CHAPTER 48

The Integration of Internet GIS and Wireless Mobile GIS

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48.1 Introduction

The paradigm of geographic information systems (GISs) is shifting from a closed, centralized GIS architecture, to an open, distributed geographic information services (GIServices) framework. With advances in computer networking and wireless communication technology, GIS is moving toward an integration of GIServices and spatial analysis functions via the internet and wireless communication. Wireless mobile GIS and internet GIS can be combined together to provide ubiquitous GIS power for various users at different locations with different tasks, such as urban planners, cartographers, first responders, bus drivers, realtors, and the general public.

The integration of GIServices (including internet GIS and wireless mobile GIS) can synergize information-sharing and facilitate the diffusion of GIS technologies into broader applications and potential users. Online GIServices will encourage multidisciplinary cooperation between the GIS community and other communities, such as the computer science community, the education community, and the geoscience communication (Plewe 1997; Tsou and Buttenfield 2002; Peng and Tsou 2003). For example, Figure 48-1 illustrates a web-based GIS education project developed for the teacher and students at the Hoover High School in San Diego. The map shows the location of fast food restaurants and the overweight population nearby the high school from the census data set. High school students and teachers can use the online mapping tools to create a community-based project regarding the obesity problem. One unique potential of this application is that the high school students might utilize handheld Global Positioning System (GPS) units to record the locations of fast food restaurants on the streets and then combine these points into the web maps (Figure 48-1). This web GIS education program was developed by San Diego State University and was funded by the National Science Foundation–Advanced Technology Education (NSF–ATE) program (project website: http://geoinfo.sdsu.edu/hightech). Besides this education example, other disciplines and communities can also adopt integrated internet GIS and wireless mobile GIServices for providing better services and functions, such as disaster management, homeland security, tourism, and natural resource conservation.

Recent developments in advanced network computing technologies, such as web services, grid computing, and semantic web provide a promising future for the next generation of internet GIS applications. Traditional GIS, designed as isolated islands, will become increasingly less attractive, and may disappear altogether. The reusable and interoperable open and distributed GIServices will broaden geographic information uses into an increasingly wide range of online geospatial applications. New wireless communication technology, such as Bluetooth, Wi-Fi, 4G cellular systems, and WiMAX, also will transform GIS into wireless mobile GIS, which can provide ubiquitous access of geospatial information from portable devices or mobile phones from anywhere.

This section will highlight the importance of combining wired internet GIS and wireless mobile GIS technology that can provide complementary GIServices for each other. Without the linkage to mobile GIS devices, most internet GIS applications will lack ground-truth information for real-time or near real-time data update and GPS tracking functions. Without the powerful databases and large-size remotely sensed imagery archived in the internet GIS

Figure 48-1 The top image combines internet GIS and wireless mobile GIS for a high school GIS education project (http://geoinfo.sdsu.edu/hightech/mapviewer.htm). The locations of fast food chains are tracked by using mobile GIS devices and GPS (a Trimble GeoExplorer XM unit), image on left. The image on the right shows an alternative method of mobile GIS by using a Pocket PC and a cellular phone). See included DVD for color version.

servers, mobile GIS applications will become very limited in restricted computer hardware with incomplete data sets. In the future, a comprehensive GIService will rely on both wireless mobile GIS and wired internet GIS. The following sections will highlight the major characteristics of internet GIS, components of wireless mobile GIS and the major challenges in integrating the two technologies.

48.2 Characteristics of Internet GIS

There are many different internet GIS applications, ranging from data clearinghouses, web mapping, data portals, web-based decision support systems and GPS tracking, to digital Earth virtual globes. In general, we can categorize various internet GIServices into three types: data sharing, information sharing and knowledge sharing (Tsou 2004a) (Figure 48-2).

The first type of internet GIServices is for data sharing, which combines the functions of online data archive and data search services. Two typical applications are online data warehouses (or data archive centers) and online data clearinghouses. An online data warehouse is for archiving, accessing and downloading both GIS databases and/or remotely sensed imagery. A web-based data clearinghouse can help users to search and index the contents of metadata, and then access the actual data through the descriptions of metadata.

Three Types of Internet GIS

Data *Sharing (Exchanging)*	***Applications*** Online data warehouses (data archive) Online data clearinghouse (metadata)
Information *Sharing (Map Sharing)*	***Applications*** Web-based map display Navigation services
Knowledge *Sharing (Spatial Analysis and Modeling)*	***Applications*** Online GIS models Web-based spatial analysis tools

Figure 48-2 Three Types of internet GIS (modified from Tsou 2004a).

The second type is for information sharing and map sharing. Multiple interactive map servers and mobile navigation services are the typical applications. Web-based mapping functions include the display, zoom-in/out and query of spatial information. The major requirement of information sharing services is to provide effective web-based display mechanisms and client/server communication protocol.

The third type of internet GIS focuses on the sharing of knowledge and GIS models. This is the most challenging task for the development of internet GIS and only a few applications are available today. The goal is to provide online GIS modeling and spatial analysis functions without running GIS engines or software packages locally. Some internet GIS applications utilize Java language or other distributed component technologies, (like .NET or web services) to develop online GIS model functions. The implementation of these web-based software components can provide ubiquitous access for all different types of GIS applications.

More recently, a new concept of internet GIS has started to emerge called "GIS portals." A web-based GIS portal can provide all three types of internet GIS services together, including data sharing, map display and some spatial analysis functions via web services. This new trend will integrate various GIS functions, maps, and data servers into a systematic framework via a single entry point rather than create scattered internet GIS applications.

Another important change in internet GIS is the dramatic growth of its users. According to recent research from ComScore Network (http://www.ebrandz.com/newsletter/2005/July/1july_31july_article1.htm), online map users are a huge market for business applications. In May 2005, Time Warner (MapQuest.com) estimated 43.7 million US visitors, Yahoo!Maps (maps.yahoo.com) 20.2 million users, Google Map (maps.google.com) 6.1 million and Microsoft's MSN MapPoint (mappoint.msn.com) 4.68 million visitors. This is a huge market for online mapping services compared to traditional GIS users. It is also very interesting to see the new online mapping providers, such as Google, Microsoft, Yahoo, and Amazon.com join the market of online mapping and provide more diversified geospatial information services to the public.

One key issue of the development of internet GIS is to provide the most updated data online. Therefore, we will need to utilize wireless mobile GIS to provide real-time or near-real-time information feed back to the internet GIS servers. The following section will highlight the major components of mobile GIS.

48.3 Components of Wireless Mobile GIS

Mobile GIS is an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wired or wireless networks (Tsou 2004b). There are two major application areas of mobile GIS: field-based GIS and location-based services (LBS). Field-based GIS focuses on the GIS data collection, validation and update in the field, such as adding or editing map features or changing the attribute tables in an existing GIS data set. Location-based services focus on business-oriented location management functions, such as navigation, street routing, finding a specific location, tracking a vehicle, etc. (Jagoe 2002, OGC 2003). The major differences between the field-based GIS and LBS are the data-editing capabilities. Most field-based GIS applications need to edit or change the original GIS data or modify feature attributes. LBS rarely changes original GIS data sets but rather uses them as background or reference maps for navigation or tracking purposes. Most field-based GIS software packages are cross-platform and independent of hardware devices. On the other hand, LBS technologies focus on creating commercial value from locational information. Each mobile phone system has its own proprietary operating system that is very difficult to customize.

The architecture of mobile GIS is very similar to the internet GIS. It follows the concepts of client/server architecture as in traditional internet GIS applications. Client-side mobile GIS components are the end-user hardware devices that display maps or provide analytical results of GIS operations. Server-side components provide comprehensive geospatial data and perform GIS operations based on a request from the client-side components. Between the client and server, there are various types of communication networks (such as hard-wired cable connections or wireless communications) to facilitate the exchanges of geodata and services. Figure 48-3 illustrates the six basic components of mobile GIS: 1) positioning systems; 2) mobile GIS receivers; 3) mobile GIS software; 4) data synchronization and wireless communication component; 5) geospatial data; and 6) GIS content servers (Tsou 2004b).

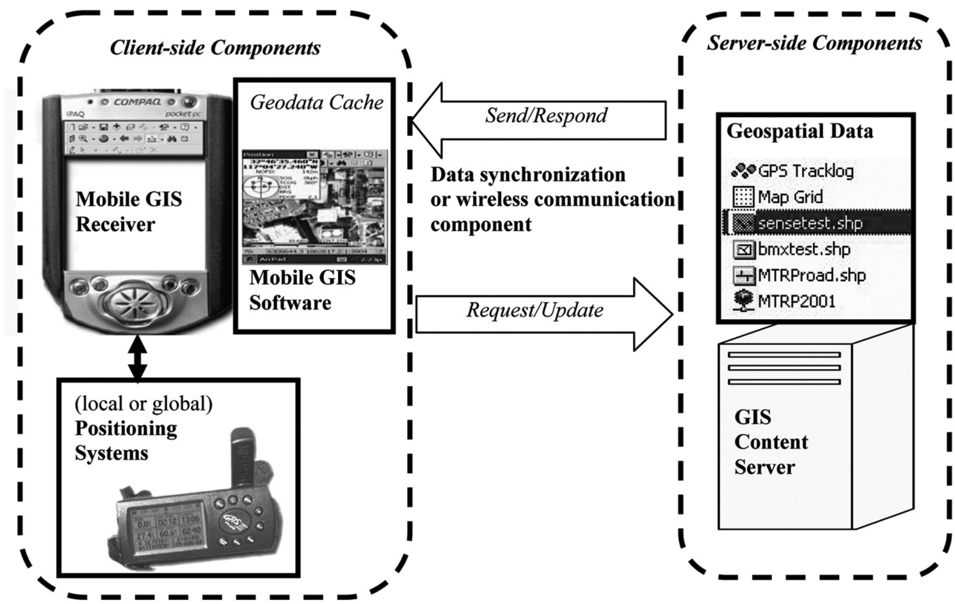

Figure 48-3 The architecture of mobile GIS (Tsou 2004b). See included DVD for color version.

Mobile GIS can provide geospatial information and GPS coordinates for field-based personnel conducting remote field (*in situ*) GIS tasks. To enable comprehensive mobile GIS, wireless communication is essential for connecting mobile GIS devices and GIS content servers. Recent progress in broadband wireless technology is the major momentum for the integration of mobile GIS and internet GIS. The wireless service coverage and the bandwidth (speed) are the two key issues for wireless communication. There are many different wireless technologies, ranging from a walkie-talkie to high-speed WiMAX, to satellite phone systems. Based on the speed of data transfer, current wireless technologies can be categorized into two groups: narrowband wireless systems and broadband wireless systems. To communicate between mobile GIS and internet GIS, broadband wireless technology is a better choice because most geospatial information and remote sensing data are very large and complicated, which require broadband wireless communication. The size of wireless coverage area is also an important criterion for mobile GIS applications.

Generally, there are three different types of wireless communication systems: ad-hoc systems, cellular phone systems and Wi-Fi/WiMAX data network systems. The ad-hoc wireless systems are custom designed for specific applications, such as direct satellite phone systems, General Mobile Radio Service (GMRS) for walkie-talkie devices, or ham radio communication. Usually, these systems are narrowband and localized for a small group of special users and require specialized user licenses. 3G and 4G mobile cellular phone communication systems can provide a good coverage area with decent-bandwidth communication. Cellular phone systems can allow other wireless devices, such as PDA and Pocket PC, to receive multimedia services (such as streaming audio and video on the devices). Most mobile GIS devices can utilize 3G or 4G cellular communication systems for collaborative work with internet or web-based GIS applications. However, the major disadvantage of cellular phone systems is the limit of bandwidth between 300Kbps to 3Mbps. Wi-Fi/WiMAX data network systems are another promising category for broadband wireless mobile GIS communication (Intel 2004). Currently, the most common wireless LAN infrastructure is the IEEE 802.11 (or Wi-Fi) technology. Many computers, PDAs, printers, etc., have begun to adopt Wi-Fi—or IEEE 802.11—as their major communication channels. The problem of Wi-Fi for wireless mobile GIS is its short coverage area from a Wireless Access Point (WAP), usually within 100 m only. WiMAX will be a better choice for mobile GIS because it can provide a large 4–6 mile coverage range. WiMAX is an emerging IEEE 802.16 standard (available in late 2006) for broadband Wireless Wide Area Network (WWAN) or Metropolitan Area Network (MAN) applications. Its communication signals can cover a large area range (up to 20 miles for the long-distance setting) with the speed of 30–75 Mbps. With such range and high throughput, WiMAX is capable of delivering comprehensive data sets or large imagery files from internet GIS servers to wireless mobile GIS units. The next section will discuss the major issue for the integration of wireless mobile GIS and internet GIS.

48.4 The Integration of Wireless Mobile GIS and Internet GIS

Different types of GIS tasks and applications will require different methods to combine wireless mobile GIS and internet GIS. Various integration techniques will be adopted for the linkage between wireless mobile GIS and internet GIS in order to fit the needs of different users, different requirements, and different data formats. The following discussion will focus on three aspects of the system integration methods: 1) asynchronous vs. synchronous connections; 2) thin-client model vs. thick-client model; and 3) loosely connected methods vs. tightly integrated methods.

48.4.1 Asynchronous vs. Synchronous Connections

The priority of data update needs is the key to deciding whether or not an internet GIS server requires synchronous connections to wireless mobile GIS. If a GIS task requires real-time information update, such as GPS tracking and emergency response, the internet GIS connection should be synchronized. A synchronous connection will allow wireless mobile GIS to provide real-time data update back to one or multiple internet GIS servers (adding new points and polygons, tracking the locations from GPS, modifying attributes, etc.) Also, internet GIS servers can provide updated information in real time and distribute to multiple mobile GIS units immediately via wireless communications. However, it is difficult to create the two-way synchronous communication because of the heterogeneous operating systems between internet GIS servers and wireless mobile GIS units. Many mobile GIS applications only provide one-way synchronization (sending data from internet GIS to wireless mobile GIS units).

On the other hand, if a GIS task does not rely on the critical information updated from the field, such as urban planning, facility and utility management tasks, asynchronous methods might be more appropriate. An asynchronous communication model can allow mobile units to work independently and save the updated information temporally in the local cache. Mobile GIS users then bring the units back to specific locations or devices to upload the new data sets back to an internet GIS server at the end of the task (per day or per week). Usually, the cost of establishing synchronized connections is much higher than for asynchronous methods. Two-way synchronized connections also are more expensive than one-way synchronized connections.

48.4.2 Thick-Client Model vs. Thin-Client Model

The second consideration is the choice of thick-client model or thin-client model. The terms thick client and thin client are defined by the computer networking community. In networking terminology, the thick-client model is defined as having major operations and calculations executed on the client side. On the other hand, a thin-client model may require that selected operations run on the server side. Therefore, the thick-client model for wireless mobile GIS indicates that the client side (mobile GIS units) will have powerful computing capability with high-speed CPU and large-size memories. Users can process advanced GIS functions locally on handheld devices or portable PCs. The thin-client mobile GIS model indicates that the client-side mobile GIS is only a terminal for internet GIS servers. In this case, the client units will need to send GIS operations and tasks back to internet GIS servers, then get the results from the GIS servers. The balance of functionality and performance between wireless mobile GIS clients and internet GIS servers will be a critical issue for the success of integration.

48.4.3 Loosely Connected vs. Tightly Integrated Systems

The third issue is the implementation of a relationship between wireless mobile GIS and internet GIS—loosely connected systems vs. tightly integrated systems. Currently, most GIS projects and applications are loosely connecting mobile GIS and internet GIS via public communication channels or asynchronous communication methods. Loosely connected mobile GIS units can be easily switched to connect different internet GIS servers. There is no mandatory regulation between client units and servers. Flexibility is the major advantage for loosely connected mobile GIS frameworks. However, the loosely connected systems are less reliable compared to tightly integrated systems because the client units are not guaranteed to access internet GIS servers during the operations. If the GIS servers shut down accidentally or the public communication network has problems, the whole system will be out of service. On the other hand, tightly integrated wireless mobile GIS are usually more reliable, but also more expensive to set up. Most tightly integrated systems are using preparatory and customized products with private communication channels for specific tasks or projects, such as E-911 systems or flood control water gauge censor systems.

In general, every GIS project requires a different strategy and method for successful implementation due to the nature of GIS tasks, geodata format and size, map display requirements, etc. There currently is no perfect framework for connecting wireless mobile GIS and the internet GIS server. Some GIS task requirements and implementation methods will rely on the progress of new technologies in web applications. The next section will highlight some potential new technologies for bridging wireless mobile GIS and internet GIS applications.

48.5 New Potential Technologies for Bridging Wireless Mobile GIS and Internet GIS

The progress of internet GIS relies greatly on new web technologies. Recently, many technology breakthroughs have been achieved in online graphic display techniques and web services. For example, Scalable Vector Graphics (SVG), mobile web services, and Ajax (Asynchronous JavaScript and XML) are three promising future technologies for the integration of mobile GIS and internet GIS. SVG is an XML-based, two-dimensional vector graphics media format specified by the W3C in 2001 (version 1.0) and in 2003 (version 1.1) (W3C 2003). There are three types of SVG profiles: SVG Full, SVG Basic, and SVG Tiny. SVG Full is suitable for desktop or laptop PCs. SVG Basic (smaller than SVG Full) is designed for Pocket PC or PDAs. SVG Tiny is designed for mobile phones. The advantage of mobile SVG (Basic and Tiny) compared to other graphic formats is that it can provide a compact, multimedia-enabled vector display format. Therefore, SVG images are scalable and dynamic, and can be used for both the regular internet mapping display on PCs and the small screen display of various mobile GIS devices, such as PocketPC and cellular phones.

Mobile web services are another promising new technology that is an extension of general web services built upon XML; Simple Object Access Protocol (SOAP); Universal Description, Discovery, and Integration (UDDI); and Web Services Description Language (WSDL). Mobile web services can combine multiple functions and customizable information provided by web service providers for different mobile applications and users. The advantage of adopting web services for mobile GIS applications is that web services can provide a flexible combination of multiple web computing techniques with modern enterprise GIS architecture. The contents of mobile web services include short messaging services (SMS), multimedia messaging services (MMS) and location-based services (LBS). Most mobile web services significantly rely on server-side computing power. For mobile GIS, web services works like the thin-client model, with more flexible choices of GIS functions provided by remote web servers.

The development of Ajax (Asynchronous JavaScript and XML) is also a promising web technology (Garrett 2005). Traditional internet GIS applications and web-based mapping tools always suffer from the slow response and the lack of high-resolution images resulting from the limitation of image data sizes and the client/server communications. The new Ajax technologies can significantly improve the performance and reponse times of internet GIS applications. [maps.search.ch] and [maps.google.com] are the two early examples of Ajax internet GIS applications. One unique advantage of Ajax is the key word "Asynchronous." According to the first Ajax paper (written by Jesse James Garrett in 2005), "An Ajax application eliminates the start-stop-start-stop nature of interaction on the web by introducing an intermediary—an Ajax engine—between the user and the server.… The Ajax engine allows the user's interaction with the application to happen asynchronously—independent of communication with the server. So the user is never staring at a blank browser window and

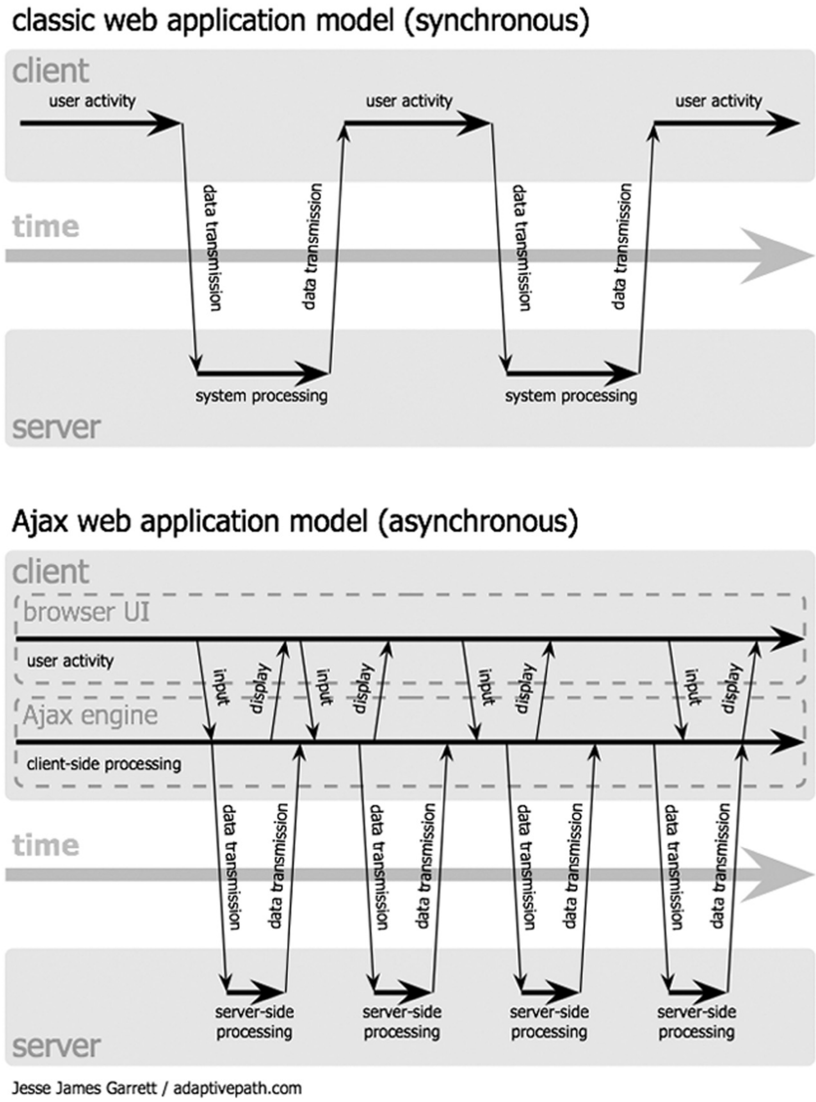

Figure 48-4 The synchronous interaction pattern of a traditional web application (top) compared with the asynchronous pattern of an Ajax application (bottom) (Garrett 2005).

an hourglass icon, waiting around for the server to do something." (Garrett 2005). Figure 48-2 illustrates the synchronous interaction pattern of a traditional web application (top) compared with the asynchronous pattern of an Ajax application.

For the internet mapping applications, Ajax can create temporary image cache functions in the background when the web browser displays the image or maps. While the user watches the downloaded imagery, the server keeps sending additional images or maps into the cache area (Figure 48-5). Therefore, when the user moves the displayed maps or imagery, the cached image will be displayed at the user's end more quickly. The key concept in adopting Ajax for internet mapping is to be able to predict the users' behaviors (Zoom-in, Zoom-out, and Pan) and then pre-cache the required images and actions before the users actual perform them. In the future, we will see more intelligent web technologies applied in internet and mobile GIS for creating more responsive, user-friendly and interactive GIServices.

The recent development of grid technology (Foster et al. 2001; Armstrong et al. 2005) might provide a possible framework for the deployment of dynamic internet GIServices with

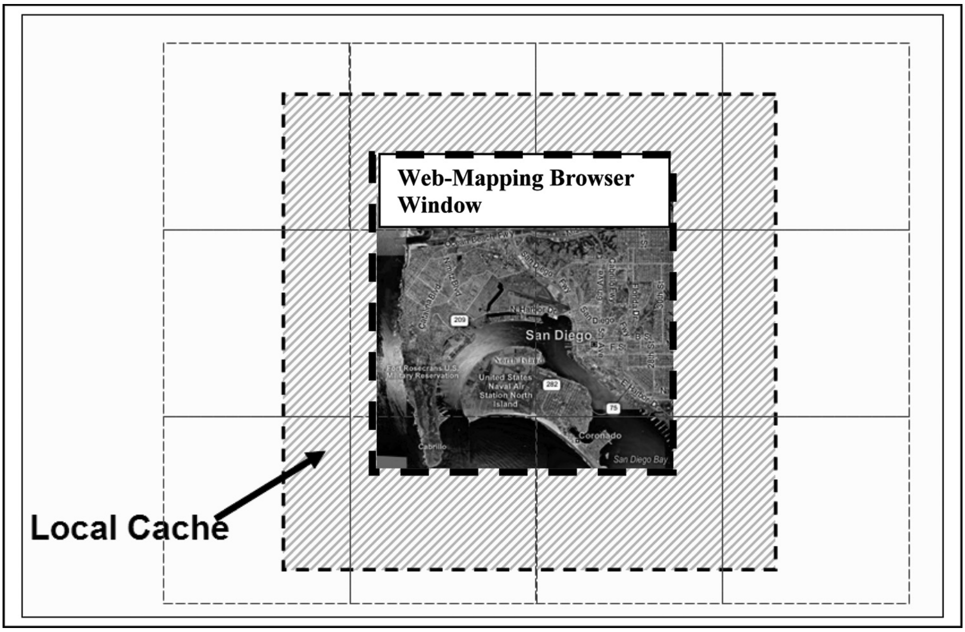

Figure 48-5 A local cache of geospatial data (bigger than the browser window) by using Ajax technology. See included DVD for color version.

its powerful computational and resource management capabilities. In the computer science community, the focus of grid technology is to resolve low-level grid computing technique issues (e.g., communication, protocols and resource management) and to build a collaborative network grid architecture (e.g., Globus Toolkit). However, the deployment of internet GIS needs a high-level application framework rather than low-level grid computing architecture.

Semantic web (Berners-Lee et al. 2001) is another important development for the future of distributed GIServices because semantic web can facilitate web-based data sharing within a global network system. The technology can provide better definition of web data and services, thus broad scale data sharing and reuse could become possible. A working group within W3C (World Wide Web Consortium) has defined related standards and languages for the real applications of semantic web technologies (www.w3.org). RDF (Resource Description Framework) was designed to organize web information into triple terms for easier data retrieval (http://www.w3.org/RDF/). To better handle terms and relations in semantic webs, a Web Ontology Language (OWL) is also proposed to define terminology used for specific contexts and properties in terms of classes and relations (http://www.w3.org/TR/owl-guide/).

One very interesting recent development is the emergence of Digital Earth viewers or digital globes by using 3D representation and visualization tools, such as Google Earth (http://earth.google.com) and NASA World Wind (http://worldwind.arc.nasa.gov/). The framework of Digital Earth provides a very promising direction for integrating multiple types of geospatial information, including remote sensing images, GIS data, GPS tracking path, etc. Open source GIS software is another promising direction in the development of internet GIS and mobile GIS. More and more GIS professionals are developing open-source internet GIS servers and toolkits because the open-source framework can provide a more flexible way to customize functions and tools (such as "Mapserver" by the University of Minnesota, "GeoTools" by a group of GIS programmers, and PostGIS by Refractions Research, Inc.). GIS professionals are increasingly choosing an open-source GIS development environment rather than proprietary, black-box and vendor-based GIS packages (Ramsey 2005).

48.6 Conclusion

The integration of internet GIS servers and wireless mobile GIS units will facilitate the adoption of geospatial technology in many fields, such as education, homeland security, disaster management and public transportation. Ideally, multiple map layers and GIS functions from heterogeneous internet GIS servers could be connected dynamically to hundreds of wireless mobile GIS units remotely. To accomplish such tasks, tremendous amounts of geospatial data and computational power would be requested and transferred across the public internet or private communication networks. Therefore, the GIS community needs to establish a comprehensive cyber-infrastructure to organize all available heterogeneous GIServices and web servers and to streamline various data flow and operation procedures across the networks. Such GIService cyber-infrastructure needs to become dynamically adjustable in order to accommodate complicated network environments (dial-up modem, cable modem service, ADSL, T1/T3, Wi-Fi, WiMAX, cellular networks, etc.) This will be a great challenge for the GIS community to establish a comprehensive cyber-infrastructure for integrating internet GIS and wireless mobile GIS applications.

One possible approach is to develop web-based GIS portals, which can utilize grid computing technology and semantic web technology to establish a high-level service-oriented cyber-infrastructure. Users can use the portal to analyze geospatial problems, to find out possible useful mapping services, to request geospatial data and to aggregate multiple GIS analysis results. The intelligence of web portals can be introduced by the semantic web technology that organizes geospatial ontologies to facilitate the interoperability between users and the machines. The computing power of web portals will be supported by the grid computing technology that can gather hundreds of computers to provide more effective online GIS functions and spatial analysis.

This chapter illustrates the major approaches of integrating internet GIS and wireless mobile GIS and highlights the importance of combining the two frameworks. In the future, a comprehensive, distributed GIService will rely on both wireless mobile GIS and wired internet GIS. As time wears on, more progress and changes will be made in internet GIS and mobile GIS, leading to infinite possibilities and great potentials. In the next decade, for example, everyone might be able to utilize their mobile phones to download a $5 e-coupon for a coffee shop in the next street block, or track their children's location remotely, or find any available parking lots near a shopping mall. To summarize, the integration of internet GIS and wireless mobile GIS will attract more people to use GIS and the new cyber-infrastructure will transform the way people live, work and behave. The general public will start to use novel ways to collect, analyze and distribute information—geographically.

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References

Armstrong, M. P., M. K. Cowles and S. Wang. 2005. Using a computational grid for geographic information analysis: A reconnaissance. *The Professional Geographer* 57 (3):365–375. <http://www.blackwell-synergy.com/doi/pdf/10.1111/j.0033-0124.2005.00484.x> Accessed 5 February 2008.

Berners-Lee, T., J. Hendler J. and O. Lassila. 2001. The semantic web. *Scientific American* 284 (5):34–43.

Foster, I., C. Kesselman and S. Tuecke. 2001. The anatomy of the grid: Enabling scalable virtual organizations. *International J. Supercomputer Applications* 15(3).

Garrett, J. J. 2005. Ajax: A New Approach to Web Applications. White paper. <http://www.adaptivepath.com/publications/essays/archives/000385.php> Accessed 25 January 2008.

Intel. 2004. Understanding WiMAX and 3G for Portable/Mobile Broadband Wireless. White paper. <http://www.itr-rescue.org/bin/pubdocs/mtg-weekly/9-16-05%20Intel_WiMAX_White_Paper%20(Hassib).pdf> Accessed 19 July 2008.

Jagoe, A. 2002. *Mobile Location Services: The Definitive Guide.* Upper Saddle River, N.J.: Prentice Hall.

OGC (Open GIS Consortium). 2003. *OpenGIS Location Services (OpenLS): Core Services (Part 1–Part 5).* Version 0.5.0. OGC-03-006r1. Wayland, Mass.: Open GIS Consortium, Inc.

Peng, Z. R. and M. H. Tsou. 2003. *Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks.* New York: John Wiley & Sons.

Plewe, B. 1997. *GIS Online: Information Retrieval, Mapping, and the Internet.* Santa Fe, N.M.: OnWord Press.

Ramsey, P. 2005. The State of Open Source GIS. White paper. Refractions Research Inc. <www.refractions.net/white_papers/> Accessed 25 January 2008.

Tsou, M. H. and B. P. Buttenfield. 2002. A dynamic architecture for distributing geographic information services. *Transactions in GIS* 6 (4):355–381.

Tsou, M. H. 2004a. Integrating web-based GIS and online remote sensing facilities for environmental monitoring and management (special issue on the Potential of Web-based GIS). *Journal of Geographical Systems* 6 (2):155–174.

———. 2004b. Integrated mobile GIS and wireless internet map servers for environmental monitoring and management (special issue on Mobile Mapping and Geographic Information Systems). *Cartography and Geographic Information Science* 31 (3):153–165.

W3C. 2003. Scalable Vector Graphics (SVG) 1.1 Specification. <http://www.w3.org/TR/SVG/> Accessed 25 January 2008.