

Ubiquitous Positioning and Mobile Location- Based Services in Smart Phones

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Chapter 9

Mobile Geographic Information Systems

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ABSTRACT

This chapter introduces the concept of Mobile Geographical Information Systems (Mobile GIS) as an evolution of conventional GIS to being available on wireless mobile devices such as smart phones. The evolution of the technology and its applications are charted in this chapter. The main elements of Mobile GIS are then discussed. This focuses on: GIS servers; wireless mobile telecommunication networks; wireless mobile devices; location-awareness technology; and gateway services. This is followed by a discussion of the main features in terms of the services and usage of Mobile GIS: mobility; real-time connectivity; location-awareness; broadened usage. Mobile Geographical Information Systems are an important facilitating technology for Location-Based Services (LBS). A range of applications of Mobile GIS for smart phones are described. The chapter closes with a discussion of the prospects and challenges for Mobile GIS. Challenges derive from four broad areas: limitations that derive from the technologies being used; areas of GIScience that still need to be adequately researched; users; and business models for a sustainable presence.

INTRODUCTION

Mobile Geographic Information Systems (Mobile GIS) can be viewed as an outcome of the convergence of wireless mobile technologies and GIS to have real-time and mobility characteristics.

With the fast development and increasingly wide usage of smart phones, Mobile GIS have become embedded in many Location-Based Services (LBS) applications, particularly in navigation functions, which are provided via smart phones. Mobile GIS can also be considered as a core part of LBS. Mobile GIS integrates GIS and wireless mobile communication technologies to offer a

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real-time capability of interacting with external software and remotely accessing and managing data and information.

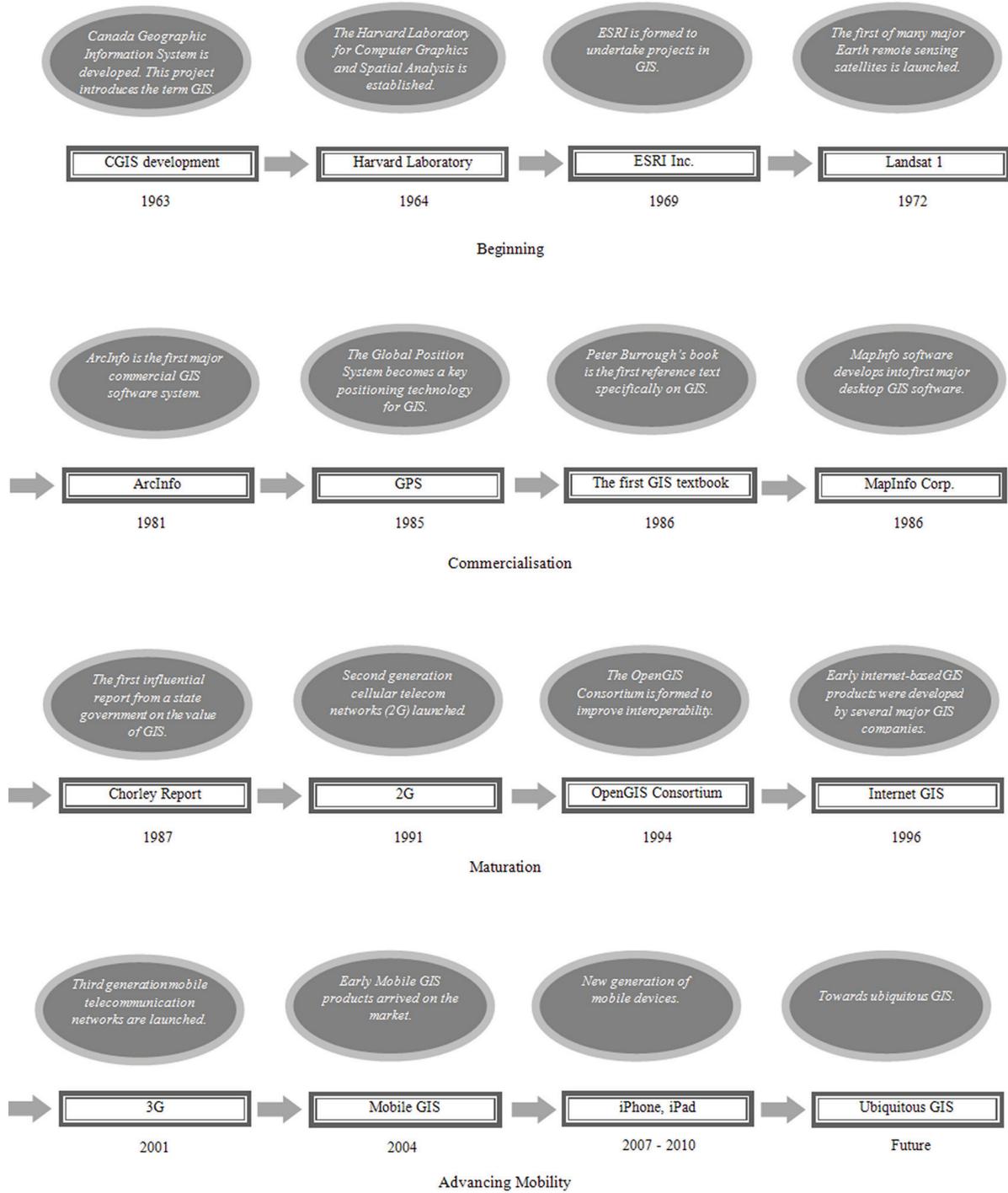
In this Chapter, the development of Mobile GIS from conventional GIS is presented in the context of GIS functionalities and mobile technologies and smart phones. The principles and main features of Mobile GIS are addressed in a systematic way, covering topics regarding its real-time connectivity, mobility and location-awareness. Mobile GIS takes advantage of mobile technologies (e.g. wireless networks, mobile devices, smart phones) to offer the possibility of exchanging and analysing spatial information in a real geographic world in real-time. Mobile GIS also offers the potential for users to employ GIS in more mobile and diverse situations and for a range of applications through smart phones. Mobile GIS are further presented in the context of Location-Based Services (LBS). LBS have been made possible due to the maturation and convergence of a range of heterogeneous technologies, such as mobile phones, the Internet and the Web, global positioning system (GPS) and GIS. LBS are defined as the delivery of spatial data and information services where the content of those services is tailored to the current or some projected location and context of a mobile user (Brimicombe & Li, 2009). LBS have been considered by many to have evolved professional GIS applications to more public-centric services and thus promoting greater ubiquity for GIS. Later in this Chapter, a wide range of Mobile GIS applications via smart phones are covered, including areas such as on-site data collection and monitoring; navigation with real-time updates; wayfinding for individuals to orientate and discover routes; real-time tracking of contacts; mobile commerce (m-commerce) with location-awareness; user-solicited information for a range of business and social purposes; coordinating emergency and maintenance responses to accidents and essential services; location-based artistic expression in the community, mobile gaming where the players and actions are location-based. The chapter ends with

a discussion of the challenges and research issues raised by Mobile GIS, such as the influence of fast development of mobile technologies.

FROM CONVENTIONAL GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO MOBILE GIS

In mid-1960s, with the prospect of handling and analysing spatial data digitally, the beginning of geographic information systems (GIS) had been explored in both professional and academic areas, as shown in the time line in Figure 1. In Canada, a prototype of GIS was started for the Canada Land Inventory which aimed to map existing land uses and analyse land capability for forestry, agriculture, wildlife and recreation (Tomlinson, 1984). The output of this early stage of GIS was regarded the cost-effective way for mapping the whole land area of Canada at the time. This system became fully operational in 1971. In 1964, in the Laboratory for Computer Graphics and Spatial Analysis, Harvard Graduate School of Design, USA, the first digital mapping software, named SYMAP, was created in 1964. SYMAP used line printers to produce primitive maps to visualise landscape themes of human and physical phenomena for identifying spatial similarities and groupings (McHaffie, 2000). These maps were represented as coarse lines of equally spaced characters and symbols. Evolving from SYMAP, the GRID package with command-line user interface and ODYSSEY as a line-based (vector) prototype were developed as GIS software in the Laboratory in 1970s. Also in mid-1960s, the US Bureau of Census aimed to produce digital maps of street blocks and census tracts for supporting 1971 census. This introduced explicit topology into the data structure. These early developments set the foundation of GIS, such as raster (grid) and vector (line) data structures, the use of database management for spatial data, the use of data layers (treating each theme as a layer of data), and

Figure 1. Time line of the development of mobile GIS and associated technologies



the use of topology in handling objects and their spatial relationships (topological relationships of points, lines and polygons).

The basic range of technological functionality associated with GIS can be generally summed up as: data entry and editing; transformation; query; interpolation, cartographic processing, map algebra and thematic mapping (Brimicombe, 2010). Data entry can be either the importing of existing digital data set(s), or digitising of secondary sources (such as existing paper-based maps). Spatial and attribute data from different sources can be integrated in a GIS database on the basis of geography. Data records can be geocoded, that is have x,y co-ordinates attached to them, through the use of geographic base files used for address-matching and postcode-matching. Data can also be edited and created within GIS. Transformation in GIS mainly includes data conversion between vector and raster, between different map projections, and between coordinate systems. Generalisation can also be viewed as an important form of a transformation in GIS, such as attribute re-classification and spatial aggregation. Examples of spatial aggregation can be re-representing clustered points as zones, or joining a number of small zones into a larger one. It can also be simplifying lines or dissolving dividing lines to reduce the complexity of objects. Query is an important functionality in GIS. Query can be searching for spatial objects according to specific attributes, or conversely viewing the attributes of selected objects or regions. Query also includes calculating the area of objects and distances between them, as well as generating a range of statistics of both the spatial objects and their attributes. Interpolation in GIS includes point to area (such as Thiessen polygons), point to field (such as using computational techniques for contouring), area to point (such as centroid of a polygon), area to field (contouring from centroid), and area to area (such as zone transformation). Another functionality of GIS is cartographic processing, mainly on vector layers, which consists of overlay

and buffering. Overlay is fusing a number of layers into a new layer containing rebuilt topology and attributes of each contributing layer often reclassifying using Boolean operators. Buffering can be performed on points, lines or polygons. Map algebra in GIS is mainly for raster data. Raster layers can be added, subtracted, multiplied, divided, and can also be weighted and compared for maximum and minimum values. Thematic mapping in GIS is for visualising data, with functions such as choosing layer combinations, class intervals, as well as colours, patterns, symbols, and layout. Producing a good thematic map is a very important aspect in GIS as it is the prime means of communicating data and the outcomes of analyses.

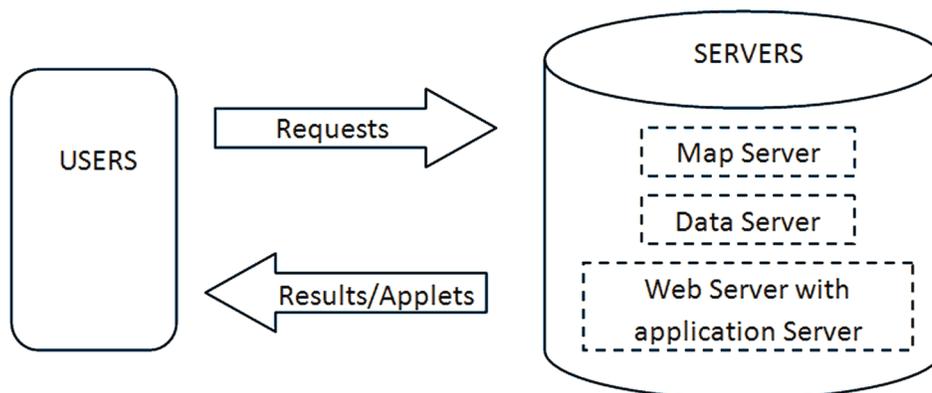
Geographic Information Systems (GIS) are often regarded as software; however, the data aspect of GIS is equally important as the software and GIS also engage people and organisations (Brimicombe and Li, 2009) in the production of spatial data and the use of software. GIS involve data collection and integration, processing, analysing and presenting in order to communicate analyses of physical and social phenomena that can assist in decision-making and problem-solving. The problems and issues analysed, being both scientific and practical, are overwhelmingly geographical in nature and focus on location. Thus GIS was traditionally presented as a technology to support science and problem solving; it has come to be more than this (Longley, Goodchild, Maguire, & Rhind, 2005). During the 1990s GIS emerged as a research discipline in its own right, often termed GIScience, to study substantive questions arising out of the use of GIS tools and spatial data. Longley et al. (2005) discuss some of different views on GIS such as: a professional user view of GIS as a tool and an analysis engine to examine data and real patterns relationships and anomalies; view from decision makers and planners of GIS as a computerised tool to solve geographic problems; a general public view of GIS as a container of maps in digital form.

Starting in the early 1990s, new opportunities became available to access and use maps on the Internet. These quickly evolved to incorporate basic GIS functionality of pan, zoom, and map customisation to be followed later by wayfinding tools for route selection. Specific products to deliver server side Internet GIS through a browser interface started to be available by in the mid to late 1990s, as seen in Figure 1. This represented a fundamental shift whereby different levels of GIS functionality and data sources could be accessed and used online by remote users. Users could have a choice of client side devices from desktop computers, laptops or personal digital assistants (PDA). GIS utilised through an Internet connection are considered as Internet GIS, a phrase which was in use by the late 1990s (Peng, 1999). There have been different terms to describe Internet GIS, such as Web-based GIS (Doyle, Dodge, & Smith, 1998), on-line GIS, distributed geographic information (Plewe, 1997). Figure 2 illustrates the main concept of Internet GIS. On the client side, users send requests for GIS functions through a Web browser via an Internet connection to the server side where GIS software and data reside. Requests have to be processed at server, and the results or applets are then sent back to users via the Internet. There are four basic parts in Internet GIS, which are the user (the client), and the map

server, data server and Web server which reside in the application server (Peng & Tsou, 2003).

Two different approaches can be adopted in principle for Internet GIS, known as the server-based approach and the client-based approach; most commonly implementations are server-based. In general, the ‘client’ is the side where requests are made whereas the ‘server’ is the side where requests are processed (Peng & Tsou, 2003). Internet GIS using a server-based approach has GIS software residing at the server site. Users will access and employ GIS functionalities via the Internet from their local computers or devices. The Web browser is used as a graphic user interface at the client side. The data processing and analysis are performed by GIS software installed at server side. At the client side, users send their requests through the Internet to the server. When the request is received at the server side, GIS software will be activated and relevant data sets opened; the request is processed using GIS functionality and the results sent back to the user, usually as image files. This is the basic principle of how the Internet GIS operate. There is a range of technologies associated with the handling user requests from browsers, which can be from desktop computers, laptops, hand-held devices to smart phones; for parsing user requests to the GIS software; and for data exchange between Web and GIS software.

Figure 2. Basic elements of Internet GIS



Apart from the professional usage of Internet GIS such as for the use of mapping and data collection in the field, popular applications accessed by the public are Web-based mapping sites such as Google maps (<http://maps.google.com>) which through their API allow other users to embed maps into their own Web pages. Access to and use of these sites from smart phones is in many ways very similar to the way these sites are accessed from a PC or laptop as they take no account of whether the user is static (at home or in an office) or on the move.

The advantages of server-based Internet GIS are mainly on its characteristics of centralisation. GIS hardware and software are managed and updated centrally, which can not only be maintained more easily than when decentralised, but also allow users to have consistent access to more up-to-dated functionalities. The server can also have much more computing power and data storage than mobile devices for example and are able to process complex operations more quickly. However, Internet GIS based on this approach can face the challenge when a large number of users send requests to a server simultaneously. Since for all user requests the functionality has to be performed at the server side instead of at the user (client) side, the system can slow down or even crash in responding to large numbers of user requests.

Another approach of Internet GIS is client-based. It provides users at the client side the ability to run GIS data processing and analysis locally. GIS functionalities as users require are downloaded from the server onto user's local devices via the Internet, which can include different level of GIS functions, required data and models. Small executable application applets can be created to carry out different tasks such as managing spatial data, handling maps, performing basic analysis. Such applets can be Java applets, ActiveX controls, or other suitable plug-ins for mobile devices. These application applets and plug-ins can be downloaded at runtime to users' local computers

or their mobile devices. The client-based approach Internet GIS have the advantage of reducing the server side burden of running GIS and data traffic on the Internet. On the other hand, there will be less centralised GIS function and data management. Furthermore, more sophisticated and advanced GIS functionalities may not be possible for users to access and perform on client-based Internet GIS due to lack of power and data storage.

The approach taken for Internet GIS implementation, therefore, depends on the criteria of applications, user volume, telecommunication network capability, and so on. In principle, the Internet GIS with server-based approach are more appropriate to users with certain demands for advanced GIS analysis and modelling functions. The volume of such users accessing any one particular site is less likely to be very high. Employing client-based approach, Internet GIS would be more suitable to applications with large user volume, but not necessary requiring professional advanced GIS functionality. Furthermore, distributed client/server approach is being developed and employed which can offer more benefit. There will be some discussion in next section.

With the development of mobile telecommunication network into its third generation (3G) in 2000s, the network offers the capability of both voice and data communication with high speed data transmission of 144Kpbs and latterly up to 8Mbps with the prospect of higher speeds. It can support mobile Internet access and multimedia applications. Mobile devices, particularly mobile phones (cellular phones), have seen rapid development from the early 1990s onwards. Mobile phones have become one of the most widely used electronic devices, largely viewed as a necessity of daily life by many people. Smart phones have the capability of always-on data connection, which offers access to mobile Internet with aims of 'any time, any place and anywhere' usage both for voice and data services. There is a convergence in mobile device development, which means the boundary is becoming blurred between types of

data-oriented handheld devices (such as tablets and PDA) and mobile phones. Smart phones can be viewed as one such product. A further technological development is the miniaturisation of GPS receivers and accelerometers to small chips so that they can be integrated within mobile devices making them location-aware. These technological developments (shown in Figure 1) and high levels of ownership of mobile devices provide opportunities for the rise of wireless Mobile GIS.

THE PRINCIPLES AND FEATURES OF MOBILE GIS

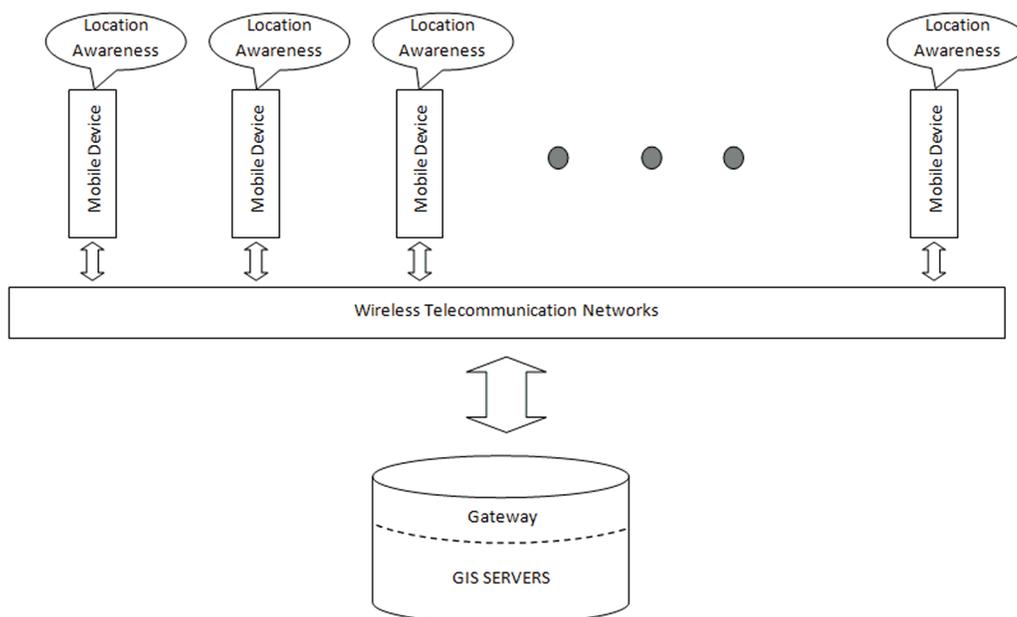
Wireless Mobile GIS are often shortened to wireless GIS or mobile GIS. In this chapter, we use the term: Mobile GIS. Mobile GIS have resulted from the convergence of wireless mobile technologies, GIS and GPS, offering users real-time access while on the move using devices that are themselves location-aware. This should not be confused with the early usage of the term ‘mobile

GIS’ which were mainly referred to those GIS used for working on site, in the field, through pocket PCs or PC tablets. Those GIS systems could also be connected to GPS to collect and manage spatial data, but most operate as stand-alone GIS. Mobile GIS using wireless technologies enable the real-time connection. Thus, mobile devices (such as smart phones) can synchronise their local data with the database of the GIS on the server, and access and manage data remotely in real-time. Mobile GIS offer the capability of accessing external GIS functionality and applications for users on the move.

Numerous components are associated with Mobile GIS. Here we focus on the following key elements of Mobile GIS as illustrated in Figure 3: GIS servers; wireless mobile telecommunication networks (connectivity); mobile handheld devices (such as smart phones); location-awareness technology; gateway services.

GIS servers provide GIS functionalities, data and applications. The core of GIS, such as GIS data structure and basic functionalities, follow

Figure 3. Key elements in mobile GIS



the same principles of conventional GIS. However, Mobile GIS are not stand-alone as are conventional GIS. As discussed in the last section, Internet GIS adopt a client/server approach to delivery of GIS services to users. In Mobile GIS, when based on client/server approach, a distributed component framework is often employed for users to access GIS. This concept of distributed component framework is different from conventional client/server structure. Distributed component technology allows clients to access heterogeneous servers dynamically (Tsou, 2004). Utilising such technology, the applications on either client or server side are broken up into a range of components that can be interoperable across networks, operating systems, applications, tools, languages and hardware. Distributed components can be structured as reusable components which are able to manage complex requests from client side. There are a range of benefits in adopting a distributed component approach in Mobile GIS. One of them is the flexibility of client and server roles in as much as a server can become a client to another server or a client can act as server depending on the distribution and functionality of components. Another advantage of using distributed component in GIS is that more complex requests from the client can be managed with sequence priority to offer more efficiency. This is can be beneficial when a server is busy when dealing with large numbers of client side requests. Peng and Tsou (2003) discuss in detail the advantages of distributed components in the Internet GIS. Three major component technologies used in the component-based application development have been widely applied in developing component-based GIS (Wu, Zhang, & Goddard, 2004). They are: Common Object Request Broker Architecture (CORBA) specification from Object Management Group (OMG); Distributed Component Object Model (DCOM) from Microsoft Corporation; and Java Remote Method Invocation (RMI) from Sun Microsystem Inc. A distributed

component framework can be applied in Mobile GIS to achieve these benefits.

Distributed Mobile GIS components can be used to provide applications across networks. Take the example of one of the popular distributed component technologies used for mobile devices – the Java platform. Java platform is able to offer support for distributed components in Mobile GIS, particularly Java Micro Edition (Java ME). Java ME emphasises applications used in mobile handheld devices, whilst Java SE (Java Standard Edition) is for more general client side applications. Java SE has been used for many Internet GIS applications and Internet mapping. On the other hand, Java Enterprise Edition (Java EE) focuses on server side applications of GIS, such as building distributed components that can be reused for various services. Java ME, with its focus on components for wireless handheld devices, can be used to build applications for Mobile GIS. The major components of Java ME consist of mobile information device profiles, connected device configuration and connected limited device configurations, aiming to provide utility programmes, security and connectivity for small mobile devices

There are a number of advantages to the Java platform. One is that it can offer a dynamic component framework of Java applets for client side and servlets for server side, which enables a more dynamic and efficient client/server interaction. Another advantage is Java's ability of cross platform performance. There is also Java's dynamic binding feature with downloadable Java applets. However, one of the disadvantages of the Java platform is that in comparison with machine level programming with binary coding, running Java programs is much slower due to its byte coding nature. Also there is no standardised distributed-object infrastructure in using Java. The reason we put Java as an example is that Java is one of the technologies that has been successfully deployed for Internet GIS, and is still evolving.

For those architectures that rely on networks for communication between the server and the client, client/server framework and distributed component framework are interrelated. Internet GIS use Web browser as their user interface. Distributed component applications can use Web browser as the user interface, but also could use their own GUI. Different protocols may be used for distributed components in Mobile GIS other than the HTTP protocol which is mostly used in Internet GIS. In general, GIS with distributed components do not have all of the system components in the same physical location. These components could be the processing, the database, the rendering or the user interface. Mobile GIS adopt a distributed component framework to support their services.

The second key element in Mobile GIS is the mobile telecommunication network, which provides wireless connectivity between Mobile GIS users and the network where the main GIS software, data and applications reside. In the early 1980s, the first generation (1G) analogue mobile network was in operation to provide voice traffic. Since then the mobile communication networks have developed through the second generation (2G) in 1990s with digital techniques and data communication ability although limited, to the third generation (3G). 3G networks provide high speed data transmission, which can support fast mobile Internet access and multimedia applications. Only at this phase of development in mobile wireless communication networks, Mobile GIS can be realistic and deliver services. Such networks enable users to access and use GIS, data and services in mobile situation and in real-time. However, geographical data are usual result in large file sizes, therefore needing high bandwidth and data transfer speeds to deliver. The bandwidth and data speed of the network have direct impact on services provided by Mobile GIS.

Another element of Mobile GIS is mobile handheld devices. A mobile handheld device is also known as mobile device, handheld device, or handheld. It is a pocket-sized computing device

with wireless connection, typically having a display screen with touch input and/or a miniature keyboard. Laptops are not viewed as mobile devices due to their size. Mobile handheld devices have developed over time, including handheld PDAs, Ultra-mobile PCs, Tablet PCs and smart phones. In order to access Mobile GIS applications and services, the type of mobile device needs to be more sophisticated in its connectivity, and computing capability in comparison to basic mobile phones focused on voice and text message communication or conventional handheld computers with limited connection. Smart phones belong to this type of mobile handheld device, which is the emphasis of this book. A smart phone can be regarded as a handheld mobile device that represents the convergence of mobile phones with handheld computers. Such mobile devices have the functions of mobile phones with wireless telecommunication connection, and operating systems to install and run advanced applications. Furthermore, operating system software offers a platform to develop applications. As discussed early in the section, Java ME is one such platform. More complex applications can also be installed and run based on a specific platform in a smart phone. Mobile handheld devices are continuously evolving and converging. Applications of Mobile GIS need to be designed and developed with characteristics of mobile handheld devices in mind, such as relatively small screen size (GIS visualisation usually associated with the display of maps), processing power, battery consumption and so on. Different types of Mobile GIS applications would emphasise different requirements of mobile devices. Applications could be navigation, finding nearest point of interest, real-time games, to real-time data collection. Some might require more fast and powerful processing capability and screen quality, while others require more accurate location-awareness technology.

Location-awareness technologies can be viewed as a key element in Mobile GIS. Conventional GIS is usually operated without concerning

where users are. It is similar for accessing Internet GIS. Mobile GIS deliver services and applications to users' mobile handheld devices, often related to the user's mobile situation and location. A typical application example can be providing a user on the move the required route to a certain destination based on where they are at that moment. The current location of the user is essential for this service. There are a range of positioning technologies that can be employed in mobile devices, such as Global navigation Satellite Systems (GNSS) including Global Positioning System (GPS), mobile network positioning technologies, wireless and RFID location technologies, sensor positioning, visual-aided positioning and hybrid indoor positioning. These positioning technologies are discussed fully in various Chapters in this book.

In order to enable mobile handheld devices (e.g. smart phones) to access GIS servers, middleware is required to link them up. This piece of middleware is the gateway service, which is another element of Mobile GIS. Gateway services provide the capability of translating user requests from mobile devices to GIS servers and formatting the output back to users at mobile device side. Gateway services also perform tasks such as protocol conversion.

Having discussed a number of key elements in Mobile GIS, we now can look into the main features in terms of the services and usage of Mobile GIS. These features are mobility; real-time connectivity; location-awareness; broadened usage.

Mobility is one important feature of Mobile GIS. Mobile GIS has the ability to operate and deliver functionalities, data and services without necessarily requiring a fixed location or wired connection. Mobility feature can also be seen as portability from one aspect. Users can access GIS via their handheld devices while on the move. The mobility feature of Mobile GIS has three characteristics, which are: mobile connectivity provided by wireless telecommunication networks; mobile handheld devices (e.g. smart phones) used to access GIS functions and applications; GIS with

distributed component framework where components could be the processing, the database or the user interface at different physical locations (servers) to deliver mobile services. Mobile GIS enable data can be captured, stored, and managed in remote locations and have the advantage of real-time updating without storing duplicated data. Data can be available from remote systems to mobile users. Information can be uploaded and downloaded between mobile devices and remote systems. The feature of mobility brings GIS out of fixed locations into the field and for people on the move. Use of GIS in mobile situations brings more emphasis on the interaction between the human, mobile device and the environment in human-computer interaction (HCI) research (Li, 2006).

Another main feature of Mobile GIS is the real-time connectivity. With this feature, Mobile GIS offer the possibility of exchanging and analysing geographical information in real-time in a real geographic world. The interactive services can be provided with real-time refresh and update. This allows more complex applications such as augmented reality where new data will be delivered as location is changed. It also opens door to applications of push-services, such as proximity advertising. For example, warning messages can be sent to users who are in such areas where disruption and danger are or might occur. The context of users can be taken into account in delivery GIS services, which including user's physical surrounding, current situation, and their personal preferences and requirements.

Location-awareness is another important feature of Mobile GIS, which differentiate Mobile GIS from conversational and Internet GIS. Mobile devices are position-enabled, such as GPS-enabled smart phones; therefore the location of a mobile device and their user can be identified. A range of positioning technologies (as discussed previously and elsewhere in this book) is employed for mobile devices, such as smart phones, to enable them to be location-aware. Using such location-aware mobile devices, more spatially-relevant

GIS applications and services can be available to users according to their location. For example, information can be received for fixed points of interest such as nearest restaurant, petrol station and hospitals, or for mobile subjects of interest such as the whereabouts of friends and children. Such devices also enable users' location to be sent back to servers, which allows Mobile GIS to manage and process real-time data and provide up-to-date applications and services more relevant to users.

Mobile GIS have broadened GIS user groups. Conventional GIS focus more on professional users, both in physical geography and in studying social phenomena to assist decision making and problem solving. GIS have been and continue to be utilised for analysing spatial data, discovering patterns, relationships and anomalies to support science and problem solving. On the other hand, Mobile GIS also provide functionalities and applications to the wider public - services relevant to people's daily lives. GIS functionality would be accessed and used by people having no GIS professional knowledge. These services can range from: viewing maps from users' mobile phones, finding nearest facilities, wayfinding, delivering location-related messages, playing mobile games. Such a wide range of user-centred services necessitates more emphasis on the interaction between users, GIS and the surrounding environment, which poses challenges in Mobile GIS research. This will be discussed further in the last section of this Chapter.

MOBILE GIS FOR LOCATION-BASED SERVICES (LBS)

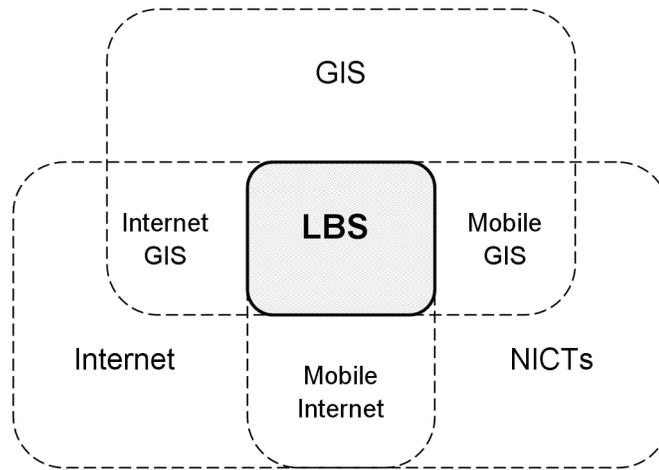
Mobile GIS have brought mobility, real-time connectivity and location-awareness into GIS, and also have broadened GIS usage and user groups. Mobile GIS provide tools and services not only for skilled professionals but also for a wider public to use in their working and social lives. Geographical data and information can thus

be accessed, extracted and displayed on user's mobile devices (e.g. smart phones) in real-time while on the move. Mobile GIS can be seen as the technology that facilitates the creation of mobile services. This leads us into the area of Location-Based Services (LBS).

Location-Based Services (LBS) are defined as "the delivery of data and information services where the content of those services is tailored to the current or some projected location and context of a mobile user" (Brimicombe and Li, 2009). LBS can be viewed as the outcome of the convergence of a range of technologies, as demonstrated in Figure 4. GIS provides geographical science, technologies and data for LBS. New Information and Communication Technologies (NICTs) have evolved from ICTs with features of mobility and location-awareness. NICTs include a range of technologies associated with wireless mobile telecommunication networks, other wireless networks, wireless handheld mobile devices (e.g. smart phones) and positioning technologies that integrated into mobile devices. NICTs also have the important feature of having wide usage, near ubiquity, in people's lives. The convergence of GIS, the Internet and NICTs has made LBS possible. We also can see that LBS are tightly coupled with Mobile GIS. LBS are therefore able to offer data and information services strongly related to user location in mobile situations, in real-time wirelessly.

The focus of LBS is on delivering location based data and information services that are mobile user centred. Location plays a major role in services provided by LBS. There are two main elements in delivering LBS services: pull and push. 'Pull' element in LBS generally employs user location obtained via his/her mobile device to offer services whereby the user can pull down (access and retrieve) data and information relevant to his/her current location and situation. 'Pull' element in LBS can be seen in applications such as navigation and wayfinding, searching for nearest point of interest. For the 'Push' element in

Figure 4. Location-based services: An aspect of the technological convergence



LBS, individual's mobile location is used to push (send) relevant information to users either as pre-subscribed requests or independently of a query. For example, information can be delivered to users according to their current locations for all kinds of business and social purposes. This may take the form of proximity advertising and offers of discounted goods, but could also be weather forecast, traffic conditions, delays to trains and flights, warning messages for potential hazards. There is also the element of 'tracking', which is monitoring the location of mobile devices continuously. 'Tracking' could be used to provide services such as monitoring or managing vehicle fleets, or in entertainment such as location-based games. Furthermore, location related information and services provided by LBS are expected to be updated according to user's current situation and needs, and to be delivered in real-time. It is essential that services provide real-time, up-to-date information pertinent to mobile users.

In order for LBS to provide needed information and services to mobile users, context is important aspect to be considered. The context in LBS mainly refers to the current situation of a user that could be relevant to tailoring location-based information. Context can be information associated to

user personal situations that might be used in setting up services particularly delivered to these users. For example, large sized text or maps, or louder ring tone could be extra features along with the information provided to those users in need. Context can also be surrounding situation at certain location, such as noisy places, unfamiliar areas. Other context may be time of day, speed of travelling. All these context will have direct effects in tailoring location-based information and services for mobile users. This will be discussed further later in this section.

Location-based geographical data and information provided as services by LBS can take many forms. One of the efficient ways to deliver geographical information is using maps, and is sometimes narrowly viewed as what LBS are. However, LBS should not be simply seen as delivery of maps to users' mobile devices. 'Location' in LBS concerns more the geographical position of a user as the key to tailoring information rather than the content of any response to a query. Response to a query can be just text or images, but such information has been tailored to the user, who makes the query, according to his/her mobile location and situation. For example, if a user queries the closing time of a car park where he/she

is, the response sent back need only be a simple text message. However, without requiring the user to describe or state exact location of the car park, LBS should be able to deliver the right information in real-time by determining the location through the user's location-aware mobile device. From this simple scenario, we can see that in adapting information and services according to location, GIS and the use of spatial data are fundamental aspects of LBS.

Information and services provided by LBS can increase their commercial potential when harnessing Mobile GIS. At the same time, LBS also bring emphasis on a range of research areas in GIS and Mobile GIS. These have been discussed in detail in the book "Location-Based Services and Geo-Information Engineering" by Brimicombe and Li (2009). Some of these key areas are issues concerning the availability of data, locating users and how to contextualise the user, their environment and the technology for delivering geographical information services. As discussed, determining the location of a user to whom services are delivered is essential for tailoring information in LBS. The location can be the current position of a user or some future projected location. A number of positioning technologies are available to determine the location of a mobile device, as discussed elsewhere in this book. However, challenges still remain to obtain user location with sufficient accuracy to enable location-based information to be provided with adequate detail and thus ensure utility. The level of sufficient accuracy also depends on the nature of services required. For example, the level of positioning accuracy required is much higher for responding say, to a car accident than in providing weather information for a user location. In addition to determining user location, contextualising the user and associated situation is important for tailoring location-based services to mobile users. Context of user's geographical location and surrounding environment could all need to be taken into account. Take a wayfinding example. A route

will be given to a user according to his/her location and requirement. The context such as time of the day could directly influence the utility of the information provided as being either as the shortest route or the safest route at night. Information associated with users and their preferences is another aspect of context in providing tailored geographical information. Technology is a further source of context, being the type of mobile device being used and its capabilities, quality of wireless connection, or the availability of data resources at the time of user request.

The key research areas in LBS and Mobile GIS include dealing with the spatial query, communicating the response and interoperability. Dealing with spatial query and communicating responses in Mobile GIS and LBS have their characteristics as processing and providing information in real-time, and providing geographical related services to the wide public who should not be required to have GIS skills. The interested reader can refer to the book "Location-Based Services and Geo-Information Engineering" for more in-depth analysis of these areas. As LBS are the result of the convergence of a range of heterogeneous technologies, interoperability is one of important research areas in GIS, Mobile GIS and LBS. Legal/social issues and business models are issues increasingly raised as GIS and LBS have wider use in society, which will be referred to again in the last section of this Chapter.

APPLICATIONS OF MOBILE GIS FOR SMART PHONES

New opportunities for Mobile GIS applications and services are rapidly growing with the rise of smart phones. A 2010 comScore study indicates 14% of smart phone users (33.5 million) use mobile mapping applications, a 44% increase from 2009. This number is expected to grow further through 2011-12 (<http://www.vce.com>, viewed on August 2011). The availability of smart phones and the

widespread use of GIS consumer products on smart phones have consequently aroused a substantial anticipation of Mobile GIS applications for smart phones (Renner et al., 2011).

However, Mobile GIS services remain in their early stage. There is potential and also challenges for mobile software development, as new hardware is being released and various support platforms co-exist. At present, most mobile GIS applications and APIs for smart phones are built on three main mobile operating systems (or smart phone platforms) which are Google's Android, Microsoft's Phone 7, and Apple's iOS. Some applications have recently extended to BlackBerry. While individual users can use smart phone applications for their daily life such as finding nearest points of interest, organizations in many sectors can use them to increase operational efficiency such as improving workflow.

The range of applications of Mobile GIS for smart phones are summarised here. Some of them are still potential applications, which are expected to emerge as Mobile GIS mature in the foreseeable future. Others applications have already been developed and are being used to a certain degree. Relevant examples are presented under each category to demonstrate different development procedures and application types.

Applications Mainly for Accessing and Using GIS Functionality through Smart Phones

Basic GIS software functionalities can be implemented on smart phones through Mobile GIS applications, which are often extended to include some location-based features, such as accessing maps and data relevant to user location, collecting location related data in real-time, real-time reporting of events with spatial tags. Such applications provide users with smart phones access to basic GIS services in real-time while on the move.

Here are some examples of this type of Mobile GIS application. One of them is *ArcGIS Apps* for

Smart Phones developed by ESRI, which allows users to navigate maps, collect and report data, and perform GIS analysis via a smart phone. Such applications offer opportunities for smart phone users to view maps and capture information related to their current situation, access content from *ArcGIS Online* or use functionalities from enterprise GIS, and develop custom applications for user needs. These apps could broaden GIS usage to a much wider public. Another example is applications built using open source software that are increasingly available. It becomes practicably feasible to build a specific single application on different mobile platforms. For instance, a new Flex/AIR GIS application for the smart phone BlackBerry has recently developed by WebMapSolutions using Web-based Flex code (www.webmapsolution.com, viewed on August 2011). Building Mobile GIS functionality for smart phones has also been aimed for Apple's iOS platform using OpenScales Flex sdk's, ArcGIS Flex API and OpenLayers.

Also in 2008, a solution for accessing GIS through BlackBerry smart phones started to be designed (<http://www.3-gis.com>, viewed on August 2011). With the introduction of an application named *Buzz* for BlackBerry smart phones, users are able to view and query GIS data with their smart phones on the move. Developed to employ the ESRI *ArcGIS Server* technology, *Buzz* is aimed at services provided to industries such as the utility, telecommunications and emergency management firms; but also could be extended to other markets with a geo-database. Currently, *Buzz* can run on the BlackBerry® Pearl™ series, BlackBerry® Bold™ and BlackBerry® Curve™ series smart phones utilizing the AT&T, Sprint, T-Mobile and Verizon Wireless telecommunication networks.

Mobile Applications for Public and Business Services

In the early stage of mobile GIS applications on smart phones, there is no clear boundary between public and business services. However, increasing

numbers of applications are expected for various specialised aspects of public and business services in the future, as mobile technology itself is evolving. Some of examples are given below to illustrate mobile GIS applications used for public and business services.

One example application is the free *BAO* (Business Analyst Online) for Apple's iOS platform developed by ESRI, aiming to give access to key demographic and market facts about any location in the U.S. through iPhone, iPad, or iPod Touch. This application provides information which can be used to evaluate an area on-site in real-time and assist businesses to understand an area in terms of its geo-demographics. The knowledge of an area can be: types of people living in the location, including a brief demographic and market data summary of a location (e.g. age, gender, socio-economics, and spending habits); the difference between people living in this location from other areas by comparing demographic and market data for two locations or one location vs. the entire U.S. national level data. Such applications may assist businesses to compare and choose preferable locations for their services based on needs and criteria. *My Place History* is another free app from ESRI's *Geomedicine* for Apple's iOS platform which links public health information with user environmental experience. This application provides services to assist users to better understand their local environment in terms of its effect on their health. U.S. street addresses are used to create and manage a personal place history. *My Place History* allows users to access geographically relevant health information, such as one's proximity to environmental hazards or exposures. The application of *My Place History* can also link user's personal place history with a number of USA governmental databases such as Dartmouth Atlas of Health Care, Toxic Release Inventory (TRI) of the United States Environmental Protection Agency, Haz-Map, and U.S. National Library of Medicine.

Another example is a location-based service developed for companies and state and local governments by GCS Research, combining the functionality of Mobile GIS with the GPS-based sensor suite of an Android-enabled smart phone (www.gcs-research.com, viewed on August 2011). This is a thin-client application, aiming to be a practical, cost-effective business tool that enables mobile users to access geographic information and geospatial functionality via their handheld device. The *Montana Parcel App*, built by GCS Research for this purpose, allows smart phone users to remotely access information of real estate in Montana. Users can use the phone's built-in GPS to get their current location in the state. They also can zoom into a mapping interface to select an area of interest by "double-tapping" the touch screen. In real-time, the application can retrieve location-specific property information for the selected site from two Web-enabled databases. The first database is a parcel boundary file maintained as part of the Montana cadastral database. This cadastral information is managed in an ArcSDE geodatabase. The smart phone application can trace the property boundaries in red on the phone's map display. The second database is the State of Montana CAMA (Computer-Assisted Mass Appraisal) System where it retrieves property details such as owner name, parcel legal description, area size, assessed value, and zoning code. Such an application can create a mobile mash-up that uses the Android mobile operation system to deliver mobile services.

The advanced functionality of mobile operating systems have made it possible to bridge the gap between the enterprise business GIS database and the mobile phone, as we can see in the case of the GCS Research application. Cost-effective, location-based business tools can be created with this technology. Users can download applications such as *Montana Parcel App* for free on their smart phones. Such mobile applications and other Mobile GIS tools can be transferred to different smart phone operating systems. The development

of location-based services, which converges a range of technologies, can provide a wide range of Mobile GIS applications for smart phones.

Applications for on-Site Data Collecting, Monitoring, and Management

Real-time communication and analysis play important roles to support efficient decision making. On-site work can comprise of data collection, monitoring and management as well as those activities carried out in the field such as identifying key variables contributing to a problem, taking measurements, and inputting and handling data residing locally or remotely. For a variety of fieldwork operations, there has historically been a lag between collecting data on-site and analysing data back at the office, also in exchanging relevant data for analysis and decision making. Mobile GIS applications delivered via wireless networks and mobile handheld devices (e.g. smart phones) offer field operatives the opportunity to do on-site data collection and monitoring while having real-time connection with remote sites (or head offices) to exchange data, to carry out analysis to support decision making or to take action rapidly. Furthermore, using mobile devices for fieldwork has a number of extra advantages such as light in weight and low in cost. Nevertheless there are also a number of disadvantages to using a mobile device in the field such as its comparatively low CPU power for processing data and graphics, small screen size and issues on its compatibility when used alongside other equipment.

One example is a Mobile GIS application aimed at providing and improving GIS ability for field surveying work. *SuperGIS Mobile Engine 3* is a Software Development Kit (SDK) developed by SuperGeo (www.supergeotek.com, viewed on August 2011), which can be used to build Mobile GIS applications to meet demands for effectively improving the surveyor's productivity. Additional GIS functionality can also be created

using *SuperGIS Mobile Engine*, and then embed into the existing mobile application to provide Mobile GIS functionality to users via their mobile devices. It is aimed for user to develop Mobile GIS applications through *SuperGIS Mobile Engine* built-in controls, read-to-use features, to achieve standard GIS functionality in mobile situations. These mobile applications include map display, GPS positioning, file editing, coordinate system settings to meet user needs in the field. They can be built for mobile devices supporting Microsoft® .NET Compact Framework, such as smart phone, Pocket PC and Tablet PC, and thus reduce the incompatibility problem that often occurs in hardware and software.

Mobile GIS applications, similar to this, often aim to offer users working on-site with capabilities such as: collecting spatial data; editing and updating data locally and remotely; accessing maps to obtain up-to-date and relevant spatial data; having positioning ability such as GPS; querying and managing data to assist their fieldwork and decision making. There is a range of examples of such application. One is using mobile handheld device for on-site monitoring of environmental processes (Nurminen, Kruijff, & Veas, 2011). Environmental parameters of certain areas are observed continuously and measured regularly. Spatial data as well as related data such as images are communicated and exchanged between people working on-site and decision maker who are in different locations. Others include field mapping to update spatial data on-site with attribute information, building and maintaining asset lists with location and attributes, and real-time incident recording into spatial database.

Another example for this category application is BlackBerry *Business Solutions* (us.blackberry.com/business/needs/field/, viewed on August 2011), which consists of a combination of applications, services and peripherals, including printers, signature capture, GPS, digital forms and barcode scanners. This application is designed to provide mobile customer services. It provides

mobile field access to details to support cases and customer activities which will raise support issues in real-time. This mobile application can be used to provide services such as updating service tickets from different locations, triggering the billing process and setting up feedback from the field. Similar applications could provide services such as checking availability of products at different locations according to user's current position and placing orders, communicating and collaboration with other business and organization using real-time on-site information.

With a mobile traffic alert application developed in Ryerson University, Canada, road geometry data can be extracted using GPS data received from smart phones (Niu, Li, & Poursaeid, 2011). Based on road centrelines, this application can be employed to assist capturing road network data. The current conventional methods to obtain such data, either by surveying or by using remote sensing data, are time consuming and expensive. In this application example, GPS data are crowd-sourced through smart phones as an increasingly popular way of collecting data that can be used to provide real-time traffic information, identify traffic patterns, and predicting traffic congestion. The same type of data can be very useful for cost-effective, fast updating of road network databases due to its rich spatial and temporal coverage and high data volume.

Applications for Navigation and Wayfinding

A range of mobile applications are particularly designed for navigation and wayfinding using mobile devices such as smart phones. Navigation applications are mainly developed for assisting motorists to identify appropriately optimized routes. For example, an optimised route can be found and sent as a map to users' mobile devices when a vehicle is to be driven from one starting point to one or more user-specified destination. Furthermore, subscription services for real-time

traffic updates can be delivered to users' smart phones according to the user's current location.

Mobile GIS applications that provide wayfinding services are more focused on the means by which individuals orientate themselves, discover, and explore surrounding or certain areas of interest. Individual users with their mobile devices could use this type of application to discover points of interest related to their current locations, to find routes to certain destinations or places such as tourist attractions, restaurants, and theatres. Modes of transport and other spatially located objects, landmarks and points of interest can also be provided using location-aware mobile devices. Such applications intend to deliver users a service in real-time according to their need while on the move.

Other Mobile GIS Applications on Smart Phones

A range of other applications can be identified, many of which have been prototyped and in development. These applications, along with those applications for navigation and wayfinding, are more closely related to LBS applications:

- **Real-time tracking:** such applications can be real-time tracking of vehicle fleets, business associates, social contacts (e.g. to know when friends are nearby) or one's family members (e.g. tracking children home by parents who are still at work).
- **Mobile commerce:** this would incorporate both transactions made by individuals on the move via a NICT and receiving (pushed) alerts (e.g. advertising, notification of discounts) to opportunities for transactions that are location-specific (such as at a nearby shopping mall).
- **User-solicited information:** this type of applications can be for all kinds of business and social purpose, such as weather forecast, traffic conditions, delays to trains

and flights, warning messages for potential threats, film showing and ticket availability, menus and local maps.

- **Location-based tariffs:** such as differentials in road pricing, pay-as-you-go car insurance and similar schemes.
- **Coordinating emergency and maintenance responses** to accidents, interruptions of essential services and disasters.
- **Artistic expression in the community** that might include digital graffiti, location-based story lines and discovery trails.
- **Mobile gaming** where the players and actions are location-based.
- **Social networks** where location-aware applications could be implemented with wireless social network tools, such as twitter. Users would share their location, and what is on their mind through updating their status, attaching a location to their thoughts and activities. The updated status, with the location graphically depicted by a map, would be available on the screen of smart phones.

The future trends of Mobile GIS applications for smart phones will be interwoven with location-based services, as Mobile GIS, smart phones, wireless telecommunication networks and related technologies are further developed. Mobile GIS enable more people without GIS professional skills to engage with GIS-based services in a more ubiquitous way. Smart phones are expected to be used by more people on the move as a powerful and readily available thin client for various applications rather than just as phones. More advanced real-time/on-site functionality of Mobile GIS will become available on smart phones due to the advancement of new information and communication technologies (NICTs). Therefore, the range of Mobile GIS application will continue grow.

PROSPECTS AND CHALLENGES OF MOBILE GIS

Mobile GIS have come a long way in a short time. They have been facilitated by the rapid development of mobile telecommunication networks to deliver higher bandwidths, the rapidly evolving design of mobile devices, and the convergence of heterogeneous technologies into single devices that are location-aware. As these technologies further develop, so too will the possibilities for Mobile GIS. However, Mobile GIS are technology dependent and any shortcomings in the technology will have knock-on effects for Mobile GIS in the implementation and delivery applications (Brimicombe and Li, 2009). Above all, by aligning GIS with mobility and mobile devices there is the opportunity for engineering GI applications that make GIS part of ubiquitous technologies and at last achieve an embedded mainstream status.

The GIS community has long thought of itself as focusing in two areas: systems and science. Once the systems had adequately matured, the science took off with research focusing on the substantive questions posed by the use of the systems in solving real-world problems. The research agenda is far from complete, particularly as new questions arise from the pace of technological development, the increasing quantity, diversity and granularity of data, and the complexity of analyses that are entailed. Nevertheless, GIScience is reaching a maturity with a body of scientific and application knowledge. Engineering is the systematic application of scientific research to successfully and dependably solve real world problems (Brimicombe, 2010). With the convergence of technologies shown in Figure 4 and the potential for designing applications that are widely used, we see the opportunity for progressing to GI Engineering, that is, “the design of dependably engineered solutions to society’s use of geographical information” (Brimicombe & Li, 2009). Examples already on the market are in-car satellite navigation systems (SatNavs), similar applications on smart phones,

and niche applications of location-based services (LBS).

Whilst the prospects for Mobile GIS are good with plenty of opportunities, there are challenges along the road to ubiquity. These challenges derive from four broad areas: limitations, even threats that derive from the technologies being used; areas of GIScience that still need to be adequately researched; users; and business models for a sustainable presence.

The rapid development in mobile telecommunication network and mobile device technologies will bring even faster data transfer speeds, better connectivity and more advanced devices. This bodes well for Mobile GIS. However, such developments and changes in these industries also raise issues concerning the reliability and consistency of network infrastructure and devices which Mobile GIS rely on to build, implement and deliver applications. For example, the release of the iPhone revolutionised smart phone technologies and required application designers to quickly gear up to this new class of device. The design of the devices (such as screen size and resolution, keyboard/keypad, memory and optional additional memory) is likely to be driven by the more popular uses such as texting, social networking and tweeting and may remain sub-optimal for Mobile GIS. For example, use of gestures across the face of the screen is likely to make query definition more difficult when compared to using a keypad, but a pop-up keypad may obscure too much of the maps being viewed. There is also the issue of battery life, that is, the length of time between charges that allows a device to remain serviceable on the move without needing additional batteries. Relatively short battery life has been an issue with smart phones because of the power demands made upon them. Continuity of connectivity and therefore of service has always been a problem with wireless mobile devices due to blocked signals in tunnels, underground systems, inside building complexes and so on. Hand over from one cell to another, particularly at speed, can cause the service

to drop. Additionally, GPS in a smart phone for location-awareness will not work and may even give seriously erroneous results where a clear view of three or more satellites is not available. Whilst assisted GPS through the telecommunications network helps overcome some of the effects, it is not a complete solution. Location-awareness may have to rely upon a number of technologies including GPS, A-GPS, accelerometers (which are now available as a chip), and RFID and Bluetooth for locating through beacons.

Mobile GIS raise a number of research areas for GIScience arising from the technology, data requirements and the nature of applications. Important areas are:

- **Distributed component systems:** This will be a fundamental departure for GIS software which has tended to be monolithic, that is, a large software package resident on a single PC or server. The smart phone and other mobile devices are comparatively thin clients with relatively low storage and processing power. An advanced desktop GIS package is unlikely to fit on a smart phone and software for mobile devices that are available on the market are usually a sub-set of the functionality geared to specific tasks. In order to overcome such limitations Brimicombe and Li (2009) have proposed a distributed component approach to GIS using agent technologies. A software agent can be defined as an autonomous, problem-solving, encapsulated entity in a dynamic and open environment (Woolridge, 1997). The fundamental difference between a conventional software program and an agent is that the former will run once and then terminate until instructed to run again, whereas the latter can sense the environment in which it is embedded and act on it autonomously in pursuit of its goals (Franklin & Gaesser, 1997). The advantage of this type of struc-

ture would be that an interface agent would reside on the thin client mobile device and would arrange for each task (such as locating the relevant data, conducting some form of analysis and displaying the result) to be carried out by other agent-based services residing on servers on the Internet. Functionality and data would be on an on-demand basis. Agent technologies are particularly suited to achieving interoperability in heterogeneous computational environments and would thus be a sound structure for Mobile GIS.

- **Scalability and response times:** For ubiquitous applications of Mobile GIS, the technology will need to be scalable to potentially millions of users without noticeable degradation of service. GIS-type queries are typically long transactions, that is, querying spatial data takes much longer than typical database queries of nonspatial data. GIS queries tend to have both high CPU cost and high I/O cost. Thus current approaches to GIS software are unlikely to be sufficiently scalable. Whilst open and interoperable middleware will be important, a large part of the solution rests in the type of interoperable component systems discussed above.
- **Data:** There has been a data explosion over the last decade of unprecedented proportions, an increasing proportion of which is spatial data. Many areas of economic endeavour have become data driven and the focus on high resolution local data has driven new services. Focusing in on local areas leads to an exponential rise in the amount of data required to satisfy informational needs (such as from Google Earth to Google Street View). Zooming in also requires data to be timelier with shorter update cycles. Whilst the technology for this exists, the costs can be high. But whilst conventionally GIS have been deployed

for map data and their attributes, the main mass markets will be for such data to be integrated into a multimedia approach to information delivery either through on-the-fly mash-ups or by incorporating into GIS non-traditional data that nevertheless have spatial tags (e.g. tweets). This will add an order of complexity to GIS.

- **Cognition:** This is central to how users of Mobile GIS are going to be able to interact with the technology in relation to their changing surroundings. Traditionally studies of spatial cognition have focused on how users conceptualise, understand and use map products. But in most interactive applications employing Mobile GIS, the user initiates the query, the framing of which will be based on spatial reasoning derived from their perception and understanding of their surroundings, desired goals and a range of contextual variables. Spatial queries will need to be framed as naïve natural language or gesture-based requests instead of more formal database queries. The formulation of the query is all important in obtaining the desired information and deriving utility from the application.

Some important considerations of the user have just been touched on. The design of the application should provide for a compelling user experience and most smart phones provide the functionality and programming environments to achieve that. But designers need to also consider the vulnerabilities that the use of smart phones can impart to users. In the UK there have already had to be public service announcements on the potentially dangerous consequences of using mobile devices while crossing the road. This and similar vulnerabilities might be an important for Mobile GIS applications for wayfinding. As a way of alerting the GI community to this issue, Brimicombe (in press) has analysed the crime wave in the theft

of portable in-car satellite navigation devices (SatNavs) once they became mass consumer products at the end of 2005. Many purchasers of these products (the first mass consumer products to include GIS software) will have been unaware of the vulnerability to theft that these devices would impart to the owner. Beyond gimmickry and status must-haves, Mobile GIS applications will need to establish markets for services that provide utility to users. That is, the perceived benefits of a service must outweigh the cost or effort in obtaining the service. This requires business models that promote the utility whilst being able to cover the costs of sustaining the service (Tsalgatidou & Pitoura, 2001). Many users of Internet and mobile services expect them for free and consequently must put up with pushed advertising and other inducements which will cover the cost for the service. This type of business model is likely to be restrictive for services based on Mobile GIS because unless the volume of users is very high, the click rate on advertisements is unlikely to supply revenue that would cover set-up and running costs. Simple applications such as accessing Google Maps are free, but are no different from mobile Internet. More complex applications that provide analytical functions and tailoring based on location-awareness are likely to be subscription services. The challenge for these services is to provide high levels of utility that are error free in order to be sustained. Services based on Mobile GIS are only at the beginning – this will be an interesting space to watch.

CONCLUSION

Mobile GIS is the successful convergence of mobile communication and GIS technologies. The driving force of growth of Mobile GIS is the rising demand for LBS applications from users of mobile devices, where smart phone users have played a key role. Wireless mobile devices, particular smart phones, offer the possibility of querying, analysing

and visualising spatial information on-site and in real-time. Mobile GIS provide core functionality in the context of LBS, while LBS bring Mobile GIS to various aspects of daily life. The research and development of Mobile GIS are still at an early stage, but great potential has been demonstrated for a range of applications. With further progress in wireless mobile technologies and GIS, Mobile GIS will certainly make a substantial contribution in the realisation of ubiquitous GIS.

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KEY TERMS AND DEFINITIONS

Challenges of Mobile GIS: Research challenges raised in Mobile GIS area including limitations derived from the technologies being used, areas of GIScience that still need to be adequately researched, users, and business models for a sustainable presence.

GI-Engineering: the design of dependably engineered solutions to society's use of geographical information.

GIS: Geographical Information Systems, also known as the research discipline of Geographical Information Science. GIS can be defined as a system of hardware, software, data, people, organisations and institutional arrangements for collecting, storing, analysing, visualising and disseminating spatial information about areas of the earth (Dueker and Kjerne, 1989; Brimicombe, 2010).

LBS: Location-Based Services, the delivery of data and information services where the content of those services is tailored to the current or some projected location and context of a mobile user.

Mobile GIS Applications: A range of software applications with characteristics of wireless communication, mobility and GIS functionality.

Mobile GIS: Mobile Geographical Information Systems, with features of mobility, real-time connectivity and location-awareness, broader user audience.

Wireless GIS: An alternative term for Mobile GIS.