predicted.
- The mean path loss is superposed by fading effects owing to
  - local shadowing effects (long-term fading) not considered by the model
  - multipath propagation (short-term fading)
- The influence of the short-term fading phenomena is normally eliminated through averaging by the receivers in the BS and the MS, respectively (especially using GSM).

Typical Variation of Shadowing



Variation of the received power along a distance with a constant, mean predicted level



Theoretical and measured distribution of probability of the receive level

Calculation of the Coverage Probability

- Description of the variations due to long-term fading by lognormal fading, i.e. the logarithmised receive level x in dBm is normal-distributed with a mean value x_m and a standard deviation σ
- Probability density function:

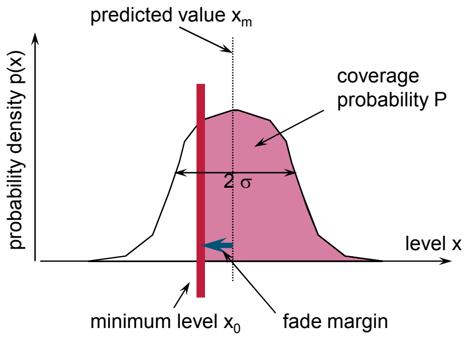
$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-x_m)^2}{2\sigma^2}}$$

- Probability that a level x_0 is exceeded (coverage probability):

$$P[x \geq x_0] = \int_{x_0}^{\infty} p(x)dx = \int_{x_0}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-x_m)^2}{2\sigma^2}} dx = \frac{1}{2} - \frac{1}{2} erf\left(\frac{x_0 - x_m}{\sigma\sqrt{2}}\right)$$

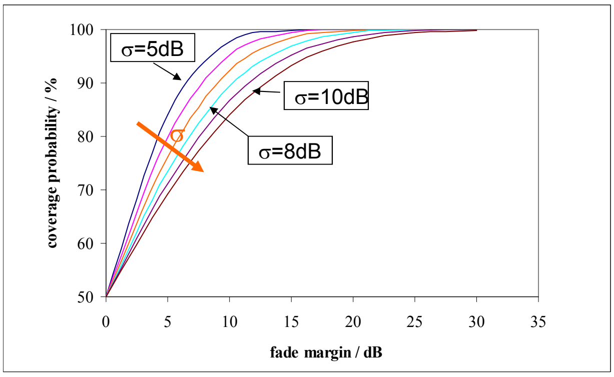
Calculation of the Coverage Probability

- In practice, x_0 corresponds to the receiver sensitivity (measured mimimum level at which reception is possible).
- Fade margin: difference between the predicted value x_m and the minimum level x_0
- Example:
  - x_0 = -100 dBm
  - x_m = -95 dBm
  - σ= 7.4 dB
  - P = 75 %



Calculation of the Coverage Probability

- Dependence of the coverage probability on the fade margin and the standard deviation



Calculation of the Coverage Probability

- $P_{x0}[x > x_0]$ corresponds to the coverage probability at a single reception point.
- In general, the lowest receive levels are obtained for the reception points located on the cell boundary.
- Therefore, a planning guideline often applied is to achieve a minimum coverage probability on the cell boundary.
- For all other reception points of the cell, lower path losses and thus higher coverage probabilities arise.
- Proportion of the reception points with a measured signal larger than x_0:

$$p_{\text{Zelle}} = \frac{1}{\text{Zellfläche}} \iint\limits_{\text{Zellfläche}} P_{x_0}(x > x_0)dA$$

- p_{zelle} is also referred to as area coverage probability.

Calculation of the Coverage Probability

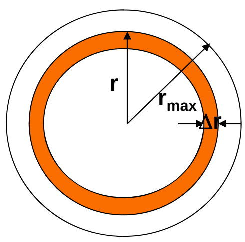
- The integral in the previous equation depends on the local distribution of the path losses. In general, it can only be solved numerically.
- Analytical solution assuming a circular cell area and a very simplified propagation model:

$$x(r) = \alpha - 10n \log \frac{r}{r_{max}}$$

$$p_{\text{Zelle}} = \frac{1}{\pi r_{\text{max}}^2} \int_0^{r_{\text{max}}} P_{x0}[x(r) > x_0] 2\pi r dr$$

$$p_{\text{Zelle}} = \frac{1}{2}\left[1 - erf(a) + e^{\frac{1-2ab}{b^2}} \left(1 - erf\left(\frac{1-ab}{b}\right)\right)\right]$$

$$a = \frac{x_0 - \alpha}{\sigma\sqrt{2}} \qquad \text{(3-7)} \qquad b = \frac{\sigma\sqrt{2}}{10n \log e}$$



Special Case

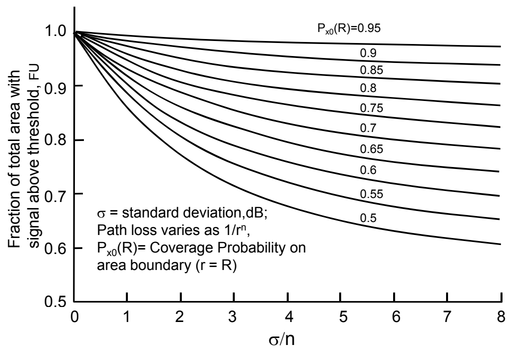
- $x_m = x_0$ for $r = r_{max} \rightarrow \alpha = x_0 \rightarrow a = 0$
- This case complies with a coverage probability of 50 % on the cell boundary.
- Equation for the calculaton of the area coverage probability is reduced to:

$$p_{\text{Zelle}} = \frac{1}{2}\left[1 - e^{\frac{1}{b^2}}\left(1 - erf\left(\frac{1}{b}\right)\right)\right]$$

- The area coverage probability only depends on the ratio σ/n.
- Example: For n = 3 and σ = 9 dB, p_{zelle} = 71 % is obtained.

Calculation of the Coverage Probability

- Relation between the coverage probabilities on the cell boundary and inside the cell:



- Example: x_0 = -100 dBm; x_m = -95 dBm; σ = 7.4 dB; P_{x0} = 75 %; n = 3.8
  $\rightarrow p_{Zelle} \approx 91$ %

Link Budget

- Maximum allowed transmission loss:
  - The cell size depends on the attenuation of the signal that may occur during radio propagation, without falling below the required C/I ratio at the receiver even at maximum transmitting power. The maximum allowed propagation loss is also called link budget.
  - General equation for the maximum allowed propagation loss:

$$L_F \leq L_{F\,\max} = \frac{P_S}{dBm} - \frac{P_{E\,\min}}{dBm} + \frac{G_R}{dBi} + \frac{G_T}{dBi} + \frac{\text{other gains}}{dB} - \frac{\text{other losses}}{dB} - \frac{\text{margins}}{dB}$$

- P_S transmitting power in dBm
- P_{emin} minimum received power
- G_R gain of the receive antenna
- G_T gain of the transmit antenna

Link Budget

- Especially, characteristics of the base station and the mobile station have an influence on the link budget, including
  - maximum level of the output power of the BS
  - characteristics of the BS antenna (antenna diagram, gain, installation height etc.)
  - cable losses between the transmission power amplifier of the BS and the antenna
  - diversity gains
  - maximum level of the output power of the MS
  - gain of the MS antenna (assumption: mostly 0 dBi)
  - receiver sensitivity

Example: Link Budget for GSM1800

- for mobile class 1 (1W output power) plus the losses antenna-to-human
- Source: GSM 03.30 Version 8.3.0. Release 1999, ETSI TR 101 362 V8.3.0

		UL	DL	
+	maximum transmit power [dBm]	30	42	Transmitter (Tx)
-	line losses [dB]	0	2	
-	Tx losses (isolation, combiner, filter) [dB]	0	3	
+	gain of the transmit antenna [dB]	0	18	
-	losses antenna-human [dB]	3	0	
-	minimum received power [dBm]	-104	-100	Receiver (Rx)
+	gain of the transmit antenna [dB]	18	0	
+	diversity gain [dB]	5	0	
-	losses antenna - human [dB]	0	3	
-	line losses [dB]	2	0	
-	fading margin (P_{xo} = 75%, σ = 8 dB) [dB]	6	6	
-	interference margin [dB]	3	3	
=	maximum propagation loss [dB]	143	143	

mobile station | base station

Cell Coverage

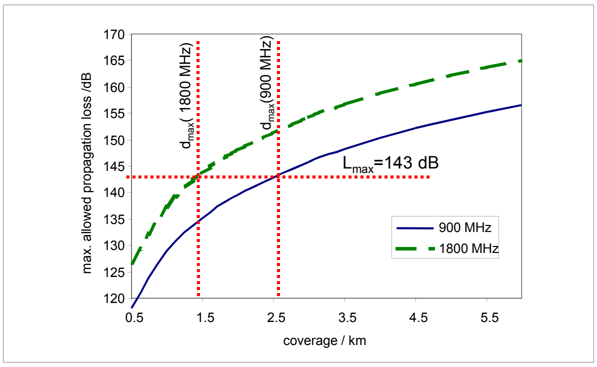
- In order to estimate the coverage of a cell, a simplified propagation model is assumed:
  - Example: Okumura Hata and Hata, respectively
    - Propagation in urban areas (“suburban“, D = 0 in eq. (2-46))
    - BS antenna height: 25 m
    - MS antenna height: 1.5 m

→ distance dependence of the propagation loss:

- 900 MHz: $$L(r) = 128.8 + 35.7\log(r/km)$$
- 1800 MHz: $$L(r) = 137.3 + 35.7\log(r/km)$$

Cell Coverage

- Reelation between the coverage and the maximum allowed propagation loss



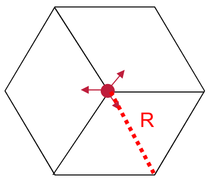
Cell Coverage

- Calculation of the cell area regarding hexagonal networks:
  - Hexagonal area (coverage area of a BS):

$$A_h = \frac{3\sqrt{3}}{2} R^2$$

  - Cell area in case of threefold sectorisation:

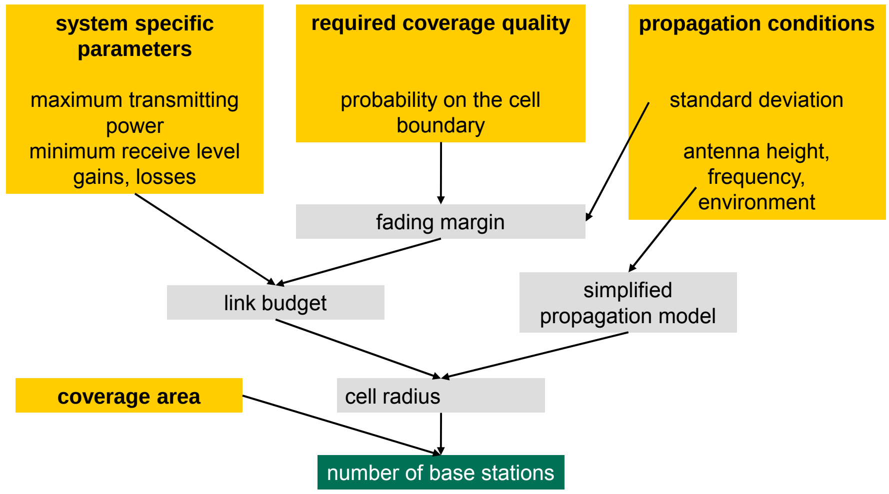
$$A_{Sektor} = \frac{\sqrt{3}}{2} R^2$$



- Number of base stations required to cover an area A:

$$n \approx 0.4 \frac{A}{R^2}$$

Approach to Estimate the Number of Base Stations



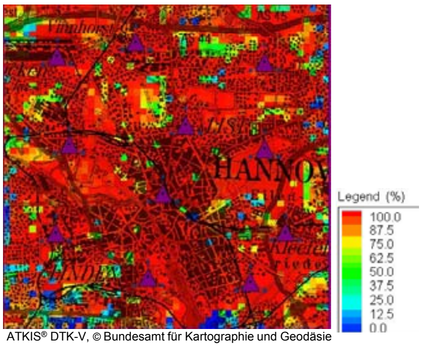
Planning Example: GSM1800 Network for Hannover

- Assumptions:
  - Link budget for GSM1800 according to GSM03.30 incl. 3dB body loss
  - Standard deviation for long-term fading: 7 dB
  - Calculation for two scenarios in terms of the assumed coverage probability P on the cell boundary:

coverage probability P	70 %	95 %
fading margin	3,7 dB	11,5 dB
maximum propagation loss	145,3 dB	137,5 dB
cell radius	1,8 km	1,5 km

Planning Example by Means of Potential Sites

- Estimation of the number of BSs using the previous equations and not idealised propagation conditions



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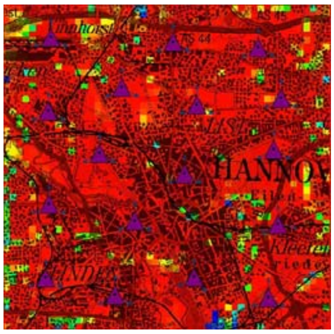
Coverage for P = 70 % (11 BSs)



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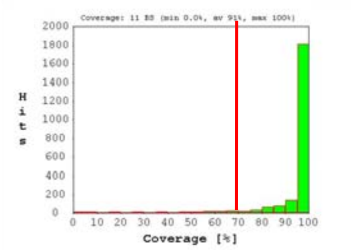
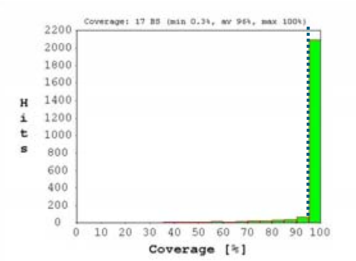
Coverage for P = 95 % (17 BSs)

Distribution of the Coverage Probabilities Considering the Planning Example Hannover



planning guideline P = 70% (11 BSs)



planning guideline P = 95% (17 BSs)

- At some reception points, the propagation conditions are less favourable than assumed in the (idealised) simplified propagation model.
- In practice, in strategic radio network planning improved methods for the estimation of the number of BSs are applied to some extent (consideration of topography and land use).

Site Planning

- Precise site planning
  - Determination of search areas for the potential sites


  - Acquisition of a suitable site inside a search area
  - Result of the acquisition: several possible sites (location candidates) if applicable

Examples of Sites for Mobile Radio Antennas




Testing of Location Candidates

- Testing of the location candidates in terms of
  - their suitability for radio communication
    - Examination of the covered area by means of a prediction
    - Performance of a CW measurement if applicable

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Testing of Location Candidates

- Space for system technology and antennas
- Possibilities to connect the BS with the BSC (radio relay, leased circuit)
  - regarding radio relay, additional test for LOS
- Application for permissions (building permit, EMCE certificate)

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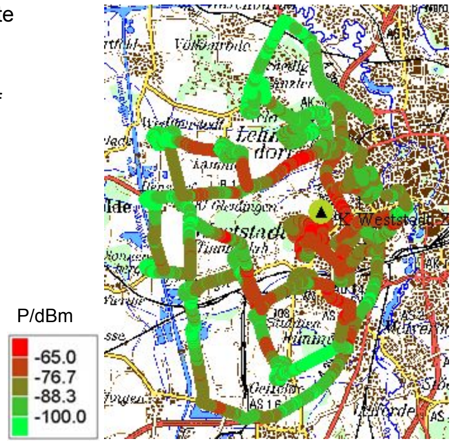
Example of a CW Test Run

- Result of a CW test run for a potential site in Braunschweig-Weststadt
  - frequency: 1800 MHz
  - omni-directional antenna with a gain of 11 dBi
  - antenna height: 38 m



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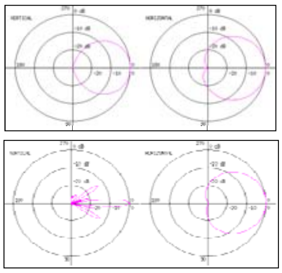
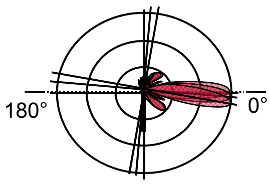
Planning in Detail

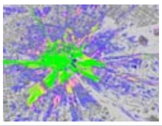
- Performance of the detailed planning:
  - Within the scope of site planning, the following parameters relevant for radio propagation have to be determined:
    - number of sectors
    - antenna type
    - antenna height
    - antenna orientation (azimuth and tilt)
      - tilt: electrical and mechanical, respectively
    - radiated power
    - number of TRXs



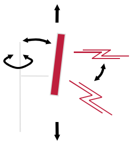


Combination of the Path Loss Prediction with the Antenna Diagram

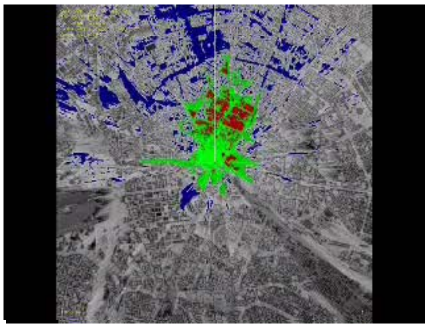
path loss without antenna



antenna configuration
- antenna type
- azimuth
- tilt

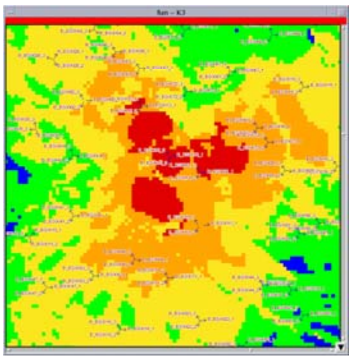


path loss incl. antenna diagram

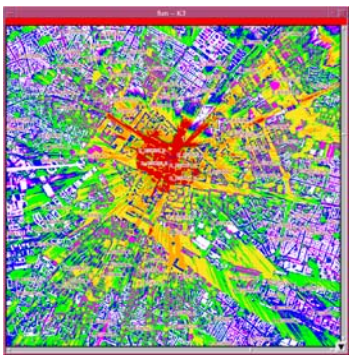


antenna height: 41 m, electrical tilt: 0-8°, azimuth: 0-120°

Influence of the Propagation Model/Geographic Data on the Prediction in Urban Areas

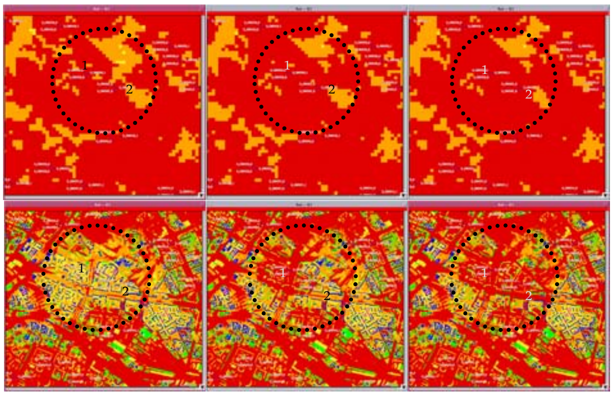


Macro cell model
+ land use data



Ray Tracing model
+ building data

Coverage Prediction for a Network Extension in an Urban Area



macro cell model
+ land use data

Ray Tracing model
+ building data

without BS1, BS2 | with BS1, without BS2 | with BS1, BS2

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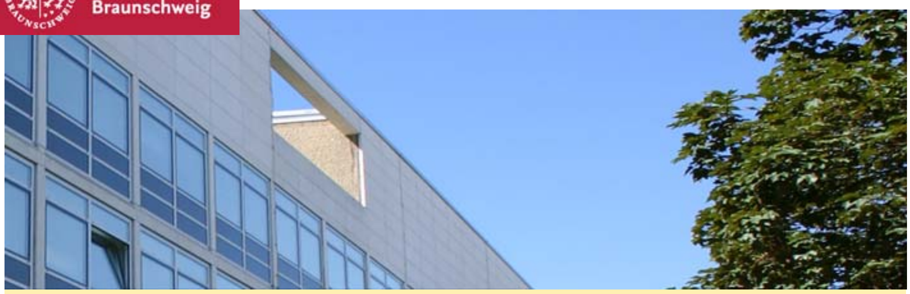
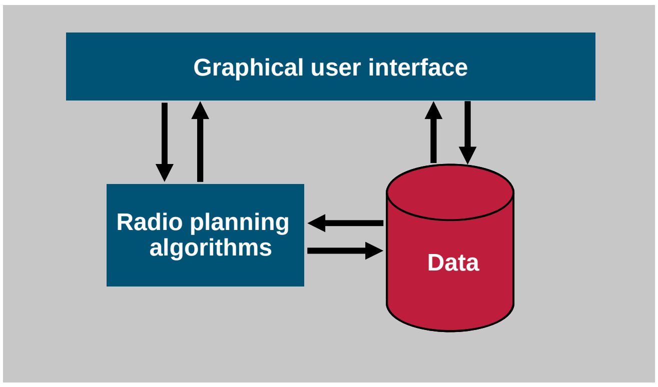


Planning Tools

Radio Network Planning Tools

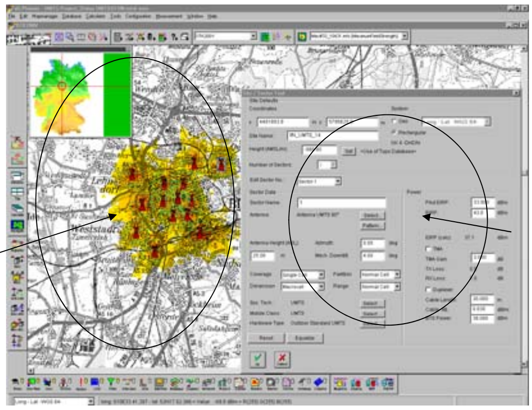
- A radio network planning tool is the central tool for the most tasks to be carried out within the scope of radio network planning.
- In principle, such a radio network planning tool consists of three main components:
  - Graphical user interface for the input of data as well as for the visualisation of calculation results and stored data sets, respectively
  - Data base for the storage of all data
  - Radio network planning algorithms for the performance of the required calculations

Components of a Radio Network Planning Tool



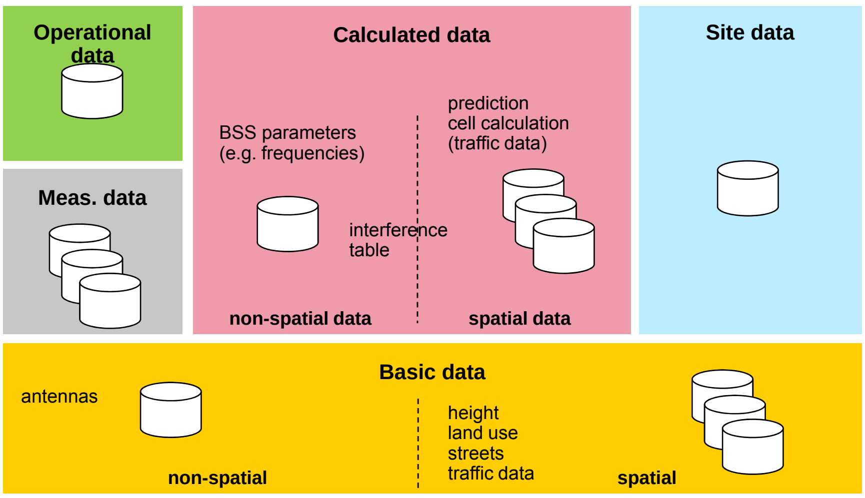
Example of a Radio Network Planning Tool for the Graphical User Interface

geographical modelling (digital terrain data)



mask for the input of the site data

Data Management in a Radio Network Planning Tool (Example GSM)



Categorisation of Data

- Spatial data
  - Raster or vector data that can only be visualised using a geographic surface (all maps, but also calculation results)
  - Large amounts of data (→ versioning is difficult)!
- Non-spatial (alphanumerical) data
  - Data that can also be described alphanumerical
- Basic data
  - Data that are not modified in the planning process, e.g. antenna diagrams as well as geographic background data
- Site data
  - Site data (antenna data, co-ordinates, antenna height etc.)

Categorisation of Data

- Spatial calculation results
  - e.g. predictions, cell presentations
- Cell-related planning parameters (planning status)
  - BSS parameters (frequencies, CI, LAC, RAC, handover parameters etc.)
- Operational data
  - Structure is identical to cell-related parameters
  - Status of data used in the operational network
  - Modifications in terms of the planning status, e.g. by manual network optimisations
- Measurement data
  - Large amounts of data where required
  - Spatial data sets (e.g. test runs based on coverage measurements)
  - Alphanumerical data (e.g. measurement data from OMC)