Chapter XVI

Bridging the Gap: Connecting Internet-Based Spatial Decision Support Systems to the Field-Based Personnel with Real Time Wireless Mobile GIS Applications

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Abstract

Internet GIS provides a collaborative communication environment for sharing data, information, and knowledge. Mobile GIS can add both geospatial information and global positional systems (GPS) coordinates from remotely located field-based personnel to spatial decision support systems (SDSS). By adopting broadband wireless telecommunication technology for connecting Internet GIS and mobile GIS devices, decision makers can gather near real-time information from field personnel and, equally quickly, distribute updated information back to the field. This chapter introduces a collaborative GIS prototype that demonstrates an interoperable framework for combining Web-based GIS technologies and wireless mobile GIS applications. The integrated framework provides real-

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time or near real-time GIS data update functions (such as adding new spatially located map features or GPS tracking locations) between mobile GIS devices and Internet GIS servers. Although these real-time GIS functions can be very important during time-urgent emergencies, they can be equally beneficial and highly cost effective during routine field activities.

Introduction

Internet GIS (Peng & Tsou, 2003) can facilitate the implementation of collaborative GIS in the form of a Web-based spatial decision support system (SDSS) having remote communication channels. Currently, the greatest challenge for Web-based spatial decision support systems is the creation of a real-time or near real-time GIS-based communication channels between senior decision makers and multiple in-field personnel (such as first-responders). The objective of this book chapter is to introduce an integrated collaborative GIS architecture that combines Web-based GIS and wireless mobile GIS with a spatial decision support system. By adopting wireless telecommunication technology and advanced Internet GIS tools, decision makers can benefit from real-time information obtained from in-field personnel. In turn, in-field personnel benefit from more timely updated information from decision makers. The two-way communication mechanism between in-field personnel (*in situ* agents) and decision makers can facilitate a better and timelier decision-making process. Such an integrated framework combined with a client-side wireless mobile GIS application and a server-side Web-based decision support system will help optimize field-based management tasks, whether they are time urgent such as emergency dispatch, or a more mundane utility service call.

Both mobile GIS and Internet GIS technologies have been available for almost 10 years. However, very few collaborative GIS projects or spatial decision support systems have adopted both technologies for collaborative work. A principle problem has been the lack of comprehensive communication framework to combine Internet GIS and mobile GIS. Recent dramatic progress in broadband wireless technology has opened a new direction for connecting Internet GIS and mobile GIS with collaborative GIS architectures. Moreover, the GIS community is working on the establishment of interoperability standards, network-based GIS communication protocols, and XML-based geospatial data structure. These efforts from the GIS and telecommunication communities are beginning to facilitate the seamless integration of mobile GIS and Internet GIS.

Figure 1 displays an integrated spatial decision support system prototype that demonstrates an interoperable framework for combining Web-based GIS tech-

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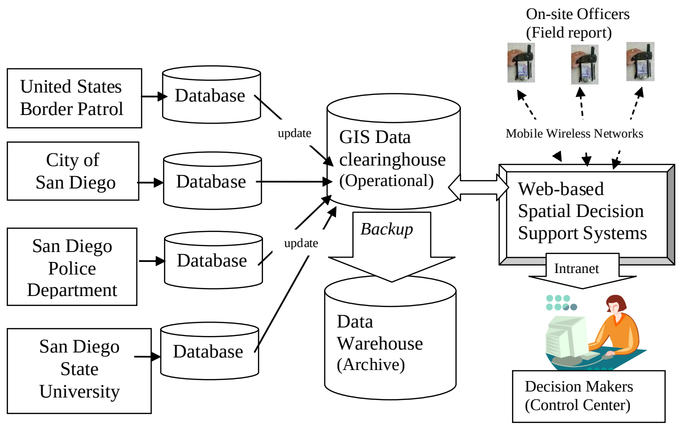
***Figure 1**. Interoperable framework for Internet-based spatial decision support systems and wireless mMobile GIS applications*



nologies and wireless mobile GIS applications. The major consideration of this prototype framework is to facilitate the interoperability between heterogeneous systems and platforms. To enhance interoperability, the integrated SDSS utilized a standardized Web-mapping interface, along with OGC Web Map Service (WMS) interfaces (provided by ESRI's ArcIMS OGC WMS connector) to provide online mapping functions and the display of remotely sensed data. By adopting XML-based metadata frameworks (ISO 19115 standard, 2003), multiple network-based geospatial information servers work together via a centralized GIS data portal (data clearinghouse) with a duplicated backup data warehouse server. Each individual participating agency (such as police departments, university GIS centers, border patrol sectors, fire departments, etc.) can implement and update their own data systems and services while maintaining an aggregated system-wide interoperability through multiple data warehouses and Web-based decision support systems. The Web-based SDSS will be used by decision makers and spatial analysts in a control center to collect and process information via a secure intranet or encrypted mobile wireless networks in order to make better and more timely decisions, and to initiate improved responses to on-site personnel.

One unique design strategy of this Web-based spatial decision support system (Figure 1) is to combine distributed database connectivity and a centralized data archive system. The GIS data clearinghouse will automatically fetch the newest updated data from remote data servers (located in US Border Patrol, San Diego

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Police Department, and City of San Diego). Then the clearinghouse will maintain an archived, centralized database inside the system. The Web-based SDSS interface will only create a single database connection channel to access the operational GIS data clearinghouse, rather than establishing multiple database connections from various data resources at the same time. If any distributed data nodes (servers) are not available (due to system shutdown or networking problems) during an operational runtime, the GIS data clearinghouse will retrieve archived datasets from the backup data warehouse automatically. This unique design will improve the efficiency of database connection, and provide a more reliable Web-based SDSS framework.

This chapter also provides an overview of current Internet GIS and mobile GIS technology, and discusses implementation issues and experiences in creating this SDSS prototype. This Web-based prototype (http://geoinfo.sdsu.edu/reason) was funded by a NASA research program, REASoN (Research, Education and Applications Solution Network). The project goal is to assist in the development of a border spatial decision support system (BSDSS) for allocating and deploying resources to secure U.S. borders. A team of security agents with the U.S. Border Patrol, law enforcement, state and local resource protection agencies, researchers from San Diego State University (SDSU), and remote sensing technology companies is collaborating on this project. Case-study experiences, data security and classification, encryption for wireless communication, and two-way communication techniques are highlighted in this chapter.

Advanced Geospatial Technologies for Collaborative Works

Collaborative GIS is an integrated GIS framework that can facilitate its participants to work on geospatial related tasks with a shared understanding of geospatial information. The development of collaborative GIS is related to collaborative spatial decision making (CSDM) (Jankowski & Nyerges, 2001), computer-supported cooperative work (CSCW) (Li & Coleman, 2002), and group decision support systems (GDSS). According to Jankowski and Nyerges (2001), the term “collaborative” indicates a higher level of operation agreement among the participants comparing to other terms such as “communication,” “cooperation,” and “coordination.” Collaborative GIS, or spatial understanding (and decision) support systems can be used to “facilitate geographical problem understanding and decision making for groups, including groups embroiled in locational conflict” (Jankowski & Nyerges, 2001, p. 50).

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One major research gap in collaborative GIS is the connection between system design and actual GIS applications and usage (Jankowski & Nyerges, 2001). Most collaborative GIS projects emphasize the location/relocation problem tasks, rather than the spatial dispatch coordination or emergency response plan. With the availability of the Internet, many collaborative GIS started to adopt the Web-based environment for their development frameworks (Churcher & Churcher, 1999; Dragicevic & Balram, 2004; MacEachren & Brewer, 2004). However, very few collaborative GIS extend the system framework from Web-based GIS to wireless GPS-enabled devices. This chapter will try to fulfill these gaps to combine both the application-oriented system design strategy and the integration of Web-based GIS and wireless mobile GIS devices. The following sections highlight recent developments in Internet GIS, mobile GIS, and wireless networks used to establish collaborative GIS architectures.

Internet GIS for Collaborative Works

Internet GIS is a collection of network-based geographic information services that utilize both wired and wireless Internet functionality to access geographic information, spatial analytical tools, and GIS Web services. The major goal of an Internet GIS is to develop a high-level GIS federation, that is, to be fully interoperable, where users can transparently access remote services and yet still maintain their autonomy (Bishr Yaser, 1996). The GIS community started to research online distributed GIS in the mid-1990s (Gardels, 1996; Peng & Tsou, 2003; Plewe, 1997; Tang, 1997). The development of Internet GIS was motivated by the adoption of an open and distributed architecture and the redesign of GIS metadata and distributed component frameworks. The contents of Internet GIS include not only displaying Web-based maps or sharing online geospatial information, but also providing advanced GIS analysis functions and new information services. Internet GIS are built upon a distributed computing framework, which is an example of the revolution of information systems from traditional architecturally closed and centralized information systems to more open and distributed information service architectures (Tsou & Buttenfield, 2002).

The driving force behind this GIS architecture transformation is the availability of new technology in network communications and programming. New languages such as Java, Python, and C# (C-sharp) support platform-independent applications across the Internet. Advanced network technologies such as Microsoft .NET framework, J2EE platform, and Common Object Request Broker Architecture (CORBA) provide a comprehensive scheme for distributed component technology essential to the development of Internet GIS. Distributed

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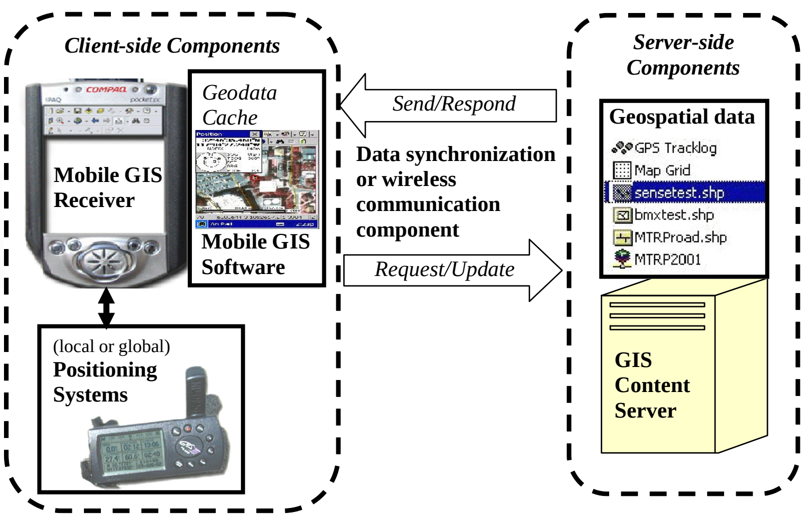
component technology allows clients to access heterogeneous servers dynamically, which is an essential feature of distributed geographic information services (GIServices). In the future, traditional geographic information systems (GISystems) designed as isolated islands, will become increasingly less attractive, possibly disappearing altogether. The cost efficiencies and flexibility of reusable and interoperable open and distributed-services interfaces provide much greater economies. GIServices focus on open, distributed, task-centered services that broaden geographic information uses into an increasingly wider range of online geospatial applications These include digital libraries, digital governments, online mapping, data clearinghouses, real-time spatial decision support tools, distance learning modules, and so on.

In general, Internet GIS can provide a collaborative communication environment for sharing data, information, and knowledge. The easy and ubiquitous access of Web-based interfaces can help various GIS users (decision makers, remotely located field agents, and the general public) to gain access to essential geospatial information for their individual needs. Online geospatial analytical functions can be combined and integrated to develop collaborative GIS architectures with other external systems and platforms (such as mobile GIS, hotel reservation systems, or financial management systems). The following section describes a mobile GIS, which is another important component of collaborative GIS architectures.

Figure 2. Architecture of mobile GIS (Tsou, 2004)



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Mobile GIS for Collaborative Architectures

Mobile GIS is an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wireline or wireless networks (Tsou, 2004). There are two major application areas of mobile GIS: *field-based GIS* and *location-based services (LBS)*. Field-based GIS focus on the GIS data collection, validation, and update in the field, such as adding or editing map features or changing the attribute tables on an existing GIS dataset. Location-based services focus on business-oriented location management functions such as navigation, street routing, finding a specific location, tracking a vehicle, and so forth (Jagoes, 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 change original GIS datasets, but rather use 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 systems that are 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 2 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, 2004).

Mobile GIS can provide geospatial information and GPS coordinates for field-based personnel conducting remote field (*in situ)* GIS tasks. For example, landscape architects may use mobile GIS to display a remotely sensed image as a background in a remote field location, and then draw a preliminary design for a tree line based on GPS locations. Facility management workers can download a newly updated power-line map to identify the connections required at a specific power pole. To enable comprehensive mobile GIS, wireless communication is essential for connecting mobile GIS devices and GIS content servers. The next section introduces recent progress in broadband wireless technology that can bridge the gap between mobile GIS and Internet GIS.

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Table 1. Suitable broadband wireless standards for mobile GIS communication (table modified from Intel, 2004b (http://www.intel.com/netcomms/bbw/) and Janowski, 2005)

	IEEE 802 Standard Groups						**Cellular Phone Network**		
	Wi-Fi	**Wi-Fi**	**Wi-Fi**	**Wi-Fi**	**WiMAX**	**Portable WiMAX**	**Edge**	**EV-DO**	**UMTS**
Standard Group	802.11a	802.11b	802.11g	802.11n	802.16d	802.16e	2.5G	3G	3G
Network Type	WLAN	WLAN	WLAN	WLAN	WWAN Fixed	WWAN Portable	WWAN	WWAN	WWAN
Speed	Up to 54 Mbps	Up to 11 Mbps	Up to 54 Mbps	Up to 200 Mbps	Up to 75 Mbps	Up to 30 Mbps	Up to 384 Kbps	Up to 2.4 Mbps	Up to 10 Mbps with HSDPA technology)
Range	Up to 300 feet (150 feet radius)	Up to 300 feet	Up to 300 feet	Up to 300 feet	Typical 4-6 miles (up to 20 miles for long distance setting	Typical 1-3 miles	Typical 1-5 miles	Typical 1-5 miles	Typical 1-5 miles
Radio Frequency	5GHz	2.4GHz	2.4GHz	2.4 or 5GHz	Sub 11GHz	2-6GHz	1900 MHz	400, 800, 900, 1700, 1800, 1900, 2100MHz	1800, 1900, 2100MHz

Recent Progress in Broadband Wireless Technology

Recent progress of 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 walky-talky 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 requires broadband wireless communication. Currently, there are no clear definitions about the distinction between narrowband and broadband in the telecommunication industry. This paper will define broadband communication as a communication speed (both input and output speed) greater than 1Mbps, such as Wi-Fi or EV-DO. Narrowband wireless systems

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have data transfer rates that are less than 1Mbps such as current GPRS and CDMA technology.

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 walky-talky devices, or ham radio communication. Usually, these systems are narrowband and localized for a small group of special users, and require specialized user licenses.

Cellular phone systems are the most popular wireless systems, and are supported by several distinct telecommunication infrastructures to provide comprehensive service coverage. Originally, the focus of cellular phone systems was to provide voice communication rather than digital data transfer. The evolution of cellular phones started from the first generation (1G: analog signal mobile communication), to 2G (digital signal communication, speed range from 9.6Kbps to 14.4Kbps), to 2.5G (larger data speeds from 20 to 100Kbps), to 3G (third generation: near broadband speed ranging from 144Kbps to 2Mbps) (Janowski, 2005). Some researchers indicate the future development of 4G (fourth generation) cellular phone systems can provide ultrabroadband speed from 2Mbps to 10Mbps. 3G and 4G mobile cellular phone communication systems can provide high-speed communication and allow other wireless devices, such as PDA and Pocket PC, to receive multimedia services (such as streaming audio and video on the devices).

Wi-Fi/WiMAX data network systems are another promising category for broadband wireless mobile GIS communication. Both Wi-Fi and Wi-Max are the wireless network standards defined by the IEEE 802 LAN/MAN Standards Committee (http://grouper.ieee.org/groups/802/). The IEEE 802 committee forms multiple working groups in developing local area network (LAN) standards and metropolitan area network (MAN) standards such as 802.3 (Ethernet), 802.11 (wireless LAN), 802.15 (wireless personal area network - WPAN), and 802.16 (broadband wireless access – WiMAX). Currently, the most common wireless LAN infrastructures are the IEEE 802.11 (or Wi-Fi) technology. IEEE 802.11 specifies the physical and media access control (MAC) layers for operation of wireless local area networks (WLAN). The 802.11 standard provides for data rates from 11Mb/s to 54Mb/s (Pandya, 2000). The term Wi-Fi (wireless fidelity) is the global brand name across all markets for any 802.11-based wireless LAN product. Many computers, PDAs, printers, and so forth, have begun to adopt Wi-Fi, or IEEE 802.11, as their major communication channels. There are four extensions in the 802.11 group technology (a, b, g, and n).

WiMAX is an emerging IEEE 802.16 standard for broadband wireless wide-area network (WWAN) or metropolitan area network (MAN) applications. WiMAX

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can provide a larger coverage of service area than Wi-Fi. Its communication signals can cover a 4-6 miles range (up to 20 miles for the long distance setting). WiMAX can provide broadband to areas that do not have cable or DSL services. Presently, WiMAX includes two steps of the IEEE 802.16 technology. The IEEE 802.16**d** is the first step, which will be used to specify large area wireless communication via outdoor antennas in a fixed location. A fixed WiMAX service can provide up to 75 Mbps speed with Sub 11Ghz radio frequency. The IEEE 802.16**e** will be the next step (under development), used to specify portable wireless hardware for mobile WiMAX services. The new mobile WiMAX can provide roaming capability and enable more persistent connectivity within a service area (Intel, 2004a).

Table 1 illustrates the major wireless standards that are suitable for mobile GIS with collaborative GIS architectures. Note that the two major wireless systems (cellular networks and IEEE 802 groups) both focus on the development of next-generation broadband wireless communication coverage. However, the two systems are not currently compatible with each other due to the different radio frequency. From a GIS user's perspective, it is very difficult to switch seamlessly between Wi-Fi and EVDO wireless network while working in the field or traveling. Actually, the two systems may have to compete with each other in the future, because the new voice-IP technology will enable Wi-Fi or WiMAX to provide wireless phone services over a large area.

Integration of Internet GIS and Wireless Mobile GIS

Collaborative GIS are required to support interactive spatial query and visualization of geospatial problems from its participants. By combining Internet GIS and wireless mobile GIS, the new framework of collaborative GIS can provide more interactive GIS functions and real-time data update from distributed participants and decision makers. However, we need to establish a seamless and robust linkage between Internet GIS and mobile GIS in order to provide such high-level services. An integrated spatial decision support system will rely on three major components: Internet GIS, mobile GIS, and broadband wireless communication networks. Each component will need to be customized in order to provide real-time or near real-time GIS functions. Interoperability and upgradeability are two key issues for successful system integration and long-term operation because these GIS technologies change rapidly. The following sections will discuss the major issue in establishing the robust linkage between Internet GIS and wireless mobile GIS, and their major challenges.

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The Linkage between Internet GIS and Wireless Mobile GIS

The first issue of the linkage between Internet GIS and mobile GIS is the communication type. There are two types of communication: real-time synchronized communication (via Wi-Fi or cellular phone signals) and cable-based asynchronous communication (via USB or serial ports). Both mechanisms can provide two-way communication between Internet GIS and mobile GIS. For cable-based connections, the Internet GIS servers can send geodata to the mobile GIS receivers whenever the connection is available. Then the mobile GIS receiver can upload geodata or new information back to the Internet GIS server later on. For real-time wireless communication, the mobile GIS receivers can create a continuous link to the Internet GIS server, and the server *responds* to the request in real time by sending the new map to the receiver. To facilitate two-way communications, several middleware or data synchronization software packages (such as Microsoft ActiveSync or Web Services) are required for bridging the mobile GIS applications and Internet GIS. For collaborative GIS, Internet-based protocols, such as TCP/IP and HTTP, can provide an open and standardized communication channels for the linkage between Internet GIS and mobile GIS applications.

The second issue of the linkage is the data exchange methods between Internet GIS and mobile GIS. There are two major methods: data transmission and database connection. The first method, data transmission, is to utilize network data transfer tools like FTP or HTTP to upload or download the whole data items. The second method is to create a database connection between the Internet GIS and mobile GIS that can provide more advanced database query and search functions. Most collaborative GIS will prefer the second method because the first method (data transmission) requires a higher network bandwidth when the size of GIS data becomes large. The format of data/databases is another consideration for data exchange methods. For example, mobile GIS units can send text-based GPS signals to the Internet GIS via a database connection. An alternative method is that a segment of GPS signals can be converted into a compressed binary file, then use FTP to send the file back to the Internet GIS server. Both approaches can fulfill the need of data exchanges between Internet GIS and mobile GIS.

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The Challenges for the Integrated Spatial Decision Support Systems

There are several challenges in creating an interoperable SDSS framework. The first challenge is to ensure interoperability across the mobile GIS and Internet GIS interface. Most mobile GIS software and devices are vendor-based and use proprietary data formats and specialized communication protocols. Proprietary data formats and protocols will create difficulty during the customization of mobile GIS software when fitting various field-based GIS tasks. Some mobile GIS platforms required a specialized combination of hardware devices, which cannot be substituted or replaced by other systems. Therefore, the ideal mobile GIS software should utilize standard data formats and protocols and be independent of hardware devices, allowing later upgrade or substitution. The same criteria should be applied to the choice of Internet GIS server and its software packages. For the development of collaborative GIS, the software and data format independence is also very important because the participants of collaborative GIS might come from different agencies that have different computing resources and hardware equipments.

Figure 3 illustrates an example of an independent hardware device upgrade used to replace a proprietary cable-based GPS. The cable-based GPS device is replaced with a wireless blue tooth GPS within the same mobile GIS unit.

The second challenge in creating an interoperable SDSS framework is the search and indexing functions for geospatial information on the Internet. Most GIS users have problems in finding online data effectively because they lack a comprehensive data search and indexing mechanism for geospatial data sets. One possible solution is to create detailed metadata information archived in an easily accessible mode, such as a GIS Web portal. The user-friendly GIS Web portal should have a powerful search engine to connect hundreds of data clearinghouses at the same time. Some researchers suggest that what is needed is a Google-like geodata search service that can rank the importance of geospatial data by their popularity and linkage numbers. For collaborative GIS, the metadata search engine will help different participants to gather the information they need effectively, and provide a better understanding of geospatial problems.

The third challenge in creating an interoperable SDSS framework is to the ability to merge the services of online data download and interactive Web-based mapping tools together. Both types of Internet GIServices are needed for creating a collaborative GIS environment. However, most current Internet GIS applications separate the functions of data downloads and Web mapping as two separate and distinct functions. From a GIS end-user perspective (or a decision maker’s perspective), both raw data and online maps can fulfill the same GIS

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Figure 3. Independent mobile GIS hardware upgrade (from a cable-based GPS to a blue tooth GPS)

need during the decision-making process. For example, a city mayor may want to find out the location of major hotels in downtown areas. He or she can either view the locations from a Web-based map viewer, or download a GIS hotel map into his/her GIS software package to view it off-line. Both approaches can provide the mayor with the same geospatial information he/she needs. Therefore, a comprehensive GIS Web portal should index both raw GIS data and Web-based mapping services together.

The fourth challenge is to enable real or near real-time data updates and two-way communications between clients (field agents) and their server (control and command centers) via broadband wireless networks. The availability of wireless networks will be the major technical challenge in setting up real-time mobile GIS applications. Many locations, such as national parks, or rural areas, lack wireless network coverage, making it difficult to implement broadband wireless devices or stations. Data security in wireless communications has also become another technical challenge. Currently, it remains very difficulty to create a fully automated mechanism on the server side to receive updates from remotely located field agents. Most current Web-based mapping servers still require manual conversions to update geodata received from field agents. Without automated data conversion and update mechanisms on the server-side, each Internet map server will require a full-time analyst operating the map server for real-time or near real-time data updates.

The following section introduces a success development of an integrated spatial decision support system that addresses some of the problems mentioned above

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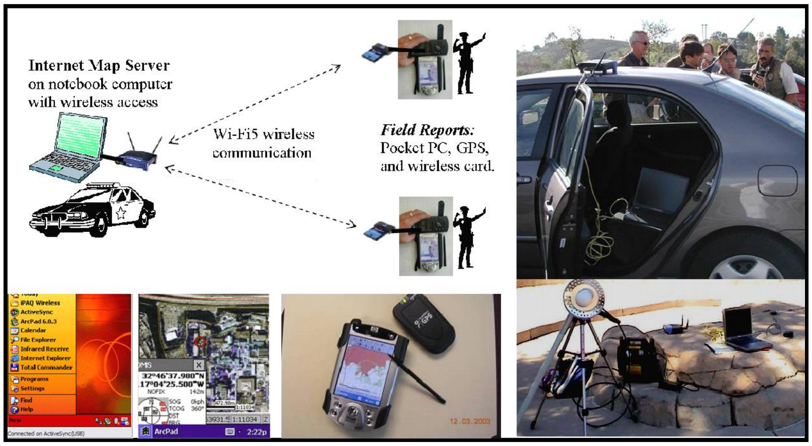
Figure 4. Level-1: Independent, mobilized wireless mobile GIS infrastructure



while providing real-time or near real-time GIS data update and GPS tracking functionality.

The Establishment of a Real-Time Spatial Decision Support System

Based on the previous considerations, the research team developed an integrated, real-time SDSS framework that utilized state-of-the-art mobile GIS application software (ArcPad and ArcPad application builder), global positional systems (GPS), and wireless networking technologies (IEEE 802.11b, Wi-Fi standard). This SDSS architecture provides a scalable client/server wireless framework to access large volumes of geospatial information and remotely sensed data. The two-level real-time SDSS allows in-field agents access to multiple Internet map servers via their mobile devices, and the ability to submit updated field reports or messages back to a control and command center.

Figure 4 and Figure 5 illustrate the two scales of wireless architecture for real-time spatial decision support systems. The first level (level-1) is an independent, localized mobile wireless framework (Figure 4). The second level (level 2) is a wide-area, control-center-based wireless systems that directly connects decision makers to in-field agents and to the first level mobile systems (when the vehicle drives back to the WiMAX cover areas) (Figure 5). Currently, our research team has completed the first level framework testing and implementa-

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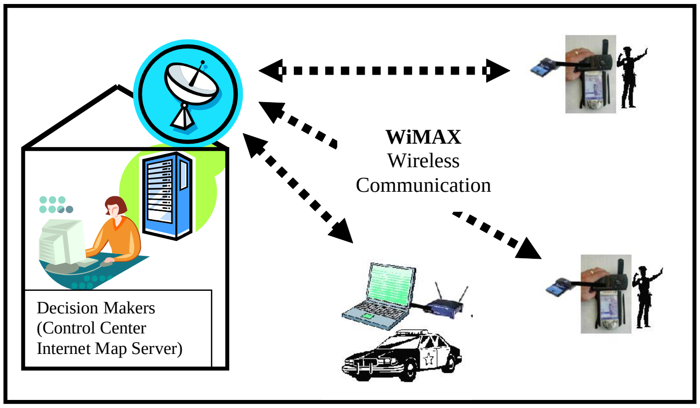
Figure 5. Level-2: Control-center-based wireless mobile GIS infrastructure (under development)



tion, and is planning to implement the second level framework once the WiMAX network is available.

The level-1 real-time SDSS framework utilizes a wireless local area network for the communications between mobile GIS receivers and portable Internet map servers. In the prototype, an Internet map server (ESRI ArcIMS) was installed on a notebook computer equipped with a wireless access port (Linksys Wireless Access Point Router). The notebook and wireless access port were placed inside a vehicle, and used the vehicle's electrical system, via the cigarette lighter socket, to power the wireless communications components. Field staff then used Pocket PC's equipped with Bluetooth GPS and Wi-Fi cards to access remotely sensed imagery and GIS data layers from a large capacity database residing on the notebook Web server via wireless communication channels (Wi-Fi) (Figure 4).

The level-2 framework will utilize WiMAX broadband wireless networks. Both in-field agents and level-1 mobile SDSS will be able to communicate to the control and command center and decision makers. Since WiMAX coverage may not reach into rural areas, updated information from level-1 systems can be uploaded to the control center map server when the mobile systems enter WiMAX coverage areas. Utilization of two levels of scalable wireless framework for real-time and near real-time SDSS will provide a more cost-effective information update and sharing mechanism between centralized decision makers and remotely located field agents.

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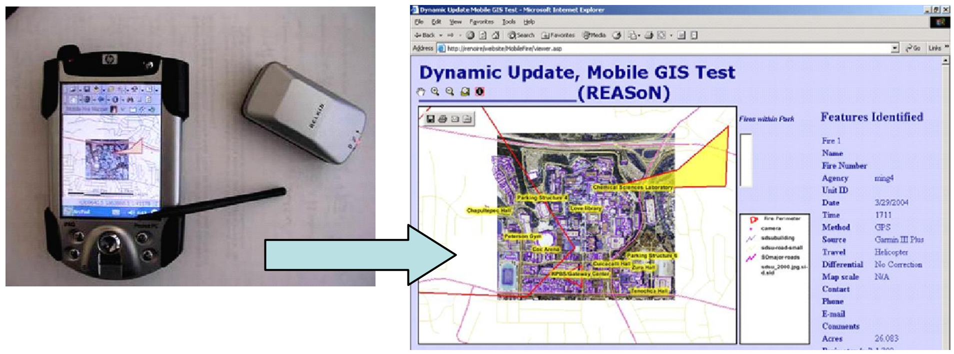
Figure 6. Real-time wireless GIS data update (adding new polygon) via an open Internet-based communication protocol between mobile GIS and internet GIS (Web map services)



Using the two-level wireless SDSS framework, Wi-Fi and WiMAX can provide two-way communication channels between Internet map servers and mobile GIS devices, such as Pocket PC and notebook computers. The Internet GIS software and mobile GIS packages will be customized to provide real-time display on the Web-based map viewer.

The following paragraphs and figures (from Figure 6 to Figure 9) will introduce some key examples in our prototype development for a real-time SDSS. These examples demonstrate the efforts to create an open, Internet-based communication channels between Internet GIS and mobile GIS, and the Web GIS data portal for collaborative GIS participants.

Figure 6 illustrates a prototype testing of real-time GIS data updates functionality from a mobile GIS device (left) to an Internet Map Server (right). The system was created by using ESRI's ArcPAD, MS Access databases, and ESRI ArcIMS. The figure shows that a triangle polygon, digitized on the Pocket PC by remotely located field agents, was successfully submitted and updated at the centralized Internet map server via Wi-Fi channels with TCP/IP. One unique feature is that the system utilizes an open Internet-based protocol (TCP/IP) that can be easily applied in a different network environment. Most traditional GPS tracking devices only utilized proprietary protocol that cannot be shared or applied by other applications or different networks. This type of functionality will be very useful during emergency response or security management incidents, such as drawing a safety buffer-zone area around an accident. The original real-time update function was develop by an ESRI technical group, and then customized by our REASoN project team.

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Figure 7. Web-based real-time GPS tracking services via an open Internet-based communication channel (sending mobile GIS device signals back to an Internet map server)

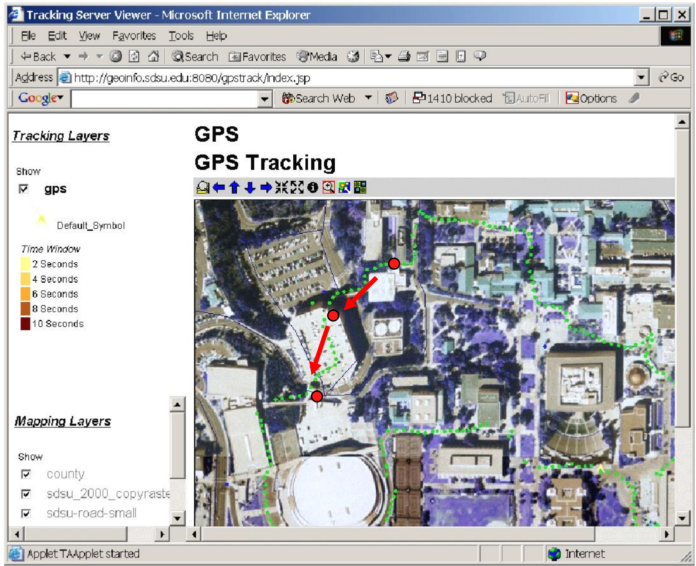

Figure 8. Web interface for the San Diego Emergency Response GIS data portal (http://geoinfo.sdsu.edu/metadataexplorer)

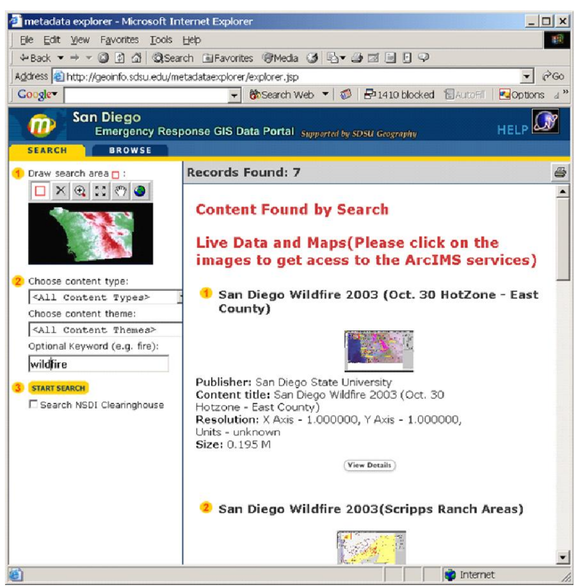

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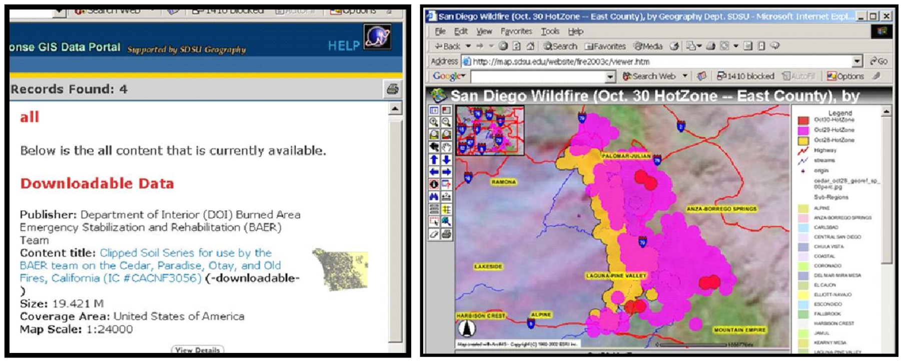
Figure 9. Data download and online mapping functions in a Web portal



In addition to real-time GIS updates or data submissions, another important real-time SDSS function is GPS tracking of all in-field agents. Figure 7 shows a Web-based GPS-tracking map browser that illustrates a simulated security officer carrying a Pocket-PC with GPS functionality across the campus of San Diego State University. In the Web browser, the red dot can dynamically move according to the GPS signals received from the security officer's Pocket PC. This testing was created by using ESRI's Tracking Server (beta-version) with customized ArcPAD GPS functions. Due to the lack of WiMAX wireless channels on the campus, the system relied on a GPS simulator to create the real-time GPS signals feeding to the Internet map server via TCP/IP.

The development of a GIS Web portal is another important component for spatial decision support systems. A comprehensive GIS Web portal should include download services for both raw GIS data and Web-based mapping services. Figure 8 illustrates a GIS Web portal, developed for our project, called San Diego Emergency Response GIS Data Portal. This Web portal was created by using ESRI ArcIMS Metadata Server Extension with ArcSDE and MS SQL server. Users can type keywords or select themes to query the metadata of geospatial information stored in the Web portal. The Web portal includes both downloadable data and online mapping services (Figure 9).

To summarize, this section introduced the development of a real-time or near real-time spatial decision support system prototype. By combining real-time GPS tracking, GIS Web portals, online mapping services, and real-time in-field agent data updates, it is possible to create a Web-based decision support system designed to help optimize field-based management tasks, such as emergency dispatch or utility service calls. The two-level Wi-Fi and WiMAX wireless networks can be used to create an effective collaborative GIS framework that

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provides the two-way communication channels for the Web-based decision support system.

There are some limitations in our prototype design. First of all, the security of wireless communication and mobile GIS devices is a major concern of the U.S. Border Patrol. Mobile GIS devices are very likely to be stolen because the device size is so small. Some critical information and criminal apprehension data are very sensitive and need to be protected within the system framework. However, the current technologies in wireless communication and mobile devices can only provide very limited protection mechanisms. The second limitation of our system is the balance between open-source packages and vendor-based GIS software. Most of our prototype system adopted vendor-based GIS software packages because the vendor-based GIS packages already have many needed GIS functions available, and can significantly save our system development time. However, vendor-based Internet GIS and mobile GIS packages might become difficult to customize or develop new GIS functions, compared to the open-source packages. In the long run, vendor-based GIS packages might need more effort to create additional new GIS functions for the future prototype development.

Future Trends

In the future development of collaborative GIS frameworks or Web-based decision support systems, many innovative Web technologies, such as Grid computing and Semantic Web, can be adopted. These Web technologies, from a technical perspective, will enable more efficient and intelligent data search mechanisms and online mapping services.

Ideally, multiple geodata and GIS functions from heterogeneous servers or platforms should be connected and integrated dynamically to conduct a specific geospatial analysis tasks. To dynamically construct distributed GIServices, tremendous amounts of geospatial data and computational results would be requested and transferred across the network. Therefore, the GIS community needs to establish a comprehensive GIService framework in order to keep all available heterogeneous GIService components synchronized in terms of data flow and operation procedures. Such a framework needs to become dynamically adjustable in order to accommodate complicated network environments (dial-up modem, cable modem service, ISDN, T1/T3, wireless channels, etc.). The recent development of Grid technology provides a possible framework for the deployment of Internet GIService with its powerful computational and resource management capabilities. In the computer science community, the focus of Grid technology is to resolve low-level Grid computing technology issues (e.g. communication, protocols, and resource management) and to build a collabora-

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tive network architecture for Grid (e.g. Globus Toolkit). However, the deployment of collaborative GIS needs a high-level application framework rather than low-level Grid computing architecture. Grid technologies have been rapidly evolving since the mid-1990s. There are two types of Grid technologies, "data Grid" and "computational Grid." Data Grid (Chervenak, Foster, Kesselman, Salisbury, & Tuecke, 2001) can offer a basic architecture for geospatial data management with coordinated data storage, data access, metadata, and security services. Data Grids can provide various downloadable GIS data and online mapping services via the grid's metadata search engine. Computational Grid (Foster & Kesselman, 1999) will primarily be concerned with issues related to building the infrastructure to meet the requirements for high-performance computational needs. Both data Grid and computational Grid are emerging to provide effective computing resources for sharing and integration.

Semantic Web is another future trend for collaborative GIS. Semantic Web can facilitate the Web-based data sharing within a global network system. This technology can provide better definition of Web data and services, allowing large-scale data sharing and reuse (*Berners-Lee, hendler, & Lassila, 2001)*. A working group in W3C (World Wide Web consortium) has defined related standards and languages for the applications of semantic Web technologies (http://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 Web, Web Ontology Language (OWL) was also proposed to define terminology used for specific contexts and properties in terms of classes and relations (http://www.w3.org/TR/owl-guide/). Besides the reorganization of online content, recent breakthroughs have been made in defining Web services using mark-up language. OWL-S is a specification designed to help Web services discover and use the mark-up language. (http://www.w3.org/Submission/2004/SUBM-OWL-S-20041122/). In addition to all of the standards set by W3C and other organizations, semantic Web tools have been developed for data parsing, metadata processing, ontology management, and RDF/OWL formatting. To facilitate the integration of heterogeneous collaborative GIS frameworks, we might need to create a geospatial semantic Web that requires developing a geographic Web ontology language (G-OWL) to facilitate the geospatial data sharing and service integration.

Conclusion

On December 26, 2004, people from around the world began to realize the power of nature, and that natural disasters are a daily risk we must address. Following a massive 9.0 earthquake in the Indian Ocean, a horrifying tsunami destroyed the

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coastline areas of 11 countries, and caused a massive number of deaths (over 150,000). Many geographers and GIS professionals asked themselves a fundamental question: "Why did such a tragedy happen in these areas and could we have responded better?" What if these areas have an advanced collaborative, Web-based emergency response system?

A Web-based spatial decision support system could assist the local governments and emergency response teams in identifying potential threat areas so critical "hot zones" could be quickly and accurately identified. A Web-based GIS data portal could be used to rapidly generate the most effective evacuation routes and emergency plans during natural hazard events including wildfires, flooding, and tsunami. Real-time or near real-time GIS could also assist public policy officials, firefighters, and other first responders with identifying areas where their forces and resources are most needed. Many people agree that an integrated and comprehensive geographic information system (GIS) is an essential component for successful disaster prevention and mitigation. Clearly, collaborative GIS could become a vital technology to save lives and assist in recovery.

This paper gives a brief introduction about the capability of collaborative GIS. It is important to educate people and organizations on the utility of collaborative GIS technology, and why it is to their benefit to adopt the technology in their daily lives. As always, the cost of disaster recovery and mitigation is much more expensive than the cost of early prevention using systems such as a Web-based SDSS.

In order for collaborative GIS to be most effective for natural hazard prevention and response purposes, the system should be incorporated into the regular planning activities; training; and exercises conducted by local, regional, and federal government officials and agencies. An example of the routine use of an SDSS in improving emergency response would be the application of real-time SDSS by local governments to monitor the roadway traffic, air quality, and E-911 responses. Monitoring daily roadway traffic can quickly be transformed into monitoring evacuation routes or routing emergency relief aid. Without training, familiarity, and exercises, any emergency response tool, including a real-time SDSS, may not be effective to an official, organization, or government when an actual hazard situation occurs.

This chapter introduced a real-time Web-based spatial decision support system for use by decision makers and *in situ* agents to collect and process information via a secure intranet or encrypted mobile wireless networks to make better and timelier decisions. The goal of an integrated SDSS is to bridge the gap between traditional control-center-based spatial decision support systems and field agents through the use of real-time wireless mobile GIS applications and their benefits to decision making.

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The unbelievable tragedy in December 26, 2004 taught us many valuable lessons. We should use collaborative GIS as a tool to understand and respect the power of Nature. When viewing online maps, satellite images, categorizing land-use data, or conducting spatial analysis, we are actually communicating with Nature, and trying to understand her behaviors at that moment. Therefore, the Web-based SDSS introduced in this chapter is not a tool to be used to conquer Nature or to fight back Nature, but a tool to learn the knowledge of Nature, and to collaborate with her.

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Section V

Conclusion

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