Using GIS in the Management of Wireless Router Network

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In this thesis, the main aim is to describe GIS application in Wireless Router Network, specifically in network management and maintenance, and what emphasized are discussing and analyzing GIS data quality requirement for the application.

This work is done based on Nokia RoofTop Router network solution. For the network management and maintenance, we develop a GIS application --- RSV (RMS Services Viewer) system in Novo Meridian Oy.

GIS is playing an important role and revealing great advantages in the Wireless Router Network's management and maintenance because of its location dependent. With GIS's Internet solution, our RMS Services Viewer (RSV) system presents power functions for network management and maintenance. With RSV, you can visualize living network in a specific area based on the background map, then monitor network performance, update network, and support router selling in market. With its simple graphic user interface, customer can check the network's visibility coverage situation to his home address without any training, just simply input his home address.

LOS analysis and address geocoding are the basic function of system. The performance and accuracy of system depend on GIS data quality at a great extend. In this GIS application, mainly two kinds of GIS data: DEM data and Street/address data. This thesis gives a detailed analysis for those data requirement in different testing city areas with different data quality. And also solutions and alternative are discussed for the future improvement.

Keywords: GIS, DEM, LOS, Geocoding, Visibility, Wireless Router Network, RSV

Language: English

Foreword

This is my diploma thesis for finishing my MS degree studying. I was writing it during my job in Novo Meridian Oy, the thesis topic is out of a project, Nokia Wireless RoofTop Network, the thesis is focus on the GIS application in Wireless Router Network and Geographical data requirement.

The thesis is organized with nine chapters. Chapter 1 is background introduction for this thesis. Chapter 2 gives basic GIS introduction, and introduces important GIS related technologies used in the thesis. Chapter 3 is general Internet and Wireless Internet concepts. Chapter 4 states in detail Wireless network architectures, especially Nokia Wireless Router Network solution. Chapter 5 is briefly saying the role of GIS in Nokia Router Network. Chapter 6 describes our GIS support system in Wireless Router Network --- RMS Services Viewer (RSV) system of NWR. Chapter 7 is geographical data requirement, which provides important description and analysis for geographical data in the GIS system. Chapter 8 provides some solutions and alternative based on last chapter analysis. Finally Chapter 9 is concluding remark and future prospect.

For the thesis ready, firstly I should express thanks to my thesis supervisor, Professor Kirsi Virrantaus, in Surveying department, Helsinki University of Technology. She carefully guide me to write this thesis, provides me important suggestion, opinion and modification in content and structure, even language.

With my special thanks to my thesis instructor, Ilkka Suojanen, in Novo Meridian Oy, who is this project manager, he instructs me to make the thesis title, content, and also help me do modification during whole writing.

Besides I also want to thank our team member, Jani Tukiainen who also gave me much help.

Espoo, March 2002

Shunxing Chen

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Abbreviations

DEM	Digital Elevation Model.
GIS	Geographical Information Syetems.
HTTP	Hypertext Transfer Protocol
LOS	Line of Sight.
LMDS	Local Multipoint Distribution Service.
LIDAR	Light Detection and Ranging.
MMDS	Multichannel Multipoint Distribution Service.
NWR	Nokia RoofTop Wireless Routers.
RMS	Nokia RoofTop Router Management System.
RSV	RMS Services Viewer
SNMP	Simple Network Management Protocol
USGS	U.S. Geological Survey.
WROMAN	Nokia Wireless Router Manager

1. Introduction

1.1 Background

Internet, with the rapid and ever growing in the past several years, has made itself very important in our daily life. One hand, it has become one of the most important tools for people and businesses to communicate with each other; in addition it's importance is getting much more demanding from people to be quick and ready access to it without location limitation. So these reasons lead to an increased dependence on the Internet that is driving up access bandwidth demands at a pace faster than the wired infrastructure can keep up with. However, upgrading wired infrastructure to provide high-speed and remote Internet access is costly, complicated and time consuming. The result is a bottleneck at the Internet access point --- the 'last mile'* of Internet infrastructure.

Instant access to corporate information sources and web applications, such as customer service, financial transactions, wireless e-mail, instant messaging, mobile commerce and location-sensitive web browsing where ever you are, requires faster wireless networks than those that are available today. These wireless services must be delivered faster and at prices that are not excessively higher than prices of wireline services. Wireline infrastructure for the Internet either exists or is being upgraded to meet the increasing demand of users. But wireless Internet is presenting an important challenge to network designers. A few network infrastructure architects are convinced that the real answer to higher speed wireless networks lies in a hybrid infrastructure. They think that once Internet is there, there is only one problem to be solved for wireless access, the last mile wireless access to the wireline infrastructure. Broadband networks achieve this through a line of sight wireless connection between any two points (point to point) or multiple points (multi-point).

Broadband technology is fast becoming an important element of wireless network solution to connect distant enterprises to the Internet bypassing traditional terrestrial connections. It has even the potential of serving small businesses and even households. Early adopters of wireless broadband technology have demonstrated the power, application and versatility of mobile broadband communications. They have proved that there is a strong business case and quick payback.

Accordingly, today's wireless broadband net works make high performance Internet access possible where wired broadband infrastructure is impractical. Wireless broadband networks avoid the upfront costs and delay of building or upgrading a wired infrastructure. Further, technology advancements are making the promise of high-speed wireless data a reality for mass consumer markets. Licence-free spectrum bands eliminate the need for an operating licence and the high fees of bidding for spectrum. This opens up market opportunities to a wide range of carriers and service providers. In addition, new wireless specific protocols enable routed wireless mesh networks that simplify line of sight requirements in wireless link intelligence enables self-configuring and self-healing networks that are simple to deploy and adaptable to changing situations. All these new technologies enable a new type of network, --- anyone can deploy without a large, upfront investment in RF engineering or infrastructure, --- is less expensive to deploy to residential markets than either a new wired infrastructure or a wireless network based on a client/base station architecture. Theses new networks emulate the topology and protocols of the Internet itself, but are optimised for wireless high-speed data transmission.

1.2 Problems and motivation

What has kept wireless broadband technology from being practical for these price-sensitive, mass markets is a combination of technological constraints and deployment costs. High performance wireless connections require a clear line of sight between links. In many neighbourhoods and local business communities, buildings, trees, hills and curvature of the earth make line of sight difficult. In addition, over time, new building, temporary obstructions, growing trees or sometime someone removed, will make effect for link or network topology.

Network management is keeping a network up and running to maximum efficiency while effectively managing its growth. It is about gaining control of the various elements that comprise the network. Network management is also taking control of a multi-vendor, complex environment and delivering the highest level of availability to the end user.

To sustain a high level of user productivity, network managers have to ensure that there are no bottlenecks in the network. If a bottleneck does exist, it must be eliminated as soon as possible. Network management tools are used to quickly identify bottlenecks by locating the device or devices that are the cause of the problem and fixing the devices appropriately.

Network Management has not evolved as quickly as the network itself; it can almost be considered an afterthought. As more and more devices have been connected to the network, it has become apparent that there were more and more opportunities for miscommunication to occur between connections; for a router to be improperly configured; or for packets of information to be overloading the system.

Therefore, to make a the network robust and reliable, network management and maintenance are very important, they should have abilities to adapt to changes in real time, easily to configure, monitor, and updating or upgrading using a dynamic graphical user interface.

The Geographical Information System (GIS) is suitable technology for those tasks in Telecommunication network, because it can manage huge quantities of data, acquire complex concepts to describe the geometry of objects and specify complex topological relationships between them. In addition, GIS data are typically used by various groups of users with different views and needs. For the network management and maintenance, GIS can offer a great relief in showing the latest positions of the features including the towers, antennae, tall buildings etc.

GIS within Telecom utilities can provide facilities for fault tracking, customer care, Planning and efficient management of a large distributive network and more importantly provide a framework for better integration and analysis of relevant facility information derived from several sources in graphics environment.

1.3 Approach and goals of the thesis

In this thesis, the main aim is to describe and analyse GIS application in Wireless Internet Router Network, specifically in network maintenance and management.

The specific application with GIS is in Nokia Wireless Router Manager, within it, a subsystem --- RMS Services Viewer, which is implemented by Novo Meridian Oy, deploying Internet GIS technology, calculates coverage prediction in background, and show the coverage analysis results through Internet. In this project, my own part work is a Java programming module, which is a real GIS application, using DEM data to calculate LOS coverage around within a area. Based on the project, my diplam thesis is a extension, a approach to describe GIS solution and system performance evaluation, and focus on the analysis of GIS data requirement, which including data availability, data quality, data accuracy, error tolerance and so on. In addition, discuss some alternative solutions.

In this GIS application, we are using ESRI's Internet GIS solution, ArcIMS technology.

*** Last mile**

The last mile is the local access network that extends from the central office (CO) to the end-user subscriber. Also called the local loop network, it is traditionally copper-based and suffers from the bandwidth limitations of that media. (**http://www.quantumbridge.com/glossary.html**)

2. GIS and related technologies

2.1 GIS introduction

Geographic Information Systems (GIS) are computer based systems designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data at different points in time [Aronoff, 1991]. There are also many other similar definitions of GIS, such as: according to the *International GIS Dictionary*, GIS is a "computer system for capturing, managing, integrating, manipulating, analysing and displaying data which is spatially referenced to the Earth." (R McDonnell & K Kemp. 1995. *International GIS Dictionary*. Cambridge: GeoInformation International).

Actually, over the years, there are also many definitions of GIS have been suggected, each of them give some focus on, never entirely satisfactory. Generally summary the points: (Paul A. Longley, 2001)

- A GIS is a container of maps in digital form. (simple explanation)
- A GIS is computerized tool for solving geographic problems. (focus on purpose)
- A GIS is a tool for revealing what is otherwise invisible in geographic information (focus on analysis)
- A GIS is a tool for performing operations on geographic data that are too tedious or expensive or in accurate if performed by hand. (focus on automatic and accurate way)

The history of geographic information system (GIS) starts from “computer mapping” program in the early 1960s (Artimo, 1994). SYMAP, the famous ancestor of GIS software, was developed in close contact with geographical applications, especially research on spatial analysis (Steinitz, 1993). The term GIS was first used in 1962 (Price 1992), and invented to be a tool for spatial analysis in geography.

GIS is different from other forms of information systems, such as databases and spreadsheets, because GIS deals with spatial information. GIS has the capability to relate layers of data for the same points in space, combining, analysing and, finally, mapping out the results. Spatial information uses location, within a coordinate system, as its reference base. The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude, or local grid references such as the National Grid.

2.2 Applications and Components of GIS

GIS is also an information system that specifics to geo-referenced information and application.

Information system helps us to manage what we know, by making it easy to organize and store, access and retrieve, manipulate and synthesize, and apply to the solution of problems.

For the different application area, GIS can be focus on different representations.

In many organizations, GIS is of interest because it is hoped that GIS will improve operational efficiencies, and application stress is very much on the basic functions of information system, means GIS are seen essentially as database packages to which geography has been added as an additional window onto data, and which can help organizations achieve their overall information processing requirements. In this situation, attribute storage and efficient retrieve are core concerns, not complex spatial modeling or analysis, only some basic GIS analyzing functions like proximity analysis etc. Operational GIS systems are typically characterized by very large, long term, databases upon which standardized, and possibly quite simple, spatial interrogations are likely to be repeatedly made. Attributes will often predate the introduction of GIS into organizations, and GIS software is likely to expected to draw information from databases which are used primarily for other purpose. This is GIS focusing on 'Information management'. Such as GIS application in 'Local government'.

In the academic research projects, GIS tends to be stressed the spatial analysis and mapping in a more efficient manner. The projects described often involve fairly complex spatial analyses, and are essentially research exercises for which GIS has been adopted simply as an appropriate technique. Here is with the power of GIS as an engine for analyzing data and revealing new insights. Such as GIS application in 'Environment'.

Nowadays, as the developing of Internet technology, GIS quickly mounts on the Internet, Intranet to offer applications, especially services on line, from simply publishing Web-based interactive map, to Location-Based Service. The Internet has proven very popular as a vehicle for delivering GIS applications, and has started to change the way we think of delivering geographic information and processing to user, change the business GIS model for many types of applications.

Based on different appearances and applications of GIS, there are six components of GIS anatomy can be included, they are Hardware, Software, Data, People, Procedures, Network (Paul A. Longley, 2001). In this thesis, I just talk more detail about GIS Hardware, Software, and Data in following sections.

2.2.1 GIS Hardware

The general hardware components of a geographical information system are presented in Figure 2.1 (Burrough, 1998). Computer and its hard disk hold GIS programs and data, besides, storage also provided via a network, digital tape, CD-ROMs. A digitizer or scanner is used to convert maps and documents into digital form so that they can be used by the computer programs. A plotter or a printer or any other kind of display device is used to present the results of the data processing. In addition, Internet and its related technology gives new communication way for GIS data exchanging, such as database server, application client.

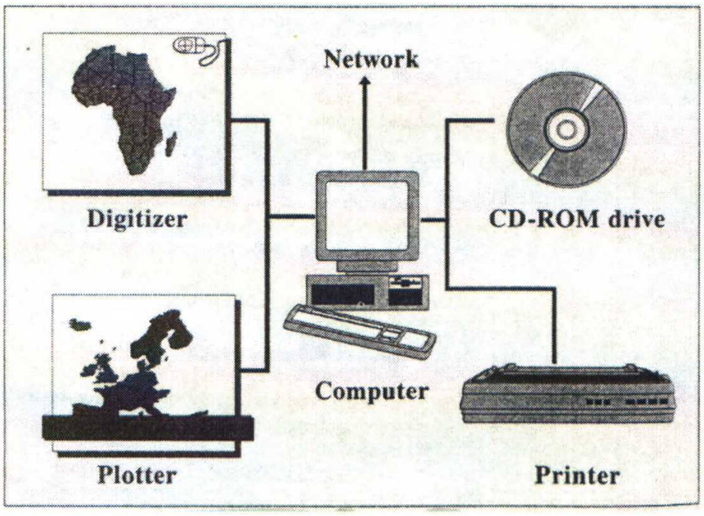


Figure 2.1 The major hardware of a GIS (Burrough, 1998, pp12)

2.2.2 GIS Software

According to (Burrough, 1998), the software for a GIS may be split into five functional groups (Figure 2.2):

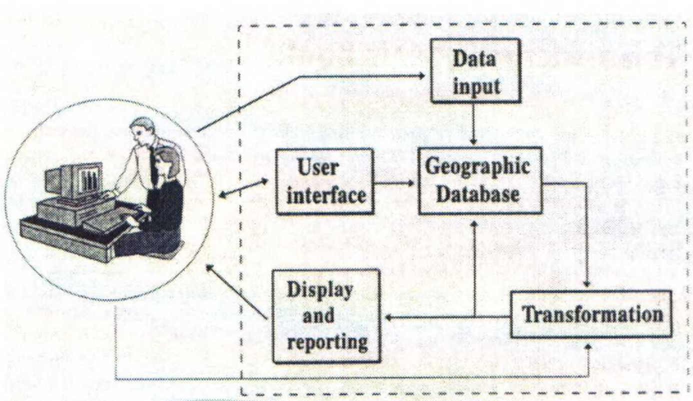


Figure 2.2 The major software of a GIS (Burrough, 1998, pp13)

a) Data input and verification

b) Data storage and database management

c) Data output and presentation

d) Data transformation

e) Interaction with user

There are some famous commercial GIS software products, such as ESRI's ArcInfo, ArcView; Integraph's GeoMedia, MGE; MapInfo Professional; etc. Among them, ESRI's products are long history and more popular.

2.3 Geographical information and management

Geographical information or geographical data consists of information of georeferenced objects, **which** may be on the earth's surface, underground, or in the air.

According to (Aronoff S. 1991), geographical data are commonly characterized as having two fundamental components:

1. The phenomenon being reported such as a physical dimension or class, and
2. The spatial location of the phenomenon.

There is another more complete definition with spatial relationship:

Geographical data describes objects from the real world in term of

- The object's position with respect to a known coordinate system
- The object's physical attributes associated with the geographical position
- The spatial relationship of the object with surrounding geographical features (topology) (Price, 1992).

The nature of any natural or economic activity with a spatial dimension cannot be properly understood without reference to its spatial qualities. Spatial data have two essential parts: **location** and **attributes**.

- A GIS requires locational references. Typical locational references are latitude and longitude and national grid references such as the National Grid. However, other geospatial codes can also be used to identify location, such as postcodes.
- Attributes. Any locality would have a number of characteristics or properties associated with it. These attributes are usually kept in tables, containing such information as vegetation types, population, annual income, and so on.

GIS systems store and process data in two formats, vector and raster data models.

2.3.1 Vector data model

In the vector data model, the world is represented as a mosaic of interconnecting lines and points representing the location and boundaries of geographical entities. In vector data models, the data are represented as:

- arcs (lines)
- polygons (traversed areas)
- points (labelled nodes)
- nodes (intersection points)

A point has zero dimension. A point feature occupies a location and is separate from other features.

A line is one-dimensional and has the property of length. A line feature is made of points: a beginning point, an end point, and a series of points marking the shape of the line, which may be a smooth curve or a connection of straight-line segments.

An area is two-dimensional and has the properties of area and boundary. The boundary of an area feature separates the interior area from the exterior area. Area features may be isolated or connected.

In this thesis, vector data will be used as street/address data for address geocoding.

2.3.2 Raster data model

In its simplest form, the raster data model consists of a regular grid of square or rectanglar cells. The location of each cell or pixel (for picture element) is defined by its row and column numbers. The value assigned to the cell indicates the value of the attribute it represents. (Aronoff, 1991)

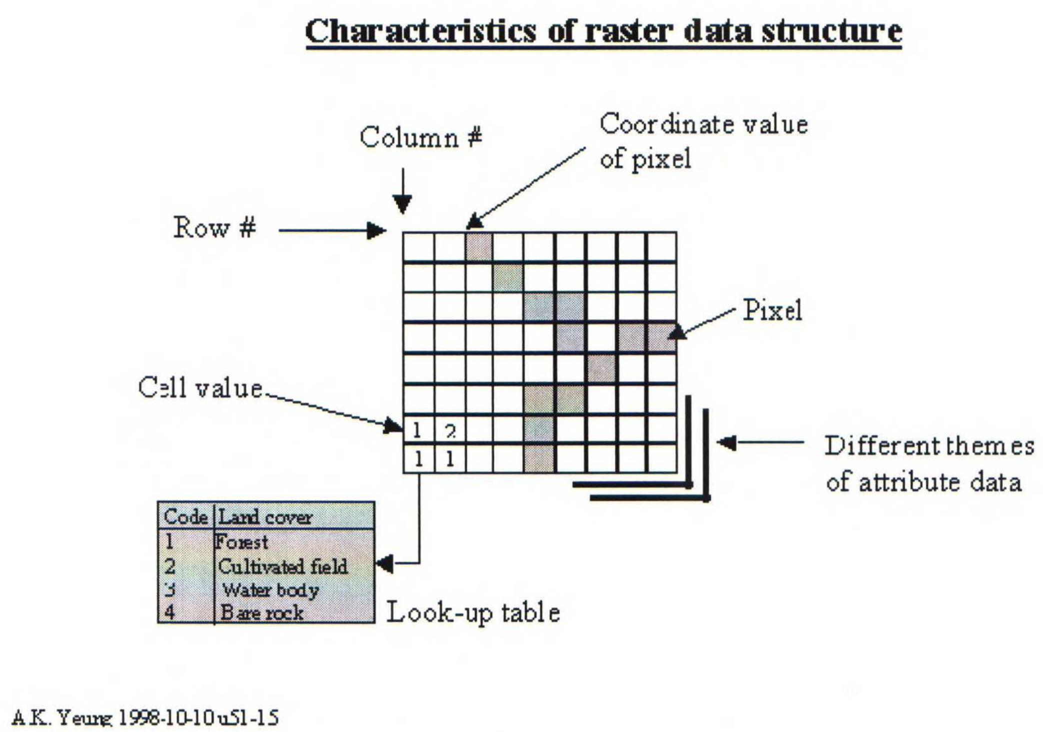


Figure 2.3 Raster data structure

The raster data model represents features as a matrix of cells in continuous space. Each layer represents one attribute (although other attributes can be attached to a cell). And most analysis occurs by combining the layers to create new layers with new cell values.

The raster data model has come out of aerial and satellite imaging technology, which represents geographical objects as grid-cell structures known as pixels.

Usually, raster file includes several million cells, however, many of the cells may contain the same value as the neighbouring cells, which results in considerable redundancy, following some significant ways to compress raster data. **Run-length** and **Quadtree encoding** are mostly used ways..

What I will use in raster data model is DEM data, as following description.

2.3.2.1 DEM data

A digital elevation model (DEM) uses elevation data in raster form in which each cell in the DEM is coded with the average elevation of the whole cell (Sorensen and Lanter, 1993). DEM data files are digital representations of cartographic information.

Figure 2.4 DEM data

A Digital Elevation Model (DEM), and the closely related Digital Terrain Model (DTM) and Digital Terrain Elevation Data (DTED) are digital representations of the elevation of the earth's surface. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. DEM data is derived from a wide variety of sources including stereopair imagery, digitizing paper topographic maps and by laser scanning technology.

DEMs may be used in the generation of three-dimensional graphics displaying terrain slope, aspect (direction of slope), hillshaded images and terrain profiles between selected points.

DEM is getting important use in Telecommunication area, especially for Wireless network planning. They are particularly suited to preliminary planning of transmission lines and telecommunication networks where intervisibility between adjacent towers is critical.

2.3.3 Databases

Every GIS needs a spatial data model for data management, which is the critical part of any GIS application. Traditionally, using file-based datasets, such as 'coverages' for ArcInfo, 'shapefiles' for ArcView, etc. which serve GIS for many years, but they have many significant limitations, like concurrent user access, file size limitations and so on. The database approach to serve GIS offers a number of advantages over traditional file-based datasets, especially the modern Enterprise GIS, which requires multiple concurrent users accessing a shared information resource, making DBMS become necessary for large GIS application.

In GIS database, there are many different database models to manage and represent GIS data. Relational database system model is the most popular one nowadays.

- **Relational Database Systems**

A relational database system is one in which the DBMS supports a relational model of the data stored. That is to say, it is more of a guideline to representing data than it is a structure for data. In many ways, it is comparable with a table, which is why "tabular database" is an alternative term for relational database.

In the relational data model there is no hierarchy of data fields within a record; every data field can be used as a key. The data are stored as a collection of values in the form of simple records. Using the relational model, a search can be made of any single table using any of the attribute fields, singly or together. Searches of related attributes that are stored in different tables can be done by linking two or more tables using any attribute they share in common. (Aronoff, 1991)

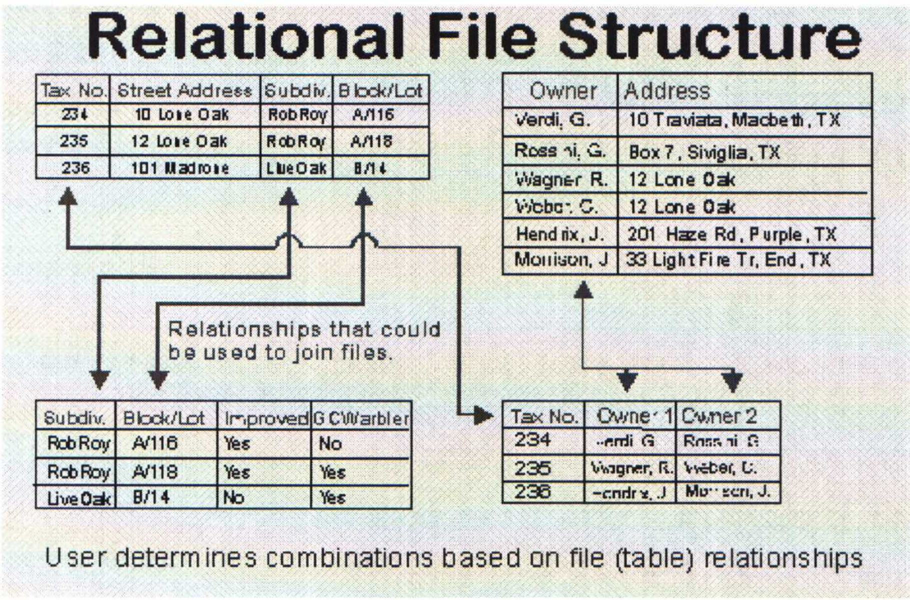


Figure 2.5 Relational Database Model

Relational DBMS model is now the most frequently used, mainly because of its simple, flexible structures, reducing redundant data, editing and updating easily, and also because it supports the complex relationshis common among real-world geographic objects. Of course, there are also some disadvantages, but for GIS application, it is still top priority.

- **ArcSDE**

ArcSDE is the GIS gateway that facilitates managing spatial data in a database management system. ArcSDE allows you to manage geographic information in one of four commercial databases: IBM DB2, Informix, Microsoft SQL Server, and Oracle, as well as being able to serve ESRI's file-based data with ArcSDE for Coverages. (ESRI ArcSDE home).

ArcSDE works with ArcInfo and ArcIMS to act as a gateway to the DBMS:

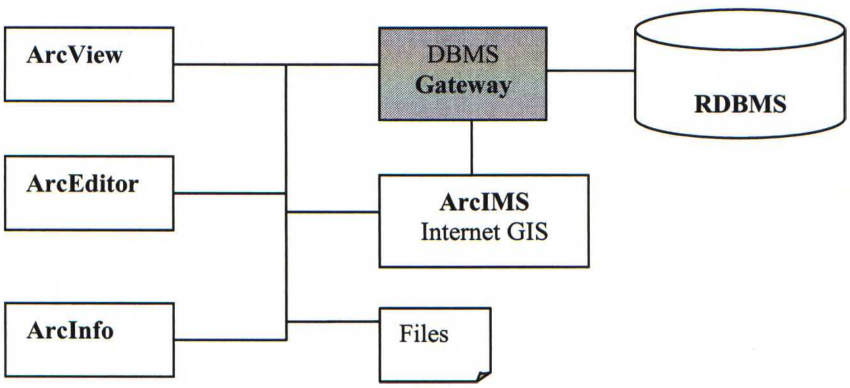


Figure 2.6 ArcSDE

ArcSDE plays a fundamental role in a multiuser GIS. With ArcSDE, your ArcGIS software (ArcInfo™, ArcEditor™, ArcView® GIS, and ArcIMS™) can work directly with spatial data managed in your RDBMS. ArcSDE also works as an application server, delivering spatial data to many kinds of applications and serving spatial data across the Internet.

ArcSDE supports a variety of feature types including points, lines, and polygons. While primarily a vector engine, it is well suited for serving raster images.

ArcSDE is designed to allow multiple users access very large datasets simultaneously with no degradation in performance.

ArcSDE provides a client /server architecture with cooperative geoprocessing. The server only responds to requests (query and retrieval), while the client performs the geometric processing (overlays, buffers, etc.). This minimizes the computational work on the server and allows many users to access the server simultaneously.

There is also a disadvantage for ArcSDE, which is difficult to handle the multiple to multiple relation tables.

- **Oracle Spatial**

Over the course of the past several years, the major RDBMS vendors have developed spatial extensions to their database platforms. Leading this effort has been Oracle with what was initially the Oracle Spatial Cartridge, and is now an integral part of Oracle's Enterprise Database Server (Oracle 8i). While these new database capabilities are still maturing, some of their spatial data storage capabilities are already very powerful. Oracle Spatial fully supports the new spatial extensions to the SQL language allowing users to do many types of spatial queries from an SQL prompt. The major promise of this type of storage architecture is that it will allow for the development of data models that fully integrate spatial and business data to the point where the distinction finally becomes inappropriate.

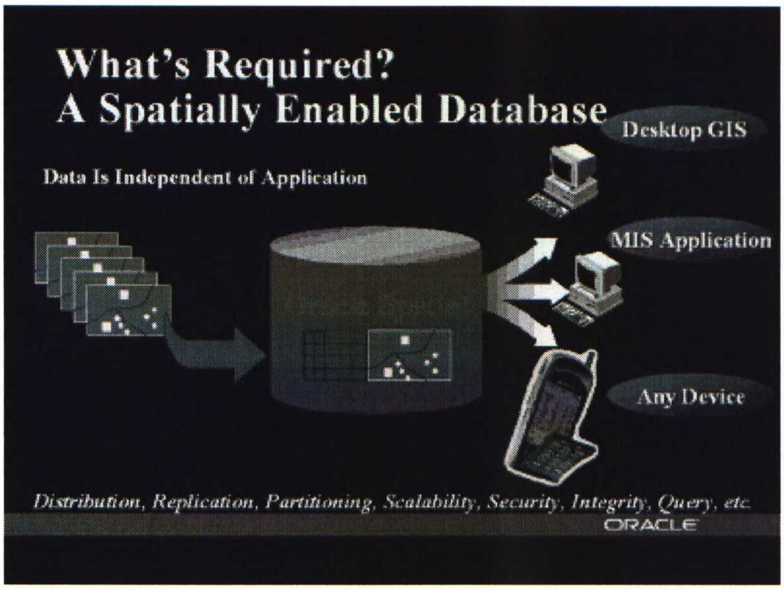


Figure 2.7 Oracle spatial

Oracle Spatial serves as a foundation for deploying enterprise-wide spatial information systems and web-based and wireless location-based applications. It provides data management for location information such as road networks, wireless service boundaries, and geocoded customer addresses that are driving innovative product development in the emerging online, wireless and in-vehicle telematics markets. These location-based services in Oracle9i extend existing Oracle-based applications by allowing users to easily incorporate location information directly in their applications and services.

The product provides an integrated set of functions and procedures that enable spatial data to be stored, accessed, and analyzed quickly and efficiently since Oracle8i. This means that spatial and attribute data can now be managed in one physical database.

Oracle Spatial (formerly called SDO and before that MultiDimension), provides a way to store and retrieve multi-dimensional data in Oracle. It is primarily used for Geographical Information Systems to implement geo-reference and solve queries such as how is something related to a specific location.

It needs to be noted that Oracle spatial only work with Enterprise Oracle, not Standard Oracle.

Current limitations of this technology include rather crude spatial data management tools, (import & export utilities etc.) immature geo-processing tools and a general lack of client applications to directly utilize this spatial data (although MapInfo is moving very rapidly in this direction). (ESRI User Conference 2000)

For the comparative of ArcSDE and Oracle spatial, depending on the client software you choose to use, for ESRI's client, the better choice is ArcSDE because they are native each other. Besides ArcSDE also support Oracle spatial. For Oracle spatial, MapInfo already chose it as native spatial data.

2.4 Spatial analysis

The heart of GIS is the analytical capabilities of the system. What distinguish the GIS system from other information system are its spatial analysis functions. Although the data input is, in general, the most time consuming part, it is for data analysis that GIS is used. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. Results of geographic analysis can be communicated with the help of maps, or both.

The organization of database into map layers is not simply for reasons of organizational clarity, rather it is to provide rapid access to data elements required for geographic analysis. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers at all levels in terms of detail. An important use of the analysis is the possibility of predicting events in the another location or at another point in time.

Spatial analysis in GIS environment is based on certain data model. For vector data model, analysis can be: (Artimo, 1995)

— For point: nearest neighbor, distance between two points,
— For polygon: map overlay (point-in-polygon, line-in-polygon),
— For lines and graphs: shortest path, routing, etc. network analysis,

For raster data model, data is in 2D matrix, analysis can be done with map algebra operations, such as local difference, focal maximum, etc. Raster data analysis is often used in land use, soil coverage, and drainage analysis, visibility analysis and so on. In this thesis, DEM data, a matrix data, will be used for visibility analysis. Detailed description is in following section.

2.4.1 DEM data & Visibility analysis

The most efficient way to determine intervisibility between features is to use a geographic information system (GIS). The GIS essentially performs the same technique as using a topographic map and pencil and ruler, but can do so more quickly and accurately. The GIS can also easily take into account the curvature of the earth's surface when determining line of sight. Once the necessary data are available to the GIS, the visibility analysis can be performed in quick.

Visibility (Viewshed) analysis uses DEM data to analyze the slopes of different cells between the source point and the entire DEM or one specific destination point using line-of-sight (LOS), which is a horizontal line connecting two points. The slopes between two intervening cells within the DEM are analyzed to determine if the LOS between those two cells is obstructed in some way (i.e. at a higher elevation). If the slope is greater than that of the two cells, then the cells are blocked from each other. Thus, there is no intervisibility between the two cells. Otherwise, they are visible to each other. This process is assessed for the entire DEM from the observation or source point. (Fisher, 1993, Sorensen and Lanter, 1993)

Many GIS softwares provide visibility analysis function, such as ESRI's ArcView, ArcInfo. There are two important geograpgical data source for the analysis, one is DEM, a Digital Elevation Model representing the terrain in the study area, and another the coordinates for each location that will be tested for visibility.

2.5 GIS application in Telecommunication

The telecommunications industry is changing rapidly, resulting in tough competition and an ever-increasing scope of services offered to customers. Solving the many business problems of a telecommunications company requires a good understanding of where your customers and facilities exist and good information about those locations.

GIS technology enables telecommunication professionals to integrate location-based data into analysis and management processes in network planning and operations, marketing and sales, customer care, data management, and many other planning and problem-solving tasks. A GIS can integrate location-based data from databases all over the world to help you resolve and streamline everyday business issues.

Speaking specifically, GIS application for telecommunication or integrating with telecommunication can be summarized as following:

- **Network planning**
  Network capacity planning with GIS takes a high-level view of network performance and trends to effectively plan new or additional facilities. In this process, defining priorities is by mapping out existing infrastructure, zoning, customer data, and topography.

- **Marketing and Sales**
  GIS allows marketers to use vital consumer and business statistics geographically, to provide input to capacity planning applications, and to direct targeted

marketing campaigns. Telecommunications sales representatives can get quick customer profiles using geographic questions such as: *Where is the customer? Which products and services are in use? What is the distance to the nearest fiber backbone? When do we plan to have coverage at this location?*

- **Location-based Services (LBS)**

  Locating people, places, and assets has always been an important endeavor. Now with the convergence of wireless communications, network computing, location determination, and increasingly portable devices, the implementation of location services and applications demands powerful and easy-to-use geographic information system (GIS) tools.

  LBS, is the ability to find the geographical location of the mobile device and provide services based on this location information. Its business market will get increasingly growth. The extent of horizontal coverage of LBS has virtually covered all the walks of life from selecting the restaurants to emergency services to aid in navigation, mainly application areas are:

  - Transportation & Navigation
  - Location-based Information
  - Emergency Services
  - Location Sensitive Billing

- **Wireless application, Decision support, and Operations support**

GIS provides the tools to help the wireless industry to plan, build, and maintain their networks in a more cost-effective manner. Using GIS, wireless telephone companies can analyzed the relationships between signal coverage, test results, trouble tickets, customer inquiries, revenue, and gap analysis. GIS can also make design, development, and wave propagation modeling a lot easier. In additional, using advanced line-of-sight and visibility features, GIS can display predicted signal strengths in three dimensions using the data in their corporate DB. The GIS provides input, output, and visualization of proposed antenna, predicted signal strength, and summary statistics of coverage area, with the information stored and distributed in a corporate, industry-standard DB. And especially, the prediction and visibility coverage analysis are also important in sales supporting to customer.

2.6. Internet GIS & Software

Internet is becoming popular in everywhere of world, and coming into many other industry fields, also in GIS industry. Internet GIS is an integrated client/server network system, a network-centric GIS tool that uses Internet as a major means to access and transmit distributed data and analysis tool modules, and to conduct analysis and visualization.

With Internet GIS, customer will be able to access GIS applications without purchasing GIS software only by using a web browser.

There are many Internet GIS softwares from vendors over the world, ArcIMS, which we are using in this thesis, is widely applied one of them, a website solution from ESRI.

2.6.1 ArcIMS

Following document from Esri homepage (http://www.esri.com/arcims).

ArcIMS is specifically built to serve GIS on the Internet and is designed to make it easy to create map services, develop Web pages for communicating with the map services, and administer sites. It allows distribution of geographic information via the Internet and allows real-time integration of data. The ArcIMS server technology is part of a multitier architecture. The wide variety of supported clients and the server potential are what set ArcIMS apart from other Internet GIS competitors

- **Architecture**

ArcIMS has a multitier architecture consisting of presentation, business logic, and data tiers. In addition, ArcIMS has a set of applications for managing a Web mapping site. Following figure provides an overview of the ArcIMS architecture.

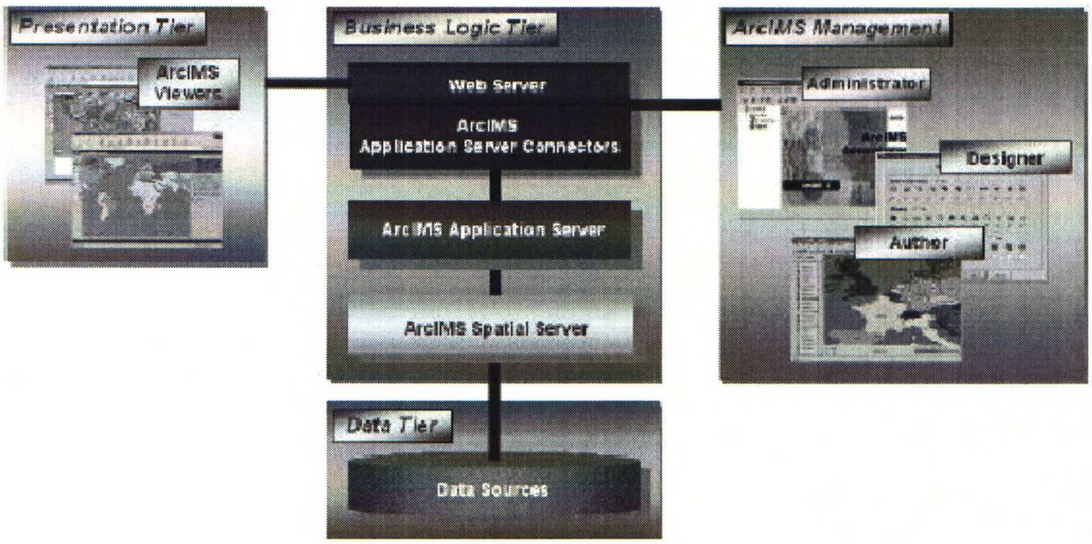


Figure 2.8 ESRI ArcIMS architecture overview

- The presentation tier includes the ArcIMS client viewers for accessing, viewing, and analyzing geographic data.
- The components in the business logic tier are used for handling requests and administrating the ArcIMS site.
- The data tier includes all data sources available for use with ArcIMS.

- The ArcIMS site management applications provide access to components in the business logic tier for authoring maps, administering MapServices and Spatial Servers, and designing Web sites.

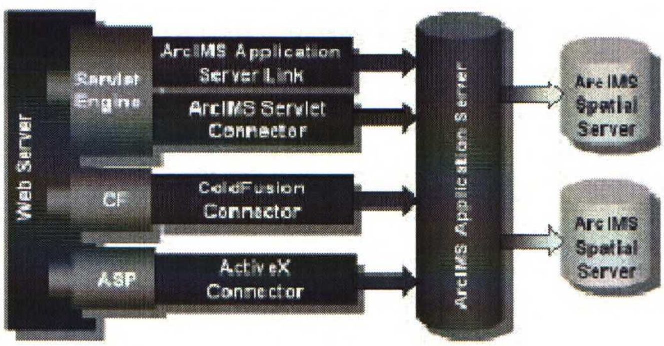
Besides, for ArcIMS to run correctly, supporting components are needed that are not part of ArcIMS including a Web server, JavaVM, and a servlet engine. These components, along with ArcIMS, provide the foundation for a working ArcIMS site.

In our project, *Apache* Internet web server and *Apache Jserv* servlet are used, which are popular and free available.

An ArcIMS site is composed of components in the business logic tier along with data in the data tier, and business logic tier is its core working part.

When an ArcIMS request is made, it is first handled by the Web server, passed through one of the connectors, and then forwarded to the ArcIMS Application Server. The Application Server, in turn, dispatches the request to an ArcIMS Spatial Server for processing. Following is a diagram showing the business logic tier components.

Business Logic Tier Components

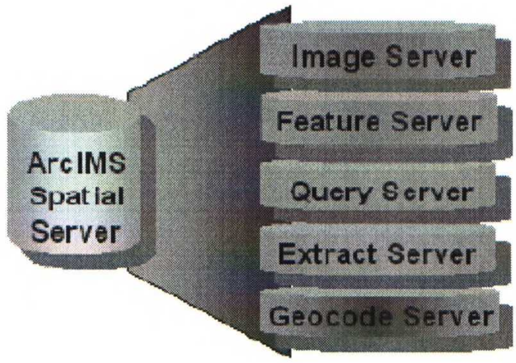


The Application Server handles load distribution and keeps track of which MapServices are running on which ArcIMS Spatial Servers. When a request is received, the Application Server hands the request to the Spatial Server running the MapServices.

An ArcIMS Spatial Server is the workhorse of ArcIMS. It provides the functional capabilities for accessing and bundling maps and data into the appropriate format before sending the data back to a Web browser. The Spatial Server is a container for holding components that support different functionality as shown in following figure. Each of these components makes up a server type inside the ArcIMS Spatial Server.

In our RMS SERVICES VIEWER project, Geocode Server and a customised Server Componet RSV will be used.

ArcIMS Spatial Server



The ArcIMS Spatial Server also has some supporting components that include:

- **Weblink.** Weblink is the communication gateway between the ArcIMS Application Server and the ArcIMS Spatial Server.
- **XML parser.** The XML parser is used for parsing ArcXML requests.
- **Data Access Manager.** The Data Access Manager provides a link between the Spatial Server and any data sources.

Finally, ArcIMS comes with three viewers: Java Custom, Java Standard, and HTML. The Java Viewers use a Java 2 Applet and support both Image and Feature MapServices. The Java Viewers contain more clientside processing capabilities, support feature streaming, and support multiple MapServices and local data within the same viewer. The HTML

Viewer is lighter weight, but supports only Image MapServices. All processing is done by the ArcIMS Spatial Server.

- **Features**

ArcIMS has many features, here introducing some of them.

- Integrate data from multiple sources
  Within a simple browser interface, you can access, display, and interact with data generated from professional GIS solutions throughout the world. Integrate geographic data from multiple sources for localized query and analysis. ArcIMS puts a world of information on your desktop by simultaneously accessing Web data, local shapefiles, ArcSDE layers, and images for viewing with local data. ArcIMS is the first Internet mapping solution that lets you integrate the world of GIS data on your desktop.

- Easily create, design, and manage Web sites
  Wizards and templates guide you through tasks for authoring and publishing maps--no programming is required. Simply create a map service, design the Web pages, and publish. Easy-to-use tools help monitor and maintain the site. For more advanced users, client and server configuration and management tools are available for building secure, reliable, and highly scalable sites.

- Powerfully intelligent clients
  Local geoprocessing results in more efficient client/server processing capabilities. Choose from ready-to-use HTML/DHTML and Java clients, or build custom clients using an Active Server Page (ASP), ColdFusion, or a Java implementation such as JavaServer Pages (JSP).

- Highly scalable server architecture

Publish GIS services from a single server or distribute services across multiple servers. By providing a highly efficient and scalable environment from the smallest Intranet to meeting the demands of worldwide Internet access, ArcIMS lets you grow your site's capabilities without rebuilding applications.

- Foundation for the Geography Network

  The power of ArcIMS has made possible the creation of the Geography Network, which is a collaborative system that connects users with data and services via the Internet. Through the Geography Network, users can publish their own data and map services, search for specific geographic content, and use services and applications built by other participants.

- Standards-based communication

  ArcIMS clients and servers communicate using ArcXML, which is a GIS extension to standard Xtensible Markup Language (XML). ArcXML also offers an easy, yet powerful, way to customize ArcIMS applications.

- **ArcXML**

ArcXML is the protocol for communicating with the ArcIMS Spatial Server. An ArcIMS Spatial Server is the backbone of ArcIMS and provides the functional capabilities for accessing and bundling maps and data into the appropriate format before sending the data back to a client. Following is a figure to show the relationship between map configuration files, MapServices, requests, and responses and how they interact with the ArcIMS Spatial Server.

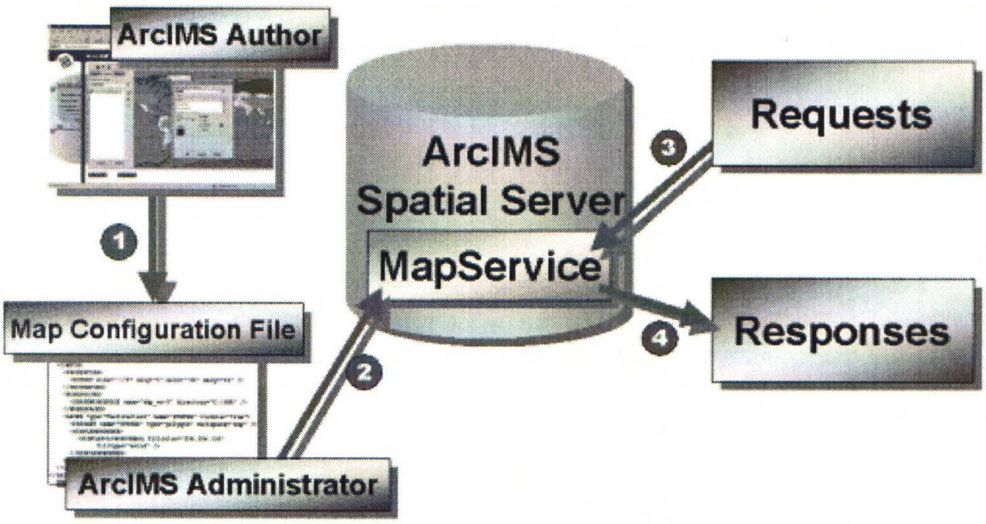


Figure2.9 Communication within ArcIMS with ArcXML

— Step 1: use ArcIMS Author, a text editor, or an XML editor to create a map configuration file. The *map configuration file* is written in ArcXML.

Map configuration files are used as input to MapServices. All information in a map configuration file provides a default set of instructions for map properties and rendering. The file's framework looks like:

```
<?xml version="1.0" encoding="UTF-8"?>
 <ARCXML version="1.1">
  <CONFIG>
   <ENVIRONMENT>...</ENVIRONMENT>
   <MAP>
    <PROPERTIES>...</PROPERTIES>
    <WORKSPACES>...</WORKSPACES>
    <LAYER>...</LAYER>
   </MAP>
 </CONFIG>
</ARCXML>
```

- Step 2: use ArcIMS Administrator to start a *MapService* on the ArcIMS Spatial Server. The map configuration file from Step 1 is the primary input to the MapService.

- Step 3: the ArcIMS Spatial Server receives a *request* in ArcXML.
  The *request* defines request to be sent to a MapServer for processing. The request can be features, image, extract, geocoding and service info. The key element tags are <REQUEST>', '<GET_xxx>' and so on.

- Step 4: the ArcIMS Spatial Server generates a *response* in ArcXML.
  The *response* contains results from a request to the Spatial Server. The results corespond to what you request. The key element tags are <RESPONSE> and also <FEATURES> or <IMAGE> … .

ArcXML is a structured format, made up of tags, tag name, attributes, and subtags. As an example of ArcXML, the following is a request to generate a map:

```
<?xml version="1.0" encoding="UTF-8" ?>
 <ARCXML version="1.1">
  <REQUEST>
   <GET_IMAGE>
    <PROPERTIES>
     <ENVELOPE minx="-180" miny="-90" maxx="180" maxy="90" />
    </PROPERTIES>
   </GET_IMAGE>
  </REQUEST>
 </ARCXML>
```

The first line of an ArcXML statement is the prolog. All ArcXML 1.1 statements are required to use a standard prolog that includes the XML version and encoding.

<ARCXML> tag is common requirement, all ArcXML statement begin and end with ARCXML.

The above request can be responsed something like following:


```
<?xml version="1.0" encoding="UTF8"?>
 <ARCXML version="1.1">
  <RESPONSE>
   <IMAGE>
    <ENVELOPE minx="-118.19793324" miny="34.03441917" maxx="-118.12940130" maxy="34.08010713" />
     <OUTPUT file="c:\output\world_MYMACHINE2052765.gif"
url="http://mymachine.domain.com/output/world_MYMACHINE2052765.gif" />
   </IMAGE>
  </RESPONSE>
</ARCXML>
```

3. Internet and Wireless Broadband Technologies

3.1. Internet

- **Definition**

"Internet" refers to the global information system that – (FNC, 1995)

1. is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
2. is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols; and
3. provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein.

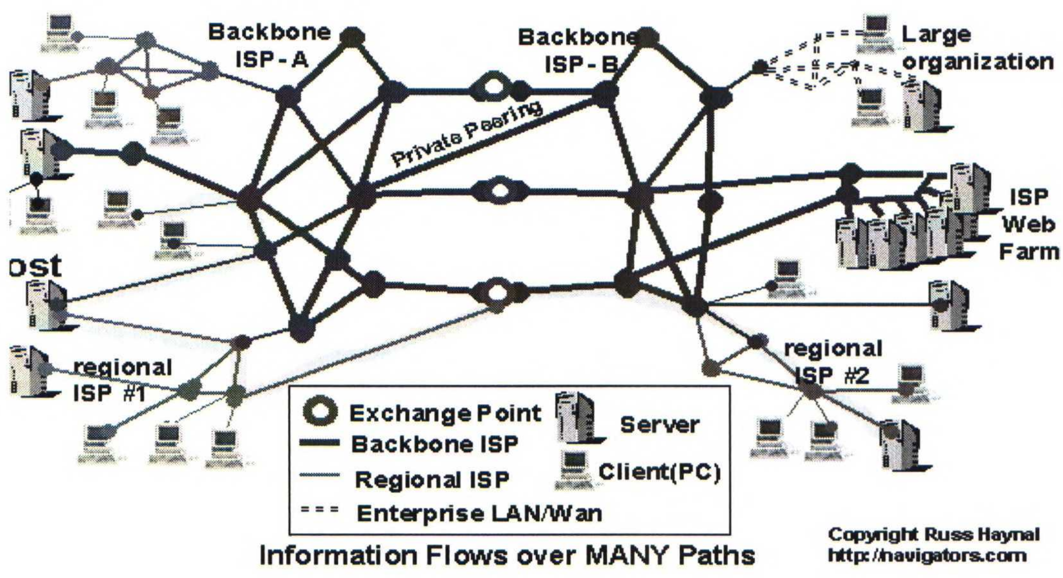


Figure 3.1 Internet architecture

In essence, the Internet is an international network of computers all connected together. Once connected, you can browse through all the computer files on the Internet and add your own files. Unlike commercial services such as America Online, the Internet is not privately owned and there's no central control. The resulting system is either wonderfully free or dangerously anarchical, depending on your point of view.

The three most popular activities on the Internet are sending and receiving email, reading messages in newsgroups and browsing the world wide web.

- **Why the Internet?**

The Internet today can potentially:

- reach millions of people cost effectively
- provide up-to-date information including publishing immediate calls-to-action
- provide cost-effective fund-raising and resource fulfillment service
- allow efficient communication among millions of geographically diverse people who do not know each other but who do share a common interest

The characteristics of electronic media are that "digital" real estate is inexpensive, when compared to the cost of paper, so there are fewer limitations on the amount of information that can be made available to individuals. Furthermore, people uses their online services regularly, usually at least once per day, as these services are relied upon to deliver electronic mail, stock quotes and even entertainment content.

The Internet is essentially open and anyone with the appropriate technology can either publish on or gain access to the "Net". Currently, approximately 25 million people are connected to the Internet around the world, and that number is estimated to be growing at 15% per month. At this time, access is opening up an enourmous rate and the "average" Internet user is beginning to become more of the general public as the interfaces to the Internet become ever simpler to use.

3.2. Wireless Broadband

While increased demand for high-speed network access has generated new opportunities for service providers, bandwidth limitations between the service providers' core network and the end-user, often referred to as the 'last mile', have constrained service providers from exploiting these opportunities. In addition, although many wide-area network backbones have been upgraded to fiber optic cable and have used technologies that allow operation at speeds up to 9 Gbps, the local access telephone network typically consists of older copper wires originally designed to transmit fixed-speed voice signals at a fraction of that speed. This last mile bottleneck is frustrating a broad base of business users, many of whom require symmetrical access to high-speed data that requires transmission at varying speeds.

Because of the 'last mile' bottleneck of wired infrastructure, broadband technology is fast becoming an important element of wireless network solution to connect distant enterprises to the Internet bypassing traditional terrestrial connections. Wireless broadband, differing from mobile communications, is using antennas, which—unlike those used for cell phones or wireless LAN devices—are typically about 12 inches in diameter, are often located on rooftops, and are pointed in a precise direction. The wireless link is part of the provider's network infrastructure—called the last mile by some, and the wireless local loop by others.

Following introduce three main solutions of wireless broadband access --- LMDS, MMDS and Multipoint to multipoint mesh network.

- **LMDS**

LMDS (Local Multipoint Distribution Service) is a fixed broadband wireless, point-to-multipoint, microwave system, which operates at high frequency above 20 GHz (typically within specified bands in the 24GHz to 40GHz range), and can be used to provide digital two-way voice, data, Internet, and video services. Transmission range is limited to 3 – 5 miles radius. The bandwidth offered by LMDS makes it the more viable option. **(WCA International)**

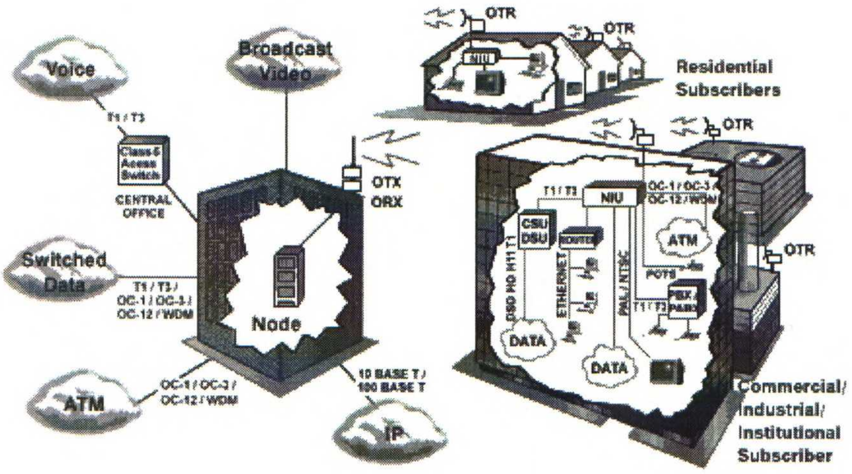


Figure 3.2 LMDS architecture

- **MMDS**

MMDS (Multichannel Multipoint Distribution Service), the wireless system consists of head-end equipment (satellite signal reception equipment, radio transmitter, other broadcast equipment, and transmission antenna) and reception equipment at each subscriber location (antenna, frequency conversion device, and set-top device). MMDS allows two-way voice, data and video streaming. MMDS operates at a lower frequency than LMDS (typically within specified bands in the 2GHz to 10GHz range) and therefore has a greater range and requires a less powerful signal than LMDS. So the range of a transmitting antenna can reach 35 miles depending on the broadcast power. **(WCA International)**

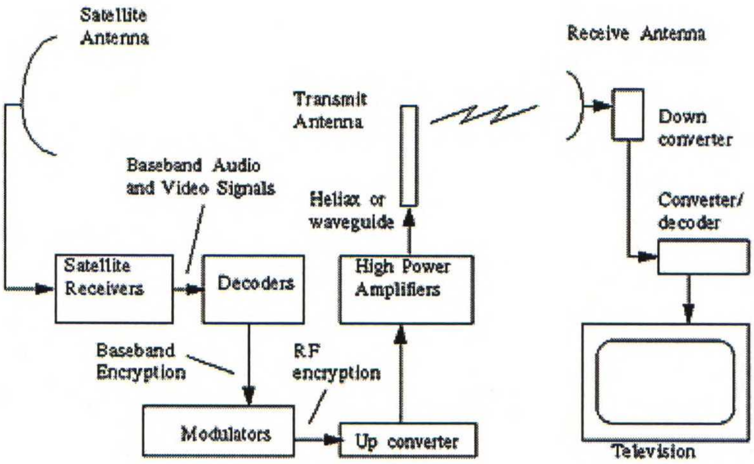


Figure 3.3 MMDS architecture

LMDS and MMDS share a number of common architectural features although they vary from one manufacturer to another according to features and capabilities. The core components are a base station transceiver (transmitter and receiver).

LMDS and MMDS both require line-of-sight between the base station and customer premise transceivers. This is a prerequisite for any system operating above approximately 2 GHz 3.5 GHz, and also bad weather will be little problem.

- **Multipoint to multipoint mesh network**

Multipoint-to-multipoint networks create wireless mesh networks that mirror the wired Internet. They offer the most flexible and cost effective solution to reach a mass market. Each radio in the network becomes part of the infrastructure and will route data through the wireless network to its destination, just like the wired Internet. This simplifies line of sight requirements and reduces the overall infrastructure costs. Multipoint-to-multipoint networks are the simplest and least expensive way to deploy large networks.

We also call it wireless router network, which is one we are using in our RoofTop Wireless Internet project. Next chapter will focus on the description of wireless mesh or router network, especially Nokia's solution.

4. Broadband Wireless Solutions

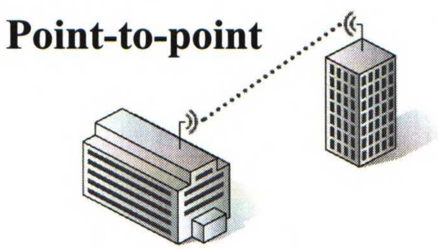
4.1. Wireless Network Architectures

There are three types of wireless network architectures: point-to-point, point-to-multipoint and multipoint-to-multipoint mesh. Each one of them is best suited for each specific type of application. In practical market, they are combined for wireless communication solution.

4.1.1. Point-to-Point Networks

A point-to-point (PtP)network is the simplest form of wireless network, composed of two radios in direct communication with each other. Point-to-point links are well suited for high performance, dedicated corporate connections or high-speed interconnect links. These links are quick to deploy individually, but do not scale to create large networks effectively. Point-to-point links typically require RF planning and professional installation. They are relatively more expensive, but also more robust and reliable, and well suited for applications requiring dedicate connections.

Best for high-speed dedicated corporate connectivity & backhaul links.



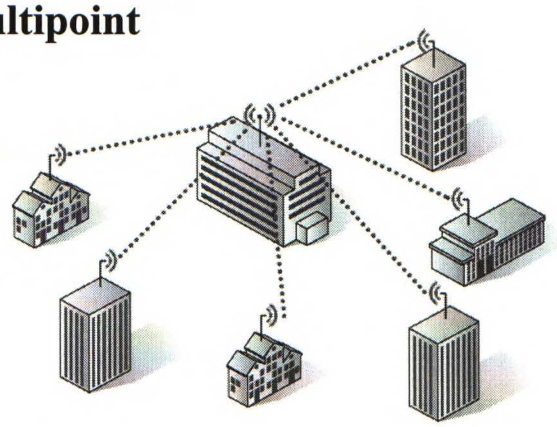
4.1.2. Point-to-Multipoint Networks

A point-to-multipoint (PtMP) network is a shared link between a base station radio and client radios at multiple sites. This type of network is easier to deploy than a network using point-to-point radios because adding a subscriber only requires new equipment at the subscriber site, not at the base station site. However each remote site must be within range and clear line-of-sight of the base station. Trees, hills, and other typical line-of-sight obstructions make point-to-multipoint networks impractical and expensive for residential and small business coverage. The only way to get complete coverage of a typical residential neighborhood or business park using a PtMP solution is to deploy multiple overlapping base stations, which requires RF engineering as well as higher upfront and recurring costs.

This type networks work well in downtown urban environments, but do not scale well to reach dense pockets of homes or small businesses due to LOS restrictions.

This network is easier to deploy – well suited for corporate, backhaul links. And it can use licensed and unlicensed engineered RF links.

Point-to-multipoint



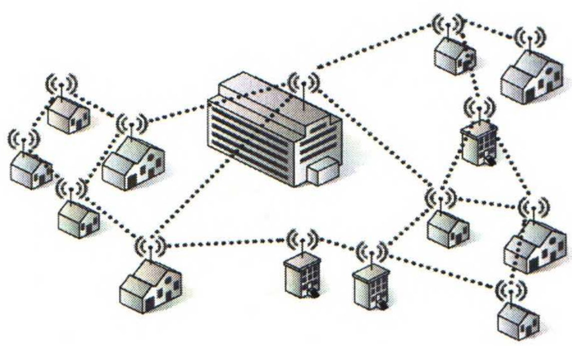
4.1.3. Multipoint-to-Multipoint Mesh Networks

A multipoint-to-multipoint network is a routed, mesh network that mirrors the structure of the wired Internet. Each radio in the network becomes part of the infrastructure and route data through the wireless mesh network to its destination, just like the wired Internet. In that LOS problem is simplified because each node only needs LOS to one other node in the network, so that traffic can around obstructions finally going to destination rather than needing additional base stations for LOS in densely populated diverse geographical locations. And the more routers added to the network, the more robust and far-reaching the network can become.

Traffic can be routed through the network over multiple hops, allowing subscribers to join the network even if they are out of range, or have no line-of-sight to the access point. This configuration is ideally suited to residential markets where price pressures necessitate fast, low-cost deployment.

The wireless solution that scales to reach mass markets.

Routed mesh



4.2. Nokia RoofTop Network

Nokia is a pioneer in utilizing Multipoint-to-Multipoint mesh design, the solution is called Nokia RoofTop Network. Its key components as following:

4.2.1 Routed mesh network

A distributed, routed, mesh network architecture that simplifies LOS requirement. As the pioneer of this mesh design, the Nokia RoofTop network utilizes a new type of wireless router and omni-directional antennas, so each node in the network can communicate with nodes in any direction. The omini-directional antennas offer a 360-degree range and do not require precise pointing or steering.

Consequently, additional wireless routers can be added in an ad hoc and incremental fashion, to grow with the number of new subscribers.

4.2.2 Wireless bridges

A high performance, license-free solution for interconnecting mesh networks to a provider's point-of-presence, is wireless point-to-point bridge that operate in the license-free 5.8GHz bands and require no frequency coordination or licensing, which results in "instant" high-speed connectivity over distances up to 10 miles and avoid the cost and delay of leasing lines or laying new wire or fiber.

4.2.3 Wireless routers

A combination of a high-performance RF modem with specialized wireless networking software that optimises the network performance while ensuring full IP support and robust and seamless IP routing.

The resulting network mirrors the routed mesh structure of the Internet, extending naturally to meet subscriber demand.
Each wireless router both receives and forwards traffic, becoming part of the network infrastructure. So every time a new subscriber is added to the network, the infrastructure is expanded, increasing its reach and robustness.

The family of Nokia RoofTop Wireless Routers includes both the subscriber unit and the "AirHead", which is the Internet access point for the mesh network. They are similar but the AirHead contains a more sophisticated software that allows you to implement automatic router configuration and over-the-air upgrades.

The router is an outdoor-mounted unit with an integrated 8 dBi omnidirectional antenna. Measuring less than 30" in height, the unit includes a versatile mount to attach to a variety of surfaces. A thin, flexible power supply and data cable runs from the outdoor router to a small interface unit indoors.

For Nokia wireless router, there are three components needed:

- Full TCP/IP protocol suite support.
- Wireless operating system that optimises the wireless network performance and robustness.
- A high-performance digital RF modem.

4.2.4 Wireless operating system

A suite of specialized protocols and wireless intelligence that optimize the use and efficiency of the spectrum and ensure an adaptive and robust network. Nokia has developed the Nokia AIR Operating System --- a wireless Internet operating system, it extends the traditional TCP/IP stack to provide efficient and robust IP-based networking in multihop, wireless mesh networks. It consists of four primary parts:

- Channel access protocols
  Efficiently schedule transmissions to avoid collisions and efficiently reuse spectrum.
- Reliable link and neighbor management protocols
  Ensure reliable transmissions on a hop-by-hop basis, and manage the automatic adaptation to changes in the network topology by monitoring the status of neighbor links.
- Wireless multihop routing and multicast protocols
  Maintain performance- optimized routing tables, and enable an efficient multicast capability.
- Standard Internet protocols
  Provide the standard set of protocols and tools (TCP, IP, UDP, SNMP, RIP, ICMP, TFTP, PPP, SLIP, ARP, Telnet, Ping) for seamless integration with the wired Internet.

4.2.5 Deployment and management

Self-configuring routers and a graphical user interface (GUI) – based element management tool make installation and ongoing management quick and easy. There is a Nokia RoofTop Router Management System (RMS), which enables administrators to configure, monitor and upgrade their RoofTop network over air.

With Router Management System, you can do:

— Configure routers either locally or remotely, this software helps get your network up and running faster.

— Remotely assign names and IP addresses, as well as changing subscriber settings in each router throughout the network.

— A rate control feature gives you the ability to control the overall flow of data in your network -- plus manage the bandwidth to each of your subscribers.

— Assists you in assigning unique authentication codes and frequency hopping patterns to all the wireless routers in your network.

— Check your network operations at a glance with a dynamic Graphical User Interface, viewing the performance of network links in a topology outlook and through graphical curves.

4.3 Features & advantage of Nokia Broadband Wireless Solutions

4.3.1 Wireless Broadband Complements Wired

- Where withouting wires
- For rapid market entry
- Where wired plants are at full capacity
- In areas with long/low quality cable
- In less dense areas

4.3.2 RoofTop Wireless Routers Models the Internet

- Each node is an IP router & becomes part of the infrastructure

— Adds robustness with subscribers
Each Nokia RoofTop Wireless Router performs routing and traffic forwarding for neighboring routers, becoming part of the network infrastructure. In this way the network actually becomes more robust as it grows.

— Minimizes upfront infrastructure – Investment is paced by demand
Because each wireless router is both a subscriber access device and a router in the network, this solution does not require a large upfront investment. Therefore you can expand with demand and invest as your business grows, rather than completely rolling out a large network before starting service.

- Routing simplifies line of sight so coverage is practical in neighborhoods

— Only need line of sight to another node
Because each node is not only a receiver, but also a transmitter, so no need the direct LOS to the 'AirHead', the path can be connected through several intermediate routers like wired infrastructure.

— Routers around obstacles
Usually, router always can find out a neighbour router between them there is LOS to avoid the obstacles.

- Adaptive intelligence self-configures and self-heals

— Installation and operations are simple
The Nokia RoofTop solution includes various features and accessories to simplify installation. For example, omnidirectional antennas do not require "pointing", which enables faster deployment and remote cell splitting without repositioning antennas. Furthermore, phone line networking means you can greatly reduce installation time per household. In addition, deployment is made even easier by the fact that the routers operate in the 5.8 GHz frequency band, which is not subject to spectrum licensing in most countries. So you can install a fixed

wireless network and launch service quickly, without lengthy and expensive license procedures.

— Robust to changes and congestion

With the intelligent operating system, allowing the network to select the best traffic router in real time, continually adapting to changes in link availability, and also allowing you to add new subscribers incrementally, growing with demand, effortlessly.

Nokia RoofTop Network makes wireless broadband scaleable and efficient, will be the leading of wireless broadband solution.

5. GIS in Nokia Wireless Router Network Management

5.1. General

Geographic Information System technology plays important roles in wireless broadband network planning and maintenance.

Usually, making simulation with GIS software or technology for network planning and maintenance is necessary. When deploying a wireless network, it is more cost-effective and time-efficient to plan the network (such as finding the best cell site location) on a computer rather than sending a team of people out to the field to take measurements. And the use of computer simulation software can also minimizes the financial risk of misplacing a cell. Thus, software that can perform this analysis for broadband wireless networks is highly desirable.

Nokia RoofTop Router Management System (RMS) includes set network operational support tool functions for Wireless Router Network. There is element management type of functionality like monitoring and configuration but as well functionality for planning, and provisioning. RMS Services Viewer system of Routers is as well supported through a web based GIS solution, as following Figure 5.1.

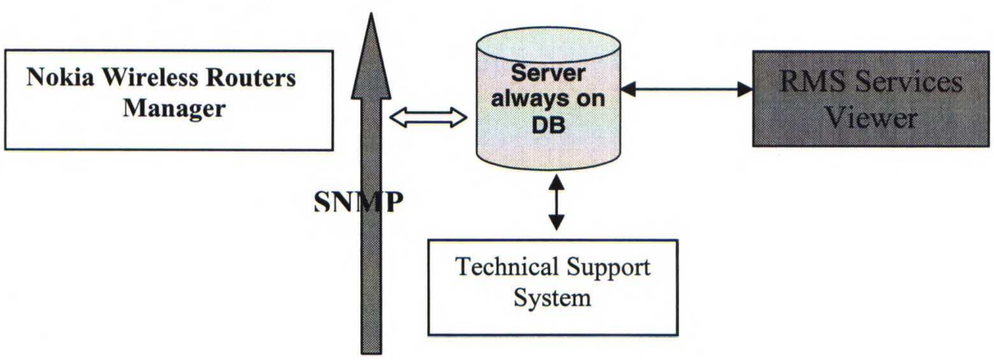


Figure 5.1 GIS application in RoofTop Network NMS

5.2. GIS application

In the RMS, GIS is used to make the network structure and router location understandable and real locations can be accessed. With satellite photographs even the houses are visible in the RMS whole network background.

For large networks, there is hierarchical visualisation of a network available. A view can consist of Airheads only or routers in a single Airhood. Airhead is the geteway router to operators backbone network from an access cluster of subscriber routers. Airhood is a cluster of subscriber routers, typically 20 routers. Maps can be attached for each view.

Specifically, GIS is sit at RMS Services Viewer subsystem. With the system, customer can graphically enter location of his building by address, and possible antenna height, then system will get all existing routers around customer's location within specified radius (km), and in background using a ready made Java module to calculate visibility prediction, finally show the results on screen.

Next chapter will focus on the RMS Services Viewer system.

6. RMS Services Viewer (RSV) system of NWR

6.1. General

RSV (RMS Services Viewer) is a subsystem for Nokia RoofTop Wireless Routers (NWR), included in Nokia RoofTop Router Management System (RMS). Its purpose is to provide important support for network management and maintenance. It can monitor the running situation of network, show the coverage information, and also can efficiently help sell routers into 'living' network, to meet the need of sales offices and shops for some basic information about the existing implemented and planned router network. RSV is a web based application giving information basically about either the required address is in the coverage of the network are or not.

6.2. Architecture of RSV

RSV is a client/server application, which is based on ArcIMS web server solution to distribute geograghic data and coverage information over Internet or Intranet.

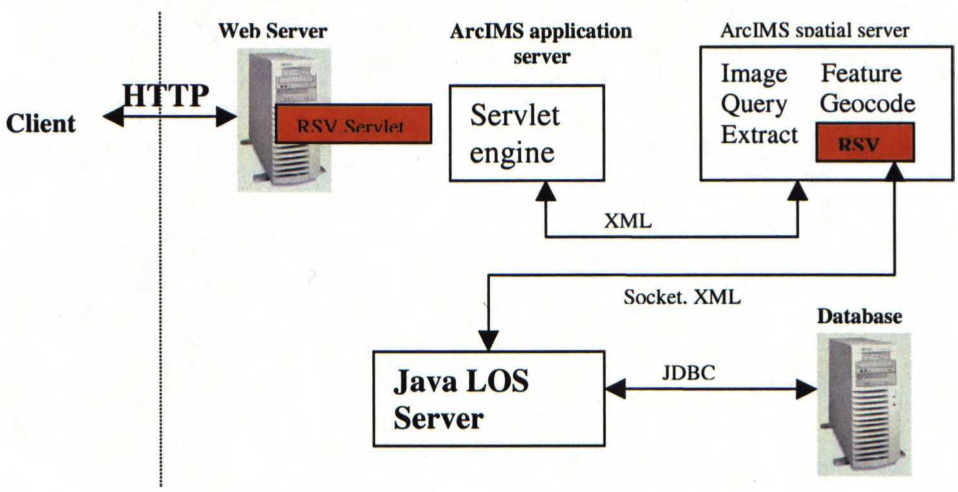


Figure 6. 1 Architecture of RSV

RSV is mainly including four parts as:

- Web Interface

  Input address info and some parameters, finally show output results

- RSV Servlet
  Communication between client and ArcIMS, create all requests and return final results to client
- ArcIMS MapService of RSV
  Forward ArcXML requests from servlet to LOS server, and send results back
- GIS analysis module
  Calculate the LOS between routers

Generally, RSV is working flow as the diagram:

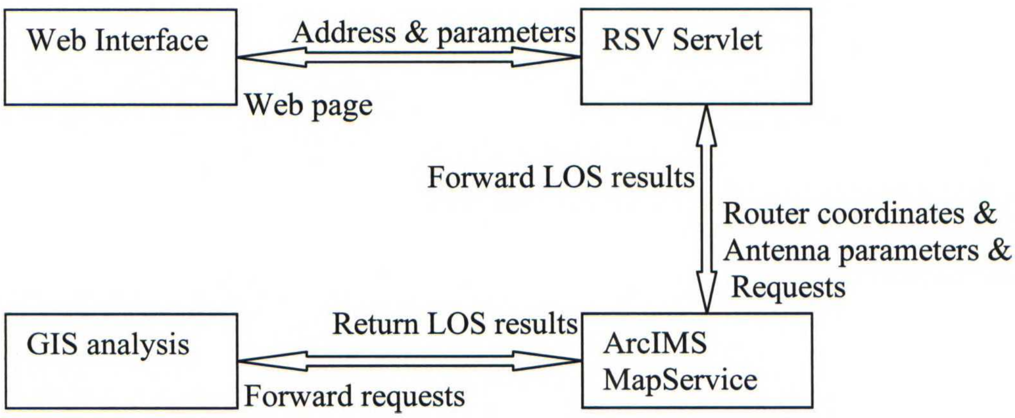


Figure 6.2 RSV working flow chart

6.2.1 Web interface

The web interface of RSV is a customised HTML viewer, including input part, map part and text part. In practical, it can be customised depending on user.

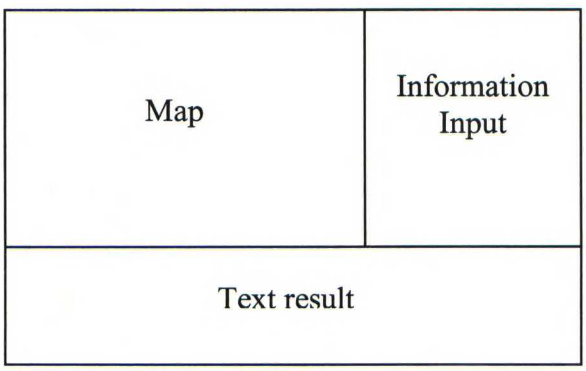


Figure 6.3 Web interface

In input part, user needs to input new customer address, RoofTop antenna height, search radius (circle buffer around the input address), and press 'Locate' to go to background calculation.

Then the coverage information for new customer location can be got and shown separately on map and result text parts, the results refer to the existing running routers within buffer. On the map, the black dot is new customer location, green dot means LOS visible, and red dot means LOS invisible. Finally, visibility situation and distance from each running router also are shown on the text table. So this is very straightforward for customer to visualise the visibility situation. For network maintenance, technical person can see the 'living' router running situation. And also accordingly sales office can find out the potential customers depending on it.

6.2.2 RSV Servlet

- **Servlet technology**

Java™ Servlet technology provides web developers with a simple, consistent mechanism for extending the functionality of a web server and for accessing existing business systems. A servlet can almost be thought of as an applet that runs on the server side -- without a face. Java servlets have made many web applications possible.

Servlets make use of the Java standard extension classes in the packages `javax.servlet` (the basic Servlet framework) and `javax.servlet.http` (extensions of the Servlet framework for Servlets that answer HTTP requests). Since Servlets are written in the highly portable Java language and follow a standard framework, they provide a means to create sophisticated server extensions in a server and operating system independent way.

Typical uses for HTTP Servlets include:

— Processing and/or storing data submitted by an HTML form.

— Providing dynamic content, e.g. returning the results of a database query or other application to the client.

Servlets are a popular choice for building interactive web applications. They are platform-independent, 100% pure Java **server**-side modules that fit seamlessly into a **web server** framework.

A Servlet is an application program you write that runs on a web server. Its work process like that:

- A Web server receives an HTTP GET or POST request from a browser (client).
- The web server directs the HTTP request to the servlet engine.
- The servlet engine then encapsulates the HTTP request into a class called HttpServletRequest and delivers it to your servlet's doPost or doGet method.
- Your servlet responds by writing HTML into HttpServletResponse which is sent back to the web server and delivered back to the TCP client.

We use Apache web server, which is free available, and also with its servlet engine JServ or Tomcat.

- **RSV servlet**

RSV servlet gets the input stream from the web client, forms several ArcXML requests and sends them to ArcIMS Application Server by using Java based connection link classes provided by ESRI. In the final stage servlet parses the ArcXML responses from the ArcIMS and forms necessary html strings to be returned in output stream back to web client.

RSV servlet is capable to return information about visible and invisible routers for an geocoded point based on received address. It also gives url link to an image that contains visual information about the text response. Method 'service' contains main functionality of the RSV servlet:

— Tries to find address

— Geocodes it

— Sends address coordinates as xml

— Takes coordinate points and sends to RSV component for Line of sight

— Returns routers coordinate points from the RSV and adds them to image

— Finally returns image url

The requests created here include geocoding for new customer address, querying DB for existing running routers around new router within search radius, and then asking GIS analysis module to calculation LOS.

6.2.3 ArcIMS MapService of RSV

RSV ArcIMS MapService is a customised Server Component with ArcIMS 3.1 Server. It provides host and port for setting up the socket to LOS Server.

Actually RSV ArcIMS MapService just a gateway between RSV Servlet and LOS Server, all requests from RSV Servlet are sent to LOS Server through the RSV MapService, after LOS Server processes the requests, results in responses are returned back with the gateway.

6.2.4 GIS analysis

- **LOS Server**

Line of Sight server listens to certain port defined in a init file and gets ArcXML requests in the input stream from RSV MapService which uses RSV customized ArcIMS Application Server component (with C++). When server is initialised it reads Digital Elevation Model data file to an abstract class into memory and also makes JDBC connection to DB. Server starts anyway even if JDBC connection is unsuccesfull because server should always function. It will try to reconnect when a new request comes. Server parses coordinates of a geocoded point and its extent, the parameters from the request and makes spatial query to DB based on the extent that is received. As a result to this query we get all the routers and their information in that extend. In this point we give the necessary information to the GIS analysis module for LOS calculating. As a new feature, server also connects to parallel DB that contains contact information. All the LOS requests with different addresses are saved to DB. DB can be totally separate for example Oracle somewhere in the operators network.

- **GIS analysis module**

This is the important module of RSV, mainly calculating the visibility for each LOS between routers based on the corresponding DEM data of studying area.

- **Overview**

In this RSV, a Java programming software --- Geographic Information System for Line-of-Sight Radio Communications, will be used, which can calculates LOS between any two transmitting and receiving antennas on the earth surface.
And then, the LOS visibility result of calculation is sent back to Web interface of system to show on the screen.

With this tool, we can load any format USGS DEM data, view it, especially calculate LOS coverage, finally show the visibility result on client brower. This Java module is based on (Jeffrey B. Otterson, 1998), especially basic LOS algorithm.

This module needs to get antenna location data and other parameters from servlet, also DEM data loaded in advance.

- **Calculation of LOS**

LOS between antennas is calculated based on the geospatial data in the DEM object and the antenna parameters. The antenna is considered a point source located at the coordinates and elevation.

For the analysis, each antenna's coordinates is needed for calculating LOS's direction and antenna's position on the DEM. The analysis distance increment is in units of the

DEM file's maximum resolution, typically 3 arc-seconds or 10 meters.

The program calculates LOS visibility by analyzing vectors originating at the transmitter location. The number of vectors is calculated based on the number of receiving antenna.

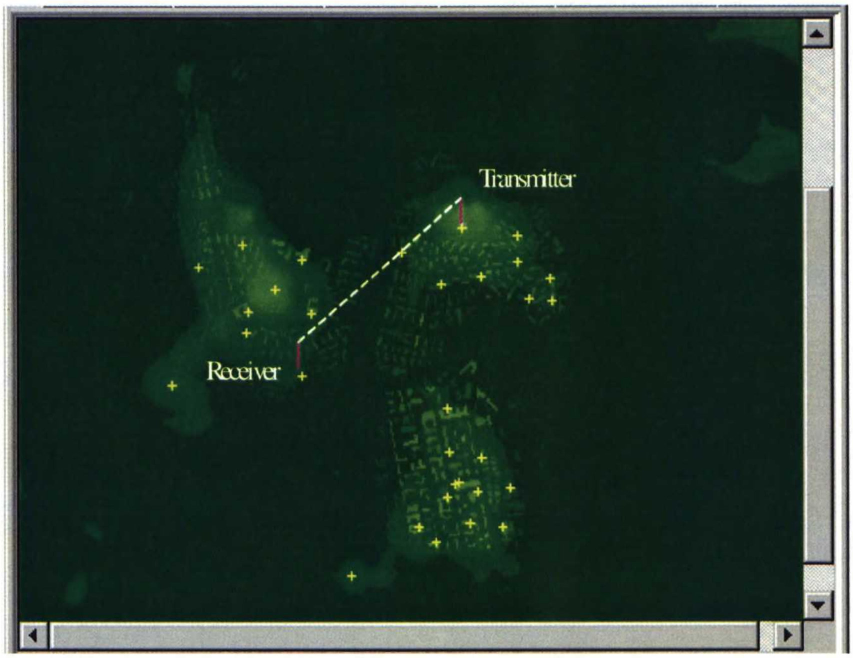


Figure 6.4 LOS visibility calculation

Each vector is analyzed at successive distances from the transmitter location to receiver location, based on the Analysis Distance Increment (1 pixel). Each point analyzed has it's antenna height calculated based on the elevation from the DEM, the receiving antenna height, and the effective loss in elevation based on the curvature of the Earth at the distance of this point from the transmitter. (The curvature of the Earth used in this calculation is based on a diameter equal to 4/3 of the actual diameter to compensate for atmospheric diffraction of the radio signal). The point of a receiving antenna analysed has an imaginary line created from the transmitting location to that point and the slope is calculated for the imaginary line. The elevation of every point analysed on the current vector is then compared to the imaginary line by calculating the elevation of the imaginary line at that point. If any point on the analysis vector is higher than the point on the calculated line, the receiver location is shadowed, then the LOS is not intervisible, whereas LOS visible, and same time the horizontal distance of this LOS vector also calculated. And then the analysis continues at the next LOS analysis vector. After all the vectors are calculated, the visibilities and distances for each LOS will be returned to client.

6.3. Functionality and Features of RSV

- Analyses coverage based on customers address
- Geocoding and Line Of Sight analysis
- NWR network coverage information for given home address
- Simple user interface, which can be customised and used without any special training.
- Compliant for operator Intranet and public Internet usage
- Collection of requested addresses for new potential customers
- Plug-in interface to enable integration with operator's home pages, databases, and map material
- Interface to DB to get network data(routers location)
- Well documented for operators own integration work into existing home pages

6.4. System reliability

RSV is a Web based GIS application. It serves RoofTop Wireless Network, offering important visibility information for network maintenance and router selling. So if the information is exact and reliable depending on some things as:

- **Geocoding accuracy**
  By geocoding, customer's home address is geocoded to location with coordinates on the map. Actually we get router's location also by this geocoding, so the router's location accuracy is depondent on geocoding accuracy.
- **LOS visibility accuracy**
  LOS visibility accuracy is meant the accuracy of LOS calculation, which returns the visibility result for each LOS.

To a great extend, above accuracies rely on the data quality what we are using. In next chapter is the main chapter to discuss the data requirement.

7. Geographical data requirements

7.1. General

Application related to Wireless Router Network requires geographical data to optimise the location of routers. Such data should include surface elevation information required to calculate visibility areas in addition to address information to identify customer/operator locations. Additional data is required in order to enhance information delivery. Locations focus upon urban/sub-urban residential areas. It is anticipated that the level of geographical information required for specific areas may differ according to customer requirements and spatial patterns observed.

In this chapter, the work is to analyse and compare the available data according to different data precision and different testing area. The GIS data used here are focus on DEM and Street/Address.

7.2. Data requirements and availability

7.2.1. DEM data

Surface elevation data provides the backbone of the data requirement. The elevation can be referred to as "bare earth elevation models" which provide the elevation of the ground surface (not including vegetation, building etc.) and "canopy elevation models" which refer to surface elevations including above-ground features such as vegetation and buildings (Canopy DEM = (mean buildings/large tree heights) + USGS DEM). The calculation of visibility areas is affected, to a greater or lesser degree dependent on local spatial patterns (building patterns, local topography etc.), by surface elevation. Natural and man-made features obstruct the "view" of routers.

USGS bare earth digital elevation models (DEM) are currently available for the USA. The resolution, in terms of grid size, ranges from 10m to 30m depending on the target area. USGS are working towards national 10m coverage, which can form a basis for RoofTop concept.

Elevation data which includes features such as vegetation (e.g. clumps of trees) and buildings requires specific data accquisition strategies. In some cases, such data may be readily available and may be sourced directly – however suburban areas tend to fall outside area where this type of data has traditionally been gathered. Novosat will employ two core methods, depending on clients needs, to acquire such data if it is not possible to source directly.

In wireless Router Network planning, we will use USGS DEMs, which have many different standard formats such as 7.5 minites, 15 minites, and 1 degree, etc., which are corresponding to different resolution. So how they are suitable for our purposes in predicting accuracy, availability, cost points of view is the task here to analyse. In the data analysis, I will use 7.5 minutes, 1 degree standard USGS DEM and 10m x 10m, 25m x 25m other DEMs for visibility coverage testing and analysing.

7.2.2. Street / address data – Geocoding

In order to locate customers and calculate their visibility coverage option, accurate address and street vector data are required to facilitate geocoding. The combination of address-geocoding and surface elevation allows the calculation of customer specific coverage.

Geocoding --- the process by matching street addresses, zipcodes, parcel numbers and other geographic place identifiers to geographic longitude/latitude coordinates that define a location.

Novosat undertakes to create/integrate additional street/address data sets throughout the world as required by client. Street vector data with address ranges are sourced from data providers. And Novosat requests sample data from each data provider for each target area, and then select the data which best fits the actual ground conditions as observable from image data. In case where the street data is not acceptable, Novosat undertakes to edit the vector data to improve the fit the fit to the reference image data.

7.2.3. Other data

In practical, except for above DEM and address-geocoding data, some additional topographic data also can be used, such as Point of Interest (school, major landmark etc.), landcover (water features), and transportation objects (railways, airports, etc.), also with the inclusion of image data (aerial photo, satellite image), all them provide visual enhancements and reference to improve the delivery of visibility coverage information. In this thesis, I am not talking more about them.

7.3. Data analysis

In this section, I will use the data what we have currently for visibility coverage and geocoding analysis, which includes quality, error, and tolerance analysis.

7.3.1. Visibility coverage analysis

As we know, even though Nokia routed mesh network architecture simplifies LOS requirement, but the LOS between neighbour routers still necessary. Especially for a new customer address, we must predict if there is at least one LOS available between it and its neighbour routers.

Actually, visibility coverage analysis also includes path loss analysis of radio microwave, not only LOS visibility analysis. Path loss is the signal attenuation between the transmitter and receiver as a function of the propagation distance and other parameters related to the terrain profile and its surface features. However, radio waves experience significant path loss only after travelling 3 – 5 kilometers. This means just keeping a dense pattern of transmitters covering the service area to avoid path loss problem.

For RMS Services Viewer system, the visibility prediction is made within 1 kilometer, so we can ignore path loss problem, just focus on LOS visibility analysis that is much more related to GIS application.

7.3.1.1. Data source

Currently, we have DEM data in Santa Rosa area of California, USA and Lauttasaari area of Helsinki, Finland.

- **Santa Rosa**

  — **Bare earth elevation:**
  1 degree(3 arcsec **x** 3 arcsec), 7.5 minutes (10m **x** 10m) USGS DEM

  — **Canopy/Surface elevation:**
  7.5 minutes(10m **x** 10m) USGS DEM

- **Lauttasaari**

  — **Bare earth elevation:**
  25m x 25m USGS DEM, 10m x 10m USGS DEM

  — **Canopy/Surface elevation:**
  10m x 10m USGS DEM

7.3.1.2. Studying Environment

To do visibility analysis, we need to do a series of simulation studies, so not only we need DEM data, but also study area and simulating tool needed.

- **Studying area**
  Depending on the DEM data what we have, we choose Santa Rosa and Lauttasaari two areas as our study areas, Lauttasaari is located in urban and Santa Rosa is in suburban area.

  - **Santa Rosa**
    The testing area is in the suburban of Santa Rosa as following Figure 7.1, red cross mark is the exact location of routers.
    From right figure, we can see testing area is just beside the mountain, which is state park.

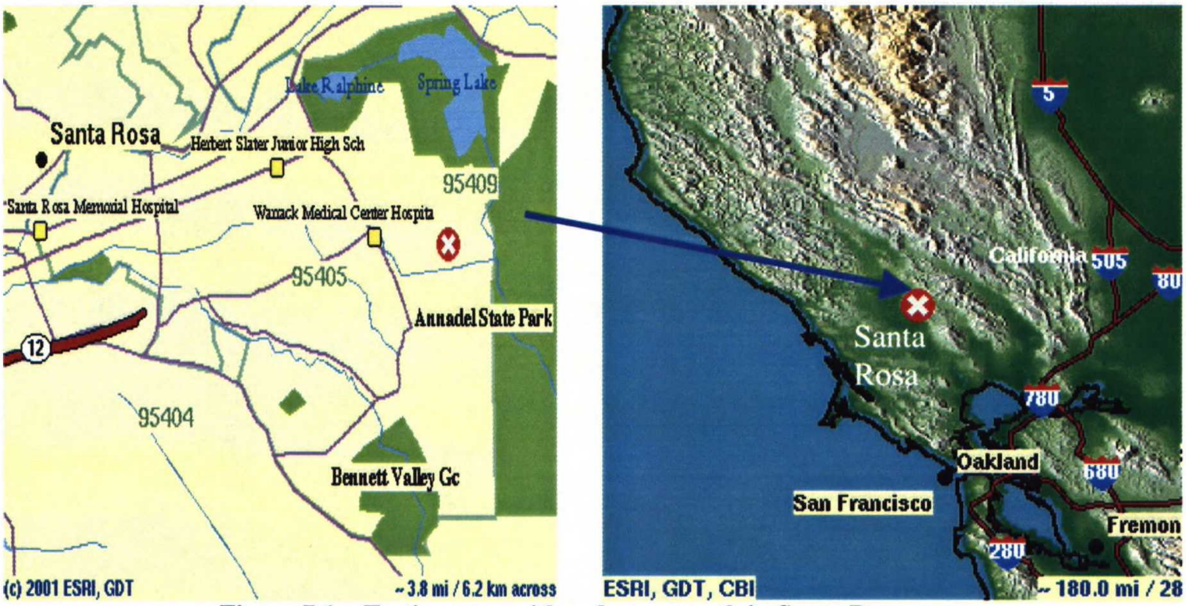


Figure 7.1 Testing area with red cross mark in Santa Rosa

Testing routers are located in suburban area of Santa Rosa, California, America. The part of area, buildings are sparse, mixed one – two storey, mean height 7.5m; and the part as low woodland/park, mean height 8m; remaining part as semi-open area (a few trees widely spaced), or open area.

- **Lauttasaari**

  Lauttasaari is located at the city of Helsinki as Figure 7.2, we can see it is a island on the sea, just nearby city center.

Figure 7.2 Testing area in Lauttasaari, Helsinki

Testing routers are located in downtown of Helsinki, Finland. The buildings are crowed, average density about 20m - 30m between neighbour buildings, the height of building from 10m – 40m, average height around 20m.

- **Study tool**

For the sake of analysis presentation, I create a Java applet interface as following:

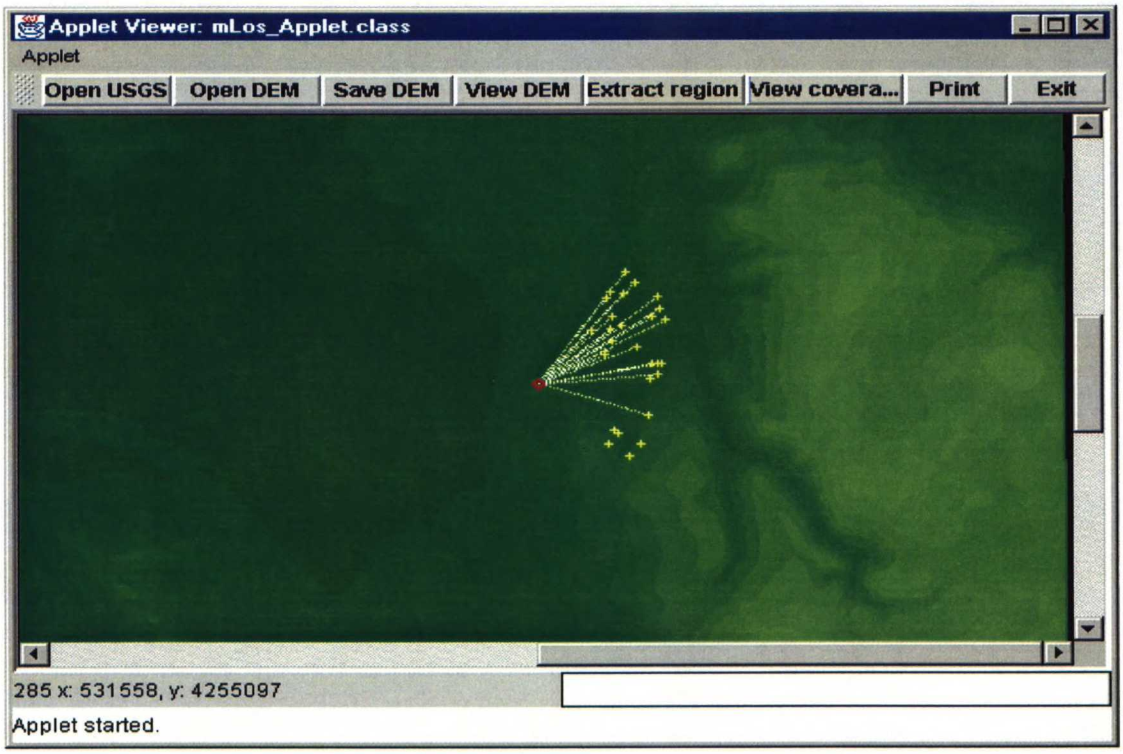


Figure 7.3 LOS visibility analysis tool

With this applet, a interactive GUI available, we can load different format DEMs, and view them, save them etc. however important function is 'View coverage', which is calculating LOS, let see the steps:

After loading the DEM data with 'Open USGS' button, a DEM data reading, then 'View DEM' to show it on the screen. After that, we can do visibility analysis with pressing 'View coverage' button, the following dialog 'Enter Antenna Location' open:

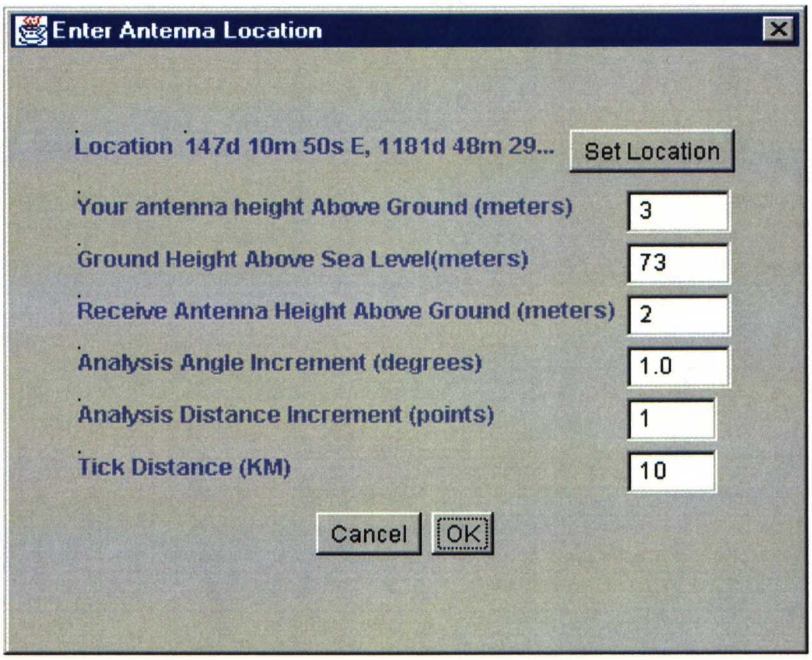


Figure 7.4 Dialogue for entering antenna location

Above dialog is setting up antenna location, including set up your antenna height above ground, receiving antenna height above ground, and analysis distance increment (points) etc., for ground height above average sea level getting from calculation after opening 'Set Location' as:

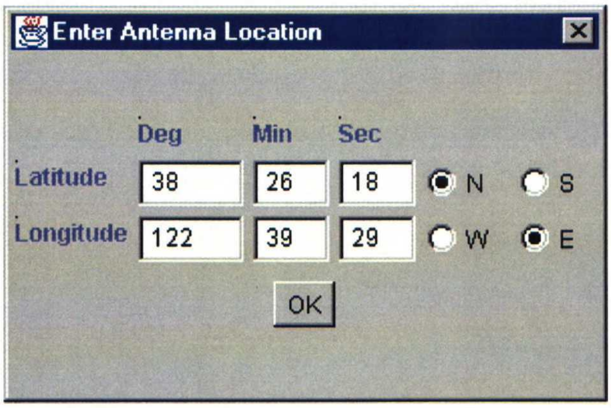


Figure 7.5 dialogue for entering coordinates

7.3.1.3. Specific plan of studying

- **Santa Rosa**

There are 28 known existing router locations, using a new router location to test the visibility to all 28 existing routers basing on various formats DEMs.

- **Lauttasaari**

  Making 30 RoofTop routers randomly, using a new router location to test the visibility to all 30 routers basing on various format DEMs.

7.3.1.4. The results and analysis of studying

The intent of the studies conducted here is to determine two things:

— How the LOS changes when using
The different resolution DEM.

— Compare the LOS results according to different DEM in both area, and find out the error rate, tolerance, and solution.

All router antennas are mounted on roof top (for canopy) or bare ground, and height above roof top or bare ground is 3 meters.

Before the analysis, I have to give a ready-made conclusion: '10m canopy DEM can be used for visibility prediction with a quite nice performance'. This conclusion quoted from (**Harry R. Anderson, 1999**) paper 'The Impact of Building Database Resolution on Predicted LMDS System Performance' as following:

Database	Number of CT servers changed	Average change in % service availability
Vector	0	0.00000
1 m canopy	141	0.00337
2 m canopy	217	0.00251
5 m canopy	337	0.00485
10 m canopy	556	0.00137

"Several databases were developed with x, y resolutions ranging from 1 meter to10meters. These databases were used to study the changes in LMDS system design performance when compared to a "perfect" vector database. The results show that the canopy databases can provide prediction performance comparable to the vector database, especially for 1 and 2 meter canopies".

Therefore, in the following LOS analysis, suppose:

10m x 10m canopy DEM can be the so-called 'perfect' as the reference data.

- **Santa Rosa (28 routers)**

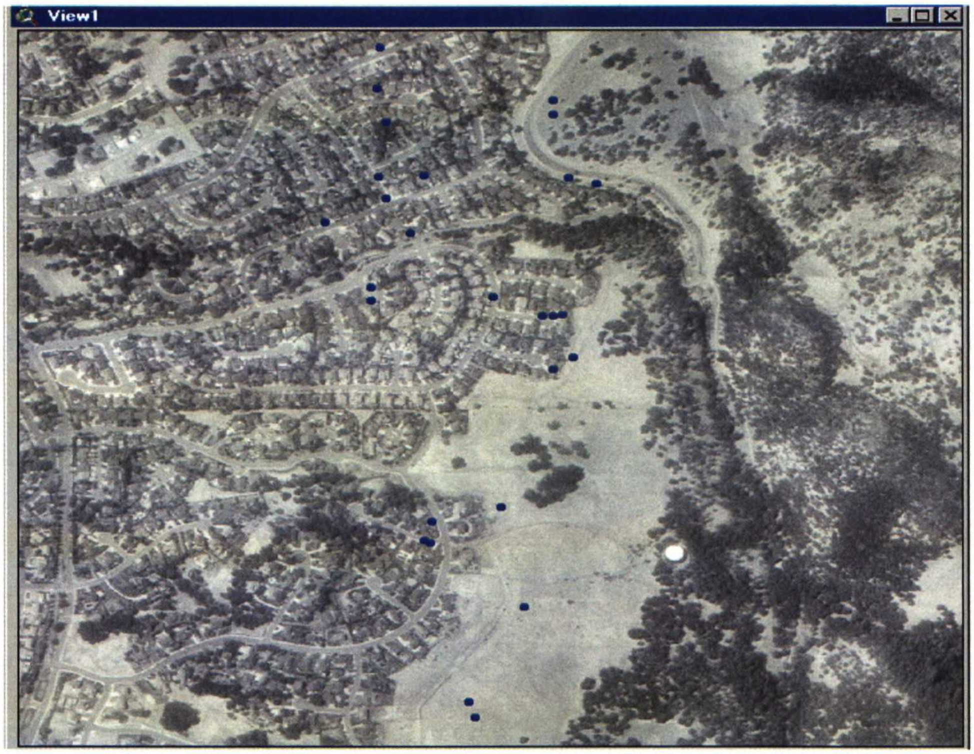


Figure 7.6 Routers distribution in Santa Rosa testing area

As above Figure 7.6, there are 28 existing living routers (blue points) for testing. The LOS results for different DEMs testing as following.

Totally there are 8 new router locations tested in the testing area, and then all the testing results can be summarised as average LOS differences and error rate for each bare ground DEM.

Now let's make a table for the results statistics, here based on the result of 10m x 10m canopy DEM to calculate the difference and error of other DEMs.

Table 1			
DEM (resolution)	**LOS difference (average)**	**Error rate (%)**	
10m x 10m(canopy)	**0**	**0**	
10m x 10m	**2.5**	**8.9**	
3arcsec x 3arcsec	**9**	**32**	

From Table 1, we can see the differences are separately 8.9% and 32% error rate between canopy and bare ground for 10m x 10m and 3arcsec x 3arcsec.

So if we make error tolerance as 15%, then in this suburban area:

10m x 10m bare ground data can be used to replace canopy to do LOS analysis in suburban area.

- **Lauttasaari (30 routers)**

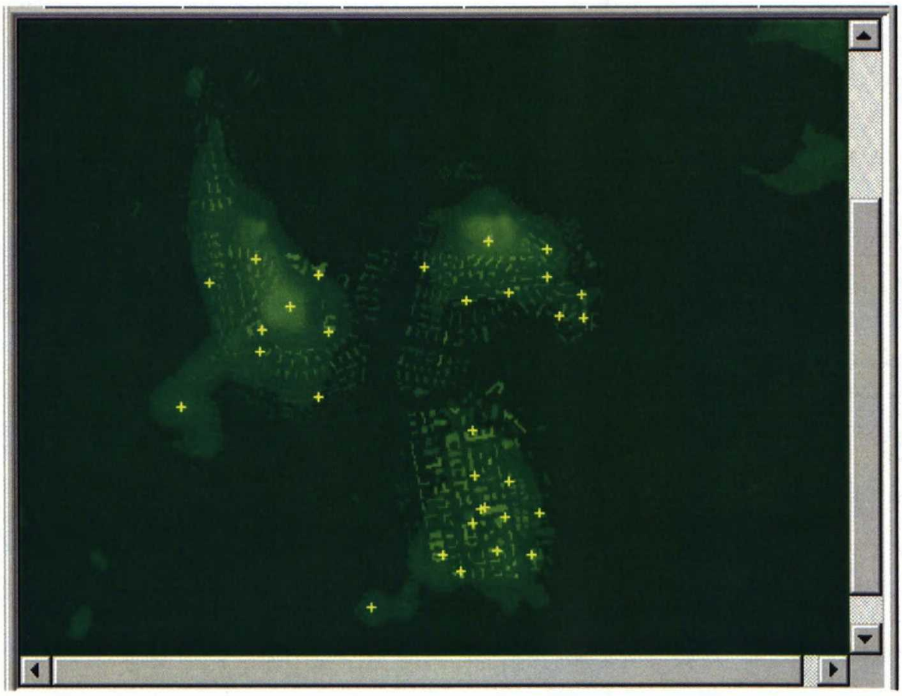


Figure 7.7 Routers distribution in Lauttasaari testing area

As above Figure 7.7, there are 30 supposed existing living routers (cross points) for testing. The LOS results for different DEMs as following.

There are also 8 different new router locations for analysis, and summarised the results in average to the following table, here also based on the result of 10m x 10m canopy DEM to calculate the difference and error of other DEMs.

Table 2			
DEM (resolution)	**LOS difference (average)**	**Error rate (%)**	
10m x 10m(canopy)	**0**	**0**	
10m x 10m	**20**	**65**	
25m x 25m	**19**	**61**	

From table 2, we can see the too big difference between canopy data and bare ground data, error rate as 65% and 61%. So based on the analysis, we can conclude it as:

In the urban area, because of crowed, high buildings and trees, standard USGS bare ground 10m x 10m DEM data is not accurate enough for LOS analysis, it must be canopy and resolution higher than 10m x 10m.

7.3.2. Geocoding analysis

Geocoding, the process of linking a common location identifier such as address to a spatial database such as street/road map data.

When we do visibility prediction for routers selling, we should give customer address(new router location), and get the coordinates of this address from geocoding, and then calculating LOS coverage. So geocoding if accurate enough is the important factor to affect the result of LOS.

(microDATA GIS 911)Geocoding is a GIS procedure of matching an address(es) to a GIS database that contains a database relationship between addresses and geographic features. The most common form of a geocoded GIS database is a road centerline data layer that contains address ranges for each road segment. Each segment contains the first and last address on each segment of road. GIS data generally has a continuous segment for each portion of road between intersections where turns may be made. Intersections without access (e.g., bridges and tunnels) should not "connect" in the GIS data. Preferably, the address ranges for both the left- and right-hand sides of the road should be included in the data.

An address is located mathematically with geocoding by finding the road segment with the correct name and an address range that encompasses the subject address. The location is determined by apportioning the address range along the road segment. There is no discrete site data when locating addresses using geocoding. The location is approximate and could cause the display of erroneous locations if the range data is not precise. Since the actual site points are not stored, site-specific information cannot be easily linked to the map display.

During geocoding the computer attempts to find a matching address in the address coverage for each raw data point. If a match is found the xy coordinates of the matched address are added to the original data record. If the address coverage is a point coverage, the geocoded data will receive the same xy coordinates as the matched point in the address coverage. Data geocoded on polygon based address coverages obtain the x y coordinates of the geographic center of the matched polygon.

7.3.2.1 Sources of Error in Geocoding (Paul Laymon, 1999)

The geocoding match rate, which reflects the accuracy of the geocoding process, depends on the quality of both address and geographic data. Some errors are inherent to the process, and it may be difficult to determine the accuracy of the results. Documenting potential error sources and understanding how they affect the quality of the results are important. Address accuracy, address allocation, and assigning locations for aggregate data are areas that were found to affect the match rate.

- **Address Accuracy**

  Error can be introduced when the mailing address (typically a post office box) is supplied in place of the residential address. New addresses created during the calendar year that do not exist in the current street/road database will also reduce the geocoding match rate.

- **Address Allocation**

  Though the geographic data used for geocoding contains a wealth of information about street locations, address ranges, and related information, it is not complete and varies in quality from area to area. In urban areas, the percentage of street segments that contain address ranges may be as high as 90 percent. However, some rural areas do not contain any address ranges. Therefore, the geocoding match rate is dependent on the study area.

- **Assigning Geographic Locations**

  In the geocoding process, each address in an event table is compared to the address ranges in a target address database. When an event address matches the address range of a street segment, an interpolation is performed to locate and assign real-world coordinates to the address in the event table. For example, given a line with endpoint values of 0 and 100 and a street address of 50, the location of the address is estimated at the line's midpoint. However, the actual street address may not be located at the midpoint of the line segment. During the aggregation process there is the potential for a small percentage of geocoded data to be captured in the wrong polygon.

7.3.2.2 Geocoding testing in Santa Rosa

For our Rooftop RMS Services Viewer, we need geocoding from new customer address to get the coordinates of new router location and show the location on the map.

With geocoding, let’s see the situation using testing routers in Santa Rosa area:

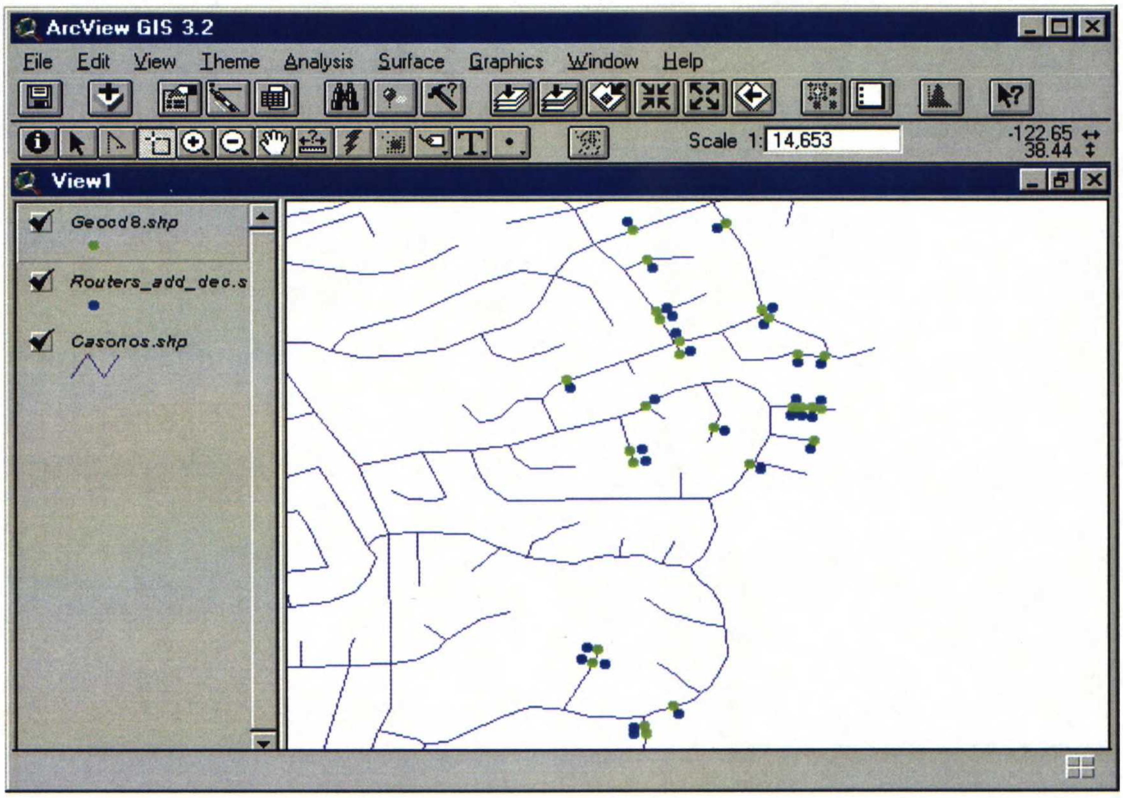
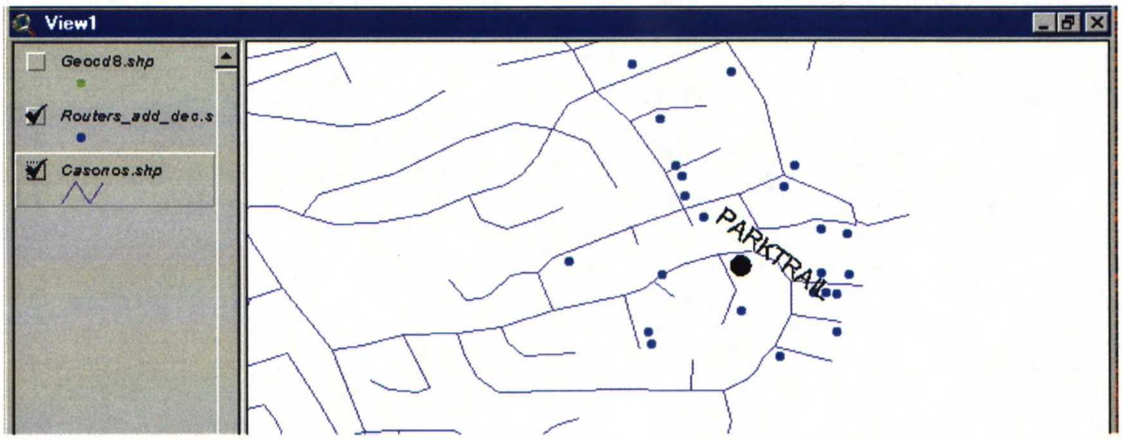


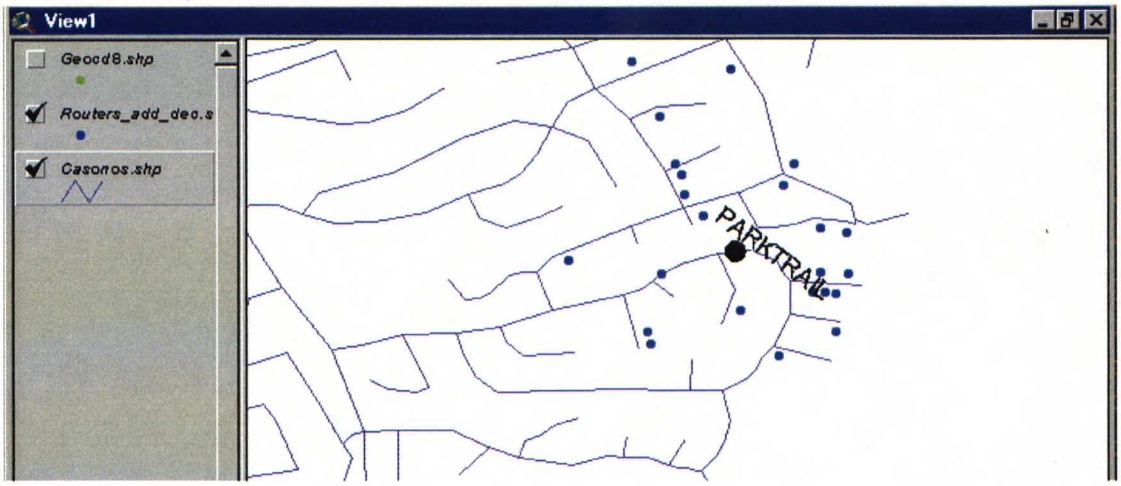
Figure 7.8 Comparation before and after address geocoding of routers. Blue is real location of router, green is geocoded router.

From Figure 7.8, we can see after address geocoding, router location is displaced to central line of street. This geocoding maybe is enough precision for some application such as routing, but for visibility predicting is far away from need. Let's see a more practical example:

Suppose we have a possible customer, address as '4825 Parktrail', its real location on map:



After geocoding, the location on map is displaced to central line of street:



So this displacement causes two problems:

1. the sight line direction to each existing router around is changed
2. the elevation on location is changed (at least building height is different or missing) because location not falling on the right RoofTop.

With these two problems, LOS result will be reasonably different or wrong, and the second problem is more serious.

So if we want to do the visibility predicting in acceptable for this building, we must do some rectification for the geocoded coordinates or geocoding self.

8. Using GIS to enhance Wireless Router Network

8.1. RSV system as a GIS application on WROMAN

About RMS Services Viewer (RSV) system, I already gave the introduction in Chapter 6. It is a GIS technology based application designed by Nokia and implemented by Novo Meridian, and is a important part of WROMAN, its main purpose are to help the management and maintenance of Wireless Router Network, especially support selling Nokia RoofTop Wireless Routers. Actually, its specific work is to predict visibility coverage for router network by calculating and displaying the results on the screen with customized client web interface.

For the performance of RSV system, in last chapter, related data requirement and analysis are already done, so now based on that analysis results, I will discuss possible improvement in RSV system and also alternative.

8.2. Improvement of visibility coverage prediction

If RSV's working results can be reliable depends on the data quality at great extends. Based on the analysis results of chapter 'Data Requirement', we can summary the points as following:

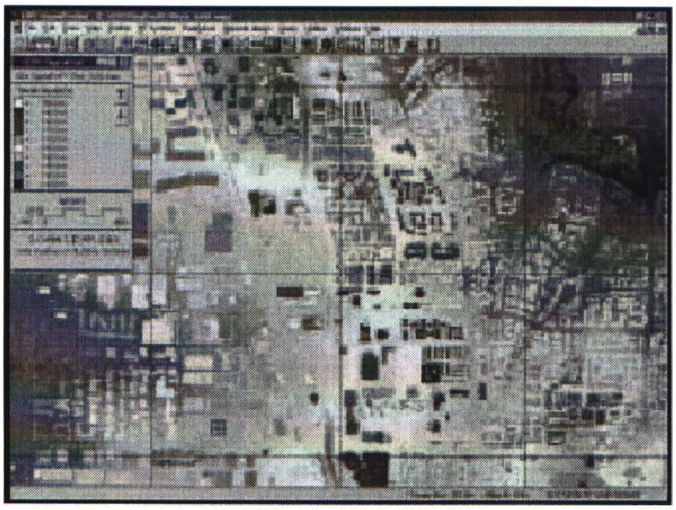
- **DEM data**

  - In suburban area, bare ground USGS DEM can be acceptable for LOS analysis instead of canopy DEM only the resolution should be equal to or higher than 10m x 10m.
  - In urban area, only canopy can be acceptable for LOS analysis, and the resolution should be equal to or higher than 10m x 10m.

For urban area, especially dense urban area and clusters of tall buildings throughout the urban area, like in Lauttasaari, we can consider to use LIDAR canopy DEM data instead of USGS DEM data.

- **LIDAR**

A technique (Light Detection and Ranging) is emerging as a new method of data acquisition, providing a highly detailed canopy DEM (**J.L. Kirtner, 2000**), as Figure 8.1:



(Lidar data courtesy of Global GeoData)
Figure 8.1 3-meter LIDAR canopy DEM

We can see LIDAR data provide a detailed description of terrain, building, foliage, highway overpasses and other surface features (**Kirtner, 2000**). Its resolution can reach 1-3 meters. LIDAR is accurate, horizontal accuracy (depending on flying height) between 0.4 meter and 1.5 meter. Vertical accuracy between 0.2 meter and 0.6 meter (**HORIZONS, INC.**).

LIDAR has several advantages for wireless telecom planning. It can provide a very realistic representation of a study area—all potential obstructions can be displayed. Since the data gathering process is completely automated, capturing more objects on the landscape costs no more than capturing fewer objects. In addition, the ability to produce a high resolution dataset fits well with the needs of LMDS system planners. Finally, the vertical accuracy quoted by LIDAR producers would give engineers a high level of confidence with which to design and display a system. (J.L. Kirtner, 2000)

In our current project, LIDAR data is still not yet used because of its expensive cost.

- **Geocoding**

For geocoding, we got two problems, one is horizontal displacement from building to nearby street center line, and another one --- vertical displacement, building height losing caused by plane displacing, shown as Figure 8.2:

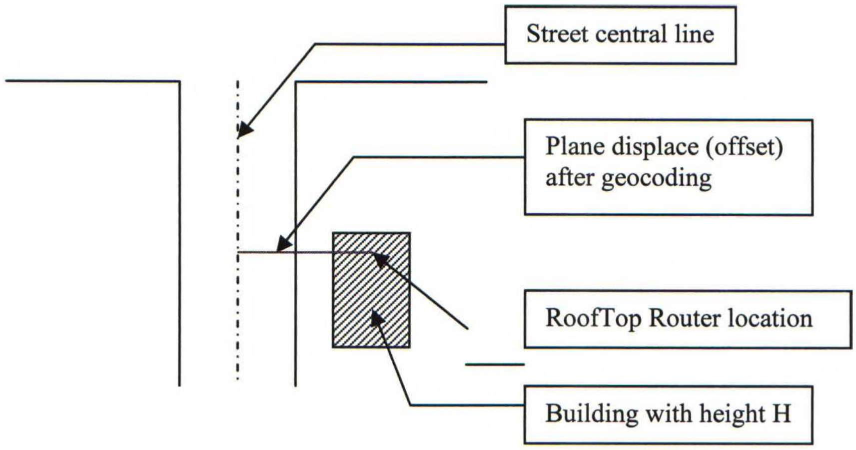


Figure 8.2 The displace in horizontal and vertical after address geocoding

For above problems, one solution can be:

1. Make an offset from central line of street to building during geocoding (not supported by ArcIMS right now, but future possible).
2. Provide the height of building by user or get it from somewhere, then plus it to antenna height directly from RSV interface.

However, above way still not so ideal because these revision still can not guarantee the location falling on the building.

Here discuss some alternatives to solve above problems completely.

- **Alternative 1**

As we know, line-based (street) address coverage, the location from geocoding is dependent on approximate interpolation on the central line of street, which is not meeting our purpose for specifying to the rooftop of building of address. As alternative, we can design a polygon (or vector) data about building, or say it as polygon-based address coverage. This polygon (or vector) data showing the exact footprint of individual building with their associated heights (Figure 8.4), each polygon is assigned a unique ID so that attributes of the polygon can also be included in the database. The associated attributes should include the name of tenant, building name and address, their coordinates of footprints centroids. And then the address of each building should be geocoded to building centroid (or House footprint centroid), as Figure 8.3 following:

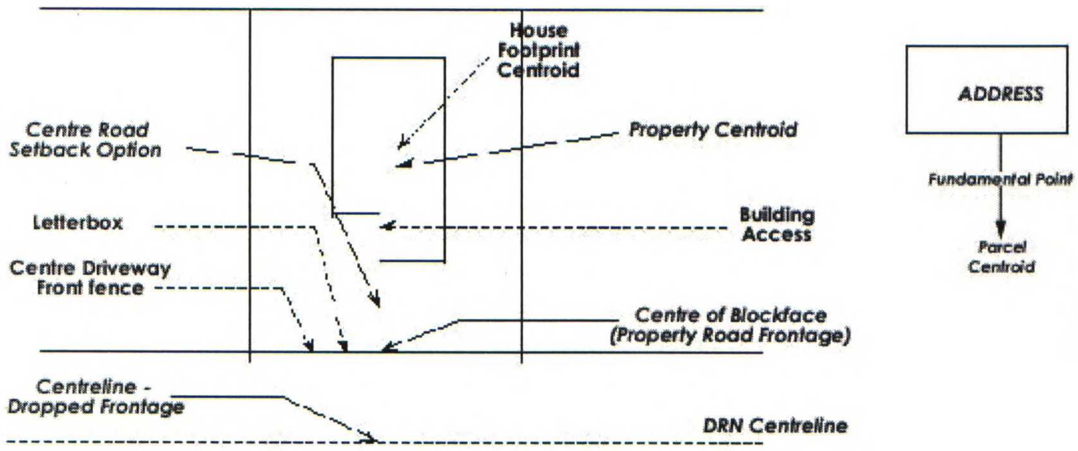


Figure 8.3 Geocode Location Options (http://www.anzlic.org.au/icsm/street/issues.htm)

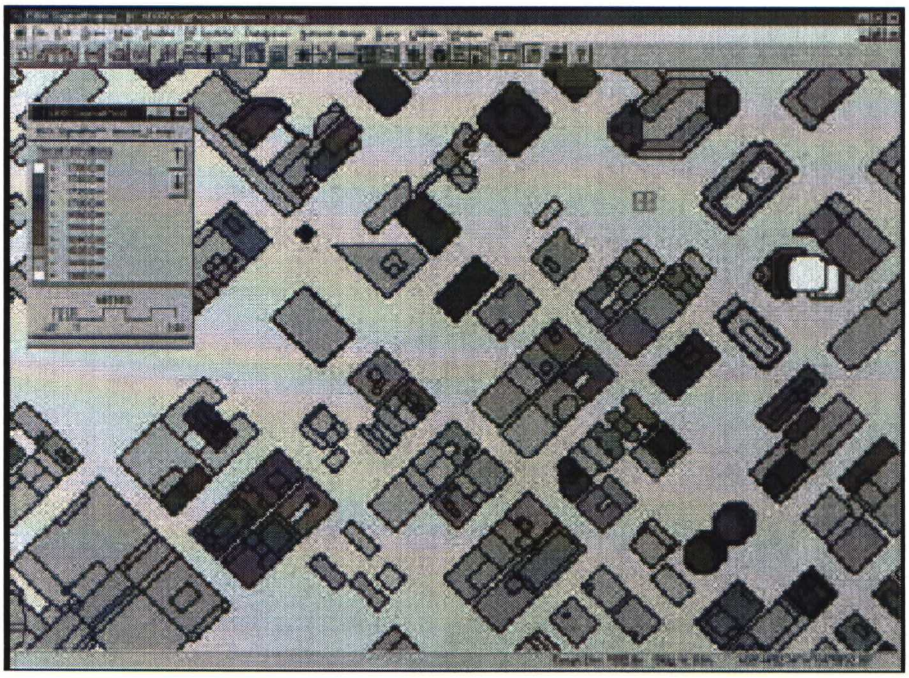


Figure 8.4 Polygon database *(Data courtesy of i3 : information integration & imaging LLC)*

Besides, all building parcels should have been assigned address ranges. So all the above requirement for polygon data is to guarantee each building address can be geocoded to the center of building (within building), and also building height available.

- **Alternative 2**

As another alternative, we also can consider creating a new point based address coverage based on both property parcel data as well as property tax files. To do that not only for improving geocoding overall in terms of the proportion of data successfully matched, but also to pinpoint exact locations of new customer rather than simply approximate their locations by means of interpolation.

- **Alternative 3**

Without changing geocoding database, and still keeping address geocoding to the street central line (this is just for finding out general building location), and then manually locating the exact RoofTop location on the screen map with mouse to get correct coordinates (as Figure 8.5). This solution needs building polygon data as background map, after geocoding, the geocoded point can be added to the map as a acetate layer. And then in background LOS calculation, the manually located coordinates will be using. By this way, the interface of RSV can be little different because one coordinates input field should be added based on original interface.

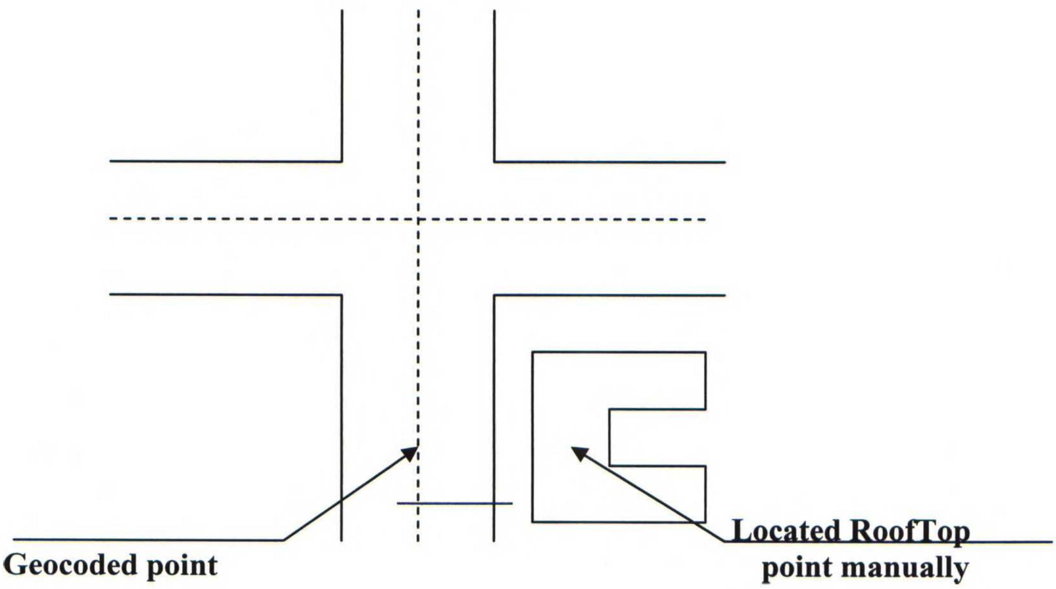


Figure 8.5 Locate RoofTop point manually

9. Conclusion

In this thesis, a main description for GIS application in Wireless Router Network, specifically in network management and maintenance, and discussing and analyzing focus on GIS data quality requirement.

A fixed wireless broadband Internet solved the bottleneck at the Internet access point --- the last mile of the Internet wired infrastructure. As a pioneer of this kind of solution, Nokia RoofTop network solution integrates the most advanced technological innovations of fixed wireless broadband network. It's routed mesh network design enables each node to function as an intermediary router, which simplifies line-of-sight problems and scales much more cost effectively than a client/base station architecture.

For the network management and maintenance, the Nokia Wireless Router Manager enables administrators to easily configure, monitor and upgrade their Nokia RoofTop Networks using a dynamic graphical user interface.

GIS is playing an important role and revealing great advantages in the RoofTop Router Network's management and maintenance because of its location dependent. With GIS's Internet solution, our RMS Services Viewer (RSV) system presents power functions for network management and maintenance. With RSV, we can visualize existing network in a specific area based on the background map, monitor network performance, update network, and especially support router selling in market. With its simple graphic user interface, user can check the network coverage situation to his home address without any training, just simply input his home address.

The performance and accuracy of system depend on GIS data quality at a great extend. In this thesis, two kinds of GIS data are discussed: DEM data and Street/address data, which are for LOS calculation and Geocoding seperately. From the analysis results, DEM data is dependent on specific area, bare ground data can be used for suburban area but with resolution restriction, should be equal to or better than 10m x 10 m. For urban area, because of crowed, high building, it had better use canopy DEM data, resolution also should be equal to or finer than 10m x 10m.

Geocoding data is much required, street address geocoding is for general use, which is not so suitable for our wireless router network application, our application requires a exact location geocoded on address RoofTop, not only street central line location, some improvements and alternatives already provided in this thesis for the future solution.

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