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Using GIS to Optimize the Design and Implementation of the RTK Reference Network in Abu Dhabi

Mustafa Abdulla Mohammed Almusawa

United Arab Emirates University
Deanship of Graduate Studies

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Supervising Committee:

Supervisor: **Dr. Ahmed Mahmoud El-Mowafy**
Associate Professor
Civil and Environmental Engineering Department
College of Engineering
United Arab Emirates University

Co-Supervisor: **Dr. Salem Mohammed Ghaleb Issa**
Assistant Professor
Department of Geology
College of Sciences
United Arab Emirates University

December 2007

The Thesis of Mustafa A. Almusawa for the Degree of Master of Science in Remote Sensing and GIS is approved.

Examining Committee Member, Dr. Ahmed El Mowafy

Examining Committee Member, Dr. Hussein Harahsheh

Examining Committee Member, Dr. Nazmi Saleous

Director of the Program, Dr. Nazmi Saleous

Assistant Chief Academic Officer for Graduate Studies, Professor Ben Bennani

United Arab Emirates University
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ABSTRACT

Several challenging applications and construction works demand real-time measurements for positioning at the centimeter-level accuracy. This positioning accuracy can be obtained by using a Global Positioning System (GPS) roving unit and employing a single reference station (base-station) or through utilizing the service of multiple reference stations forming a Real-Time Kinematics (RTK) Reference Network.

The limitation of the single reference approach is that measurement errors are distance dependent and good accuracy can be only obtained when distances are less than 10 kms. In addition, this method requires a nearby Geodetic Control Point (GCP). Recently, RTK reference networks are widely established in modern cities all over the world. The popularity of RTK reference networks is due to the benefit of providing real-time accurate and consistent GPS data over a wide geographical area using a single GPS rover without the need to be referred to a nearby GCP.

Designing and implementing an RTK reference network is a challenging task. The system performance and cost are highly related to the distance between stations, nature of buildings hosting the reference stations as well as type and methods of communications. Thus, a modern tool such as the Geographic Information Systems (GIS) that can integrate geographic information and several types of heterogeneous data can be used to effectively optimize the design and implementation of the RTK reference network.

This research discusses the use of GIS as an advanced tool to study efficient approaches for designing and operating the Global Navigation Satellite System (GNSS) RTK

reference network in the Emirate of Abu Dhabi, United Arab Emirates. GIS functionality is mainly used for manipulating, analyzing, evaluating and presenting the results of different design and implementation approaches.

The main design aspects that are considered include: reference station locations, their distribution and separating distances, station site selection and the communication methods. Recommendations concerning the selection of the most appropriate options for designing and operating the system are given.

As a result of the study, to ensure precision and reliability, it is proven that station distribution and selection can be best based on service demand while maintaining the user buffer of a radius of 35-50 km from the nearest reference station.

Finally, some of the applications that can be integrated with the RTK reference network are explored and analyzed. Focus is made on the integration with Machine Control & Automation due to the benefits of providing increased production and efficiency to many phases of the construction projects.

LIST OF ABBRIVATIONS

ADM	Abu Dhabi Municipality
ADSL	Asynchronous Digital Subscriber Line
DGPS	Differential Global Positioning System
DMA	Department of Municipal Affairs
DoD	Department of Defense
DVRS	Dubai Virtual Reference System
FKP	The German Abbreviation of "Area Correction Parameterization"
FM	Frequency Modulation
GBAS	Ground Based Augmentation Systems
GCP	Geodetic Control Points
GLONASS	**GLO**bal'naya **NA**vigatsionnaya Sputnikovaya Sistema (Russian)
GNSS	Global Navigation Satellite Systems
GPRS	General Pocket Radio System
GPS	Global Positioning System
IDW	Inverse Distance Weighed
ISS	Internet Service Supplier
LAN	Local Area Network
NCC	Network Computer Center
NTRIP	Networked Transport of RTCM via Internet Protocol
PDA	Personal Data Assistant
RF	Radio Frequency

RTCM	Radio Technical Commission for Maritime
RTK	Real Time Kinematics
SBAS	Satellite Based Augmentation Systems
SDI	Spatial Data Infrastructure
TETRA	Terrestrial Trunked Radio
UAE	United Arab Emirates
UHF	Ultra High Frequency
UTM	Universal Transverse Mercator
VHF	Very High Frequency
VRS	Virtual Reference Station
WADGPS	Wide Area Differential Global Positioning System
WAN	Wide Area Network
WGS84	World Geodetic System 1984

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CHAPTER 1

INTRODUCTION

1.1. Background

Over the last two decades, the Global Positioning System (GPS) has become a significant tool for civilian navigation and positioning. The need for positioning and recording the coordinates in the field has become a crucial requirement for all of the daily activities in civil constructions, surveying and utility services. It is estimated that over 80% of data processed by local governments have a spatial component (Longley *et al.*, 2001). Spatial data is constructed and built based on a well defined coordinate system. Today, new and challenging applications and construction works demand real-time positional accuracy at sub meter and centimeter-level. Sub-meter positioning accuracy can be achieved by using the Deferential GPS (DGPS) technique, employing code (phase smoothed) measurements, utilizing either a dedicated single reference station or a satellite or ground based correctional service.

Centimeter-level positioning accuracy can be achieved using a GPS roving unit referenced to a single reference station (base station) and utilizing code and phase measurements. However, the limitation of this setup is that the distance dependent error will be significant when the baseline exceeds 10 km as well as the dependence on the availability of the nearby GCP. Instead of relying on a single reference station, many modern cities nowadays establish GPS multi reference stations that can be used for post mission or real-time positioning. These networks are widely known as Real Time Kinematic (RTK) reference networks. The wide spread of this type of networks is due to their benefits of not only providing real-time high quality accurate and consistent GPS positioning at an economical cost over a wide geographical area, but also they help in increasing the surveying productivity, reducing capital equipment costs and their ease of use. The need to get accurate positioning in real-time becomes of great importance either in the navigational field or in the geodetic surveys. However, designing and implementing an RTK reference network is a challenging task. The system has specific constrains as far as the distance between stations, nature of building hosting the reference stations as well as type and methods of communications.

The GIS has the capabilities for transforming the original spatial data in order to be able to answer specific queries and provide analysis capabilities that will be able to operate on the spatial aspects or the topology of the geographic data. Hence, it can be used as an advanced tool to optimize the design and implementation of the RTK reference network.

Abu Dhabi, the capital city of the United Arab Emirates (UAE), (see Figure 1.1), is becoming one of the most fast developing cities in the world. The rapid development of the city is driven and oriented by the vision of the government to make the city enjoying better life with perfect balance (Barney, 2007). The biggest challenge with quick urban development in Abu Dhabi is to maintain the balance as far as environmental, traffic, infrastructure as well as social and economical aspects are concerned. Optimizing the

Geospatial data infrastructure is one of the key factors to allow the government to make the right strategic planning decisions. Spatial data positional accuracy generated through surveying equipments and systems is one of the most critical factors affecting the quality of the Spatial Data Infrastructure (SDI). Hence, improving standards, practices and tools that assure spatial data location accuracy is a trend that goes in line with the government strategy to expedite first class results toward a sustainable development in today's challenging and competitive world. Thus, the local authority in the Emirate of Abu Dhabi, in United Arab Emirates has recently realized the need for establishing a regional RTK reference network and decided to have it operational before the end of year 2007.

This research investigates the use of GIS as an advanced tool to optimize the design and implementation process of the newly under construction Abu Dhabi RTK reference network.

Fig. 1.1 United Arab Emirates Map

1.2. Thesis Objectives

Designing and implementing RTK reference networks is a challenging task due to the complexity of the system components. The distance separating reference stations, network configuration, communication between the computing center and the user, and network algorithm are the main design parameters to be considered for the RTK reference network (El-Mowafy, 2005).

This research work focuses on investigating the capability of GIS as an advanced tool to help optimizing the design and implementation of the RTK reference network. The thesis has the following research objectives:

- Investigate the role of RTK reference networks in achieving the positioning accuracy requirements of the spatial and GIS data - A case study of Abu Dhabi will be discussed.
- Investigate the use of GIS to analyze and evaluate the design approaches of the RTK reference network system. A case study is selected as the newly under-construction network of Abu Dhabi. Emphasis will be on main parameters such as: reference stations locations and their separating distances, reference station's site selection, and the communication methods between stations, rovers and the center. Recommendations will be drawn for the most suitable design approaches.
- Investigate and examine the deployment of GIS functionality and analysis tools to analyze and evaluate the operation approaches of the RTK network such as serving the corrections via broadcasted wireless signals, and integration of the network with

GIS-based applications. Recommendations will be provided for the optimal design of broadcasting the RTK reference network correctional signal.

- Investigate, explore and evaluate some advanced GIS-based applications that can benefit from RTK reference network such as volume machine automation.

1.3. Thesis Outline

The challenges in designing and implementing the RTK reference networks and the need for effective tools such as GIS to optimize the design define the objectives of this research. This thesis is structured in such a way as to address each of its objectives in detail as follows:

Chapter one gives an introduction to the thesis background, objectives and its outline. The background explores the significance of GPS for civilian navigation and daily activities in civil constructions, surveying and utility services. The need for real-time measurements at centimeter-level positional accuracy for the new and challenging applications is highlighted. RTK reference network popularity and its benefits of providing real-time accurate positioning over a wide geographical area is highlighted as an alternative surveying solution for the traditional RTK positioning with a single reference station. The latter method has the limitation of experiencing large errors when measuring over distances that are more than 10 Km from the base station. The chapter is concluded with details of thesis objectives and its outline.

Chapter two gives an overview of the GIS system and its analysis tools. GIS definition and concepts are explored. The components of GIS (hardware, software, data and users) and their roles are explained. The analysis tools that are used in this research such as buffering, overlaying, raster interpolation, contour calculation, model builder and line of site are described.

In chapter three, the concepts, practices and positioning techniques of GPS are introduced. A historic background about the GPS and its objectives are given. Segments that form the GPS are explained. The main two types of GPS observations, code and phase, are described. The main positioning techniques, post mission and RTK are compared. Different types of RTK positioning techniques are explained and compared. These techniques include the use of Ground or Satellite Based Augmentation Systems (GBAS, SBAS), the use of a single reference station, and the use of RTK multiple reference stations (networks).

Chapter four discusses the currently used RTK positioning techniques in Abu Dhabi and the positional accuracy requirements of the spatial data. Available GBAS Beacon service and SBAS OmniSTAR services in Abu Dhabi are described and tested. RTK positioning using single and multiple reference stations are compared. The chapter concludes with highlighting the importance of the role of RTK Reference Network in the Abu Dhabi Spatial Infrastructure.

In chapter five, the use of GIS to study and evaluate the design aspects of reference station locations and their separating distances is examined. Adopted methodology for developing the distribution options and their evaluation criteria is discussed. The most suitable design approach is proposed based on GIS investigation.

In chapter six, the capability of GIS tools to select the optimal sites for the RTK reference network stations that satisfy preset criteria is investigated. Investigating, evaluating and selecting the best building for each reference site is conducted using ArcGIS tools such as selection by attribute, analysis model builder and 3D presentation. A generic model is developed using ArcGIS model builder to run a series of automated queries governed by the above mentioned criteria against a unique set of data input for each site.

In chapter seven, examining, analyzing and selecting the best approaches for telecommunication infrastructure of the RTK Reference Network using GIS tools is discussed.

Chapter eight highlights the potential benefits of integrating GIS with the RTK reference network to enhance some of the vital field construction application. Field Machine Automation is investigated as an example of such integration.

The thesis is concluded with a summary of the research findings. Recommendations for enhancing the Abu Dhabi RTK reference network are given.

CHAPTER 2

AN OVERVIEW OF GIS

Geographic Information Systems (GIS) are increasingly being integrated into the IT infrastructure of major organizations in government as well as the private sector. It is estimated that over 80% of data processed by local government have a spatial component (Longley *et al.*, 2001), and would benefit from the capabilities of GIS. This chapter provides a short introduction to basic concepts of the GIS. Definition of the system and its components are briefly discussed. Next, the GIS analytical tools that are used in this thesis are addressed.

2.1. Definition of GIS

Different GIS definitions of GIS can be found in a large number of articles, books and web resources. GIS is defined as 'a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for particular set of purposes' (Burroughs, 1986). Another definition is "Systems designed to store and manipulate data, which relate to locations on the Earth's surface" (Taylor and Blewitt, 2006). A more detailed GIS definition can be given as "a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information."(ESRI, 2007).

2.2. GIS Components

The main components of GIS are hardware, software, data and people as shown in Figure 2.1. This section describes GIS components and their role in forming the GIS system.

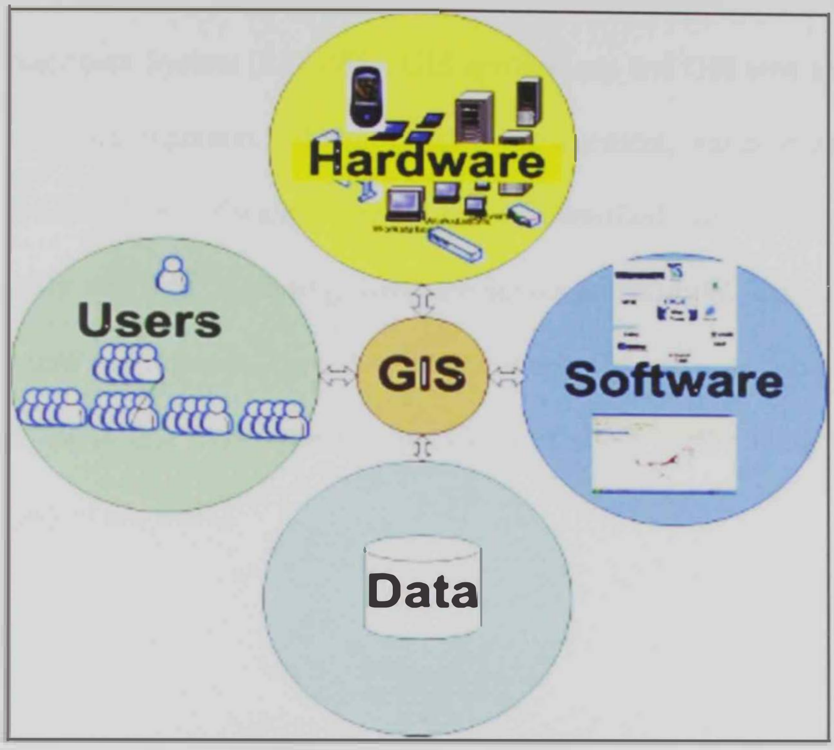

Fig. 2.1 GIS components

2.2.1. Hardware

The GIS hardware component is centered on the computer platform and has peripheral devices related to its input and output. These include, data collection and input devices such as GPS and scanners as well as devices for storing and processing data such as servers, workstations, desktops, laptops, networking devises, together with output devices such as monitors, printers and plotters.

2.2.2. Software

GIS software manages the processes of accessing, editing, analyzing and presenting the data in its spatial form as geo-referenced data (spatially adjusted) as well as non spatial linked attributes. Software includes the computer operating system, Adopted Relational Database Management System (RDBMS), GIS applications and GIS web applications. In general, GIS software organizes and controls data management, geo-possessing tools and user interface. Main GIS software packages can be classified into six groups based on their functionality and type, including: database server professional, desktop, hand held, viewer component and Internet. There are many commercial software packages available in the market. Table 2.1 shows the key packages of some of the main GIS software vendors (Longley *et al.*, 2001).

	AutoDisk	ESR	Intergraph	MapInfo	GE Small World
Database server	Vision	ArcSDE	Oracle Spatial	Spatial Ware	Small World
Professional	AutoCAD	ArcInfo	GeoMedia Pro	MapInfo Professional	Small World
Desktop	World	ArcView	GeoMedia	MapInfo Professional	Spatial Intelligence
Internet	Map Guide	ArcGIS Server/ArcIMS	WebMap	MapXtreme	IAS

Table 2.1 Key packages of some of the main GIS software vendors

All vendors except Intergraph have their own proprietary database server that works as a middleware to optimize geospatial data management and processing as well as interfacing with Oracle database which in most cases is used as the backend enterprise database. A professional package usually has an advanced functionality that satisfies the expert users, GIS data management and editing teams. A desktop package is meant to satisfy the normal GIS users with minimum GIS functionality. The Internet Server package is the package that provides GIS services through the Internet where the client needs only a typical Internet browser. Google Earth (www.googleearth.com) and Map24 (www.map24.com) free services are two examples of the most popular GIS web services. The popularity of those services is due to the ability to access a huge amount of continuously updated high resolution images with a global coverage overplayed with rich vector data without the need to buy any software or data.

Looking at the overview of the system architecture of Abu Dhabi Municipality new upgraded GIS architecture is given here as an example of a typical enterprises GIS system as shown in Figure 2.2, the system consists of three main tiers: data, application services and client tier (Abu Dhabi Municipality, 2007).

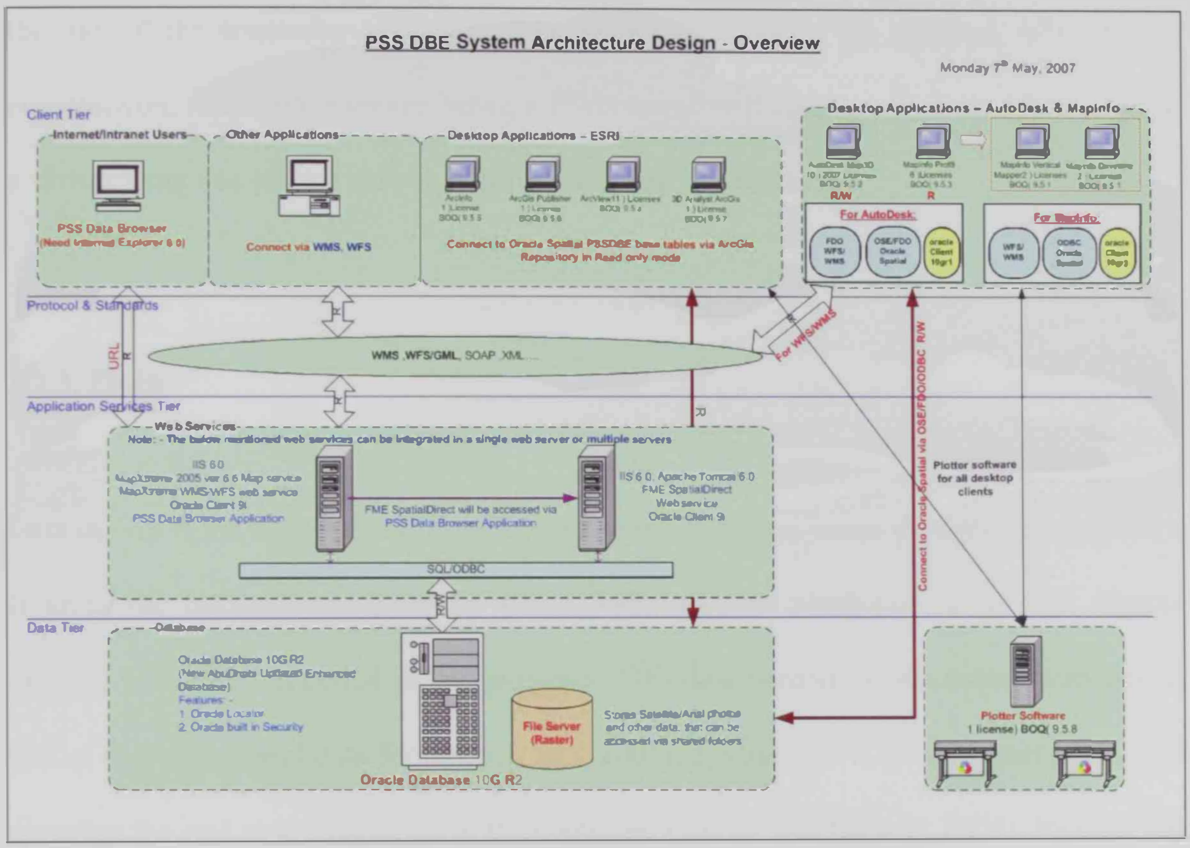

Fig. 2.2 Abu Dhabi Municipality new upgraded GIS architecture

Data tier is based on Oracle version 10g enterprise where the spatial data is managed and stored. It provides the functionality to support data editing, topology rules, geo-coding, spatial analytical functions and coordinate system transformation. The application services are based on MapXtreme web server from MapInfo on top of the Microsoft Internet Information Server and data retrieving from Oracle. It provides the enterprise data browser services through Web Map Services (WMS) and Web Feature Services (WFS). The client tier is the user interface to view, browse and query the spatial data. Client can be based on the standard Internet browsers or one of the standard GIS desktop viewers. MapInfo and Autodesk Map 3D clients can access oracle database directly, where the editing software has been selected to be Autodesk Map 3D since it would be the tool of the contractor who is contracted out to maintain the database after project construction. Autodesk package being a CAD based software is usually used for editing and digitizing due its rich drawing and engineering functionality.

2.2.3. Data

Data in GIS is the abstractions of reality organized in digital forms (Longley *et al*., 2001). It gives the information about the shape, locations and attributes of the real objects existing in reality but coded in the computer. GIS data consist of two main components: spatial and non-spatial data (Longley *et al*., 2001). Spatial data is used to manipulate and visualize the real object modeled in the computer (Taylor and Blewitt, 2006). Most of the new GIS software packages store both types of data in one database. Usually, GIS data is organized in different themes or layers. Each layer represents a specific feature class such as road edges, buildings or parcels (Taylor and Blewitt, 2006).

In GIS, data is held in raster or vector type format according to the used data model. GIS molding means abstracting and simplifying geographic reality in GIS (Longley *et al*., 2001). The abstraction and simplification increases gradually as it is presented in the conceptual, logical and physical data modeling. Raster data is about features and their attributes related to the pixels of the images. Vector data exist as features with their attributes. The features are represented as point, line or polygon representing the spatial information, where their associated attributes contain the non-spatial data.

GIS data collection is one of the most important and expensive processes while constructing or maintaining GIS. The data can be collected from heterogeneous sources, including: a field survey, paper maps, existing structured databases, satellite imagery or aerial photography.

2.2.4. People

The GIS is designed, programmed, managed, maintained and used by people. The needed GIS skills for people vary according to their role and use of GIS. Most of the GIS industries hire people who have skills in system analysis, programming, software design, and sales staff with a background of computer science, geography and others (Longley *et al.*, 2001). The people working in firms that provide GIS education and training need to have the theoretical and practical experience in the disciplines of GIS, Geodesy and Remote Sensing. Specific experience in the relevant software used in the lab, i.e. ESRI, Intergraph, ERDAS or similar software packages is needed for the trainer in order to be able to provide the required knowledge about the used GIS software.

People in charge of managing the GIS system are few in number but should be highly qualified and have practical experience in working with GIS. There job is to manage, maintain the GIS hardware, software, application and data. Relevant experience about the specific used software packages such as Oracle, ESRI, MapInfo and others is definitely required. Expert users who are making complex spatial analysis, queries and thematic mapping are most likely engineers with relevant business experience and have GIS educational background and long working experience in spatial data and its analysis.

The majority of the GIS users are the general viewers. They need to be trained on the relevant used GIS package (Longley *et al.*, 2001). Traditionally, the relationship between number of users and GIS needed skills is inversely proportional. Figure 2.3 shows this relationship.

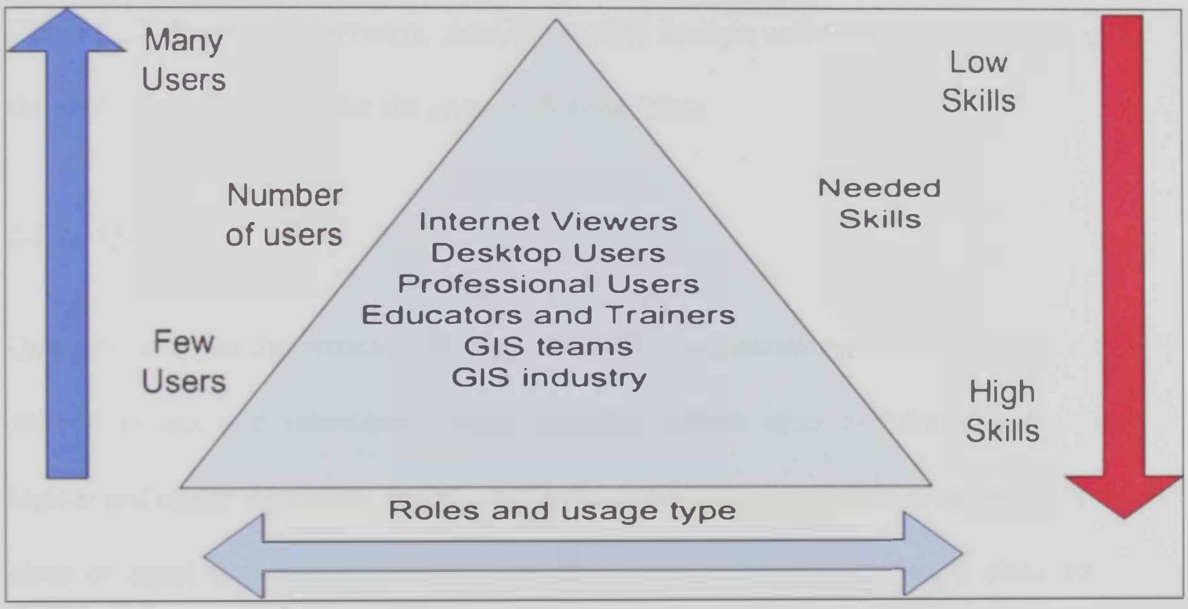

Fig. 2.3 GIS Users

2.3. GIS Analysis Tools

Spatial analysis is defined as the process by which useful information is derived from raw data. It adds a value to the GIS data after applying a set of transformation, manipulation and methods to the data (Longley *et al.*, 2001). New information can be derived when spatial operations are applied to the GIS data. This section discusses the analysis tools that are used in this research for optimal designing of RTK reference networks. The tools include queries, buffering, polygon overlay, and spatial interpolation. ArcGIS 9.2 software is used to analyze the data for the case study of optimizing the design of Abu Dhabi RTK Reference Network. ArcGIS Spatial Analyst extension is used particularly in the analytical operations for the raster cell-based data.

2.3.1. Queries

Querying is about the retrieval of information from a database using a language with well defined syntax and semantics. Query language allows users to retrieve data based on logical arithmetic operators. In GIS, attribute queries extract feature from an input feature class or input feature layer, and stores them in a new output feature class based on Structured Query Language (SQL) expression. SQL is the language of querying tables and relational databases (Longley *et al.*, 1999).

Model Builder is an application in ArcGIS in which models are created, edited and managed. Workflow can be automated by stringing processes together in the model diagram that will execute the geo-processing and query operations in sequence when the model is executed.

2.3.2. Buffering

Buffer tool creates buffer polygons to a specified distance around the input feature. An optional dissolve can be performed to remove overlapping buffer. Figure 2.4 illustrates an example of the buffer and overlay (intersect) tools. In this example, a river is buffered to 1000 meters creating a polygon layer to the river buffer. "Intersect" tool of the overlay analysis tool is used to combine the low land and the river buffer creating a new polygon defining the low land that intersects with the river buffer.

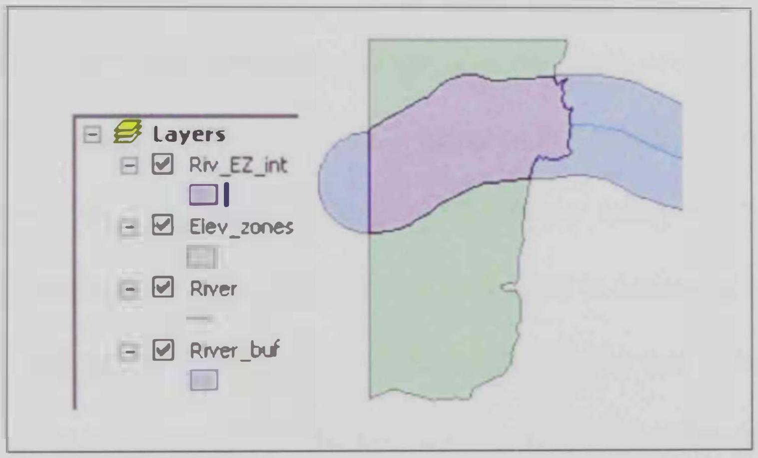

Fig. 2.4 An example of the buffer and overlay (intersect) tools.

(Source: UAEU MSc. Program)

2.3.3. Polygon Overlay

In the overlay operation, two or more thematic layers are integrated through analytical operations in order to generate a new layer. When using the polygon overlaying operations, a new polygon is created based on the intersection of two polygon layers. The value assigned to each point in the created polygon is a function of the independent values associate with that location on two or more existing overlays (Longley *et al.*, 1999).

2.3.4. Raster Interpolation

Interpolation is defined as predicting values for cells in a raster format from a limited number of sample data points. For example, instead of visiting each site of the study area and measuring the height, selected measured samples and predicted height values can be assigned to all other locations. Interpolating a surface from points can be done by using different techniques. In this research, raster interpolation using the Inverse Distance Weighted (IDW) technique is used. In IDW, the cell value is estimated by averaging the values of sample data points in the vicinity of each cell (McCoy and Johnson, 2002). The interpolation to raster is used to create the elevation model for the Emirate of Abu Dhabi from the set of points that have height values. Additional information from the interpolated raster can be derived such as contours, angle of slope, aspect, hillshade, viewshed and cut & fill. In the research, the contours and the viewshed are derived from the interpolated raster data.

Contours are poly-lines that connect point of equal values such as elevations. Area of the same height can be found using contours. Elevation values for specific locations and the overall graduation of the land also can be examined using the contours.

Cells in an input raster that can be seen from one or more observation points or lines can be identified using Viewshed. This helps to know how visible objects might be (McCoy and Johnson, 2002). In this research, the viewshed is used to find the well-exposed places for the communication towers of the repeaters of the RTK reference stations. The line of sight tool in the raster interpolation analysis tool uses an input poly-line feature class along with a raster surface to determine visibility between two points, which can be defined as the 'from' and 'to' points. It produces output line feature class that contains line and target visibility information.

CHAPTER 3

AN OVERVIEW OF THE GPS TECHNIQUES

3.1. Fundamentals of GPS

Currently, there are two operating Global Navigation Satellite Systems (GNSS), the American Navigation Signal Timing and Ranging (NAVSTAR) system and the Russian GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (GLONASS) system. NAVSTAR is widely known as the Global Positioning System (Red Sword Corporation, 2007). Another GNSS planned for the future is Europe's "Galileo". GPS is a satellite positioning system developed by the US Department of Defense (DoD) for real time navigation four decades ago. The key objectives of the GPS is to provide worldwide, all weather, continuous radio signals to users to determine position, velocity and time throughout the world (Taylor and Blewitt, 2006).

There are three segments forming the GPS (See Figure 3.1):

- Space Segment, which includes 27, consolidated satellites orbiting the earth (24 active and 4 spares). There are always more than four visible satellites in the sky anywhere on the planet. The satellites send continuous radio signals to users.
- Control Segment: The control segment consists of five monitoring stations that monitor the satellites and one processing center in Colorado Springs which sends correctional data through three stations to keep the satellite in their right positions.

- User Segment: The user segment includes measurement hardware and software (GPS receivers) for data collection and processing. The receiver needs simultaneously to look onto at least four satellites to be able to determine its 3D position on the ground any time and anywhere on Earth or in the space around the Earth. GPS receivers can be classified into two main categories: hand held receivers and geodetic grade receivers. The hand held receivers use only code measurement (or phase-smoothed code measurements), and usually work in a single point positioning mode. They are usually used in coarse navigation and produce low positioning accuracy (1m-10m).The geodetic-grade receivers use both code and phase measurements. They work in relative mode and are used in surveying with high precision (cm accuracy).

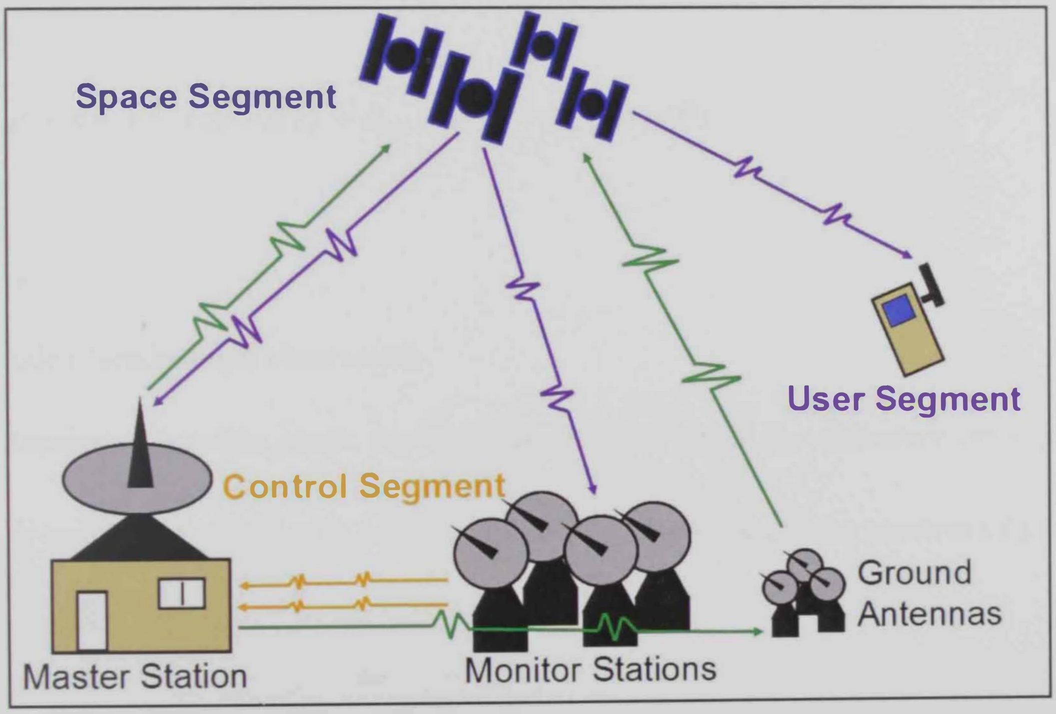

Fig. 3.1 GPS Segments.

(www.geog.ubc.ca/courses/geog376/notes/GPS/gps_06.ppt)

Observations by GPS are mainly offered through two main types, code and phase observations. Using code observation techniques, positioning accuracy at the sub-meter to meter level can be achieved, whereas phase measurements can give accuracy in the millimeter or centimeter range. To determine the unknown coordinates of a point, code or phase measurements from at least four satellites are collected and processed using a single receiver. C/A Code - the standard (Course/Acquisition) GPS code is used in most GIS operations. Orbital, atmospheric, satellite and receiver clock errors, and receiver noise governs the accuracy of GPS single point positioning. This can be shown from the code observation equation, which can be formulated as follows (Hofmann-Wellenhof *et al.*, 2001):

$$P = \rho + d\rho + C\,(dt - dT) + d_{ion} + d_{trop} + \varepsilon_{mult} + \varepsilon(P) \qquad (3.1)$$

Where:

P - Code (Pseudorange) observation

ρ - Receiver-to-satellite range, representing in vector space the difference between the known position of the satellite ($\vec{R}$) and the unknown position of the receiver ($\vec{r}$), in the form $= \| \vec{R} - \vec{r} \|$

$d\rho$ – Orbital errors

C - Speed of light

dt, dT - Receiver and satellite clock errors

d_{ion}, d_{trop} - Ionospheric and tropospheric errors

ε_{mult} - Multipath noise

$\varepsilon(P)$ - Receiver noise and remaining errors

Two radio carrier wave signals are transmitted by GPS, known as L1 and L2. Processing usually uses the L1 frequency of 1575.42 MHz in the Ultra High frequency (UHF) band.

The phase observation equation can be given as:

$$\Phi = \rho + \lambda N + d\rho + cdT + cdt - d_{iono} + d_{tropo} + \varepsilon(\varphi) \quad (3.2)$$

Where:

Φ: - phase range (- λ φ)

φ: Measured phase

ρ: - True range

λ: - wave length

N: - carrier phase ambiguity

C: - Speed of light

dT: - Receiver clock error

dt: - satellite clock error

d_{iono}: - range error due to the ionospheric error

d_{tropo}: - range error due to the Tropospheric error

$\varepsilon(\varphi)$: - phase Noise

From Eq. (1) and (2) it can be concluded that positional accuracy is affected by several sources of errors, including: satellite orbital and clock errors, atmospheric errors, receiver clock error, multipath and receiver noise error. The cheapest handheld GPS receiver is affected by all sources of errors and provides an accuracy of 1 – 10 meters.

To mitigate measurement errors, the user should either work in a relative mode or apply a form of measurement corrections. Methods of sending measured corrections to the users such as Differential GPS (DGPS) can increase the accuracy to the sub-meter and centimeter level. Differential correction can also be applied on-line in the field, which is usually refereed as Real Time Kinematic (RTK) positioning. It can be also performed after data collection using a post processing technique. The principle of differential GPS is based on using two receivers. One receiver is placed at accurately and previously surveyed point of known coordinates, usually called the base station. The other GPS receiver is commonly called "the rover" and is used to determine the required unknown position. Differential GPS (DGPS) is used whenever sub-meter and centimeter accuracy is required. Sub-meter accuracy can be obtained by using code measurements whereas cm positioning requires using carrier phase measurements (Elliote, 1996).

Handheld GPS receivers in a single positioning mode use code measurement mostly smoothed by phase measurement. They are usually used in coarse navigation achieving 1-10 meter accuracy. The price of such devices is in the range of few hundreds of Dirhams. The geodetic grade receivers use code and phase measurements typically in a relative mode. They are relatively expensive due to the fact that they use better and complex hardware to acquire and store phase measurement. They usually give higher accuracy (sub-meter to centimeter level), qualifying the device to be used in precise engineering, mapping and surveying. For more details, see (Terry, 2001).

3.2. Post- mission and Real-Time Positioning

GPS measurement accuracy without correction would be in the range of 1-10 meters. In most of the applications other than coarse navigation, this accuracy is not sufficient. To achieve meter or centimeter accuracy, DGPS corrections are required. The corrections can be used in real time or post processing. In real time processing, usually known as RTK positioning, GPS receivers equipped with correctional signal receivers applies the correction instantaneously as soon as the signal is received.

Post processed corrections is made after collecting the data from the field and then later apply the corrections using a computer software to compute the unknown position using corrections received from the reference station. RTK positioning usually is less accurate than post processing because the observation time while collecting the satellite data used in computation of point coordinates is limited, resulting in a reduced redundancy of data (Satirapod and Hominiam, 2006).

Real-time precise positioning is even possible when the GPS receiver is in motion and makes the use of GPS-RTK feasible for many time-critical applications such as engineering surveying, GPS-guided earthworks/excavations, machine control and other high precision navigation applications (Rizos, 2003). Types of RTK techniques are reviewed in these following sections. Those techniques include single point positioning, Wide Area DGPS Augmentation services both Ground based or Satellite based (GBAS and SBAS, respectively), using a single reference station, or multiple reference stations.

3.3. RTK from Single Point Positioning

The single point positioning technique mainly uses code measurements, or phase-smoothed code measurements (Terry, 2001). Handheld receivers are the common types of receivers that use this technique and are usually used in coarse navigation. They are affected by all sources of errors such as faulty clocks, ephemeris variation, receiver fuzziness, multipart. Vehicles navigation, for example, as a stand alone user using standard positioning service cannot achieve real time accuracy of about 1-10 m (Hofmann-Wellenhof *et al.*, 2001).

3.4. Wide Area DGPS (WADGPS) Techniques

WADGPS uses a network of reference stations and covers a larger area that cannot be covered by a single reference station. The WADGPS networks include one master station, which collects the range correction from the monitor stations; process this data to form the corrections, which are next transmitted to the user community (Mueller, 1994, and Mueller *et al.*, 1994). WADGPS can be applied in two forms, Satellite Based Augmentation Service (SBAS) or Ground Based Augmentation Service (GBAS). SBAS and GBAS have an objective to provide enhanced accuracy, integrity, availability and continuity of service capabilities for any underlying navigation satellite system (GPS, GLONASS and Galileo) (NASA, 2007). Satellite Based Augmentation Service (SBAS) provides national or global Real Time Kinematic (RTK) correctional service to achieve sub-meter positioning accuracy. Ground Based Augmentation Service (GBAS) provides correctional service to allow users to measure with sub-meter positional accuracy in national and regional coverage (Euler *et al.*, 2004).

Both SBAS and GBAS utilize L1 signals modulated with C/A code. They eliminate satellite related errors and reduce atmospheric errors to achieve 1-5 meter accuracy in RTK, which is good enough for medium accuracy surveying works and navigation. SBAS and GBAS differ in some aspects such as their coverage area and running cost as illustrated in Table 3.1.

Camped Item	SBAS	GBAS
Running cost (Subscription)	Yes	No
Example	Omni Star , WAAS Services	Beacons Service
Geographical Coverage	Global	National
Type of Receiver	SBAS Enabled GPS Receiver	GPS Receiver connected to RF Receiver

Table 3.1 Comparison between SBAS and GBAS

3.4.1. Satellite Based Augmentation Service (SBAS)

SBAS system is used to improve the performances of GPS with the objective to make it more accurate if no dedicated reference station exists within a large distance. This is achieved by providing signals of a set of corrections from Geostationary Satellites that improve the position and time calculation performed by the user receiver. Currently, there are several SBAS that can provide this type of corrections including: EGNOS in Europe, WAAS in U.S.A., MSAS in Japan, and Biduah in China.

The popular OmniSTAR service owned by Fugro surveying company is an example of a commercial worldwide SBAS service. The service provides an international correctional signal for the subscribers to improve their GPS positional accuracy. The service system consists of 70 reference stations distributed around the globe, and 3 network control centers utilizing Geostationary Satellites to broadcast the corrections over large areas. Many OmniSTAR enabled GPS receivers can receive the correction data in a standard format Radio Technical Commission for Maritime (RTCM-104). The result is a real-time correction for the user's GPS measurements. The "Commercial" GPS receivers can achieve horizontal accuracy of less than (0.5 to 1.5 meter). Vertical accuracy will be 2 to 2.5 times greater than the horizontal accuracy (Fugru World Wide, 2005). The service subscription cost is approximately $ 800 per year. Figure 3.1 illustrates the components of the OmniSTAR system as an example of SBAS; it shows sequence of correction process as follows:

1- GPS satellites broadcast the positioning signal.
2- OmniSTAR reference stations around the globe continuously receive and observe the GPS signals.
3- Observed data from the stations is sent from all reference stations through a global Wide Area Network (WAN) to the central calculation center.
4- The center uploads the corrections to a geostationary satellites distributed around the globe.
5- Geostationary satellites receive the corrections.
6- The geostationary satellites broadcast the corrections encoded through a carrier signals.
7- Subscribed user receive the correction signals with OmniSTAR enabled GPS receivers to decode the correction, which will be used to improve the accuracy. The receiver has to be compatible with a module to receive the corrections. Most commercial receivers contain this module.

The above mentioned process is illustrated in Figure 3.2.

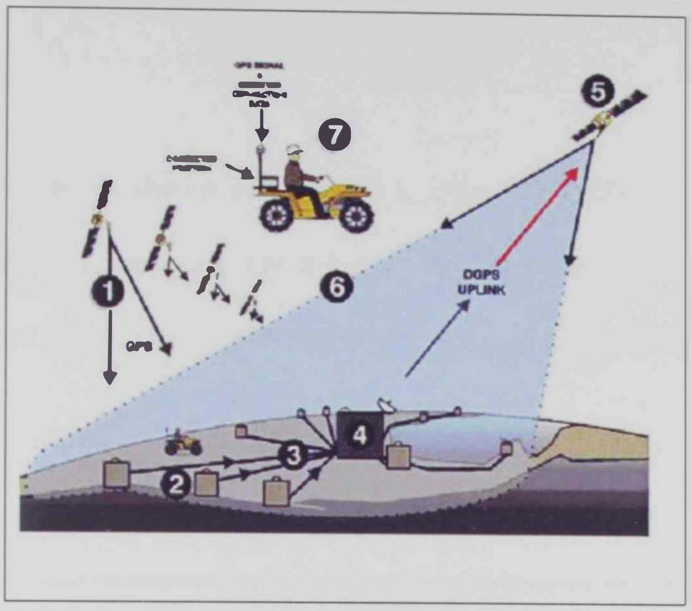

Fig. 3.2 SBAS Service Exemple : Omni STAR SBAS service

3.4.2. Ground Based Augmentation Service (GBAS)

GBAS is a system of satellites and ground stations that supports augmentation through the use of terrestrial radio messages and provides GPS signal corrections, giving the users better positioning accuracy. The GPS information collected by the ground reference stations that are located in known locations are forward to a master station via a terrestrial communications network. The master stations collect information from the reference stations and, through a series of algorithms, correct the information received to account for standard GPS errors. The corrected message, now known as a differential message, is then broadcast through the ground stations. These messages contain information that allows GPS receivers to remove errors in the GPS signal, allowing for a significant increase in location accuracy and reliability. The GBAS correction data typically provides 1 to 5-meter accuracy in real time (Forest Service Technology and Development Program, 2004).

Marine beacon stations, as shown in Figure 3.3, are an example of GBAS, where they broadcast their correction message via a Very High Frequency (VHF) radio data link from a ground-based transmitter to user receivers (Australian Maritime Safety Authority, 2007)

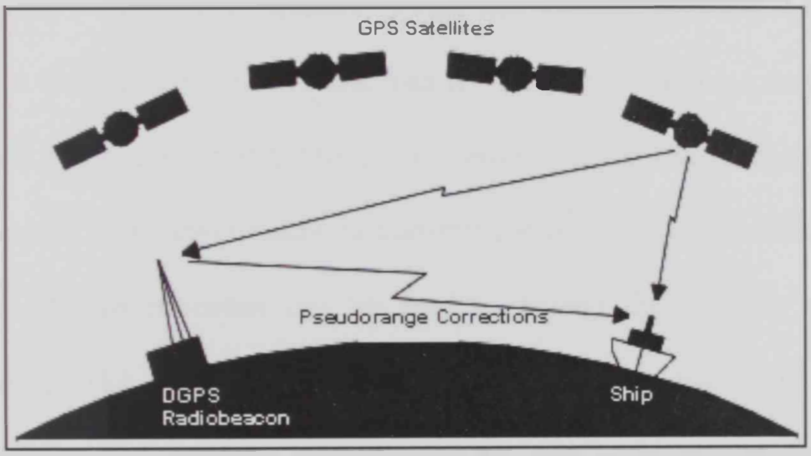

Fig. 3.3 Marine beacon stations

Beacon reference station service broadcasts DGPS corrections through marine beacon stations most likely along the sea coast line (Euler *et al.*, 2002).The purchase of a DGPS beacon receiver is the only cost of this kind of service. There is no running cost to use the service. This receiver is then coupled with the GPS receiver via a three-wire connection or blue tooth connection which relays the corrections in a standard serial data format called Radio Technical Commission for Maritime (RTCM Specified commission -104). With a beacon receiver, GPS measurement errors can be reduce to 1 to 5 meters. When averaged over a period of time, accuracy can improve (Johnny Apleseed GPS Company, 2000).

3.5. RTK Positioning Using Single Reference Station

RTK positioning using single reference station is a differential positioning technique that uses known coordinates of a reference station occupied by one receiver to determine coordinates of unknown points visited by a rover receiver. The reference station coordinates and measurements are transmitted to the rover via data link to process the data in real time. Very High Frequency (VHF) and Ultra High Frequency (UHF) are usually used for distance less than 15 km. The RTK uses two radios, a transmitter at the reference station and a receiver at the rover. A license from the local authorities is usually required to transmit high power radios to transmit corrections over distances longer than 20 Kilometers. Radios repeaters can be used to extend distance for radios. Single frequency receivers (L1 only) can be used for RTK as well as dual frequency ones (L1 and L2). Dual frequency receivers are preferred for long base-to-rover distances due to the fact that faster acquisition of correct ambiguity can be obtained (El-Mowafy, 2002).

3.6. RTK Positioning Using Multi Reference Stations (RTK Reference Networks)

One main disadvantage of the single base RTK approach is that the maximum distance between reference and rover receiver must not exceed 15 kilometers in order to be able to rapidly and reliably resolve the carrier phase ambiguities. Thus, RTK positioning is extended from a single base to a multi-base technique (Euler *et al.*, 2001) and (Raquet and Lachapelle, 2001). RTK Reference Network approaches ideally provide positioning with errors independent of the rover position within the network as well as it covers the desired area with fewer reference stations compared with the single reference station approach (Raquet, 1998). The studies of RTK Reference Network aim to develop a centimeter accuracy RTK system operating over distances up to tens of kilometers. The estimated distance between reference stations can be in the order of 50-100km. In addition, the rover needs to operate within the region defined by the reference station network (Santana and Tottwrstrom, 2002). RTK Reference Network process data from multiple reference receivers that are connected to master control stations, which will provide correction information to users, in real-time or in post-mission. The RTK Reference Network has a data management system and data communication systems. There are two types of data communication system: (a) communications between the master control center and reference stations, and (b) communication between the master control center and users (Rizos and Han, 2002).

An RTK Reference Network system mainly consists of three basic segments. These are: data collection, data manipulation and broadcast elements (Cruddace *et al.*, 2002), see Figure 3.4. These elements can be summarized as follows:

1- Data Collection Segment: Reference stations are continuously operating and permanently transmitting the GNSS observations to the Network Control Center (NCC) via direct data links. This link could be via leased lines, WAN or the Internet.

2- Data Manipulation Segment & error calculation at the NCC:

The center is equipped with servers, loaded with the computational software that manipulate the errors and disseminate the corrections to the roving users (El-Mowafy *et al.*, 2003).

3- Data broadcasting segment: Several methods can be used to transfer network information to the user. Mediums could be GSM, General Pocket Radio System (GPRS) or VHF. Some of the most widely used computational methods used for estimating the corrections include:

- Area Correction Parameterization method (FKP, in German).
- Virtual Reference Station (VRS).
- Master Auxiliary Corrections (MAX).

Details of these methods can be found in (Raquet, 1996) and (Wübbena *et al.*, 1996). However, their description is outside the scope of this thesis.

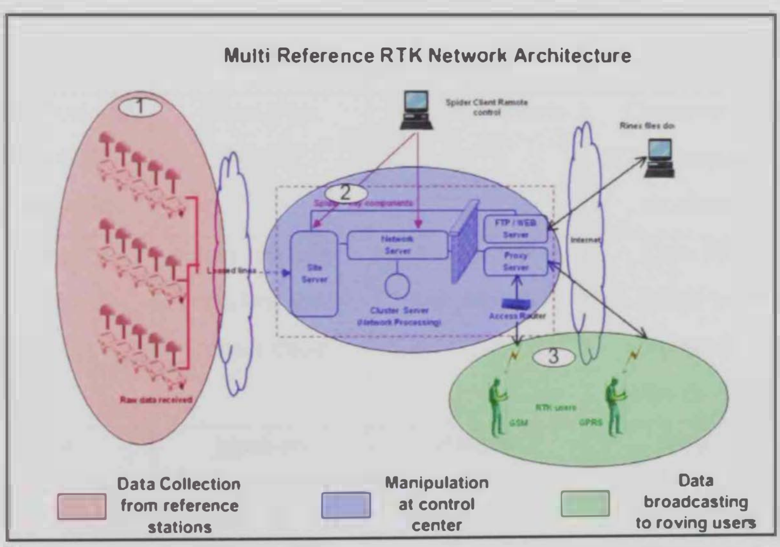

Fig. 3.4 RTK Reference Network architecture (Source: Lieca Geosystems)

3.7. Summary of GPS Positioning Techniques

RTK GPS positioning techniques and equipments can be classified according to their positioning accuracy into three categories: meter-level, sub-meter and centimeter levels. The measured positional accuracy level depends on the purpose of the surveying works. Hence, the proper type of surveying equipments and methods should be adopted accordingly. Table 3.2 summarizes the comparison between the three categories as far as geographical coverage, accuracy, and cost. An example for each type is also given.

	Meter-level	Sub meter		Centimeter	
Receiver and service type	Single Positioning Observation	S.B.A.S	G.B.A.S	Single Reference Station	Multiple Reference Station
Geographical Coverage	Global	Global	National	Within 10 KM	Regional
Horizontal Accuracy	1-10 m	Less than 1 meter	Less than 1 meter	< 5 cm	< 5 cm
Examples	Hand-held and PDA GPS receivers	Omni Star, WAAS	Beacon Services	Commercial RTK frequency receivers	Dubai Multi Reference Stations
RTK	Direct	Needs receiver, modem and subscription	Needs receiver and modem	Uses RF, Limited to 10 Km, needs 2 radio devices	Needs receiver, modem and subscription
Capital cost	Low	Medium	Medium	High	High

Table 3.2 RTK GPS positioning techniques and equipment classification

CHAPTER 4

RTK POSITIONING AND ACCURACY REQUIREMENTS IN ABU DHABI

There are a few techniques of RTK DGPS that are currently used in Abu Dhabi. SBAS based OmniSTAR and GBAS based beacon services are widely used for marine surveying providing corrections data positioning with sub-meter accuracy. RTK single reference station is commonly used for surveying works that require centimeter level accuracy. Multi reference station service that allows positioning with centimeter level accuracy in a wide geographical area with a single GPS receiver (rover) is only available at the areas near the border of Dubai Emirate. Dubai Municipality has established its RTK Reference Network consisting of five stations in 2001 (Almrzooqi *et al.*, 2005). Abu Dhabi Municipality has commenced a project to establish the RTK Reference Network to cover the Emirate of Abu Dhabi. The project started in March 2007 and expected to be completed in 8 months. This chapter explores the RTK positioning techniques that are currently used in Abu Dhabi and describes the accuracy requirements for surveying works.

4.1. Real-time Positioning from Augmentation Systems in Abu Dhabi

There are two operating beacon stations located in the territory of the UAE. One in Abu Dhabi and the second is located in Ra's Al Khaimah. The detailed information about these stations is given in Table 4.1.

	Abu Dhabi Station	Ra's Al Khaimah Station
Position:	24°6'N, 52°56'E	25°59'N, 56°4'E
Frequency (kHz)	314	292
Nominal Range (km)	460	460

Table 4.1 Beacon stations in UAE. (Source: Trimble, 2007)

4.1.1. Positional Accuracy of the SBAS and GBAS Systems

A field test to examine the positioning accuracy of the beacon correctional services as a GBAS system, and positioning accuracy from measurement using OmniSTAR as an SBAS system was carried out in Abu Dhabi in March 2007. Trimble Pro XRS receiver was used in the test. The device has an antenna that can receive both beacon correction signal and OmniSTAR. A known Geodetic Control Point (GCP) of known coordinates was selected inside Abu Dhabi Island to be the reference for comparison, where its known position was compared with the output position from the receiver after observing for a few minutes. The GCP is located 150 km away from the beacon station as illustrated in Figure 4.1.

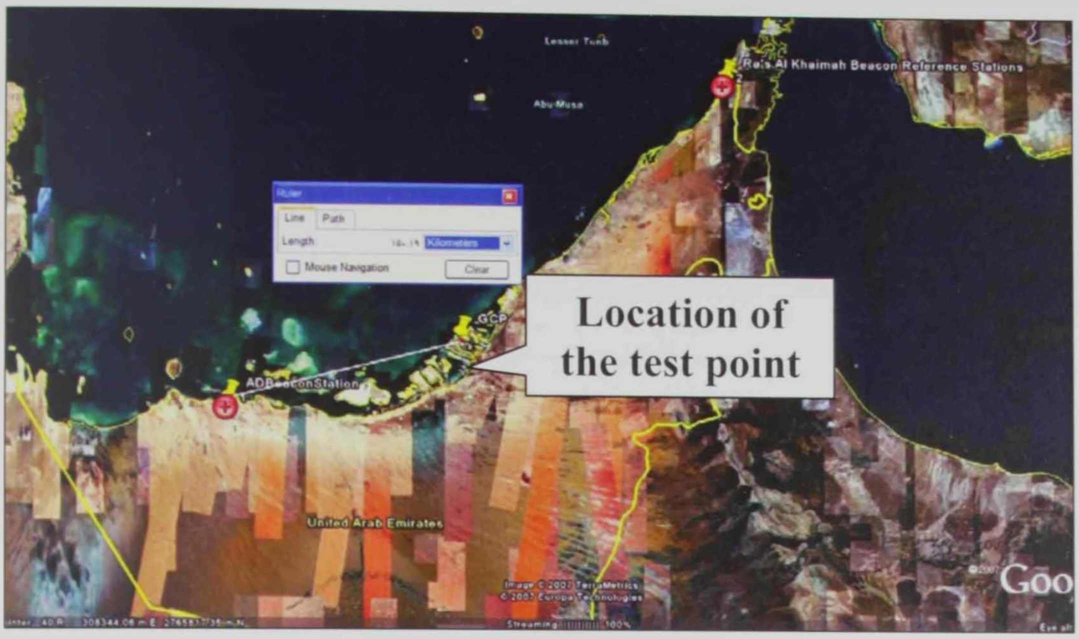

Fig. 4.1 Beacon reference stations and testing point

(Image source: Google Earth)

The positions and estimated errors from the SBAS (OmniSTAR) and GBAS (Beacon) method are summarized in the Table 4.2. The projected coordinate system utilized the Nahrawan 1967 datum, using Universal Transverse Mercator (UTM) Zone 40N projection. The beacon received frequency is 314 KHz. The signal to Noise Ration SNR recorded from the testing was (18 db). Results show that the GBAS system gave better positioning accuracy. However, both systems gave accuracy at the sub-meter level.

Item	GCP III order Coordinates	Trimble Pro OmniSTAR	Trimble Pro XRS Beacon	Error in using OmniSTAR (meter)	Error in using Beacon (Meter)
E (UTM)	234799.04	234798.12	234798.41	.92	.63
N (UTM)	2710900.56	2710900.79	2710900.03	-.23	.53
Error (meter)				.94	.82

Table 4.2 Accuracy Measurement of OmniSTAR and Beacon Services.

4.2. RTK Positioning

RTK positioning can be carried out using either a single reference station or using multiple reference stations.

4.2.1. RTK Positioning Using a Single Reference Station

Many surveyors and civil engineers in Abu Dhabi use the single reference station DGPS on daily bases. They rely on the existing GCPs obtained from the Municipality. In most of the cases, RTK mode is used to determine positions in the field. Some of them use post processing. The recorded accuracy in most projects range from 1 cm to 5 cm.

4.2.2. RTK Positioning Using Multiple Reference Stations

Currently, Dubai Virtual Reference System (DVRS) is the only multiple RTK reference station system working in the UAE. The second coming system is planned to be operational in Abu Dhabi before the end of 2007. It is planned to integrate both systems to give the users seamless service with more coverage area. Fortunately, both systems are manufactured by the same supplier "Lieca Geosystems" such that it is expected that the integration process of the two systems would be less challenging.

The multiple reference station projects was launched by the Department of Municipal Affairs in Abu Dhabi (DMA) to serve the entire Emirate of Abu Dhabi, with an objective of providing real-time measurement corrections with accuracy better than 5 cm. The network is planned to consist of 20 stations distributed with a proposed average distance between stations of 70 km. The control center would be in Abu Dhabi Municipality. It is expected to use different types of communication mediums and methods for data linking between the reference stations and the control center, as well as between the center and the users. Figure 4.2 illustrates the proposed RTK Reference Network layout in Abu Dhabi by the supplier. Option 1 is to build the RTK network with partial converge of the emirate of Abu Dhabi whereas the second option is to build the system with full coverage of the emirate area.

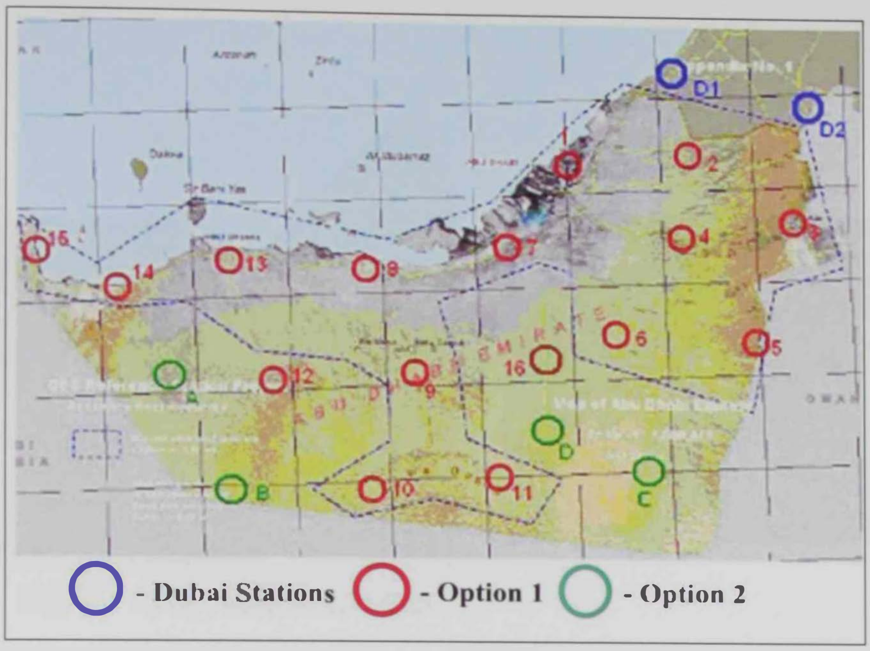

Fig. 4.2 Proposed distribution of the multi reference station in Abu Dhabi

4.3. Positional Accuracy Requirements in Abu Dhabi

In practice, there are a variety of applications and fieldworks that require GPS measurements with location accuracy at the centimeter level. Surveyors have to comply with standards and accuracy requirements of their local authorities. These requirements may vary according to their local conditions. For instance, Ordnance Survey in UK requires, for internal data collection activities, a horizontal position accuracy of 5cm to 12cm (standard deviation) for its GPS coordinated points, at 1:1250 scale (Cruddace, *et al.*, 2002).

Figure 4.3 illustrates an overview of the positional accuracy requirements for mapping in Abu Dhabi according to the As-built regulation manual of Abu Dhabi Municipality (Abu Dhabi Municipality, 2007).

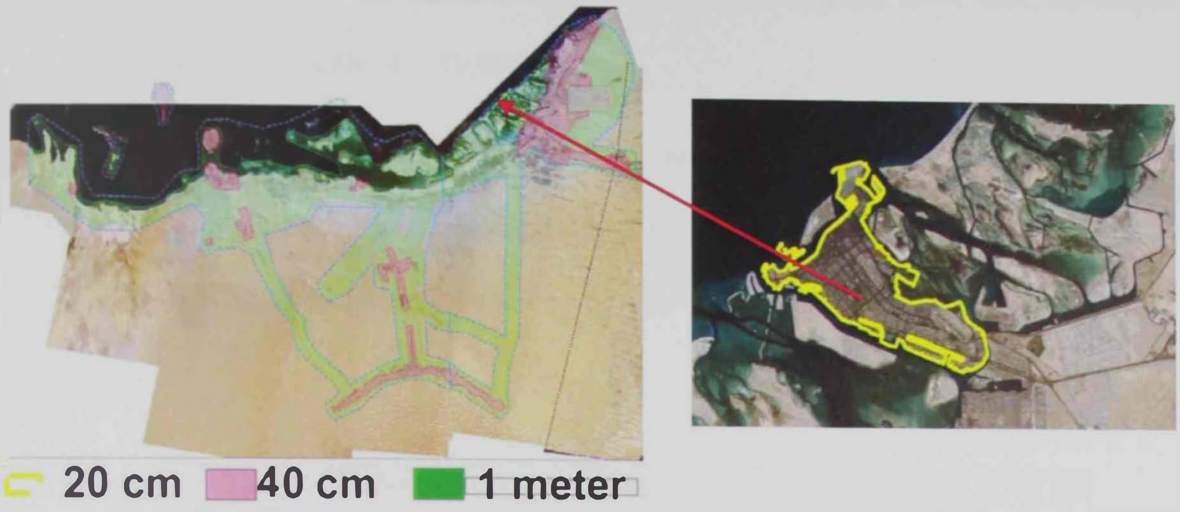

Fig. 4.3 Mapping Accuracy requirement in Abu Dhabi

(Source: Abu Dhabi Municipality)

According to the As Built regulation manual of Abu Dhabi Municipality (ADM As Built, 2007), accuracy ranges in the Emirate of Abu Dhabi is classified into 4 categories, which are illustrated in Figure 4.4. These categories can be summarised as:

1. City (Abu Dhabi City) defined by developed areas and areas of special importance. The required positional accuracy should be better than (1-20 cm) in order to be used for mapping purposes with a scale of 1:1000.

2. Township, villages, settlements, industrial areas and defined development areas. The required positional accuracy should be better than 40 cm in order to be used for mapping purposes with a scale of 1:2500.

3. Farm land, scattered populated area, area with scattered buildings. The required positional accuracy should be better than 1.5 meter in order to be used for mapping purposes with a scale of 1:10,000.

4. Desert, sand dunes, mountain area and other not populated area. The required positional accuracy should be better than 15 meters in order to be used for mapping purposes with a scale smaller than 1:10,000.

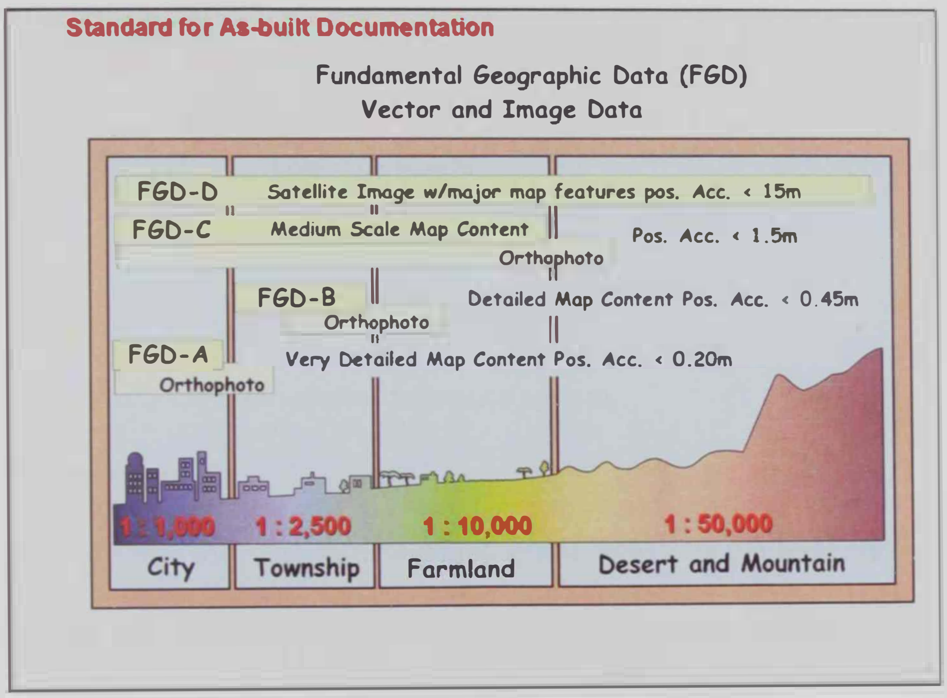

Fig. 4.4 Area-categories classification (Source: Abu Dhabi Municipality)

4.4. Network Reference Datum

One of the biggest challenging tasks when constructing the RTK Reference Network is selecting the suitable reference coordinate system. Points of concern include:

- Compliance with the existing coordinate system.
- Calculating the exact Orthometric heights of the reference stations.
- Acquiring the precise Geoid model in order to be able to serve the users with true Orthometric heights on the fly. This is needed to convert ellipsoidal heights determined from the GPS to the orthometric heights that are referenced to the Mean Sea Level. This relation can be formulated as (Hofmann-Wellenhof *et al.*, 2001) and (Rosenthal, 2005):

$$\mathbf{H = h - N} \tag{4.1}$$

Where H orthometric height

h ellipsoidal height

N geoidal height (undulation)

- Compliance with the international reference system.
- Need for the future use.
- Compatibility with the existing data which is available with the local authorities.
- Determining transformation parameters between different coordinate systems.

For Abu Dhabi, there are three proposed options for selecting the coordinate reference system of the RTK Reference Network: the old datum, the currently used datum and the new datum. The old reference system is based on Nahrawan datum using Clark 1880 ellipsoid, following the old national reference, which was created by the Military Surveying Department (MSD). MSD has the mandate to create and manage the horizontal and vertical reference system at the UAE national level. Abu Dhabi old base-maps and the geodetic control network that was created in 2001, was based on some of MSD first order control points in Nahrawan datum. Many local planning and utility authorities have built their spatial data in reference to the old base map. Currently, the new geodetic control network and the new base-map are based on the new MSD network which is based on World Geodetic System 1984 (WGS84) and International Terrestrial Reference Frame (ITRF2000) reference frame. The RTK Reference Network will be based on WGS84 and ITRF2005 reference frame. The three coordinate reference options are compared with respect to the impact on compliant with international reference coordinate frames, consistency with the old and the existing geodetic network, compliant with the old and the existing spatial data and the user needs.

Looking at the compliance with the new international reference frame, ITRF 2005, using Nahrawan datum as suggested in option 1, will have the worst compliance with new international reference. This is due to that points were determined in the old system using traditional methods, which has less accuracy compared with GPS. Proper transformation is also required. In the second option, using WGS84-ITRF2000 is relatively compliant with the international reference frame. Few centimeters can be observed as a difference between IRTF2000 with the ITRF2005. The new reference system WGS84-ITRF2005 will have the maximum compatibility with the international reference frame.

The existing geodetic ground network and spatial data is based on WGS84-ITRF2000. option1, Nahrawan, will have the worst compatibility with ITRF2000 due to its poor accuracy, and coordinate transformation should be applied to re-project the data. Options 2, ITRF2000, will have the maximum compliance with the current reference. Option three, ITRF2005, will have a difference of few centimeters with ITRF2000 where it can be negligible for many applications. Looking at the compliance with the old geodetic ground network and with the old spatial data, option1, Nahrawn, will have the maximum compliance with the old geodetic network and with the old data since it has the same reference. Option2, ITRF2000, will not be compliant with the old data and with the old geodetic network due to the difference and due to the need to apply coordinate transformation. Option3, ITRF2005, will have the worst compliance with the old data and geodetic network.

The summary of the above discussed comparison is given in Table 4.3. A weighing factor for the degree of compliance is given ranging from 1 to 5, where 1 represents the worst compliance and 5 represents the best compliance, it can be concluded that building up the Abu Dhabi RTK Reference Network based on WGS84-ITRF2000 or WGS84-ITRF2005 are the best options.

	Compliance with the International Reference	Consistency with the existing geodetic network	Compliance with the existing spatial data	Need for future	Compliance with the old spatial data	Compliance with the old GCP Network	Total weight
Old datum (Clark 1880 - Nahrawan)	1	1	2	1	1	4	**10**
Existing WGS84 (ITRF 2000)	3	5	5	3	5	3	**24**
New WGS84 (ITRF 2005)	5	4	4	5	5	2	**25**

Weights: 1: Very Low 5: Very High

Table 4.3 Comparison between different options for choosing a Reference Datum

4.5. Importance of RTK Network in Abu Dhabi for Supporting Spatial Data Infrastructure

Spatial Data Infrastructure (SDI) is defined as "the technology, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain, and preserve spatial data" (US Federal Government, 2002). SDI is usually consisting of centrally managed fundamental data based on the common base-maps, geodetic network and commonly used data. RTK Reference Network services, being utilized by all agencies, can be considered as one of the main components of the infrastructure of spatial data. Figure 4.5 shows a typical SDI structure where the RTK

Reference Network can be considered as a part of the core of the commonly used data and services. The principle of SDI is to keep the data close to the source. Each decentralized data provider from the main entities is responsible for creating, maintaining and sharing his own data to the central common data browser hosted, most likely, by the city GIS centre.

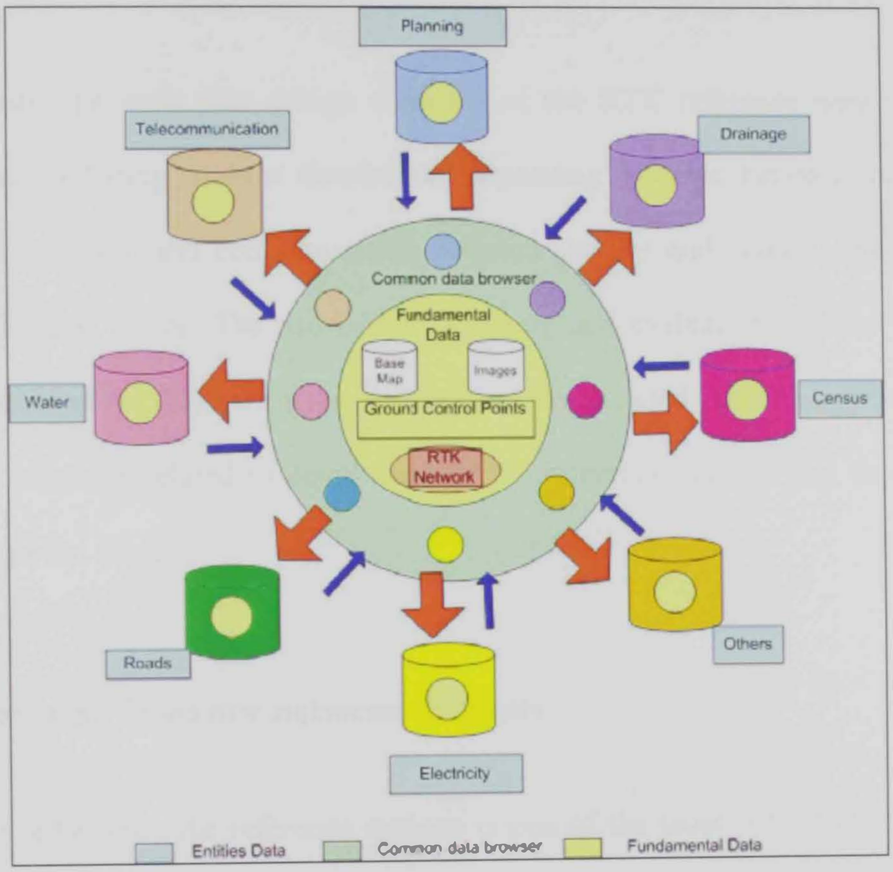

Fig. 4.5 Typical SDI Architecture

CHAPTER 5

USING GIS FOR THE DESIGN OF THE RTK STATIONS DISTRIBUTION

In this thesis, the main four design elements of the RTK reference network will be investigated, including: station distribution, separating distance between stations, site selection of stations, and communication between stations and control center, and the user with control center. The use of GIS to study and evaluate the above mentioned design aspects of the RTK reference network are investigated. This chapter investigates the design elements related to distribution of the reference stations and the separating distance between them.

5.1. Separating Distance between Stations

The distance between the reference stations is one of the most critical elements in the design of an RTK reference network due to its impact on the system functionality and cost. Although increasing the number of stations will usually increase the system accuracy and reliability, it comes with the tradeoff of high establishment coast. In practice, for the roving users wishing to achieve high positional accuracy, e.g. better than 5 cm, they have to be located within a certain distance from the nearest reference station (Petrovski *et al.*, 2001) and (Wübbena *et al.*, 2001A and 2001B).

Recently, several studies and researches have been conducted to investigate and figure out the relationship between the distance of the roving users from the nearest reference station and the achieved accuracy. This distance has a major impact on selecting the separating distance between the reference stations. El-Mowafy (2005) has concluded that "To achieve a fast and reliable integer ambiguity resolution, it is recommended to select average baseline length between reference stations of 50-70 km, with a maximum value of 100 km". This means that the distance between the user and the nearest reference station can be selected as 25-50 km. Seeber (2000) mentioned that it has been proven recently in an operational reference station network in Germany that it is possible to achieve 1 cm positional accuracy over a distance as large as 30 to 50 Km. Santana and Tottwrstrom (2002) mentioned that it is possible to make VRS RTK measurements with good accuracy - even at the distance of 40-45 km from the nearest physical reference station.

Based on the above references, it could be assumed in this research that the expected typical range of the distance between the roving user and the nearest station might be from 35 to 50 km. In this case, the separating distance between two neighboring stations can be double that value. Hence this can be used as a guideline to design the separating distance between the reference stations with an objective of keeping the user in the above mentioned range from the nearest reference station.

5.2. Use of GIS for Selection of Reference Stations Distribution

The GIS can be used as an advanced tool to help in selecting the best station distribution approach. This section discusses the adopted methodology to select the best distribution approach using GIS as well as analyzing and evaluating the station distribution options. The use of GIS geospatial functionalities (buffering and overlaying) to distribute the reference stations is addressed.

5.2.1. Methodology to Select the Best Distribution Approach using GIS

In this research, the adopted methodology in using the GIS as an advanced tool for selecting station distribution consists of two steps. First, few options are proposed for the station distributions based on proposed baseline lengths. A set of criteria are identified for evaluating the options. Next, different options are tested against preset criteria to select the best approach. A weight is given for each option related to each criterion. The selection of the best option is based on finding the distribution that has the maximum overall weight.

5.2.2. Distributions Options

Different approaches are proposed using GIS to aid designing the network to achieve the optimal separating distance between the reference stations which would lead up to the most cost effective setup. The following approaches are suggested to distribute the reference stations, where a radius refers to the distance between the user and the nearest reference station. An overlap refers to the overlap between circles formed from the tested radius, with their centers are taken as the reference stations.

1. Maintaining a radius less than 35 km with no overlap.
2. Maintaining a radius less than 35 km with overlap.
3. Maintaining a radius less than 50 km with no overlap.
4. Maintaining a radius less than 50 km with overlap.
5. Distributing the stations according to demand of service

5.2.3. Distribution Evaluation Criteria

The evaluation criteria based on which the tested distribution of the reference stations can be compared are: cost of establishing the system, system reliability, and degree of satisfying service demands and user needs. The cost of the system is directly proportional to the number of reference stations to be established in the network. This includes capital and running costs. However, the more stations in the system, the more robust, redundant and reliable the system would be, due to the short distance between stations. Reliability includes system availability and integrity. If one station goes out of order or malfunction, the roving user should still be covered by another buffer domain from the nearest reference station. User need and demand for network service includes assuring centimeter level accuracy and high reliability and availability. This is highly needed in the built up areas.

5.2.4. Use of GIS Tools in Selecting Stations Distribution

The use of GIS geospatial functionality to distribute the reference stations based on the above mentioned options is essential. Two main GIS functionalities are used in this exercise, buffering and overlaying. The buffering is used to draw the 35 and 50 KM buffer around the location of each proposed reference station. This helps in locating the stations for the options 1 to 4 within the project area while editing the data to maintain the required coverage with or without the overlapping option. The overlaying functionality is used along with buffering to help locating the stations for option 5. Overlaying the stations using layers of the built up areas representing the user demand of service helps in locating the stations in a balanced order.

5.3. Use of GIS to Examine Results of the Distribution Options

This section discusses the general analysis strategy assessing the design of locating and distributing the reference stations. Distribution options are developed, evaluated and compared. The section concludes with selecting the best distribution option according to the analysis results of each option tested against a preset evaluation criteria.

5.3.1. General Analysis Strategy

The general procedure that was used to evaluate the distribution options starts with creating a point feature representing the reference stations layer. A circular buffer to a distance equal to 35 km or 50 km, according to the tested option, is created forming the user range around each reference station. Next, the reference stations with their associated buffers are distributed over the project area (Emirate of Abu Dhabi) with or without the overlapping according to the tested option. The distributed reference stations with their buffers are overplayed on top of the built up areas to examine compliance with area coverage of the user demand for the RTK Reference network service. Finally, each distribution option is analyzed considering the following factors: number of reference stations, system reliability and satisfaction of users need for the service. Weights for each of these factors are calculated for each option, and tested against preset criteria to select the best distribution option. The selection is based on finding the distribution that has the maximum overall weight.

5.3.2. Acquired and Created Data

Several fundamental types of data were used in this study when considering distribution of reference stations and selecting their locations. These data include:

- A geo-referenced image from the Indian Remote Sensing (IRS) Satellite of 5 meter pixel resolution covering the entire project area (Emirate of Abu Dhabi), obtained from Abu Dhabi Municipality (ADM). This image is used as the background for the project layout.
- The UAE boarder with neighboring countries expressed in a shape file format, (polygon vector data), obtained from ESRI tutorial data. This data is also used as an additional background for the project area layout.
- Built up areas within cities of the Emirate of Abu Dhabi in a shape file format (polygon vector data), obtained from Abu Dhabi Municipality base map which has a scale 1:2,500. This data is used to define the built up areas that are representing for the user the highest areas of need and demand for the RTK Reference network service.

- Built up areas in the urban cities in the Emirate of Abu Dhabi in a shape file format (polygon vector data), obtained from Abu Dhabi Municipality base-map of scale 1:10,000. This data is used to define the urban built up areas that represent areas of medium user need and demand for the RTK Reference network service.

Table 5.1 describes the data used for the analysis.

Layer Name	Data type	Data format	Data source	Used for
UAE Image	Raster	Geo Tiff	IRS 5 meter resolution	Background of the project area
UAE Boarder	Polygon	Shape	ESRI	Background of the project area
Built up areas at 1:2,500 map scale	Polygon	Shape	ADM	Shows the areas of maximum demand and need of the RTK network service
Urban built up areas at 1:10,000 map scale	Polygon	Shape	ADM	Shows the areas of medium demand and need of the RTK network service

Table 5.1 Used data for the analysis of the station distribution

Buffers of reference stations and distance between them are created for each distribution option in the following data files:

- Point features in a shape file format, representing the reference station.

- Polygon feature, in a shape file format representing the buffer around each reference station.
- Line feature representing the distance between adjacent reference stations for each option.

5.3.3. Station Distribution Based On 35 km User Buffer

For all distribution options, the GIS was used to examine this option with the following steps:

- The layer of the project area of coverage was first added which was defined as "Emirate of Abu Dhabi Territory".
- A point feature was next created representing the reference stations.
- A buffer polygon was next generated to a 35 km distance around the reference stations.
- Buffered stations were distributed equally to cover the entire coverage area. Two buffering zones were created. The first is without any overlap and the second with an overlap of 30% between circles representing the coverage area of adjacent reference stations to cover the entire area.

Figure 5.1 illustrates the distribution of the stations and their separating distances for the first option, station distribution based on 35 km buffer without any overlap.

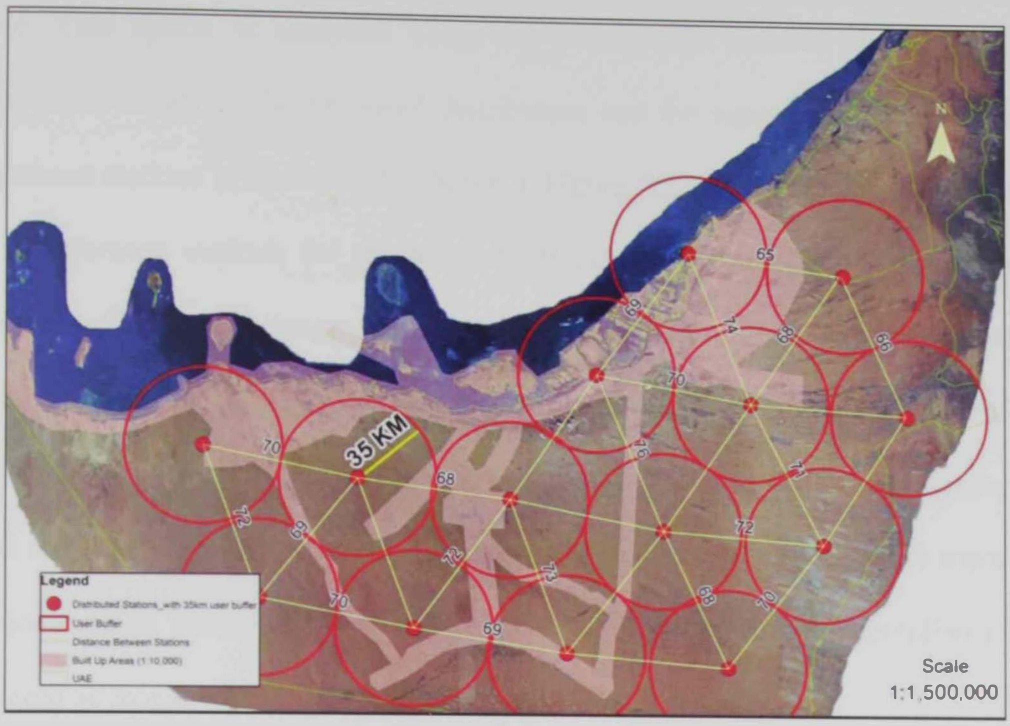

Fig. 5.1 Station Distribution based on user buffer of 35 km without overlap

Adopting the distance separation based on the user buffer of 35 km without coverage overlap as shown in Figure 5.1 ends up with 14 reference stations for the network. This has an advantage of a relatively low cost in establishing the network. However, this option has a drawback of not covering the entire user area by the buffering zones, as shown from the regions between the coverage circles that were not covered. In addition, poor reliability and service demand satisfaction would be expected in this case. This is also shown from Figure 5.1, as the stations were not properly located at the built up area that require demand of centimeter accuracy.

The second option of station distribution is also based on maintaining the roving user within 35 km radius, but with an 30% overall overlap with adjacent reference stations, on average. This option is analyzed using the same steps detailed above. Figure 5.2 illustrates the results of the proposed distribution and the separation distances between the reference stations in this case. As shown in Figure 5.2, this distribution option ends up with 25 reference stations for the network. Hence, it provides the maximum system reliability and service coverage due to the high number of utilized stations. However, it has the maximum cost of system establishment as well. The number of the reference stations that were located in the built up areas is not sufficient. Denser stations were needed for the built up areas to cover instances of malfunctioning of one or more of the reference stations. Hence, the level of user needs and service demand compliance can be considered as medium.

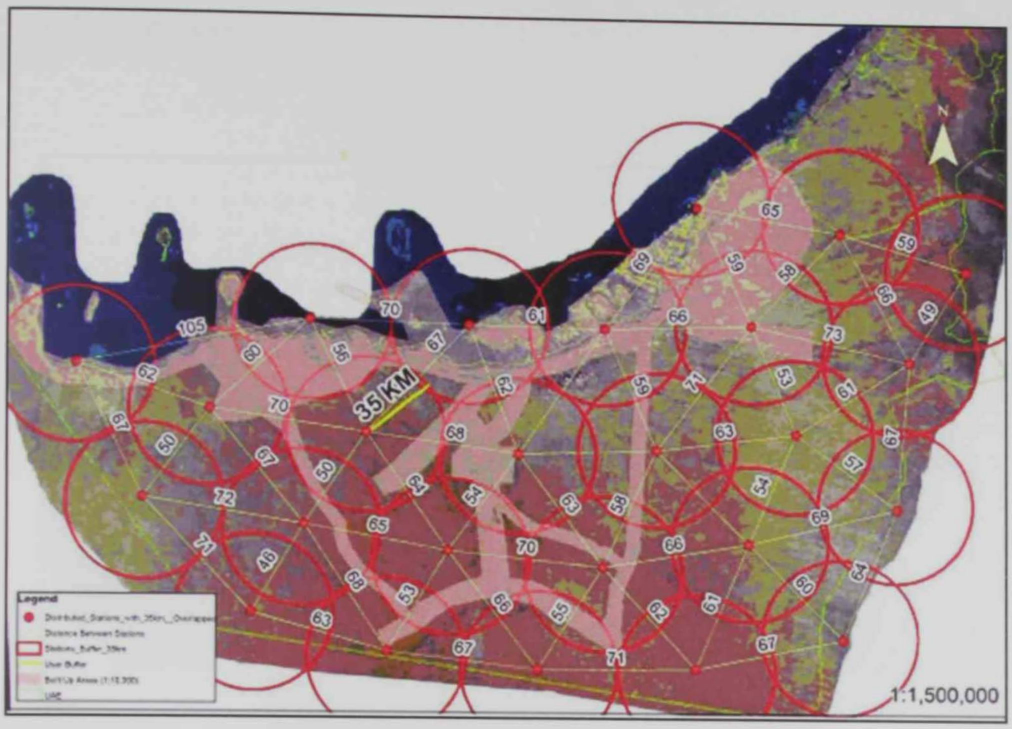

Fig. 5.2 Stations distribution based on user buffer of 35 km with overlap

5.3.4. Station Distribution Based on 50 km User Buffer

Another proposed approach for station distribution is based on maintaining a user buffer of 50 km from the nearest reference station. Utilizing the GIS to examine this option without overlapping the stations buffer, the results are illustrated in Figure 5.3. As shown from the figure, this option ends up with using only 7 stations. The biggest advantage of this option is that it will bring the project cost to a minimum due to the small number of stations used. However, the system reliability becomes very poor. If one station fails, the service will significantly degrade, and may become unreliable for a very large geographical area. Another drawback for this option is that many areas were not covered by the 50 km buffer; hence, the user needs and the service demand compliant criterion would also be very poor.

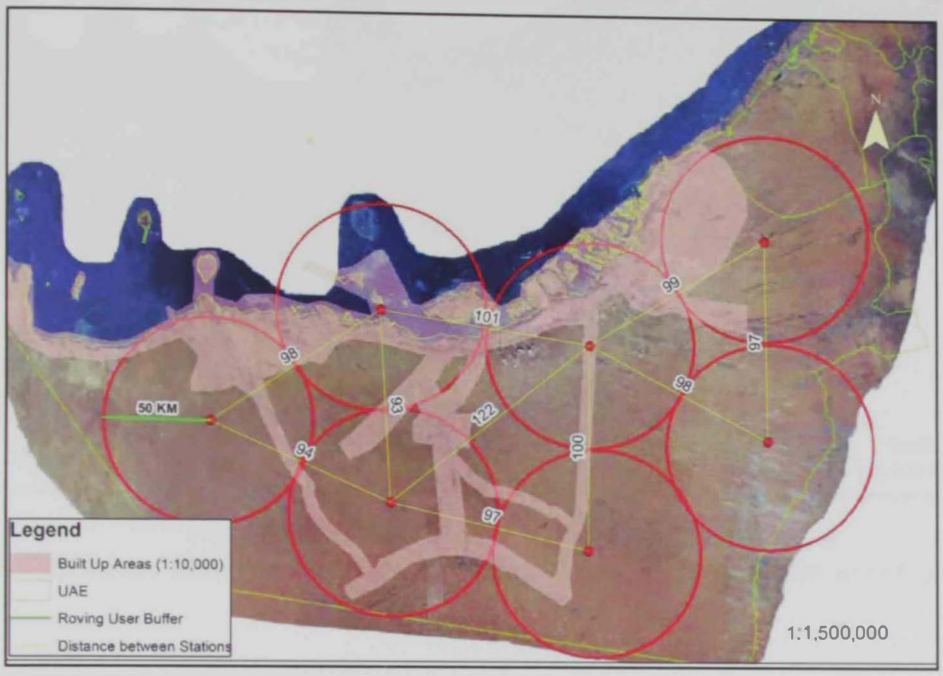

Fig. 5.3 Stations distribution based on user buffer of 50 km without overlap

Examining the stations distribution based on a 50 km user buffer with an overall overlap of 30% on average between adjacent reference stations utilizing the GIS functionality is illustrated in Figure 5.4. In this case, there would be 11 reference stations. This has an advantage of a relatively low cost of system establishment. However, this option has a drawback of not covering the entire user area, with poor reliability and service demand satisfaction. As shown from Figure 5.4, the stations are not properly located at the built up areas with high demand of centimeter accuracy as discussed earlier. In addition, network reliability and coverage for the service demand and user needs are still poor.

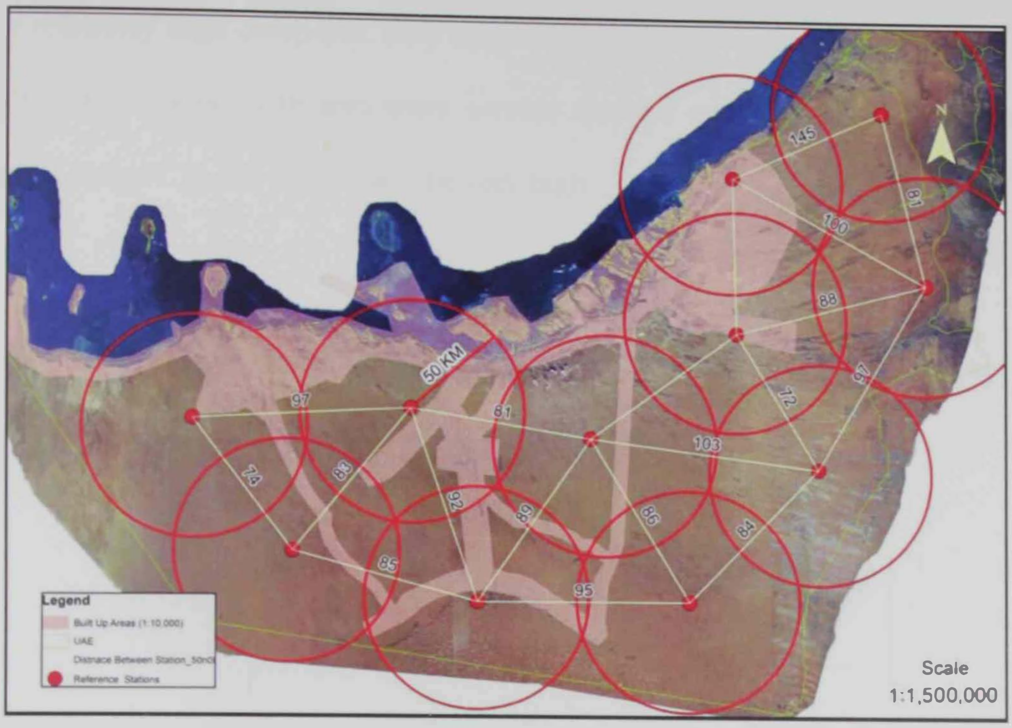

Fig. 5.4 Stations distribution based on user buffer of 50 km with overlap

5.3.5. Station Distribution Based On Service Demand

The last proposed option for distributing the reference stations is to select locations of the stations according to the service demand and user needs. Service demand is considered to be high at the built up areas in Abu Dhabi where the need for precise surveying is high due to the extensive amount of construction works. Thus, the service will be more needed and mission critical in the cities and township areas. As discussed in the previous section, the target accuracy of the base map and the GIS as built data can reach up to the 40 cm level. Applying the GIS functionality of overlaying the accuracy domain layers allows for distributing the stations and their buffer (while in the editing mode) in the most appropriate locations. The resulting created layout map is illustrated in Figure 5.5. This approach leads to ending up with 20 stations in the network. Although the project cost will be relatively high compared with the previous distribution options, but the system reliability at the areas with maximum service demand and user need of service (the regions A, B and C in the figure) will be very high.

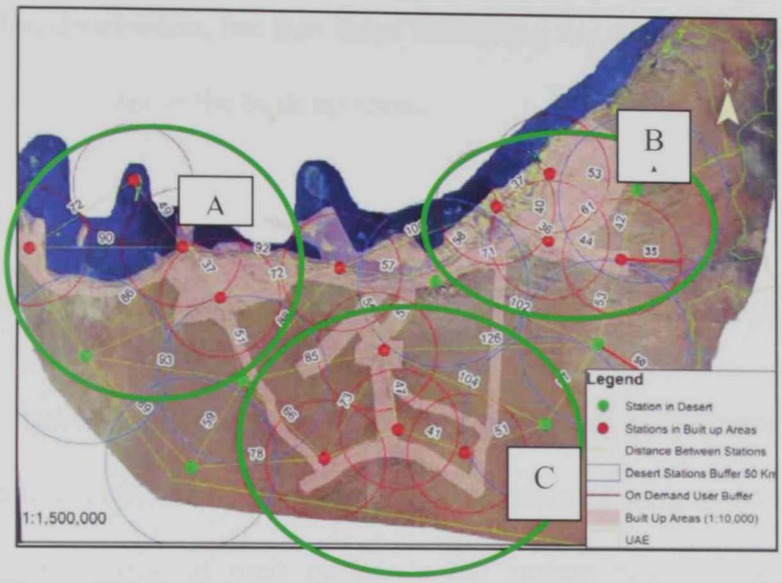

Fig. 5.5 Station distribution Based on Service demand

5.3.6. Benefits of GIS as a Tool to Design the RTK Reference Network

The GIS helps in identifying the number of stations needed for each option. Using the buffer function in the GIS allows the system designer to distribute the stations properly. This is important due to several factors. For instance, the number of stations needed for the network is inversely proportional to the selected separating distance. It is feasible to increase the number of stations in the built up areas to increase system reliability and enhance the accuracy even with compromising the number of stations in the desert, where the need of the network service is low. Once the average distance between stations is defined, the next step is to determine the reasonable location of each station to maintain that separating distance. Hence, the GIS becomes one of the best tools to help defining the approximate station location due it's functionality of distance measurement and buffering. This helps to distribute the stations while visualizing and measuring the distance to the neighbor stations. Notably, GIS becomes an excellent tool not only to design the station distribution, but also helps examining the availability and reliability of the RTK network services in the built up areas.

5.4. Evaluation and Comparison of Station Distribution Options

RTK Reference network system cost and reliability is directly proportional to the number of reference stations in the network. Comparing the reference stations distribution options based on the contribution of each option to the system cost and reliability can be summarized as follows:

Reference station distribution based on maintaining a radius less than 35 km with no overlap, and distribution based on maintaining a radius less than 50 km with overlap, as well as distributing the stations according to user demand of service, ended up with 14 reference stations for the network. This makes the system cost and reliability relatively low. Reference station distribution based on maintaining a radius less than 35 km with overlap ended up with 24 reference stations for the network, which makes the system cost and reliability very high. Reference station distribution based on maintaining a radius less than 50 km without overlap ended up with 7 reference stations for the network, resulting in very low cost, but also with low reliability, which are competing factors. Distributing the stations according to demand of service has the maximum compliance with the degree of satisfying the user's needs and demand for the network service.

The summary of the above discussed comparison between the above discussed stations distributions options are shown in Table 5.2. Applying weights to the degree of compliance with evaluation criteria related to cost, reliability and user needs satisfaction can be given in a range from 1 to 5 for a better quantification assessment. In weighing, 1 represents the worst compliance and 5 represent the best compliance. From the table, it is shown that distributing the stations based on 50 km has the lowest weight, where station distribution while maintaining 35 km buffer has a medium weight, whereas and the distribution based on service demand has the maximum weight. It can be concluded that distributing the stations according to demand of service is the best option.

Options	Number of Stations	Cost	Reliability	Satisfying User Need	Total Points
35 km buffer	14	3	2	2	7
Overlapped 35 km buffer	25	1	4	3	8
50 Km buffer	7	4	1	1	6
Overlapped 50 KM buffer	11	3	2	1	6
Service Demand	20	2	3	4	9

Bad Good

(Evaluation weights: 1= Minimum, 4= Maximum)

Table 5.2 Reference Stations Distributions Options

A comparison between the reference stations distribution options and their weighs derived from the above table is represented in a bar chart as illustrated in Figure 5.6.

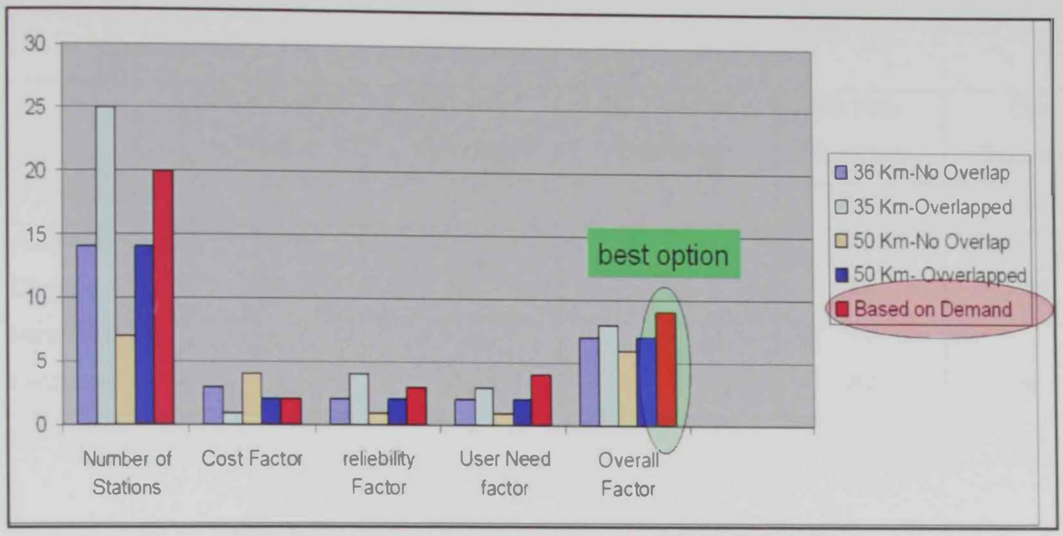

Fig. 5.6 Station distribution options with their weighing factors

Due to the fact that the distance between stations is an important factor in the RTK Reference network design, based on the above discussion, it is recommended to select average baseline lengths ranging between 50 and 70 km between adjacent reference stations as long as it satisfy the user service demand. This is required to achieve fast and reliable integer ambiguity resolution (El-Mowafy, 2005). The statistics of distances between stations for the examined distribution derived from the analysis of different options is given in Table 5.3.

	35 Km-No Overlap	35 Km - Overlap	50 Km-No Overlap	50 Km-Overlap	On Demand
Max Distance	76	105	122	145	126
Average Distance	70	64	100	89	67
Minimum Distance	65	46	93	67	36

Table 5.3 Distance between stations

To have a better view for the statistics of distances between stations for the examined distribution derived from options analysis statistics, the results of the distances between stations are represented in a bar chart, and are illustrated in Figure 5.7. The average distance between stations in Abu Dhabi's network is about 100 km. Thus, it can be concluded that the roving users would be always in the approximate range of 50 km from the nearest reference station.

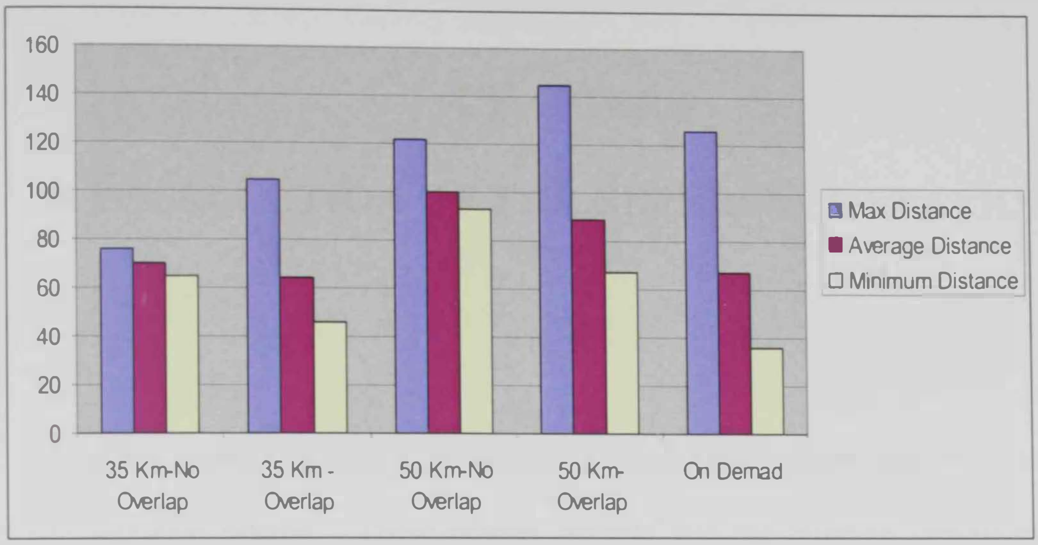

Fig. 5.7 Distance between stations

CHAPTER 6

SITE SELECTION OF THE REFERENCE STATIONS

Reference stations should be installed in carefully selected sites that would satisfy preset site selection criteria. These criteria include that the building containing the reference station hardware and software should be secured, powered, has access to communication, stable and open to sky. In this chapter, the capability of GIS tools to help selecting the optimal sites that satisfy the above criteria is investigated. ArcGIS tools such as selection by attribute, analysis model builder and 3D presentation are used to help investigating, evaluating and selecting the best building for each reference site. A generic model is developed using ArcGIS model builder to run a series of automated queries governed by the above mentioned criteria against a unique set of data input for each site.

6.1. Site Selection Criteria

The location and type of the building hosting a reference stations can not be randomly selected. It has to be based on specific criteria that would meet the requirements of the best functionality of reference stations. Ordinance survey in UK adopted site selection criteria that requires the selected site as to be secure, suitable for good GPS observations (clear horizon etc.), as well as having access to communication (Cruddace *et al.*, 2002).

In this research, the proposed site selection criteria require that the building containing the reference station should be stable, owned by the government, powered, have access to communication, open to sky and will not be demolished in the near feature. The criteria have some aspects related to the building type and some aspects related to factors affecting the building. Building related factors include building stability, lifetime and usage. The aspects affecting the building include surrounding buildings, location within the network grid, and availability of power, communication, and security.

6.1.1. Building Type Criteria

It is preferred that the building containing a reference station to be a government building. This is due to the fact that such a building will be most likely secure, powered, has access to telecommunication and built in a good structural status. For the Abu Dhabi case, the municipal centers owned by the municipality would be the most preferred sites due to the easy process of getting the license and approval of using the building and easy site access since the municipality owns and runs the RTK reference network.

6.1.2. Building Stability Criterion

One important criterion in selecting a reference station for positioning activities is that the building on which the reference station is fixed should have the maximum level of stability. This means that its vibration or movement with time should not exceed a certain level that would change the coordinates of the reference station to the level that could lead to inaccurate network solution, and consequently wrong determination of the rover (user) position. The reference station antenna should be firmly mounted on top of the building and should be very stable without any movement. The building stability is directly proportional to the building height as well as the relation to the nature of soil on which the building exists. Studying the recommended maximum drift of a building, Segui (2003) concluded that serviceability limitations on building drifts under wind or earth quick loads requires that the drift should not exceed H/500, where H is the building height in meters. Similarly, Smith (1996) suggested that the drift value should not exceed (H/500). However, Simiu (1996) recommended that the allowed drift should not exceed (H/600). Hence, since most studies recommend the former figure, the relationship between the building height and its maximum allowed movement as illustrated in Figure 6.1 can be formulated in general as:

$$\sigma < L/500 \qquad \textbf{(6.1)}$$

Where L is the building height and (σ) denotes the maximum allowed displacement.

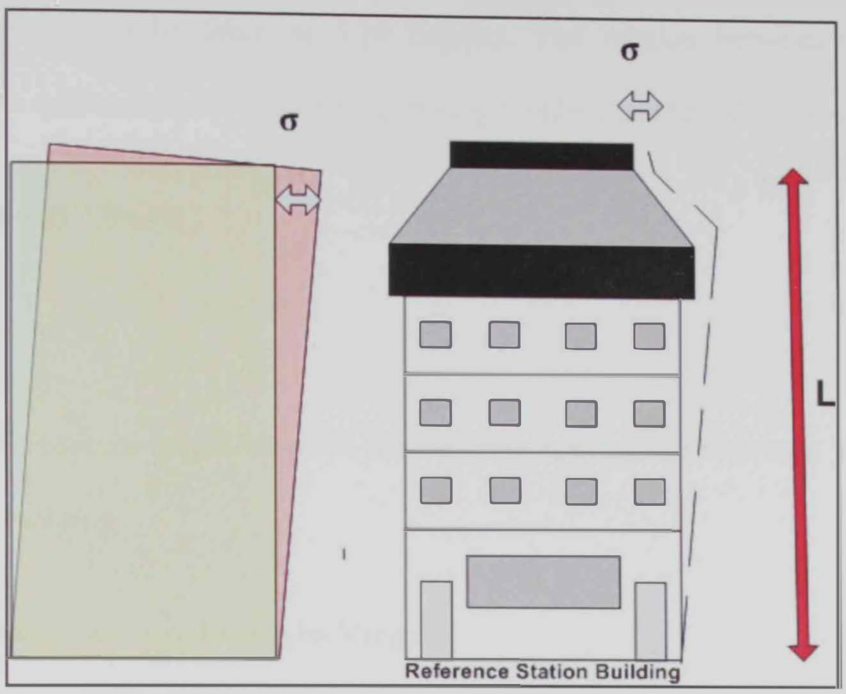

Fig. 6.1 Building drift

In this research, it is assumed that the maximum building drift should not exceed 10 cm, such that point positioning at the same level can be achieved from the network solution (in the worst case). Hence, from equation (6.1), it can be concluded that the maximum high of the building that would be used for the reference station should not exceed 50 meters.

6.1.3. Sky Visibility Criterion

The selected buildings for the reference stations should be open to the sky to be able acquire signals from as maximum as possible of satellites all the time. Thus, any obstruction should be located as far as possible from the reference station antenna. This means that the antenna of the reference station must have relatively clear visibility above the horizon without any obstructions within an arbitrary angle, defined as the mask angle. This mask angle can be taken as 5-10 degrees. The relation between the building containing the reference station and a neighboring building can be formulated as:

$$h = D * \tan(\theta) \quad (6.2)$$

Where

h: is the difference in height between the building hosting the reference station and a neighboring building.

D: is the distance between the two buildings.

θ: is the mask angle

Eq. (6.2) can be depicted in Figure 6.2.

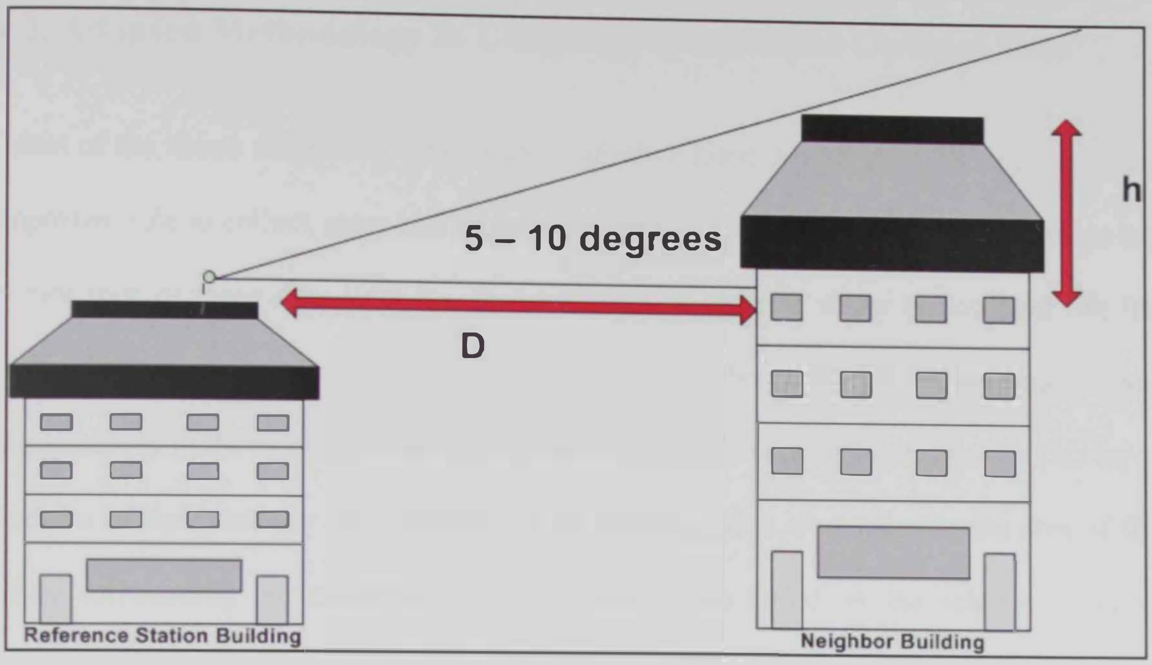

Fig. 6.2 Mask angle of the reference station's antenna

As shown in Figure 6.2. and substituting in equation 6.2 with a 5-degress mask angle gives:

$$D = h / \tan(5^{o}) \quad (6.2)$$

As an example, let us assume h is 5 meter, representing the approximate height of one additional floor for the surrounding building, and assuming that the two buildings have the same elevation for their base. Hence, (D) which represents the distance between the reference station site and the surrounding building would be approximately 50 meters. For such a distance, it can also be concluded that surrounding buildings that might block the satellite visibility for the reference station antenna are those buildings that have heights more than 55 meters.

6.2. Adopted Methodology in Using GIS to Select the Optimal Sites

Most of the above mentioned criteria are spatially related, hence, the GIS would play an important role to collect, store and analyze the data of the proposed sites and examine the compliance of these sites with the above criteria in order to select the optimal site for each reference station. In order to do that, a series of GIS spatial and attribute queries are implemented to the existing building layer to select the area covering each site. This layer consists of the geometry and attributes of all buildings that are located in the area of the study surrounding the candidate site. The queries are based on the selection criteria discussed in the previous sections including building containing the reference station should be stable, owned by the government, powered, have access to communication, open to sky and will not be demolished in the near feature. For each criterion, one query was formulated. Running each query will lead to filtering out the buildings that do not satisfy each criterion, singling out the proper building. The sequence and logical order of the queries is illustrated in Figure 6.3. The logical chart defining the logic and the sequence of steps and processes is realized through a model developed using ArcGIS software package. Structured Query Language (SQL) is used in the GIS to build the search process throughout the database.

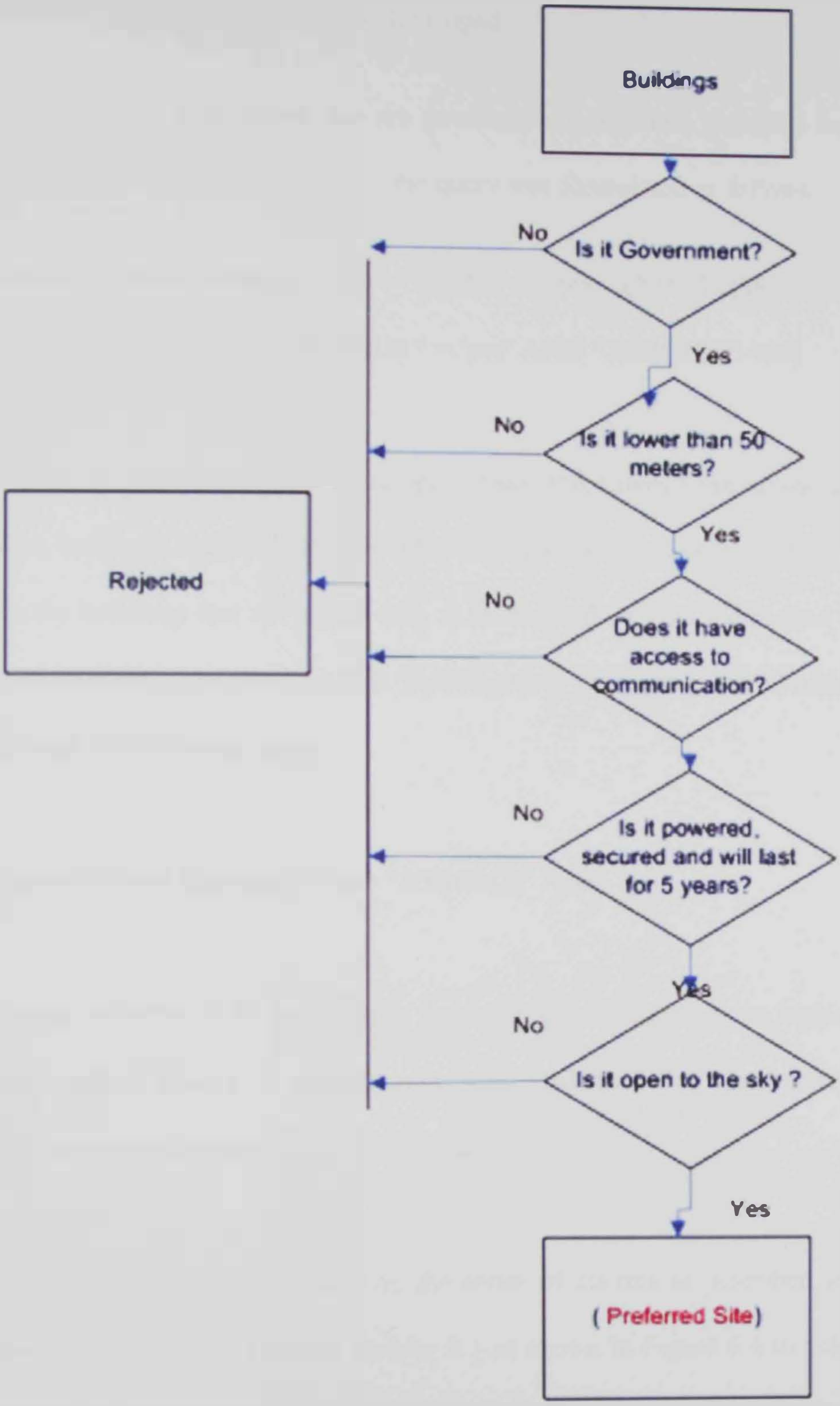

Fig. 6.3 Logical Flow Chart for Site Selection

The following SQL queries were developed:

1- To select the buildings that are governmental, secured, powered and lower than 50 meters in height (see Eq. 6.1), the query was formulated as follows:

(Select * From Building Where "TYPE" = 'gov' AND "POWERED" = 'yes' AND "SECURED" = 'yes' AND "NEW" = 'yes' AND "HEIGHT" <50)

2- To select the buildings that are open to sky, three steps were followed:

First, buildings that are higher than 55 meters are selected (see Eq. 6.2). Those buildings are the buildings that are higher with at least one floor than the desired buildings, which were selected in the previous step. Buildings that are higher than 55 meters were selected through the following query:

(Select * From Building Where "HEIGHT" > 55)

Second, a buffer of 50 meters from the selected buildings that are higher than 55 meters was created. Finally, a spatial query was used to define the buildings that are not intersecting with the above created buffer.

A spatial analysis model based on the series of queries as described in Figure 6.3 was developed using ESRI Model Builder 9.1 as shown in Figure 6.4 to help automating the process of the running the queries in a batch mode .The model is employed for evaluation of each site to help selecting the best location for each reference station. Each selected site for any reference station in the network should comply with all site selection criteria. The model is generic such that it can be used for all sites. For each specific site, the model output was related to the input data to the model. The model starts with receiving the input layer which is in this case the building layer. Next, it runs the query to select buildings that are governmental, secured, powered and lower than 50 meters in height. Then, it runs a query to select the buildings that are higher than 55 meters in height, where the result is used to create a buffer of 50 meters around each building. Finally, the filtered government buildings that are 50 meters away from the buildings, that are higher than 55 meters, are selected.

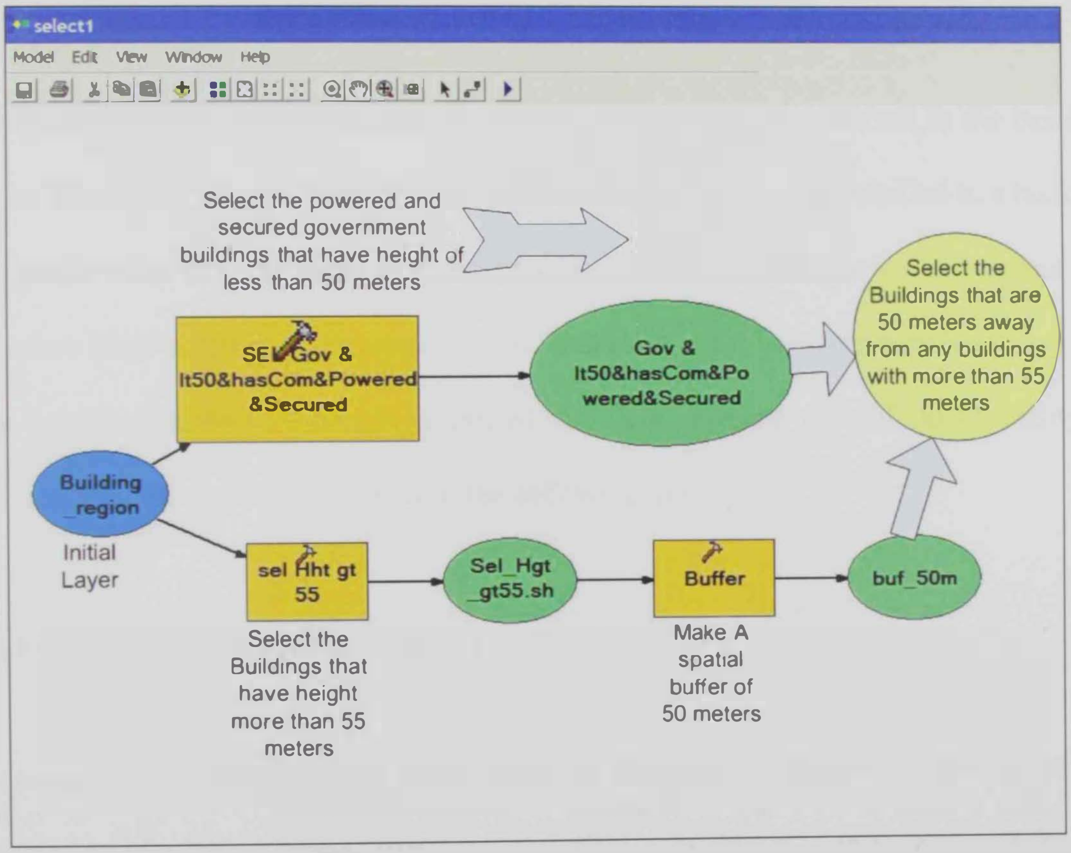

Fig. 6.4 Spatial Analysis Model (Using ESRI Model Builder 9.1)

6.3. Case Study Example – One Site in Abu Dhabi Island

The site of a proposed reference station to be located in Abu Dhabi Island is used as an example to test the above methodology and the developed spatial analysis model that was discussed in the previous section. Data of the existing buildings in Abu Dhabi Island obtained from Abu Dhabi Municipality were used. The data is given in ESRI shape format populated with rich attributes related to each building, including its name, type, subtype and height. Each process of the spatial analysis model is discussed, explained and presented in the following sub-section.

6.3.1. Using GIS in Examining Stability of Buildings

As discussed in the previous section the building stability is proportional to the building height. The assumption made is that the reference station cannot be installed in a building with height taller than 50 meter to avoid a value of building vibration and movement that can cause large positioning errors (>10 cm). Extraction of the government buildings that have heights less than 50 meters is carried out through using the GIS functionality of selection by attribute in ArcView as in the following query:

SELECT * FROM Buildings WHERE "HEIGH" < 50

The result of this query for Abu Dhabi Island is illustrated in Figure 6.5. Out of 30,850 buildings in Abu Dhabi Island, 30507 are classified as buildings with heights less than 50 meters, which are marked in Figure 6.5 and thus were included in the next step. The remaining 343 buildings were excluded.

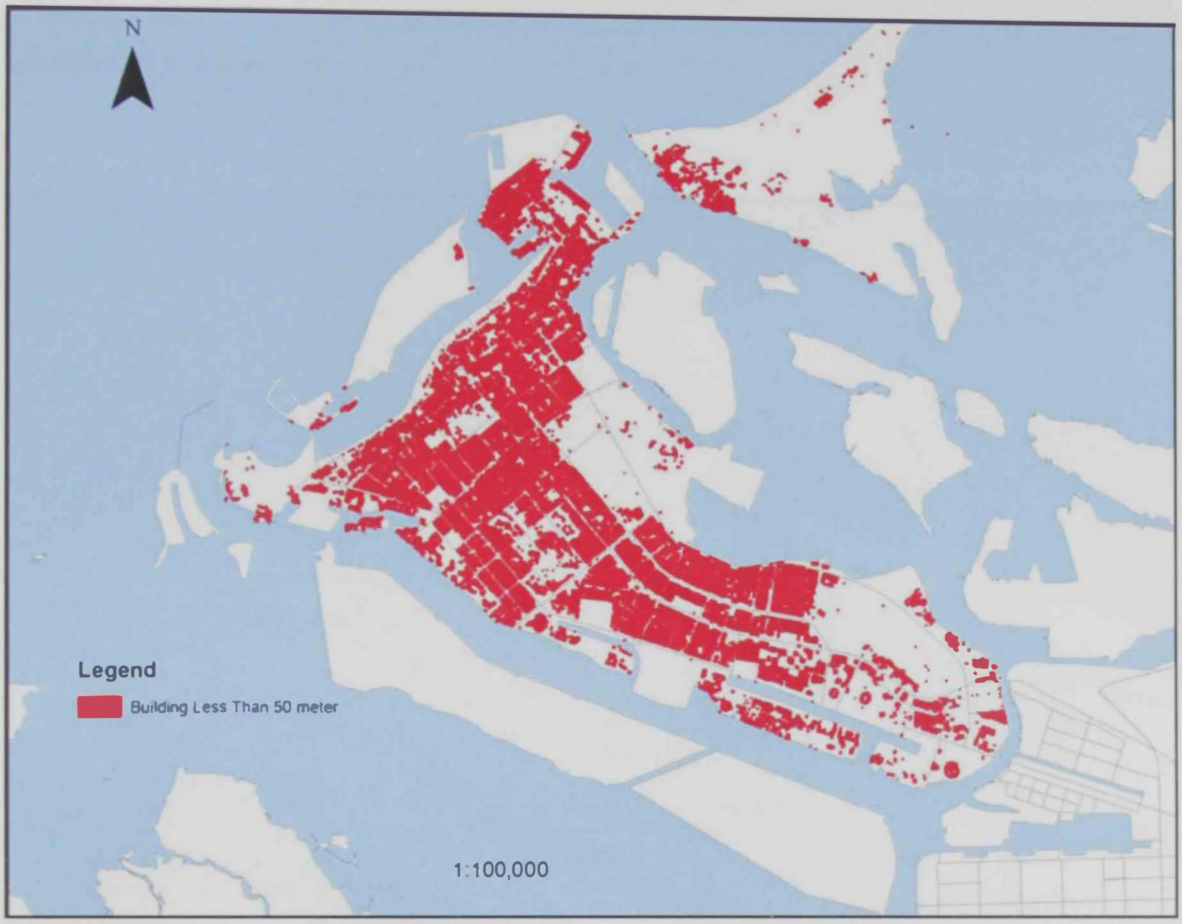

Fig. 6.5 Buildings in Abu Dhabi of heights less than 50 meters

6.3.2. Using GIS in Examining Type of Buildings

Extraction of the government building for the above case study of Abu Dhabi Island was performed by using the GIS functionality of selection by attribute in ArcView software as follows:

SELECT * FROM Buildings WHERE "TYPE" = 'gov'

The result of this query is illustrated in Figure 6.6. Out of 30,507 buildings with height less than 50 meters selected from the first query, 215 are classified as government which are marked in Figure 6.6.

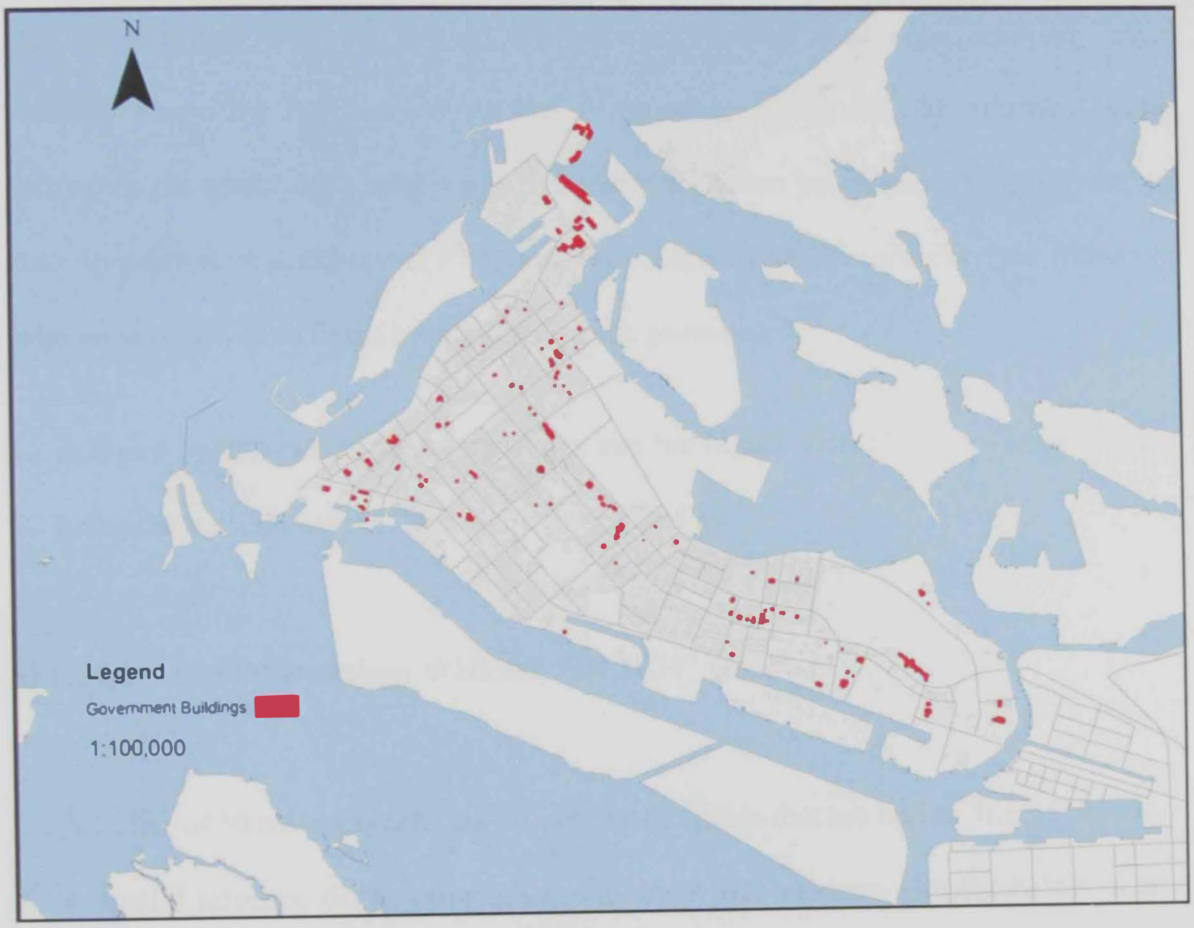

Fig. 6.6 Government buildings in Abu Dhabi

6.3.3. Using GIS Tools to Verify the Building's Good Satellite Visibility

In order to select the sites that are open to sky and have good satellite visibility, a spatial analysis was carried out for the surrounding buildings of the candidate sites. As discussed earlier, it was concluded that the desired site for the reference station should be at least 50 meters away from any surrounding building that is higher than 55 meters. This means that the building which is hosting the reference station must have relatively clear visibility above the horizon without any obstructions higher than an arbitrary angle, defined as the mask angle reference. This mask angle can be taken as 5-10 degrees. In order to maintain a minimum of 5 degrees mask angle of satellite visibility, the following steps were followed to find a building with such geometry:

1. A query by attribute to select buildings that are higher than 55 meters is formulated using the building layer. This can be formulated as:

SELECT * FROM Buildings WHERE "HEIGH" > 55.

2. A buffer of 50 meters is selected around the buildings that are higher than 55 meters.
3. A spatial selection of the government buildings that intersect with the buffer of any building higher than 55 meter is performed.
4. An inverse selection is made to select the buildings that do not intersect with the buffer. These include the buildings that are 50 meters away from the surrounding higher buildings. Those are the buildings that are meeting the criteria of government buildings that are lower than 50 meters and are open to sky. A sample of the results

showing the government buildings that are open to Sky (Blue color) and the building that are not open to sky (Red Color) is illustrated in Figure 6.7.

Fig. 6.7 Example of the Government buildings that are open to Sky

After performing the series of sequential queries as described above, it was found that out of the 30805 buildings in Abu Dhabi Island that pass the first criterion, only 282 buildings are higher than 55 meter. It is also found that only 3 government building are not open to sky. Finally, the number of candidate buildings that have a height less than 50 meters and are open to sky are 212. The obtained results are summarized in the table 6.1.

Total number of buildings in Abu Dhabi Island (Source ADM)			
Higher Than 55 meter	No. of buildings lower than 50 meters – 30159		
282	Government	Government Not Open to Sky	Government Open to Sky
	215	3	212

Table 6.1 Number of buildings according to their type

6.3.4. 3D Investigation and Presentation Using ArcScene

Site clearance to sky can also be investigated by analyzing the relation between building heights using ArcScene software module by examining the surrounding buildings and displaying results in a 3D form. Figure 6.8 illustrates the results of verifying the suitability and openness to sky of buildings in the example of Abu Dhabi Island using ArcScene.

The following steps were used to come up with the 3D presentation:

- A building layer was added to ArcMap.
- Symbology of each building was categorized by the unique value of its height. The result was coloring the building according to their heights.
- Categorized buildings were next copied and pasted in ArcScene.
- Building polygons were turned into 3D blocks. The buildings were extruded by their heights.

- In order to see the difference in height between the Municipality building and the surrounding buildings, a rectangular polygon plate of 50 meter width was created and extruded by the height of the municipality building, which is 38 meter, a 50% transparency of the plate layer was used to help in visualizing the buildings that are shorter than the Municipality building.

As shown in Figure 6.8 which illustrates the above example, it can be concluded that the GPS receiver in this site will have good satellite visibility since the building is not surrounded by taller buildings that can block satellite signals according to the preset criterion.

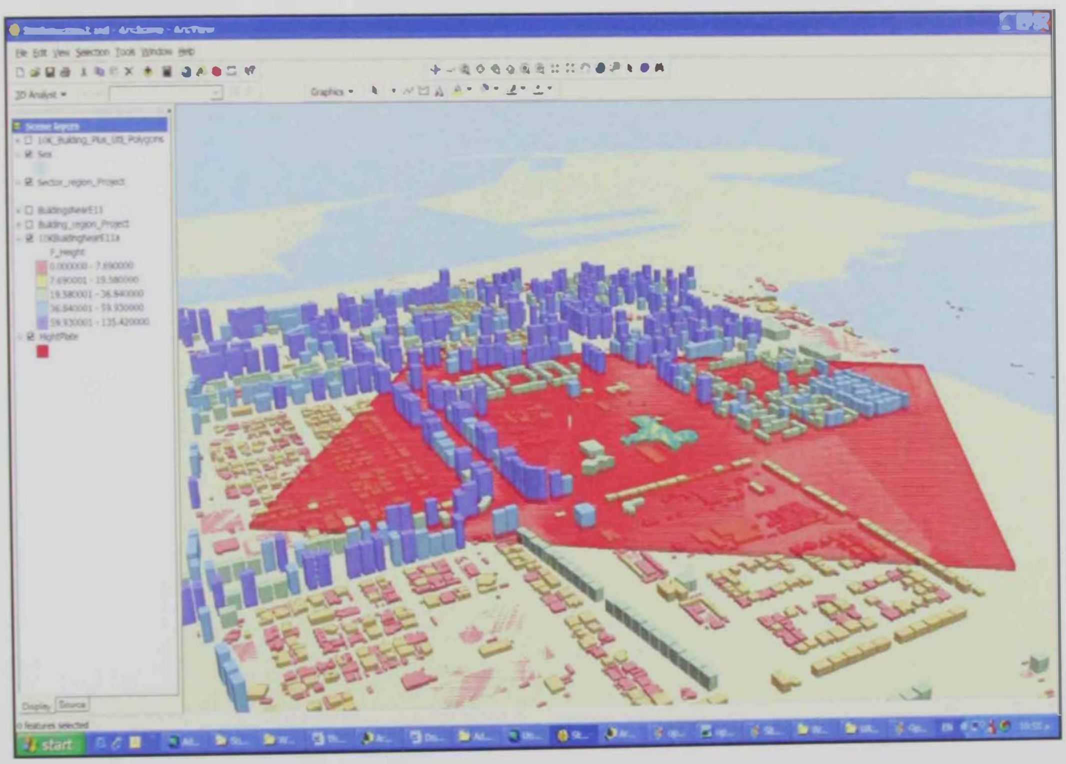

Fig. 6.8 Openness to sky presentation in 3D

The site can also be seen from different angles to verify its visibility to satellites as shown in Figure 6.9.

Fig. 6.9 Selected site as seen from different angles to verify its visibility to satellites

CHAPTER 7

COMMUNICATION NETWORK DESIGN

The communication medium is one of the most important system components of the RTK reference network. Thus, selection of the best communication medium is an important design aspect. It is generally recommended that each reference station should be connected through a direct link with a minimum of 256 kb/s to the system control center. However, the medium selection for each site would be based on its availability and according to the cost benefit analysis model. This model would examine the performance, the reliability, the capital and running costs. On the other hand, the roving users will be connected to the center through a wireless link. This link could be the Global System Mobile (GSM), the General Pocket Radio System (GPRS), a Radio frequency (RF), or through the satellite communication. In this section, the use of GIS to examine, analyze and select the best approaches for telecommunication infrastructure between reference stations and system control center and between it and users is discussed.

7.1. Communication between the Reference Stations and the Center

The reference stations need to be permanently connected through a data link to the network center located at the operating organization premises. The currently available options of connecting the stations to the center might include Corporate Wide Area

Network (WAN), government fiber backbone, service provider leased lines, and Radio Frequency (RF) transmission.

7.1.1. Corporate Wide Area Network (WAN)

The corporate wide area network used can be the private network owned by the firm operating the RTK reference network. Since the RTK in most of the countries is generally operated by the local Authorities, for example Ordinance Survey in UK, such organizations usually own a wide area network connecting their regional offices. The RTK network can utilize a minimum bandwidth of 256 kb/s to link each station to the center, thus, it would not be a challenge to make a provision for this requirement with today's modern communication networks. The main advantage of this option is its quick deployment of linking the stations with minimal installation and running cost. It would be obvious to use this link wherever applicable for any reference station site. It might have the disadvantage of having a limited coverage and it might not reach the sites located in buildings that are not owned by the operating organization.

7.1.2. Government WAN Network

Many cities have a government owned WAN linked by fiber optics. Usually, this link type mainly connects important government buildings. Typically, it has a very big bandwidth. The advantages of using this type of networks are its free running cost and high reliability. However, the geographical coverage and usage availability have to be investigated. Some cities are equipped with a government network that is based on

"Terrestrial Trunked Radio (TETRA) with different parties involved. TETRA is an open digital trunked radio standard defined by the European Telecommunications Standardization Institute (ETSI) to meet the needs of the most demanding professional mobile radio users. It is described as "Private network for own business communications for Voice, data and telephony calls on 1 Network with 1 Radio" (Motorola, 2007).

7.1.3. Local Telecommunication Services

Currently, local telecommunication private companies provide a variety of paid data linking services. The service might include leased lines, RF and Internet based solutions. Each type of link has a specific functional specification, reliability status, pricing framework and geographical coverage. Asynchronous Digital Subscriber Line (ADSL) data-link service can be utilized as a good example. In Abu Dhabi, the local telecommunication service provider has a wide coverage area of high speed data link. The bandwidth of this service reaches up to 1 Mb/s. The geographical coverage extends to all built-up areas. From practice, it has been proven that the service is very reliable. It has one time installation fee and reasonable fixed monthly charge on the average.

7.1.4. Corporate Radio Frequency Network

Building a dedicated RF network for communication between the reference stations for transmission of the network corrections can be considered as one of the communication medium options. The disadvantages are it requires getting an approval for a dedicated radio frequency - Very High Frequency (VHF) or Ultra High Frequency (UHF), which may take a long time, and significant investment is required in building up towers, buying communication equipments and funding operation and maintenance expenses. Choosing this option can be driven by two main factors. One is to reduce the running cost, and the second is to provide the link wherever other options are not applicable. The major advantage of this option would be in saving the communication running charges of connecting the stations. The capital cost and finding free carrier frequencies are the significant disadvantages of this option.

Each of the above discussed communication media for connecting the reference stations to the control center has advantages and disadvantages as far as geographical coverage of service availability, required capital cost for establishing the system, running cost of using the service, and service reliability. A comparative summary of the advantages and disadvantages between different methods is given in Table 7.1. A weighing factor is given for each aspect, ranging from 1 to 5, where 1 represents the lowest weight and 5 represents the highest weight. From the comparison given in table 7.1, it can be concluded that connecting the reference stations to the center using the government network, wherever available, is the first best option. Using the service provider land line connectivity is the second preferred option, whereas using the RF connectivity is a reasonable option for the stations that are not reached by either government network or service provider land-line connectivity.

	Geographical Coverage	Capital Cost	Running Cost	Reliability
Corporate WAN	2	5	1	4
Government Network	4	1	1	5
Service Provider (RF)	1	1	3	2
Service provider - Land Line	3	1	3	4
Corporate RF	1	5	1	2
Government TETRA	1	1	1	5
Internet	2	2	3	3

Weights: 1 – Very Low, 2- Fair, 3- good, 4-very good, 5 – Excellent

Table 7.1 Comparison between different types of communication media

7.2. Using GIS in Communication Infrastructure Assessment

The GIS can serve as an important tool to help carrying out the needed assessment for the selection of the appropriate type of communication infrastructure between the reference stations and the computing center. GIS is useful in such assessment due to the involvement of a large extent of geographical area as well as the relationship to the terrain of the project area. To utilize the GIS in studying the available connecting options, data related to the existing communication infrastructure and service as well as the terrain data would be needed.

7.2.1. Studying Abu Dhabi RTK Network Communication Methods

As discussed earlier, Abu Dhabi RTK reference network can be designed using approximately 20 reference stations. By investigating different options, it was found that 15 stations can be connected using the available corporate Abu Dhabi Municipality (ADM) WAN as illustrated in Figure 7.1. Hence, examining the applicable ways of connecting the remaining reference stations to the computing center and proposing recommendation for the best method based on a systematic process of analysis and evaluation are needed. By investigating possible communication methods for the proposed reference station locations, it was found that five stations lack the ground-based connections and better to be connected using the wireless Radio frequency (RF) method. GIS is proposed here to examine the possibility of connecting these five sites to the network and select the most cost effective approach. This can be performed as in the following steps:

- The line of sight from each unconnected site to the nearest connected sites is examined using the GIS line of sight tool.
- The terrain surface of the project area is created based on the heights of the Geodetic Control Points (GCP). This data is obtained from Abu Dhabi Municipality.
- The shortest direct connection is selected with a clear line of sight per each Station.

- For sites lacking the line of sight to the nearest connected reference station, a system of repeaters is proposed. GIS analysis is used to locate the repeaters in the best cost effective way.

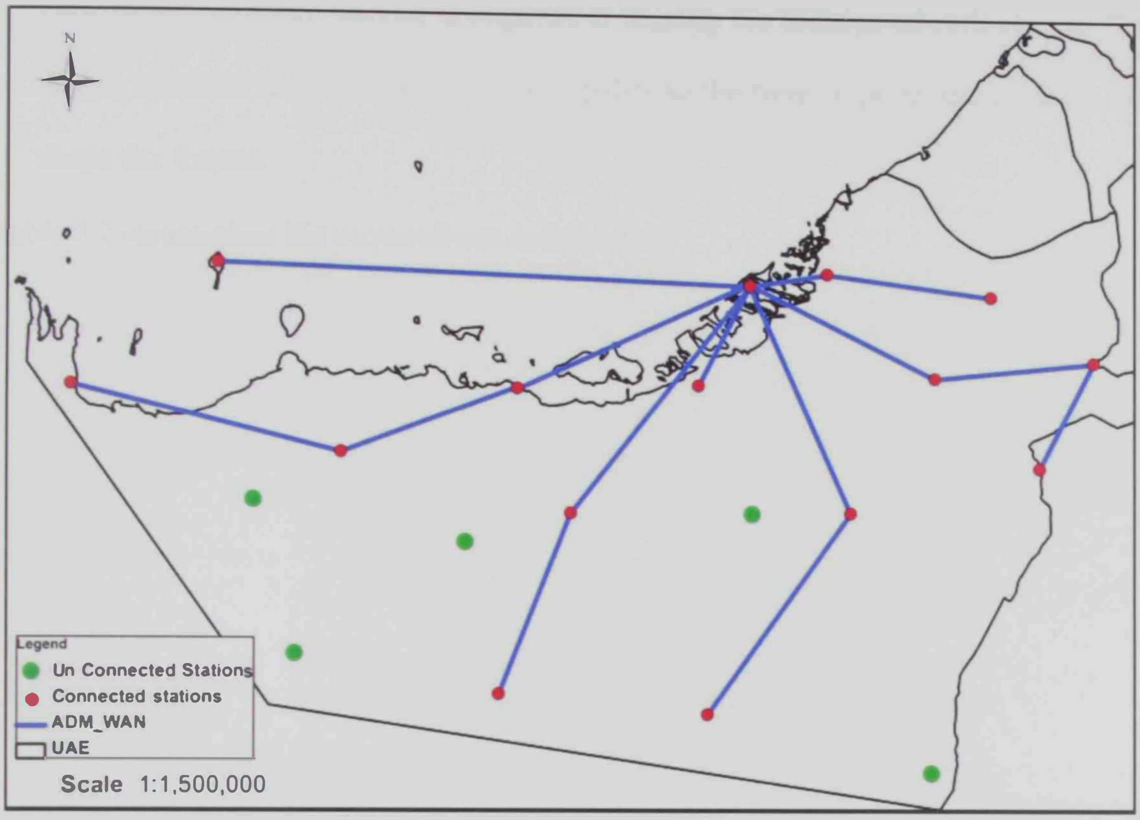

Fig. 7.1 Reference stations connectivity

To examine the line of sight for possible RF locations, the following GIS data, analysis and presentation are utilized.

- Data of the UAE border is needed to define the project area. This data was obtained from ESRI tutorial materials in the form of polygon layer in a shape file format.
- Data of the Geodetic Control Points is required to make use of its height information to interpolate the raster elevation surface. This data was obtained from Abu Dhabi

Municipality in the form of point feature layer in a shape file format. Two layers were created and derived from the GCP data: a raster layer of an interpolated surface, which represents the elevation model of the project area, and a contour line layer that represents the terrain elevations.

- Data of the reference stations is required to identify the location of each station. This data is obtained from Abu Dhabi Municipality in the form of point feature layer in a shape file format.

Table 7.2 summarizes the acquired and created data.

Layer	Feature Type	Format	Source	Used attributes / Role
UAE Boarder	Polygon	Shape	ESRI	Background
Geodetic Control Points	Point	Shape	ADM	Height, a source to derive DTM and contours
References Stations	Point	Shape	ADM	Name, identify station locations
ADM WAN	Line	Shape	ADM	Distance, indicating existing connections
Elevation	Raster	GRID	Created	Elevation model as a source of generating Contours
GCP Contour	Line	Shape	Created	Elevation, indicating elevation heights
RF	Line	Shape	Digitized	Distance, indicating RF connections

Table 7.2 Acquired and created data for the assessment of RF locations

7.2.2. Analysis Approach for Examining the RF Communication

To examine the best RF communication method between the five sites that require this type of connections and the remaining stations of the network, the following steps were carried out:

- Layers of input data were added in the ArcMap software. These layers include: UAE Boarder, Geodetic Control Points (GCP) and reference stations.

- Using the 3D Analyst extension, a raster surface was created by interpolation, applying the Inverse Distance Weighed (IDW) method using the height attributes of the GCPs as their Z values.
- Using the 3D analyst extension, contours were created using the surface analysis tool from the created raster data produced in the previous step. Interpolated raster data is added as a surface that reflects the terrain heights with the created contours in ArcMap. The contours features were labeled with the height attribute.
- Using 3D analyst extension in ArcGIS, lines of sights were generated from each of the unconnected five reference stations (considered as an observer) to the nearest reference station (considered as a target). The line of sight between the observer and target points determines visibility (between "from" and "to" points).
- The outputs were analyzed and classified according to the visibility status. Invisible sites were investigated for further studying and analysis in order to figure out the best approach for best locations of repeater stations and required heights of transmitters and receivers antennae.

7.2.3. Results and Conclusions

Figure 7.1 shows the available WAN connections between stations and Abu Dhabi proposed RTK reference network. As shown in the Figure, the RF connection for data transfer is needed for 5 stations that are out of the Municipality WAN. RF connections can be established using communication equipments (Transceivers) that transmit mutual electromagnetic waves in a Very High Frequency (VHF) or Ultra High Frequency (UHF). The VHF and UHF waves propagate in the speed of light reaching the target areas in the line of sight. To establish an RF connection between two stations, the two stations should be able to see each other without any obstacle intercepting the line of sight. To link the stations that have no clear line of sight, a repeater system is proposed in a location that can be seen by both stations. The repeater is a communication system that works as a mirror to reflect the RF signals. It consists of a receiver and a transmitter working in a duplex mode.

In this exercise the GIS was mainly utilized to solve two main issues. First, it is used for examining the line of sight for each station, and assessing finding the optimal location to setup the repeaters. The second GIS function is to examine the line of sight for each station by using a tool that creates line of sights in 3D Analyst Extension using ArcGIS. This was performed based on the elevation surface layer that was created from data of the GCPs.

The visibility from each of the tested five stations to their neighboring reference stations were examined by studying line of sights between them. Results are shown in Figure 7.2, where the color of the lines determines visibility between points. The green color represents good visibility, whereas red color indicates invisibility.

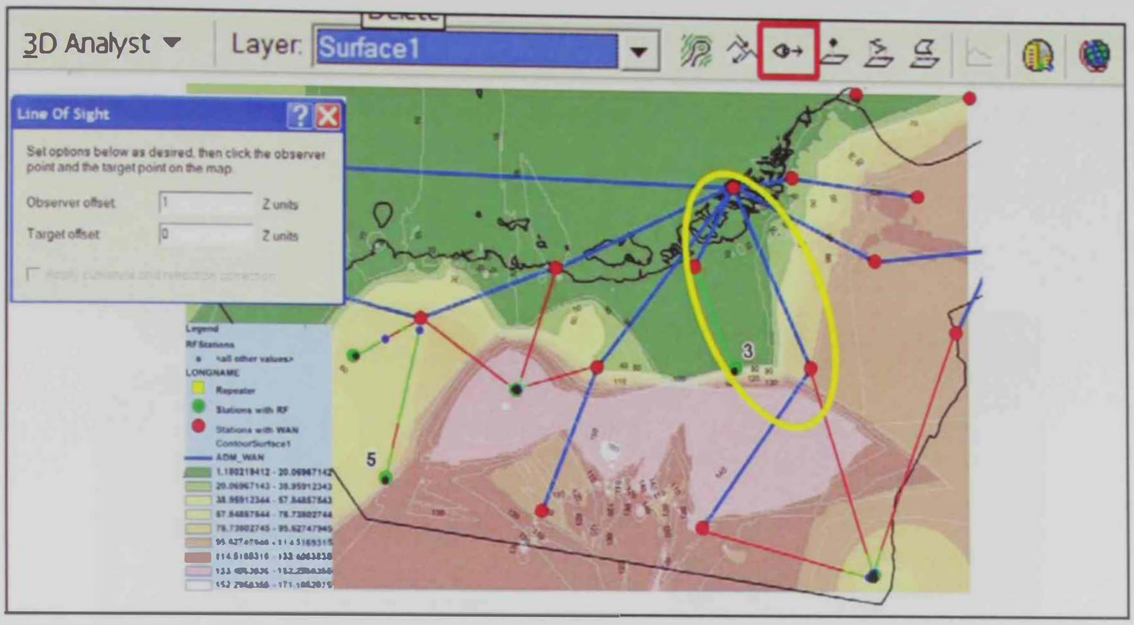

Fig. 7.2 Line of sight status for RF connections

As shown from the Figure 7.2, the only station that has complete visibility is station 3. This means that direct RF connection can be established only for station 3. Thus, all of the remaining four reference stations need a repeater system to be installed in proper places within the network to provide the required connectivity.

7.2.4. Selection of Repeaters Locations and Antenna's Heights

The GIS spatial 3D analyst extension was utilized to help finding the optimal location of the repeaters in the network. The following procedure was developed to achieve this task:

- First, the raster surface, which was generated from the GCPs representing the elevation model, is added to ArcMap software including all reference stations that are connected with DMA WAN and the stations that need to have RF connection.
- A group of vectors denoting line of sights were generated from the unconnected stations with a gradual increase of the observer offset height and target height

representing the antenna heights. These vectors were used to examine the extent of the visibility from the station to the neighboring stations as illustrated in the Figure 7.3.

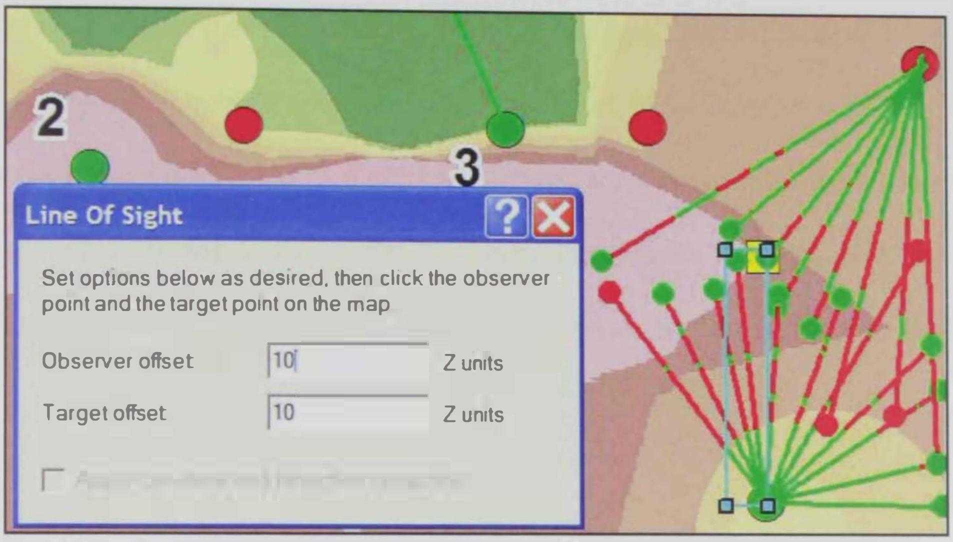

Fig. 7.3 Examining the line of sight between stations according to the observer and target heights from ground

- The same exercise for generation vectors denoting line of sights was performed to generate vectors from the connected reference station toward the unconnected sites. The offset from ground representing the antenna height was also changed gradually at the observer and target points.
- The gradual increase of antenna heights is incremented by few meters while inspecting the meeting point of visibility defining the possible repeater location.
- The above steps were repeated using a trial and error approach. The possible locations of the repeater stations were examined while inspecting the line of sight from both sides and changing the antennas heights. Finally, the optimal repeater location can be selected.

For the tested five stations, utilizing GIS functionality and tools, as discussed in the above procedures, helped in figuring out the optimal location of the repeater stations, the needed heights for the communication towers repeater stations, and the nearest neighboring station that is connected with the network. As an example, it was found that the required height of antennae was 10 meters for the tested station number 1, the repeaters needed a length of 3 meters and 10 meters was required for the neighboring station, which is connected to the network. The results of the calculated antenna heights based on the above carried out spatial analysis are summarized in Table 7.3.

Station number	**Station Antenna Height (m)**	**Repeater Antenna Height (m)**	**Network station antenna height (m)**
1	10	3	10
2	10	10	15
3	3	3	3
4	30	25	30
5	15	10	10

Table 7.3 Antenna height for the RF stations and their repeaters

The repeaters locations and the connecting paths derived from this study are shown in Figure 7.4. This concludes that there is a need for establishing 3 repeater systems. The height of the antennas mounted in structured towers for the stations and the repeater system varies from 3 to 30 meters to ensure clear line of sight between the stations and the repeaters.

From the above discussion, it can be concluded that the GIS 3D analysis tool represents extremely powerful tool to support the optimal decision to properly locate the repeaters. GIS 3D analysis tool has the following benefits:

- It helps in defining the exact number of needed repeater systems.
- It helps in defining precisely the optimal locations of the needed repeater systems.
- It helps in defining the needed height of each antenna at the stations and at the repeaters.

This would make GIS a very useful tool to support decision making leading to optimal cost effective solutions.

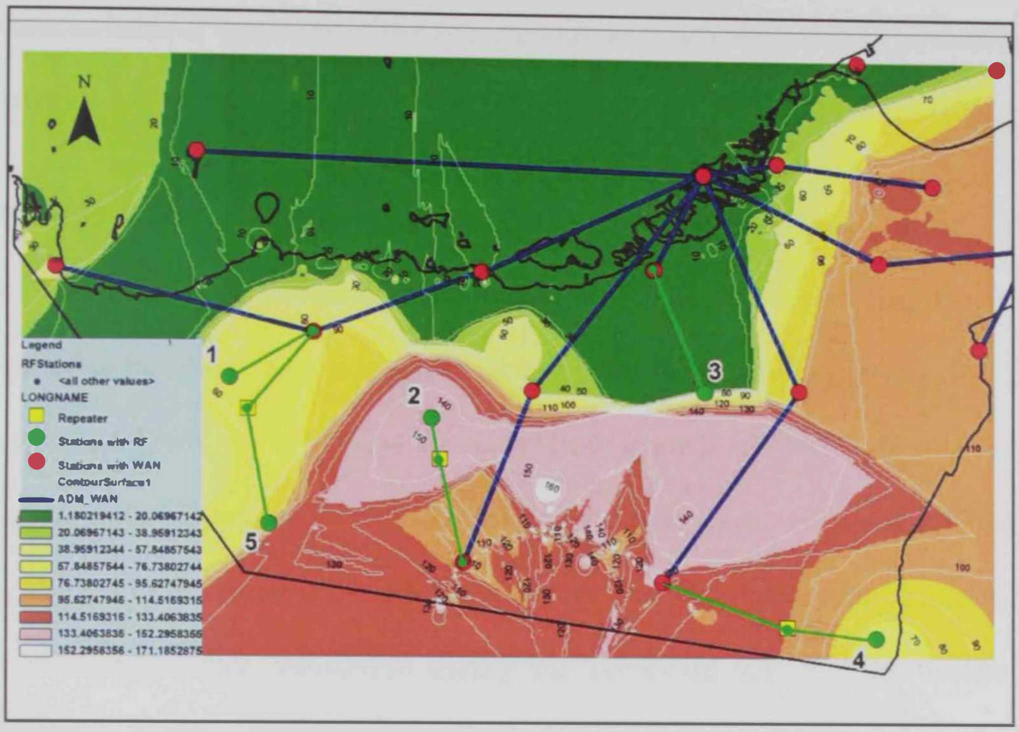

Fig. 7.4 Final RF communication network: Stations and repeaters

7.3. Communication Methods between Control Center and Users

In real-time positioning using the GNSS RTK reference network service, users employ GPS receivers that are equipped with wireless modems to receive the measurement correctional signal from the Network Control Center (NCC). The wireless link could be a GPRS Internet connection, a Dial up with GSM modem, VHF, UHF, Frequency Modulation (FM) or Satellite communication. The type of used medium depends on the local environment of each country. For instance, in UK, approximately 20% of the total usage of the network is carried out via GSM. The remaining 80% is achieved via VHF (Cruddace *et al.*, 2002).

The characteristics of each type of the above communication methods can be summarized as follows:

- **GPRS**: In this case, the roving user needs a geodetic-grade GPS receiver equipped with GPRS modem. Subscription with the local Internet Service Supplier (ISS) is required to be able to access the Internet to receive the correction service through the Networked Transport of RTCM via an Internet Protocol (NTRIP). NTRIP supports wireless Internet access through mobile IP networks like GPRS and GSM. The advantage of this option is the low running cost since the charges are estimated as per the size of the data transferred during the surveying session. This makes it an economical option considering that the amount of transferred data is usually small. However, the speed of linking and data transfer would depend on the data traffic condition of the service provider. This type of communication passes the data in a duplex mode. This means that the system is composed of two connected parties or devices which can communicate with one another in both directions.
- **Dial up with GSM modem**: In this case, the roving user needs a geodetic-grade GPS receiver equipped with compatible GSM modem. The user calls the center in a dial up mode. Independency of the service provider as far as link speed and availability might be an advantage, however, the running charges when using GSM modem might be higher than GPRS due to the fact that calling charges is based on the duration of the

call, which may take the whole period of the surveying session. This type of communication also passes the data in a duplex mode.

- **VHF:** In this mode, the correction data can be broadcasted in one or two ways communication using wireless VHF transceivers and repeater networks. The roving user in this case needs an RF data modem. The main disadvantage of this option is the limited geographical coverage due to need for a clear line of sight. The high capital costs that might be needed to build up communication towers represents another disadvantage. However, the biggest advantage of this option is the free running costs as no calling charges are needed. An example of such system is the 2m-band VHF delivery system being used with excellent results in Germany. This type of communication passes the data in a simplex mode. This means that the system is composed of two connected parties or devices that can communicate in one direction. In this case, the data is sent only from the broadcasting station to the roving user.

- **Satellite communication**: In this case, the roving user is connected through the Internet or dials up to the network processing center to receive the corrections from the center through a satellite based service. This service works in a similar principle as the GSM dial up or GPRS through the Internet by dial up access to the service provider. The satellite-based system 'Thuraya' is one example of such service providers. It provides access to the Internet in its dual mode handset. Thuraya subscribers can browse the Internet anytime and anywhere within its coverage area. The coverage area of this Satellite service in the Middle East region is illustrated in

Figure 7.5 (Thuraya, 2006). This type of communication also passes the data in a duplex mode.

Fig. 7.5 Satellite communication geographical coverage by Thuraya

The advantage of this option is its global coverage giving unlimited geographic access to the service within the regional RTK reference network, which makes it advantageous for remote areas. However, the drawback is the high cost of the equipment and running cost of calling charges.

The summary of the comparison between different medium options that can be used for broadcasting the network measurement correction signal as far as range of coverage, reliability, capital costs and running charges are given in Table 7.4. It can be concluded that using GPRS as a communication medium is the best option that satisfies the optimal benefits as far as range of coverage, reliability, capital costs and running charges

	Geographical Coverage	Charging Basis	Capital Cost	Number of Concurrent Users	Running Cost by users
NTRIP : GSM, GPRS	National	Data packet	Low	Few	Low
GSM Dial up	National	time	Low	Few	Medium
Satellite communication	Global	Time and data	Med	Few	High
VHF –UHF Broadcasting	Limited	Subscription	High	Many	Minimal
FM Broadcasting	Limited	Subscription	Low	Many	Minimal

Table 7.4 Comparison between the broadcasting media options

7.4. Using GIS to Examine the VHF Broadcasting in Abu Dhabi

Studying the feasibility for using the VHF communication for broadcasting the RTK reference network information in Abu Dhabi seems from different aspects an important option for future needs. It is suggested in this research to mount the broadcasting station at the highs points in Abu Dhabi. One of possible locations would be the Sky Tower that will be established in Al Ream Island. According to (Cribs, 2007), the Sky Tower will have 83 stories, with approximate height of 379 meters. The completion date of the project is scheduled for May 2009. The Sky Tower location is shown in Figure 7.6. The area of coverage, inside and outside the city, should be accurately determined as it is considered as one of the main factors for evaluation of the service potential. The GIS is the proper tool to identify the required area of coverage.

Fig. 7.6 Design view of Sky Tower in Abu Dhabi . (Source TEN Real Estate)

7.4.1. Required Information for VHF Broadcasting

In order to study the feasibility of using the Sky Tower for broadcasting the measurement corrections from the RTK reference network, the following GIS data, analysis and presentation are required:

- Data of the UAE border is needed to define the project area. This data is obtained from ESRI tutorial materials in the form of a polygon layer in a shape file format.

- Data of the Geodetic Control Points is required to make use of its height value to interpolate the raster elevation surface. This data is obtained from Abu Dhabi Municipality in the form of a point feature layer in a shape file format.
- Two layers were created and derived from the GCP data: a raster layer of an interpolated surface that represents the elevation model of the project area, and a layer including contour lines, representing the terrain elevation levels.
- Data of the reference stations is required to identify the location of each station. This data is obtained from Abu Dhabi Municipality in the form of a point feature layer in a shape file format. Table 7.5 summarizes the acquired and created data.

Layer	Feature Type	Format	Source	Used attributes / Role
UAE Boarder	Polygon	Shape	ESRI	Background
Geodetic Control Points	Point	Shape	ADM	Height, a source to derive raster surface model
Elevation	Raster	GRID	Created	Elevation model as a source of Contouring
Contour	Line	Shape	Created	Elevation, indicating elevation heights
Building	Polygon	Shape	ADM	Height, representing obstacles
Building spot heights	Points	Shape	Created	Height to generate raster surface model

Table 7.5 Used data for the Sky Tower broadcasting signal analysis

7.4.2. Implementing Geospatial Process and GIS Analysis

To examine the possibility of using the Sky Tower for the broadcasting of the measurement corrections from the RTK reference network via VHF signals, the following steps were carried out:

- A terrain model for all of the Emirate of Abu Dhabi is created based on heights of the GCPs.
- A raster elevation service model is generated using ArcGIS 3D analysis.
- A point feature is created at the Sky Tower location in Al Reem Island in Abu Dhabi. The height attribute assigned to it was set as 380 meters.
- Using ArcView 3D analyst extension, a raster surface model is generated from the GCP layer, mentioned above, to reflect the topographic changes.
- Using the line of sight functionality, visible and invisible places are identified to determine the possible areas of coverage. This task is illustrated in Figure7.7.

From the Figure 7.7, it can be concluded that the majority of the areas within the Emirate of Abu Dhabi are visible from the Sky Tower, which guarantees that the broadcasting signal will be received. This exercise shows that without GIS in such study, it would be hard to achieve such important conclusion. Thus, GIS facilitates achieving important conclusions with minimal effort and in a speedy manner. The traditional normal approach would be a tedious and time consuming alternative.

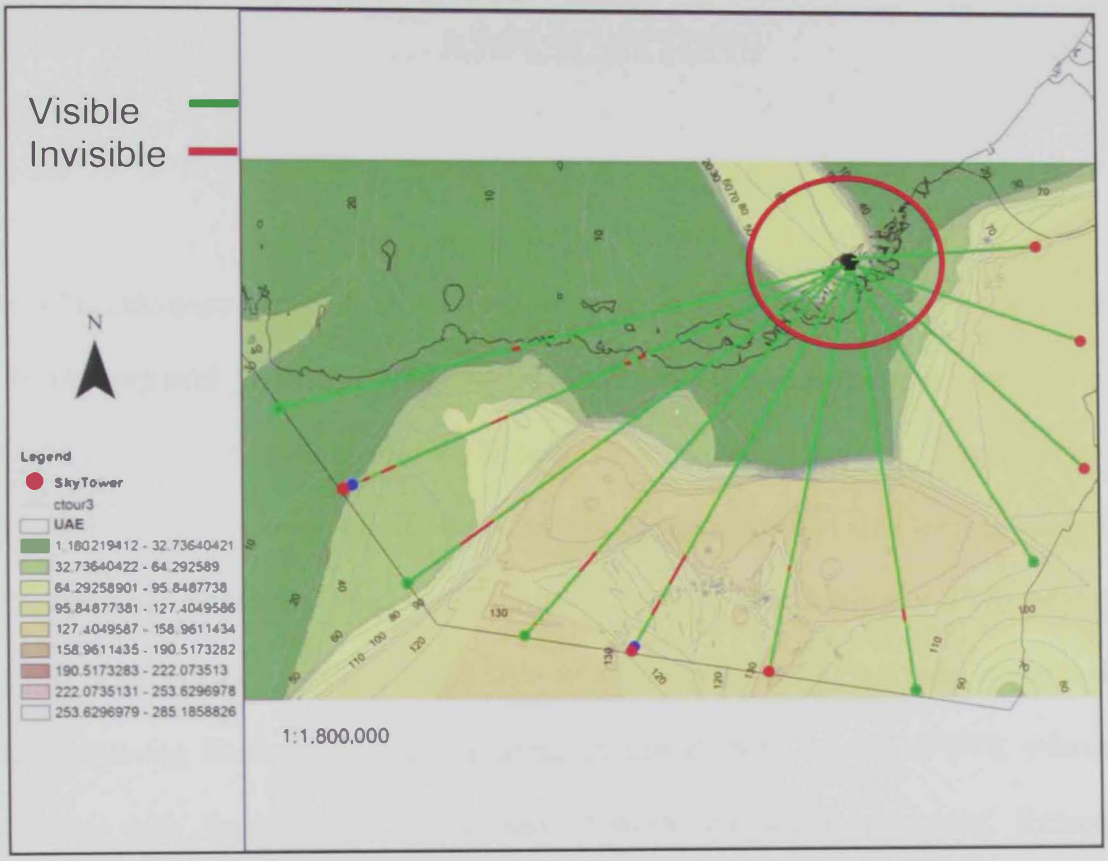

Fig. 7.7 Visible and invisible line of sights from the Sky Tower Building

CHAPTER 8

ADVANCED RTK NETWORK BASED GIS APPLICATIONS

The RTK reference networks provide real time positioning at the centimeter level for a wide geographical coverage, which gives a chance for many research institutes and solution providers to develop a variety of new GIS applications and enhance current ones. This section explores some of the advanced GIS applications that are based on using the RTK reference networks. Machine automation solution that integrates RTK reference network with Supervisory Control and Data Acquisition (SCADA) is a good example that helps improving fieldworks in several areas. In this chapter, the use of RTK reference networks, with machine automation and SCADA systems is presented. Remotely monitored and controlled field machine application is explored as an example to investigate and study the concepts and feasibility of integrating RTK reference network service with GIS and SCADA. Some other applications that are based on RTK reference networks and can benefit from GIS techniques include mapping, volume calculation, cut & fill, dredging, machine automation and land leveling.

8.1. Remotely Monitored and Controlled Machine Automation

Integrating RTK reference network with SCADA can enhance location-based applications with additional functionalities and capabilities. Having real-time accurate

GPS positioning information as a newly introduced field input to the SCADA system gives a lot of opportunities to develop many solutions for planning, designing, constructing and monitoring field operations that require precise positioning.

Figure 8.1 illustrates a developed architecture as a proposed example of such integration. An automated machine such as a field tractor that can be automatically operated, unmanned and fully remotely monitored and controlled is presented. The machine would be controlled by the analogue and digital outputs from a Remote Terminal Unit (RTU). It is proposed that the RTU will have preloaded Programmable Logic Control (PLC) software that activates the outputs according to the field inputs from the machine primary sensors, as well the real-time accurate coordinates fed from the GPS roving unit receiving measurement corrections from the RTK reference network. The field operations, events, logs and alarms can be fully remotely monitored through the SCADA system. For the SDADA system programming software, standards such as IEC1131-3 is proposed to be used. IEC 1131-3 is the international standard for programmable controller programming languages. As such, it specifies the syntax, semantics and display for the PLC programming languages. An open standard communication protocol such as Distributed Network Protocol (DNP) is also suggested. DNP is a set of standard and interoperable communication protocol used between companies in process automation systems. These open standards and interoperable platforms will allow the system design to be implemented in any of the industrial proven commercial SCADA systems away from any proprietary platform or vender specific solution. The functionality and process automation of the proposed integrated system can be described in the following steps:

1- The roving GPS which is mounted in the field machine receives the corrections from the RTK reference network. The roving GPS should be enabled with a GPRS modem and proper subscription to the RTK reference network in order to be able to receive the corrections. The GPS receiver continuously feeds the RTU with the real-time positioning information (x, y and z coordinates) representing the exact location of the machine in the field.

2- The RTU controls the field machine based on a preloaded automation process program that produces the controlling outputs based on a set of variable inputs from the primary sensors as well as the input of the variable position information which is produced from the GPS receiver.

3- When the machine changes its status and location, the RTU receives the new signals from the inputs including the new positioning information. This process loop keeps running according to the soft PLC program, which is pre-loaded in the RTU to govern the automated field process.

4- The RTU is connected through a modem to a remote monitoring and control center equipped with SCADA monitoring and controlling hardware and software. The SCADA system will be integrated with the GIS through an interface where the mimics are truly geo-referenced maps representing the reality of the field in a full 3D mode. The field automated process is fully monitored and controlled in a remote mode. Report, alarms, trends and historical records can be retrieved and archived at the SCADA centre.

5- Field construction works such as cut & fill, land leveling or dredging can be planned at the backend office using GIS and utilizing an accurate planning and base-map data.

SCADA system will extract the 3D accurate coordinates of the field points from GIS and get it impeded in the soft PLC program, which can be downloaded remotely to the field RTU.

6- Real time data from the GPS and the primary sensors can be sent remotely from the field through the RTU to the SCADA system to update the GIS map with real time information. This would help monitoring the actual field progressed work against the planned one.

The developed integration architecture proposal is shown in Figure 8.1.

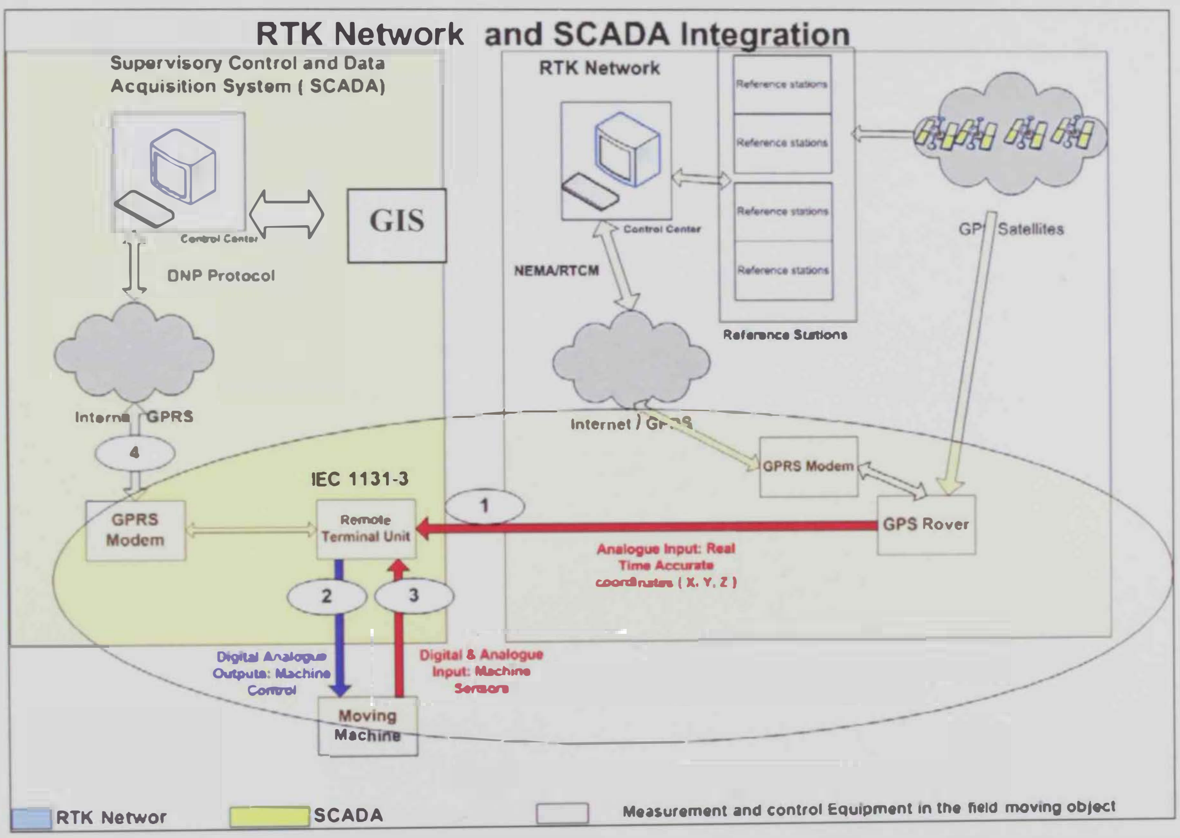

Fig. 8.1 Proposed RTK reference network & SCADA integration

The logical sequence of the soft PLC process program of the RTU is illustrated in Figure 8.2 as a flow chart. The program starts with initializing and testing the system availability and health status. It reads the current positioning information of the machine as well as the status of the inputs from primary sensors. It executes the RTU process program while monitoring any alarms or malfunction signals for an emergency stop. The RTU events, logs and alarms are sent to the remote SCADA center.

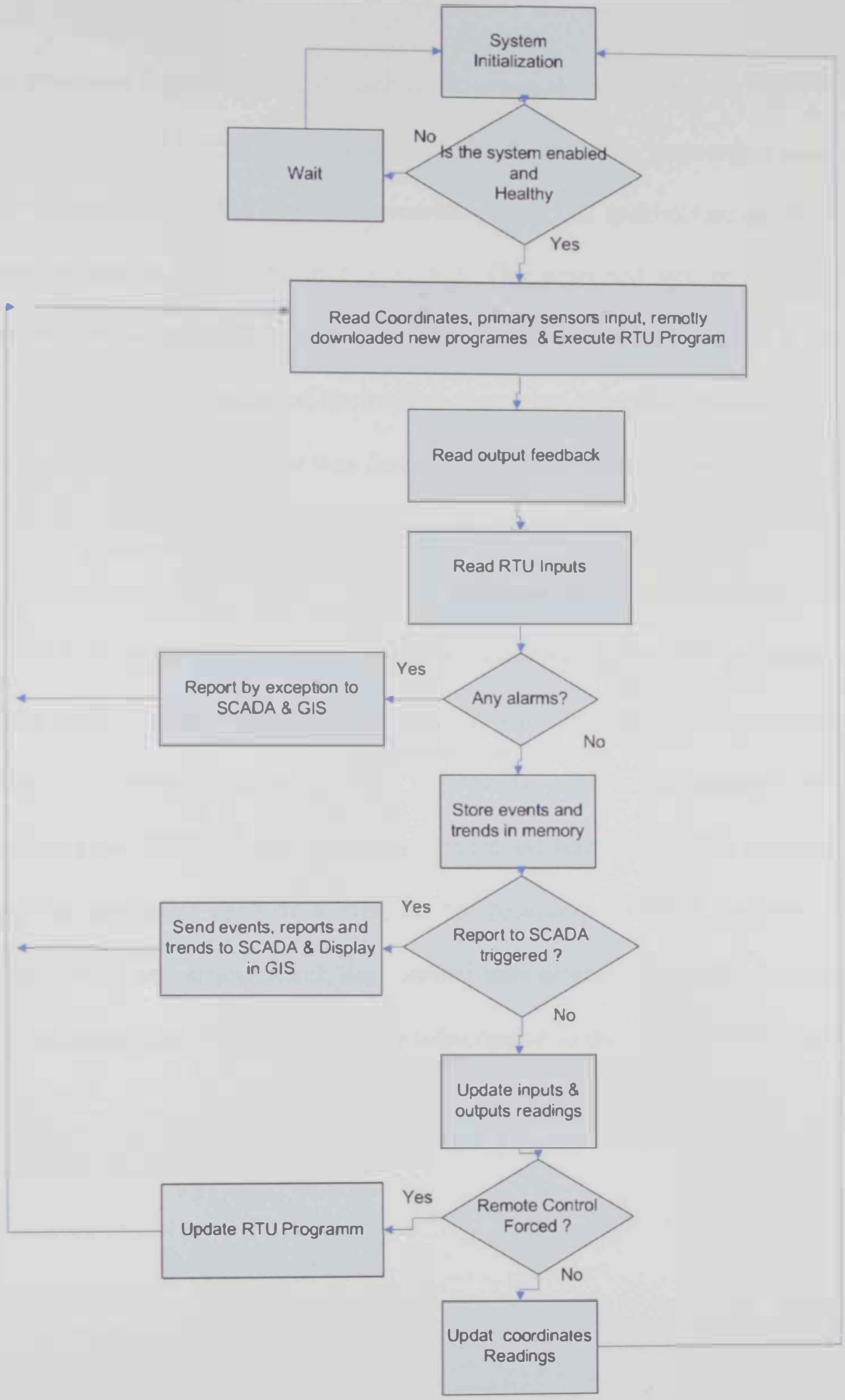

Fig. 8.2 Flow chart for the RTK Network & SCADA/GIS Logic control

Another proposed scenario of field machine automation integrating the RTK reference network with SCADA system is to allow a field operating excavating machines to precisely excavate according to preset accurate plans. The architecture of the proposed integrated system is illustrated in Figure 8.3. The proposed system presents a cost effective solution to automate a process of land leveling and excavation that is carried out in the field by using a group of excavators. Applying the same proposed design for automating the field machine that was discussed earlier; each excavator will be equipped with a roving GPS receiver which is equipped with a wireless Local Area Network (LAN) modem to enable receiving the RTK reference network corrections through the router, which is installed in site. The router is connected to the RTK reference network through an ADLS Internet link. The excavator is also equipped with a pre-programmed RTU which is connected to the SCADA system. To achieve the optimal running cost when utilizing the RTK reference network service, an Internet enabled wireless LAN is proposed on site to be used as a medium for receiving the RTK reference network corrections. With this arrangement, the running cost of communication charges will be only limited to the monthly payment of the subscription to the Internet ADSL service.

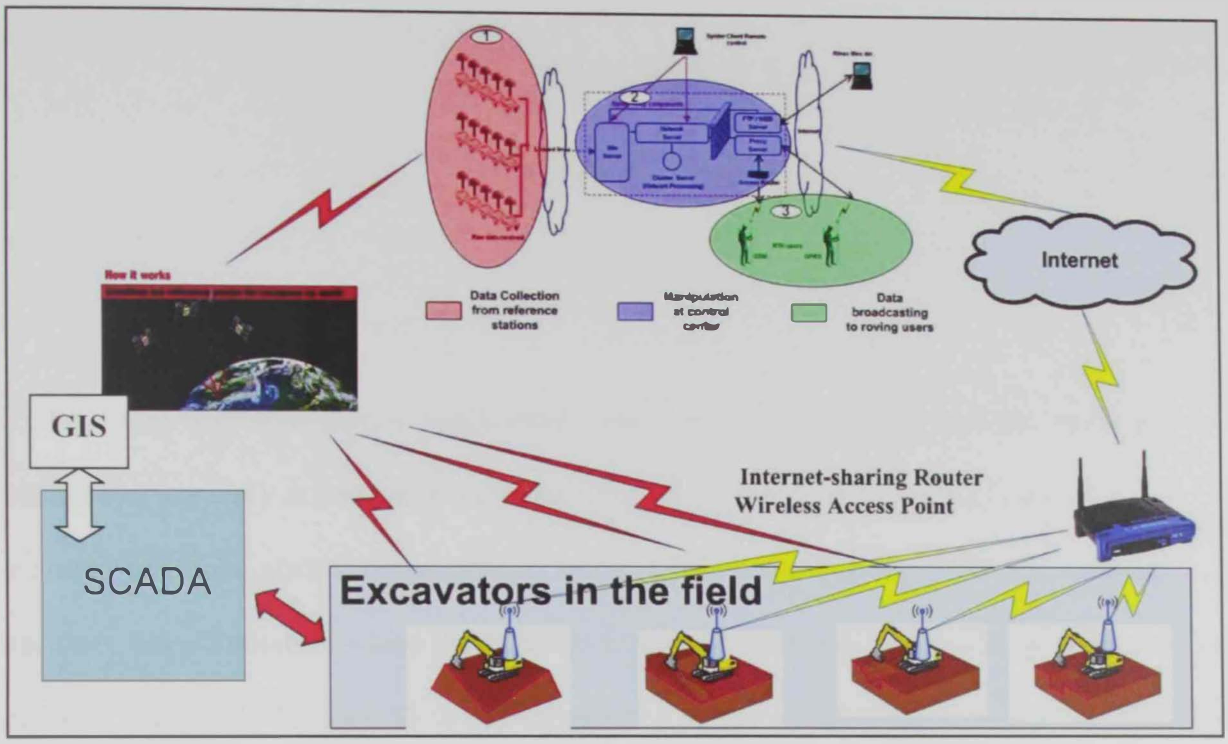

Fig. 8.3 The architecture of the proposed integrated system of RTK Network & SCADA/GIS for machine automation

CHAPTER 9

CONCLUSIONS

Today, new and challenging applications and construction works demand real-time positioning accuracy at sub meter and centimeter-level. The traditional technique of using a single reference station (base-station) and a GPS roving unit to achieve centimeter accuracy has a limitation where the distance dependent error will be significant when the baseline exceeds 10 km as well as the dependence on the availability of the nearby GCP. Instead of relying on a single reference station, many modern cities nowadays establish GPS multi reference stations that can be used for post mission or real-time positioning, which are widely used as Real Time Kinematics (RTK) reference networks. This is due to the benefits of this type of networks of not only providing real-time high quality accurate and consistent GPS positioning at an economical price over a wide geographical area, but also increasing the surveying productivity, reducing capital equipment costs and its ease of use. RTK reference networks services, being utilized by all agencies, can be considered as one of the main components of the infrastructure of spatial data.

GIS can be used as an advanced tool to optimize the design and implementation of the RTK reference networks. In this research, it has been concluded that the use of GIS can help in optimizing the design and implementation process of the newly, under construction, Abu Dhabi RTK reference network. The main considered design parameters for the RTK reference network included: the distance separating reference stations, type and location of sites hosting the reference stations, the communication between reference stations and the system center, and between the computing center and the users.

A field test was performed to examine the positioning accuracy from the available augmentation systems in Abu Dhabi. Testing the beacon measurement correctional services as a GBAS system, and positioning accuracy using OmniSTAR as SBAS system was carried out in March 2007. Results showed that the GBAS system gave better positioning accuracy. However, both systems gave accuracy at sub-meter level.

For Abu Dhabi, there are three options for selecting a coordinate reference system for the RTK reference network: the coordinate system of the old datum, which is based on Nahrawan datum using Clark 1880 ellipsoid, the currently used ITRF2000 coordinate system, which is based on WGS84 Datum, and the new ITRF2005 coordinate system reference which is also based on WGS84 Datum, but in a different measuring epoch. It was concluded that building the Abu Dhabi RTK on either the ITRF2000 or ITRF2005 WGS84 coordinate system reference is the best option. This is due to the fact that this would be the best approach when considering the overall compliance with international reference coordinates frames, consistency with the old and the existing geodetic network, compliance with the old and the existing spatial data and the user needs.

Few approaches were suggested for distributing the reference stations in Abu Dhabi. Those include: maintaining a distance between the user and the nearest reference station of 35 km with/without overlap of the coverage area, maintaining a distance between the user and the nearest reference station of 50 km with/without overlap of the coverage area, and distributing the stations according to the demand of service. It was concluded that for Abu Dhabi RTK reference network, distributing the stations according to demand of service is the best option due its greatest compliance with cost of establishing the system, system reliability, and degree of satisfying service demands and user needs.

In general, reference stations should be installed in buildings that are secured, powered, have access to communication, stable and open to sky. It was proven in this research that GIS tools can help selecting the optimal sites that satisfy the above criteria. ArcGIS tools such as selection by attribute, analysis model builder and 3D presentation were used to help investigating, evaluating and selecting the best building for each reference site. A generic analysis model was developed using ArcGIS model builder to run a series of automated queries governed by the above mentioned criteria against a unique set of data input for each site. ArcScene software module was very useful tool to examine the surrounding buildings for sky visibility and displaying results in a 3D format.

It has been proven in this research that the GIS is a powerful tool to examine and analyze different approaches of the telecommunication infrastructure for the RTK reference network, and next select the best one based on the optimal compliance with performance, reliability, capital and running costs of the network. The options of permanently connecting the stations to the center might include: Corporate Wide Area Network (WAN), government fiber backbone, service provider leased line and Radio Frequency (RF). It was concluded that connecting the reference stations of Abu Dhabi network system to the center using the government network wherever available is the first preferred option. Using the service provider land line connectivity is the second best option, whereas using the RF connectivity represents a reasonable option for the stations that are not reached by either the government network or service provider land line connectivity.

GIS was instrumental when utilizing the spatial 3D analyst extension in order to help finding the optimal location of the repeaters in the case-study of Abu Dhabi network for the areas where RF communication medium was required. GIS 3D analysis tool represents extremely powerful tool to support the optimal decision to properly locate the repeaters due to the fact that it enabled facilitating defining the exact number of needed repeater systems, defining precisely the optimal locations of the needed repeater systems and defining the needed height of each antenna at the stations and at the repeaters.

The roving users can be connected to the center through one of several options of wireless links including: Global System Mobile (GSM), General Pocket Radio System (GPRS), or Radio frequency (RF) and Internet satellite communication. It was concluded that using GPRS as a communication medium in Abu Dhabi is the best option due to the fact that it satisfies the optimal benefits as far as range of coverage, reliability, capital costs and running charges.

Using the VHF communication for broadcasting the RTK reference network information in Abu Dhabi is an important option for future needs. It was suggested in this research to mount the broadcasting station at a high point in Abu Dhabi. This would include the Sky Tower building that will be established in Al Ream Island in 2009. It was concluded by using the GIS tools that the majority of the areas of interest are visible from the Sky Tower, which guarantees that the broadcasting signal will be successfully received.

Integrating RTK reference network service with GIS and advanced applications such as SCADA gives a chance to enhance the current location-based applications and field machine automation with additional functionalities and capabilities. To achieve the optimal running cost when utilizing the RTK reference network service, an Internet enabled wireless LAN is proposed on site to be used as a medium for receiving the RTK reference network corrections. With this arrangement, the running cost of communication charges will be only limited to the monthly payment of the subscription to the Internet ADSL services.

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الطريقة المقترحة توفر تقديم خدمة تصحيح أرصاد نظام تحديد المواقع العالمي بتغطية جغرافية واسعة وبالحد الأدنى من تكاليف التشغيل.

وتقترح الدراسة التطبيق المستقبلي لتكامل نظام الشبكات المساحية المرجعية مع نظم التحكم الآلي والمراقبة ونظم المعلومات الجغرافية. وقد تم إجراء دراسة مقارنة لاستخدام هذه المنظومة في عمليات الحفر الآلي كأحد الأمثلة العملية الهامة، وتظهر الدراسة بأن هذا التكامل يوفر فرص كبيرة لتطوير وتحسين تطبيقات نظم السيطرة والمراقبة الآلية عن بعد لميكنة أعمال الحفر وتسوية الأراضي بكفاءة ودقة عالية وتحقيق توفير ملموس في التكلفة والجهد.

وتكامل ومعالجة وحسن عرض العديد من البيانات المكانية والوصفية والمرتبطة ببعضها البعض مما يساعد على الرفع من كفاءة التصميم للشبكة وتحسين نتائجه.

ويستعرض البحث خيارات توزيع المحطات المساحية جغرافيا وتحديد المسافات بينها ثم يتطرق إلى تحليل هذه الخيارات والتوصية بأفضلها بناء على مدى توافق نتائج المقارنة مع معايير التقويم والتي تأخذ في الاعتبار مدى الكفاءة والتكلفة لكل خيار. وبناء على تحليل ومقارنة خيارات التوزيع المقترحة لشبكة المحطات المساحية في إمارة أبوظبي فإنه يمكن الاستنتاج بأن توزيع المحطات المساحية بناء على احتياجات الاستخدام من حيث دقة القراءات وتوفر الخدمة مع المحافظة على ألا تتجاوز المسافة بين المحطات 100 كم هو أفضل الخيارات كونه يوفر أعلى توافق لمتطلبات المستخدمين مع تحقيق كلفة مناسبة لإنشاء نظام شبكة المحطات المساحية المرجعية.

ويتطرق البحث إلى استعراض إمكانيات أدوات نظم المعلومات الجغرافية في التحليل والمقارنة في المساعدة على اختيار أفضل المباني التي يمكن أن يتم تركيب المحطات عليها حيث يجب أن يكون المبنى حكوميا وثابتا ومتصلا بتغذية منتظمة للكهرباء. كما يستعرض البحث خاصية تحليل النتائج والعرض بالبعد الثلاثي باستخدام نظم المعلومات الجغرافية والتي يمكن أن تكون أداة فعالة في معرفة إمكانية استقبال إشارات الأقمار الصناعية بصورة جيدة من المباني المقترحة. وبناء على نتائج توظيف أدوات نظم المعلومات الجغرافية لدراسة أحد المواقع في إمارة أبوظبي كمثال، فإنه يمكن الاستنتاج بأن الأدوات المقترحة ذات فاعلية وأهمية قصوى لإتمام تحليل البيانات والوصول إلى أحسن النتائج بدقة وسرعة وكفاءة عالية.

أخيرا، تضع الدراسة مقترحات للتحسين المستقبلي لنظام شبكة المحطات المساحية في إمارة أبوظبي من خلال تحسين طرق ووسائط إرسال خدمة تصحيح أرصاد نظام تحديد المواقع العالمي للمستخدمين وتطوير التطبيقات القائمة على تكامل الأنظمة الأخرى مع نظام شبكة المحطات المساحية. وتقترح الدراسة إضافة إستخدام وسيط البث اللاسلكي عبر موجات الراديو ذات التردد العالي لنقل بيانات الأرصاد المساحية من الشبكة للمستخدمين وذلك عن طريق تركيب جهاز البث اللاسلكي في أعلى نقطة في إمارة أبوظبي (قمة برج سكاي تاور، والمقترح بناؤه في جزيرة الريم سنة 2009 م). وبناء على دراسة وتحليل البيانات المتوفرة لهذه المنطقة فإنه يمكن الاستنتاج بأن

ملخص الرسالة

مع زيادة الاعتماد على نظام تحديد المواقع العالمي (GPS) في الكثير من التطبيقات المساحية ورسم الخرائط والملاحة تظهر الحاجة الملحة في كثير من تطبيقات البناء الحديثة في أيامنا هذه إلى قراءات مساحية ميدانية آنية عالية الدقة و لنطاق جغرافي واسع. وحيث أن الطريقة التقليدية باستخدام محطة مستقلة مرجعية واحدة لا يمكن تطبيقها إلا في نطاق جغرافي ضيق لا يزيد عن 10 كم، عوضا عن ضرورة احتلال النقطة المرجعية مما يؤدى إلى زيادة التكاليف نتيجة زيادة عدد الأجهزة المستخدمة والموارد البشرية إضافة إلى تأخر إنجاز الأعمال المساحية الدقيقة، لذا فأن كثير من المدن المتقدمة في الآونة الأخيرة قد بدأت في بناء نظم شبكات المحطات المساحية المتعددة والتي تعمل بصورة مستمرة كبديل أفضل للطرق التقليدية. وتمتاز شبكة المحطات المساحية بتقديم خدمة القراءات التصحيحية المساحية الدقيقة بطريقة آنية متجانسة أفقيا ورأسيا وفي نطاق جغرافي واسع وبأقل جهد ووقت وتكاليف في المعدات والموارد المستخدمة.

تناقش هذه الدراسة إستخدام نظام المعلومات الجغرافية كأداة متقدمة وفعالة في رفع مستوى تصميم وتنفيذ شبكة المحطات المساحية الجاري تنفيذها حاليا في إمارة أبوظبي في دولة الإمارات العربية المتحدة. ويركز البحث على إستخدام وظائف وقدرات التحليل والمعالجة والعرض في نظم المعلومات الجغرافية في تحليل وتقييم وحسن عرض نتائج دراسة خيارات تصميم شبكة المحطات المساحية.

وتشمل الجوانب الأساسية لعناصر تصميم الشبكات المساحية والتي يتم التركيز عليها في هذا البحث على : دراسة مواقع المحطات المساحية والمسافات بينها, دراسة نوعية وأماكن المباني التي يتم تركيب المحطات عليها، دراسة وسائط الاتصال المتاحة بين المحطات ومركز الشبكة ووسائط الاتصال بين المركز ومستخدمي خدمة الشبكة المساحية. ونظرا لصعوبة وتعقيد عملية التصميم لمثل هذه الشبكات فيهدف هذا البحث إلى دراسة دور نظم المعلومات الجغرافية كأداة فعالة في دعم وتحسين أعمال التصميم والتنفيذ لنظام شبكة المحطات المساحية وذلك لكونه يمتاز بإمكانية جمع

جامعة الإمارات العربية المتحدة

عمــادة الدراســـات العليـــــا

برنامج ماجستير الاستشعار عن بعد و نظم المعلومات الجغرافية

عنوان الرسالة

إستخدام نظم المعلومات الجغرافية في التصميم والتنفيذ الأمثل لشبكة المحطات المساحية في أبوظبي – دولة الإمارات العربية المتحدة

اسم الباحث:

مصطفى عبدالله محمد المساوى

المشرفين

م	الاسم	الوظيفة
1	د. أحمد محمود الموافي	قسم الهندسة المدنية والبيئية كلية الهندسة - جامعة الإمارات العربية المتحدة
2	د. سالم محمد غالب عيسى	قسم الجيولوجيا كلية العلوم جامعة الإمارات العربية المتحدة

جامعة الإمارات العربية المتحدة
عمادة الدراسات العليا

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إعداد

مصطفى عبدالله محمد المساوى

رسالة مقدمة إلى
عمـــادة الدراســـات العليـــــا
جامعة الإمارات العربية المتحدة

لاستكمال متطلبات الحصول على درجة الماجستير في علوم الاستشعار عن بعد ونظم المعلومات الجغرافية

ديسمبر 2007