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GIS Data for Radio Network Planning

Prof. Dr.-Ing. Thomas Kürner


Digital Terrain Data and their Processing

- For the application of propagation models to natural terrain and building structures, respectively, digital terrain data are required.
- With regard to this, three aspects play an important role:
 - Classification of data (content, resolution, accuracy and format, respectively)
 - digital terrain height models (raster data)
 - land use data (raster data)
 - street information (vector information)
 - digital building models (raster or vector information)
 - Co-ordinate systems
 - geographical co-ordinate systems
 - Cartesian co-ordinate systems
 - Efficient processing of digital terrain data
 - determination of profiles
 - line-of-sight check
 - determination of main obstacles
 - etc.



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Classification of Data


Classification of Data

- Digital terrain models (in German: Digitale Geländemodelle DGM)
 - Describe the height of the terrain, relating to sea level without buildings and vegetation, respectively
 - Normally, data are available country-wide
 - Example 1: digital elevation model DGM 50 M745 for Germany
 - raster width of the original data: 1 arc second in length and in width (in Germany equivalent to approx. 30 m x 20 m)
 - applied as raster with a resolution of 50 m x 50 m
 - source: topographical maps (TK 50 M745)
 - accuracy: position ± 26 m, height ± 20 m
 - Example 2: digital terrain model 250 (DGM 250) for Germany
 - raster width 200 m x 200 m (also raster resolution)
 - source TK50
 - accuracy as in case of DGM 50 M745
 - The description of digital terrain models is normally also valid across borders between countries.



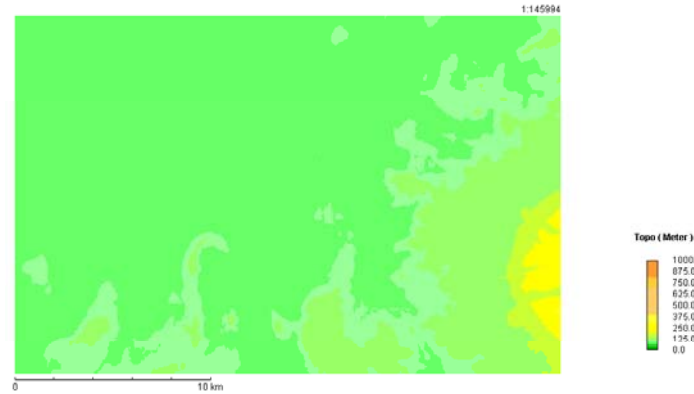
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Example: Digital Terrain Model for the Environment of Braunschweig (Raster Data with a Resolution of 50 m)



ATKIS® DGM50 M745, © Vermessungsverwaltungen der Länder und BKG 2003



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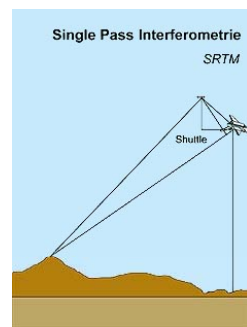
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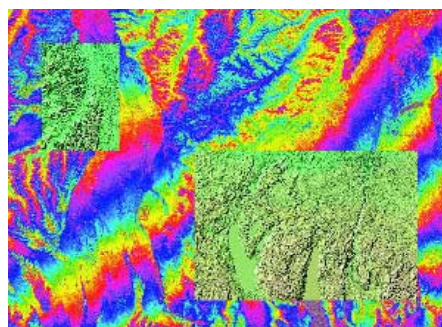
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Example of Generation of Digital Height Models

- SAR (Synthetic Aperture Radar) Interferometry SRTM (Shuttle Radio Topography Mission)



Mode of record



Interferogram

source: <http://www.dlr.de/srtm>



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Land Use Data

- Classification of the surface on the basis of satellite records (e.g. Landsat Thematic Mapper [TM])
- Data sets are not consistent, but dependent on the specification of the respective customer (problems if areas located at borders between countries are considered)
- Example: land use data available at IfN
 - 15 different classes, originally recorded with a resolution of 25 m x 25 m
 - classification errors < 10 %
 - typical resolutions: 50 m x 50 m and 200 m x 200 m, respectively
- Aggregation of data for the transition from data with high resolution to data with low resolution, e.g. by means of the majority principle (may cause problems!)

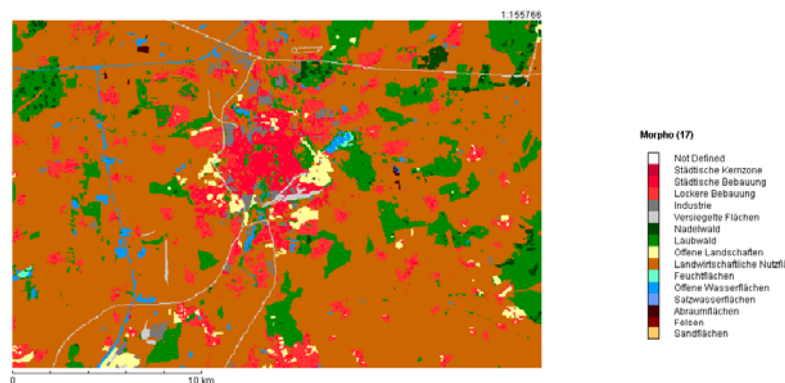


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Example: Land Use Data for the Environment of Braunschweig (Raster Data with a Resolution of 50 m)



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Specification of Land Use Data

- Specification of land use data considering as an example three classes in urban areas:
 - Dense urban area:

Urban area with buildings of more than five storeys (estimated), connected building lines; „dense urban areas“ only exist in large cities; Large building complexes, very small proportion of green space. The precise number of those large cities and the minimum number of residents, respectively, is not given. In villages and small towns this class does not exist within „dense urban areas“, open space and green space etc. have also to be classified. Outside the city centre and the historic centre, respectively, „dense urban areas“ can also be found
 - Urban areas:

Urban areas with buildings of up to five storeys (estimated), interrupted building lines and a higher proportion of green space
 - Suburban areas:

Urban areas with smaller detached buildings of up to two storeys; building lines are located near streets and can also be unsteady and interrupted; a high proportion of green space



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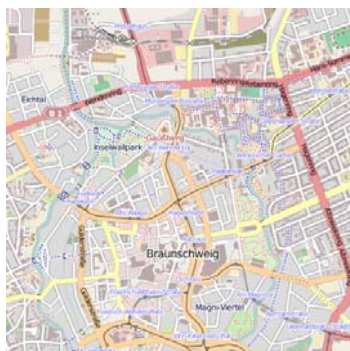
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Generation of Land Use Data

- Example of the generation of simple land use data on the basis of maps at OpenStreetMap data (www.openstreetmap.org)



Map at OpenStreetMap



Land use data



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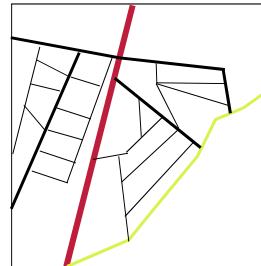
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Street Vector Data

- Street vector information serves as an additional source to improve the propagation models in urban areas.
- Street vectors are described by their location (typ. accuracy ± 10 m in urban areas; ± 30 m in rural areas) as well as by their attributes (federal road, major street etc.).
 - Utilisation of the location information
 - Detection of propagation along street canyons
 - Utilisation of the attribute information
 - Upgrading of the land use data by combining the land use classes with the street attributes
 - From n different land use classes and m street attributes, n x m different classes can be built.



- federal road
- national road
- major street
- side street



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Digital Building Models

- Contain information in terms of location and contour of the buildings
 - Including superstructural parts, courtyards and styles of roofs
 - Height of the buildings (relative and absolute)
 - Information about the vegetation
 - Area-wide information about the electrical characteristics of the building walls are not available at present
- Use of vector and raster data formats
- Typical accuracy of the vector data: 1-2 m standard deviation in terms of location and height
- Typical raster width using raster data: 5 m



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Example: relative building heights and vegetation in a digital building model



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Generation of Digital Building Models

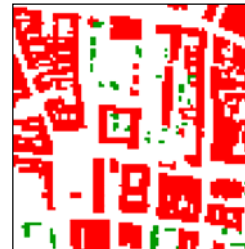
- Generation of digital building models from aerial images using methods from the stereo photogrammetry
- The derivation of raster data from the vector data guarantees the data consistence between both data sets (important in case that raster and vector data are used simultaneously).



arial image



vector data



raster data



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Example: Digital Building Model of Braunschweig

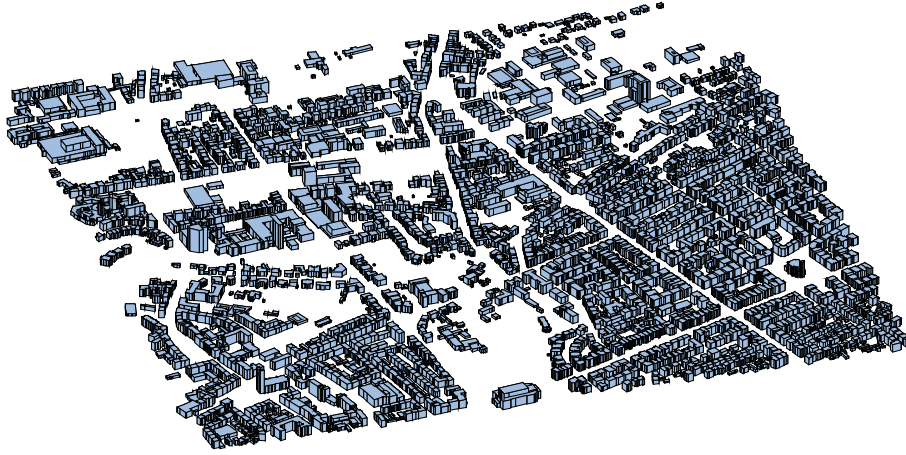


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Digital Building Model of Braunschweig



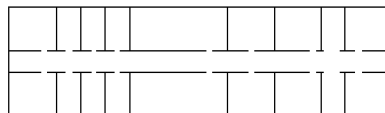
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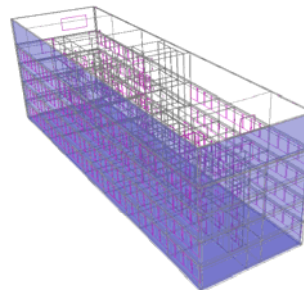
Building Plans

- For use of prediction models in buildings, detailed building plans are required
- Similar as in case of the digital building models, it is problematic to determine the characteristics of the wall materials systematically



↑ 2D building plan (sufficient for the prediction at a storey)


3D building plans for the prediction over multiple storeys →




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Coordinate Systems


Coordinate Systems

- For acquisition, processing and presentation of geometrical information incurring in the field of radio network planning, some basic knowledge in the field of geodesy is required
- For practical reasons, data of a radio network planning tool are ideally processed and presented at one layer using a Cartesian co-ordinate system
- Due to the form of the earth, such a presentation is only possible by approximation in a small area
- Describing the surface of the earth as a layer, distortions (e.g. distortions in length, angular distortions) occur
- In order to minimise these distortions, there are different co-ordinate systems for the different regions of the earth and for the different types of problems, respectively



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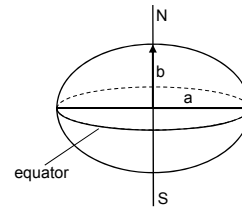


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Coordinate Systems

- Considering the **earth as an ellipsoid of rotation**
 - Oblateness at the poles of the earth
 - Measurement for the oblateness:

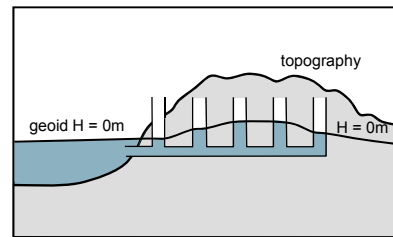
$$f = \frac{a-b}{b}$$



- Considering the **earth as a geoid**
 - Transition from the geometric description of the earth (ellipsoid) to the physical approach (geoid)

- Definition:

The geoid describes the shape of the earth and is defined by the ocean surface assuming that the surface is quiescent.

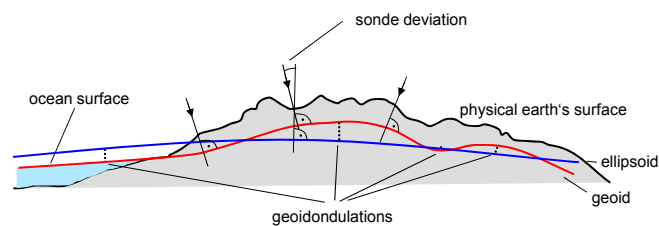


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Topography, Geoid and Ellipsoid



- Three-dimensional positioning
 - Geoid: physical origin, reference face for the height
 - Height date for Germany (zero point of the geoid)
 - Old West German States: level of Amsterdam
 - New Federal States: level of Kronstadt
 - Ellipsoid: analytical surface, reference system for the position



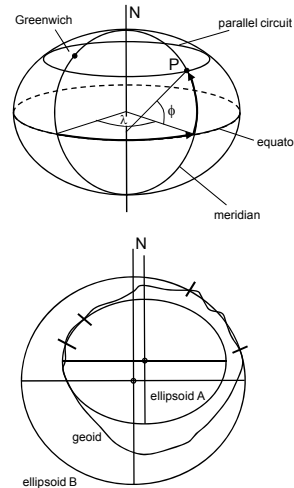
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Ellipsoid of Rotation

- Ellipsoid of rotation as a reference system for the rotational positioning sensing
→ geographical coordinate system
- Reference ellipsoid
 - Provides for an optimal adaptation between the ellipsoid and the geoid
 - Optimised adjustment range between ellipsoid and geoid mostly limited to state areas
- Geodesic date of the position reference systems
 - Determines the reference system for the position and describes the relative position to the earth
 - Mathematical description by 5 parameters (2 parameters determine the dimension of the ellipsoid and 3 parameters determine the position relatively to the earth)



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Ellipsoid of Rotation

- Most countries use special ellipsoids, that approximate the respective geometrical conditions reasonably well:

ellipsoid	semi-major axis a	oblateness f
Bessel	6377397.155	1:299.1528128
Hayford	6378388	1:297
Krassowsky	6378245	1:298.3
WGS 84 (World Geodetic System 1984)	6378137	1:298.257223563

- In Germany, Austria, Switzerland, The Netherlands, Norway and Sweden the Bessel ellipsoid is mainly used.
- In Eastern Europe, the Krassowsky ellipsoid is commonly used. Therefore a lot of maps in the new Federal States are based on this ellipsoid.
- WGS 84 is used e. g. within the scope of the frequency co-ordination at the country borders as well as in case of the GPS rotational position sensing.



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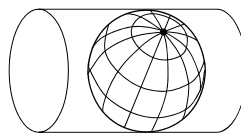
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Map Projections

- Goal of map projections
 - Image of the three-dimensional earth on a plane
 - Graphical and numerical determination of the system
- Consequence
 - Distortions that are minimised by the kind of projection applied
 - Depending on the required accuracy and the extension different projections can be chosen



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Map Projections commonly used

- Gauß Krüger Projection (Germany)
 - Type of image: conformal cylindrical image according to Gauß
 - Feature of the image:
 - Length-preserving image of the main meridian
 - Conformal, i. e. angle-preserving in the smallest parts
 - Deviation of the isometrism on the axis of ordinates
 - for minimising of the distortion a 3° stripe system exists
 - Overlap range of 0.5° at both sides of the limiting meridians
 - Main meridians exist at:
 - 6° E (= GK2), 9° E (= GK3), 12° E (= GK4), 15° E (= GK5)
- UTM (Universal Transversal Mercator) projection
 - Application of meridian stripes of 6° width (= zones)
 - Zone number is calculated from the relative position to the prime meridian (Germany is located in the zones 32 and 33)
 - Application particularly in the USA, in Russia, in the aviation as well as in the military



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Coordinate Transformation

- Coordinate transformation
 - For the conversion of co-ordinates from different projections and from reference ellipsoids respectively, transformation methods exist that are available in most radio network planning tools.



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Processing of Digital Terrain Data

Processing of Digital Terrain Data

- The goal of terrain data processing is to determine the parameters relevant for the propagation calculation from the digital terrain data as well as from the positions and antenna heights of BS and MS, respectively.
- Thereby, a compromise between the achievable accuracy and the computation time often has to be made.
- In this section, some of the most important methods are explained.



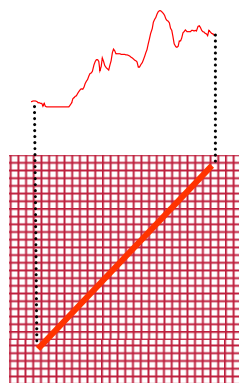
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Determination of Profiles from Raster Data

- Profiles
 - A profile (profile vector) is understood as the terrain section between any two points within a terrain. This vector contains information about the point co-ordinates of the single points, their height, the distance from the point to the starting point as well as further attributes where applicable (e.g. the land use class).
 - The digital elevation model is referred to plane earth. Additionally, in the profile vector the curvature of the earth has to be considered.
 - For the determination of these profiles, different methods exist which have an influence on the accuracy of the prediction model and on the computation time.



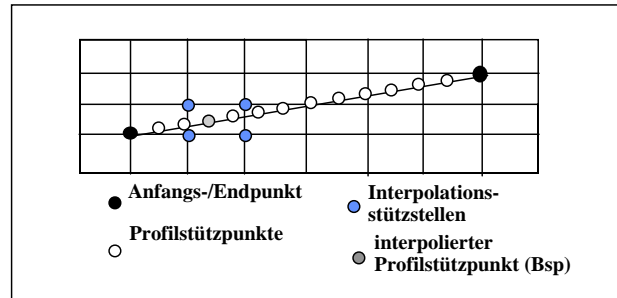
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Methods for the Bilinear Interpolation of the Elevation Values

- Determination of the profile at equidistant nodes along a curve between mobile station and base station



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Methods of the Bilinear Interpolation of the Elevation Values

- Since the nodes do not coincide with the centres of the pixels (x_p, y_p) , the respective elevation values h_p from the elevation values h_{ij} of the 4 neighbouring pixels (x_0, y_0) , (x_1, y_1) , (x_0, y_1) and (x_1, y_0) have to be interpolated:

$$h_p = \sum_{i=0}^1 \sum_{j=0}^1 h_{ij} \prod_{\substack{k=0 \\ k \neq i}}^1 \frac{x_p - x_k}{x_i - x_k} \prod_{\substack{k=0 \\ k \neq j}}^1 \frac{y_p - y_k}{y_j - y_k}$$

- The value of the pixel (x_i, y_i) with the shortest distance to (x_p, y_p) is taken as the value for the land use class (clutter class) of the respective pixel (x_p, y_p) .



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Approximation Methods from Computer Graphics

- The basic principle of a method known as Bresenham algorithm says that the point next to the direct connection between the starting and the end point is always chosen.
- In principle, there are two possibilities to determine the nodes:
 - Connecting lines between nodes running parallel to the co-ordinate axes (single Bresenham algorithm).
 - Connecting lines can also run diagonal (double Bresenham algorithm and digital differential analyser, respectively). In this case, the nodes of the double Bresenham algorithm form a subset of the nodes of the single Bresenham algorithm.
- In both cases, the elevation and clutter values of the appropriate raster point, respectively, are assigned to the nodes.



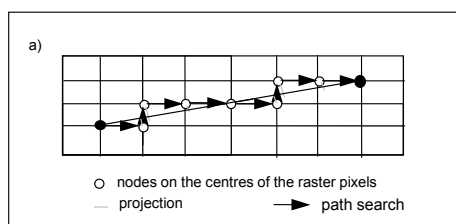
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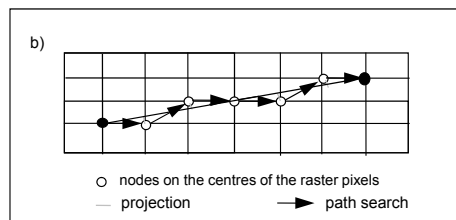


Approximation Methods from Computer Graphics

- Profile determination using the single Bresenham algorithm



- Profile determination using the double Bresenham algorithm



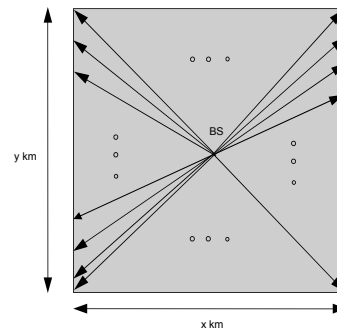
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Approximation Methods from Computer Graphics

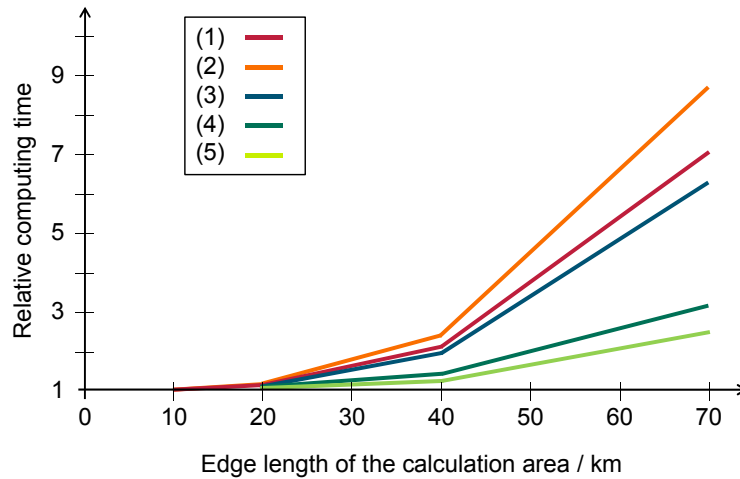
- Quick profile algorithms for area calculations
 - so far: determination of a profile for every pair of a BS and MS
- In case of area prediction, in the profiles of the MS positions on the edge of the calculation area, all points between MS and BS are also included
- The determination of the profiles on the edge of the calculation area is sufficient



Comparison of Different Profile Algorithms for a Macro Cell Prediction

method	profile calculation all BS → MS	fast profile calculation only BS → edge
profile algorithm with bi-linear interpolation of the elevation values	(1)	-
single Bresenham algorithm	(2)	(4)
double Bresenham algorithm	(3)	(5)

Relative Computation Times for Five Different Alternatives



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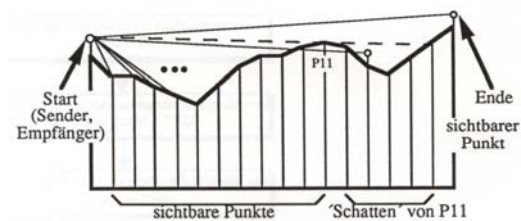


Line-of-Sight Check

- Line-of-Sight (LOS) Check
 - Between two observation points P_0 and P_i , line-of-sight exists if the following condition is fulfilled:

$$\frac{h_i - h_0}{d_i - d_0} > \max_{j; 0 < j < i} \frac{h_j - h_0}{d_j - d_0}$$

- h_i elevation value of point P_i including the height of the observation point above the profile (antenna height)
- d_i distance between P_i and P_0



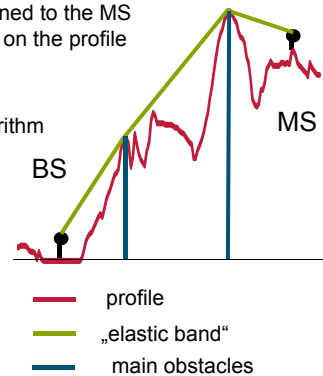
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Main Obstacles

- Determination of main obstacles
 - Depiction for the determination of the main obstacles (HK):
 - From the BS antenna a virtual elastic band is tightened to the MS antenna: At the points of support of the elastic band on the profile the HKs are located.
- Calculation:
 - Recursive application of a modified LOS check algorithm
 - Determination of the maximum slope
BS → MS
 - Point with the maximum slope: 1st HK
 - Determination of the maximum slope
1st HK → MS
 - Point with the maximum slope: 2nd HK
 - Continuation until no more HK is found



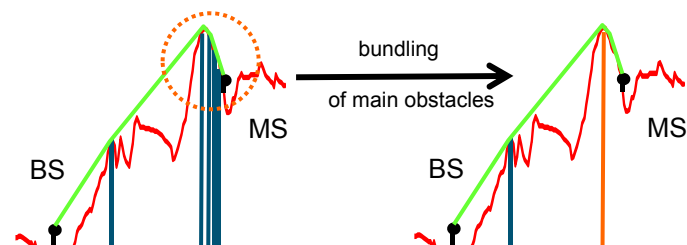
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Reduction of Main Obstacles

- In case of very extended obstacles it might occur that an obstacle is represented by several main obstacles. This leads to an overestimation of the diffraction loss.
- Bundling of several main obstacles is required.



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Reduction of Main Obstacles

- Criterion for the bundling of obstacles
 - A method practically applicable to macro cells allows the combination of main obstacles for the calculation of the diffraction loss according to the knife edge method in case that one of the following two conditions is fulfilled:

$$d_{HK(i+1)} - d_{HKi} < 0.5km$$

$$\frac{d_{HKi}(d_{MS} - d_{HK(i+1)})}{d_{HK(i+1)}(d_{MS} - d_{HKi})} \geq 0.91$$

- d_{MS} distance between mobile station and base station
- d_{HKi} distance between i^{th} main obstacle and base station



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Effective Antenna Height

- Determination of the effective antenna height (h_{eff})
 - Regarding propagation of electromagnetic waves over the surface of the earth, further contributions caused by reflection and scattering at the surface of the earth also exist in addition to the free-space contribution.
 - In this context, the procedures are often too complex to carry out an exact modelling of these effects. It is possible, however, to model these effects quite well by stating an effective antenna height.
 - The effective antenna height has a decisive influence on the calculated propagation loss. Very strong variations or inaccuracies in terms of the calculated effective antenna height normally results in large prediction errors.
 - From literature, different methods for the determination of effective antenna heights are known, the advantages and disadvantages of which depend on the different terrain configurations.



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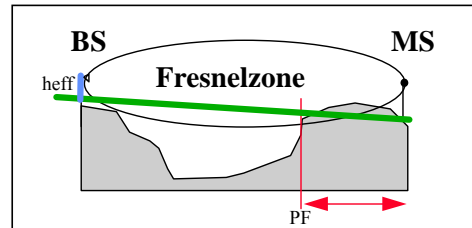
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Method A

- Determination of the effective antenna height according to the **method of the sphere of influence of the Fresnel zone**



- Reflection and scattering at the surface of the earth have a very strong impact on the received signal, especially in case the reflection point is located within the first Fresnel zone.



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Method A

- Reflection points located close to the mobile station have a stronger impact than reflection points close to the base station.
- Therefore, it is obvious to use only those parts of the profile for the calculation of the effective antenna height which extend into the first Fresnel zone.
- In case several of those sections exist, the one located nearest to the mobile station is chosen.
- Therefore, the sphere of influence of the first Fresnelzone is defined that way that, initially, the first point in case of which the elevation profile subtends the first Fresnel zone is determined.
- Starting from this point, the profile is observed towards the BS until the first Fresnel zone is left again (point PF in the graphic).



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Method A

- Between PF and MS, the regression line over the profile is calculated.
- The effective antenna height is calculated from the distance between the BS antenna and the regression line.
- Advantages of this definition:
 - The effective antenna height is invariant compared to a virtual rotation of the terrain and antenna configuration.
 - Configurations matching by rotation are physically equal.
- Disadvantages of this definition:
 - Very large gradients of the elevation profile located close to the mobile station can result in extremely high or negative effective antenna heights.



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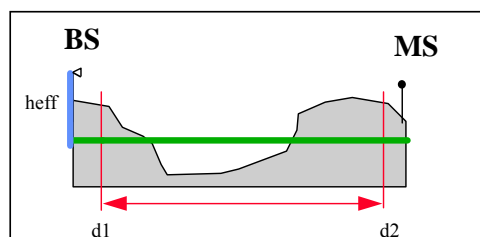
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Method B

- Determination of the effective antenna height relating to the **mean terrain height**



- Okumura: calculation of the effective antenna height relating to the mean terrain height at a distance of 3 km to 15 km to the base station



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Method B

- Only reasonable for distances smaller than 15 km, since otherwise the terrain behind the mobile station would also be considered
- At distances shorter than 3 km, the terrain between BS and MS does not have an influence on the calculation at all
- Modified version of the definition according to Okumura: The mean terrain level is generally determined between the distances d_1 and d_2
 - Reasonable values adapting to the respective distance d between MS and BS are $d_1 = 0.1d$ and $d_2 = 0.9d$
- This definition is quite easy to handle and considers the terrain between MS and BS
- The disadvantage is that very often a – physically not reasonable – negative effective height might occur



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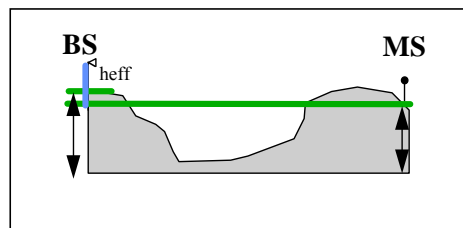
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Method C

- Determination of the effective antenna height according to the **method using the lower antenna ground level** („Spot Height“)



- The effective antenna height can be simply defined by calculating the antenna height of the BS above the lower of the two base antenna heights of the MS and the BS, respectively.



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Method C

- Disadvantage of this definition:
 - Profile between MS and BS is not considered.
- Advantage:
 - No negative effective heights occur.
- This method provides realistic values, especially in case a high site is located above a lowland plain



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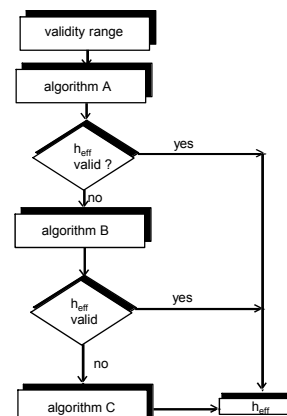
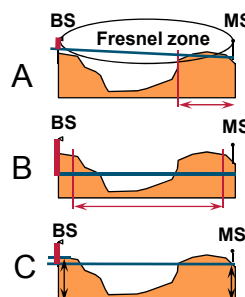


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Combining the Methods

- The advantages of the three methods described can be combined in a heuristic method.

- Definition of a validity range for h_{eff} : $h_{\text{eff,min}} < h_{\text{eff}} < h_{\text{eff,max}}$
 $h_{\text{eff,min}}$ height of the base station above the base antenna
 $h_{\text{eff,max}}$ difference between the height of the base station antenna and the lowest height along the profile



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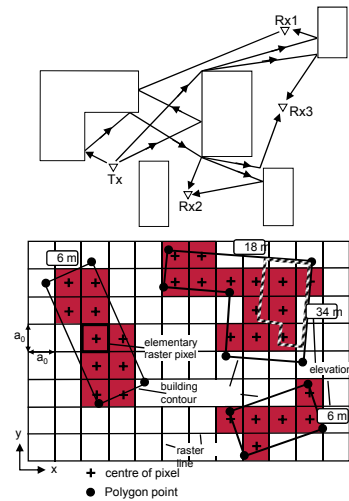
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Propagation Paths in Urban Areas

- Ray Determination
 - In urban areas, lots of propagation paths exist that have to be considered when using ray-optical methods:
 - Consideration of direct, reflected, diffracted and, where applicable, diffusely scattered contributions
- For this task, vector data are more suitable than raster data.
- Methods for ray determination:
 - **Ray Tracing**
 - **Ray Launching**



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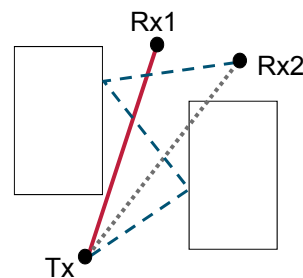
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Ray Tracing

- Ray Tracing is a method to find valid ray paths between a base station and a fixed mobile station.
- Straightforward programming, mainly consisting of search for line-of-sight connections
- Line-of-sight exists if the considered ray does not subtend a building polygon
- Consideration of reflection, diffraction or scattering, section by section
- Consideration of multiple processes requires high computation times



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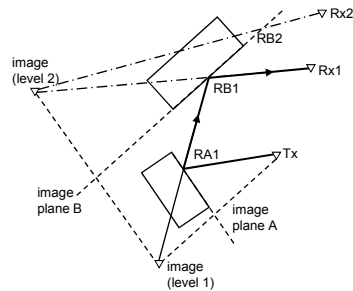
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Image Method

- With the image method, at first all surfaces are determined that are seen from the source.
- By reflection at those surfaces, the image sources are determined.
- Examination whether line-of-sight exists between the respective walls and all other walls and, where applicable, determination of the respective image sources etc.
- With this method, the contributions by reflection can be determined.
- Where applicable, extension to diffraction or transmission is possible



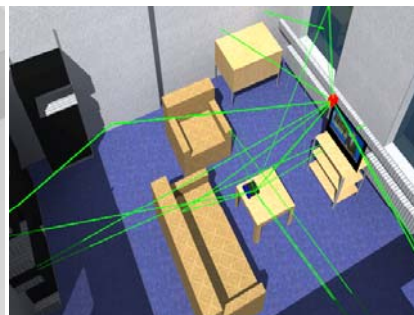
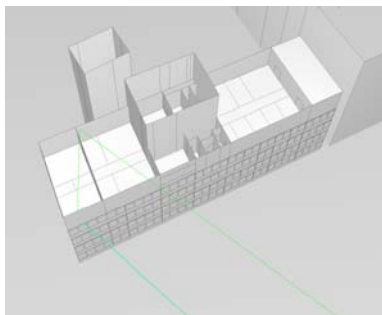
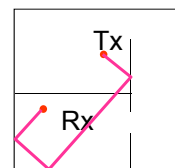
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Example: Application of the Image Method to an Indoor Scenario

- Consideration of reflection and transmission



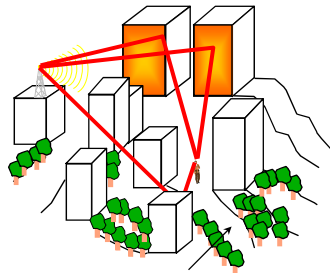
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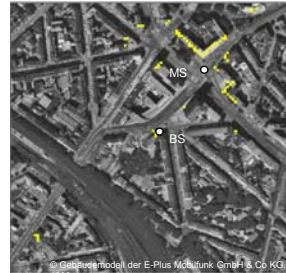


Search for Scattering Areas

- Search for scattering areas
 - Considering diffuse scatter contributions, all scattering areas with line-of-sight to the base station as well as to the mobile station have to be found.



Scenario for the determination of scattering areas



Example: walls with line-of-sight to BS and MS

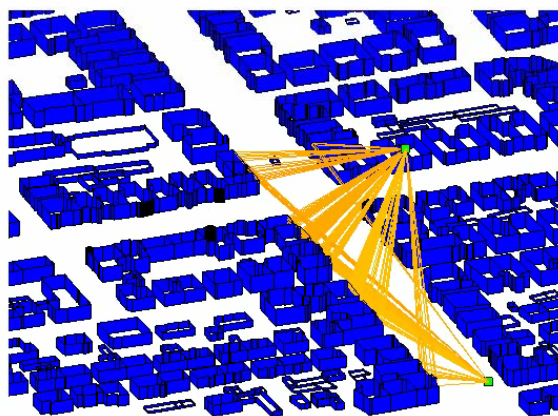


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Example: Scattering Areas Relevant for a Vehicle



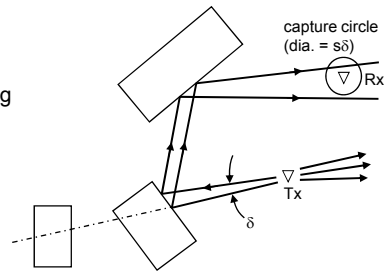
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Ray Launching

- With the Ray Launching method, rays are sent in all directions in space starting from a fixed base station.
- Tracing of rays on their way through the building model
- Contributions of all rays are summed up at all potential receiver positions.
- Due to the discrete radiation, strictly speaking not receiver positions, but receiving areas are considered.



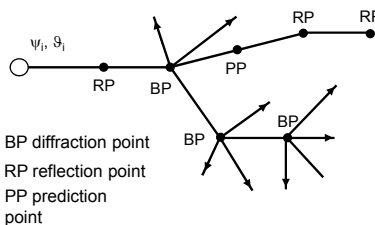
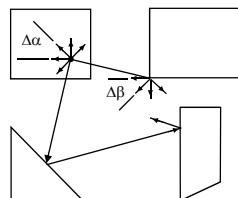
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Number of Rays

- Thus, a wave front spreading from the BS under the angles ψ_i and ϑ_i can lead to multiple valid propagation paths.
- Especially, consideration of multiple diffraction is critical in terms of the computation time.
- Considering diffuse scattering, the same effect occurs.



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Comparison of Ray Tracing and Ray Launching

- Considering the same propagation effects with both methods, both algorithms result in the same geometrical propagation paths
- For the applicability in practice, the computation effort A is the crucial factor (consideration of specular reflection):
 - Ray Tracing: $A \sim w^2 P$
 - Ray Launching: $A \sim wZN(\Delta\vartheta)$
 - w number of walls
 - Z maximum number of interactions
 - P number of receiving points
 - $N(\Delta\vartheta)$ number of rays sent out at the transmitter



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Characteristic Features of Ray Tracing and Ray Launching

Ray Tracing	Ray Launching
Suitable for point-to-point calculation	Fast algorithm for area-wide calculations
Flexible range of receiving points and special ray paths	Simultaneous calculation for different receive heights is possible
Effort increases in case of area-wide calculation and multiple reflections	Unsuitable for point-to-point calculations



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Methods for the Acceleration of Algorithms

- Search for scattering areas
 - Determination of scattering areas seen by the base station (valid for all receiving points)
 - Based on this (reduced) number of scattering areas, those scattering areas are determined which are seen by the mobile station.
 - The number of scattering areas within the reduced number of scattering areas and with it the computation time depend on the antenna height of the base station!
- Subdivision of the area to be investigated into substructures
 - A simple classification of that kind is the combination of buildings within quadrants
 - Reduction of the number of required calculations of intersection points
 - At the best, with this up to three quarters of all buildings can be excluded a priori for investigations of intersection points



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