HELSINKI UNIVERSITY OF TECHNOLOGY
Laboratory for Theoretical Computer Science

Master's Thesis

Radio Network Optimisation with Spatial Database Tools

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Preface

This work was created between summer of 2004 and winter of 2006, and represents the final part of my Master of Science (Tech.) at the Helsinki University of Technology.

The work was done in the context of NetAct Optimizer product development in Nokia Networks Corporation.

Optimizer is a product in a NetAct™ product family. The goal of developing Optimizer is to provide radio networks that are optimized to be as fast, reliable and secure as possible. The aim of Network Operators is to use the full potential of the capacity of a network. To fulfil this requirement is a difficult task and that is why we need to optimize radio networks.

Acknowledgements

First of all, a big thank to my supervisors, professor Hannu H. Kari at the Helsinki University of Technology and the Optimizer team at Nokia Networks for giving instructions, ideas and feedback. I specially want to thank Mikko Kylväjä, Riku Ertimo and Jaana Laiho from Optimizer project and Tomi Janhunen from TKK for helping me to graduate finally.

I want to thank my wife Taati who supported me through this almost endless project passing my studies. Many thanks to my sons Akseli and Elias, who gave me infinite amount of stunning ideas and smiling support.

HELSINKI UNIVERSITY OF TECHNOLOGY — ABSTRACT OF THE MASTER'S THESIS

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The objective of this thesis is to find those radio network optimisation tasks which are easily performed with spatial tools. Software developer would benefit from the usage of geospatial database tools. Geospatial data is information about the shape and location of objects on the Earth's surface which can be manipulated in desktop mapping or GIS[1] programs. This data can be based either on vectors or rasters. The theory part of the thesis concentrates on spatial functions and the way how to use them properly. The spatial functionality is visualized using four use cases of optimisation. The main task of this thesis is to improve the performance of user interface in optimisation process. The use cases are, (1) loading data into user interface on demand and on the fly, (2) coordinate transformation between standard geographical format and different local projections, (3) automated adjacency creation and (4) fast dominance calculation algorithm. The most important criterion for all these use cases is the performance. All of them are required to function with quick response. Because developers of optimisation management are not experienced with spatial tools used in such applications, the use cases was selected so that it shoud have the maximum help for them. Geographic information systems are confronting rapid change and development. The benefit of spatial databases can be used to improve the performance and structure of software development in that field. This thesis concentrates on methods to make better the process of optimisation using visualisation in software.

Keywords: spatial, geographic information, radio network optimisation, performance

[1] Look at explanation of terms in chapter 2.1

TEKNILLINEN KORKEAKOULU DIPLOMITYÖN TIIVISTELMÄ

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Työn tavoitteena on löytää ne radioverkon optimoinnin tehtävät, jotka voidaan luontevasti toteuttaa relaatiotietokantojen Spatial-ominaisuuksilla[2]. Ohjelmistokehittäjät hyötyvät selkeästi tietokantojen spatiaali-laajennuksista. Geospatiaalinen tieto on informaatiota karttaobjektien sijainnista ja muodosta maapallon pinnalla. Spatiaalitietoa käsitellään erilaisilla GIS[3] työkaluilla. Spatiaalitieto voi olla joko rasterimuodossa tai vektorimuodossa. Työn teoriaosuudessa keskitytään spatial-ominaisuuksiin, jotka ovat käytettävissä tietokantojen sisäisissä funktioissa. Spatiaaliominaisuudet havainnollistetaan työssä neljällä käytännön esimerkillä. Tämän työn päätavoite on graafisten radioverkon optimointityökalujen suorituskyvyn lisääminen. Käytännön esimerkit ovat: (1) tietojen lataaminen näytölle ilman viiveitä, (2) koordinaattimuunnokset geograafisen koordinaattijärjestelmän ja paikallisten projektioiden välillä, (3) automaattinen naapuruuksien luominen radioverkon soluille sekä (4) nopean dominanssilaskennan kehittäminen. Kaikkien esimerkkitapauksien yhteisenä vaatimuksena on suoritusnopeus. Koska geograafiset sovellukset kehittyvät voimakasta vauhtia, on hyvä liittää sovelluksien tietokantoihin spatiaaliominaisuus. Ominaisuus, joka on tarjolla jo hyvin monessa tietokantatuotteessa. Tämän työn tarkoitus on myös osoittaa visuaalisten työkalujen käytön mielekkyys radioverkon optimoinnissa.

Avainsanat: geograafinen, paikkatieto, radioverkko, optimointi, suorituskyky

[2] Spatial-ominaisuuksilla tarkoitetaan vektoripohjaista karttakomponenttia
[3] Katso termien selitys kappaleesta 2.1

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ABBREVIATIONS

2G	*Second Generation mobile network*
3G	*Third Generation mobile network*
BEARING	*antenna bearing: direction to which the main lobe of the antenna is pointing (angle on the horizontal axis, 0° towards North)*
BSC	*Base Station Controller*
BTS	*Base Transceiver Station, represents a BTS cell.*
BTS site	*Base Transceiver Station* site
CDMA	*Code Division Multiple Access*
CM	*Configuration Management* of a radio network
EDGE	*Enhanced Data rates for GSM (or Global) Evolution*
FOCI	*Points related to the construction and properties of an ellipse. Noncircular ellipses have two distinct foci*
GIS	*Geographic Information System*
GPRS	*General Packet Radio Service*
GSM	*Global System for Mobile communications*
GUI	*Graphical User Interface*
HLR	*Home Location Register, a database containing information on the permitted services and current location of mobile stations.*
IP	*Internet Protocol*
LA	*Location Area*
MDT	*Oracle Map Definition Tool*

MSC	*Mobile Services Switching Center*
MO	*Managed objects, in the network management system, a managed object is a theoretical representation of a network element, and the outcomes of the actions that are done on managed objects appear in the network elements.*
NMS	*Network Management System*
NMT	*Nordic Mobile Telephone*
O&M	*Operation and Maintenance*
QoS	*Quality of Service*
RA	*Routing Area, part of the service area of a serving GPRS support node (SGSN) that consists of one or several cells and is a subset of the GSM location area. The concept of a routing area is needed to optimise GSM mobility management to the needs of GPRS.*
RAC	*Radio Access Configurator*
RNC	*Radio Network Controller*
SIR	*Signal to interference ratio*
TRX	*Transceiver, a unit in the BTS containing radio and signaling* channels.
UMTS	*Universal Mobile Telecommunication System*
WBTS	*WCDMA Base Station*
WCDMA	*Wideband CDMA*
WCEL	*Cell of a third generation radio network*

1. INTRODUCTION

Tools that have been meant for the optimisation of the radio network are developed with the help of this thesis. Especially the properties of the relational databases (and their spatial options) have been taken as the subject of the investigation.

In this section the structure of the introduction is told. The introduction contains background information and a commentary from the structure of this thesis about the optimisation of the radio network, especially in Nokia. We also pose a question "Why to do optimisation?" and then later we give some answers for it. The optimisation of the radio network is not possible effectively any more without the optimised software. In this thesis, some methods with the help of efficient software are demonstrated.

1.1 Background

Geographic information is about geographic entities and phenomena, and the spatial and temporal properties and relations characterising them. Typical geographic entities are mountains, lakes and coastlines, but artificial features such as city borders and roads are also among them. Phenomena are things like weather systems and floods; the things that happen. *[Longley et al., 1999]*

Geographic entities can be represented as discrete objects of the three types: point, line and area. Map scale plays a major role in defining what is the best object type for an entity. Entities can be represented in two-, or three-dimensional space and they can be classified to object types according to their dimensionality:

- A zero-dimensional entity is a point object. Location of a point is specified with x and y coordinate pairs and sometimes it is beneficial to have also the z coordinate to tell the height above the Earth's surface. A point can represent, for example, the location of a railway station.

- Lines are one-dimensional entities that have length, but no width. Lines are defined as an unclosed series of x and y coordinates, or an unclosed series of x, y and z coordinates. A line can represent, for example, a path of a mobile phone.

- Areas are two-dimensional entities. The same way as point and line entities, area can have x and y coordinates, but the series of points completely enclose a region. Area entity can represent, for example, a coverage area of radio network. *[Slocum, 1999]*

The concept about continuous fields is needed in addition to the previously explained concept of discrete objects (point, line and area). One good example about continuous fields is a geographic phenomenon, the elevation of terrain. The field concept assumes that in each point of the terrain the phenomenon has an attribute value. Fields are continuously varying, multivariate and dynamic.

The point, line, and area entities can be used in vector approach. Another approach is raster, where tessellations of equal size raster cells in a grid of a fixed resolution represent one variable over the study area *[Robinson et al., 1995]*. The geographic location of each cell is known, because the raster grid has an origin with a specified location and each raster cell is associated with a uniform offset.

A common way to model discrete entities is the vector approach. The raster approach is normally used with continuous phenomena. It is also possible to use the raster approach for discrete entities and to use the vector approach with continuous phenomena.

Traditionally geographic information is divided into two groups. Topographic information visualize the Earth's surface, for example, infrastructure, land use, relief and hydrology, and thematic information represent the distribution of particular phenomena. Phenomena can be, for example, population, earthquakes, or drainage areas. Both of the information types are needed to be visualized together, so that the user is able to understand the phenomena and locate it as well. How much the topographic information is needed depends on the phenomena. For example, a map with drainage areas needs the rivers and canals, and sometimes the relief information. *[Kraak et al., 2001]*

A map layer is a set of data explaining a single characteristic of each location within a geographic area. The layers are a common way to combine information for visualization. Each layer contains information about a particular subject and it is stored as a separate file or set of files. A layer can be either raster or vector layer, and when the latter one is the case, it can contain only point, line or area vectors. Although stored in different files, the layers can be shown together, as a stack of layers. The information from each layer can be seen, and the layers together form a map. *[Heywood et al., 1999]*

An alternative for the layer-approach, is an object-oriented model. Entities are not divided to separate layers but grouped into classes and hierarchies of objects. *[Heywood et al., 1999]*

1.2 Network Optimisation in Nokia

The Network Optimisation team at Nokia Networks develops software for the operators of radio networks using measurement based data rather than prediction based data. Optimizer product is part of a Network Management System called Nokia NetAct. The main task performed with Optimizer is to optimize capacity and coverage of the network, and to improve the performance of the network and services. Nokia Optimizer users are network and service providers throughout the world. Later in this thesis term Optimizer means the same as Nokia NetAct Optimizer™.

Optimizing products enable operators to manage both their second and third generation networks (2G,3G), specifically the GSM and WCDMA networks.

Radio networks are optimized with a tool that use geographic information in visualisation and analysis tasks. For example, the Dominance calculation is based on measurements[4] of each antenna in the network. Thus we can calculate the dominance of antennas in each point in a radio network map. Geographic information is seen as a very important component that adds value to optimizing process. At the moment, only very few radio network planning products have geographic visualisation and analysis capabilities.

[4] Prediction is used if the measurement of an object is not available.

As the number of mobile phones increases and new technologies are introduced in the network, the number of network elements will increase. During the same time, the network configuration management will get more complicated, if more sophisticated information management and visualisation techniques are not developed. Geographic visualisation is one way to help the management of the information. *[Päivi Pöyry, 2003]*

This thesis concentrates on using the radio network data which is already available in some database. The retrieval of that data into information system is handled with other system components of NetAct and is out of scope here. All spatial examination is concentrated on two dimensional space.

1.3 Structure of this thesis

The rest of this thesis is organised as follows. Chapter 2 presents some definitions of the terms what are used in this thesis. The problem statement is introduced and we tell what is an actual research problem. Then we explain the structure of the radio network management and the evolution of the radio network planning and optimisation. Use cases are introduced in the end of this Chapter.

Chapter 3 describes the criteria which are used to evaluate the implementation and the results obtained with it. The criteria for every use case have been presented separately. Chapter 4 presents the generic model of the problem and the frames for the result.

Chapter 5 explains the solution of the research problem. Chapter starts with the section of previous work. Then the implementation of every use case using Oracle database has been told separately. Last section of this Chapter explains the implementation of use cases with PostGIS database.

Chapter 6 gives an analysis of the results and shows a direction to conclusions. The performance of both databases is compared. Chapter 7 concludes this thesis with a summary of the preceding chapters, and presents some ideas how to continue this work.

2. PROBLEM STATEMENT

This chapter gives definitions of terms which are later used in Criteria and Implementation chapters. After definitions, it is time to introduce the main problem in section 2.2.

The rest of this chapter brings radio network management and optimisation familiar to the reader. Practical part of the thesis is to introduce four use cases which were selected so that the optimisation problem can be easily understood.

Four use cases have been chosen so that they can be best used to examine the problem of the optimisation of the radio network. One can say that the use cases provide the basis for the whole research problem.

2.1 Definitions of terms

In the following we introduce some terms which may not be clear to all readers of this paper. This part of thesis introduces such terms which are specific for radio network optimisation, spatial data handling and using geographical database tools.

2.1.1 Geospatial Data

Geospatial data is information about the shape and location of objects on the Earth's surface which can be manipulated in desktop mapping or GIS programs such as ArcView, MapInfo or PostGIS *[PostGIS, 2005]*. This data can be either in vector or raster format.

Vector data represents geographic features (entities) as x,y coordinates. Features are described as points, lines and polygons. For instance, on a map of Finland, cities may be represented as points. Rivers and roads would be examples of lines and the provinces would be polygons. Examples of common vector formats are Arc/Info Export (E00 files), MapInfo MID/MIF files and DXF. *[Johnson, 2004]*

2.1.1.1 Raster data

Raster data is a cell or pixel-based method of representing the Earth's features, with each cell or pixel having a value. Satellite images are raster data, as are maps or images created via scanning. Examples of raster formats are TIFF, GIF, JPEG, and BMP. *[Ryerson, 2004]*

2.1.1.2 Vector data

The vector data model represents each feature as a row in a table, and feature shapes are defined by x,y locations in space (the GIS connects the dots to draw lines and outlines). Features can be discrete locations or events, lines, or polygons. For example, city map is drawn by using rectangulars as a blocks and properties as illustrated in Figure 1.

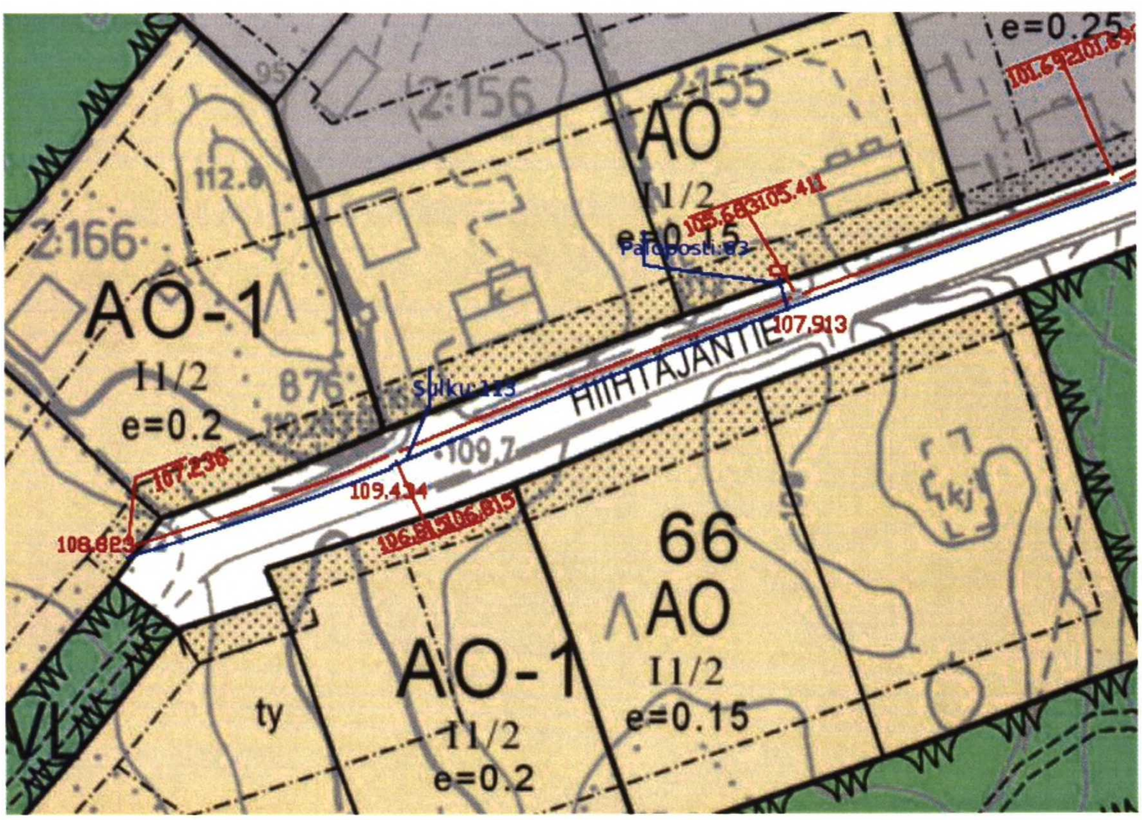


Figure 1 : City block zoned for buildings

2.1.2 GIS

GIS (geographic information systems) is a technology which combines data, software, hardware, database management and spatial analysis tools to permit researchers to explore and understand geographically distributed phenomena.

2.1.3 OpenGIS

The OpenGIS[5] defines standard GIS object types, the functions required to manipulate them, and a set of meta-data tables. In order to ensure that meta-data remain consistent, operations such as creating and removing a spatial column are carried out through special procedures defined by OpenGIS. *[Buehler K., 2003]*

2.1.4 Coordinate systems

A coordinate system is a means of assigning coordinates to a location and establishing relationships between sets of such coordinates. It enables the interpretation of a set of coordinates as a representation of a position in a real world space. *[Oracle Spatial UG, 2003]*

Any spatial data has a coordinate system associated with it. The coordinate system can be georeferenced (related to a specific representation of the Earth) or not (that is, Cartesian, and not related to a specific representation of the Earth). If the coordinate system is georeferenced, it has a default unit of measurement (such as meters) associated with it, but spatial can automatically return results in another specified unit (such as miles).

Spatial data can be associated with a Cartesian, geodetic (geographical), projected, or local coordinate system:

- Cartesian coordinates are coordinates that measure the position of a point from a defined origin along axes that are perpendicular in the represented two-dimensional or three-dimensional space. If a coordinate

[5] Simple Features Specification for SQL

system is not explicitly associated with a geometry, a Cartesian coordinate system is assumed.

- Geodetic coordinates (sometimes called geographic coordinates) are angular coordinates (longitude and latitude), closely related to spherical polar coordinates, and are defined relative to a particular Earth geodetic datum. A geodetic datum is a means of representing the figure of the Earth and is the reference for the system of geodetic coordinates.

- Projected coordinates are planar Cartesian coordinates that result from performing a mathematical mapping from a point on the Earth's surface to a plane. There are many such mathematical mappings, each used for a particular purpose.

- Local coordinates are Cartesian coordinates in a non-Earth (non-georeferenced) coordinate system. Local coordinate systems are often used for CAD applications and local surveys.

Coordinate transformations can be done between following coordinate systems

1. Cartesian Coordinates
2. Geodetic Coordinates (Geographic Coordinates)
3. Projected Coordinates
4. Local Coordinates

2.1.5 Geodetic Coordinate Support

The spatial options of databases' provide a rational and complete treatment of geodetic coordinates. Before that spatial computations were based solely on flat (Cartesian) coordinates, regardless of the coordinate system specified for the layer of geometries. Consequently, computations for data in geodetic coordinate systems were inaccurate, because they always treated the coordinates as if they were on a flat surface, and they did not consider the curvature of the Earth's surface.

With current databases, ellipsoidal surface computations consider the curvatures of arcs in the specified geodetic coordinate system and return correct, accurate results. In other words, with the current databases, spatial queries can be assumed to return the right answers.

2.1.6 Geodesy and Two-Dimensional Geometry

A two-dimensional geometry is a surface geometry. A flat surface (plane) is accurately represented by Cartesian coordinates. However, Cartesian coordinates are not adequate for representing the surface of a round sphere, like Earth. A commonly used surface for spatial geometry is the surface of the Earth, and the laws of geometry are then different than they are on a plane. For example, on the Earth's surface there are no parallel lines: lines are geodesics, and all geodesics intersect. Thus, closed curved surface problems cannot be done accurately with Cartesian geometry. *[Oracle UG, 2003]*

The spatial options of databases provide accurate results regardless of the coordinate system or the size of the area involved, without requiring that the data be projected to a flat surface. The results are accurate regardless of where on the Earth's surface the query is focused, even in "special" areas such as the poles. Thus, we can store coordinates in any datum and projections that we choose, and we can perform accurate queries regardless of the coordinate system.

2.1.7 Choosing a Geodetic or Projected Coordinate System

For applications that deal with the Earth's surface, the data can be represented using a geodetic coordinate system or a projected plane coordinate system. In deciding which approach to take with the data, one should consider any needs related to accuracy and performance.

Accuracy

For many spatial applications, the area is sufficiently small to allow adequate computations on Cartesian coordinates in a local projection. For example, most local projections provide adequate accuracy for spatial applications that use data for that entity. *[GEOG5121]*

However, Cartesian computations on a plane projection will never give accurate results for a large area such as Canada or Scandinavia. For example, a query asking if Stockholm (Sweden) and Oulu (Finland) are within a specified distance may return an incorrect result if the specified distance is close to the actual measured distance. Computations involving large areas - or requiring very precise accuracy - must account for the curvature of the Earth's surface.

Performance

Spherical computations use more computing resources than Cartesian computations, and take longer time to complete. In general, a Spatial operation using geodetic coordinates will take two to three times longer than the same operation using Cartesian coordinates.

2.1.8 Local Coordinate Support

Databases with spatial options provide a level of support for local coordinate systems. Local coordinate systems are often used in CAD systems, and they can also be used in local surveys where the relationship between the surveyed site and the rest of the world is not important.

Several local coordinate systems are predefined and included with spatial option. These supplied local coordinate systems, whose names start with non-Earth, define non-Earth Cartesian coordinate systems based on different units of measurement (meters, millimeters, inches, and so on). In the current databases, these local coordinate systems can be used only to convert coordinates in a local coordinate system from one unit of measurement to another (for example, inches to millimeters) by transforming a geometry or a layer of geometries.

2.1.9 Signal strengths based on a model of ellipse

The signal coverage of a radio antenna used in this Thesis is based on an elliptic model. This means that the strength of a signal weakens the same way as an ellipse enlarges. This model assumes that signal strength is the same in every point of an arc of an ellipse. Traditional model is a circle (a special case of an ellipse). When using ellipses instead of circles, it is possible to direct antenna gain.

The shape of an ellipse is determined by its eccentricity (e) which is defined as the ratio of the distance between foci (*2c*) and the length of the major axis (a). Thus $e = c / a$ or another words $c = ea$. Eccentricity is a parameter value for ellipses. We can use either one eccentricity value for all used ellipses or a specified value for each ellipse as illustrated in *Figure 2*.

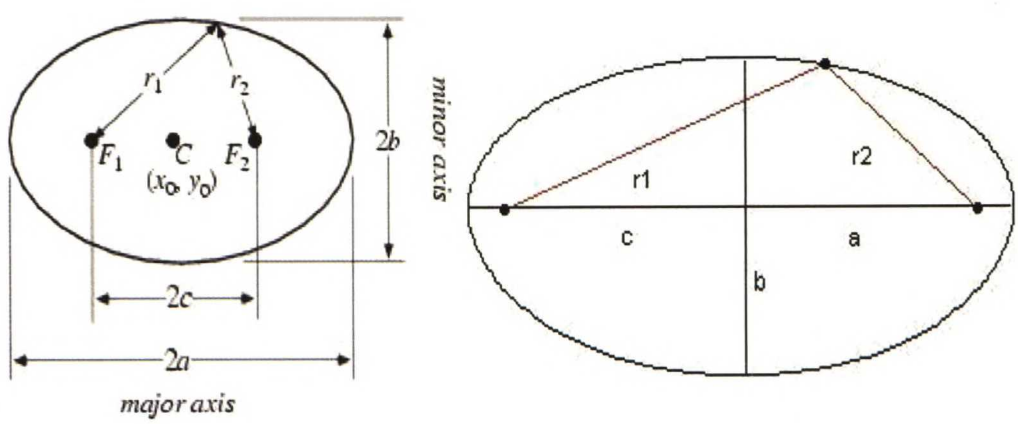
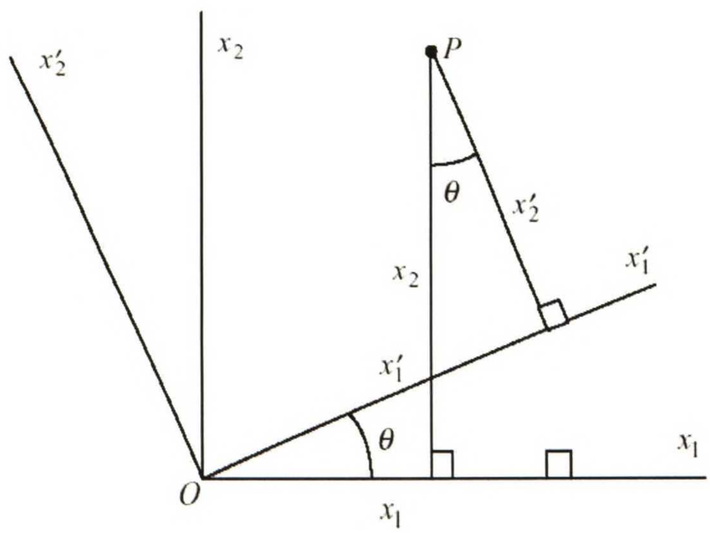


Figure 2 : Definition of an ellipse

An ellipse is a curve that is the locus of all points in the plane the sum of whose distance r1 and r2 from two fixed points F1 and F2 (the foci) separated by a distance of 2c is given positive constant 2a. [Hilbert and Cohn-Vossen 1999]. This results in the two-center bipolar coordinate equation, r1 + r2 = 2a, where *a* is the conic section and a Lissajous curve. The corresponding parameter *b* is known as the semiminor axis.

Ellipses are placed in a way that each antenna is located in one focus of an ellipse. The major axis of an ellipse is pointing to the same direction as the bearing of an antenna. When the bearing is something else than 0 degrees we use a transformation of axis of coordinates. We use formulas which are illustrated in *Figure 3*.

The last four equations in *Figure 3* are used to perform rotations. First two on the left, are used when we change the axis from 0 angle to some specified angle. The last two on the right, are used when we change the axis from a specific angle to 0 angle.



$\{x'\} = [\beta]\{x\}$ or $\{x\} = [\beta]^T\{x'\}$, where $[\beta] = \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$

thus

$\begin{cases} x_1 = x_1'\cos\theta - x_2'\sin\theta \\ x_2 = x_1'\sin\theta + x_2'\cos\theta \end{cases}$ or $\begin{cases} x_1' = x_1\cos\theta + x_2\sin\theta \\ x_2' = -x_1\sin\theta + x_2\cos\theta. \end{cases}$

Figure 3 : Rotation of Coordinate Axes

Then we need also a simple transformation of axes of coordinates, because we need to locate the origo at the center of an antenna as illustrated in *Figure 4*.

2.1.10 The structure of PostGIS

PostGIS adds a support for geographic objects to the PostgreSQL object-relational database. In effect, PostGIS "spatially enables" the PostgreSQL server, allowing it to be used as a backend spatial database for geographic information systems (GIS), much like ESRI's SDE or Oracle's Spatial extension. PostGIS follows the OpenGIS "Simple Features Specification for SQL". [PostGIS, 2005]

PostGIS has been developed as a research project in open source spatial database technology. PostGIS is released under the GNU General Public License. The list of future projects by PostGIS includes enhanced technology for data loading and dumping, user interface tools for direct data access and manipulation, and support for advanced topologies at the server side, such as coverages, networks, and surfaces.

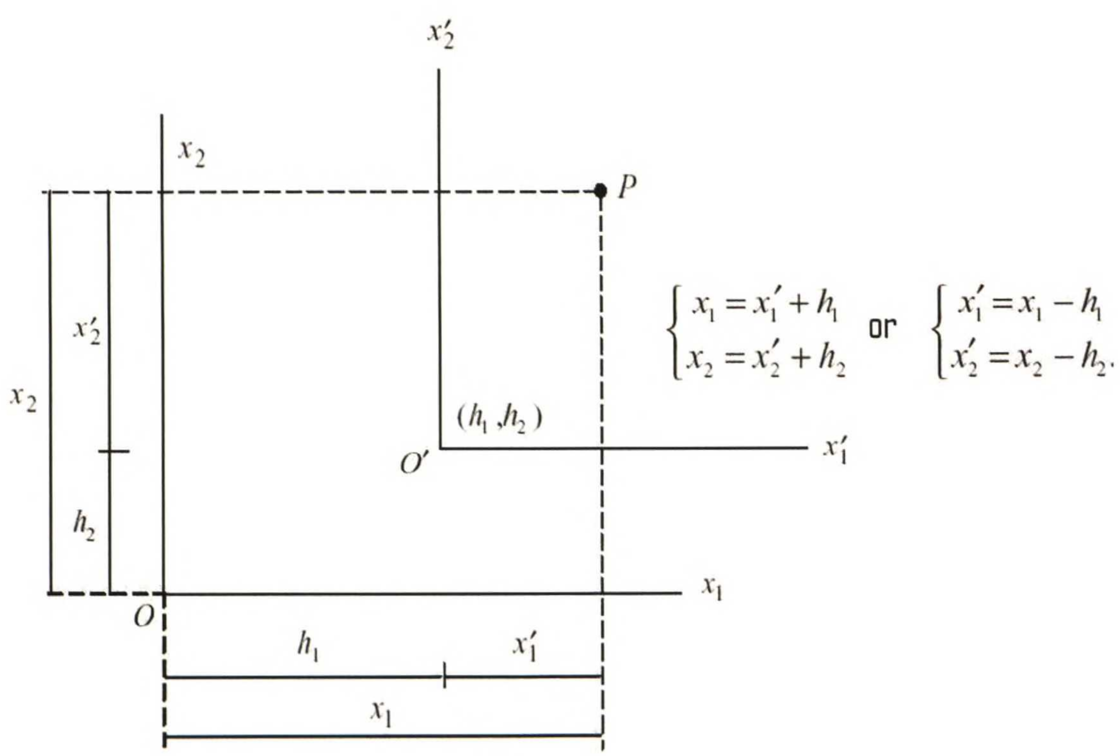


Figure 4 : Moving location of the origo

PostGIS includes the following additional tools for spatial rendering:

The *Proj4* reprojection library is required if we want to use the *transform* function to reproject features within the database. See appendices where available projections of PostGIS are listed.

The *GEOS* library provides support for exact topological tests such as Touches, Contains, Disjoint and spatial operations such as Intersection, Union and Buffer.

Program *proj* is a standard Unix filter function which converts geographic longitude and latitude coordinates into cartesian coordinates, $(\lambda,\phi) \rightarrow (x,y)$, by means of a wide variety of cartographic projection functions. For many of the projection functions the inverse conversion, i.e. $(x,y) \rightarrow (\lambda,\phi)$, can also be performed.

The principal purpose of this paragraph is to provide an overview of the technical usage and execution of program *proj*. However, the cartographic characteristics of the projections are given minimal coverage in this thesis and the reader should refer to Map Projections—A Working Manual *[Snyder, 1987]* and An Album of Map Projections *[Snyder and Voxland, 1989]* for more complete discussions. Program *proj* supplements these publications in terms of computational applications in the Unix environment.

A tutorial description of the general usage of the cartographic projection program *proj* along with specific cartographic parameters and illustrations of the approximately 70 cartographic projections supported by the program is presented. The program is designed as a standard Unix filter utility to be employed with other programs in the generation of maps and charts and, in many cases, used in map digitizing applications. Tables and shell scripts are also provided for conversion of State Plane Coordinate Systems to and from geographic coordinates.

2.1.11 Spatial design

The Spatial design process is used to find the tasks that would benefit from the usage of geographic information. Only spatial methods are included in this study. A few tasks related to GIS management are excluded because Nokia

NetAct products, like Nokia NetAct Planner™, provide geographic information tools for those purposes.

A spatial property of geographic information is the geographic reference, expressed as coordinates, like latitude and longitude, or a relation, like "near the lake" or "next to the bookshop". A temporal property is not just 'when something happened', but also 'what could have caused this', 'what else happened at the same time' and 'what happens after these changes'. *[Longley et al., 1999]*

2.1.12 ILOG java library

ILOG JViews Maps Package allows developers to add interactive asset-management maps to Web-based user interfaces. ILOG JViews Maps Package provides a full range of features, including:

- Georeferencing for easy placement of assets in proper locations
- Multiple projections that support the most popular methods of projecting the earth's surface
- Mix-and-match vector and raster data in the same map
- Native support for common map formats
- Load-on-demand for efficiently handling very large sets of map data
- Connection to the popular Oracle Spatial Map server
- MapBuilder, an editor for defining map data used in applications
- Complete customization of all map features and all objects atop a map
- Multiple Web-deployment options, including Java clients and thin DHTML clients *[ILOGwww]*

2.1.13 Oracle Application Server MapViewer

Oracle Application Server MapViewer (or simply, MapViewer) is a programmable tool for rendering maps using spatial data managed by Oracle Spatial or Oracle Locator (also referred to as Locator). MapViewer provides tools that hide the complexity of spatial data queries and cartographic rendering, while providing customizable options for more advanced users. These tools can be deployed in a platform-independent manner and are designed to integrate with map-rendering applications.

MapViewer includes the following main components:

1. A rendering engine (Java class library) that provides cartographic rendering capabilities (map renderer)
2. An Extensible Markup Language (XML) API that provides a programmable interface to MapViewer

The rendering engine connects to the Oracle database through Java Database Connectivity (JDBC). It also loads the map metadata (such as map definitions, styling rules, and symbology) from the database, and applies it to the retrieved spatial data. The XML API provides high-level application developers with a convenient interface for submitting a map request to MapViewer and handling the map response.

In addition to these components, the *Map Definition Tool (MDT)*, a tool available through the Oracle Technology Network, simplifies the process of creating and managing map, theme, and symbology metadata in a spatial database. MDT is a Java program which enables visual management of Oracle spatial databases.

2.2 The Problem Statement

The main objective of this thesis is to evaluate possibilities to use spatial information in radio network optimisation. This analysis gives a basic view how and where to use spatial functionalities and what problems can be solved with it. Use cases, as to be introduced in section 2.6 show the direction of solutions for the problems and what is the value of a particular solution for the software designer.

2.3 Introduction to cellular radio network management

Cellular radio network management allows operator to manage the network configuration in the Mobile services Switching Centre (MSC) and the Mobile services Switching server (MSS). Network management is done by the operator staff using the Man-Machine Language (MML) interface.

Radio Network Operator is able to do the following tasks:

- Create and delete radio network configuration elements: location area (LA), base station combiner (BSC), base transceiver station (BTS), radio network controller (RNC), service area, and multimedia gateway
- Modify parameters of radio network configuration elements
- Handle administrative states for BSC, BTS, RNC, service area or multimedia gateway
- Define relationships between radio network configuration elements
- Output data of radio network configuration elements and relationships of radio network configuration elements
- Initialize interfaces between MSC - BSC, MSC – MGW, and MSC - RNC

The main functions of cellular radio network management are:

- Handling location areas under the MSC / MSS (GSM and UMTS)
- Handling network location areas (GSM and UMTS)
- Handling base station controllers (GSM)

- Handling base transceiver stations (cells/GSM)
- Handling multimedia gateway (UMTS)
- Handling radio network controllers (UMTS)
- Handling roaming areas (zone codes) (GSM and UMTS)
- Handle Gs-interface (interface between MSC and SGSN) definitions (GSM)

2.4 Evolution of Radio Network planning

Radio network planning and its development through time can be easily mapped to the development of the access technologies and requirements set by those. The first analog networks were planned based on low capacity requirements. The radio network planning was based purely on coverage. *[Laiho, 2002]*

The Ogumura-Hata propagation model was and still is widely used for coverage calculation in macrocellular network planning. Based on measurements made by Y. Okumura *[Okumura, 1968]* in Tokyo at frequencies up to 1920 MHz these measurements have been fitted to mathematical model by M. Hata *[Hata, 1980]*. In the original model, the path loss was computed by calculating empirical attenuation a correction factor for urban areas as a function of the distance between the base station and mobile station and the frequency. This factor was added to the free space loss.

The result was corrected by the factors for the heights of the base station antenna and the mobile station antenna. Further correction factors were provided for street orientation, suburban, open areas, and over irregular terrain. Hata's formulas are valid when carrier frequency is between 150 to 1000 MHz, the base station height is between 30 to 200 m, the mobile station height is between 1 to 10 m and the distance is between 1 to 20 km.

During the course of time, together with the evolution of the 2G systems, site density was getting higher due to increasing capacity requirements.

Furthermore, the initial assumption that cellular customers would mostly be vehicular turned out to be incorrect. Thus the maximum transmission power levels of the user equipment were reduced by at least 10 dB.

All this forced cellular networks to omit the omni-directional site structure and lead to the introduction of cell splitting, i.e. on site consisted of three sectors instead of just one *[Gamst, 1987],[Lee, 1990]*. Owing to the increased spectral efficiency requirements the interference control mechanism became more important. In addition to the sectorisation also antenna tilting was introduced as a mechanism for co-channel interference reduction *[Lee (2), 1990]*. Furthemore, the macrocellular propagation model was not anymore accurate enough; new models were needed to support microcellular planning.

Recently, methods for GSM frequency planning based on mobile station measurements reports have been introduced and implemented. *[Wille, 1998]*, *[Barco, 2001]* The possibilities offered by the mobile's radio quality measurement reports in GSM and WCDMA should be more utilised in the network control process (planning, optimisation, and the integration of those two).

In addition to the propagation model development it was noticed that the increasing capacity demands could be met only with more accurate frequency planning. The frequency assignment together with neighbour cell list (for handover purposes) planning and optimisation were the main issues when planning GSM networks. In the case of GSM, frequency hopping was introduced to further improve the spectrum efficiency. Advanced frequency allocation methods can be found in litterature, for example simulated annealing *[Duque-Anton, 1993]* or a method for automatic frequency planning for D-AMPS *[Almgren, 1996]* or advanced features for FDMA/TDMA systems *[Frullone, 1996]*.

A new trend in the radio network planning research is plan synthesis, meaning an automatic generation of base station site locations depending on a cost function output. The target is to utilise a cost function to minimize implementation costs, maximize the coverage, maximize the offered traffic, and maximize the SIR in the network. Additional challenge for this type approach is to take antenna directions, number of sectors and tilting into account.

In cellular networks, the network utilisation control requires a functionality that can utilise the measured feedback information and react correctly on the basis of that. Therefore, it is crucial that the planning phase is tightly integrated to other network control functions and network management system. This is especially important in the case of WCDMA, owing to the fact that there will be a multitude of services, that is, customer differentiation setting a multidimensional matrix of Qos reguirements. Planning such a network very accurately is not feasible due to limited accuracy of the input data (propagation, traffic amount, traffic disturbution etc.) *[Mende, 1998]*.

2.4.1 GSM

GSM is a digital, second generation (2G) mobile telephone network, as is also the CDMA network in the USA. The primary function of GSM is to provide a high quality voice service, but in addition the transmission of data is possible. These data services are, for example, Short Message Service (SMS) and connections to data networks such as the Internet. Before digital 2G systems, there were analog cellular systems referred as first generation systems. An example of first generation systems is the Nordic Mobile Telephony (NMT).

2.4.2 The Third Generation

The third generation systems (3G) are designed for multimedia communication, like images and video. With 3G, the access to information and services will be enhanced by higher data rates and new flexible communication capabilities. The 3G system in Europe is known as Universal Mobile Telecommunications System (UMTS), and it is standardized within European Telecommunication Standard Institute (ETSI). The 3rd Generation Partnership Project (3GPP) has specified with other standardization bodies from Europe, Japan, Korea, USA and China the third generation radio interface, WCDMA. *[Holma et al., 2000][3GPP]*

2.4.3 3G compared to GSM

Basically there are two popular 2G technologies, IS-95 (cdmaOne) which is a narrow band Code Division Multiple Access (CDMA) scheme and GSM900/1800/1900 which is Time Division Multiple Access (TDMA) scheme. The most popular 3G technology is Universal Mobile Telecommunications System (UMTS). UMTS is a Wide Band CDMA (WCDMA) scheme and hence the radio network planning side has more in common with IS-95 that GSM but still it has differences. There are other technologies such as Enhanced Data Rates for Global Evolution (EDGE) which are more of an evolution path for existing GSM networks. Most 3G networks will be based on UMTS or CDMA2000 (very similar to UMTS). The biggest difference compared to GSM is that code planning[6] almost completely replaces frequency planning (apart from the fact that we may have 3 or 4 channels to use compared to GSM which is in the dozens of channels) due to a frequency reuse factor of 1 in most cases. Other design differences are that a lot more work is needed upfront in calculating predicted traffic loads since a lot more services will be available in 3G as opposed to just voice (and a little data) in 2G. This will be a deciding factor in determining cell radii and link budgets/required signal levels for different services (voice, Circuit data and Packet data). As the tools for 3G planning are developed, more and more of the tools will rely on simulations to verify the network design whereas in 2G most tools rely just on coverage predictions. *[Teixeira P., 2004]*

The main difference between 2G and 3G is the radio interface standard - the UMTS standards will allow larger bandwidth connections to mobile terminals - therefore, the applications that can run on a UMTS system can be far more data hungry (such as video conferencing, internet TV). For the Core network (land) side, the European standard will be based on GPRS because packet data will be required. There are three different varieties of UMTS - Europe & Japan (looks like Japan are going to drop cdma2000) will be using the FDD variant.

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[6] Code planning is essential in CDMA systems for expediting resource allocation to subscribers during the access process. Code reuse schemes need to be devised during network planning. The reuse plan should make allowance for incorporating additional growth sites in traffic hotspots as demands increase over time.

The USA are going to use their own way for a bit with cdma2000 (1xEV) because they have invested a lot in Qualcomm's 3G upgrade plan. China is going to use the TDD variant. Regarding upgrading systems (mobile in London) - US operators will not upgrade by replacing boards as 2.5G systems and 3G systems will have to run side-by-side.*[Laiho, 2002]*

2.5 Radio Network Optimisation

Radio Network Optimisation is a very important feature of managing 2G and 3G networks where the mobile station's power level is adjusted continuosly and adjacencies between transimitters can change quit often.

All use cases introduced in this thesis are related to performance and usability of optimisation software which is heavily based on map visualisation. We test two technically very different database systems, Oracle Spatial and PostGIS. Use cases are introduced in order of importance. The circle of radion network planning and optimisation is illustrated in *Figure 5.*

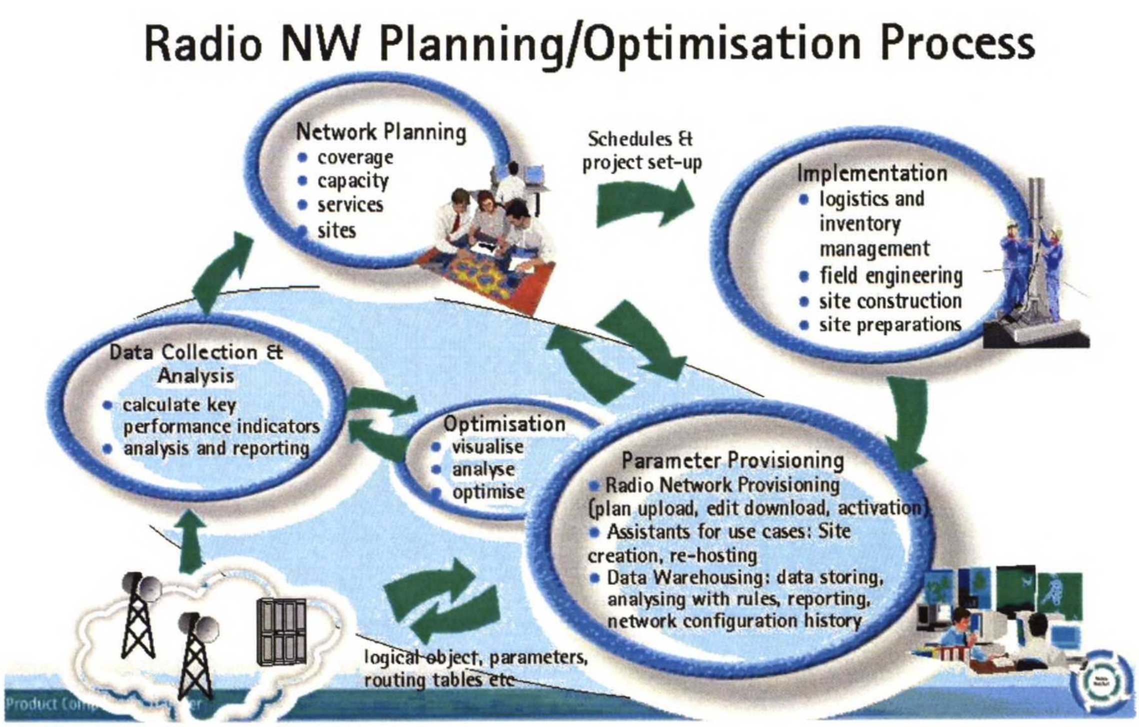

Figure 5 : Network planning process

Optimisation process starts when we already have data of an existing radio network. Normally the data is in a database and what we need to do is to find out how to optimize the behaviour of the network. On one hand, optimisation is visualisation of the network. Visual network view reveals to an expert user such anomalities that we are not able to recognize without a map. For operators, it is useful to see how the network is constructed and how the elements of the network behave (sites, cells, transmitters etc.). On the other hand, optimisation is about analyzing the network. For example, using dominance maps users are able to visually review the construction of network. Finally, when we have a powerful analyzing tool we can find out the methods how we can optimize the network, i.e. to improve the performance and the capacity of the network. For example, we can change the parameters of the network or even change the topology of it.

Figure 6 illustrates the dominance of each antenna in the network.

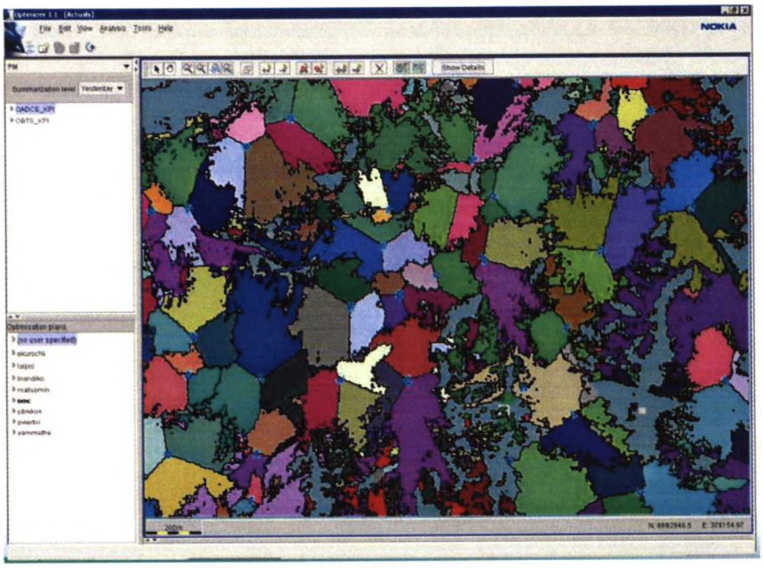

Figure 6 : Example of a Dominance map view

Dominance calculation provides a very useful base for many other solutions. For example with accurate dominance map we can easily define an initial set of adjacencies for each cell. We can also make frequence allocation using dominance polygons (in 2G). Each frequency is mapped to some colour and thus every dominance polygon has an own colour related to the frequency used in that area. Once we know this relationship, we can easily check that the same way coloured dominance polygons are not allowed to be too close to each other. Dominance calculation is also the basis for interference calculation.

2.5.1 Nokia NetAct Optimizer product

Optimizer is used in the statistical network wide optimisation process in NetAct. Optimizer provides visibility to current network behaviour by combining the actual GSM and WCDMA network configuration parameters and measured performance statistics with advanced visualisation and analysis functionality. Parameters can be optimised manually for small changes or automatically by choosing from the range of optimisation solutions provided by Optimizer. Optimizer can be used for a single cell or for a whole region.

The result of optimisation algorithms can be visualised on a geographical map before downloading the optimisation plan to the network. The plan with the changed parameters is sent to *Radio Access Configurator* (RAC) where it is validated and provisioned to the network.

The advantages of the solution are:

- As Optimizer uses statistical performance measurement data, the input data for algorithms is accurate (measurements of a real network), the output is also more accurate than with a signal propagation estimate based process in a planning tool.
- The use of measurements makes the tuning process faster. Instead of heavy raster map based calculations - where, for example, the interference matrix is calculated by considering signal strengths in each map pixel - a mobile measurement report is used. When the data is processed in Optimizer, only some analysis is needed.
- With Optimizer, the whole optimisation cycle is faster than with planning tools. As Optimizer is implemented in the NetAct Framework, the actual configuration data and measurement reports are available for processing. The network topology in Optimizer is always consistent with the actual network data. When running Optimizer for the first time, some customising is needed, such as parameters needed to guide the

generation algorithms. Once the parameters are set, the next optimisation round is easier.

Optimizer is a functional module of the Radio Access Configurator (RAC) module of Nokia NetAct. Performance data is obtained from BSC measurements via an interface to a reporting tool. The reporting functionality in the NetAct basic package can be used for network monitoring and for collecting Key Performance Indicators (KPI) into Optimizer.

The Optimizer solution is composed of basic and licensed functionalities. Geographical map based visualisation, manual object and parameter management are basic optimisation functionalities. The following four functionalities are optional:

- Advanced visualization
- Automated adjacency management
- Multi Vendor Integration (MVI)
- Frequency allocation, including BSIC planning (Performance Optimisation)

2.6 Introduction to use cases

In this section, we introduce use cases of this thesis. Use cases are introduced in an order of priority. Selected use cases are different examples of the most important issues in optimisation process. In every use case table, we use following rows:

- Name - short name of a use case
- Need - explains what is the need for this use case
- Frequency - this tells, how often this functionality is needed
- Actor(s) - this describes who is using this use case

- Course of events - short explanation of the workflow
- Alternatives - if some alternatives exist to described use case
- Exception - what exceptions are needed for this use case
- Triggers - explains triggers which launch the use case
- Preconditions - describe the situation before use case handling starts
- Postconditions - describe the situation after use case handling ends

These use cases are selected from a group of Nokia NetAct use cases. Selected use cases are the most critical ones in the sense of performance in radio network optimisation process.

2.6.1 Use case 1: Map views, load-on-demand

Optimizer is a map-based optimisation tool. This brings up a requirement to handle maps fast. Load-on-demand means the ability to load user-requested maps fast enough to browser as illustrated in *Table 1*.

Table 1: Load-on-demand

Name	Map-views, load-on-demand.
Need	Optimizing products provide displays that show the location of assets. These displays typically include maps overlaid with graphics pinpointing the positions of network objects. Some of these displays can be very complex, and have to redraw themselves in real time as network objects change status or user performs map scrolling.
Frequency	Very often
Actor(s)	Network planning user
Basic course of events	Once the map is displayed the user can access its layers and change their appearance, ordering, visibility or add and remove layers from the map.
Alternatives	None
Exception:	User selects a map area which is out of map scope.
Triggers	User selects a new map view.
Preconditions	Old map view is loaded.
Postconditions	New map view is taken into effect.

2.6.2 Use case 2: Coordinate transformations

In optimisation database, we have coordinates in one standard format. This format is World Geodetic System 1984 (WGS-84). Normally customers want to use some local projection from WGS-84, for example, to Transverse Mercator KKJ projection in Finland. Thus, we need to provide coordinate transformations to various projections in the world. The aim is provide fast and accurate transformations. This use case describes the need of coordinate transformations. *Table 2* illustrates this use case.

Table 2: Coordinate transformations

Name	Coordinate transformations.
Need	Most geo-spatial data are stored in different *coordinate reference systems* (CRS). To enable services to use data from different sources stored in different CRS each service has to access a transformation service.
Frequency	Very often
Actor(s)	Network planning user
Basic course of events	Once the map is displayed the user can move mouse on map and when the mouse stops he can see the coordinates of the position in his local coordinate projection.
Alternatives	The coordinates are not shown or they are shown in standard WGS-84 format.
Exception:	User selects map area which is out of map scope.
Triggers	User moves mouse and stops the movement.
Preconditions	Old coordinate positions are shown.
Postconditions	New coordinate positions are shown.

2.6.3 Use case 3: Automated adjacency creation

Adjacencies are used to provide smooth transfer of a mobile phone from one radio network cell to another. This transfer is called handover. A successful handover needs working adjacency between two neigbor cells. For example in New York, we need thousands of adjacencies in one network. Manual handling of adjacencies is tedious or boring. It is convenient to provide automated adjacency creation in some trivial cases, for example antennas within the same cell.Table 3 illustrates this use case.

Table 3: Automated adjacency creation

Name	Automated adjacency creation.
Need	Adjacency is a relationship that is defined between a GSM (or a WCDMA) cell and a neighbouring cell. When mobile phone moves from one cell to another a handover is needed. The handover is possible if an adjacency is created between these two cells.
Frequency	Often
Actor(s)	Network planning user
Basic course of events	An adjacency is shown as a line from one adjacent cell to another. Bi-directional adjacencies are coloured differently than unidirectional adjacencies.
Alternatives	None
Exception:	Mandatory adjacency-cells are missing.
Triggers	Maximum number of adjacencies is not reached and suitable adjacencies are found during search process.
Preconditions	A selected cell does not have adjacencies.
Postconditions	A number of adjacencies are defined between selected cell and adjacent cells.

In case of internal adjacencies, both WCDMA cells are controlled by the same RNC. If WCDMA cells are controlled by different RNCs, the adjacency is called an external adjacency. Several adjacency relationships can be defined for one and the same WCDMA cell, as is the case when adjacency relationships are defined between a given WCDMA cell and all of its neighbour cells.

2.6.4 Use case 4: Dominance calculation

Dominance calculation gives us a result of a dominance map, which is a visual way to express the relationships of each cells (or antennas) in the network. With dominance map an expert can easily find the biggest conflicts of antenna powers, i.e. dominance. *Table 4* illustrates this use case.

Table 4: Dominance calculation

Name	Dominance calculation.
Need	Dominance calculation is the way to determine a radio network cell which produces the best quality criterion for a detected point. Rough and fast calculation is needed to show the dominance effect of each cells in a selected area.

Frequency	Occasionally
Actor(s)	Network planning user
Basic course of events	A new cell is brought into a network and dominance calculation should build a dominance polygon for this cell.
Alternatives	None
Exception	Neighboring cell is missing.
Triggers	A dominance calculation is started for a new cell.
Preconditions	Cell does not have a Dominance polygon
Postconditions	New dominance polygon is created for a cell.

The dominance is calculated on the fly for each pixel. In 2G, BCCH signal power is used in the calculations while pilot power signal is used for 3G [*Götz R., 2003*]. It is possible to calculate the signal strength at any pixel.

Conventionally, the dominance raster will compare (for each pixel) the resulting signal strengths from different cells and will choose the best serving cell. Each pixel, which is served by the same serving cell, is coded with the same colour. An example of the overall result for a dominance raster is illustrated in *Figure 7.*

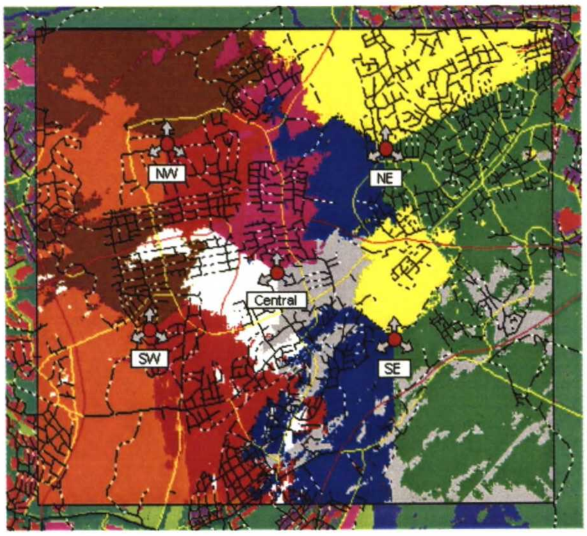

Figure 7 : Conventional dominance calculation

3. CRITERIA IN SPATIAL NETWORK OPTIMISATION

In this chapter, we introduce criteria for our four use cases. The idea is to make frames for use cases in a way that we can later check how well our solution is suited into selected frames. Concept "frames" means here functional and non-functional requirements. Functional requirements are requirements for the behaviour of the application, subsystem, or component. Non-functional requirements are requirements for an application, subsystem or component, that relates to a non-functional ability, such as usability, capacity, scalability, reliability or performance.

3.1 Map views, load-on-demand

The purpose of this use case is to provide Optimizer with geographical objects within a selected scope. User can, for example, select a rectangular in a map when Optimizer zooms in showing the whole rectangular on screen. Another example is to roll map on screen to search for some object.

Functional Requirements

Spatial tools database must provide the objects to be shown on a GUI. These objects are cells and sites (with the polygon size of it), GSM and WCDMA transmitters inside sites, adjacencies between BTSs and/or WCDMA cell (WCEL), topology of specified area (raster data together vector data), different layers on map distance between two map objects.

The main task in this use case is to provide required network element using spatial functions. The requirement is to produce a list of objects to be visualized on a map view.

Also the GUI should be able to call some spatial functions directly from database, for example the calculated dominance polygon which encloses a cell.

Non-functional Requirements

1. Performance

The second task is to verify the performace of these functions compared with traditional database operations. The performance of operations like map-rendering, zooming in or out, selecting map area should be fast enough. This means that map operations must be executed in real time (i.e. normally in less than one second). Every operation should take time less than five seconds when drawing a map. Typically user selects a rectangular under observation.

This use case also includes the possibility for user to define a rectangular area. The selected rectangular area here represents the operational scope, i.e. target area and objects to be retrieved from database. Also some buffer area needs to be handled because objects inside the selected area are related to those objects which are outside that area. Buffer area, in this case, means some frame outside selected scope.

2. Usability

Once all objects have been detected from a scope, the information is delivered from database to GUI. Both, raster data and vector data should be analyzed in the same way. GUI is only responsible for showing the selected objects and data on screen.

3.2 Coordinate transformations

Optimizer uses CRS in two different purposes. First, data is converted into standard CRS when it is imported into the system. Inside the Optimizer all coordinate data is in WGS-84 format.

Secondly, every instance of Optimizer is configured to use one customer defined map projection. All coordinates of map items are transformed on browser from WGS-84 into this projection or vice versa.

Functional Requirements

When user operates a GUI map and moves mouse from one place to another coordinates are transformed from WGS-84 to a selected projection. The projection can be any well-known coordinate projection in the world.

The main requirement for this use case is to check if Oracle Spatial or PostGIS can satisfy needed accuracy of coordinate transformation.[7] One interesting verification can be done by making transformation from local projection (L1) to WGS-84 and back to local projection (L2) and to verify how close to each other L1 and L2 are, in other words what is the transformation error in this situation.

The second requirement is to check how Oracle Spatial or PostGIS offers a coordinate transformations from a seleted projection to WGS-84. This requirement is used when the network operators' map data is imported into Optimizer's database.

Non-functional Requirements

The third requirement is that coordinate transformations on GUI (when user moves mouse) must be performed without any detectable delay. This means that transformation should be very fast. Another solution is to provide a transformation only when mouse movement stops. In that case we do not need extremely fast transformation.

3.3 Automated Adjacency Creation

This use case is to find out the appropriate GSM/WCDMA cells from the area of a given radius from detected cell. After this operation adjacencies are chosen to be established between specified cells.

Functional Requirements

The user can define a number N, which is the maximum number of created adjacencies. In that case after determining all the cells that belong to the neighboring cells, the strongest N cells (strongest signals) are chosen for creating the adjacency.*[Optimizer 1.3 AAM, 2004]* The neighboring cells are detected by selecting a suitable radius around the cell. The strongest signals are detected by using the elliptic distance calculation (c.f. use case 4).

[7] (5 meters from WGS-84 to a local projection. At the moment the accuracy is 200 meters in Optimizer with ILOG).

Non-functional Requirements

1. Performance

There is a number of cells at the beginning of optimisation process without any adjacency definitions. The Automated Adjacency Creation is not so critical process in the sense of performance. This process is done once and basically it can be done as a batch process during night time.

The other need is to perform an adjacency generation within a selected map area on the fly. In that case the performance is more important.

2. Usability

The generation of adjacencies should be defined so well that at least 95% of automatically generated adjacencies are correct.

3.4 Dominance calculation in Radio Networks

This use case is to find out the conflicts with neighboring cells in Radio networks. Typically this conflict is due to a mis-directed antenna or too powerful/weak antenna strength.

Functional Requirements

The user of Optimizer should be able to choose a rectangular area for which dominance is to be calculated. The area typically contains 50 – 100 cells. The main task of this use case is to produce a dominance polygon on screen in time which is acceptably fast (i.e. less than a minute).

The calculation of dominance starts from measuring elliptic distances in selected positions of a map. These positions should be selected with an appropriate method, for example using intersections of service areas.

The later examination in this thesis will show if iteration steps in calculation are needed. The desired result is that a user would see a dominance map with different colours indicating dominances of different cells.

The produced dominance map must alarm the user if some cells have too large, small or clearly wrong dominance areas.

Non-functional Requirements

1. Performance

In the beginning of a dominance calculation, the first iteration step should be very fast. In this step, dominances are based on distances of adjacent cells. The parameters of transmitters inside cells are not taken account (i.e. transmitting power). In the beginning of this use case, we should decide how accurate dominance map is needed or how much time we want to spend creating the final dominance map. The more steps we take the more accurate dominance map we get.

2. Usability

After we have taken the desired amount of iteration steps we have created a dominance map. This map should indicate any problems of dominance in the Radio Network. The map is populated by polygons with different colours. Each colour describes dominances of cells. The map should be visually clear to show defects immediately.

4. THE GENERIC MODEL

This chapter introduces the radio network planning process and optimisation on a general level. Radio Network Planning and Optimisation can be thought to consist of two following parts:

1. modelling and tools for radio network planning

2. optimisation for the operational network

General challenges faced in radio network control are based on the fact that many issues are interconnected and should be simultaneously considered, such as

- Planning means not only to meet current status and demands, but also to comply with the future requirements by providing an acceptable development path.

- Traffic modelling is not only the question about the total amount of traffic flow, but also the question about the future service distribution and performance demands.

All radio network systems have a relation between capacity and coverage. Consequently, the network planning itself is not only based on propagation estimation but also on the interference situation in the network. Ideally, site selection consideration will be done based on the network analysis with planned load and traffic/service portfolio, taking possible neighbor siting constraints into account[8].

Provision of multiple services and seamless management of at least two multiple access systems require rapid evolution of the management tools and processes. The network performance in terms of capacity, quality, and implementation and operational costs forms a complicated environment.

[8] We have constraints when placing base stations. Lakes and hills, for example, make challenges for placements.

4.1 Modelling and tools for Radio Network Planning

One of the main tasks of radio networks is to provide successful mobile phone calls in the entire network. Radio Network planning is responsible of the creation at such a network which fulfils this demand. Very important criterion of a well-working radio network is called Handover Success Rate (HSR). This ratio tells us how the network is able to keep existing phone calls when people move in the network. The physical structure of a network is thus the key issue to provide good HSR and a good network in general.

The contribution of modelling and tools is as follows:

- Improvement of the accuracy of radio link budget by introducing power control (also called fast fading margin)
- Development of theory and modelling for a planning tool capable of multi-service and multi-carrier interference, capacity and coverage analysis
- Development and implementation an interface taking into account the true traffic distribution (not uniform) and terminal speed. *[Laiho J., 2002]*

Radio network planning contains the radio link budget and its application to BS design to meet coverage requirements, traffic estimation and its application to cell design to meet capacity requirements, interference analysis and its application to frequency allocation to meet interference outage requirements in FDMA/TDMA based radio networks, relationship between capacity and coverage especially in CDMA networks.

Also, the Radio Network planning user will have to have a knowledge of the methods to tune the network for maximum capacity and overall economy during the radio network life cycle (see radio network optimisation).

4.2 Optimisation for the operational network

Radio Network Optimisation is the process where existing network is tuned to serve with maximum capacity and coverage. Normally, radio network parameters can be changed to improve the performance of a network. In some cases, physical network elements must be re-located. Changing the direction (i.e. bearing) of antenna is a quite normal optimisation procedure. Another example is to increase or decrease the transmitting power of some antenna.

Radio network Optimisation is very important task for operators, because network capacity is straightly connected to the profit of an operator.

The contribution of optimisation of the operational network is as follows:

The optimisation will be capacity-quality trade-off management instead of plain quality improvement process. *[Laiho J., 2002]*

4.2.1 Provisioning

The provisioning parameters phase is one important part of the network optimisation process. The goal in provisioning is to create new managed objects (MOs), to remove existing MOs, or to modify parameters of MOs in a network element database. The user can do this by activating existing plans in the NetAct or creating, removing and modifying the MOs directly in the network. When plans are used, the user has always the same tasks, but when changes are done directly to the network element database, the tasks depend on the MOs and the task at hand. *[NetAct documentation 1]*

To provision parameters from plans in the network element database, the user needs to perform two tasks as illustrated in *Figure 8*.

The objective in plan preparation is to automatically set adjacency parameters equal to the associated cell's parameters. In plan activation, all the operations (create, remove and modify) defined in the plan are provisioned in the network element database *[Rasinaho, 2002]*.

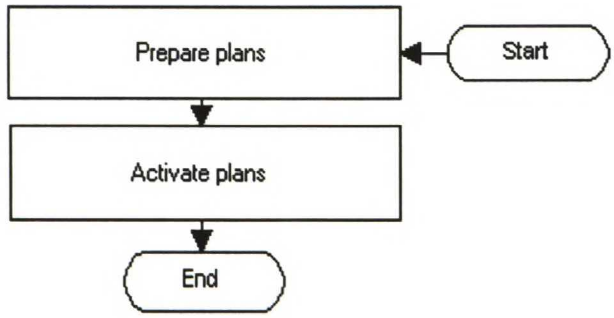

Figure 8 : Provisioning parameters with plans.

The user is able to select network elements to be provisioned in the network element database in GSM networks. In WCDMA, the plan for each RNC can be provisioned separately.

In GSM networks, the user might want to provision network elements from a particular area in the network, or to exclude network elements within a particular area from the provisioning operation. If cell locking is needed in plan activation, the user might want to set the order in which cells are provisioned in the network, so that cells close to each other are not provisioned one after another in the network. The reason is that, if a cell is locked, all calls in that cell have to be transferred to a neighboring cell with a forced handover. If the neighbor cell is not operational, the provisioning operation can cause dropped calls. The user might also want to follow the provisioning operation, so that he is able to see which cells are locked and when they are coming back to the operational state. This way the user can verify that the operation is proceeding and all cells are functioning again.

Information about the provision operation, the area that the operation has an effect on and the cells that need to be locked could be provided to the customer service center as a paper or digital map. In this way, the operator could inform the customers calling to the customer call center that the network maintenance caused the problems, and discard the problems without creating a trouble ticket[9].

[9] A system for managing user requests or problem reports in the system administration.

Independently from how the parameters are provisioned in the network (with plans or directly to the network), if WCDMA MOs or adjacencies to the WCDMA networks are provisioned, the user has to perform an upload task for the WCDMA networks. This is at the moment the only way to make sure that Nokia NetAct™ is consistent with RNC databases. If a plan was used, the user has to merge the data to the NetAct that is not stored to the network element database. In this way, the user gets, for example, the antenna and external cell related data to the NetAct. *[Rasinaho, 2002]*

5. IMPLEMENTATION OF USE CASES

This chapter describes how we have solved the problem we set earlier in Chapter 2. We give one solution for each use case. In connection with every use case the used spatial functions have been presented. The implementation has been naturally made so that it would fulfil the set criteria.

5.1 Previous work

Previously, almost all publications about radio network optimisation have concentrated on the concept of network planning. Radio network planning is already a very-well known subject. In contrast for this, network optimisation is a quite new concept. Actually, previously radio network planning included also network optimisation which has been lately separated into different topic.

5.1.1 Using dynamic channel allocation

The relationship between the network capacity and the quality of service It has been investigated in order to increase the utilization of radio resources. Instead of using fixed channel allocation (FCA) the usage of dynamic channel allocation (DCA) has been studied.

In DCA algorithms studied so far, the effect of the channel allocation on existing calls is considered by the evaluation of the call outage rate or a cost function. The first algorithm is called Minimum Call Outage (MCO) algorithm. With MCO one can evaluate the call outage caused by candidate channels. It has been presented a method of estimating the average signal-to-interference ratio (SIR) variation of on-going calls. The MCO scheme minimizes the call outage rate of the existing calls when assigning a channel to a new call. The MCO scheme improves the capacity or QoS performance compared with the First Available (FA) and Maximum SIR (MSIR) schemes. However, there are some limitations in this algorithm, for example, a wrong decision on channel allocation may be made due to usage of obsolete SIR values and the error of SIR measurement. *[SHAOJI, 2001]*

5.1.2 Using neural networks

Self Organizing Maps (SOM) based applications are not widely used in the analysis of radio networks at the moment. The power of SOM has been proved and the SOM based analysis is recommended for future cellular networks (WCDMA) to aid effective network management. SOM based tools could be utilised in real network management systems. The strength of the SOM based analysis is in its ability to combine multiple measurements and thus provide the result in a simple format despite the fact that the input space is very complex. The motivation of using SOM is to perform analytical analysis on the simulation results using the cost function approach. A cost function in this context is a linear function combining different performance measures to classify the cells with traditional means. *[Laiho, 2002]*

5.1.3 GIS and database implementations

In early GIS implementations, spatial data and related attribute information were stored separately. The attribute information was in a database (or a flat file), while the spatial information was in a separate, proprietary, GIS file structure. [Blasby D., 2002].

Relational databases were usually implemented without support for map objects, or GIS objects. Currently, all commonly used databases have options for geographical data handling. For example, Oracle's map handling option is called Oracle Spatial.

Normally, maps are in raster format and they are outside databases. When they are installed into database they are in large binary objects (blobs) so the information inside a map is not in a usable format as such.

In spatial databases, raster data is still in blobs but all metadata and topological data is inside the database and in the spatial format. In Oracle, the format is called sdo_geom and in PostGIS the format is called geometry.

5.1.4 How adjacency creation works currently

First we have to define cell templates (for BTS in 2G and WCEL in 3G). We can name them freely but something like "macro", "micro", "pico" or then extensions like "urban-macro", "suburban-micro" would make sense. Then we have to assign each BTS/WCEL one of these templates and we have to create adjacency templates according to the following rule:

Under correct adjacency type, define a template whose name is composed of the source and the target cells' template names. Here is an example:

(for 2G) Let's suppose our source cell is of type macro and we assigned cell template "macro". Furthermore, our target cell is of type micro and we assigned cell template "micro". Whenever we create an adjacency between these two constellations, we need to define an adjacency template called "macro_micro", i.e. from the format

"<sourceCellTemplateName><Separator><targetCellTemplateName>"

where the separator is definable in some configuration file and in this example has been assumed to be "_".

Now some configuration tool uses this template for any *new* created adjacency between our macro and micro cells. If there is no matching adjacency template found, our tool will assign them always as default being present "System" template.

5.1.5 How adjacency creation should work in the future

For each adjacency type we can define/create as many templates as we wish. Naming is arbitrarily used. Optionally the BTSs/WCELs should have the Cell type info available and correctly set from predefined values. There must be no automatic relation between cell template and adjacency templates. This is illustrated in *Figure 9*.

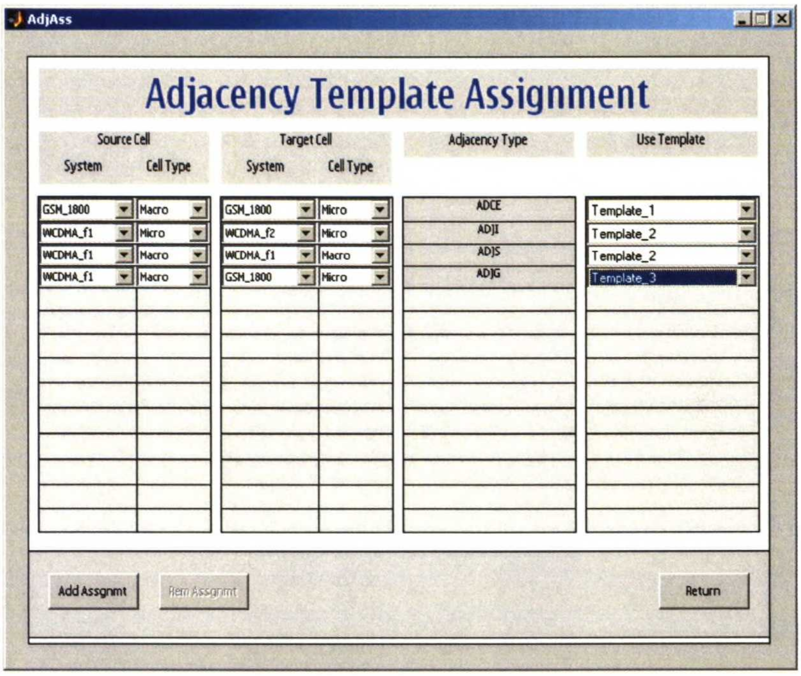

Figure 9 : Adjacency template assignment

The workflow of adjacency assignment can be as follows:

User selects source cell system and cell type and same for target. Adjacency type is selected automatically and the display is only informative. Then from drop down list on the right user can select which template to use from all available ones for the combination of selections on the left hand side.

Now user creates manually or automatically adjacencies and above rules are taken into account, using the system template if no matching rule is found. After a while (or e.g. for another region) user would like to use other templates. He just stops the creation, changes above assignments and continues. This proposal probably requires that assigned templates are written to the plan as well. During provisioning it then must be made sure that the template still exists and, if not, probably use the system or any other default template. This can be enhanced so that if the source and target combination template is not available, the source is only taken into account. The system template is taken only if this is not possible.

5.1.6 Workaround solution

When the user wants to continue with a different adjacency template for the same source/target cell combination, he must delete the corresponding adjacency template and create a new one with the same name. This however makes confusion if this happens within one plan. The original one is lost.

Then we could create new cell templates and call them "macro1" and "micro1" and create an adjacency template called "macro1_micro1" but then we would have to reassign new cell templates to all cells before this would take effect.

5.1.7 How the dominance calculation works currently

The dominance calculation starts with creation of a raster matrix, for example, of the size of 3000 x 3000 raster pixels. There can be 150 cells in this map. The algorithm goes through all positions of this matrix and calculates link losses for each cell in each position. Thus there are 1.35 billion (3000x3000x150) link loss calculation events. Normally, this calculation takes time more than 8 hours. It is obvious that the performace is very critical part in the dominance calculation.

5.2 Load-on-demand

Load-on-demand is implemented by storing map objects inside database using Oracle's geometry (*sdo_geometry*) where objects can be points, lines, curves, polygons or a combination of previous.

The implementation is done by using Oracle Spatial functions inside Oracle's PL/SQL stored procedures. GIS layer of Optimizer sends request through Java library to Oracle's stored procedure. The request consists of following parameters:

- boundary of rectangular view on a map
- layer(s) to be shown
- data element(s) to be shown, i.e. data by type

- resolution of the map

The *boundary* is a mandatory parameter. The boundary will tell Oracle the area which contains requested objects. Actually Java program calls a stored procedure which takes the parameters, implements a select-clause to database and returns the answer. The answer is an array of returned objects.

The *layer* is an optional parameter. If it is omitted then all layers are accepted in selection. If it is given, only objects which are included in the layer's array are accepted.

The *data element* is also an optional parameter. If it is omitted then all data elements are accepted in selection. If it is given, only objects which are included in data element array are accepted.

The *resolution* is the resolution of the raster map used. Map objects are divided into raster categories. When map is using a specific resolution every object in this category shall be shown on the map window.

The database table which serves load-on-demand database requests is called *optimizer_map_objects*. The structure of database table is illustrated in *Table 5.*

- column name is the name of the column inside optimizer_map_objects table
- column type is the type of column in the table
- description is the description of a column in the table

Table 5: The structure of optimizer_map_objects table

column name	column type	description
layer	integer	layer where object is
data_element	varchar(50)	data element of a object
resolution	integer	a resolution of map
geometry	mdsys.sdo_geometry	given Oracle's geometry

The described table has three indexes. *Map_geometry_idx* is a R-tree index of Spatial index type. *Map_data_element_idx* is an index which serves data_element restrictions. *Map_layer_idx* is an index which serves layer restrictions.

In appendices A and B, there is an example of Oracle's procedure which return an array of objects (radio station names) which are inside a view requested. First when we create the procedure and define an array which can contain up to 1000 objects, we create an array which is called *objarray*.

Then, we create a procedure with one function called get_objects as illustrated in appendix C. Next, we define the body of a function. Inside the function we have a select-clause where we select all objects which are inside the boundary (b_x1, b_y1, b_x2, b_y2 : the coordinates of a rectangular) requested.

We also use three more parameters (layer, data_element, resolution) if they are given. The results of using this API are described in the Analysis chapter.

5.3 Coordinate transformations

Coordinate transformations are divided into two categories. First, in GUI when the user moves mouse from one position to another coordinates are shown in the information line. The coordinate transformation is done on the fly from WGS-84 to the operator's local coordinate projection.

Second, when the operator's map data is imported into Optimizer the local projection data is converted into global WGS-84 format, which is the only format inside the database.

Oracle Spatial supports about 1000 CRSs and over 40 local projections. In the current release, we can use these local coordinate systems only to convert coordinates in a local coordinate system from one unit of measurement to another by transforming a geometry or a layer of geometries.

The coordinate transformation on screen is done by the following steps:

1. At any time the system knows the coordinates of a map view where the user operates.

2. GUI sends WGS-84 coordinates of the mouse pointer to a database .
3. The database calculates the transformation of a specific map point using a client specific map projection.
4. Database sends the answer to GUI.
5. GUI shows the coordinates on the information line.

During a data conversion the coordinate transformation is done by the following steps:

1. In the beginning, we define which coordinate projection is a used.
2. During the importing process we make the transformation to all coordinates (from a projection to WGS-84);
3. or alternaltively we first import the local projection data into temporary tables in the database and after that we move the data to the permanent tables and do the coordinate transformation during this process

The projection can be the same what GUI uses when showing the position of mouse, but it can also be some other projection.

As an example, the transformation from WGS-84 to Transverse Mercator KKJ is done by calling a Oracle procedure (wgs_to_kkj). The procedure moves a pair of coordinates into *sdo_geometry* datatype. After that procedure transforms a geometry into KKJ-3 using sdo_cs.transform function. The definition of the procedure is provided in Appendix C for the reader's inspection.

In the previous function we first create a sdo_geometry object of Oracle Spatial. There we define a point in WGS-84 coordinate system (i.e. srsid = 8307). Then we transform coordinates into KKJ-3 projection (i.e. srsid = 294914). The results of using this stored procedure is described in Chapter 6.

5.4 Dominance calculation

The dominance calculation is performed using the distance between adjacent cells. When the scope of inspection has been selected the following algorithm is used:

1. The initial dominance area for each cell is 0.0002 degrees in WGS-84 coordinate system (i.e. about 1000 square meters). This initial distance is a starting point to form an ellipse surrounding each antenna[10] as illustrated in *Figure 10*.

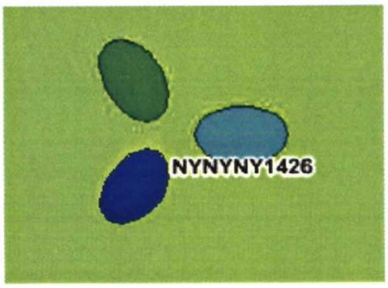

Figure 10 : Initial dominance areas

2. An antenna is located in a focus of an ellipse. The axes of ellipse are chosen using the bearing (i.e. direction) of an antenna: X-axis is chosen to be in the same direction as the bearing and Y-axis is orthogonal to X-axis. The eccentricity of ellipse is defined by a parameter. The value of eccentricity is between 0 and 1. Zero value means a circle and value 1 means a line segment.

3. The initial ellipse is divided into sectors. The amount of sectors can be for example 18 or 36 (can be defined in parameters). These sectors and points of division in ellipse form positions of view for dominance calculation as illustrated in *Figure 11.*

[10] To make sure that dominance areas of neighboring antennas are able to grow, dominance areas do not overlapping in the beginning of iteration

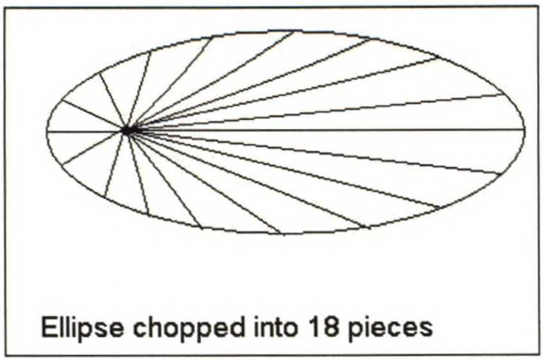

Figure 11 : Sectors of divided ellipse

4. Then we enlarge the ellipse and divide it again into sectors. Next step is to check if new reference points along enlarged ellipse arc are closer to our antenna. If some reference point is closer to some other antenna, we reject this reference point. In each iteration step we accept only such new points whose dominance (i.e. elliptic distance) belongs to a reference antenna. Another words, we keep older reference point if new reference point belongs to some other neighboring antenna. Accepted and rejected reference points are illustrated in *Figure 12.*

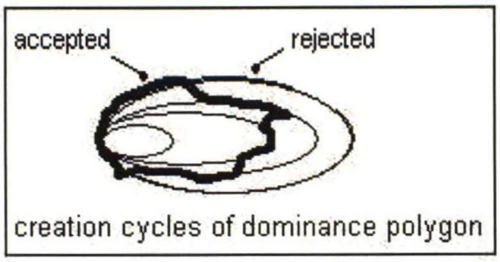

Figure 12 : Creation cycles of the dominance polygon

5. When building a dominance polygon for one antenna we create new reference ellipse (which is always larger than previous reference ellipse) until we reach a situation when we are not able to use any new reference points of new ellipse for creating a dominance polygon. Finally, we create a polygon which consists of each accepted reference point in each sector. All reference points in one sector and the point which is currently checked against neighboring ellipse are illustrated in *Figure 13.*

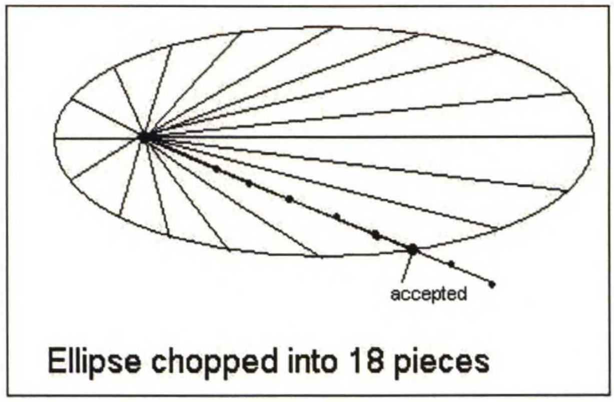

Figure 13 : Checked point in one sector of reference ellipse

6. Each iteration step is M times bigger than previous iteration step. (1. step is M from focus, 2. MxM, 3. MxMxM from focus and so on). In *Figures 14 and 15* we illustrate dominance polygons after 1st iteration step and after 7th iteration step.

7. After each iteration step we create a polygon surrounding each antenna. These polygons are dominance areas of cells. The initial step is defined in parameters (for example 25m)

Depending on the amount of iteration steps we make, the final map of dominances forms a map over selected scope with different colours. Each colour indicates an initial frequence used in antennas.

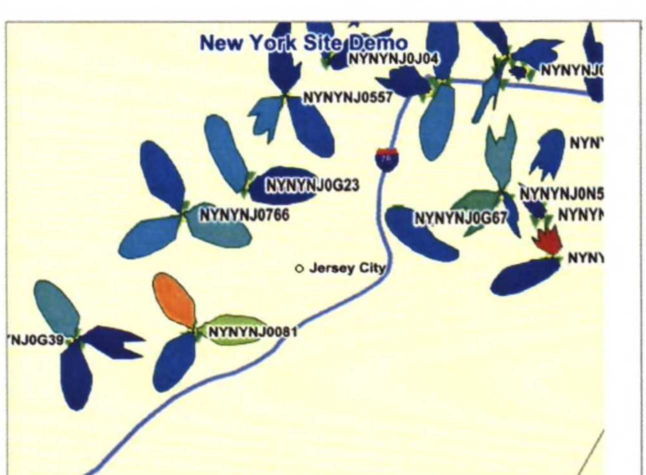

Figure 14 : Dominance – 1^{st} iteration

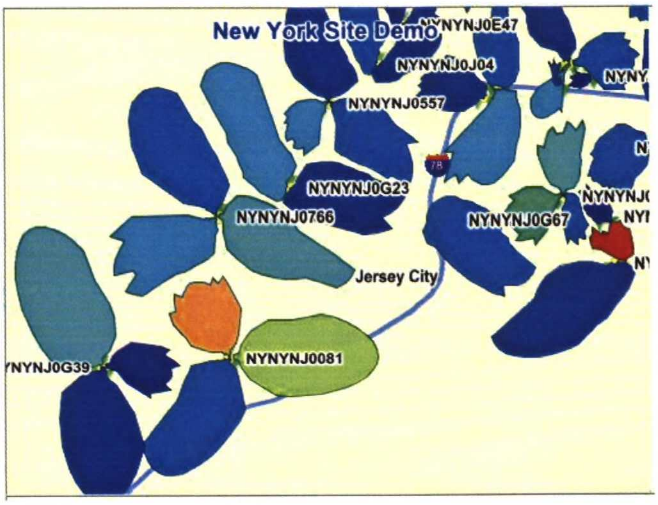

Figure 15 : Dominance – 7th iteration

5.4.1 Elliptic distance

The dominance of each inspection point is calculated by using an elliptic distance. The elliptic distance means the distance from one focus of an ellipse to the other end of its main axis. If the main axis is length of 2A and foci are placed in positions of (-C,0) and (C,0) the elliptic distance is *2A – C*. The formula of eccentricity is *E=C/A*.

Before calculating a dominance polygon for a reference antenna we know the position of the antenna. We also know the position of an inspection point. So we can easily construct an ellipse over the antenna and calculate the elliptic distance. After that we find every antenna in a specific distance. We construct ellipses over these antennas using their positions and an inspection point. Then we create elliptic distances for each antenna (calculating A and C) and after that we compare calculated distances to a reference distance and find out the antenna which has shortest elliptic distance to the inspection point. If the reference antenna has the shortest elliptic distance it is a winner and we continue by selecting a new inspection point for the reference antenna.

In *Figure 16* we have two antennas which are situated in points A and B. We also have an inspection point C. The bearing of antenna A is 90 (East) and the bearing of antenna B is 270 (West). Then we calculate reference ellipses for both antennas so that the reference point C belongs to both ellipses. Now we are able to calculate elliptic distances for A and B (lines). We can easily see in this example that the distance of ellipse B is smaller from reference point which means that this point belongs to antenna B (when both A and B are using the same transmission power[11]). Elliptic distance means that SIR value is the same in each position of an arc of a reference ellipse.

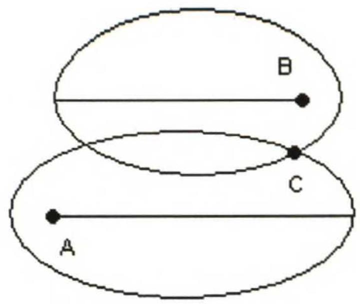

Figure 16 : Calculating dominance of a selected point

If the value of eccentricity (E) is near to zero (i.e. the cell is a circle) the initial dominance map could be like in *Figure 17*. The dominance areas are on the top of the picture. Green parts of the picture are antennas and with their bearing directions. Yellow spots are the centrum of sites[12].

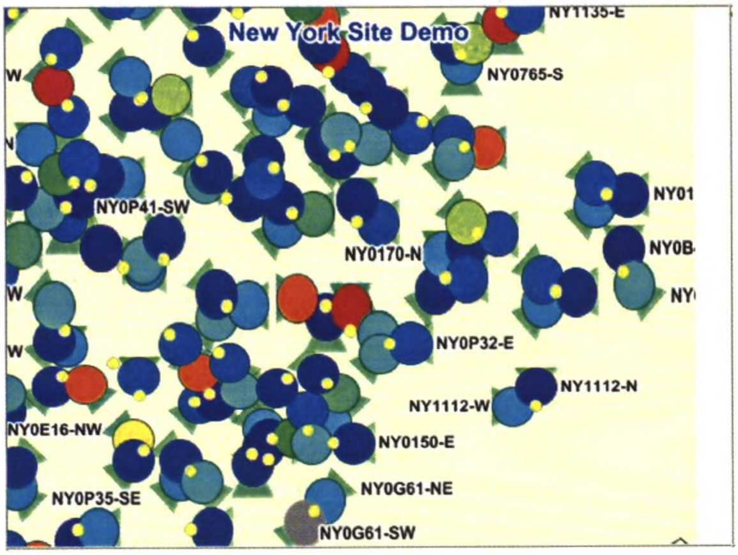

Figure 17 : Initial dominance map when eccentricity equals zero

[11] The different size of ellipses is not indicating the different transmission power in this example, it indicates the iteration step what has been taken (i.e. ellipse B has less steps than ellipse A)
[12] Actually, the centrum of the site should be drawn in the middle of the circle

Elliptic distance is used in this thesis because it gives better basis for the directional pattern of an antenna. If the excentricity of the ellipse is 0, it gives us a circle. Directional patterns of antennas are not normally circles, that is why we have bearing for each antenna and we can model quite accurate directional patterns of antennas using ellipses. Normally, signal strength along antenna's direction is much higher than opposite direction (i.e. behind the antenna's transmitter).

5.5 Automated adjacency creation

The implementation of automated adjacency creation is based on the same algorithm as the implementation of dominance calculation in the previous section. Here we use also the elliptic distance calculation. The implementation is based on distance and antenna bearing. We create an ellipse over the reference antenna (i.e. service area) and then we find out every antenna which is related to the reference antenna. Then, we calculate the overlapping area of these ellipses i.e. the combined area between adjacent ellipses (we use spatial functions: *sdo_intersection* and *sdo_area*). If the area is large, it is quite sure that an adjacency should be created between two cells. Service area is illustrated in *Figure 18*.

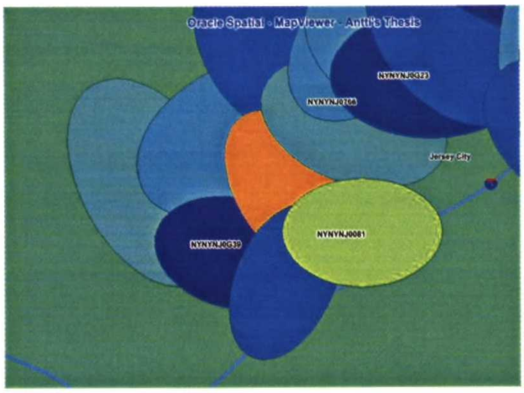

Figure 18 : Service Areas of cells

The adjacency candidates are selected in two phases. First, we get a list of candidates which have the area of intesection with a reference cell. At this phase we probably have about 50 candidates or more. Second, we check the requirement for the number of adjacencies and the maximum allowed distance to adjacent cells. After this second phase, we have a desired amount of candidates for an adjacency creation.

The procedure in Oracle takes four parameters which are:

- Max number of adjacencies per cell
- Min number of adjacencies per cell
- Max distance to neighboring cell
- Bi-directional creation (yes/no)

The result of the database query is an array of coordinates for antennas which consists the set of initial adjacencies for a reference antenna. An example of automatically created adjacencies is illustrated in *Figure 19*.

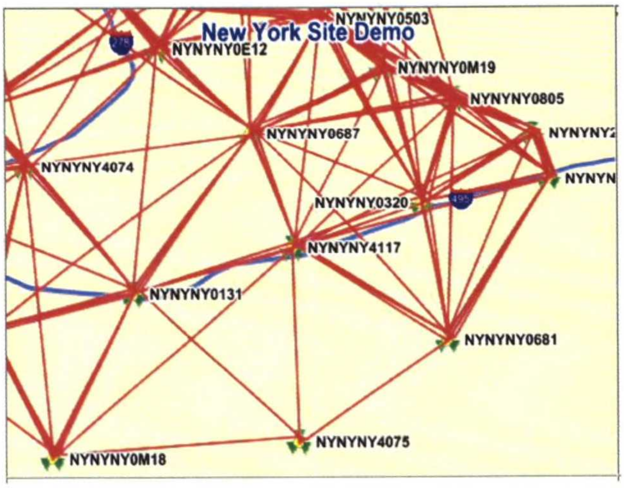

Figure 19 : Automatically created adjacencies

The results of this use case is described in the Analysis chapter.

5.6 PostGreSQL / PostGIS

Here, we describe shortly four use cases using PostGIS. Mainly this part describes the similarities and differences between the solutions with obtained Oracle Spatial or PostGIS.

5.6.1 Load-on-demand

Load-on-demand is implemented by storing map objects inside database using PostGIS's *geometry* datatype where objects can be points, lines, curves, polygons or a combination of previous (like in Oracle). The implementation is done by using PostGIS functions inside PostGreSQL stored procedures.

The table which serves load-on-demand database requests is called *optimizer_map_objects*. The structure of the table is the same as in Oracle's solution described earlier.

In PostGIS, we use a spatial function called *relate*. We call the function with 3 parameters, relate(geometry, anotherGeometry, intersectionPatternMatrix).

The function returns 1 (*true*) if this *geometry* is spatially related to *anotherGeometry,* which is evaluated by testing for intersections between the Interior, Boundary and Exterior of the two geometries as specified by the values in the intersectionPatternMatrix.

5.6.2 Coordinate transformations

PostGIS supports about 70 local projections. PostGIS uses the Proj4 library to provide coordinate transformation capabilities. The **proj4text** column in an exemplary table spatial_ref_sys contains the Proj4 coordinate definition string for a particular SRID. For example, string can be*:*

+proj=utm+zone=10 +ellps=clrk66 +datum=NAD27 +units=m.

Database table spatial_ref_sys is described in *Table 6.*

Table 6: The definition of spatial_ref_sys table

Column name	column type
srid	integer not null primary key
auth_name	varchar(256)
auth_srid	integer
srtext	varchar(2048)
proj4text	varchar(2048)

5.6.3 Automated adjacency creation

Service areas of cells are created the same way as in Oracle Spatial and creating a polygon is basically a similar procedure than in Oracle. When we have created ellipses over cells we calculate overlapping areas using PostGIS functions *intersection* and *area*. We call these functions as follows:

intersection(geometry1,geometry2) and *area*(geometry).

Then the rest of the solution is the same as with Oracle Spatial.

5.6.4 Dominance calculation

The dominance calculation is performed using the distance between adjacent cells like with Oracle Spatial. No specific spatial functions are used in this use case. (Building a geometry inside the database is used but this feature is needed everywhere when constructing spatial objects.)

6. ANALYSIS OF THE RESULTS

In this chapter we concentrate on analyzing the results of the previous Chapter. We go through the results by evaluating how well we could fulfil the requirements we placed earlier. We analyze both spatial systems Oracle Spatial and PostGIS and the results of each use cases on those systems.

During this work we did not face a situation that some use case could not be solved. That situation would have ruined the practical usage of the result.

6.1 Initial summary

As mentioned earlier, all use cases have high performance requirements. Spatial tools allow us to move some business logic inside a relational database. This means that executing heavy data handling inside the database reduces significantly data transfer between different software modules, such as GUI and the database.

Databases can handle operations quickly with complex data relations. This leads to remarkable performance improvements. For example, in dominance calculation spatial relationships can be calculated in seconds instead of reading large amounts of data into Java module and then making array-based calculations. The latter approach takes time even hours because of so large amount of data handling.

6.2 Oracle Spatial against the requirements

Oracle Spatial succeeded well to fulfil the requirements we agreed in the beginning of this Thesis. We could find solutions for every problem we had with four use cases. In Chapter 7 we discuss more Oracle's license policies because it has an influence when making decisions.

6.2.1 Load-on-demand

Load-on-demand has a functional reguirement where all different map objects should be able to be shown on screen. First of all, spatial functions inside Oracle allow the construction of objects needed in radio networks such as cells, site borders, adjacencies between cells, and dominance areas.

A new Java client API provides access to most MapViewer (see Definition of terms) functions from a Java application, a Java applet, a servlet within a Java2 Enterprise Edition (J2EE) container different from the J2EE container that contains the MapViewer service, or JavaServer Pages (JSP) code within the J2EE container that contains the MapViewer service. *[Mapviewer UG]* MapViewer is very powerful tool for visualizing map objects. This module can be embedded inside any Java based GUI. Mapviewer is made by Oracle which means that its implementation is very close to Oracle itself and this feature gives us significant performance benefit when we access Oracle via MapViewer.

When we want to create different map layers we create styles, themes and maps. Oracle Spatial allows us to create different *styles* which are the basic elements of spatial map views. We are able to create colours, markers, lines, areas, etc.

Then we can build *themes* which are made up of the data of a database table and one geometric column of a table. We show each element of this table using a previously created style. Themes can also be called as layers because we can show them one on top of another.

Finally, we build *maps* which are made up of themes as illustrated in *Figure 20*. So when we show a map on screen we see all the themes (layers) of it. Oracle provides a Java based definition tool , called The Map Definition Tool[13].

[13] MDT component is an unsupported GUI tool that lets us create, modify, and delete styles, themes, and maps. The unsupported Map Definition Tool is included as a separate download. MDT is freeware software and it is available to all Oracle users.

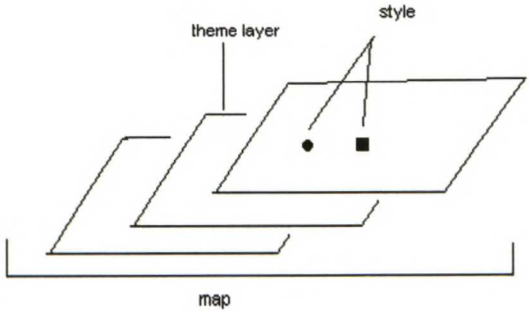

Figure 20 : The structure of items in MDT

The primary benefit of MapViewer is its integration with Oracle Spatial and Oracle Locator. The current release of MapViewer supports only two-dimensional vector geometries.

All these map components are inside a database. So, the access to these components is again very fast. Combining different map components to map data itself is also very fast.

Traditionally, all map components are stored outside the database. Map data is also outside the database. Only some controlling information is in the database, which means that lots of data access is performed and this procedure which takes time.

Next, we have an example how to select objects from a PL/SQL procedure. In the database, we have a table called *optimizer_map_objects* where we have radio stations in Finland. We want to find all radio stations inside a rectangular of (24,60) (27,68)[14] in WGS-84 coordinate system.

So, we call the procedure with previous boundary and a data-element called 'RADIO' (test 1). Retrieving data from database can be done with the following sql query:

select optimizer_map.get_objects(24,60,27,68,NULL,'RADIO',NULL) from dual;

And we get radio stations as the result:

[14] 24 degrees of East,60 degrees of North and 27 degrees of East,68 degrees of North

RADIO DEI, RADIOASEMA Q, RADIO MEGA, RADIO POOKI, RADIO MEGA,RADIO JYVÄSKYLÄ, RADIO 99, RADIO PLUS JYVÄSKYLÄ, RADIO AALTONEN,RADIO SPUTNIK, RADIO FONI,RADIO-PROVINSSI, RADIO POOKI, RADIO ANKKURI, RADIO 957, RADIO PLUS, RADIO PLUS,RADIO PLUS TAMPERE, RADIO JANNE, RADIO CITY, RADIO HELSINKI

We made 3 different tests to request list of objects. In these tests we requested three different geometry types and we measured the performance of retrieved objects. We use a database table called optimizer_map_objects and last rows in the following tables indicates time used for the test, respectively.

Test 1:
Table name: optimizer_map_objects
Rows in table: 1163
Geometry type: point
Selected objects: 251
Time used: 0.04s

Test 2:
Table name: optimizer_map_objects
Rows in table: 1163
Geometry type: point
Selected objects: 1163
Time used: 0.10s

Test 3:
Table name: service_area
Rows in table: 1063
Geometry type: polygon (36 points / polygon)
Selected objects: 1063
Time used: 0.16s

We can use the previous example to find out radio network elements inside a selected rectangular. Then we receive a list of objects that we can show in screen using a GIS tool, for example ILOGS or MapViewer.

6.2.2 Coordinate transformations

The coordinate transformation tests have been done between WGS-84 and *Transverse Mercator Finnish KKJ* –local projection. Test coordinates are located over Finland from Hanko to Utsjoki. The reference values of coordinate transformation are from National Land Survey of Finland (NLSF). Test positions are Finnish FM radio station antennas. *Table 7* illustrates the test results. In the table we have following columns:

- Commune A commune where radio station is located

- Radio station — Name of the radio station
- Longitude — given WGS-84 longitude
- Latitude — given WGS-84 latitude
- Ref_long — NLSF longitude for given coordinate
- Ref_lat — NLSF latitude for given coordinate
- Oracle_long — Oracle's longitude for given coordinate
- Oracle_lat — Oracle's latitude for given coordinate
- Error — Error between NLSF reference value and Oracle

Table 7: Finnish FM radio stations

COMMUNE	RADIO STATION	LONGITUDE	LATITUDE	REF_LONG	REF_LAT	ORACLE_LONG	ORACLE_LAT	ERROR (m)
KUHMO	RADIO KAJAUS	29E5702	64N3220	3641723	7163354	3641725.18	7163353.85	2.19
SOTKAMO	NOVA	28E1523	64N0734	3561370	7114649	3561372.35	7114648.61	2.38
SIEVI	KISS FM	24E2014	64N0036	3369953	7103823	3369955.76	7103822.38	2.83
OUTOKUMPU	RADIO REX	29E0034	62N4346	3602925	6959962	3602927.98	6959961.84	2.98
OULU	CLASSIC FM	25E3543	65N0026	3433926	7213013	3433929	7213013.4	3.03
TAIVALKOSKI	YLE	28E2127	65N1804	3563488	7245726	3563491.04	7245725.45	3.09
KRUUNUPYY	ISKELMÄRADIO	23E3033	63N4406	3327808	7075158	3327810.92	7075156.85	3.14
TORNIO	KISS FM	24E2118	65N4930	3379283	7306005	3379286.25	7306005.35	3.27
VARKAUS	RADIO SALMINEN	27E5601	62N1815	3548601	6911311	3548604.35	6911310.61	3.37
SAVONLINNA	NRJ ENERGY	28E5203	61N5215	3598429	6864080	3598432.42	6864079.52	3.45
PELLO	YLE	24E0712	66N4746	3373533	7414675	3373536.32	7414676.08	3.49
VIRRAT	RADIO PLUS	23E4748	62N1301	3333565	6905364	3333568.45	6905363.24	3.53
MÄNTSÄLÄ	SUOMIPOP	25E1206	60N3359	3401551	6718658	3401554.61	6718657.83	3.61
VAASA	CLASSIC FM	21E3823	63N0550	3229687	7010650	3229690.57	7010649.24	3.65
IKAALINEN	RADIO 957	23E0000	61N4657	3289179	6859319	3289182.57	6859317.94	3.72
PIHTIPUDAS	JÄRVIRADIO	25E3902	63N1717	3432469	7021338	3432472.72	7021336.99	3.85
ESPOO	SUOMI PLUS	24E4516	60N1101	3375578	6676780	3375581.88	6676779.88	3.88
RAUMA	RADIO RAMONA	21E3041	61N0918	3204884	6795301	3204887.94	6795300.39	3.99
TURKU	SUOMIPOP	22E2020	60N2853	3244012	6716915	3244015.91	6716914.04	4.03
TAMPERE	KISS FM	23E4447	61N3016	3326974	6826162	3326977.95	6826161.2	4.03
MIKKELI	YLE	27E2807	61N3504	3525058	6830842	3525061.99	6830841.39	4.04
PORVOO	YLE	25E3130	60N2114	3418749	6694544	3418753.2	6694543.75	4.21
EURAJOKI	YLE	21E4205	61N1653	3216232	6808509	3216236.21	6808507.81	4.37
TAMMELA	YLE	23E5405	60N5548	3332185	6761798	3332189.4	6761797.13	4.49
SODANKYLÄ	YLE	27E0900	68N0236	3506434	7550857	3506438.55	7550857.16	4.55
SALO	RADIO 88,2	23E1106	60N2315	3289865	6703469	3289869.56	6703468.68	4.57
HELSINKI	SÄVELRADIO	24E5535	60N1216	3385188	6678789	3385192.68	6678788.17	4.75
HANKO	KISS FM	22E5617	59N5014	3272493	6643052	3272497.75	6643051.58	4.77
ENONTEKIÖ	YLE	22E5037	68N2456	3329577	7598123	3329581.51	7598124.73	4.83
SUND	ÅLAND	20E0812	60N1245	3120114	6697673	3120118.82	6697671.78	4.97
MARIEHAMN	RADIO VÄST	19E5621	60N0519	3107728	6685079	3107732.96	6685077.99	5.06
ENONTEKIÖ	YLE	20E5135	69N0233	3255322	7674566	3255326.82	7674567.97	5.21
INARI	RADIO INARI	27E3410	68N3825	3523327	7617540	3523332.59	7617540.24	5.6
UTSJOKI	YLE	27E3754	70N0250	3524238	7774507	3524244.3	7774507.93	6.37

Average error: 3.87

The requirement for transformation error is 5 meters. We can see from the table that test positions which are either in the south-western part of the projection or in the northern part of the projection exceed the limit of requirement. The test was made using over 500 transformations where the total transformation time was 1.84 seconds. This means that the average transformation time is 0.0035 seconds / a coordinate transformation (WGS84 -> KKJ -> WGS84).

We also found out that latitude error was from –1.5 meters to 2.2 meters and longitude error was from 2.2 meters to 6.9 meters. So, in this transformation the latitude error is constanty positive and over 2.2 meters. We made a test where we shifted latitudes by 4.4 meters which means that errors after shifting were in range of –2.2 meters to 2.5 meters.

Using the latitude shifting the average error was 1.2 meters (without shifting 3.87m), maximum error was 2.7 meters (6.37m). After very simple shifting the maximum error became within the requirement. (less than 5m)

The performance is good enough for immediate transformation when we accept that the transformation is done every time when mouse movement stops. Still we have to take care that we do transformations only when mouse pointer stops because otherwise we have to make hundreds of transformations per second.

If we compare this result to the current situation in Optimizer, improvement is significantly. Many situations the error was so small that it could not be seen on the map. The previous errors of 200 meters were so big that antennas in the coast line could be shown in water. That was not acceptable.

6.2.3 Automated adjacency creation

Overlapping service areas between adjacent cells give us a very good basis for creating adjacencies. The performance of this kind of spatial examination takes lots of time. For example, if we have network where we have 1000 cells we need to do almost one million (1000x1000) examination. As a result we get about 500000 candidates for adjacencies in the whole network. In our tests this takes time about one hour and 20 minutes. Used time is not dependent on the size of the service area, but the amount of examinations what we make. Anyway this operation is done basically only once for the whole network. In a normal case we either detect the whole network once or make an incremental operation for few cells. If we insert a new cell into an existing network we check this cell against other cells of the network and we can calculate an estimate for creating adjacencies to that cell (and neighbors also) which is about 5 seconds. This response time is good enough for normal interactive use. The service areas of the whole Network are illustrated in *Figure 21*.

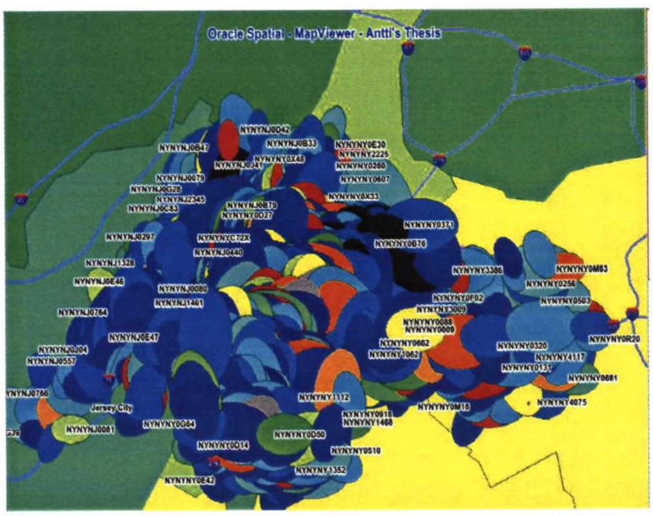

Figure 21 : Example of service areas of a whole network

Another way to automate the creation of adjacencies is to use a dominance calculation. This solution is useful in situation where we already have an existing network and we have an existing dominance calculation map for a network and we just want to add or delete a cell from a network. Dominance with allowed overlapping illustrated in *Figure 22*.

Thus we can do a desired change in the network and then calculate a dominance allowing overlapping in the edges of the dominance polygon.

For example when we have added a new cell into the network we can easily find out all other cells which have an overlapping dominance polygons with a new cell.

Figure 22 : Dominance with allowed overlapping

If we add new cell called NJ0473-E, we can check related cells using Oracle's *sdo_relate* function, and we have a list of adjacent cells:

- NJ0473-NW
- NJ0473-SW
- NJ0E39-S
- NJ0C83-S
- NJ0440-N

In this example, we retrieve adjacent cells from the database in 0.19 seconds. This indicates that we are able to recalculate the adjacencies of the whole network[15] in about 3.5 minutes.

When we use the first method to find out adjcencies, we encouter a problem in a situation where cell has many adjacent cells in one direction and few adjacent cells in another direction. This means that if we create the maximum amout of adjacencies to one narrow sector, other sectors may not have any adjacencies. So we can think of a restriction which allows only some limited number of adjacencies in specified sector as illustrated in *Figure 23.*

The second method to find out adjacencies does not "forget" the cells which have more distance in the direction where there are fewer cells.

[15] The radio network of New York and New Jersey has 1024 sites.

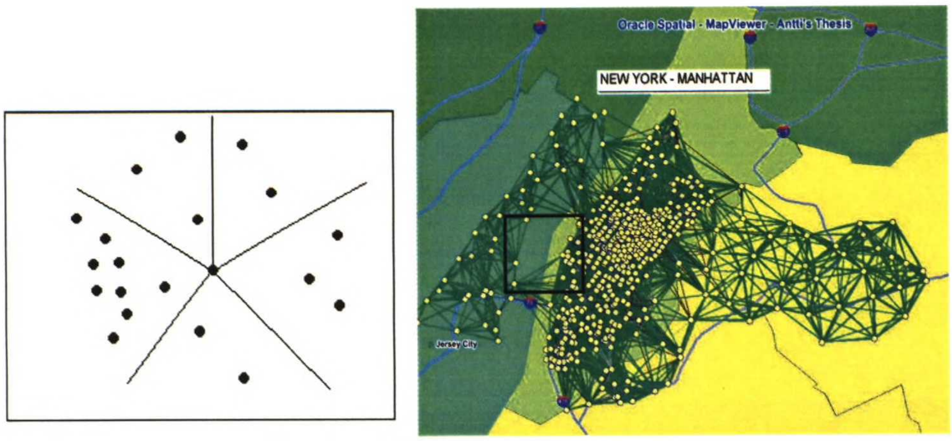

Figure 23 : Limitation of adjacencies & Missing adjacencies

Currently, almost all adjacencies are made manually in Optimizer. This means hours of routine work in the beginning. In some situations, for example inside one cell, adjacencies between 2G and 3G units are very easily created. Such adjacencies covers more than 50% of all adjacencies in the network. These adjacencies can be automatically created with a reliability of more than 99%. The benefit of automated adjacency creation is thus evident.

6.2.4 Dominance calculation

Dominance calculation is based on iteration steps. This means that results can be seen very quickly, but the dominance after first iteration step is very rough. One iteration step includes five sub steps. Each sub step is twice as big as previous sub step. This means that first we examine smaller distances and then we take bigger steps to find out the edges of dominance polygon of a cell. One iteration step for a cell takes time about 3.5 seconds. After 10 iteration steps we have quite exact results on dominances between adjacent cells.

This method always leaves some distance between dominances of adjacent cells as illustrated in *Figure 24*.

However, if we allow overlapping in dominace maps we can create dominances without significant spaces between dominances of adjacent cells.

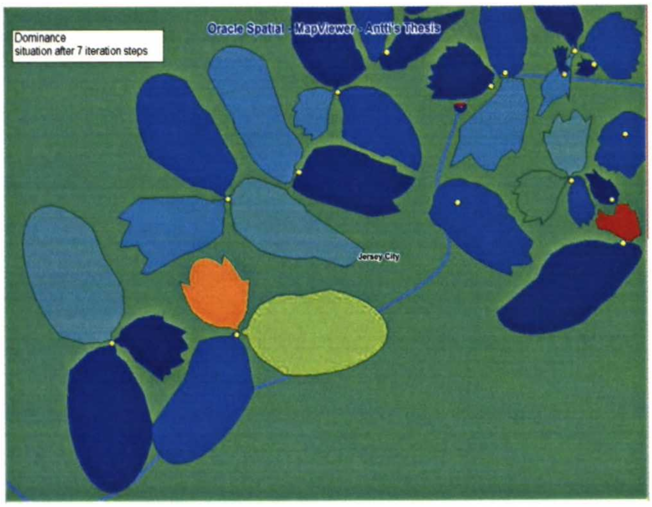

Figure 24 : Dominance map

Iteration steps in dominance calculation gives the user a guick overview of dominance in the whole network. After a couple of seconds the user is able to see if there is very bad dominance in some area of the network. Then waiting not more than couple of minutes he is able to see quite accurate result. Currently dominance map of Optimizer is very accurate but receiving the result takes time more than one working day. If network topology changes rapidly user is practically never able to see valid dominance map.

6.3 PostGIS against the requirements

PostGIS is based on the functionalities of PostGreSQL object-relational database and two additional packages: *proj4* and *geos*. As mentioned earlier the same functions exist in PostGIS as in Oracle Spatial. The main difference is that PostGIS is an Open Source package and Oracle Spatial is a commercial product. Thus all functions are available in the basic distribution unlike in Oracle where the basic package is called Oracle Locator and extra functionalities are in Oracle Spatial.

6.3.1 Results of analysis

Here is a short description of the results compared to Oracle Spatial. Everything what is similar to the results with Oracle is not repeated.

6.3.1.1 Load-on-demand

Load-on-demand in PostGIS is based on the same functionality as in Oracle Spatial except Java calls are different. Of course we can make Java calls through *jdbc* but Postgis already uses an API which is called Java Topology Suite (JTS).The JTS is a Java API that implements a core set of spatial data operations using an explicit precision model and robust geometric algorithms. JTS is intended to be used in the development of applications that support the validation, cleaning, integration and querying of spatial datasets. It implements the geometry model specified in the OpenGIS Simple Features Specification. It provides functions for evaluating spatial relationships using the Dimensionally Extended 9-Intersection Matrix (DE-9IM) model. Spatial analytic functions such as intersection, union, and buffer are provided. Metric functions include length, area and distance. JTS is written in 100% pure Java. The JTS package also provides the TestBuilder, a simple GUI application which allows creating geometry and running all the spatial functions in JTS. TestBuilder can be compared to Oracle's MapViewer.

Like with Oracle Spatial, we created a database function called *optimizer_map.get_objects*. Then we made a test where we requested FM radio stations from database. We got the same result set as with Oracle (parameters: 24,60,27,68,null,'RADIO',null). Query time was 0.03 seconds (0.04s using Oracle). So, the result is approximately the same than with Oracle.

6.3.1.2 Coordinate transformations

Coordinate transformations are performed using *proj4* package. We made the same test using radio stations as with Oracle. The main difference was that we did not need to do any error corrections to latitudes. The average error of transformations was 0.9 meters and the maximum error was 2.4 meters. The total time of transformations was 1.2 seconds where the average transformation time was 0.0023 seconds per coordinate transformation.

These results mean that coordinate transformations are faster and more accurate with PostGIS than with Oracle Spatial.

6.3.1.3 Automated adjacency creation

We made the same two tests with PostGIS as with Oracle. The first test was performed using 500000 candidates for adjacencies which took time 55 minutes. The second test, creating adjacencies using dominance polygons, took time 3 minutes which was 0.175 seconds per cell.

This test indicates that PostGIS with PostGreSQL is significantly faster also in this use case.

6.3.1.4 Dominance calculation

We made the same iteration steps as with Oracle. One iteration step took time 2.9 seconds and 10 iteration steps took time 25 seconds. This use case is slightly faster than in Oracle Spatial.

6.3.1.5 Results of Analysis

In *Table* 8 we have collected the results of spatial functions between Oracle and PostGIS. Named functions are Oracle functions. In the table, when the PostGIS column has an 'X' sign it means that function is supported. This table illustrates how different functions are supported in each case.

Table 8: difference of compared databases

function	use case	info	locator	spatial	postgis
getvertices *	**1**	**Gives vertices of a polygon**		**X**	X
sdo_aggr_centroid		Returns a geometry object that is the centroid ("center of gravity") of the specified geometry objects.		X	X
sdo_aggr_convexhull		Returns a geometry object that is the convex hull of the specified geometry objects.		X	X
sdo_aggr_mbr		Returns the minimum bounding rectangle of the specified geometry objects	X	X	X
sdo_aggr_union		Returns a geometry object that is the topological union (OR operation) of the specified geometry objects.		X	X
sdo_arc_densify		Changes each circular arc into an approximation of a polygon		X	X
sdo_area	**3,4**	**Computes the area of a two-dimensional polygon**		**X**	X
sdo_buffer		Generates a buffer polygon around a geometry		X	X
sdo_centroid		Returns the centroid of a polygon.		X	X
sdo_convexhull		Returns a polygon-type object that represents the convex hull of a geometry object.		X	X
sdo_difference		Returns a geometry object that is the topological difference (MINUS operation) of two geometry objects)		X	X
sdo_distance	3,4	Computes the distance between two geometry objects.	X	X	X
sdo_elem_info	1,2,3,4	base element of spatial geometry operations	X	X	X
sdo_filter	4?	Specifies which geometries may interact with a given geometry	X	X	X
sdo_geometry	1,2,3,4	base element of spatial geometry operations	X	X	X
sdo_intersection	**3,4**	**Returns a geometry object that is the topological intersection (AND operation) of two geometry objects)**		**X**	X
sdo_length		Computes the length or perimeter of a geometry.		X	X
sdo_mbr		Returns the minimum bounding rectangle of a geometry		X	X
sdo_nn		Determines the nearest neighbor geometries to a geometry.	X	X	X
sdo_nn_distance		Returns the distance of an object returned by the SDO_NN operator	X	X	X
sdo_ordinate_array	1,2,3,4	base element of spatial geometry operations	X	X	X
sdo_relate	1	Determines whether or not two geometries interact in a specified way	X	X	X
sdo_union		Returns a geometry object that is the topological union (OR operation) of two geometry objects.		X	X
sdo_within_distance		Determines if two geometries are within a specified distance from ane another	X	X	X
sdo_xor		Returns a geometry object that is the topological symmetric difference (XOR operation) of two geometry objects.		X	X
transform	**2**	**Transforms a geometry representation using a coordinate system (specified by SRID or name).**		**X**	X
transform_layer		Transforms an entire layer of geometries (that is, all geometries in a specified column in a table).		X	X
validate_geometry		Determines if a geometry is valid.	X	X	X
validate_layer		Determines if all the geometries stored in a column are valid.	X	X	X
viewpoint_transform		Transforms an optimized rectangle into a valid polygon for use with Spatial operators and polygon	X	X	X

use case 1: load-on-demand
use case 2: coordinate transforms
use case 3: automated creation of adjacencies
use case 4: dominance calculation

Bold text: Feature is used in use-case
* = Vertices are needed if we want to read all vertices of polygons through Java API
PostGIS has different names for Spatial functions, but they are not named here.

7. CONCLUSIONS

It is a well-known fact that when we handle data in any data system we need to maintain our data in some data storage. When the amount of data is very large, the most realistic place to maintain our data is a database. Relational databases are still most commonly used database types. In this thesis, we had a problem where we had lots of data and we needed to maintain the data in a database. Actually, accessing this data is the most difficult task. Relational databases are not very efficient when we need to transform lots of data in and out of a database and to access them rapidly. We were able to solve this problem by moving some of the business logic inside the database, using spatial tools, and so to reduce the traffic between other software modules and the database. Spatial tools allow us to use vector based maps instead of raster based maps.

Spatial functions in relational databases give significant benefits as regards performance. The amount of map data increases fast when we use geographical data. The traditional way of handling data in databases (input and output transactions) is not enough anymore. We can also make the structure of our data much more clearer when we store our data using spatial functions.

Spatial databases are able to treat our spatial data like any other data in the database. Earlier solutions without spatial databases did not offer such data handling opportunities. Thus we can use basic database functionalities like transactions, backups, integrity checks, less data redundancy, fundamental organization and operations handled by the database, multi-user support, security/access control and locking.

Spatial databases significantly reduce the development cycles of client applications. When we do spatial querying using SQL we use simple SQL expressions to determine spatial *relationships* like distance, adjacency and containment.

Disadvantages of Spatial Databases are such that cost to implement can be high due to complex algorithms, some inflexibility (difficult to change the structure of applications because of the huge amount of data), incompatibilities with some GIS software (different map format, MapInfo, Esri etc.), slower than local, specialized data structures, (database gives more features but is not so specified for one solution) and user/managerial inexperience and caution.

In this Thesis we have compared two spatial databases, Oracle Spatial and PostGIS. The biggest difference is that Oracle Spatial is a commercial product when PostGIS is an Open Source package. Both databases succeeded with our use cases. We needed some functions which are not supported in Oracle Locator, so we need Oracle Spatial (extra licence fee). PostGIS has all required functions in the basic package because there is no enlargement package.

Oracle Spatial is based on Oracle Locator which has all basic spatial functionalities. Oracle Locator is included in Oracle's normal licence fee. Oracle Spatial has however some extra functions which are useful when handling maps related to Radio Network Optimisation. Oracle Spatial's licence fee is distinctively more than the normal price. (about 1000 euros per CPU).

The main contribution of this thesis is as follows. Use of the elliptic distance in modelling of the radiation figure of the antenna is not known earlier. Also, use of the intersecting area of the radiation figure for determination of the adjacencies is not known earlier.

7.1 Summary

PostGIS is faster and less expensive than Oracle. Spatial database allows faster and easier access to GIS based map handling than old raster based maps. Selected use cases work with Spatial databases. Criteria what placed in Chapter 3 are fulfiled. When we use maps to handle radio networks we need more data and we need to have spatial handling in our relational databases. This thesis proved that spatial databases are made for handling graphical map data. We also found out that nowadays the amount of data is so big that large radio networks cannot be handled anymore with normal relational databases, the performance is not good enough.

7.2 Future work

Next, one could specify use cases more accurately and take some new use cases into account. One can, for example, use different antenna transmitting powers in dominance calculation so that one can achieve more realistic model for antenna coverage (i.e. all cells are not using the same transmitting power).

One could also build a pilot software which is based on Spatial database and after that compare this product with previous products (i.e. NetAct Optimizer).

APPENDICES

Appendix A: Coordinate Systems

Coordinate System (Spatial Reference System)

A coordinate system (also called a spatial reference system) is a means of assigning coordinates to a location and establishing relationships between sets of such coordinates. It enables the interpretation of a set of coordinates as a representation of a position in a real world space.

Cartesian Coordinates

Cartesian coordinates are coordinates that measure the position of a point from a defined origin along axes that are perpendicular in the represented two-dimensional or three-dimensional space.

Geodetic Coordinates (Geographic Coordinates)

Geodetic coordinates (sometimes called geographic coordinates) are angular coordinates (longitude and latitude), closely related to spherical polar coordinates, and are defined relative to a particular Earth geodetic datum.

Projected Coordinates

Projected coordinates are planar Cartesian coordinates that result from performing a mathematical mapping from a point on the Earth's surface to a plane. There are many such mathematical mappings, each used for a particular purpose.

Local Coordinates

Local coordinates are Cartesian coordinates in a non-Earth (non-georeferenced) coordinate system.

Geodetic Datum

A geodetic datum is a means of representing the figure of the Earth, usually as an oblate ellipsoid of revolution, that approximates the surface of the Earth locally or globally, and is the reference for the system of geodetic coordinates.

Authalic Sphere

An authalic sphere is a sphere that has the same surface area as a particular oblate ellipsoid of revolution representing the figure of the Earth.

Transformation

Transformation is the conversion of coordinates from one coordinate system to another coordinate system.

If the coordinate system is georeferenced, transformation can involve datum transformation: the conversion of geodetic coordinates from one geodetic datum to another geodetic datum, usually involving changes in the shape, orientation, and center position of the reference ellipsoid.

Appendix B: Optimizer_map PL/SQL procedure

The next procedure returns an array of objects which are inside a given rectangular on map. Rectangular is defined by giving four corner positions in WGS-84 coordinate system.

```
CREATE OR REPLACE TYPE OBJARRAY is VARRAY(1000) OF VARCHAR2(50)
/

CREATE OR REPLACE PACKAGE optimizer_map
AS
FUNCTION get_objects
(b_x1 IN NUMBER -- boundary from x1.y1 to x2.y2
,b_y1 IN NUMBER
,b_x2 IN NUMBER
,b_y2 IN NUMBER
,layer IN INTEGER -- map layer
,data_element IN VARCHAR2 -- selected data element
,resolution IN INTEGER -- resolution of map view
)
RETURN OBJARRAY;
END optimizer_map;
/

CREATE OR REPLACE PACKAGE BODY optimizer_map
AS
FUNCTION get_objects
(b_x1 IN NUMBER
,b_y1 IN NUMBER
,b_x2 IN NUMBER
,b_y2 IN NUMBER
,layer IN INTEGER
,data_element IN VARCHAR2
,resolution IN INTEGER
)
RETURN OBJARRAY
IS
CURSOR c_test
(cb_x1 IN NUMBER
,cb_y1 IN NUMBER
,cb_x2 IN NUMBER
,cb_y2 IN NUMBER
,clayer IN INTEGER
,cdata_element IN VARCHAR2
,cresolution IN INTEGER
) IS
SELECT A.object_name FROM optimizer_map_objects A
WHERE (A.layer = clayer OR clayer IS NULL)
AND (A.data_element = cdata_element OR cdata_element IS NULL)
AND (A.resolution = cresolution OR cresolution IS NULL)
AND sdo_relate(A.geometry, mdsys.sdo_geometry(2003,NULL,NULL,
mdsys.sdo_elem_info_array(1,1003,3),
```

```
mdsys.sdo_ordinate_array(cb_x1,cb_y1, cb_x2,cb_y2)),
'mask=anyinteract querytype=window') = 'TRUE';


l_data ObjArray := ObjArray();

BEGIN

  FOR map_rec IN
c_test(b_x1,b_y1,b_x2,b_y2,layer,data_element,resolution)  LOOP
           l_data.extend;
           l_data(l_data.count) := map_rec.object_name;
  END LOOP;
  RETURN l_data;

  EXCEPTION
  WHEN NO_DATA_FOUND THEN RETURN NULL;

END get_objects;

END optimizer_map;
/
```

Appendix C: Coordinate transformations

The next function returns coordinates transformed from WGS-84 coordinate system to Finnish KKJ projection.

```
CREATE OR REPLACE FUNCTION wgs_to_kkj(latitude IN NUMBER, longitude IN
NUMBER)
           RETURN mdsys.sdo_geometry
           IS g mdsys.sdo_geometry;
              gT1 mdsys.sdo_geometry;

BEGIN

 g := mdsys.sdo_geometry(2002,8307,null,
           mdsys.sdo_elem_info_array(1,1,1),
           mdsys.sdo_ordinate_array(longitude, latitude ));

 gT1 := mdsys.sdo_cs.transform(g,294914);

RETURN(gT1);

END;
```

Appendix 4: List of Spatial Databases

- ESRI ArcSDE (on top of several different DBs) http://www.esri.com/software/arcgis/arcsde
- Oracle Spatial http://www.oracle.com/technology/products/spatial/
- IBM DB2 Spatial Extender http://www-306.ibm.com/software/data/spatial/
- Informix Spatial DataBlade http://www-306.ibm.com/software/data/informix/blades/spatial/
- MS SQL Server (with ESRI SDE) http://www.microsoft.com/sql/default.mspx
- Geomedia on MS Access http://www.functionx.com/access/
- PostGIS / PostgreSQL http://www.postgis.org/

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