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NETWORK ANALYSIS METHODS FOR MOBILE GIS

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ABSTRACT

The mobile GIS is emerging at the intersection of the evolution of mobility with the development of geoinformatics, it represents the user demand and ambition to exploit the geographic knowledge in decision support everywhere and anytime. Network analysis is a major requirement for many people moving with mobile devices, they need to comprehend their nearby location and manage their trips and movement. This aspiration is facing many challenges in online navigation from the accurate position to the geodata and up to algorithms and solutions for navigation problems.

This research defines the mobile GIS and emphasizes the role of network analysis for mobile users. It differentiates the mobile GIS from other realizations of GIS such as desktop GIS and Web-GIS. Its architecture and main components are presented like wireless communications, geodatabase and indoor/outdoor positioning, in addition to its major applications similar to the acquisition of geospatial data, temporal applications, transportation applications and the use of mobile GIS for knowledge transfer.

The optimal path is a main task in mobile GIS and its computation is based on the graphs mathematical model of the transportation network. This study provides new approach for tackling the Traveling Salesman Problem (TSP) based on the minimum travel cost approach for each node as well the multi-objective navigation problems.

The research covers the mobile geovisualization. The mobile Cartography performs high abstraction in order to display the geodatabase on mobile devices. The holography is a promising new technology for 3D geovisualization for mobile GIS. A new metric system is introduced for absolute geographic coordinates. These concepts are discussed in details.

The new findings include a standalone framework for mobile GIS to enable the mobile GIS functionality in offline mode and the intelligent landmark system to acquire the relative position of moving objects and avoid map matching problem. Also, a new approach is proposed for the solution of the travelling salesman problem based on minimum travel cost of each node and mathematical manipulation for the multi-objective navigation problems. Finally, a metric geographic minute is proposed for geographic coordinates to facilitate the use of geographic coordinates to mobile GIS user.

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As a foreign student in the University of West Hungary, I found from my first days the friendly environment and the assistance from all the professors and colleagues who made me feel at home.

All the visitors to Hungary including myself, we all appreciated the warm hospitality of Hungarian people and how they respect and welcome others.

I really thank my wife Sanaa Issa for her support for the completion of my studies and also my parents for everything.

ACRONYMS

2D	Two Dimensions
3D	Three Dimensions
AGILE	Association Geographic Information Laboratories Europe
A-GPS	Assisted GPS
CRS	Coordinate Reference System
DBF	Database Field
DBMS	Database Management System
DGPS	Differential GPS
EPSG	European Petroleum Survey Group
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GSM	Global System for Mobile Communications: originally from Groupe Spécial Mobile
ICANN	Internet Corporation for Assigned Names and Numbers
ICT	Information and Communications Technology
ITRF	International Tterrestrial Reference Frame
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union
LBS	Location Based Services
MSL	Mean Sea Level
NMEA	National Marine Electronics Association
OGC	Open Geospatial Consortium
PC	Personal Computer
PDA	Personal Digital Assistant
RF	Radio Frequency
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematics
SMS	Short Message Service
TAZ	Traffic Area Zone
TSP	Travelling Salesman Problem

VRS	Virtual Reference Station
WAP	Wireless Application Protocol
WGS84	World Geodetic Datum 1984

ABBREVIATIONS

R_1	Rotation applied to X-axis (degree)
R_2	Rotation applied to Y-axis (degree)
R_3	Rotation applied to Z-axis (degree)
a	Semi-major axis for ellipsoid
b	Semi-minor axis for ellipsoid
B, φ	Geodetic Latitude
dX	Translation in X direction
dY	Translation in Y direction
dZ	Translation in Z direction
f	Inverse of flattening
h	Ellipsoidal (geodetic) height, height above ellipsoid
H	Orthometric (physical) height above MSL
L, λ	Geodetic Longitude
M	Scale Factor
N	Geoid height (height above geoid)
X	Cartesian coordinate in X axis
Y	Cartesian coordinate in Y axis
Z	Cartesian coordinate in Z axis

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1. INTRODUCTION

Network analysis is a major requirement for more than half of the world population moving with mobile devices. The geoinformatics reached a matured comprehensive level as it appears in accurate absolute positioning using GNSS (Global Navigation Satellite Systems), widespread of remote sensing analysis of traditional and hyperspectral images, the use of standards for geospatial data, and the availability of huge commercial and free online softwares and geodatabases such as Google Earth and similars. The mobile GIS emerges at the intersection of the evolution of mobility with development of geoinformatics, in the same time it depends on the exponential advancement in hardware mainly wireless networking and computing, and it represents the user demand and ambition to exploit the geographic knowledge in decision support everywhere anytime. Telegeomatics, Telecartography, and Location Based Services (LBS) were used to refer to the science and art of manipulating geographical information on mobile device.

This new released hardware commonly known as Smartphone, mobile phone, ubiquitous computing, PDA (Personal Digital Assistant) and others is not anymore a mobile phone, it evolved to a mobile computer or mobile device as it will be referred to in this research. This new device comes at the stage of incorporation between the notebook (laptop or portable computer) and the mobile phone. The mobile device inherited all the functionalities from laptops and personal computers, in addition to the mobility and GSM communications from mobile phone, however it suffers only from the small screen size which acts as a confront to geovisualization.

The positioning in mobility is of extreme importance to mobile user, he/she needs to know, store, and analyze their positions. Also, the mobile users are moving with the knowledge of their positions and the geodatabase of the geographic area stored on their mobile devices, and they need to devote this geospatial awareness into network analysis intrinsically trip planning, navigation aid, path tracking, trip management, and realtime traffic information in addition to many other spatial applications.

The network analysis is scientifically based on theory of graphs as its mathematical foundation and their algorithms are known with their hard and non-polynomial complexity which represents a real challenge for the mobile device platform.

1.1 Aims of Study

This study analyzes the mobile GIS and its role and impact in mobility and the importance of network analysis and optimal path in mobile GIS. The aims of this study can be summarized as:

- **Exploit the power of mobile GIS**

  The mobile GIS is a new paradigm in Geography and it has the power not only to deliver the geospatial data to the mobile user everywhere and anytime, but also it personalizes the geographical data and enables the capture of the geographical dimension of the personal information and the ease interaction with geographic coordinates.

  The standalone framework is proposed to enable the full functionality of mobile GIS with complete independence, the intelligent landmark is a new system for the capture of the relative position of the mobile user in realtime, and metric geographic minute is a proposed geographic coordinate for the ease of use of geographic coordinates.

  This research covers the mobile geovisualization and recommends the use of holography in capture and display of 3D geographic objects.

- **Emphasize the role of network analysis in mobile geoinformation**

  The network analysis plays an important role in mobility as it provides the mobile user with the vector structure of the transportation or other networks and enables him/her to discover the different alternatives and places of interests and provides a spatial decision tool and knowledge in realtime. The network analysis provides the quantitative base for the decision support in transportation and public utilities. Also, the study presents a new approach to solve the travelling salesman problem.

- **Analyse the optimal path for mobile user**

  The mobile user is always moving, and his/her time and energy are limited, and it is required to determine the optimal path in realtime to minimize the time and energy consumed in navigating from origin to destination. This study analyses the optimal path and how it can be optimized in mobility with example on Kuwait city.

These aims are discussed in details through this study.

1.2 Scope and Limitations

The scope of this research is limited to the mobile GIS and its applications in network analysis. It covers the mobile GIS definition and its main applications with emphasize on geovisualization, and optimal path in mobility.

The study does not cover all the possible applications of mobile GIS as it is beyond its scope. Also, the algorithms of network analysis neither the Human-Mobile interface are not covered in this study. Another important issue is beyond the scope of this study which is the privacy concern which needs important attention and dedicated studies.

1.3 Content Organization and Overview

The content of this study is organized as follows. Chapter (1) includes the introduction and the aims of the study in addition to its scope and limitations.

Chapter (2) provides a background about mobile GIS and its worldwide situation and the impact of ICT on GIS. It also includes a generic review about the mobile GIS in the scientific literature, a definition for mobile GIS problem and analyzes the current status and trends. In the same time, the motivation of the study will be discussed in this chapter.

In chapter (3), the architecture of mobile GIS is presented in details and it includes the components of mobile platform, communications capabilities for mobile device and the positioning techniques indoor and outdoor. Finally, the proposed standalone framework for mobile GIS is introduced.

The major applications for mobile GIS are presented in chapter (4) and they cover the acquisition of mobile geospatial data, the absolute and relative positioning, the application of mobile GIS in transportation science and safety, the intelligent landmark, and the use of mobile GIS in knowledge transfer.

Chapter (5) covers the network analysis in general and its relation with theory of graphs. The optimal path for mobile user is presented as well a new approach for travelling salesman problem with its algorithm and application. The solution of multi-objective problems in navigation is introduced with application on Kuwait City.

In chapter (6) the geovisualization techniques in mobile device and mobile cartography are presented. The roles of new paradigms such as holography and cartography hypermedia in mobile GIS are discussed. Also, a new metric system for geographic coordinates is proposed.

Chapter (7) summarizes the study and provides the conclusion, and finally, chapter (8) presents the new scientific results in this study.

2. BACKGROUND

The mobile GIS is a new discipline that evolved at the intersection of science and technology. The advancement in Geography, spatial analysis, Cartography and Remote Sensing parallel with the revolution of Information, Communications and hardware give the name of our time to be the Information Age. In this chapter, the evolution of ICT, GIS, and mobile GIS will be briefly discussed with spotlighting the definition of mobile GIS and its challenges.

2.1 Evolution of ICT and GIS

The science and technology triggered a new revolution. After successfully investing the industrial revolution in huge advancement in the human life crowned by the invasion of space, the ICT (Information and Communication Technology) revolution is changing all the aspects of live as it enables the collection, storage, access and analysis of huge volume of information in a well organized manner and easy to reach online via internet browsers.

Evolution of ICT

The ICT (Information and Communication Technology) witnessed a huge development in the last century, starting from computing machines in the mid of 20^{th} century to the contemporary mobile devices in 2010. This evolution was monitored based on Moore's law (Moore 1965). In parallel, the communications developed from telegraphs using Morse code to fiber optics networks connecting voice, video and data cross continent all over the world. A historical milestone in the ICT development was the invention of the internet in 1980 contemporaneous with the production of the 2G mobile phones, then followed by the transition from wired network to wireless network in 1990 when the 802.11 work group was established to standardize wireless communications.

Development in GIS

The history of GIS is complicated, and it is beyond the scope of this research to cover this critical subject. The history of GIS is closely related to medicine precisely in year 1854, when the famous map of water pumps with the spot of deaths due to cholera outbreak in London were correlated by John Snow to locate the contaminated water pump (Vinten-Johansen 2003).

Although the map of John Snow is referred to be the first geographic analysis map, 1000 years before it, Rhazes started his well known process to select the environmentally suitable location for a new hospital in Baghdad. In 915, the famous physician had chosen four locations in four different districts in Baghdad and established a unique biological test to rank the environment suitability in the selected places. Four strips of meat from the same source were placed for two weeks in each location. Rhazes selected the site where the meat had given the least evidence of decay (Browne 2001).

In 2010, the satellite images and mobile GIS were used to fight the wildfires in Russia and floods in Pakistan and save people lives as shown in Figure (2.1).

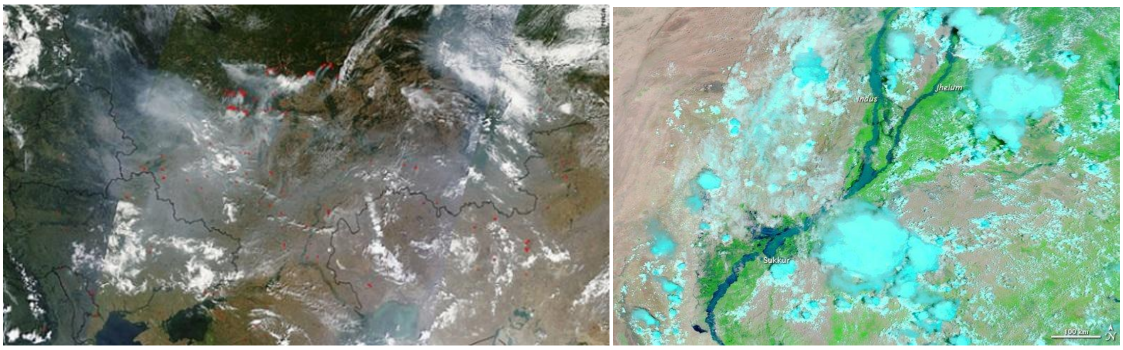

Figure (2.1) Wildfires in Russia (Left) and Floods in Pakistan (Right)

Courtesy DigitalGlobe

2.2 Evolution of Mobile GIS

The mobile GIS is in the core of the ICT revolution. The mobile users are moving in a geographic space and they know their positions and they have access to the wide available geographical data and information. It is essential requirement to exploit these tools online for spatial decision support and for movement management and operations. The main objective of the mobile GIS is to minimize the time and energy of navigation and movement and make them more efficient.

Several reasons motivated the mobility computing in general and mobile GIS in particular. First, the expansion of wireless communication, second the mobile networks are everywhere worldwide, third the exponential advancement in hardware, and finally the availability of geographical databases. The revolution of the PC and internet was dissolved in the mobility revolution that replaced it.

The figures and statistics about the mobile phone and ICT penetration provide a clear vision about the mobility. At the end of 2009, the number of mobile cellular subscriptions had reached around 4.6 billion out of world population of 6.8 billion, and ITU (International Telecommunication Union) expects the number of mobile cellular subscriptions to reach globally five billion in 2010.
(http://www.itu.int/net/pressoffice/press_releases/2010/06.aspx)

The overall mobile cellular coverage reached 86% from urban and rural areas (ITU 2010). Internet users attained 1.8 billion in June 2010.
(http://www.internetworldstats.com/stats.htm)

The number of worldwide mobile cellular subscription doubled from 33.6 in 2005 to 67.8 per 100 inhabitants in 2009. In the same period, number of worldwide telephone land lines dropped from 19.1 to 17.7 per 100 inhabitants.
(http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom.html)

From the above information, over 65% from world population possess a mobile phone and this is more than double the population with internet access and the number of land line telephones is decreasing. The global smartphone shipments reached 54 million units during Q1 2010, accounting for growing a huge 50% from 36 million in Q1 2009. (http://www.cellular-news.com/story/43109.php). It should be noted that the smartphone or PDA will be referred to as mobile device as will be described in Chapter (3) in this research.

Historical Milestone

The United States set of legislation known as 'e-911' (enhanced 911) is a historical milestone in the history of mobile GIS. In 1996, the Federal Communications Commission (FCC) required from all the wireless communication operators to provide the *automatic location information* (ALI) of callers to 911 emergency services. Later in 2001, EU introduced a similar e-112 directive (Mateos and Fisher 2006). This legislation forced the wireless communication operators to invest in locating the position of mobile phone and in order to get revenue from this investment, huge investment in Location Based Service (LBS) started. The LBS business faced disturbance due to its start in standalone track separated from geoinformatics, but later merged back to geoinformatics with the raise of mobile GIS. It can be concluded that displaying maps on mobile device and the determination of its position in mobility were the first two applications for mobile GIS.

GIS, Mobile GIS and Web GIS

The mobile GIS is a new paradigm in geoinformatics that has a unique feature, it is held by the user anytime and everywhere. The mobile user knows its location, has a small screen, and may be connected to the internet or other device/networks or in offline mode. It possesses limited hardware resources such as RAM, storage and processing power. The battery is its main source of power.

From operational aspect, the geoinformatics operation is performed via four components each has a different location. These components are the location of the user and its user interface to the GIS system denoted by U, the location of data repository denoted by D, the location of processor denoted by P, and the area of interest to the user itself denoted by S. In traditional desktop GIS, U=D=P≠ S, where S can be anywhere in the world, this is the classic GIS lab and the field site. In web-GIS, (U=P) ≠ S ≠ D, where the user is accessing the data from a location other than the field site, in another place. In mobile GIS, U=D=P=S, where the user with his mobile device accessing the data in the field (Longley et al. 2005).

Although in some literature they may refer to the same system, two differences exist between mobile GIS and Web-GIS. The Web-GIS does not have any GIS software neither application at the client side, and needs to be connected to the internet for functionality. The mobile GIS requires GIS applications and software to be installed on the mobile device, and from communications aspect, the mobile GIS can be online (connected mode) or offline (standalone mode) (Eleiche and Markus 2009).

Mobile GIS Market

The global market of mobile devices considers mobile GIS as a main stream application for mobile users. In 2007, Nokia the world leader in mobile devices acquired Navteq Company for $8.1 billion which provides digital street maps for about 70 countries. In 2010, Nokia provided the digital street maps for free for the owners of its mobile devices.

(http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aofyAChPI4TM&refer=home). In the same year, the TeleAtlas Company, the competitor of Navteq was purchased by TomTom Company the manufacturer of automotive navigation systems for $2.77 billion.
(http://www.gpsmagazine.com/2007/07/tomtom_acquires_tele_atlas_for.php).

2.3 Mobile GIS in Literature

There are dozens of scholarly refereed and non-refereed journals dedicated to cover several aspects of the geoinformation such as geospatial science, remote sensing and others. Each issue of these journals includes one or more article about mobile GIS. However, there is only one single refereed journal dedicated for mobile GIS, its name is "Journal of Location Based Services" published by Taylor & Francis Ltd. which started in 2007. On the other side, The 7th International Symposium on LBS & TeleCartography was held in Guangzhou, China in September 2010. Rich amount of literature exists and it includes key concepts of mobile GIS such as mobility, telegeoinformatics, mobile mapping services, and Location Based Services (LBS). Karimi has edited the reference "Telegeoinformatics: Location-Based Computing and Services". Reichenbacher has research record in mobile cartography and the adaption of geographic content on mobile devices. There are a lot of other researchers who accomplished a considerable thorough research in different aspects of mobile GIS.

In the late fall of 1994, the University Consortium for Geographic Information Science (UCGIS) was established in the United States. It is a non-profit organization of universities and other research institutions dedicated to advance our understanding of geographic processes and spatial relationships through improved theory, methods, technology, and data. One major goal included the creation of a national research agenda, which was initiated in the summer of 1996 in Columbus, Ohio. This research agenda included 10 main areas for research in GIS. The UCGIS recognizes distributed and mobile computing as a significant area of research because the problems that geographic information technologies are designed to address are better solved in some places than others, and because in a distributed world it is possible to distribute the software, data, communications, and hardware of computing in ways that can convey substantial benefits (McMaster et al. 2004). Also, the National Research Council (U.S.) published the book “IT ROADMAP TO A GEOSPATIAL FUTURE” in 2003 and it included a complete chapter about location-aware computing (National Research Council, U.S. 2003).

Other research agencies in geographic industry stated the mobile GIS among its top listing such AGILE which included mobile technologies as an application area to exploit the geographic information (Craglia et al. 2001).

The geographic information and technology achieved a matured level and currently exist a huge amount of geospatial data not exploited neither accessed (Al Gore 1998).

The huge available geographic content need to be accessed in mobility and used to perform geospatial and network analysis. This research exploits the theories, algorithms, and tools required to use and apply GIS in mobility.

2.4 Mobile GIS Problem

The mobile GIS needs to access the geodatabases whatever public, private or special and with the knowledge of its location, it needs to perform spatial analysis, acquires geospatial knowledge, and obtains spatial decision support in realtime everywhere. As it appears from the definition of mobile GIS problem, there are many limitations and challenges need to be fully addressed for the success of mobile GIS. First, the position of the mobile device and its accuracy and semantic (indoor or outdoor) has to be determined. Second, the required geospatial data relevant to the user, and the geospatial analysis tools needed to achieve user requirements have to be available on the mobile platform. Third, the geovisualization of the data to a user, who is not aware about cartographic science and needs data to comply with his mind understanding about location, has to be presented on the mobile screen.

Criteria for Mobile GIS Problem

1) Geodatabases are matured and available (locally or remotely),
2) Mobile device is aware of its position, and
3) Geospatial functions and algorithms are available on mobile device.

2.5 Analysis of Mobile GIS Status

The mobile GIS as described from the previous discussion is widely spread across the globe, however, it does not yet fulfill the full set of requirements for the mobile users as there are some limitations in the mobile GIS system, and in this section these limitations will be discussed.

No complete solution for navigation

The mobile GIS appeared as an extension for the mobile device itself. The exponential hardware development, the open and growing market, and the increasing demand are all factors motivated the mobile device manufacturers to develop powerful devices to attract more customers and the LBS were among these business development activities which started quickly to accommodate the market and regulation requirements. The available navigation solutions do not share common applications although they share a large portion of geographic data. For example, there are applications for marine navigation and special geographic data, also specific navigation applications for automotives and vehicles, pedestrian applications and indoor navigation systems. As it is clear, there are diversity of navigation applications according to specified usage not a unique system for all.

The transit transportation is a complex system in metropolitan areas, however there is no applications which provide the user about the optimal path to minimize the time and cost of using transit system.

Mobile GIS versus LBS

The LBS was established to pay back the cost of the legalization of e-911 in USA and e-112 in EU. The design of LBS was a business process rather than scientific or engineering process. The LBS is based on the determination of the location of the mobile device based on the cell ID of the mobile network then receives from the user his/her inquiries then returns the answer via SMS or WAP service (Navratil and Grum 2007).

Characteristics of LBS:

1) Position is relative to the cell ID of mobile network
2) The service has a cost paid by user upon request

3) It is a non-voice service based on text
4) No maps are provided
5) The user does not perform any GIS operations

The mobile GIS was developed as an extension to classical GIS systems and is a part from it.

2.6 Trends of Mobile GIS

The mobile device is spreading, and the demand on mobile GIS is increasing. This high demand is a driven power to advance the mobile geoinformatics systems. The advancement will be in several aspects like hardware, geodatabases, positional techniques, wireless networking and algorithms.

The areas of applications will increase also, in both directions vertically and horizontally. Horizontally, new applications areas for mobile GIS will be applied, such as medical applications and education, while vertically, in the penetration of mobile GIS as main tool same as notebook and PC for enterprises with heavy geoinformatics applications like public utilities and oil companies.

From the hardware aspect, mobile device processors will be faster, and it will be smaller size with higher storage, more RAM, and increased resolution for screen. The use of nanotechnology is promising in processor manufacturing. The operating systems for mobile devices face diversity, which make it hardware dependent systems. These trends will make operating systems interoperable and consistent.

The geodatabases will increase in size, and ontology will reduce the gap between geospatial models and allow for data fusion and integrity. As defined by Guarino, "an ontology refers to an engineering artifact, constituted by a specific vocabulary used to describe a certain reality" (Guarino 1998), and its main objective is to enable the interchange of concepts, models and relationships among geodatabases cross platforms (Khun 2005). The accuracy of positioning will increase and seamless integration between indoor/outdoor positioning techniques will be achieved. More functions and new algorithms will be developed and implemented for mobile GIS, such as dynamic shortest path and travelling salesman problem.

The knowledge is hard to detach from knower and hard to model and store. The mobile device will be the tool to connect the knower to the knowledge requester via mobile GIS as the space is a mean for organizing knowledge (Goodchild 2007).

The mobile GIS plays a role in the acquisition of the semantics of the position and movement as it describes the (physical) meaning of its quantitative value. For example, semantic value of a position means these coordinates are in land or sea, rural or urban. Also, the semantic of movement means the reason, direction, purpose of movements, (http://en.wikipedia.org/wiki/Semantic_Web).

2.7 User of Mobile GIS

The internet, geodatabases, and mobile devices changed dramatically the type of the user of GIS. Not anymore the use of GIS is restricted to experts and specialists, now the normal user who can communicates via mobile phone needs to use the mobile GIS, and even more, they are currently the collectors for geospatial data. As example, the US census 2010 used ArcPad as the main device of collecting data, making it as per Chief Geographer- Mr. Timothy Trainor - "by far the largest deployment of mobile GIS in the World " (http://arcpadteam.blogspot.com/2009/07/us-census-2010-address-canvassing.html). The mobile GIS has to target the normal user as consumer and source for geospatial data. In 2009, number of mobile phone subscribers exceeded 4 billion users (http://www.internetworldstats.com/stats.htm).

2.8 Privacy, Human Rights, and Mobile GIS

The Privacy is regarded as a fundamental human right, internationally recognized in Article 12 of the UN Universal Declaration of Human Rights (General Assembly of the United Nations 1948). However, the use of location aware devices captures the private location data according to legalization enforcement as e-911 in USA and e-112 in Europe. The privacy of location is violated by mobile devices, and the protection of the privacy required special considerations (Duckham and Kulik 2006).

This issue as mentioned in article 1.2 in the previous chapter is beyond the scope of this research and it requires a dedicated research.

3. ARCHITECTURE OF MOBILE GIS

The mobile GIS is a typical information system ported by a single user everywhere and anytime. The mobile GIS hosts applications related to geography and it is essential for the access of the geodatabases locally or remotely.

In this chapter, the architecture of mobile GIS is presented which include the hardware, operating system, GIS software, and geospatial data. The communications capabilities and outdoor positioning techniques are analyzed in details.

Components of Mobile GIS System

The mobile GIS system is a micro-level cloning of GIS systems. It has the main components of classical GIS systems with obvious differences. The main components of desktop GIS are hardware, software, data, applications, and users.

The mobile GIS has the same GIS components, mobile device as hardware, light GIS software, limited data, and special applications.

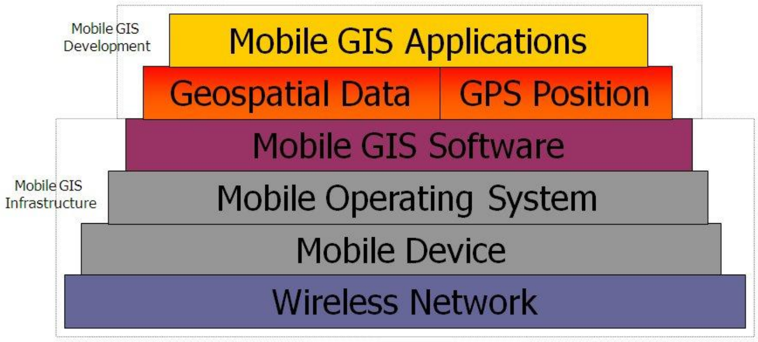

Figure (3.1) General architecture of mobile GIS system

The general architecture of mobile GIS as shown in Figure (3.1) is composed of the hardware of mobile device with its operating system connected to a wireless network. The mobile device has mobile GIS software installed in the hard disk with the required geospatial data. The positioning tool within the mobile device displays the position of the mobile device on the geospatial data. The GIS applications are performed based on the geospatial data, position value and mobile GIS applications. Also, the figure defines the infrastructure of mobile GIS which the user acquires before moving (or in mobility) and it is composed of the wireless network, the mobile platform and the mobile GIS software. The development of mobile GIS is the upper part of the system and it is variable according to the place of interest and the application to the user.

3.1 Mobile Platform

The mobile platform is the combination of the hardware architecture of the mobile device and its operating system, both of them are the base of the mobile GIS that is installed and used on this platform.

Mobile Device Hardware

The mobile device has specific and unique characteristics, first it belongs to a single and unique person, it is a user identifiable device and two persons do not share the same mobile device such as desktops and land line telephones. Second, it is always-on wearable device. Third, the most used device all over the world, almost each adult holds one (Mateos and Fisher 2006). Mobile phone is considered the seventh mass media (wiki http://en.wikipedia.org/wiki/Seven_mass_media). It has several realizations such as smartphone, PDA, intelligent device, handheld navigator and others.

The mobile device is a multi-objective equipment, with fundamental characteristics of small size and GSM connectivity, in addition to modern accessories such as digital camera, video recording, sound recording, GPS, A-GPS, Wi-Fi, Bluetooth, IrDA, FM receiver and transmitter, keypad (mobile phone or qwerty), processor, RAM, hard disk, and a small (touch) screen (2 – 3.5 inch). The mobile device is a cellular phone, executes computer programs, and connects to the internet and/or mobile/computer devices. The mobile device moves on earth, on water, on air, can be used indoor or outdoor.

The mobile device as all other hardware devices witnessed exponential development triggered by high demand at the global level and endless user requirements. It has the three main hardware components of the classic Personal Computer (PC) which are processor, RAM, and storage, in addition to other hardware peripherals and accessories. The trend in hardware development for the last 30 years was in one direction cheaper price, better performance, and smaller in size (Bossler et al. 2005). The nanotechnology play a major role in leading the hardware industry in its direction.

From the Technology point of view, the mobile device is expanding, more users and more applications. The current approach to mobile device is to clone the personal computer capabilities with smaller size to provide mobility or to reduce the gap between the mobile phone and notebook. Another approach is to be considered as a separate device other than known computers and create for it separate environment as done by special mobile web pages to deliver web content to the mobile device. However, considering the mobile device as new separate device is important and constructs a new hardware and operating system capabilities to manage it. As an example, there is a variety of wireless network capabilities using close band width, it will be easier to the user if he/she can manage through one interface all the kind of wireless communications and GPS signals also.

Although this exponential development in all hardware components, one hardware item is required to be larger in size, which is the screen. The screen size of mobile device has huge impact on the internet industry. The web pages and internet browsers were designed for screens of 15” size and larger. The huge content of the internet faced a serious challenge when displayed on the screen of mobile device and this was overcome by designing special pages for mobile browsers, and the geovisualization of spatial data on mobile device also is suffering from the same symptom: screen size. To understand the impact of the screen size on the ICT as whole, we should refer to the critique of Bernard-Lee to ICANN against mobile web as it will split the internet seamless and heterogeneity which were reserved for all its short and important life and for the first time it will make it device dependent (http://en.wikipedia.org/wiki/Mobile_Web).

The significant hardware component to geoinformatics is the GPS receiver of the mobile device. It can be embedded inside the device or separated from it and connected via bluetooth or direct cable. The capabilities of mobile device are augmented by adding GPS chip to it, so that it knows its absolute position. These two features, wireless connectivity to internet, and location awareness, in addition to the advancement in hardware capabilities, smooth the road to mobile GIS, as evolution of web GIS and traditional (Desktop) GIS.

Mobile Device Operating System

The operating system of a computer system is the layer that transforms the hardware components and their attached peripherals to a single unified computer. The operating system of any computer including mobile devices, performs two main functions, the first is extending the machine into a virtual friendly machine where the user and programmer can access its resources without going to a deep level. The second function is managing the hardware complex resources such as processors, timers, memory, I/O devices, and many others (Tanenbaum 2008).

The major operating systems installed on desktop computers are Linux which is open source based on Unix, and Windows family from Microsoft. Both have great impact on the development of operating systems for mobile devices.

The mobile device has its own family of operating systems, some are open source while others are licensed. Figure (3.2) describes the worldwide shipment percentage of different operating systems for mobile devices in 2009. Also, Table (3.1) lists the basic data about the most popular mobile devices.

Almost the operating systems are based on simplified Unix kernel while Windows Mobile family is based on win32 API libraries.

Table (3.1) List of most popular operating systems for mobile devices

Operating System	Owner	Processor	Royalty	Special Features
Symbian	Nokia	ARM, Intel	Free	C++
RIM	Blackberry	Intel	Propriety	QWERTY KB
iPhone	Apple	ARM	Propriety	Touch Screen
Windows Mobile	Microsoft	ARM, Intel	Propriety	C++
Android	Google	ARM, Intel	Free	

The manufacturers of mobile devices are going to make the operating system for their devices more and more free and open source to encourage programmers to develop more applications on it. Symbian from Nokia became open source in February 2010, Android from Google is also open source, while iphone, RIM and Windows Mobile are licensed. In general, the design basics of mobile operating systems are towards multimedia, real time applications and wireless communications.

From 1970, when Bell labs produced the Unix OS (Operating System) and C programming language, no breakthrough was achieved up to present. All other developments in operating systems were based on interfaces and ease of use. Same thing for programming languages, they were built around C language and object-oriented concept. Although Java represents a breakthrough to produce portable executable programs cross-platforms without the need of re-compilation, but it is still not matured. Research in operating system and programming languages are needed mainly for the benefit of parallel processing, security and privacy protection, networking, and embed geospatial data as essential element in operating systems, programming and query languages.

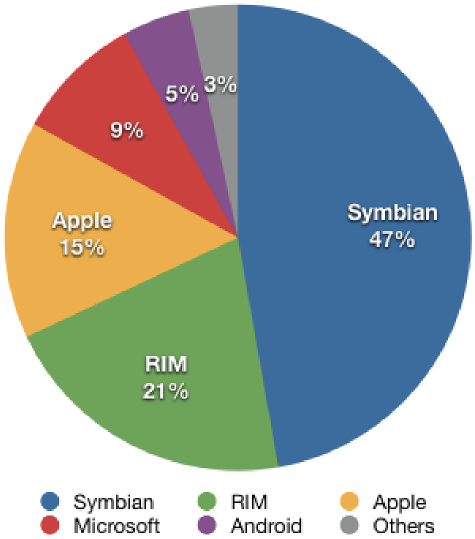

Figure (3.2) Share of 2009 Smartphone shipments by operating system
by Canalys From http://en.wikipedia.org/wiki/Smartphone (accessed 22 Apr 2010)

The law of Moore about the prediction of hardware development (Moore 1965) is also applicable to mobile devices, however, there is no equivalent prediction for operating systems development. The current operating systems for mobile device (and for PC) lack of standards. Although the PC has Microsoft Windows as de-facto standard, there is no similar standard for mobile device. The operating systems for mobile devices (and PC) do not have spatial capabilities and needs new concepts to accommodate the exponential advancement of hardware.

3.2 Communications in Mobile GIS

From the mobile (GIS) applications, there are two distinct connections for the mobile device, the first is peer to peer where the mobile device can work in standalone mode such as receiving current location from GPS chipset or using camera or connecting directly to another device. The second is the cooperative services when it must be connected to a network to be accomplished such as voice connection, web download or online chat.

The mobile device is rich with its communications technologies. Mainly, it has its GSM voice and data communications, in addition to Wi-Fi wireless communication, infrared communications, and bluetooth communications.

In general, all the communications within mobile device is transmitted through the range of RF (Radio Frequency) from the spectrum defined from 0.03 GHz to 3GHz, and the wavelength varies from 100,000 mm to 100 mm as shown in Figure (3.3). Also, the complementary technologies are shown in Figure (3.4).

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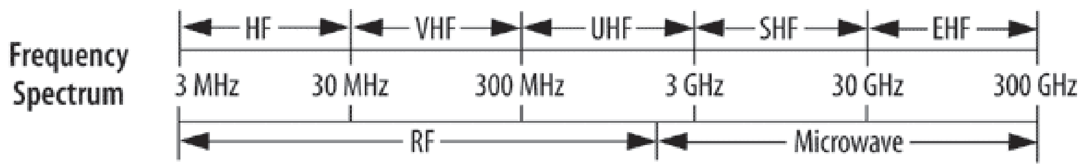

Figure (3.3) The frequency and description of spectrum used in communications

Bluetooth technology operates in the unlicensed industrial, scientific and medical (ISM) band between 2.4 to 2.485 GHz, using a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/sec. The 2.4 GHz ISM band is available and unlicensed in most countries. The Wi-Fi is a wireless data network has the standard 802.11 with several realizations, it uses band 2.4 GHz which is divided into 14 channels as shown in Figure (3.5), and these channels are used for standards 802.11b and 802.11g. The standard 802.11a uses band 5.0 GHz.

There are 14 bands defined for GSM, the most popular are the GSM-900 and GSM-1800. GSM-900 works in the band from 870 to 960 MHz while the GSM-1800 works from 1710 to 1880 MHz. The Infra-Red is the only wireless data outside the RF (Radio Frequency), it has a wavelength of 1500 nm.

The GSM bands enable the mobile device to connect to GIS servers or other mobile devices via cooperative services while the Wi-Fi enables the same communications directly or via Internet Service Provider (ISP). The bluetooth is a short range communications and usually used to communicate the mobile device to standalone GPS receiver or other devices in short range.

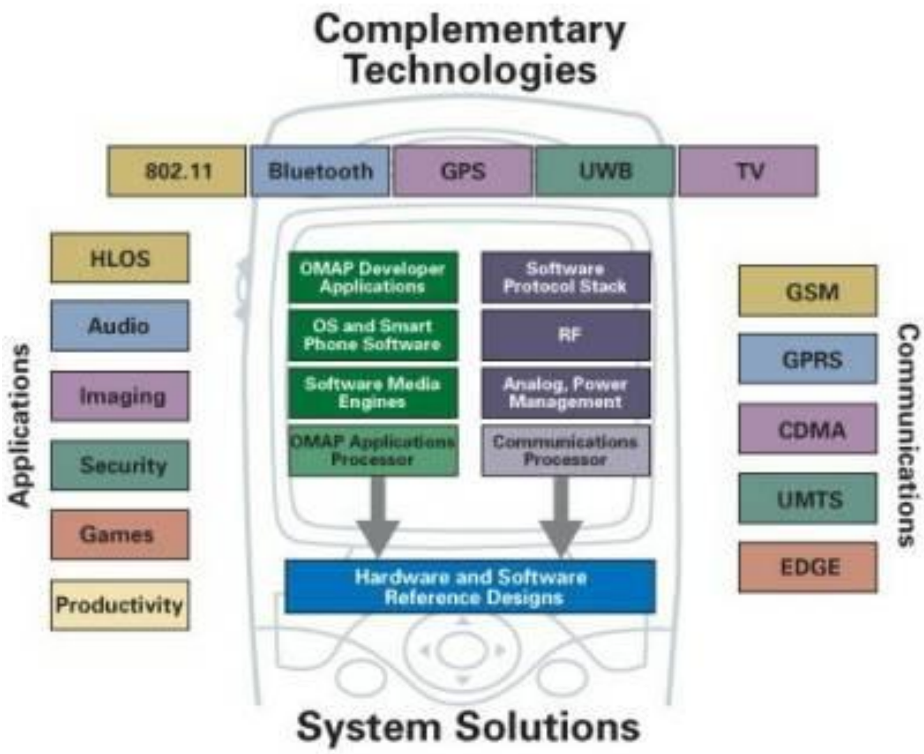

Figure (3.4) Communications options in mobile device

http://www.design-reuse.com/articles/7655/pressure-mounts-in-next-gen-mobile-phone-designs.html

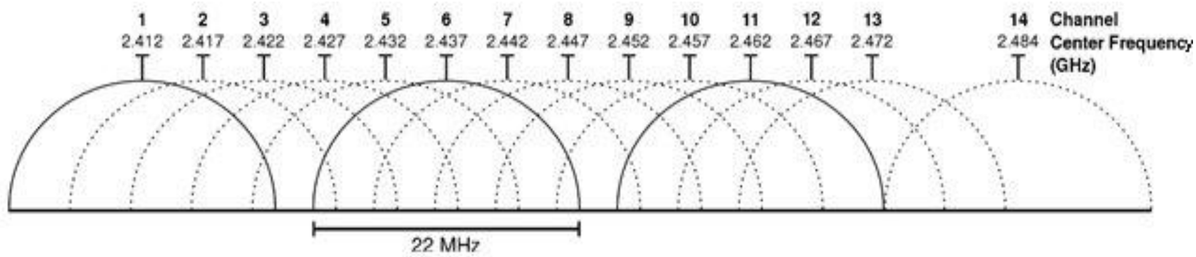

Figure (3.5) The 14 channels of Wi-Fi wireless networking

3.3 Outdoor Positioning

The position of mobile device is an essential requirement for mobile GIS and LBS. The current positional technologies are divided into two major methodologies, one for outdoor where the mobile device is free to air, and the other is for indoor positioning, where the mobile device is inside building or in a tunnel. There are several outdoor positioning techniques for mobile GIS such as GPS, Assisted-GPS (A-GPS), the mobile GSM network, and the position of mobile device can be delivered quantitatively in the format of three or two independent coordinates or qualitatively as near of or close to a landmark or a point of interest.

GPS Positioning

The traditional problem in satellite geodesy is to determine the unknown vector R_P (X_P, Y_P, Z_P) from the information broadcasted by the navigation satellites as shown in Figure (3.6). The point P is occupied by the GPS receiver, and numbers of satellites are observed to solve the unknown vector R_P (X_P, Y_P, Z_P). The GPS antenna receives the signals from satellite S_i at time (t). The vector R_{Si} represents the distance from the earth center of rotation to the satellite S_i at time (t) which is determined from its ephemeris data. The length of the vector B_{PSi} is determined by measuring the signal travelling time from the satellite S_i to the receiver at point P. This length is called pseudo range due to the error in the receiver clock.

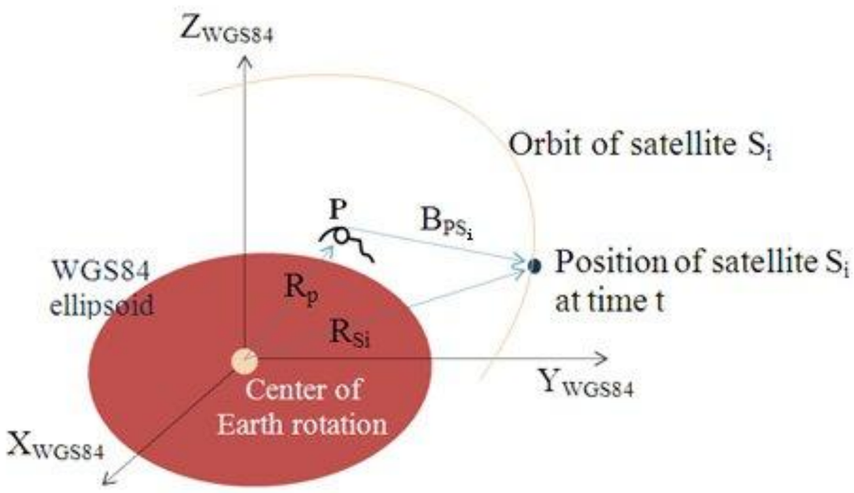

Figure (3.6) Satellite Geodesy Problem

The vector R_P is computed from observing at least four satellites simultaneously (Seeber 2003). As described, the position problem in GPS is solved within ECEF (Earth Centered Earth Fixed) coordinate system which is very close to WGS84 ellipsoid.

The coordinate reference system is defined by a geodetic datum and coordinate system. The geodetic datum is defined by an ellipsoid and its orientation relative to earth, and a prime meridian. The ellipsoid is defined by its semi-major axis (a) and flattening inverse (1/f). The coordinate systems may be Cartesian or ellipsoidal for geocentric and geographic coordinate reference systems respectively.

The vector R_P (X_P, Y_P, Z_P) is converted from Cartesian geocentric CRS into ellipsoidal CRS (φ_P, λ_P, h_P), where

φ_P is the geodetic latitude of point P,

λ_P is the geodetic longitude of point P, and

h_P is the height of point P above the surface of the ellipsoid.

The conversion from geocentric to geographic in the same datum (same ellipsoid) given as function of geodetic coordinates X, Y, Z, is:

$$\begin{bmatrix} \phi \\ \lambda \\ h \end{bmatrix} = \begin{bmatrix} a\tan(Z + e^2 N \sin\phi) / \sqrt{(X^2 + Y^2)} \\ a\tan Y / X \\ \dfrac{X}{\cos\lambda\cos\phi} - N \end{bmatrix}$$

Where b is semi minor axis of the ellipsoid, and the eccentricity

$$e^2 = 1 - \frac{b^2}{a^2}$$

and N is Radius of curvature in prime vertical defined as

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 B}}$$

It should be noted that φ and h need iterations to be computed.

The quantity h_P is also known as the geometrical height or ellipsoidal height, however the most common coordinate system for geographical coordinates is the combined coordinate system, where the point is defined by the geodetic latitude and longitude and the third quantity is the orthometric height, which is the height above the geoid H_P. This combined CRS requires another quantity which is the geoid height N_P for defining the coordinate of point P as shown in Figure (3.7) and equation (3).

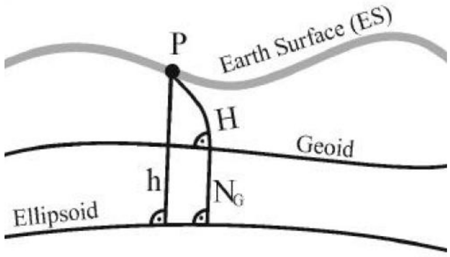

Figure (3.7) Relation between geoid and ellipsoid

$$H = h - N_G \qquad (3)$$

The computed vector R_P has the accuracy of standalone GPS which is in the range from 10 to 30 meters. In order to increase the positional accuracy of vector R_P, a differential GPS correction has to be applied in real time through receiving the correction parameters from a single or a network of permanent or temporarily GPS receivers. These corrections are variable and have to be transmitted in real time.

The Radio Technical Commission for Maritime Services (RTCM) is an international non-profit scientific, professional and educational organization. Its Scientific Committee SC104 is dedicated for Differential Global Navigation Satellite Systems (DGNSS). The SC104 provides standard RTCM 10402.3 and its updated version RTCM 10403.1 for differential correction for DGPS and RTK, in addition to transformation messages such as the required geoid height N in real time so that the orthometric height is computed (Eleiche 2009).

The DGPS correction for the GPS receiver at point P is usually sent in RTCM format which includes the range error and the range error rate to be applied to R_{Si} in Figure (3.7), and then the unknown vector R_P (X_P, Y_P, Z_P) can be calculated.

The RTCM defines another message for providing the geoid height of point of interest to the GPS receiver in the mobile device to provide the position of point accurately within the required combined coordinate reference system.

However, the use of realtime differential correction needs special networks coverage of GPS base stations and special connection for mobile device to receive the corrections and implement it, in addition to software capabilities to handle these procedures. Usually this technique is very expensive and yields 1m or less accuracy.
The mobile GIS can use the RTCM 3.1 for the conversion of coordinates and mainly for the computation of the orthometric height.

GSM Network Positioning

The mobile GSM network is composed from a base station which represents the hub of the network and distributed towers for coverage area of service. This coverage area is divided into overlapped cells, and each cell has its own ID, and the network is capable to determine the CellID where the mobile device is located as shown in Figure (3.8). The cell size varies from 2 to 20 km which is not satisfactory positional accuracy to the mobile device, and it is dependent on the GSM network coverage area (Roxin 2007).

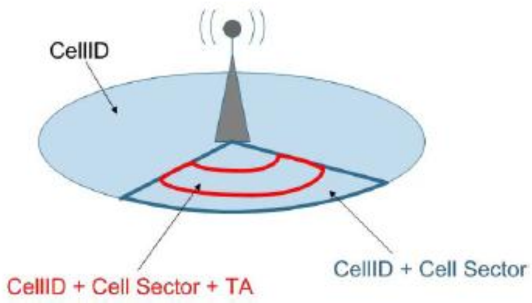

Figure (3.8) Position of mobile device from cell ID

A-GPS (Assisted GPS)

The assisted GPS (A-GPS) is widely considered as an accurate technique to increase the accuracy of GPS observations for mobile device. It is combination between standalone GPS and GSM network technique and usually yield to better accuracy. The mobile device sends an assistance request to the wireless network to know its location. This request is forwarded to the location server with the approximate location of the handset (generally the location of the closest cell site) as shown in Figure (3.9). The location server then tells the mobile device which GPS satellites should be relevant for calculating its position. The GPS chipset collects the proper GPS signals, calculates its distance from all satellites in view and the position is determined. The message RRLP (Radio Resource Location Protocol) defines the exchange message between the mobile device and the GSM network according to the standard 3GPP TS 04.

Figure (3.9) Assisted-GPS

3.4 Indoor Positioning

The GPS positioning is the preferred technology for location determination in open areas, and with differential corrections it leads to higher accuracy. However, GPS does not work inside building or in covered areas. Galileo EU satellite system is designed to overcome these limitations.

Different techniques are used for indoor positioning such as infra red, ultra sonic, radio signals or visible light. Among these techniques, Time of Arrival where the travel time of a signal between a transmitter and receiver is obtained, Cell of Origin where the location of the user is described in a certain cell area around the transmitter, Time Difference of Arrival where the time difference of signals sent from a transmitter is determined at two receiving stations, signal strength measurement for location determination using fingerprinting (e.g. WiFi or WLAN fingerprint) where the signal strength values are compared with previous stored values in a database and the location of the user is obtained using a matching approach. For height determination, barometric pressure sensor can be used for floor determination (Retscher 2007).

Figure (3.10) summarizes the positioning technologies and their nominal accuracy.

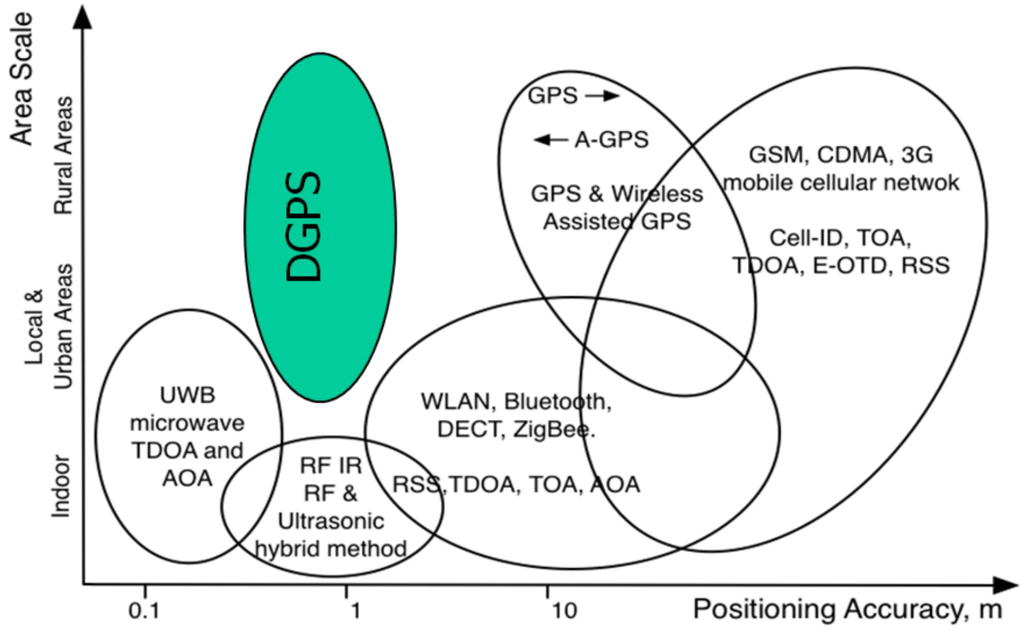

Figure (3.10) Comparison of different positioning technologies

(Courtesy TOPO laboratory, Ecole Polytechnique Fédérale de Lausanne, EPFL)

3.5 GIS Software for Mobile Device

There are huge varieties of GIS softwares that work on desktop platforms, this diversity includes open source and propriety softwares, also softwares for Microsoft Windows and Linux operating systems. However such diversity is very limited on mobile devices where few GIS softwares can be installed on mobile devices. Table (3.2) lists the most popular GIS software for mobile GIS.

Table (3.2) List of most popular mobile GIS softwares

Mobile GIS Software	Owner	Operating System
ArcPad	ESRI	Windows Mobile
PocketGIS	PocketGIS	Windows Mobile
CadcorpmSIS	Cadcorp	Windows Mobile
Recon	Trimble	Windows Mobile
MapX Mobile	MapInfo	Windows Mobile

On the other hand, very limited functionalities exist in mobile GIS software compared to traditional GIS softwares on desktop computers. The geospatial functions that does not exist on mobile GIS softwares are the network and topological analysis, and spatial analysis for remote sensing data due to their huge size.

The GIS software for mobile device require more development to include more functionalities such as network analysis, transportation networks, trip planning and others.

3.6 Geospatial Data

The digital geospatial data are divided into two main types which are the raster and vector data, this classification is according to the technique of their acquisition. The raster data are acquired via satellite imagery or through scanning hardcopy maps while the vector data are acquired using manual digitizing, automated or semi-automated raster to vector conversion, or through importing surveying data from GPS or total station.

Main characteristic of digital geospatial data is their huge size and usually they need high end computers and servers to store them. Another important characteristic is their storage format which is platform dependent. Many organizations such as OGC (Open Geospatial Consortium) have goals to put standards for the geospatial data, however such goals seem to be far in the near future. The geospatial standards are related to the conversion operations, metadata and interoperability not for a universal operational format.

The most used metadata standards are the ISO 19115 from ISO/TC 211which is adopted also by OGC.

Classical Geodatabases on Desktop

The geodatabase refers to digital pools storing geographic (geospatial) data and their attributes. The geospatial record is classically decomposed intro three main components, the absolute location, the geometry of the object, and its attributes. Geodatabase is a realization of GIS, and it can be established as file systems, RDBMS (Relational Database Management Systems), ORDBMS (Object Relational Database

Management Systems), hierarchical database, or network database. Majority of geodatabases are stored in file systems and ORDBMS.

After 1970, when the RDBMS became the main data repository, all the attributes data were stored inside RDBMS engines, and the geospatial data were linked to them. Later in the early nineties, the RDBMS engines enabled the storage of geospatial data inside their relational tables, such as Oracle Spatial engines and others. In the same time, the commercial and open source GIS softwares developed Spatial Data Engines (SDE) for the storage of geospatial data inside RDBMS engines. The storage of geospatial data inside RDBMS engines is accomplished by using the BLOB (Binary Large Object) field in a relational table to store the geometry of geospatial object which is usually of variable length to accommodate the diversity in the size of the geometry field from one object to the other (Longley et al. 2005). Although the advancement in RDBMS engines and their spatial capabilities, many of geospatial data are still stored in binary proprietary files rather inside geodatabase. The geospatial analysis tools for spatial engines are still beyond the capabilities of geospatial analysis tools for binary files, in addition to the performance of binary files is usually faster than spatial engines. The raster data are rarely stored inside geodatabases, due to their large sizes, and their usage requirements. The huge content of geographic data can be accessed publicly via web-GIS, which achieved a matured level such as Google Earth and others. In addition to connectivity, the internet provides unprecedented searchable reservoir for knowledge and information. Geography is not an exception, a vast volume of geospatial data exists on the internet, at the globe, regional, and local levels in addition to astronomical level.

Architecture of Classical Geodatabase

The geodatabases are the main objective and product of GIS projects. They have objectives and metadata which describes the details of the stored data. The logical design defines the entities and objects in the geodatabase and their relationships. The physical design is the realization of the logical design on a specific database engine and depends on it. The coordinate system is an essential component of the geodatabase and is associated with the geometry of the data and described in the metadata. The geospatial data are stored inside the geodatabase, and they are software dependent. Geodatabases can be static or dynamic which are time dependent and store temporal data. The geodatabases store the earth surface topography at different details for land cover, land use, and oceanography in addition to environmental parameters and climatology data. Also, the geospatial data beneath earth surface are stored in geodatabases such as public utilities and geological data (Parent et al. 2006).

Typical Geospatial Data Required For Mobile User

1. Limited portion of geodatabase
2. Detailed data for specific locations
3. Topological data for pedestrian, realtime traffic data, vehicle and public transportation
4. Overview for the whole area of interest
5. Environmental and weather data.

Challenges in Geodatabases

Geodatabases and their technologies achieved a matured level in geoinformatics industry. Problems such as uncertainty, storage and query of temporal data and 3D, interoperability, domain ontology and data fusion, are main challenges within geodatabases for their use within mobile GIS (Li 2006). Regarding mobile GIS, more issues occur such as the compact format for the data and the interoperability between different data in different servers stored in different format.

3.7 Conceptual Framework for Standalone Mobile GIS

The mobile GIS framework is designed to overcome the limitations of the current framework, and extend the functionalities of GIS to mobile users even in offline mode when the mobile user is outside the coverage area or when the GIS server is down.

Current Framework

The legacy framework for connecting the mobile GIS with geographic data is based on the concept of web-GIS, where the data are resident on the server and send when requested to the mobile user (Fangxiong and Zhiyong 2004). In this framework, the GIS functionalities (software) are also resident on the server or can be installed on the mobile device itself (Li et al. 2002).

Proposed Framework

The proposed framework is based on sending the area of interest from the geodatabase in the GIS Server to the mobile device where it will be stored, and the second thing is to build GIS applications for mobile device to access the local stored partial geodatabase in the hard disk of mobile device instead of using the application at the server side (Eleiche and Markus 2009).

As shown in Figure (3.11), the proposed mobile GIS framework is designed to extract the part of interest from the geodatabase in the GIS Server and send it to the mobile device to be stored on its local hard disk, the part is extracted from geodatabase (1), then sent to internet server (2), then moved to communication server (3), then finally stored on the hard disk of mobile device (4). The mobile device will have mobile GIS application to perform GIS operations on the part of geodatabase resident on mobile device.

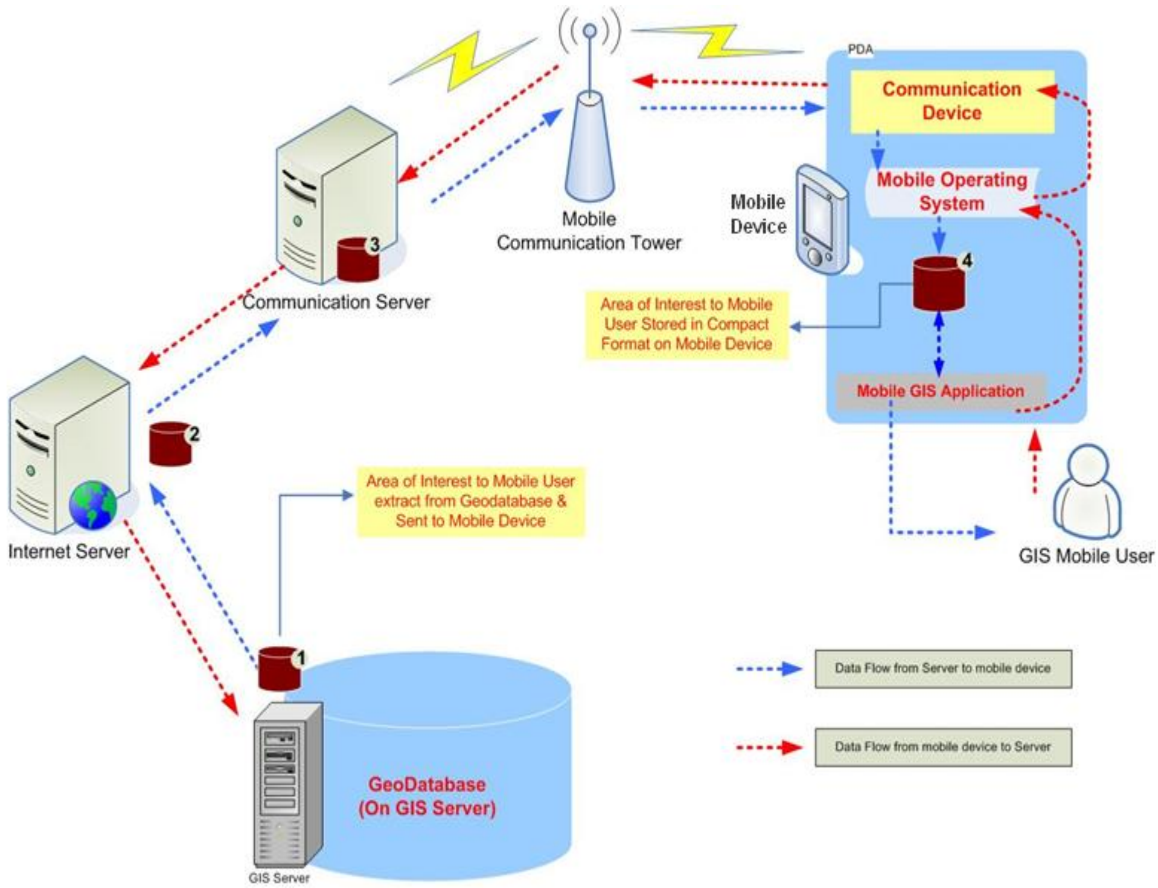

Figure (3.11) Proposed Framework for Standalone Mobile GIS (Eleiche and Markus 2009)

Advantages of Mobile GIS Framework

The proposed conceptual framework for mobile GIS has several advantages, firstly it allows the mobile GIS user to work in offline mode, which leads to reduce the bandwidth load on the communication network and decreases the operation cost. Secondly, the performance of the GIS operation will increase, due to its dependence on RAM-Processor-Hard Disk only rather than depending on the performance of both the communication and GIS servers in the current framework. Thirdly, the GIS user can perform the required analysis, edit the geospatial data, and executes the required tailored GIS applications according to his needs more precisely than the limited GIS functionalities enabled from GIS server to the mobile client. Finally, the security of the mobile GIS user is achieved in the proposed framework, since only the transmission of data from server to client can be monitored not the requests nor the results of mobile GIS operations.

It is evident that the proposed framework will provide for mobile GIS users in case of emergency and loss of wireless communications with servers a valuable tool for navigation and decision support, especially if it is equipped with GPS receiver.

Requirements for Proposed Framework

The proposed standalone framework will require re-engineering the GIS applications to accommodate the limited hardware capabilities of mobile device such as limited RAM, small processor and limited hard disk space. Mobile GIS applications should perform the same functionalities of traditional GIS applications but based on the limited hardware resources of the mobile device. In the same time, it will be needed to implement the mobile cartographic methodology to display geospatial data on the small size screen of mobile device with its limited resolution. New compact geospatial data models are required to reduce the storage size on the mobile device and increase the performance of processing. The seamless interoperability of geospatial data between GIS server and mobile device has to be maintained to enable the exchange of data. Also, the system should provide new update techniques and versioning capabilities for main geodatabase on GIS server due to receiving several versions of the same data from several mobile GIS users. Finally, the development of standards to enable the re-use of data and applications for the immense and heterogeneous base of mobile device users will enhance the use of mobile GIS.

Summary

In this chapter, the mobile GIS was introduced in details, starting from the hardware and operating system, then communications capabilities. The positioning techniques were discussed and how mobile GIS determines its absolute (or relative position). Also, the mobile GIS software and geospatial data were covered and a conceptual framework was proposed for standalone mobile GIS.

The mobile GIS is evolving and it requires more and more functionalities and applications. The new design of GIS systems considers the mobile GIS as an essential part from the GIS system. More data need to be available and updated taking into consideration language localization as well compact format for less storage space. Standards are important requirements for mobile GIS and use of open format for data transfer and interoperability.

4. MOBILE GIS APPLICATIONS

The mobile GIS has a wide range of different applications such as spatial query, proximity analysis, navigation, optimal path, communications and many others.

Generic Taxonomy of Mobile GIS Applications

Taxonomy of mobile GIS applications is confusing due to the diversity of applied fields and heterogeneity of GIS systems and their geographic distribution. The taxonomy of desktop GIS applications can be a start, as it is involved in substantive scientific, engineering, technical, and other disciplines.

There are major classifications for geoinformatics applications which imply to mobile GIS such as military and civil applications, read/update/insert for database operations, and others. Fotheringham and Wilson (2008) mentioned a taxonomy level for geoinformatics, first acquisition and second storage of geospatial data, then geovisualization, and spatial analysis, and finally applications specific such as forestry, environmental, transportation, social and others (Fotheringham and Wilson 2008).

From its name and definition, awareness of location, direction and speed are fundamental information from mobile GIS. Navigation is then the second requirement that comes to the mind of the mobile user, he/she will ask how to go from here to there, how to avoid traffic jam or risk. Geovisualization is a very important aspect of mobile GIS as it is the direct contact between mobile user and the geoinformatics. For professional and experts, the mobile GIS is a contemporary tool for efficient work, such as geospatial data acquisition and temporal applications. For enterprises, mobile GIS is the tool which connects the field to the office. Both normal and expert users will need to receive the geographic knowledge from geoinformatics repository to their location in realtime.

In this chapter, the main applications for mobile GIS will be analyzed, first the acquisition of geospatial data, which is changing the classical image of Geography, then the temporal applications where the time is essential element in mobile GIS applications, third is navigation which is the most popular application for mobile GIS, and finally the use of mobile GIS as a mean for knowledge transfer and acquisition.

This gallery of mobile GIS applications declares the main applications area only not a complete coverage for mobile GIS applications.

4.1 Mobile Acquisition of Geospatial Data

The acquisition of geospatial data is an important application for mobile GIS. The mobile device has an edge over the traditional surveying equipments like GPS and Total station. These equipments collect geospatial in 3D with accuracy, but they do a little in collecting attributes or multimedia data. The main objective of field surveying is the collection of geospatial data as whole, not only geometrical description of geographical features. The data acquisition task includes, in addition to geospatial and attributes, quality control procedures to ensure the compliance of acquired data to the geodatabase requirements like data model, field types, mandatory fields, predefined lists and others. Also, the mobile device acquires both the metadata and uncertainty, which have to be determined and stored to evaluate the accuracy of the data. The mobile GIS provides the necessary tool for acquisition of geospatial data (Pundt 2002). It is connected to GPS so that it stores the geospatial data, and it has the data entry template in digital format as defined in the data model within the geodatabase.

The modern sensor networks, known as geosensors are distributed in many places, and broadcasting their data to receivers. Mobile device communications tools are capable of acquiring and storing these data according to the data model.

The mobile device hardware includes several multimedia capabilities to capture photos, record voice and videos files. The acquired multimedia data are geotagged, where each file has a geographic coordinates associated with it.

Also, receiving data from other mobile devices via Bluetooth or Wi-Fi is a common task. The mobile device is able to receive a huge amount of data in addition to original data already stored in the mobile device.

The acquired data can be stored into the mobile device or sent immediately to another computer. In addition, the mobile GIS has a direct connection to geodatabase server, so that the acquired data are transmitted online and received in the server which starts the process of final quality control before the complete insertion of the data in the geodatabase. This process is usually done using versioning techniques of database engines. US census 2010 will depend on mobile GIS for navigation, adding and removing living quarters, and updating street features (http://www.esri.com/news/arcnews/summer06articles/uscensus-2010.html). It is the favorite tool for massive geospatial data collection.

The mobile GIS has a notable impact on geoinformatics and mapping agencies. Previously, national organizations were the only collectors and suppliers of geospatial data, however, now normal users without any previous experience of geoinformatics can be source for acquisition of geospatial data as he/she carry this device everywhere. Goodchild explained how the geographic world is being turned upside down and inside outside as those national mapping authorities are being challenged by non-authorities using Web 2.0 tools and approaches. The new bottom-up approach is here to stay and people ought to learn to figure out how to work together (Goodchild 2006).

Practically, this volume of data cannot be stored in a single pool for universal access, and needs to be distributed across several servers with reference of metadata to describe the content of the geodatabase.

The acquisition of geospatial data is not restricted to outdoor only, mobile GIS enables the collection of indoor geospatial data inside covered areas.

The Travel Trajectories

The mobile GIS is a tool to acquire the long travelled roads as it is the only available device for this task. As an example, the trajectory of the road from Kuwait to holly Muslim places in Saudi Arabia is used for daily travel between the two countries. This road is subjected to heavy daily traffic and higher traffic volumes in the weekends (Friday and Saturday). The Holly Muslim places exist in Mecca city and Medina City at the East coast of the Red Sea in Saudi Arabia while Kuwait city is at West coast of the Persian Gulf at the other side of the Arabian Peninsula. The round trip from Kuwait to Mecca then Medina and back to Kuwait is around 2850km as shown in Figure (4.1).

Figure (4.1) Road from Kuwait to Mekkah

The mobile GIS plays an essential role in navigation, the first is to collect the navigation path so that it is available for use such as the route from Kuwait to Mecca in the previous section and the other is the trip management and monitoring for the movement along the path. The mobile GIS has impact on transportation, it has the ability to enhance the input data to the design urban transportation networks and enhance the navigation for pedestrian and vehicles.

The mobile device enabled the acquisition of the trajectory of the roads and the important point of interests such as fuel stations, restaurants, and motels. This data can be used for tracking the vehicles along this important road.

4.2 Intelligent Landmark for Mobile GIS

The real geographic world has a complex 4D (3D + time) dimensions, however the classical 2D geoinformatics applications started from projected maps which are static geographic representation neglecting the height (Maguire 2006). The representation of real world dynamic processes in 3D space, such as moving objects, is a contemporary challenge to classical GIS defined in static 2D. The trends in GI (Geographic Information) research are oriented towards 4D (X, Y, Z, t), and the jump from static 2D GIS (X, Y) to dynamic 4D GIS needs to be achieved step by step (Giannotti and Pedreschi 2008). Adding temporal dimension to 2D static GIS will allow managing dynamic processes.

In the previous section, the mobile GIS has the capability to acquire the complete data about a geospatial object such as absolute (or relative) position, geometrical extension, attributes, and multimedia. The mobile GIS adds time stamp to these collected data, which provides a time series data for the object in interest and furnish the geodatabase with a temporal dimension. The modeling of moving objects acquired more interest with the expansion of mobile devices equipped with positioning systems enabling real time determination of location and recording it as trajectory composed from 2D + time (or 3D + time). The trajectory data are required to be stored and analyzed in real time for analysis and prediction of movement.

Tracking and analyzing moving objects is not restricted only to man-made vehicles, ancient scientists monitored the movement of planets and sun, and they established a mathematical model for their repetitive and cyclic movement. Also, our contemporaries are monitoring the movement of migratory birds across continents which is affected by global warming and drought. This monitoring is usually performed via attaching GPS devices and communications equipments around the neck of selected birds, and there are a lot of other examples in zoology to monitor the movement of other animals. Here, the focus will be on the movement of objects (vehicles) on predefined networks such as railways for trains and paved roads for cars.

Processes and Events

Temporal geoinformatics applications monitor and record processes and events. Process systems are for recording the state of an object by continuous observations such as environmental monitoring. Event based systems observe the occurrence of specific state or object such as early warning systems for tsunami or earthquake (Gouveia et al. 2006). Mobile GIS applications for future (or near future) prediction play important role in decision support. It provides modeling and analysis of current situation, and planning for (near) future.

There are two main objectives for modeling moving objects. The first is realtime tracking and future prediction of object position (Wolfson et al. 1998). The second is the query and analysis of stored trajectories. The realtime tracking was analyzed by Wolfson et al., and they described the location of moving object as a linear function of time with two parameters: the position and velocity, so that at future time t, the position of object is determined. The second objective was analyzed by Guting et al. that enabled the analysis and query of past trajectories (Guting et al. 2000).

Temporal applications for mobile GIS can be classified as 1) temporal data acquisition for storing time stamp for geographic objects continuously or discrete, 2) modeling current situation locally on the mobile GIS or at geodatabase server (by sending to it time stamp), and 3) predicting the future (or near future) locally or receiving it from server.

Absolute and Relative Positioning Systems

The mathematical depiction of a location on earth surface can be defined by two ways, the absolute position and relative position. The most used system for depicting the location on earth surface is the absolute position defined as longitude, latitude, and height in a well established coordinate reference system for the observed point. The

GPS is the preferred modern positioning tools for real time and absolute positioning including time stamp for each position e.g. (longitude, latitude, height, time).
The relative positioning is different and uses another technique for depicting the location of an object. The total station is the widely used contemporary positioning tool for relative positioning. Usually, a reference point is selected in the site by the surveyor, and considered as point of origin, and other points in the nearby are measured in Euclidean 3D reference relative to the selected origin (x, y, z).
The relative positioning can be used for small sites, usually 2-3km in size, while in projects exceeding this distance, its use is not feasible.
Although the absolute position of a geographic object is of extreme importance, its main usage is for spatial analysis and relationships with its nearby environment within a geographic database. The human recognition of geographical environment is based on relative positioning rather than absolute positioning (Egenhofer and Mark 1995). The human brain has strong spatial and topological capabilities for relative positioning and very little absolute positioning capabilities (Goodchild and Haining 2004). Human recognition of location information is the relative distance (near, far), direction (up, down, right, left) and placement (inside, outside) (Inoue et al. 2006). A taxi driver can explain how to take the best route to a specific location, and he does not know anything about the latitude of this location. The use of landmarks is a fundamental element in human description of a location. It is important to the normal user to depict the trajectory of his/her trip relative to the road network in order to be useful and meaningful.

Limitations of current system

The position of the train relative to its railway is of higher importance than its absolute positioning, as it indicates the semantic of the movement. The relative position transfers the description and orientation of the position to user, and where he/she is within the surrounding geographic environment.
From the theoretical point of view, the geodatabase is stored in absolute coordinates, and the position of moving object is acquired in absolute coordinates, and then by overlaying both of them, the relative position (theoretically) is determined and the semantic of the geographic position is created, but (practically) this not the case. The uncertainty in the geodatabases and the errors in GPS measurements deviate the relative

position of moving object from its actual position as shown in Figure (4.2). This deviation overloads the system by a map-matching requirement to find the precise relative position of the moving object. This problem is tackled via many map-matching algorithms that convert the absolute position of moving object to its relative one, however, these algorithms have limitations, and usually work in offline mode. They are time consuming, need high processing power, and they prevent the use of mobility data in realtime.

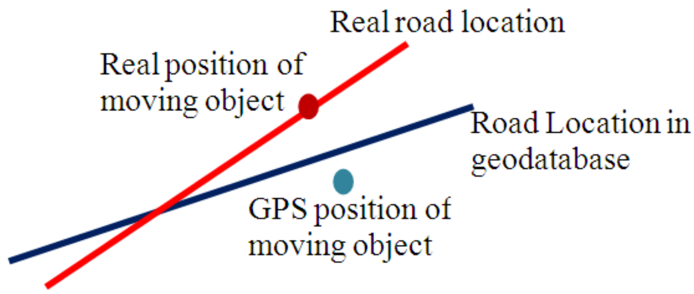

Figure (4.2) The map-matching problem

Intelligent Landmarks

The Bluetooth technology has proven a success in two ways short distance communications, as it is efficient, cheap, and has a lower consumption of energy. The urban transportation network has dense number of landmarks and points of interests. Each point has its own position, name and identifier. By adding a bluetooth device to landmarks so that each landmark is broadcasting its data to other devices and moving objects, the relative position for moving objects can be resolved with higher accuracy. In Figure (4.3), a bluetooth device is attached to a traffic signal, and it is broadcasting its data to moving cars. The transmitted message from landmark will include (ID, Name, Type, X, Y, h, time) as the data model described in Figure (4.4). Adding such a device to landmarks will enable each moving object with bluetooth to receive the transmitted data and store it in order to avoid the map-matching step, and to have the relative position of the object in realtime (Eleiche 2010 b).

The moving object has a bluetooth device that receives the broadcasted message from intelligent landmark. The same message (m) can be received several times by the same moving object but at different time stamps such as (m, t1), (m, t2), and so on. The received message determines the position of the moving object as in the covered area of the bluetooth, which overlays the road network in the position of the moving object. The direction of the movement can be determined from two or more messages received from two or more intelligent landmarks.

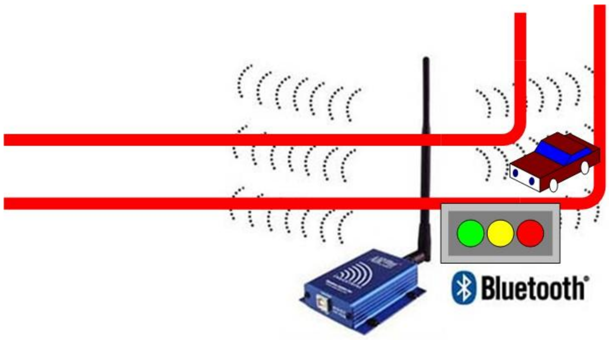

Figure (4.3) The intelligent landmark: Traffic signal with bluetooth device

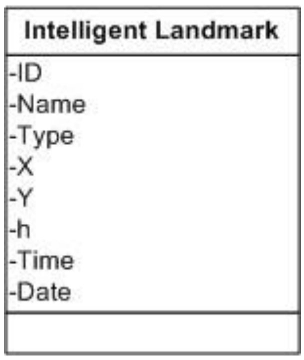

Figure (4.4) Model of intelligent landmark

Advantages of intelligent landmark

The intelligent landmark system has the ability to enhance the positioning of moving objects in realtime as it will deliver the relative position and eliminate the map-matching step. As well, it will ensure the user awareness of the surrounding geospatial environment and directions.

4.3 Transportation

Transportation is a core economic activity and it plays an important role in the development of societies. Indeed, there is a diversity of vehicles that move around the globe, and they generate high demand on roads infrastructure more than the supply capacity. The modern transportation design for highways and railways is focusing on minimizing energy consumption, maximizing safety, with positive impact on the environment (Sayed and deLeur 2005).

Navigation is associated with transportation, it relates to how to move from one location to other sharing the same objective as the design of modern transportation. Navigation refers to a wide range of applications, that includes pedestrian and vehicle navigation, indoor and outdoor navigation, Table (4.1) shows some typical navigation categories.

Table (4.1) Navigation Types

Navigation	Indoor	Outdoor
Pedestrian	Walking inside building or airport	Walking in urban, rural, wild area
Vehicle (car, boat, plan, bicycle, …)	Moving inside factories or airports	Vehicles moving in urban transportation network or free on land, marine, air

Mobile GIS in Transportation Science

The mobile GIS, as advanced tool for collecting, displaying and manipulating geospatial data, will have impact on the classical 4-step model for modeling transportation in urban areas. The objective of this model is to model the transportation volume in urban areas by dividing the studied area into Traffic Area Zones (TAZ) and for each one of them the trip generation and trip attraction are computed according to the socio-economic data. After the determination of the volume of traffic generated and attracted for each TAZ the convenient transportation mode is selected. The last part of this model is to assign the suitable route to the selected transportation mode, and this step will allow measuring the level of service of the urban transportation network (McNally 2000).

In order to apply this model, the socio-economic data for the area have to be collected such as the household, the income, the number of cars in addition to the details of the transportation network to be modeled in topological structure. As the urban areas have heavy population, the complete collection of data is not feasible. So that, a sample data are collected then applied to whole TAZ. The most important parameter in computing the trip generation is the type of the trip from houses such home-work trips. The trip attraction is computed as function of trip generation and characteristics of TAZ. The trip distribution creates the Generation-Attraction pairs for all the TAZ, through complicated empirical algorithms. The role of mode choice is to divide the Generation-Attraction volume on each mode of transportation such as such as private car, taxi, shared taxi, or transit (bus or metro). Finally, the shortest path between each TAZ is determined and it is assigned the volume of traffic for each mode and here the comparison between the capacity of the route and its assigned volume is judged.

This 4-step model started in 1956 when Beckmann, McGuire and Winsten completed their seminal formulation and analysis of an integrated model representing origin-destination, route and link flows on a congested road network, as a function of flow-dependent link costs (Boyce 2004).

The GIS and mobile GIS are able to enhance the 4-step model in several ways. First, the socio-economic data can be computed from census which provides accurate data than the sampled data gathered in traditional methodology. Second, the mode spilt instead of being acquired from survey or questionnaire, the user can store its mode precisely using mobile GIS. Finally, the route used can also be stored using mobile GIS and send to main server. The mobile GIS will enable the contribution of more users for accurate data collection for the model, also the gathered data will be complete. It will include the socio-economic data of the user, the used mode and the assigned route exactly. Another important factor, the user will download the template from the internet, fill it, and submit the data back, which reduce the required field work in data collection. In general, the mobile GIS and GIS will harmonize the transportation application by making it use the main geospatial data instead of working in totally separated environment.

Transportation Safety

The safety in transportation is an important issue and there are many researches tackling this vital problem, and covers all kind of transportation such as pedestrian and vehicles, and also includes safety of transportation in land, in air, in marine and even under water safety for divers and submarines. As the subject of transportation safety is beyond the scope of this research, but the role of mobile GIS in enhancing the safety in train transportation will be analyzed.

Railway accidents are usually catastrophic, and result many casualties. In Egypt, train accidents occurs occasionally, the last deadly accident happened in 24 October 2009, when a train coming with its full velocity crashed the rear of another train that was stopping as shown in Figure (4.5).

Figure (4.5) Train accident in Egypt

This accident caused the minister of transportation to resign, and 18 persons reported dead, and tens wounded. The main cause of this accident was the moving train did not know about the status and position of the stopping train.

Figure (4.6) Two passenger trains collide head on at Halle, Brussels

Figure (4.7) Two cargo trains collide head in Mexico

The same thing happened in Halle near Brussels in Belgium. In 15 February 2010, two passenger trains were collided head-on in peak hour killing 18 and tens reported wounded. One of the trains missed the stop signal as shown in Figure (4.6). In Mexico, two cargo trains collided by head in 16 June 2010 due to a mistake in track operation as shown in Figure (4.7).

From the operation of train movement, the train driver is just guiding it along the railway according to the control signals. The driver is not aware about what is going on around his train or what if other trains are using the same track.

The mobile GIS has significant role in enhancing the safety of train movement as it acts as early warning system for accidents and risk. Such a system can be implemented so that each train broadcasts its position, and receives the position of other trains in the same railway. This can be achieved by displaying the position of the train on the screen along the used railway and enabling the mobile GIS to receive the position of other moving train via a specific radio frequency wave, and when there is a probability of collision, the system can send an alarm to the driver and establish a communication channel between both trains. This proposed mobile GIS early warning system can be used to prevent train accidents.

Intelligent Transportation Systems (ITS)

The Intelligent Transportation Systems (ITS) are concerned with applying the high technologies of information and communications in transportation management and operations. The main concepts in ITS are to combine the position of the vehicle, the information about the transportation infrastructure, the communications and computer capabilities to achieve better transportation operations in real-time (Sussman 1996). From its definition, ITS involve the position of the vehicle and ubiquitous hardware in the transportation management which are fundamental components of mobile GIS.

The traffic applications that provide online information to traffic user via mobile GIS achieved a matured level, but still needs standards to be software/hardware independent. Theory of graphs is the mathematical foundation for navigation in urban transportation networks. The transportation network is defined as nodes connected to links. Many problems in the theory of graph are fundamental to navigation process, and need to be implemented for mobile GIS like shortest path, longest path, Chinese postman problem and others. A new approach for travelling salesman problem was implemented for trip planning (Eleiche and Markus 2010) and will be discussed in the next chapter. The usefulness of applying these applications to mobile GIS is based on three parameters, first the acquisition of mobile GIS to the topological model of the network, second, the update of the network data to reflect the realtime situation, and finally the performance of the mobile GIS application and its ease of use and display.

The mobile GIS requires network topology model for indoor navigation also, these include navigation in horizontal plan or multistory building.

4.4 Knowledge Transfer through Mobile GIS

There are a flood of data and information, this is obvious in geographic domain. Collecting data and producing information is not the main aim of geoinformatics although it is of vital importance, however it is the mean to acquire the geographic knowledge and provide spatial support in decision process and making. The ICT provided the infrastructure for collection, storage and transmission to huge amount of geographical data, but still the main aim and objectives are not achieved.

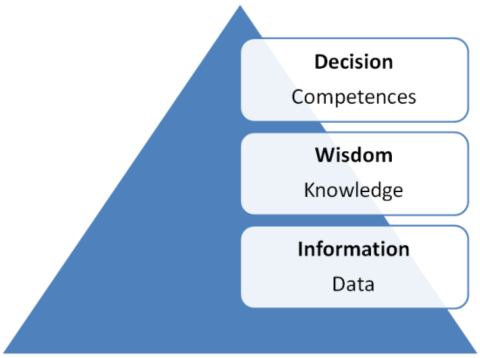

Figure (4.8) Worldwide Learning Infrastructure (Markus 2005)

Acquisition, creation, dissemination and exploitation of knowledge are contemporary dominant features. In the dynamically changing world, the competitiveness depends heavily on the ability to find, for a given problem, the right knowledge in the right moment (Markus 2005) as shown in Figure (4.8).

Russell Ackoff in his DIKW hierarchy, classified the content of the human mind into five categories:

1. Data: facts or figures (geographic data);
2. Information: data that are useful; answers to "who", "what", "where", and "when" (relation between geospatial entities and topology);
3. Knowledge: application of information; answers "how" (e.g. shortest path);
4. Understanding: appreciation of "why" (geospatial patterns and causes);

5. Wisdom: evaluated understanding (principles, rules,).

While information ages rapidly, knowledge has a longer life-span and only understanding has an aura of permanence. It is wisdom that he considers to be permanent. Ackoff indicates that the first four categories relate to the past as they deal with what is known. Only the fifth category, wisdom, deals with the future because it incorporates vision and design. With wisdom, people can create the future rather than just grasp the present and past (Ackoff 1989).

Difference between knowledge and information appears that knowledge entails a knower and intimately related to him, while information exists independently. Knowledge is harder to detach, transfer and quantify from the knower than information. Knowledge requires much more assimilation, while we may hold conflicting information, we rarely hold conflicting knowledge (Longley et al. 2005).

The mobile GIS will request knowledge related to its location, and search knowledge base for relevant knower and ask him to establish communications for knowledge transfer for knowledge that are hard to detach from their owner.

The mobile GIS is an effective tool for knowledge transfer and this role requires deep analysis and experiments with emphasize on emergency cases.

5. OPTIMAL PATH

Network Analysis is an essential requirement for mobile GIS, and it has wide applications in several areas such as transportation, navigation, public utilities and others. In mobility, the network analysis becomes of higher importance especially for emergency cases, severe traffic congestions and public utilities maintenance.

5.1 Network Analysis

The word network is used intensively in many disciplines at the engineering level, such as public utilities networks, transportation networks, and also at social level for social networks. In the engineering side, network analysis is related to physical networks such as communications, water, electrical, gas, in addition to the transportation networks and similar public and private utilities networks. Network analysis includes the planning, analysis, design, construction, management, and operation for physical networks, these can be micro scale networks such as electronic circuit networks, national networks such as local electrical/water networks, or regional networks like cross countries gas/oil pipelines and super mega networks at the international level as for the internet and communications network. The network science emerged from network analysis to include both science and theory that target the structure and behavior of networks. National Research Council (NRC) in the USA defined the network science as “organized knowledge of networks based on their study using the scientific method” (Lewis 2009). Network representations are widely used for problems in diverse areas such as production, distribution, project planning, facilities location, resource management, and financial planning. They provide a powerful visual and conceptual aid for portraying the relationships between the components of every network. In recent years, operations research (OR) developed advanced methodologies and applications for network optimization models. A number of algorithmic breakthroughs have had a major impact, as have ideas from computer science concerning data structures and efficient data manipulation (Hillier and Lieberman 2000).

Mathematical Foundation of Network Science

The networks are physical connected facilities that follow systematic and engineering rules and need to be modeled for analysis purposes. The graphs are the fundamental mathematical model used in network modeling, representation, and analysis, therefore many network problems are direct applications for classical graph theory problems. Graph theoretic problems are representative of traditional and emerging scientific applications such as complex network analysis and data mining, besides graph abstractions are also extensively used to understand and solve challenging problems in scientific computing. Real-world systems such as the internet, telephone networks, the world-wide web, social interactions and transportation networks are analyzed by modeling them as graphs. To efficiently solve large-scale graph problems, it is necessary to design high performance computing systems and novel parallel algorithms. (http://www.graphanalysis.org/)

Theory of Graphs

The theory of graphs has been applied to practical problems since its inception in 1736, when the Swiss mathematician Leonhard Euler solved the very real-world problem of how best to circumnavigate the Bridges of Königsberg, using graph theory. From this time, graph theorists were heavily investigating various theoretical problems (Lewis 2009).

The graph theory is used intensively in operations research, discrete mathematics, combinatorial optimization and network analysis. There are classical problems presented as graphs such as shortest path, longest path, travelling salesman problem, Chinese postman problem, graph isomorphism, four-color problem, and many other problems.

A graph G consists of a set V of vertices and a set E of edges such that each edge in E joins a pair of vertices in V. Graphs can be finite and infinite, when V and E are finite then G is also finite.

Graph G = (V(G), E(G)), where: (1)

Set of vertices V(G) = $\{ v_1, v_2, \ldots, v_n \}$ for n vertices

Set of edges E(G) = $\{ e_1, e_2, \ldots, e_m \}$ for m edges with weights w such that: W(E(G)) = $\{w_1, w_2, \ldots, w_m\}$, where $w \in \mathbb{R}$

Adjacent vertices are a pair of vertices joined by a single edge and the two vertices in this case are incident to the same edge. Adjacent edges are two or more edges having a single common vertex. Figure (5.1) shows a graph G (V, E), where V(G) = {v1, v2, v3, v4, v5}, and E(G) = {e1, e2, e3, e4, e5, e6}.

Order of G = |V| = 5 and Size of G = |E| = 6.

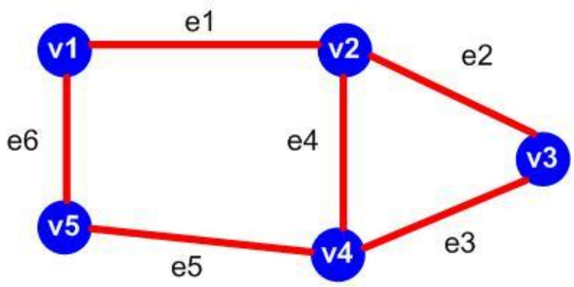

Figure (5.1) Typical graph

Graph Characteristics in Geoinformatics

The graphs were among the main models used in geoinformatics, in both vector and raster Geographic Information Systems (GIS). They were used for modeling the height of surfaces, known also as TIN (Triangulated Irregular Networks) and mainly to represent transportation and other networks in GIS, to perform network and spatial analysis (Mathis 2007).

From the mathematical perspective, graphs have many characteristics such as finite and infinite, plane and planar, dynamic and static, full and partial, Euclidian and non-Euclidian graphs, directed graphs, and other characteristics.

In GIS, the graphs are geographically referenced, and each vertex has a well defined absolute coordinates related to earth. In transportation networks and rare situations in other networks, the vertices are on the earth surfaces, and the common practice in public utilities networks is their installation beneath the earth surface with depth varying from 0.5 to 2.5 meters with exception of the sewage and surface irrigation networks that are constructed in accordance to gravity. The structure of networks is 3D, and they are represented as planar graphs in 2D, and their edge lengths are the Euclidian distances between vertices.

The graphs in geoinformatics are finite not infinite, also they may have dynamic behavior at two levels, at the graph structure itself such that vertices and edges are added and removed dynamically, and in another way, the attribute value associated with the edge is dynamic value such as the time consumed in moving along a road is related to the peak hours of the traffic or the flow (or its direction) in a pipe.

Directions are essential in networks, for example in transportation, the roads can be one-way, two-ways, or blocked, while in electrical networks, cables have a unique direction, opposite to other networks such as gas and water where cycles are allowed and the flow can change direction in the same pipe.

An important issue is special in dealing with graphs in geoinformatics is the graph drawing, as it is stated by Bondy and Murty: "Graphs are so named because they can be represented graphically, and it is this graphical representation which helps us understand many of their properties. Each vertex is indicated by a point, and each edge by a line joining the points representing its ends. There is no single correct way to draw a graph; the relative positions of points representing vertices and the shapes of lines representing edges usually have no significance." (Bondy and Murty 2008).

However, in geoinformatics the situation is different, the graph is a projection of earth surface on a plan, and the location of each vertex is précis and the edge length is calculated. This leads that graphs in geoinformatics are drawn to scale and accordance to their geospatial existence in the real world. Vertices (or nodes) are not just points, they represent a key component of the physical network where there is allowance to choose to go forward to two or more edges (links) or to block the flow there. The same concept for edges, they represent a physical component of the network that must be passed all until its end vertex.

Graphs can be full or partial, full graphs are graphs where each vertex is connected to all other vertices by edges, while not all vertices are connected to each other in partial graphs.

Graph Theory and Network Analysis in Mobile GIS

In mobile GIS, two main objectives are essential for mobile user, the first is the spatial query about place and direction: where am I now? Where is a specific location? The second is the optimal navigation path for a trip from an origin to one or more destinations.

The first objective can be achieved by visual inspection of the display of the current position (relative or absolute) on a map of the area of interest displayed in the background, while the second objective requires the storage of transportation network as graph, and apply the relevant algorithm for the trip purpose.

Applications of Network Analysis in Mobile GIS

Main area of applications of network analysis in mobile GIS can be classified into generic and engineering. Generic applications are mainly navigation and its associated family of related applications, while engineering applications are related to public utilities network applications. In mobile GIS, the navigation applications are based on three fundamentals, first the transportation network, second the current location of the user and the destination location, third the algorithms required to solve the problems and represent the optimal path.

The public utilities applications for mobile GIS have special objectives and usage. They are specific to certain users according to its authority and responsibilities towards the network operations. For example, an operator in the field requires to determine the nearest control device to its position to close the flow of water due to leakage. Such spatial information is not for public use and is restricted to persons in charge.

5.2 Optimal Path for Navigation Problems in Mobile GIS

As mentioned previously, the networks are modeled as graphs within GIS environment, and network analysis problems are modeled as graph problems based on the underlying graph model of networks. The optimal path in navigation is an optimization problem that finds the optimal path (minimum or maximum value) among many alternatives. For example, the optimal path to navigate from origin to destination is modeled as shortest path problem in a graph between two nodes, and trip planning for visiting several places can be modeled as traveling salesman problem. Figure (5.2) displays a graph (G) as defined in (1), with assigned weight values (W).

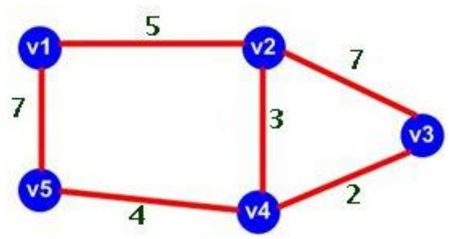

Figure (5.2) Graph (G) with assigned weight values (W)

Problem (1): Optimal Path from Origin to Destination

The origin-destination navigation problem is a classical and main problem in navigation and it is mandatory for mobile GIS. It has multiple realizations and is highly dependent on the nature of transportation network and user mode. The simplest form of the problem is the car user mode using urban network to navigate from one place to another based on minimizing the trip distance, this problem is known in theory of graphs as shortest path problem. The distance is not the only variable which is required to be optimized (minimized), as will be discussed later other parameters are also required.

As mention in (1), the cost of shortest path between two nodes v_i and v_j is C_{ij}, such that Cij = $_{i\ to\ j}$ w is minimum. Figure (5.3) shows the shortest path for graph (G) from vertex v1 to vertex v3 with a cost of 10.

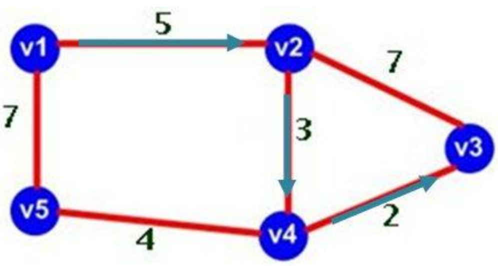

Figure (5.3) Shortest path from v1 to v3

Problem (2): Optimal Path from Origin to Multi-Destinations

The origin to multi-destinations navigation problem is to arrive to a specified destination via predefined intermediate locations, it is known in theory of graphs as minimum connector problem or minimum spanning tree. As mention in (1), the minimum cost path connecting number of nodes from graph G(V,E) such that the cost of path C is minimum. As shown in Figure (5.4), it is required to find the tree from vertex v1 to all other vertices in graph (G).

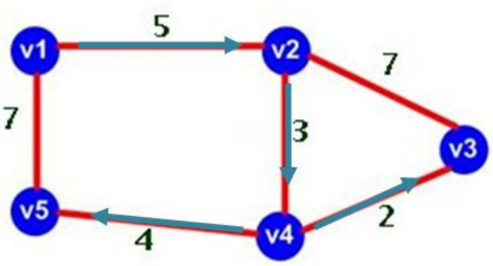

Figure (5.4) Minimum spanning tree for graph (G) from v1

Problem (3): Optimal Path from Origin to Multi-Destinations and Back to Origin

The origin to multi-destinations and return back to origin again, is a navigation problem that appears in many navigation situations for mobile users, such as delivery and collections tasks and trip planning for tourists. The solution for this problem is approached via travelling salesman problem in theory of graphs. As mentioned in (1), the cycle C in graph G(E,V) that visits all the vertices in V starting from one vertex and returning back to it has the minimum cost among all other cycles. As shown in Figure (5.5), the cycle in graph (G) that visits all the vertices from vertex v1 and return back to it again is through v1, with minimum cost of 25.

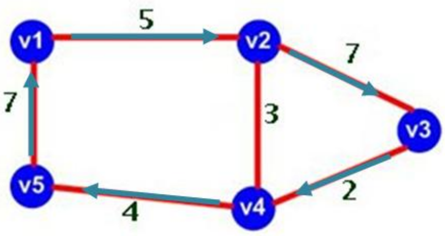

Figure (5.5) Travelling salesman cycle for graph (G)

Problem (4): Optimal Path from Origin to Multi-Streets and Back to Origin

The problem of visiting all the streets from an origin then returning back to the same origin, is another detailed form of delivery/collections tasks where the user is required to pass through all the streets. This problem is known in theory of graphs as Chinese postman problem or explorer problem. As shown in Figure (5.6), the cycle which visits all the edges of graph (G) and returns back to origin v1 with cost of 31.

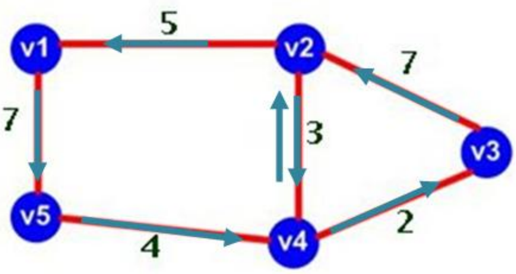

Figure (5.6) Chinese postman path from v1 for graph (G)

Problem (5): Optimal Path for Origin to Destination Using Longest Path

The problem of using the longest path is important for pedestrians who require walking through the longest path from origin to destination for sport purpose for people with limited time. This problem is known as longest path problem in theory of graphs. As shown in Figure (5.7), the longest path from v1 to v3 is through v1, v5, v4, v2, v3 with a cost of 21.

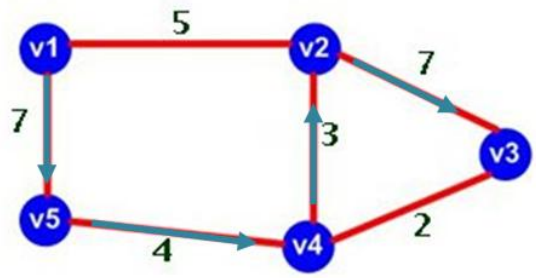

Figure (5.7) Longest path from v1 to v3

5.3 Complexity of Algorithms

The theory of complexity in computer science determines the efficiency and class of the algorithm used to solve a problem. Regarding navigation problems, they are solved by means of algorithms which are developed as computational functions and it is important to evaluate the complexity of these algorithms to allocate the required hardware resources required to solve them, taking into consideration their limitations in mobile devices, and in the same time measure their time complexity.

The big Oh notation “O” is usually used as a measure to the time and storage required for solving the algorithm by using a simpler function to predict the behavior of algorithm on the theoretical Turing machine. There are many classes for algorithms complexity, among them two fundamental classes are P and NP classes. Class P refers to algorithms that can be solved in polynomial deterministic time versus NP class which refers to polynomial non-deterministic time (Arora and Barak 2009).

The class P consists of all those decision problems that can be solved on a deterministic sequential machine in an amount of time that is polynomial in the size of the input. The class NP consists of all those decision problems whose positive solutions can be verified in polynomial time given the right information, or equivalently, whose solution can be found in polynomial time on a non-deterministic machine. (http://encyclopedia.kids.net.au/page/co/Complexity_classes_P_and_NP)

The NP class of problems has two main subclasses, the NP-complete and NP-hard problems. The needed time for NP-complete algorithms is function in the exponential of the problem size.

Using big Oh notation, P problems are solved using algorithms which complexity is O(cn), where c is constant and n is the size of input, while algorithms for NP problems are $O(c^n)$.

Unfortunately, the problems of graph theory, which model the main navigation problems, are the classical examples for highly complex computational problems. The travelling salesman problem is the classical example for NP-hard and NP-complete problems, same as longest path problem. However, Dijkstra's algorithm for shortest path has the complexity of $O(|V|^2)$ or O(|V| log|V|), depending on edge storage in memory. The exact brute force algorithm for travelling salesman problem is O(n!), the heuristic and approximation algorithms are widely used to solve many navigation problems. The next section proposes a new approach for travelling salesman problem.

5.4 New Approach for Travelling Salesman Problem (TSP)

The proposed approach for TSP is based on minimizing the cost of passing through each node, which means minimize the cost of arrival to the node and the cost of departure from it. Connecting these minimum traveling costs for each node should theoretically lead to the required least cost tour (Eleiche and Markus 2010).

A full graph of N nodes (with number of edges equals (N *(N-1)/2) (Gries and Schneider 1993) with edges of equal cost C, the tour cost is (N * C) and there are ((N-1)!) tours satisfying this cost (Bonaydi et al. 2008).

For asymmetric graphs, where $C_{ij} \neq C_{ji}$, the TSP states that there are ((N-1)!) tours visiting all nodes (each node once) and returning to the origin, but the required is the tour of least cost. This can be achieved by visiting each node with by its least travel cost. The least travel cost for each node is the sum of the cost of incident edge with minimum cost and cost of outgoing edge with minimum cost.

$$C_i = \min C_{incident} + \min C_{outgoing} \quad (2)$$

where

C_i is the least travel cost of node i,
$C_{incident}$ is the edge cost from node k to node i, and
$C_{outgoing}$ is the edge cost from node i to node j.

In ideal situations, which is very rare, the aggregation of the sequence of minimum travel cost (nodes: k, i, j) for each node will be the tour with least cost. Consider the following full asymmetric graph with 5 nodes in Table (5.1),

Table (5.1) Cost of edges (Origin-Destination Matrix)

	1	**2**	**3**	**4**	**5**
1	9999	5	10	10	4
2	8	9999	9	15	22
3	14	17	9999	11	1
4	6	28	14	9999	9
5	7	13	14	16	9999

Minimum $C_{incident}$ for node 1 will be $C_{4,1}$ of edge (4,1) which has the least cost to arrive to node 1, while the minimum $C_{outgoing}$ of node 1 is $C_{1,5}$ which has the least cost to move from node 1.

By other words, node 4 is the closet node to arrive to node 1, and node 5 is the closet node to depart from node 1. In order to visit node 1 with minimum cost, we have to start from node 4, then visit node 1, and finally exit to node 5 as shown in Table (5.2).

Table (5.2) Minimum travel cost of each node

$C_{incident}$	**From**	**Node**	**To**	$C_{outgoing}$	C_i
6	4	**1**	5	4	10
5	1	**2**	1	8	13
9	2	**3**	5	1	10
10	1	**4**	1	6	16
1	3	**5**	1	7	8
31				26	57

From Table (5.2) the sum of $C_{incident}$ is 31 and the sum of $C_{outgoing}$ is 26, this means that the least cost tour will exceed 31, and some nodes (node number 2 and 4) have same node as origin and destination which does not conform with TSP definition and it will be adjusted using the second minimum cost as shown in Table (5.3).

Table (5.3) Adjusting minimum travel cost for node 2

$C_{incident}$	From	Node	To	$C_{outgoing}$	C_i
5	1	**2**	1	8	13
13	5	**2**	3	9	22
5	1	**2**	3	9	14
13	5	**2**	1	8	21

The first row is the minimum travel cost for node 2, it is from node 1 to node 2 then exit to node 1 again. As this is not allowed by TSP definition, the second row displays the next lower cost value to incident to node 2 and the second value to exit from node 2, which are from node 5 to node 2 then exit to node 3. The minimum travel cost between combination of the first and second rows in Table (5.3) are compared to compute the minimum which is to start from node 1 to node 2 then exit to node 3. Same procedure will be applied on node 4 also.

Table (5.4) Adjusted minimum travel cost of each node

$C_{incident}$	From	Node	To	$C_{outgoing}$	Sum
6	4	**1**	5	4	10
5	1	**2**	3	9	14
9	2	**3**	5	1	10
11	3	**4**	1	6	17
1	3	**5**	1	7	8
32				27	59

From the analysis of Table (5.4), the sum of $C_{incident}$ is 32 and the sum of $C_{outgoing}$ is 27, this means that the least cost tour will exceed 32.

The solution from incident side is closer to the least cost tour because it has higher cost. In our case, the “From” column misses node (number 5) and repeated twice incidence from node 3. In this case, node 3 is a source node, which has more than one incidence in

the adjusted minimum cost table. Same thing for "To" column where nodes 2 and 4 are missing and nodes 1 and 5 are repeated twice, which means that nodes 1 and 5 are sink nodes. It is also obvious that the solution of incident nodes is closer to required tour since it has only one missing node while the outgoing solution has two missed nodes.
The source node is cheaper to move away from it and sink nodes are cheaper to arrive into it.
The least cost tour is closer to the higher value of the sum of $C_{incident}$ and $C_{outgoing}$, and it can be achieved by substituting the repeated nodes in the "from" column (or in "To" column in case ($\sum_{1}^{N} C_{outgoing} > \sum_{1}^{N} C_{incident}$) by the missed nodes. From Table (5.4), the following are concluded:

1. $\sum_{1}^{N} C_{outgoing} = 27$
2. $\sum_{1}^{N} C_{incident} = 32$
3. $\sum_{1}^{N} C_{incident} > \sum_{1}^{N} C_{outgoing}$
4. Cost of least tour > 32
5. By substituting the repeated nodes (node 3) in "From" by the missed node (node 5), the least solution is achieved.

The required tour will be achieved by connecting the solution from incident side with minimum cost.

Table (5.5) Initial start

$C_{incident}$	From	Node
6	4	**1**
5	1	**2**
9	2	**3**
11	3	**4**
1	3	**5**
32		

From Table (5.5), the path (4, 1, 2, 3) includes the least travel cost to move from node 4 to node 3. Node 3 has two options: first to return back to node 4 which is not allowed by

TSP definition (it was visited before) and the second to move to node 5 which is allowed as shown in Table (5.6).

Table (5.6) First Convergence

$C_{incident}$	**From**	**Node**
6	4	**1**
5	1	**2**
9	2	**3**
1	3	**5**
11	3	**4**
32		

Current solution has least path from node 4 to node 5 and it needs to return back to start node 4, then we have to change last edge to be from node 5 to node 4 as shown in Table (5.7).

Table (5.7) Second Convergence

$C_{incident}$	**From**	**Node**
6	4	**1**
5	1	**2**
9	2	**3**
1	3	**5**
16	5	**4**
37		

The current example has small size N = 5, and by applying the direct solution to calculate the least cost of all tours (total number of tours = (N-1)! = (5-1)! = 24 tours), it was found that the least cost is 37, and the tour is (1,2,3,5,4,1).

The Asymmetric Travelling Salesman problem (ASTP) is the general case for the TSP. However, the general case with large size sets is hard for exact algorithms (Gutin and Punen 2002). There are varieties heuristic algorithms, and they can be roughly partitioned into two classes: construction heuristics, and improvement heuristics. Construction heuristics build a tour from scratch and stop when one is produced, while improvement heuristics start from a tour normally obtained using a construction heuristic and iteratively improve it by changing some parts of it at each iteration (Gutin 2003).

The minimum travel cost for each node is a new approach for solving the general case of TSP for the real problem itself (not for an easier problem like cutting-plane), and it does not search for edges with minimum cost like other approaches. This approach focuses on the minimum cost to go through the node (the least incident cost and least outgoing cost) and then determines a level below the lower bound and starts to unify the directions of paths for the minimum travel cost of each node minimizing the TSP total cost.

5.5 Algorithm for TSP Problem

In the previous section, the solution for the new approach was presented on a sample problem. In this section, the algorithm for this solution is presented, and it has the following steps:

1) Create node, link, and sub-graph arrays
2) Assign a status of "new" for all nodes
3) Create the minimum travel cost array
4) Exclude the part with minimum sum and start from the maximum sum
5) Join possible nodes from minimum travel cost array
6) Fill sub-graph array with joined nodes
7) Update the status of nodes to be "new" for non-processed nodes, "start" for nodes at the start of sub-graph, "end" for nodes at the end of sub-graph, and "finished" for nodes at the middle of sub-graph.
8) Create a new minimum travel array by excluding "finished" nodes considering the status of nodes
9) Exclude the part with minimum sum and start from the maximum sum
10) Join possible nodes and sub-graphs from minimum travel cost array
11) Go to step 8 until the existence of single sub-graph which is the required solution of the problem

Figure (5.8) shows a diagram for the steps of the algorithm

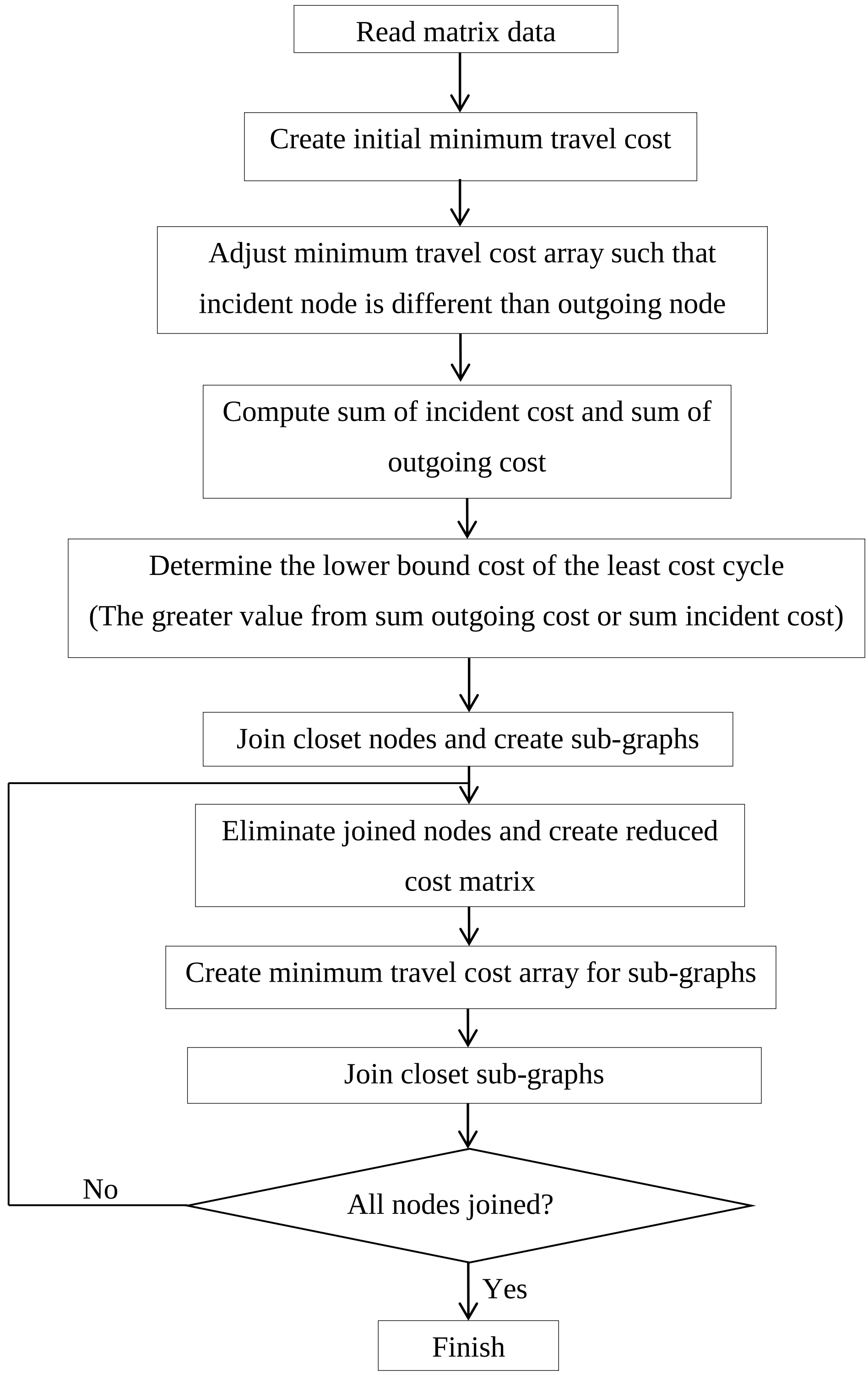

Figure (5.8) Diagram for the minimum travel cost algorithm

Applying the TSP Algorithm

In order to apply the minimum travel cost algorithm on the problem in Table (5.1) and its minimum travel cost array in Table (5.4), it is required to create and initialize two new arrays: the Node_Array and the Graph_Array as shown in Tables (5.8) and (5.9) respectively. Each node has one of four status:

1) Status = 0, (New or Virgin), not processed yet
2) Status = 1 , start-node of sub-graph
3) Status = 2, end-node of sub-graph
4) Status = 3, finished or processed node, which is intermediate in a sub-graph

Table (5.8) Node_Array initialized

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
0	0	**1**	0	0	0	0
0	0	**2**	0	0	0	0
0	0	**3**	0	0	0	0
0	0	**4**	0	0	0	0
0	0	**5**	0	0	0	0

Table (5.9) Graph_Array initialized

Sub-Graph ID	Start Node	End Node
0	0	0
0	0	0
0	0	0

Start of solution, connect node 4 to node 1 and create sub-graph (1) as shown in Figure (5.9) and updated in Tables (5.10) and (5.11).

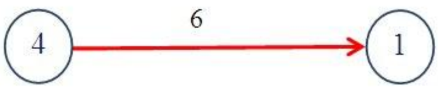

Figure (5.9) Creation of sub-graph (1)

Table (5.10) Graph_Array updated

Sub-Graph ID	Start Node	End Node
1	**4**	**1**
0	0	0
0	0	0

Table (5.11) Node_Array updated

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
6	**4**	**1**	0	0	**2**	**1**
0	0	**2**	0	0	0	0
0	0	**3**	0	0	0	0
0	0	**4**	**1**	**6**	**1**	**1**
0	0	**5**	0	0	0	0

Second step is to connect node 2 to the end of sub-graph (1) as shown in Figure (5.10) and updated in Tables (5.12) and (5.13).

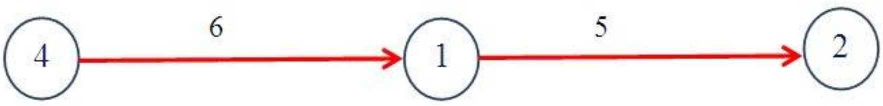

Figure (5.10) Join node (2) to sub-graph (1)

Table (5.12) Graph_Array updated

Sub-Graph ID	Start Node	End Node
1	**4**	**2**
0	0	0
0	0	0

Table (5.13) Node_Array updated

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
6	4	**1**	**2**	**5**	**3**	1
5	**1**	**2**	0	0	**2**	**1**
0	0	**3**	0	0	0	0
0	0	**4**	1	6	1	1
0	0	**5**	0	0	0	0

After that, the node 3 is connected to the end of sub-graph (1) as shown in Figure (5.11) and updated in Tables (5.14) and (5.15).

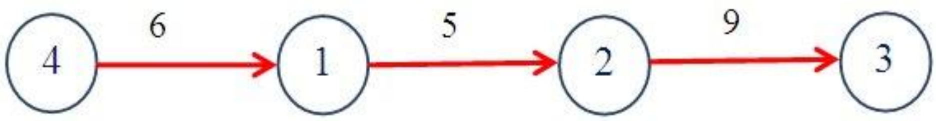

Figure (5.11) Join node (3) to sub-graph (1)

Table (5.14) Graph_Array updated

Sub-Graph ID	**Start Node**	**End Node**
1	**4**	**3**
0	0	0
0	0	0

Table (5.15) Node_Array updated

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
6	4	**1**	2	5	3	1
5	1	**2**	**3**	**9**	**3**	1
9	**2**	**3**	0	0	**2**	**1**
0	0	**4**	1	6	1	1
0	0	**5**	0	0	0	0

And then, there are two options: From 3 to 4, which is refused to prevent closed loop, and from 3 to 5, is allowed and connected as shown in Figure (5.12) and updated in Tables (5.16) and (5.17).

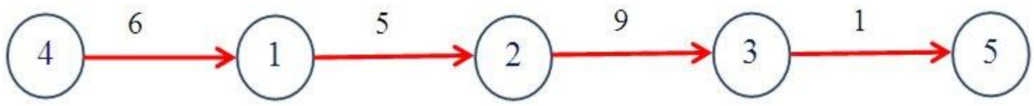

Figure (5.12) Join node (5) to sub-graph (1)

Table (5.16) Graph_Array updated

Sub-Graph ID	Start Node	End Node
1	**4**	**5**
0	0	0
0	0	0

Table (5.17) Node_Array updated

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
6	4	**1**	2	5	3	1
5	1	**2**	3	9	3	1
9	2	**3**	**5**	**1**	**3**	1
0	0	**4**	1	6	1	1
1	**3**	**5**	0	0	**2**	**1**

Since all the nodes status is 3 (intermediate within sub-graph) expect only two, one status is 1 (start node of a sub-graph), and the other status is 2 (end node of sub-graph), then the solution is achieved by closing the sub-graph into the required cycle by connecting node 5 to node 4 with a cost of 16, as shown in Figure (5.13) and updated in Tables (5.18) and (5.19).

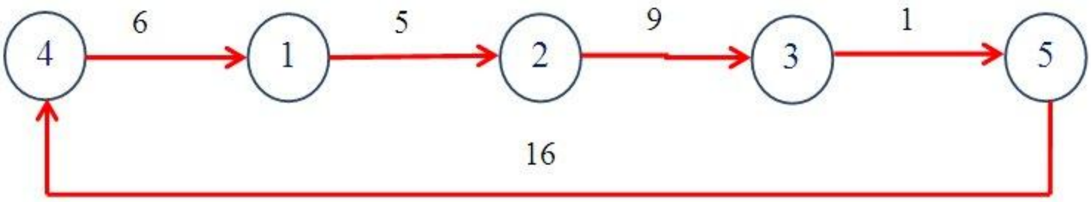

Figure (5.13) Complete solution of 5 nodes

Table (5.18) Graph_Array updated

Sub-Graph ID	Start Node	End Node
1	**4**	**5**
0	0	0
0	0	0

Table (5.19) Node_Array updated

$C_{incident}$	From	Node	To	$C_{outgoing}$	Status	Sub-Graph
6	4	**1**	2	5	3	1
5	1	**2**	3	9	3	1
9	2	**3**	5	1	3	1
16	**5**	**4**	1	6	1	1
1	3	**5**	**4**	**16**	**2**	1

5.6 Application of TSP Algorithm on A-TSP17 Problem

In this section, the TSP algorithm will be implemented on a C program and applied on the problem A-TSP17 from TSPLIB website which is shown in Table (5.20) (http://www.tsp.gatech.edu/problem/index.html, October 2010). This problem is solved manually by this approach as it will be shown in this section and has cost of 39 (Eleiche and Markus 2010). Table (5.21) shows the initial minimum travel array for A-TSP17, and this table discovers the group of nodes with equal cost and most related to each other and called neighborhood nodes. Table (5.22) presents the adjusted minimum travel array where the incident node cannot be the outgoing node. The higher sum from outgoing and incident cost is the lower bound for this problem, which means that the cost of the minimum cycle will exceed this value. For the A-TSP17, from Table (5.22), the sum cost C_o for outgoing cost equals 24 and is higher than C_i for incident side. This means that the lower bound for A-TSP17 is 24 and the cost of minimum cycle will exceed 24.

Table (5.20) Origin-Destination cost matrix for A-TSP17

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	9999	3	5	48	48	8	8	5	5	3	3	0	3	5	8	8	5
2	3	9999	3	48	48	8	8	5	5	0	0	3	0	3	8	8	5
3	5	3	9999	72	72	48	48	24	24	3	3	5	3	0	48	48	24
4	48	48	74	9999	0	6	6	12	12	48	48	48	48	74	6	6	12
5	48	48	74	0	9999	6	6	12	12	48	48	48	48	74	6	6	12
6	8	8	50	6	6	9999	0	8	8	8	8	8	8	50	0	0	8
7	8	8	50	6	6	0	9999	8	8	8	8	8	8	50	0	0	8
8	5	5	26	12	12	8	8	9999	0	5	5	5	5	26	8	8	0
9	5	5	26	12	12	8	8	0	9999	5	5	5	5	26	8	8	0
10	3	0	3	48	48	8	8	5	5	9999	0	3	0	3	8	8	5
11	3	0	3	48	48	8	8	5	5	0	9999	3	0	3	8	8	5
12	0	3	5	48	48	8	8	5	5	3	3	9999	3	5	8	8	5
13	3	0	3	48	48	8	8	5	5	0	0	3	9999	3	8	8	5
14	5	3	0	72	72	48	48	24	24	3	3	5	3	9999	48	48	24
15	8	8	50	6	6	0	0	8	8	8	8	8	8	50	9999	0	8
16	8	8	50	6	6	0	0	8	8	8	8	8	8	50	0	9999	8
17	5	5	26	12	12	8	8	0	0	5	5	5	5	26	8	8	9999

Table (5.21) Initial minimum travel array

$C_{incident}$	**From**	**Node**	**To**	$C_{outgoing}$	**Group**
0	12	**1**	12	0	G1
0	10, 11, 13	**2**	10, 11, 13	0	G2
0	14	**3**	14	0	G3
0	5	**4**	5	0	G4
0	4	**5**	4	0	G4
0	7, 15, 16	**6**	7, 15, 16	0	G5
0	6, 15, 16	**7**	6, 15, 16	0	G5
0	9, 17	**8**	9, 17	0	G6
0	8, 17	**9**	8, 17	0	G6
0	2, 11, 13	**10**	2, 11, 13	0	G2
0	2, 10, 13	**11**	2, 10, 13	0	G2
0	1	**12**	1	0	G1

0	2, 10, 11	**13**	2, 10, 11	0	G2
0	3	**14**	3	0	G3
0	6, 7, 16	**15**	6, 7, 16	0	G5
0	6, 7, 15	**16**	6, 7, 15	0	G5
0	8, 9	**17**	8, 9	0	G6

Table (5.22) Adjusted minimum travel array

C_i	From	Node	To	C_o
0	12	**1**	2	3
0	10	**2**	11	0
0	14	**3**	2	3
0	5	**4**	6	6
0	4	**5**	6	6
0	7	**6**	15	0
0	6	**7**	15	0
0	9	**8**	17	0
0	8	**9**	17	0
0	2	**10**	11	0
0	2	**11**	10	0
0	1	**12**	2	3
0	2	**13**	10	0
0	3	**14**	2	3
0	6	**15**	7	0
0	6	**16**	7	0
0	8	**17**	9	0
0			Sum C_i	24

From Table (5.21), each group of nodes will be joined to make a sub-graph as shown in Figure (5.14) , and each sequence of joining will lead to another realization of the minimum cycle as it will be shown later in the next section. The reduced cost matrix will be created for possible joining for sub-graphs and is displayed in Table (5.23).

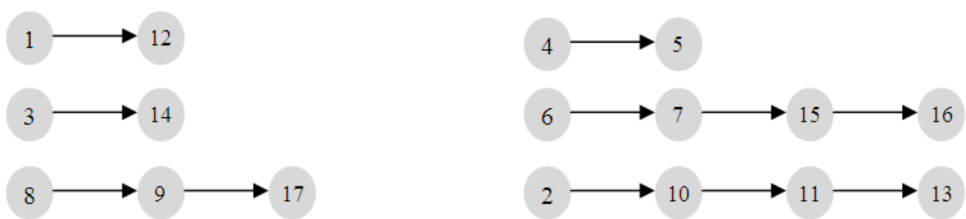

Figure (5.14) Sub-graphs generated from the table of minimum travel cost

Table (5.23) Reduced cost matrix for sub-graphs in Figure (5.14)

		To					
		1	**2**	**3**	**4**	**6**	**8**
FROM	**5**	48	48	74	-	6	12
	12	-	3	5	48	8	5
	13	3	-	3	48	8	5
	14	5	3	-	72	48	24
	16	8	8	50	6	-	8
	17	5	5	26	12	8	-

Table (5.24) Minimum travel cost for the sub-graphs in Figure (5.14)

$C_{incident}$	From	Start Node	End Node	To	$C_{outgoing}$
3	13	1	12	2	3
3	12, 14	2	13	1, 3	3
3	13	3	14	2	3
6	16	4	5	6	6
6	5	6	16	4	6
5	12, 13	8	17	1, 2	5
26	-	-	-	-	26

We have to choose: (5 to 6) or (16 to 4) to avoid loops. In order to make the right decision (with minimum cost), a comparison will be performed between both cases, and the minimum cost will be selected. First, the next higher cost for both nodes 5 and 16 will be determined as shown in Table (5.25).

Table (5.25) Highlighting minimum travel cost for the sub-graphs in Figure (5.14)

$C_{incident}$	From	Start Node	End Node	To	$C_{outgoing}$
3	13	1	12	2	3
3	12, 14	2	13	1, 3	3
3	13	3	14	2	3
6	16	4	5	6	6
6	5	6	16	4	6

5	12, 13	8	17	1, 2	5
26	-	-	-	-	26

It will be (5 to 8) with cost=12 (+6 from current cost), and (16 to 1 or 2 or 8) with cost = 8 (+2 from current cost). In order to maintain minimum cost, (5 to 8) will be discarded and (5 to 6) will be selected as shown in Figure (5.15).

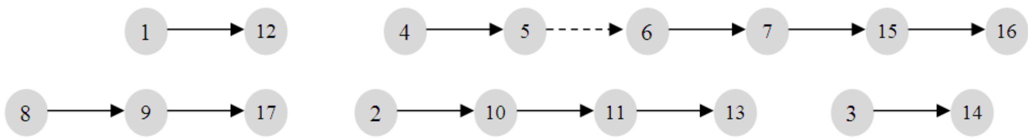

Figure (5.15) Sub-graphs generated from the Table (5.25)

Now both nodes 5 and 6 are removed from the reduced cost matrix and the second reduced cost matrix is shown in Table (5.26).

Table (5.26) Reduced cost matrix for sub-graphs in Figure (5.15)

	1	**2**	**3**	**4**	**8**
12	-	3	5	48	5
13	3	-	3	48	5
14	5	3	-	72	24
16	8	8	50	6	8
17	5	5	26	12	-

In the minimum travel cost in Table (5.27), the sum of incident cost is higher than sum of outgoing cost (26 > 22), then the incident side will be considered and outgoing side will be neglected. Next higher cost will be used for node 4 which is from node 17 (17 to 4) as shown in Figure (5.16).

Table (5.27) Minimum travel cost for the sub-graphs in Figure (5.15)

$C_{incident}$	From	Start Node	End Node	To	$C_{outgoing}$
3	13	1	12	2	3
3	12, 14	2	13	1, 3	3

3	13	3	14	2	3
12	17	4	16	1,2,8	8
5	12, 13	8	17	1, 2	5
26	-	-	-	-	22

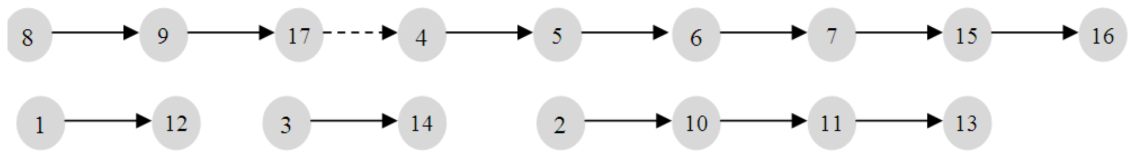

Figure (5.16) Sub-graphs generated from the Table (5.27)

Now, 17 and 4 will be removed from cost matrix as shown in Table (5.28).

Table (5.28) Reduced cost matrix for sub-graphs in Figure (5.16)

	1	**2**	**3**	**8**
12	-	3	5	5
13	3	-	3	5
14	5	3	-	24
16	8	8	50	-

From Table (5.29), the outgoing total cost of 17 will be considered as (17 > 14) and its outgoing side only is shown in Table (5.30).

Table (5.29) Minimum travel cost for the sub-graphs in Figure (5.16)

$C_{incident}$	**From**	**Start Node**	**End Node**	**To**	$C_{outgoing}$
3	13	1	12	2	3
3	12,14	2	13	1,3	3
3	13	3	14	2	3
5	12,13	8	16	1,2	8
14	-	-	-	-	17

Table (5.30) Outgoing minimum travel cost for the sub-graphs in Figure (5.16)

Start Node	End Node	To	$C_{outgoing}$	Main cost
1	12	2-3,8	3,5	0
2	13	1,3-8	3,5	0
3	14	2,1,8	3,5,24	0
8	16	1,2	8	18

Next higher cost is 8 to move from node 16 (16 to 1 or 2). There are two alternatives, (16 to 1) or (16 to 2), and both solutions will be compared and minimum cost will be selected.

If (16 to 1) is used then:

- (12 to 8) cannot be used, to prevent loops.
- (14 to 2) will add (+0), and (12 to 3) will add (+2), and (13 to 8) will add (+2), the total added cost is [+4] as shown in Figure (5.17).
- (14 to 8) will add (+24) and (12 to 2) will add (+0) and (13 to 3) will add (+0), the total added cost is [+24].

If 16 to 2 is used then:

- (13 to 8) cannot be used, to prevent loops.
- (14 to 1) will add (+2) and (12 to 8) will add (+2) and (13 to 3) will add (+0) the total added cost is [+4] as shown in Figure (5.18).
- (14 to 8) will add (+24) and (12 to 3) will add (+2) and (13 to 1) will add (+0) the total added cost is [+26] which is higher than the previous solution and will be excluded.

This means that the minimum cost is 39 (35 + 4), and it has more than two realizations as the re-order of the sequence of the neighbourhood nodes will lead to these solutions as mentioned previously. Both solutions are shown in Figure (5.17) and Figure (5.18).

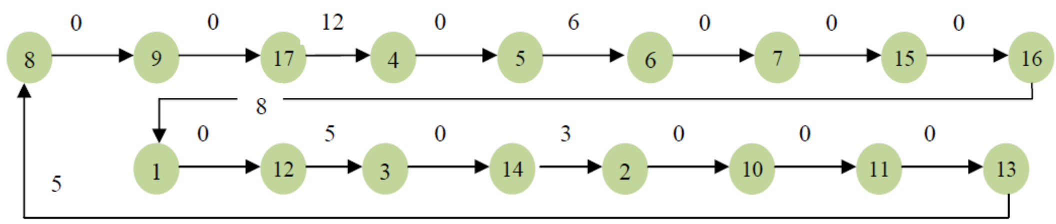

Figure (5.17) The first solution for A-TSP17 problem

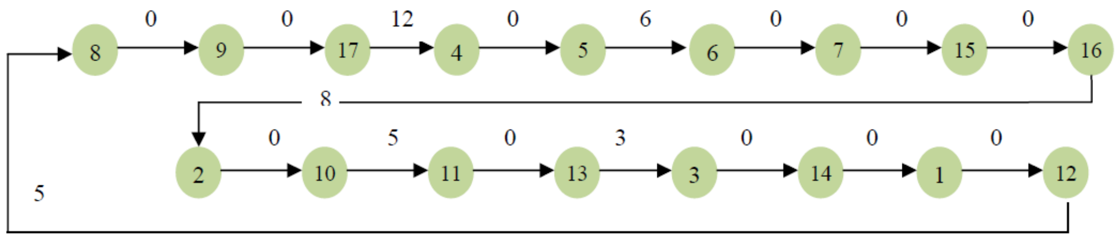

Figure (5.18) The second solution for A-TSP17 problem

Figure (5.19) presents the solution of the C program developed to apply this algorithm.

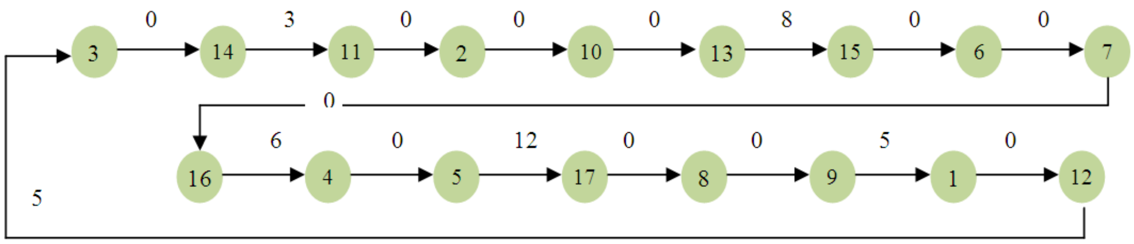

Figure (5.19) The solution of A-TSP17 problem from C program

The node numbers are inside the circles and the cost between each two nodes is displayed over the arrow connecting them.

5.7 Other realization for TSP minimum cycle

Regarding the solution of the TSP, it is not only required to know the cycle of minimum cost, but also to discover the other realizations of this minimum cycle. By other meaning, what are the other cycles which have the same minimum cost as it is a research requirement for TSP (Applegate et al. 1998).

The minimum travel cost solution has the ability to discover these realizations. By the analysis of Table (5.21), there are six groups of node which are identical in there relationships between each other and the other nodes of the graph. For example group G2, is composed from four nodes which are (2, 10, 11, 13). The cost between the four nodes is equal. The cost between each node in G2 and other nodes in the whole graph is the same. These groups define the other realizations for the minimum cycle. For example, the sequence (2, 10, 11, 13), the other sequence (2, 10, 13, 11) and any other sequence will not change the cost of the cycle and will lead to the other minimum cycle realizations.

Figure 5.20 presents the six groups and how they are interconnected to achieve minimum cycle. There is only a single degree of freedom at the group level while inter-group connection is fixed. This means that the sequence order for each group can be changed without any change in the cost of the cycle.

For this problem particularly, the number of realizations for the least cost equals:

$$\text{Number of least cost realizations} = \, {}^{g}_{1} M_i\,!$$

where g is number of groups and M is number of nodes in each group i, and this equation can be applied on the problem A-TSP17 as follows:

Number of least cost realizations of A-TSP17 = $M_1! * M_2! * M_3! * M_4! * M_5! * M_6!$

= 2! * 4! *2! * 2! * 4! * 3! = 27648. This means that there are twenty seven thousands and six hundred realizations forty eight realization for the minimum cycle.

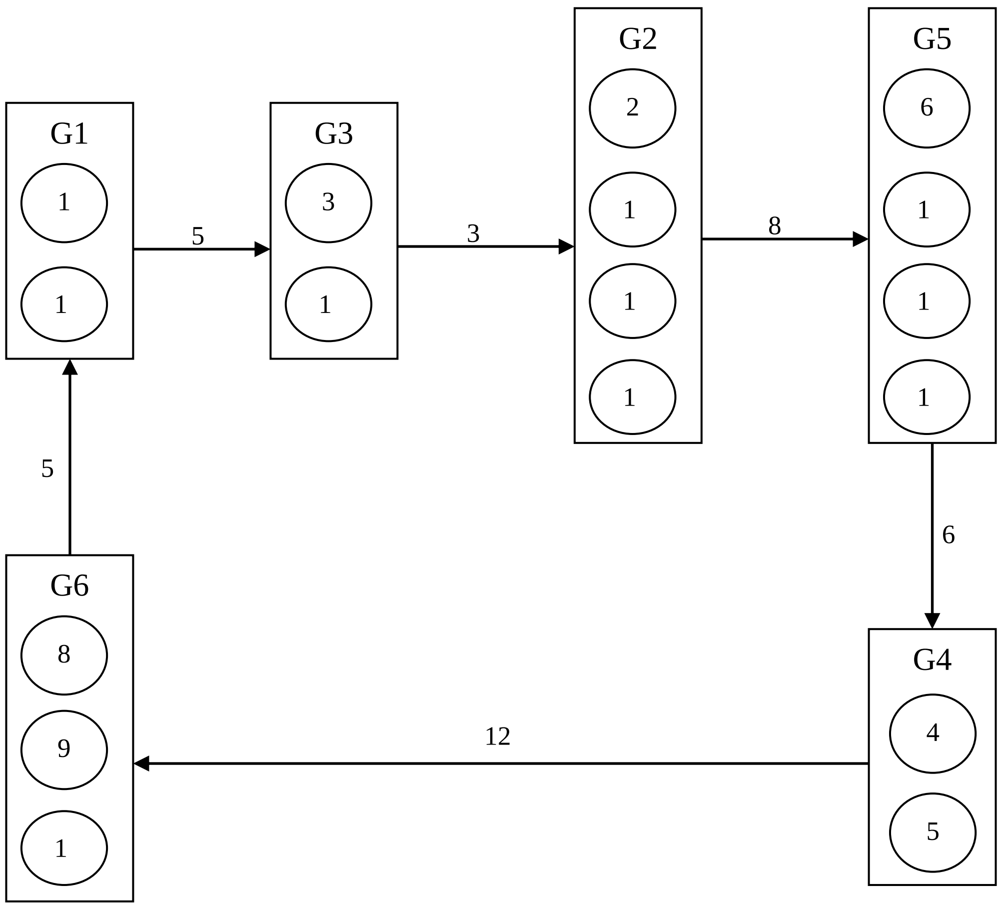

Figure (5.20) The possible realization for the least cycle of A-TSP17

5.8 Multi-objective Navigation Problems

The mentioned navigation problems are modeled and solved as direct applications for theory of graphs. However an important issue appears in this mathematical manipulation, the optimization problems in navigation are multi-objective problems not single objective as traditionally approached in discrete mathematics (Tarapata 2007). Usually, single criterion is not adequate for the required decision for optimal path, and more criteria are required for decision support. For example, the shortest path problem is solved by minimizing the travelled distance in the classical problem definition in combinatorial optimization, while in real situation, not only the distance needs to be minimized, but also the time and energy while the safety needs to be maximized, and this is applicable for other problems as well.

If the decision function f(cost) represents the different criteria for the navigation problem, then the optimization requirements can be expressed mathematically as minimizing the partial derivatives for the cost function for the path:

$$f(cost) = f(Distance, energy, time, safety)$$

optimal path conditions: minimize(distance, energy, time) and maximize(safety), and could be expressed as follows:

$$\text{minimize}\left(\frac{\partial\, f(\text{cost})}{\partial\, distance}\ ,\ \frac{\partial\, f(\text{cost})}{\partial\, energy}\ ,\frac{\partial\, f(\text{cost})}{\partial\, time}\ \right) \text{ and maximize}\left(\frac{\partial\, f(\text{cost})}{\partial\, safety}\right)$$

Theoretically speaking, the extreme values of the partial derivatives resolve the optimization problems for continuous functions but this not the case in discrete graphs.

Optimization Approaches for Multi-objective Navigation Problems

There are several approaches to tackle multi-objective optimization problems, and they can be divided into two main strategies, traditional and evolutionary approaches (Zitzler 1999). Traditional techniques convert the multicriteria into a single aggregated criterion that represents the whole other objectives based on transforming the values into dimensionless variants and assign weights for each criterion such that $\sum w_i = 1$, then apply single objective solutions to the problem.

The other strategy is to apply the evolutionary algorithms to tackle the multi-objective problem, which is a new technique known to achieve the optimal alternatives fast.

The weighting technique is widely used in GIS software and remote sensing for spatial analysis, however it requires interaction from the user to assign the weights for each criterion.

Applying multicriteria approach to solve this problem, by generating a single criterion which represents the whole criteria instead of using single criterion as time or distance is not the only solution for these problems. There are other solutions and they need more research.

5.9 Application of Multi-Objective on Kuwait City Network

A sample road network from Kuwait metropolitan area was selected to apply the multi-objective optimization approach and shown in Figure (5.17). The data are connected lines digitized in the traffic flow direction. Each record represents a connected part of the road and it has two parameters used in optimization, the first is the length in meters to be used in non-congested case, and the second is the travel time, which is observed during the peak hours.

The function cost C of the trip from origin to destination was assumed to be dependent only on the time and length of the segments of the route. In order to compute the cost as a function in length and time at peak hour:

$$\text{Cost } C = C(t,l) = f(t, l) \qquad (5.1)$$

Where t is the trip time of route segment and l is its length and f is the cost function.

In case of distance zero where no movement of car, the cost will depend only on time t with a constant C_t, such that:

$$\left(\frac{df}{dt}\right)_{l=0} = C_t \qquad (5.2)$$

Which implies that:

$$f\;t, 0 \;=\; C_t \,.\, t + C_1$$

The differential increase in cost due to move a differential distance dl in time t where C_l is a constant, implies:

$$\frac{df}{dl} = C_l \,.\, t \qquad (5.3)$$

$$f\ \ t,l\ \ = C_l\,.\,t\,.\,l + C_2\,(t)$$

$$f\ \ t,0\ \ = C_2\,(t)$$

Then the cost function f(t,l) will become:

$$f(t,l) = C_t\ .\ t + C_l\ .\ t\ .\ l + C_0 \qquad (5.4)$$

Where C_l, C_t, C_0 are constants.

Linear Regression Analysis

In order to compute the cost for each road segment based on its congestion time and length, the three coefficients C_t, C_l, and C_0 need to be determined and this requires the cost of other segments to be known also such that the cost is computed in US$.

Five destinations were selected in the Kuwait City metropolitan area to determine the travel cost between them at the peak hour of traffic congestion. These destinations are Seif Palace, Sharq, Salmiyah, Hawally, Sheiwkh as shown in Figure (5.17). The cost of travel between them is displayed in Table (5.20). The fare is observed in KD (Kuwaiti Dinar) then transformed to US$ as 1 KD = 3.2 US$. The equation (5.4) $f(t,l) = C_t\ .\ t + C_l\ .\ t\ .\ l + C_0$, of cost is also applicable to Table (5.20) also.

From Table (5.20), the coefficients C_t, C_l, and C_0 were computed with two options with intercept as shown in Table (5.21) and Table (5.22).

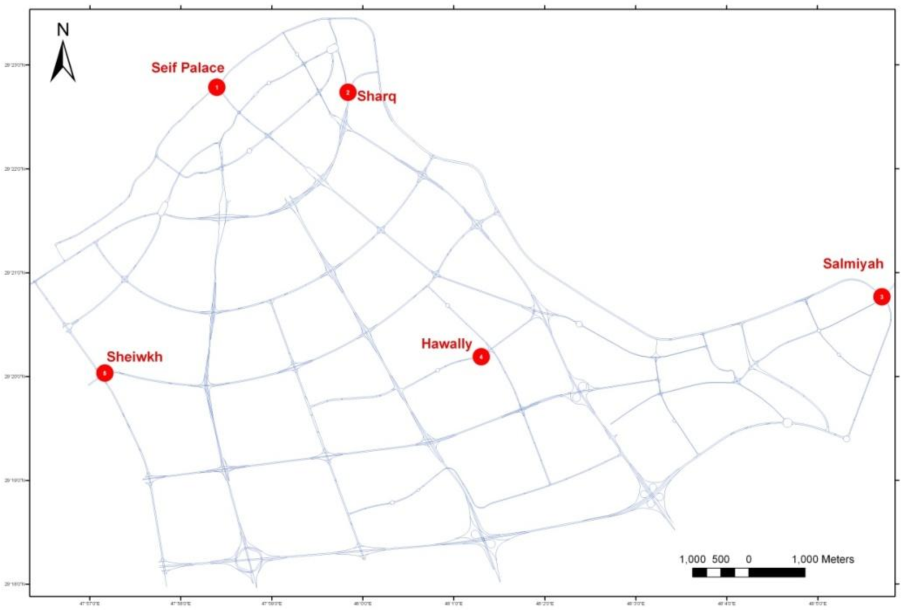

Figure (5.21) The road network of Kuwait City with 5 destinations

Table (5.31) Computed data for regression analysis

ID	From	To	Time - min	Length - m	Taxi Fare KD	Fare $
1	Seif Palace	Hawally	57.2	11675	2.25	7.2
2	Seif Palace	Salmiya	83.1	19286	3	9.6
3	Seif Palace	Shweikh	57	44592	2.25	7.2
4	Seif Palace	Sharq	16	2737	1.25	4
5	Salmiya	Sharq	45	11950	1.5	4.8
6	Salmiya	Hawally	49.2	12735	1.5	4.8
7	Salmiya	Shweikh	69.5	16591	3	9.6
8	Salmiya	Seif Palace	70.3	14780	3	9.6
9	Hawally	Salmiya	58.2	12368	2	6.4
10	Hawally	Seif Palace	52	7568	2.5	8
11	Hawally	Shweikh	44.7	8930	3	9.6
12	Hawally	Sharq	42.3	8186	2	6.4
13	Shweikh	Seif Palace	44.5	7520	2	6.4
14	Shweikh	Sharq	28.6	8396	2	6.4
15	Shweikh	Salmiya	72.7	16407	3.5	11.2
16	Shweikh	Hawally	43.6	10829	2.25	7.2
17	Sharq	Hawally	37.3	8434	2	6.4
18	Sharq	Salmiya	58.3	13134	2.5	8
19	Sharq	Seif Palace	20.1	3420	1.25	4
20	Sharq	Shweikh	38.2	9382	2	6.4

By applying linear regression, the coefficients are as follow:

Table (5.32) Coefficient with intercept

Coefficient	Value
C_t	0.103291
C_l	-0.00000045
C_0	2.366607

Case of intercept = 0,

Table (5.33) Computed data for regression analysis

Coefficient	Value
C_t	0.1564059
C_l	-0.000001
C_0	0

As the length of links is small compared to the length of travel distance in Table (5.20), then the Table of coefficients with intercept = 0 will be used to compute the cost depending on time and length.

By applying equation (5.4) on all segments of the sample data, the cost value for each segment is computed and minimum cost path is computed from origin to destination, and results are shown in Table (5.23).

Table (5.34) List of optimization results for length, time and cost

Optimized Parameters	Computed Length (meters)	Computed Time (minutes)	Computed Cost (US$)
Length	15,146	81.09	12.65
Time	16,533	71.99	11.21
Cost	16,235	71.99	11.20

There are three paths computed to move from origin and destination, the first is based on minimizing the length and the second in minimizing the time during peak hour, and the third is based on minimizing cost as shown in Figure (5.18).

By analyzing the results in Table (5.23) and shown in Figure (5.18), it is obvious that the minimum cost path has a time close to minimum time rather than the time of minimum length path. This methodology can lead to a better decision making in deciding the best route in case of peak hour traffic.

This approach requires more research to be generalized on several criteria instead of two only, and adopt mathematical manipulation for the general cost function.

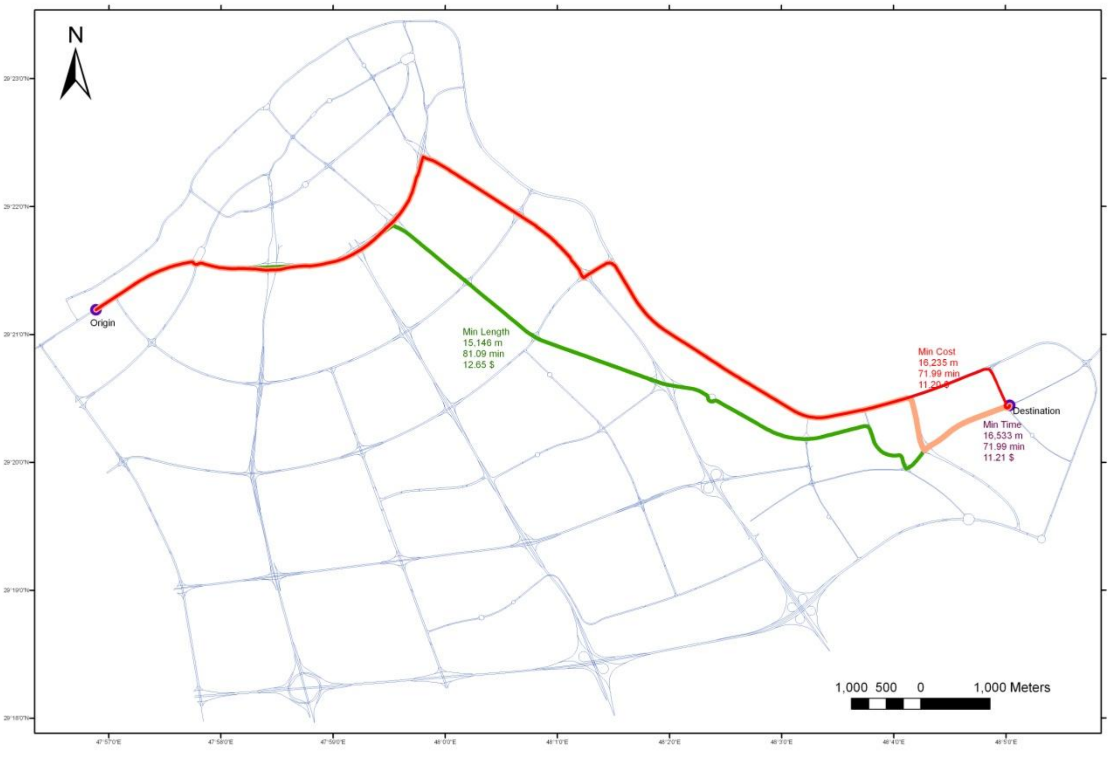

Figure (5.22) Different solution for multi-objective problem of Kuwait City with the minimum length (in green), minimum time (in orange) and minimum cost (in red) from origin at the West to the destination at the East.

6. MOBILE GEOVISUALIZATION

The visualization of the geospatial data is the main concern of the mobile user. Through it, the user can build his/her mental image about the space around. The digital cartography allows the user to control the display and presentation of geospatial data on digital screens and it has a close relation with scientific visualization (Kraak 2003). The scientific visualization is an ancient science related to the visualization of 3D phenomena, an example is the Minard chart, published in Paris 1869 that depicted the Napoleon expedition to Russia in 1812 in the number of soldiers, dates, and weather conditions as shown in Figure (6.1). Another example existed in chemistry for describing the molecules components. With the advancement in IT, the scientific visualization observed huge enhancement realized in the 3D, simulation and animation for different problems.

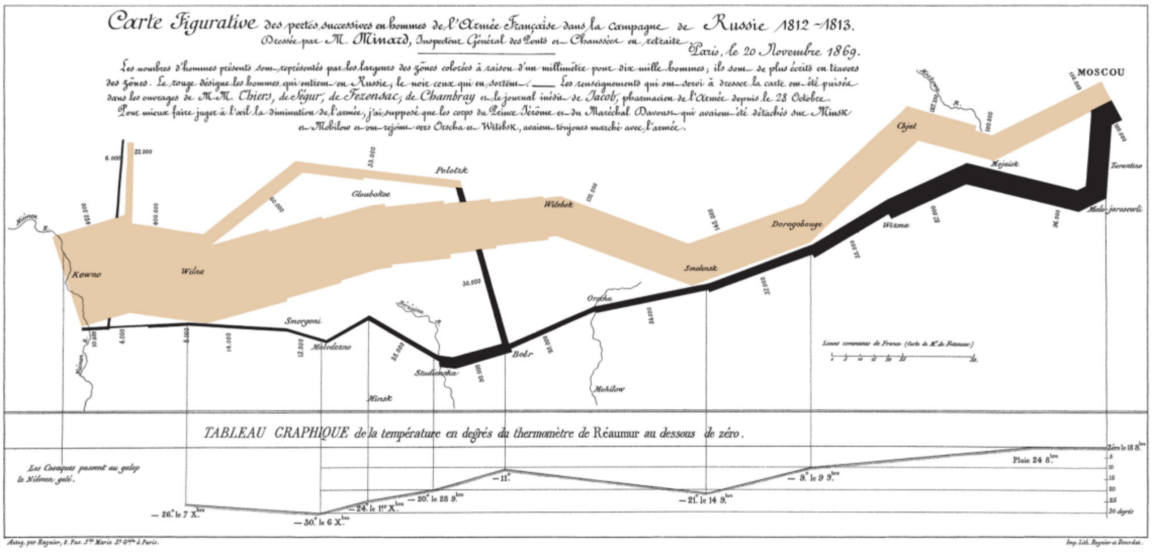

Figure (6.1) Minard Visualization for Napoleon expedition to Russia 1812

The Geovisualization is the merge of the scientific visualization technology based on computer graphics and the cartography to represent and analyze geospatial data. The computer graphics are the modern tools used to visualize the geoinformation as the painting were the tools used by ancient cartographers. The main objective of geovisualization in mobile device is to transfer the semantic of the location to the user and ensure his/her spatial comprehension about it.

Historical Change

The Cartography is one of the sciences and arts that witnessed huge evolution due to the boom in the ICT. Although it was a well established art and science for hundreds of years, the digital age changed totally the shape, technology, and fundamentals of Cartography. Before 1960, cartographers received the data and information about earth from several resources, and then they had to compile and merge huge and enormous volume of data into accurate, elegant and beautiful product called maps, known later to be hardcopy maps.

After 1960, a historical change took place in Cartography. The storage of geographic data were separated from their presentations, and the geospatial data are stored digitally in computers, and their presentation become mainly on digital screens, which were characterized by their large size to accommodate the display of detailed geographic information. From this time, the emphasis of Cartography is mainly about the display and representation only which released it from the burden of data storage.

In 1990, the Cartography faced up another challenge to display the geographic information on the small size screen of mobile device for mobile GIS applications.

Computer Graphics and Visualization

Computer graphics are the basis and tools used for digital visualization. The transformation of feelings, data, situations, plans, and history into a single or more images is an intrinsic human tradition such as Minard map shown in Figure (6.1). Both graphics and visualization use color as a mean to encode data and information (Bethel et al. 2008). Graphics use color to depict reality such as satellite images, while visualization use color to encode information such as the display the depth of sea bed shown in Figure (6.2).

The natural colors are recommended to be used in the background in order to give the user the feel of reality. As an example, the water color is usually blue and the desert background is yellow and the agriculture background is green. Important features may have red or yellow colors to attract human eyes or the use of blinking has the same effect also.

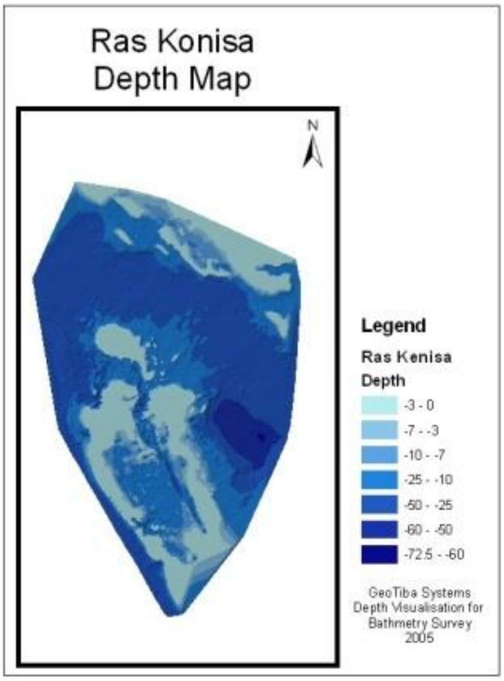

Figure (6.2) Depth geovisualization for Ras-Kenisa (Suez Gulf, Egypt)

6.1 Mobile Cartography

The mobile cartography is related to the display of geographic information on the screen of mobile device. It has distinct differences from digital cartography, first the screen size and resolution are much smaller, second, it targets only single user in mobility, third, it is not connected to a plotter or printer for hardcopy output, fourth, the user current location is the fundamental feature at the center of the display, and finally it displays minimal amount of features. The main objective of mobile cartography is to make the user aware of his/her location, direction, and important features around, and this is for the realtime display of geographic information. The other applications of mobile cartography are the enquiry of existing geographic data and performing proximity and network analysis for the required destinations, such as the optimal path from origin to destination.

The mobile cartography presents to the user the required geospatial information in the required time and adopts the geospatial data to fit the mobile device requirements at information level. The mobile device has limited hardware resources and most notably small screen with low resolution, which has effect on cartographic representation (Reichenbacher 2001). The statistical and isolines thematic maps are hard to be displayed on mobile device, same as for cartograms and dasymetric maps related to dense analysis of geospatial data. The dot thematic maps are essential in mobile cartography in order to represent the locations important to mobile user.

The mobile user expects from the mobile GIS to display on its screen the position and direction of the user, the location of specific features and how to navigate from one place to another (Rowe 2009).

Abstraction

The main objective of the mobile cartography is to visually communicate with the user by means of producing extremely generalized digital maps similar to mental maps about the location of interest to the user and transform to him/her the required geospatial information quickly. Since the user is moving, then his/her geospatial requirements are also changing and the mobile GIS has to accommodate this temporal change and use the available technology for this purpose.

The mobile cartography is not an abstraction of reality, this was achieved already by cartography and stored in the geodatabase, however it represents an abstraction of geospatial data to fit in the mobile environment. The geodatabase is a generalization of the reality and the mobile cartography is the generalization of the geodatabase which means that it is the generalization (abstraction) of the generalization or second order generalization.

In mobile environment the user does not have the control over the display as in desktop. The audience of mobile map is one single user not a wide number of users neither public such as web maps.

Display Modes

There are three display modes for the mobile cartography, the first is the tracking and realtime mode, the second is the map mode, and finally the combined mode which displayed the realtime location on predefined map.

In the tracking and realtime mode, the current location is displayed. The stored points are called waypoints and the stored trajectories are called tracks. Tracks can be stored based on time interval, distance interval, or combination between them.

The map mode displays the previously stored data on the screen for the user such as waypoints (points of interests), geographic features, stored tracks, and routes between two or more points of interest.

In the combined mode, the routes are the optimal path between an origin and destination, and both should be stored on the device previously. The tracking and realtime mode can also monitor the process of the movement progress over the route.

Orientation

There are two main orientations for the displayed map on the mobile device, the first is the traditional orientation where the north direction is in the upper direction, this orientation is important for the understanding of the directions and the relative position between origin and destination. The second orientation is in the navigation direction where the map is displayed in the direction of movement.

North direction

The north direction is an essential element in the mobile cartography as it indicates the direction of the map. Figure (6.3) describes the map orientation in the north direction and in the navigation direction.

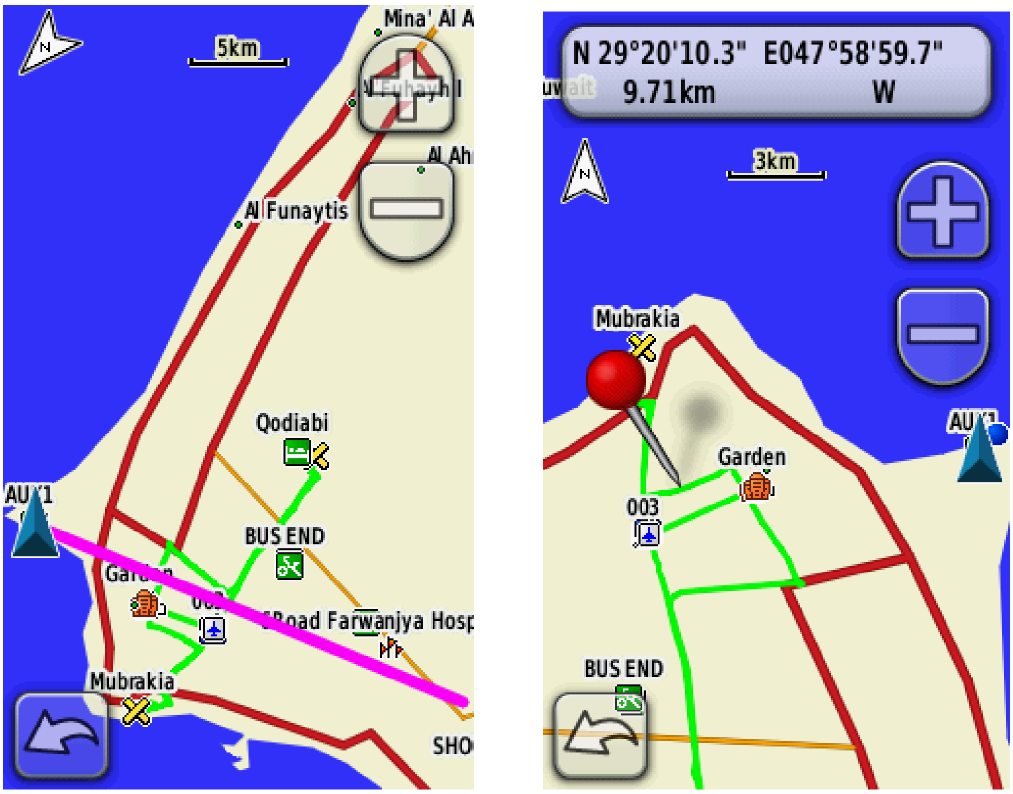

Figure (6.3) North direction in mobile GIS

Projections

The displayed maps in mobile GIS are usually representing small geographic area where the curvature of earth has no influence, and there are two options for projections, one is the use of longitude and latitude and the other is the use of projected coordinates such as UTM.

Typography

Due to its complexity and large size, the labels should be minimized on the mobile screen as possible. The language of the labels is also important and has to be set according to user preferences. One of the important options in mobile cartography is to hide the label and display it when the user is pointing to the feature or by an explicit request to show the labels. The size of the font has to be convenient in size and type should not be italic neither bold.

Mobile Geospatial Data

The mobile GIS stores different types of geospatial data. It stores and display raster data, vector data, descriptive data, voice data, photos, and videos about the geographic features and point of interests.

Generalization

In its traditional objectives, the generalization is to fit the geospatial information in the required output size while maintaining the goal of the visualization of geospatial data. Among the different operations in generalization are the aggregation, displacement, enhancement, selection, simplification, classification, exaggeration, elimination and refinement. However in mobile GIS, generalization requires specific operations due to the limited display size of the screen, the main generalization operation for mobile GIS is to transform area features into point features for vector geospatial data. This abstraction is important for mobile cartography as it informs the user about the existence of a feature at a specific place and the user's mind will complete the picture about the area feature from the point symbol. Another generalization operation has an equal importance which is the use of meaningful symbols and minimizing the use of labels on mobile map as possible. Labeling cartographic features is difficult on wide screens and hardcopy maps, and many of its rules are still not automated as many of generalization operations. Maps are in general abstraction of reality, and in mobile environment abstraction should be higher (Li 2007).

Cartographic Environment

The mobile GIS has a predefined settings that reflect the different navigation environments such as pedestrian, vehicle, marine, coastal, bike and others. For each environment the colors used for geographic features should guide the user to understand and interact with it. Table (6.1) compares the different aspects of different mapping outputs.

Map Message

Enables a new form of communications other than SMS and voice, it can send a map of the user current location and/or the coordinates of the location as image to another mobile device.

Voice mapping

The voice mapping is a unique feature for the mobile GIS. It guides the user through telling him/her which direction to take at joints and cross sections.

Current Position

The current position is a fundamental element in the mobile GIS and it has a clear symbol. In some applications, blinking of the user position symbol provides better description for current position especially in case of dense geographic features.

Table (6.1) comparison between the aspects of different mapping outputs

Parameter	**Paper Map**	**Desktop Map**	**Web Map**	**Mobile Map**
Audience	Unknown and unlimited	Known group of people and limited	Unknown and unlimited	Single one user and strictly limited
Life Time	One day to hundreds of years	One day to few months	One day to months	One second to one hour
View	Static	Static	Dynamic	Dynamic

Animation and Simulation

Animation is an important tool for mobile cartography to explain to the user the geospatial characteristics of the location in interest, and it depicts by voice and vision how to arrive at the required destination. Mobile GIS should have the capability to store the movement of the user as animated file so that it can be retrieved. However, simulation also is a requirement for mobile GIS. The simulation provides a solution based on input, when the input changes the result is also changed as opposite to animation which is displays the same data each time as a single sequence of events (Pappo 1998). The simulation is used in modeling while animation is rather a data storage technique.

Hypermedia

The hypertext introduced new paradigm to navigate through available digital information in a new manner by interactive browsing. It enables the reader to jump from one section to another via hyperlink. The hypertext divides the available digital information into separated sections (nodes) with defined cross-references and provides its hyperlink when mentioned to enable its access, and the World Wide Web (WWW) was based on this concept. Later on, this concept was extended to include not only text, but also other media data such as graphics, videos, photos, sound files, emails and others, and was known to be hypertext multimedia or just hypermedia.

The multimedia cartography is the association of geographic feature with its related multimedia data such as videos, photos and others so that the user after displaying the required location he/she can view this associated multimedia data. The multimedia cartography tends to represent the world in a more realistic way (Plesa 2006).

Geographic Hypermedia (GH) adopts and extends the concepts and tools developed in hypermedia and multimedia cartography. Geographic Hypermedia Systems (GHS) are software systems that allow distributed geographic content (data and services) with various forms of media being interlinked and exploited in different ways. The term hypermap is commonly used to indicate this combination. Hypermedia systems and services have been inspired by the idiosyncratic associative and recall scheme within human memory (Bush 1945) and (Reich et al. 1999).

The mobile geographic hypermedia has important role in mobile GIS because it allows the navigation through the geodata via the geographic and multimedia data itself. As an example, the tourism geodatabase is important for any mobile user. By browsing the available places to visit, he/she will select the preferred place from the multimedia files such as photos about these places. Then, by clicking the photo of the selected place, he/she will display the map of the feature and how to navigate to it, and from this he/she can spatially query the close features to this selected place in order to plan his/her visit.

Summary

The mobile cartography was presented in this section and how it has different characteristics other than traditional cartography. It is required to standardize the mobile cartography and how the geographic features have to be displayed on mobile devices and the interoperability of geospatial data from geodatabase at server and its version on mobile device.

6.2 Holography

In 1947, Hungarian physicist Gábor Dénes (the father of holography) produced the first hologram ever made and had been rewarded Nobel Prize in Physics in 1971. He mentioned that holography can be used as a screen to allow viewers to see stereographic movies without needing special glasses and he used a light beam in his experiment. The hologram is an image which stores the interference pattern between a wave field scattered from the object and a coherent background named reference wave. Later in 1960, when laser (or LASER, Light amplification by stimulated emission of radiation) was invented, Leith and Upatnieks (at the University of Michigan) reproduced Gábor's 1947 experiments with the laser, and launched modern holography (Ludman et al 2001). In the GIS, the 3D model of the area of interest can be stored as digital hologram and then recreated to give the user the real impression of the 3D as shown in Figure (6.4).

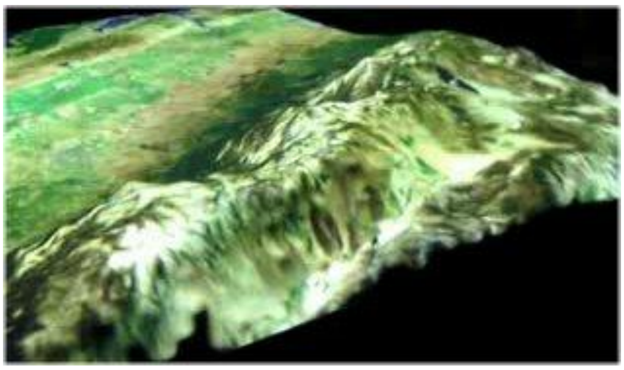

Figure (6.4) Display of a 3D hologram from a screen (video file)

Holography in GIS

Holography is an active imaging senor technique, it does not capture the reflecting spectrum from the object as done by passive sensors but it uses laser lighting to capture the required image. Digital Holography (DH) process allows the full wavefield information: amplitude and phase, to be recorded. With this information, it is possible by using devices known as Spatial Light Modulators (SLM), to reconstruct the optical wavefield in another place at another time.

The holography provides GIS with an important geovisualization tool. It creates for a 3D object its hologram which is a 2D storage for the 3D data and it can be retrieved and rendered as 3D image such as the 3D surface in Figure (6.5).

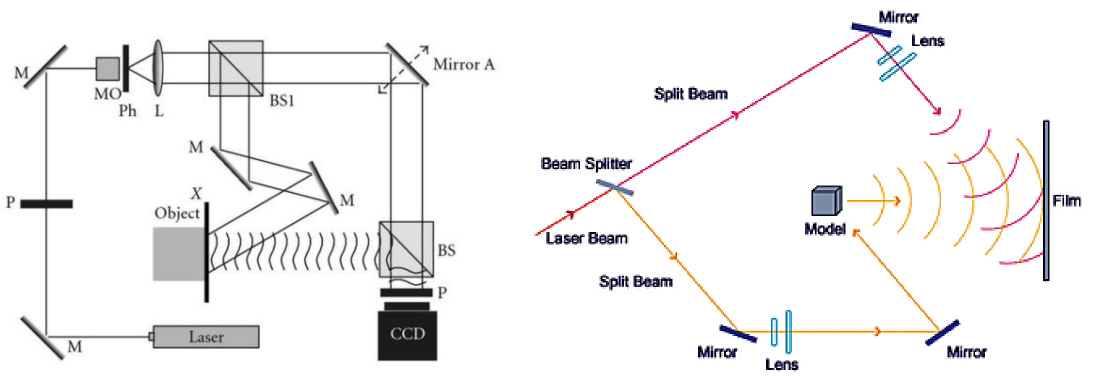

Figure (6.5) Schematic depicting a typical inline DH setup

M: Mirror, P: Polarizer, BS: Beam Splitter, Ph: Pinhole, and MO: Microscope Objective (Kelly et al. 2010).

The diverging spherical wave that emerges from the pinhole is collimated using a lens to form an approximately flat plane wave that is split into two beams, the reference beam and object beam, by the beam splitter BS1 as in Figure (6.6).

The reconstruction of a digital hologram in real 3D space is achieved by replaying its information using optoelectronic techniques as shown in Figure (6.6). Briefly, some of the information contained in the captured hologram is loaded onto an SLM (Spatial Light Modulator) device. A plane wave is then reflected off the surface of the device, and an approximation to the original object wavefield is created.

There is a distinct difference between stereoscopic 3D and holographic 3D as both store different data and uses different technique for 3D visualization. The stereoscopic 3D records a pair of 2D images are focused on a film plane (or 2D projection screen) as stereo pair so that the brain can reconstruct later using binocular vision where each view is perceived separately by left and right eye. In holographic 3D, an interference volume of laser emission interfering with laser reflection from scene (as modulation) is recorded without focusing on a plane but by the photo plate situated in the interference volume and it requires no separation devices and can be viewed without 3D glasses from any vantage point.

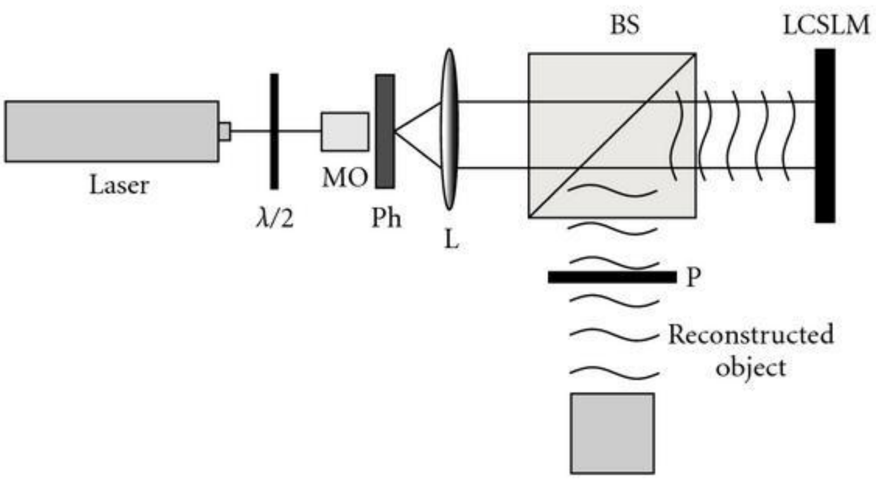

Figure (6.6) Scheme of setup for optical reconstruction with SLM
P: Polarizer, BS: Beam Splitter, Ph: Pinhole, and MO: Microscope Objective, L: Collimator lens, λ/2: Half-Wave Plate (Kelly et al. 2010).

Holography in Mobile GIS

The mobile hardware device will be capable in near future to capture, store and display holograms (http://www.digitaltrends.com/mobile/ibm-forecasts-holograms-in-mobile-phones-for-2015/) and in the same time, Nokia and Intel established a research center in Oulu University to enable 3D mobile phone calls using holography technology (http://www.pcworld.com/article/203989/nokia_intel_team_on_3d_holographic_phone_tech.html). However, the use of holography is still in its experiment, capture and display of GIS holograms should be used in a wide scale and used also in mobile GIS as shown in Figure (6.7). It is a promising technology and required for mobile GIS user to handle real 3D data in realtime.

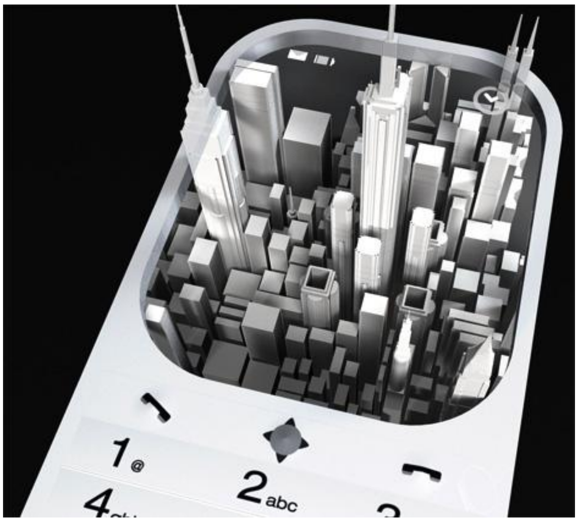

Figure (6.7) Holography display on mobile device
(http://www.yankodesign.com)

6.3 Metric System for Geographic Coordinates in Mobile GIS

The geoinformatics inherited an ancient sexagesimal system for geographic position from Babylon civilization aged more than 5000 years which base was 60 rather than 10 in the traditional decimal system. This is the reason of the division of one degree to 60 minutes, and one minute to 60 seconds. The realization of a point location by this ancient system has two formats, the first is composed from three different quantities which are degrees, minutes, and seconds, while the other is the decimal degree which has the form of 2 digits before the decimal point and 8 digits after it. The use of this sexagesimal system for mobile user is not suitable as he/she requires a simple quantity that reflects the accuracy of navigator GPS.

Degree and Geoinformatics

The degree has a long relationship with geoinformatics, as it describes the position on earth by the two fundamental quantities based on angles: longitude and latitude. The ellipsoid is the best geometrical shape that fits the geoid which is the real shape of earth. Classically the earth latitude is divided into 90 degrees between Equator and North Pole, and also 90 degrees between Equator and South Pole. The earth longitude is divided into 180 degrees east Greenwich line, and 180 degrees west Greenwich line.

This earth grid of one degree size has variable length from 111km side length at Equator to 79km at latitude 45, to zero at pole as shown in Figure (6.8).

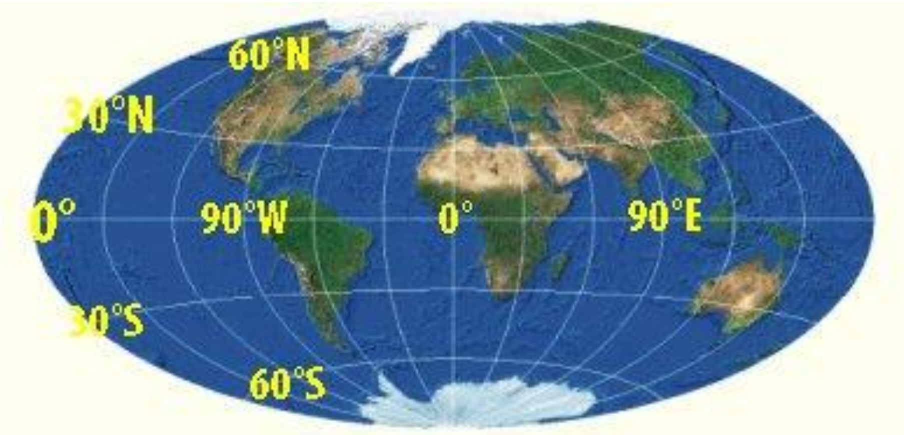

Figure (6.8) Classical geographic coordinate of 30° grid on Aitoff projection

The latitude (or longitude) on earth surface is defined as three quantities, which are degrees, minutes, and seconds, and most often 100 parts of a second, as an example, the South-West corner of great pyramid of Khufu in Giza, Egypt has geographic coordinates realized on WGS84 as N 29° 58’ 44.3830” latitude and E 31° 07’ 57.0194” longitude as shown in point P in Figure (6.9).

One of the reasons of using map projection instead of geographic coordinates is its complexity in geometric calculations and its realization. The users of mobile GIS require easy to use metric system for their continuous geospatial activities (Gouveia et al. 2006) and (Mateos and Fisher 2006). The use of degrees based on sexagesimal system is facing difficulties in mobile GIS industry, and many mobile devices do not display coordinates for the user, instead they display the relative position on background raster map.

Table (6.2) The coordinates of pyramid corner (point P) and point B (20.4m from Pyramid)

	Sexagesimal degrees, minutes, seconds		**Decimal degree**	
Point	***Latitude (DD MM SS.ssss)***	***Longitude (DD MM SS.ssss)***	***Latitude (dd.dddddddd)***	***Longitude (dd.dddddddd)***
P	29° 58’ 44.3830”	31° 07’ 57.0194”	29.97899528	31.13250539
B	29° 58’ 43.8830”	31° 07’ 57.5194”	929.9788563	831.1326442

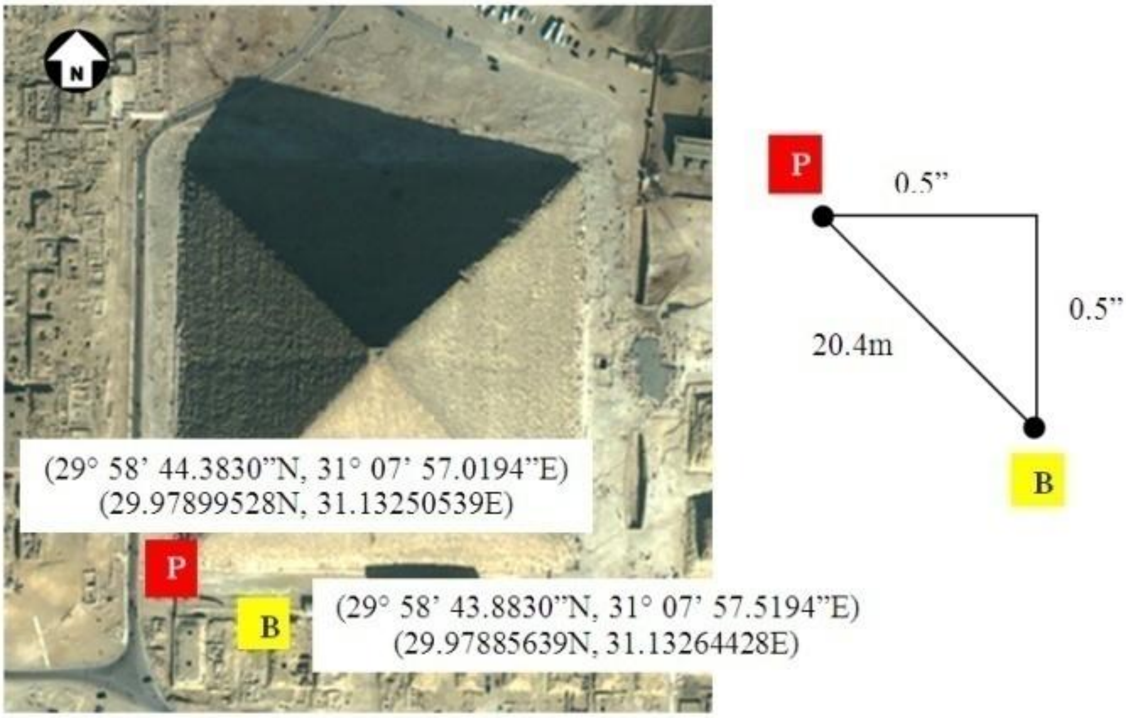

Figure (6.9) Khufu Pyramid in Giza, Egypt

The red point P and yellow point B are expressed in classical geographic coordinates: degrees, minutes, and seconds, and in decimal degrees. The sketch at the right depicts the geometry between two points (Satellite image from Quickbird)

Mobile GIS Requirements for Geographic Metric System

The advancement in geoinformatics enabled the establishment of global seamless geodatabase for the whole world describing the main topographic features and land cover/use, and these geodatabases are available on the web. In the same time, advent in positioning techniques and mobile devices, enabled the tracking of the movement in realtime. These advancements require a modern metric system for geographic coordinates that is easy to use and display for users, unified and seamless over the globe, consistent with GPS measurements, has accuracy of standalone GPS, can be easily embedded inside algorithms and mathematical functions, and consistent with other conventional metric systems (Li 2006) and (Pundt 2002). Also, the proposed metric system has to define a single unit and quantity for the latitude and longitude without need of conversion when used in calculations and in the same time easy for oral and written communication by normal user. Table (6.2) shows the coordinates of points P and B with 20m nominal accuracy which is the accuracy of standalone GPS, it has half second accuracy and 5 digits for decimal degree as shown in Figure (6.9). The accuracy of standalone GPS equipments is in continuous enhancement.

Proposed Metric System for Mobile GIS Based on Minutes

The main requirements for proposed geographic system are to be an easy quantity for the mobile user and it has the accuracy of the GPS standalone receiver which is in the range of 20-25m. Table (6.3) shows the variation of the distance on the earth ellipsoid relative to latitude value.

From Table (6.3), the unit of 1% from the minute has higher accuracy than 1 second, this is obvious because it divides the minutes to 100 parts more than the 60 parts of the seconds. If the minute is used as the main quantity for angle measuring for latitude and longitude, with two digits accuracy of 1% of minutes, this system will fulfill many the geoinformatics requirements for mobile GIS (Eleiche 2010 a). In the previous example of great pyramid, the position P in minutes coordinates will be realized as 1798.74N and 1867.95E and the position B will be 1798.73N and 1867.96E, which changes 1% minute in each direction, and can be noticed and understood by the normal user as shown in Table (6.4) and Figure (6.11).

Table (6.3) The coordinates of Pyramid corner and point B with 20m nominal accuracy

	Sexagesimal degrees, minutes, seconds		**Decimal degree**	
Point	***Latitude (DD MM SS.s)***	***Longitude (DD MM SS.s)***	***Latitude (dd.ddddd)***	***Longitude (dd.ddddd)***
P	29° 58’ 44.4”	31° 07’ 57.0”	29.97900	31.13251
B	29° 58’ 43.9”	31° 07’ 57.5”	629.9788	31.13264

Table (6.4) The length of arc at different latitudes on earth ellipsoid WGS84

Latitude (Degree)	**1 degree**	**1 minute**	**1/100 minute**	**1/1000 minute**	**1 second**	**1/100 second**
0	111 km	1.85 km	18.5 m	1.85 m	30.83 m	0.31 m
15	108 km	1.80km	18.0 m	1.80 m	30.00 m	0.30 m
30	96 km	1.60km	16.0 m	1.60 m	26.67 m	0.27 m
45	79 km	1.32km	13.2 m	1.32 m	22.00 m	0.22 m
60	56 km	0.92km	9.2 m	0.92 m	15.33 m	0.15 m
75	29 km	0.48km	4.8 m	0.48 m	8.10 m	0.08 m
90	0 km	0 km	0	0	0	0

Source (http://geophysics.ou.edu/solid_earth/readings/testkey/geographic%20coordinates.htm)

Table (6.5) the proposed coordinates of Pyramid corner and point B (20.4m from Pyramid) for mobile GIS with 20m nominal accuracy based on minutes

	Sexagesimal degrees, minutes, seconds		**Decimal degree**		**Proposed minutes system**	
Point	***Latitude (DD MM SS.s)***	***Longitude (DD MM SS.s)***	***Latitude (dd.ddddd)***	***Longitude (dd.ddddd)***	***Latitude mmmm.mm***	***Longitude mmmm.mm***
P	29° 58’ 44.4”	31° 07’ 57.0”	29.97900	31.13251	1798.74	1867.95
B	29° 58’ 43.9”	31° 07’ 57.5”	629.9788	31.13264	1798.73	1867.96

The proposed metric system based on minutes defines the position with the two quantities latitude and longitude using minutes and 1% of minute. Each quantity is composed of 4 integer digits and two digits after the decimal point. The number is easy to use by normal users, and it has nominal accuracy of 20m which is accepted for navigation purposes and daily use of mobile GIS as shown in Table (6.5) and Figure (6.11).

The use of degrees is changed to minutes as the essential quantity for geographic coordinates, and seconds are converted to decimals of minutes. This solution will define the latitude from 0 at equator to 5400 minutes at the pole, and from 0 to 10800 minutes in longitude as shown in Figure (6.10).

Figure (6.10) Proposed geographic metric system for mobile GIS users based on minutes

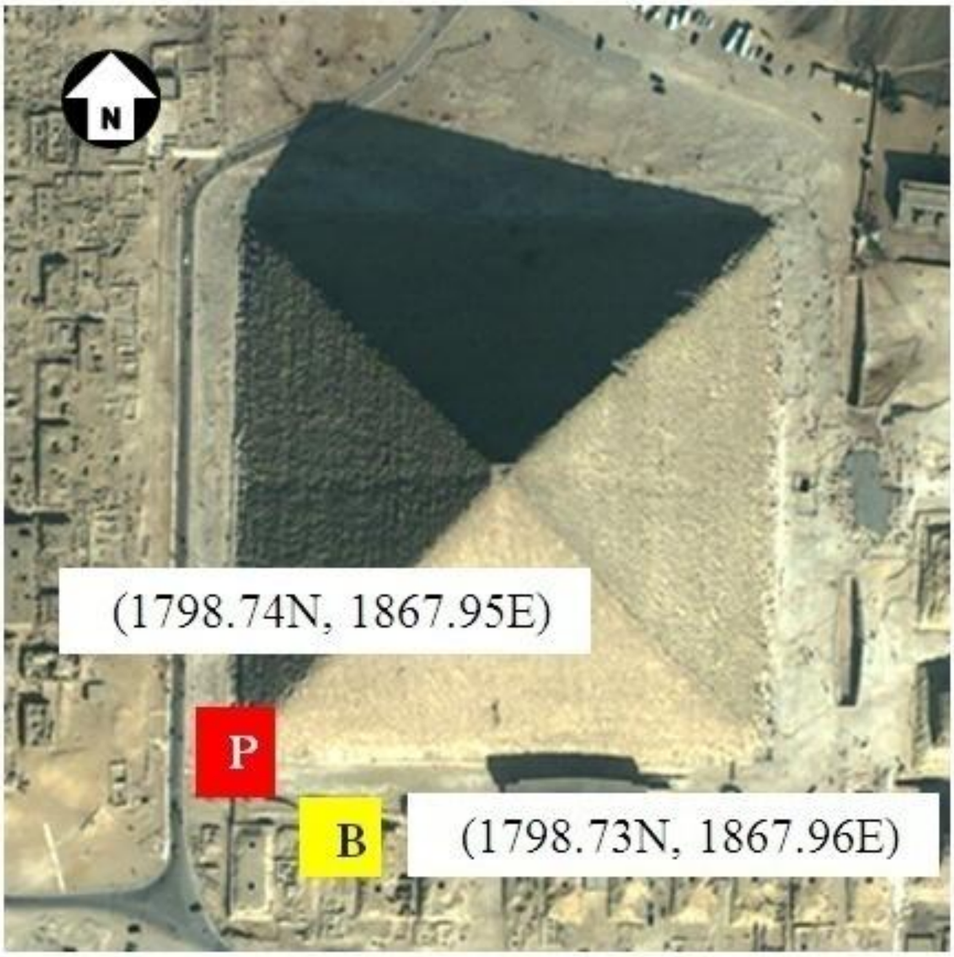

Figure (6.11) The coordinates of Khufu Pyramid expressed in proposed minutes system

Summary

The mobile GIS is used by millions of moving people, and it changed the nature of geoinformatics from a complex scientific discipline to a basic handy tool embedded in mobile device. The conventional sexagesimal system for geographic coordinates is more than 5,000 years old, and is not suitable to mobile GIS users. The proposed metric system for geographic coordinates based on minutes only with two decimal digits has 20 m nominal accuracy and is suitable to mobile GIS.

The metric minute can be used instead of postal code as it have geographic semantic and it represents physical quantity. Also, the metric minute represents the value of coordinates of a point on the surface of ellepsoid which has 3D curvature. In the computation of area and length, it requires different mathematical manipulation other than simple cartesian coordinates, and this requires more research to be covered.

7. SUMMARY AND CONCLUSION

In this study, the mobile GIS was introduced and defined. Its different aspects were analyzed in details, and focused on mobile GIS applications, network analysis and geovisualization. The following will summarize the chapters of this study then the conclusion is presented.

7.1 Summary

Chapter (1) introduced the study aims and objectives with a general overview. Chapter (2) discussed the evolution of ICT and mobile GIS with review for the literature related to mobile GIS. The mobile GIS problem is presented and its current status and trends were discussed.

In chapter (3), the architecture of mobile GIS and its components were described in details and it included the mobile device platform with its rich communications capabilities such as GSM, bluetooth and Wi-Fi, the outdoor positioning techniques and how the GPS and other techniques are used to deliver accurate position to mobile GIS, then the indoor positioning techniques were summarized. The different mobile GIS softwares were discussed and the geospatial data for mobile GIS were declared and how they should be compacted to fit the limited resources of mobile device. Finally, a new framework for mobile GIS was introduced so that the mobile device can be distinct from webGIS and it can work in offline mode.

Chapter (4) presented a generic description for the different applications for mobile GIS with emphasize on four major applications areas. First, it described the use of mobile GIS for acquisition of geospatial data including multimedia, descriptive data and trajectories data for different mode of transportation. Second, the temporal applications for recording the spatial processes and events using relative and absolute positioning were presented as well the concept of intelligent landmark and how it can be used for relative positioning. Third, the role of mobile GIS in transportation and traffic safety were analyzed. Finally, the use of mobile GIS to transfer the required knowledge in the right place at the right time was discussed.

Chapter (5) started with an introduction about the network analysis and theory of graphs as its mathematical foundation and discussed the relation between geoinformation and graphs with emphasize on the role of network analysis in mobile GIS and its applications. The optimal path problems in navigation were presented as direct applications for theory of graphs and the complexity of their algorithms was discussed. Then, a new approach for solving the Travelling Salesman Problem (TSP) was introduced based on the minimum travel cost for each node. The algorithm for this approach was presented and its programming implementation. A sample problem was solved with the program. Finally, the multi-objective optimal path problems in mobile GIS were introduced and how it should take into consideration the available criteria. An application from the metropolitan area of Kuwait City was applied for optimal path for length and time in congested traffic situation.

In chapter (6), the mobile geovisualization was defined and presented as a scientific discipline to display the geospatial data on mobile device in an adaptive context that is relevant to the mobile user. The historical change in the cartography role was discussed and new digital tools for visualization were presented, then the details of mobile cartography were introduced. The role of animation and simulation were discussed. Also, the holography was introduced as a modern technology in 3D visualization. The new paradigm of geographic hypermedia depicted the use of multimedia inside digital cartography in mobile GIS. Finally, a metric system for geographic coordinates based on minutes was proposed to facilitate the use of geographic coordinates for the user of mobile GIS.

In chapter (7), summary of all the chapters is presented with reference to all included applications within the study, and finally the conclusion is provided.

In chapter (8), five new scientific results were presented which are the standalone framework for mobile GIS, the intelligent landmark, the least travel cost for travelling salesman problem, the multi-objective optimal path problems, and finally the metric geographic minute.

7.2 Applications Presented

This study included several applications to validate the revealing concepts. In chapter (4), the international road from Kuwait to Mekkah and returning back was captured using mobile GIS and showed in section (4.1) and its map in Figure (4.1). The data model for intelligent landmark was introduced in section (4.2) and shown in Figure (4.4).

In chapter (5), the algorithm for solving the Travelling Salesman Problem (TSP) using the least travel cost approach was presented in section (5.5), and a sample problem was solved manually using this algorithm. A C program was developed to implement the algorithm and applied on the same problem as shown in section (5.6). The multi-objective optimal path problem was presented in section (5.8) and showed in Figure (5.11).

In chapter (6), an example on metric geographic minute use in pedestrian movement was presented in section (6.3).

7.3 Conclusion

The mobile GIS is evolving and is driving the science and technology to a new horizon. The hardware of mobile device is developing at a higher rate than the development of its operating systems, which require a new vision and design based on the exponential development in hardware. The mobile device is rich in its communications capabilities with the increasing bandwidth of present wireless networks, and it is a handy tool to geospatially transfer knowledge online as it connects the owner of the knowledge to the requester.

The mobile GIS is an important tool in the acquisition of geospatial data, gathering its attributes data, and collecting the trajectories of moving objects even by non-experts. The acquisition of accurate 3D coordinates in realtime, the orthometric height, indoor coordinates, and the discovery of surrounding location environment are challenges facing mobile device and require more research. The lack of standard format for the geospatial data is a challenge to the geospatial industry. For the mobile GIS, this challenge requires also a compact format for vector, raster, and multimedia data.

In transportation, the mobile GIS has a positive effect in transportation safety as well it can enhance the collection of data related to transportation modeling and analysis, and it plays important role in Intelligent Transportation Systems (ITS).

The current status for network analysis is not satisfactory in mobile GIS. The mobile GIS software requires adding more spatial functionalities and specifically network analysis and multi-objective optimal path modules to enable the user to control these functions in mobility. It is required to store the topological data of networks on the mobile device so that it can be used to enable the computation of optimal path online.

New data models and format are required, also breakthrough algorithms with higher efficiency are needed. The new approach proposed for the Travelling Salesman Problem (TSP) needs to be widely tested among known problems to determine its efficiency same as the multi-objective optimal path problems.

The geovisualization for mobile GIS requires special manipulation as the mobile cartography is different than digital cartography and it has its own rules to provide to the mobile user the required information. The Map Message is a new proposed message as SMS to transfer the location of mobile user to other mobile users. The hypermedia cartography will provide the mobile user with the capability to navigate from map to other data and media stored on mobile device. The holography is a promising 3D visualization tool and will have important role in the future of mobile GIS.

The standalone framework was presented as a concept to release the GIS functionality in mobility from the dependency on the communications network and to allow the mobile user to perform geospatial functions in offline mode. The intelligent landmark was proposed as relative positioning tool for tracking vehicles precisely and to avoid the map-matching required in traditional tracking. The current sexagesimal system for the quantitative representation of geographic position in longitude and latitude requires revision to a more generic system based on the contemporary decimal system. In this study, a new metric system based on geographic minute was proposed to overcome the difficulties associated with the sexagesimal system. However, the proposed system needs to compute the lengths and areas from this metric system, and it requires new mathematical handling.

In final, the mobile GIS is on the priority of the research agenda of several scientific disciplines within the geoinformation community, its user base is increasing exponentially generating high demand on mobile GIS. This important research area requires more research and fund. Also, cooperation between different research centers is required in order to integrate the research efforts instead of its duplication.

8. NEW SCIENTIFIC RESULTS

In this chapter, the new scientific results achieved in this study will be summarized.

1) **Conceptual framework for standalone mobile GIS**

   This framework was introduced in section (3.7) in chapter (3). The use of mobile GIS in offline mode when the mobile device is not connected to any network is vital, and the standalone framework provides the solution for this problem. The solution is based on the storage of the area of interest in the local hard disk of the mobile device as well to install mobile GIS software, so that the user is freed from the dependency on the communication network to perform GIS functionality in mobility.

2) **Intelligent landmark for relative positioning**

   This system was introduced in section (4.2) in chapter (4). The position of the moving object provides the geospatial semantic to the user, and it can be acquired using intelligent landmark. This solution will overcome the step of map-matching to determine the accurate position of the moving object in realtime and deliver a semantic value of the position.

3) **New approach for Travelling Salesman Problem (TSP)**

   This approach was presented in section (5.4) in chapter (5). The least travel cost for each node is a new approach for tackling the TSP. This new approach computes the minimum incident cost and outgoing cost for each node and arranges them in order to achieve the least cost to visit all the nodes then return back to the first node. The algorithm for this approach was presented in section (5.5) as well its implementation in C programming languages were applied on a sample problem was presented in section (5.6).

4) **Multi-objective Navigation Problems**

   This approach was proposed in section (5.7) in chapter (5). The single criterion for the classical solution for navigation problems is not suitable for real navigation problems where many criterions have to be optimized. The function model for the representation of navigation parameters should include all the criteria for optimal path. An example on Kuwait City road network was applied in section (5.8) to minimize both the time and length of trip in traffic peak hours.

5) **Metric minutes system for geographic coordinates**

This system was proposed in section (6.3) in chapter (6). The use of metric minutes as a base for geographic coordinates is easier for normal user and will expand the use of geographic information as it represents a modern quantity as opposed to sexagesimal presentation of geographic coordinates.

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