3D - URBAN DATA FOR PLANNING CELLULAR RADIO NETWORKS

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ABSTRACT

Mannesmann Mobilfunk GmbH with its D2 network is the first private GSM network operator in Germany. The D2 network is a cellular radio network with small cellular sites. The size of a cell depends on the topography and the expected traffic load, and also on the performance of the base and mobile station. Up to now the radius of a cell varied between three and 35 kilometers. For planning cellular radio networks, topographic data will be used. This includes demographic data, the information about the land use and terrain height data. Especially in the major cities the topographic data which has been used up to now is no longer sufficient. In order to plan optimized coverage and capacity, precise digital data of the terrain height is currently needed. The knowledge of city structures is a requirement for the planning of further antenna locations for the so-called microcells.
City structure data is defined as geocoded terrain height data including the location and the height of the buildings. This data is not yet available, so it was derived by placing an order. For this purpose the requirements (pixelsize, accuracy, degree of detail, etc.) and the possible methods for generating 3D building data are discussed. Finally, the generated data sets and those German cities which have been examined so far (with a total area of more than 1000 km^2) are presented.

Die Mannesmann Mobilfunk GmbH ist der erste private GSM-Netzbetreiber in der Bundesrepublik Deutschland. Das D2-Netz ist ein zellulares Funktnetz. Die Größe einer Zelle ist dabei abhängig von der Topographie und dem erwarteten Telefonaufkommen, sowie den Leistungsparametern der Basis- und Mobilstationen, bisher lag der Radius einer Zelle zwischen drei und 35 Kilometern. Für die Planung zellularer Funknetze werden unter anderem topographische Daten benötigt. Dazu gehören neben den Informationen über die Geländenutzung und den demographischen Daten die Informationen über die Geländehöhe. Für den weiteren Ausbau des digitalen D2-Mobilfunknetzes in den Städten reichen die bisherigen Kenntnisse über die tatsächliche Geländeoberfläche nicht mehr aus. Für eine optimale Versorgungs- und Kapazitätsplanung in den Städten sind genaue digitale Daten der Stadtstrukturen (ein sogenanntes digitales Stadtmodell) erforderlich. Die Kenntnisse über diese Stadtstrukturen sind dabei Voraussetzung für die Planung von möglichen Antennenstandorten für die Mikrozellen.
Ein digitales Stadtmodell ist als eine geocodierte höhenmäßige Darstellung einer Stadtoberfläche zu verstehen. Die Höhendarstellung umfaßt dabei nicht nur die geometrische Beschreibung der Erdoberfläche, sondern zusätzlich noch die Beschreibung der Gebäude. Da diese Art Daten derzeit am Markt nicht erhältlich sind, wurden sie im Auftrag erzeugt. Dabei werden zunächst die Anforderungen (Pixelgröße, Genauigkeiten, Detaillierungsgrad, usw.) und dann verschiedene Methoden zur Generierung diskutiert. Zum Schluß werden die erzeugten Daten und die bisher bearbeiteten deutschen Städte (in der Summe mehr als 1000 km^2 Fläche) vorgestellt.

1. INTRODUCTION

Mannesmann Mobilfunk GmbH with its D2 network is the first private GSM network operator in Germany. Up to now 98 % of its citizens within 95 % of the area of Germany can use this modern mobile telephone service. In a relatively short period of a few years the GSM initiative (Global System Mobile) has been accepted as a standard for mobile communication. Nowadays it is possible for subscribers to roam between more than 30 countries, using the advantages of the same technology. The D2 network is a cellular radio network with small cellular sites. Each cell has a Base Transceiver Station (BTS) which establishes the connection to and from the subscribers. The size of a cell depends on the earth surface and the expected traffic load, and also on the performance of the base and mobile station. Up to now the radius of a cell varied between three and 35 kilometers.

For planning cellular radio networks, topographic data will be used. This includes demographic data, the information about the land use and terrain height data.
Terrain height data is geocoded within a 100 m grid and is processed for the entire area of Germany and a 70 km strip of the neigboring countries. The accuracy of the supporting points is ± 5 m. The height of the antennas used for the coverage of the cells is approximately 30 m above ground. This data is the basis for specified propagation models for the calculation of the field strength, which is the basis for further planning. The results of the planning process are optimized locations of the base stations, the relevant initial parameters and the frequencies of the base and mobile stations.

Fig.1: The D2 network - a cellular network

2. MICROCELL PLANNING

Due to the growth of the subscribers of the D2 network, the resulting high traffic load and the use of low performance mobile phones, the network must continuously adjusted. One possibility to expand the capacity, that means more subscribers are able to set up calls at the same time, is the introduction of smaller cells with their own BTS. The capacity (Erlang/km^2) is proportional to the number of cells within a specified area.

However, the growing number of cells (and BTS) leads to a problem. Each BTS uses a specified frequency for the connection to and from the mobile. However, the number of available frequencies is limited, therefore each frequency must be used as often as possible. On the other hand the same frequencies sent from different BTS 's may not disturb each other to avoid interference problems and dropped calls. Therefore the knowledge of the topography is very important.

Especially in the major cities the topographic data (100 m by 100 m pixelsize) which has been used up to now is no longer sufficient. In order to plan optimized coverage and capacity precise digital data of the terrain elevation, including the location and the height of the buildings (city structure data) is currently needed. The knowledge of city structures is a requirement for the planning of further antenna locations for the so-called microcells. The height above ground of these antennas will not project neighbouring buildings and the coverage performance of a microcell will be within a radius of about one kilometer and less.

For modelling the urban areas, sophisticated fieldstrength propagation models have been developed. Mannesmann Mobilfunk is using the so-called 3D-Urban-Micro-Model (Cichon et al., 1993) describing multipath wave propagation by three components (Vertical Plane, Transversal Plane Model and Multipath Scattering Model). These models calculate the propagation loss for over-roof-top propagation, propagation through street canyons and propagation via reflectiong walls of buildings. The computer-aided planning software bases on the use of precise raster data, i.e. building data.

2.1 Demands on the data

A 3D building dataset includes a geocoded height representation of a city surface. The height representation includes the terrain and also the buildings. The modelling of the terrain surface can be considered as sufficiently precise or can evaluated during the measurement. Therefore the greatest attention must be given to the generation of the buildings. The following main questions must be answered in advance:

- which areas are important (dense urban, urban, dense suburban, suburban) ?
- in which horizontal accuracy the buildings must be evaluated and what pixel size is sufficient ?
- in which vertical accuracy the buildings must be evaluated, in relation to the points of support and in relation to different heights within a building ?
- how should irregular shaped buildings be handled ?
- at which height above ground a building must be evaluated ?
- at which size a building must be evaluated - in other words, are isolated buildings necessary or are rows of buildings sufficient ?
- is it necessary to generate the different shapes of the roofs, gables, projections, front attributes, passages and if so, how can they be stored ?
- is it necessary to also take into account precise information about single trees or line of trees, and how this information can be stored ?
- which methods can be used for the generation, what are the advantages and disadvantages ?

2.2 Methods

For the generation of the microcell planning data several methods are available in theory. The methods must be considered with respect to:

- up-to-dateness
- accuracy
- rights
- costs
- controlling and updating
- availability
- degree of specification (detail of buildings)
- homogeneity
- reliability

In addition the data must be generated or transformed in the same coordinate system as other data used at Mannesmann. This means Gauss-Kruger coordinates with Bessel ellipsoid and Potsdam datum, which must be transferable to the commonly used format within the company. In a feasibility study, the following methods have been considered or tested.

2.2.1 Terrestrial surveying methods with use of existing maps

The planimetric information can be evaluated by means of digitizing or scanning of appropriate maps. The vertical dimension can be achieved by using official information (number of floors) or hand-held laser devices on the spot. The up-to-dateness, accuracy and the degree of specification depends on the used maps; the vertical accuracy is low (in the case of using floor heights) or relatively expensive to derive (in case of using surveying methods or hand-held laser devices). The generation of additional land use information is possible. The method is operationally available, the high effort of manual works leads to higher costs, and controlling and updating of the delivered data is easily possible.

2.2.2 Analytical photogrammetry

Both the horizontal and the vertical determination can be done by means of analogue aerial images with appropriate scales within analytical photogrammetric devices. Further processing of the derived vector information will be done with geographical information systems.
The actuality, accuracy and the degree of detail depends on the date of flight and the used image scale. Both terrain elevation and buildings heights can be derived in common processes, additional information can be derived also by the operator. The method is operational, but due to manual works costly, controlling and updating (with newer images) is easily possible.
Alternatively just the heights can be derived by analytical processing and the planimetry by maps.

2.2.3 Digital photogrammetry

On the base of scanned aerial images (or airborne scanner images) the horizontal and vertical determination can be performed by computers. The methods are not yet operational and differ from the pure transfer of the analytical world into digital to almost fully automatic procedures. Automatic 3D recognition is a wide field of research (e.g. Huertas and Nevatia, 1988; Dang et al., 1994, Haala, 1995, Lang, Schickler, 1993). Especially in dense urban areas with complicated building shapes and hidden areas due to shadow or nature ground cover, automatic processes are not able to detect the outlines and the heights of the building precisely. In comparison to analytical methods the digital approach is cheaper due to automation. However the accuracy of the human operator will not be reached (but is it necessary ?) and the costs rise, the more manual corrections are necessary. Controlling and updating is easily possible.

2.2.4. Further methods

There are some possible methods which have some restrictions up to now, but could be valuable in the future.

- ATKIS data (Authoritative Topographic and Cartographic Information System)

the medium - scale mapping database DLM25/1 of Germany 's federal states support some area-based objects, which are of interest. But due to some limitations, the insufficient diversification of buildings, the insufficient height representation and economical aspects, the data will not be further considered.

- Remote Sensing

The evaluation of satellite images, either in analogue or in digital form available, is conceivable. However, the information content and the derivable accuracy is currently not sufficient. Next generations of earth observation systems (Baudoin, 1995, Fritz, 1995) promise some improvements. At present optical satellite images can be just a cheap help for controlling the completeness of building datasets. Satellite radar systems (interferometry) do not seem applicable yet for this purpose.

- Laser scanner for range measurement

The evaluation of high precision elevation data will be operational. The systems use differential GPS and an inertial navigation system for positioning and attitude determination. The laser scanner measures during the aircraft flight the distances strip by strip (Lohr and Eibert, 1995). Less experience, no possibility to get additional information, economical aspects, and missing controlling possibilities lead to no further inspection yet.

2.3 Studies

Due to the lack of available 3D city structures and no experiences, what kind of data would be sufficient, an order to evaluate a testsite within the city of Munich was given. The restrictions caused by the used fieldstrength propagation model were: generation of raster data, evaluation of terrain heights including all buildings as rectangles with flat roofs and without any additional information.
Instead of testing many several different methods it was decided to use one approach and to manipulate this data in order to find the appropriate parameters.
The analytical photogrammetric approach was chosen because of its well known operational technique and accuracy. A test site in Munich (approximately 30 km^2) was evaluated by aerial images, recorded in the scale of 1:23000 with a wide angle camera. The accuracy of the measured terrain heights and the outlines and heights of the buildings laid in the range of some [dm], relative height differences within building blocks of more than one meter had to be recorded separately. The final output raster size was 1m by 1m, the heights were stored in [dm],
This high precision dataset was the base for further investigations. For testing also different accuracies, the data was manipulated. Based on the 1x1 m^2 data, two further datasets have been generated by means of resampling techniques with output pixelsizes of 5 m by 5 m and 10 m by 10 m respectively.
In the following figure, a part of the dataset of Munich (centre of Munich around the Frauenkirche) is displayed. For better recognition only building heights are shown (the darker the shading the higher the building).

Fig.2: city of Munich 1x1 m^2 building dataset

Furthermore, an already available data set (from the Institut für Rundfunktechnik München) based on a city map was tested. This data was generalized in such a way, that only the outlines of building blocks and the average number of floors per building was determined. By assuming a typical height for a single floor, the relative height above ground could be derived. The combination with a terrain model led to absolute heights. However the accuracy was the poorest of the tested four datasets. Figure 3 shows the city map dataset. Although the plots are black/white, the different accuracies and the degree of specification of the two displayed datasets is recognizable.

Fig.3: city of Munich city map dataset

2.4 Results

The three-dimensional propagation model used for fieldstrength prediction was fed with the different datasets (Feistel, Baier, 1995). For comparison of the results some drive tests have been carried out. Hereby the fieldstrength was measured by a receiver every 10 ms along the measurement route (driving route) and the geographical coordinates were delivered by the Travel Pilot navigation system.
It was shown that the comparable 10x10 m^2 and city map datasets will not fulfil the requirements of precise network planning. The use of the 1x1 m^2 pixelsize caused a huge amount of data (e.g. a ctiy size of 200 km^2 led to about 800 MByte uncompressed data) and large computing times for propagation. Moreover the 1x1 m^2 data is not automatically better than the 5x5 m^2 data in the sense of propagation. The planning of radio cellular networks is a complex business with the input of many different parameters and their mutual dependence. So the prediction accuracy will not increase in line with the accuracy of the geographic data. Therefore the 5x5 m^2 dataset was the best compromise of both economical and accuracy/storage aspects.

In total the following requirements are fixed (in respect to the model, which is now used):

- combined dataset of both terrain and building heights
- pixelsize of 5x5 m^2
- horizontal accuracy of about half pizelsize, vertical accuracy $\pm$ 2 m
- generation of all buildings with a larger size than 50 m^2 and above ground height of more than 3 m
- generation of the buildings as boxes with flat roofs (highest representative point)
- perpendicular rise of heights between ground and building (height discontinuity)
- divide of building blocks into several parts, if the height differs by more than 3 m

3. Orders

Main aim of the studies was to find out the necessary geographic parameters for planning microcells, not the method to fulfil these requirements. After defining these parameters some companies have been requested to propose appropriate generation methods and to approve their methods by demonstration data. Finally it was decided to select both analytical and digital photogrammetric methods for the first German cities to evaluate. Photogrammetric methods seemed to fulfil the requirements pointed out in part 2.2 at best. In addition the scanned aerial images can be an additional help for the planners. Resampled as orthoimages appropriate locations for base stations can be preselected in a simple way. The controlling of the delivered data is possible within a digital (stereo-) workstation with the same base from which the data was generated. Updating is possible by evaluating specified areas with up-to-date images in the future.
The analytical way is unquestionably a precise, but also a relatively expensive method. The human operator with his experience and interpretation ability can hardly be beaten by automatic procedures.

On the other hand, the advantages of the digital approach will increase. The way to get the city structures is not uniform and standard. Finally a semi-automated way was chosen (Guretzki, Erhardt, 1996). Hereby the height determination and the horizontal determination of the buildings is separated into different steps. Firstly two very dense height models will be created by matching procedures, the digital terrain model (DTM) without man-made or natural features and the digital elevation model (DEM) with all the features above ground. Secondly the building outlines will be digitized on-screen by using orthoimages (which are created with the help of the DTM). A special technique enables avoiding the distortions due to projection and height differences. This is done by linking the orthoimage window and the DEM window, so that the operator can easily move the outline to the correct place.
Special software combines now the elevation model and the building polygons. By using statistical reports the heights per building are defined, the location of misclassified buildings (no representative height could be defined) are shown and the heights are added as attributes to the vector dataset. In addition the kind of roof (flat roof or top ridge) and natural features greater than 3 m above ground can be evaluated.
In the first phase of the planning process of microcells four German cities (Berlin, Düsseldorf, Frankfurt and Munich) with a total area of approximately 900 km^2 have been evaluated with the two described methods. During 1996 we expect the delivery of further city structures. This will be the cities of Hamburg, Hannover, Dortmund, Cologne, Dresden, Mannheim and Nuremberg with a size of approximately 1.500 km^2 in total.

3.1. Experiences

As it was expected the analytical approach was very precise and fulfils the requirements completely. Base of the evaluation were aerial images in the scale range of 1:15000 up to 1:18000 (recorded with a wide angle camera). The controlling of the data produces some less errors or misclassifications.
The digital approach was carried out with aerial images in the scale range of 1:12500 up to 1:15000 (recorded with a normal angle camera). The images have been scanned with about 25 μm pixelsize, that led to a pixelsize at the ground of about 30 cm. The results are a little less precise in comparison to the analytical methods, but the requirements are completely fulfilled. Nevertheless automatic procedures require a greater expenditure of controlling in order to ensure reliable data.
The greater scale and the greater focal length in combination with the manual digitizing led to no significant reduction of generation time and costs up to now. However, the digital approach is continuously improving. The progress in automatic triangulation and improvements in the field of image recognition (at least the automatic detection of simple buildings) will increase the advantages of the digital method.
There are still some general questions concerning the propagation model that must be solved. The 2.5D solution used up to now causes some problems with tunnels, buildings on pillars etc. Another question is the general type of data. It was found out that the zigzag building outlines caused by the nature of raster data lead to additional diffraction edges that do not exist in reality. Currently, work is going on to examine whether vector data will show more realistic behaviour of the model. To be prepared for this cause the city structure data was also ordered as vector data. Together with the height information, it would be easily possible to generate real 3D data.
Over the last years the market of the telecommunication industry has seen an almost exponential increase. This has brought also a great benefit to both the private and the public sector of geographic data supplement. The planning and modelling of radio networks is just possible and economic by using modelling software and digital (geographic) data. Terrain models, in urban areas in combination with city structure data help to increase the correlation between predicted and measured signal coverage. So the diffraction and reflection effects on radio waves caused by various terrain and building heights can be modelled. The lack of existing city structure data leads to great efforts on the mobile telecommunication sector to generate this data. The public administration with its maxim to generate high precise (and of necessity expensive) data is of lesser help. For Mannesmann Mobilfunk it is more important to get data in volume and in acceptable time. Moreover it is found out, that often available public digital data sets are so expensive that a new generation (with the advantage of defining the own appropriate requirements) will be cheaper.

City structure data is not only useful for planning radio coverage. It can also be used in the wide field of pollution investigations, environmental planning, transportation services, marketing and so on.

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