16 Network Geographic Information System

Chaowei (Phil) Yang, Menas Kafatos, David Wong and Ruixin Yang

16.1 Introduction

Since its interception in the 1960s (GIS World, 1996; Tomlinson, 1998), Geographic Information System (GIS) has been well established as an information system for acquiring, storing, processing, analyzing and visualizing spatial data. The success of GIS is reflected from the following developments: (1) numerous GIS software have been developed and are widely used; (2) A large amount of spatial datasets have been collected and used; (3) Many books and papers have been written to introduce and discuss different aspects of GIS. They range from providing an overview of GIS (Davis, 2003; Tomlinson RF and Tomlinson R, 2003), discussing selected advanced topics (Kreveld et al., 1997; O'Sullivan and Unwin, 2002), to recording the relevant history (Foresman, 1997).

However, relevant problems also arise: (1) Different software companies, such as ESRI (www.esri.com) and Intergraph (www.imgs.com), developed their own software with full GIS functions, and sold their software at a fully functional price. However, most customers just use the mapping function which accounts for no more than 30% of the full GIS functions, and almost no software are used all the time. (2) A large number of spatial databases are constructed from national level (such as NASA and USGS), state level (such as Virginia and Maryland), to county level (such as Fairfax and Loudoun). National applications (such as Homeland Security) call for full integration of these spatially dispersed databases. To save the investment on GIS nationally and internationally requires sharing and connecting spatial data and software. (3) While current literatures focus on using existing software for application research, GIS basic functions need to be revisited (Wise, 2002) for building new software platforms for sharing spatial data and processing (Yang et al., 2002).

Fortunately, the emerging and fast development of computer networks, especially WWW and the Internet, provide a communication framework to solve these problems. The marriage of GIS and computer networks has produced many types of GIS: such as On-line GIS (Plewe, 1997), Internet GIS (Peng, 1999; Huang et al., 2001; Peng and Tsou, 2003), Intranet GIS, Wireless GIS (Braun, 2003), and Distributed GIS (Peng and Tsou, 2003; Yang, 2000, etc.). To integrate GIS among networks for sharing the data and software, scholars propose many new architectures, such as agent-based GIS (Luo, 1999), distributed geospatial information services (e.g. Yang et al., 2002), and GridGIS (http://www.niees.ac.uk/events/GridGIS/). Although having different names, these different manifestations of GIS have the same characteristic of using computer networks as the communication infrastructure to implement GIS. Therefore, these different types of GISs can be grouped under the label of Network GIS.

These new manifestations reflect the rapid growth of Network GIS. however, they have no clear definition. What are the differences among Network GIS, Internet GIS, Intranet GIS, WebGIS, Mobile GIS, and Network GIS? What is the communication framework of a Network GIS and how would one build a Network GIS? How could we use Network GIS in disseminating remote sensing and other spatial data, and providing useful functions or services to users? What research aspects of Network GIS are needed? This chapter attempts to examine these questions based upon recent research on Network GIS (Yang, 2000; Kafatos et al., 2003; Peng and Tsou, 2003; Yang et al., 2003; Yang and Wong, 2003; etc). It is also hoped that this chapter could serve as a brief technical introduction of Network GIS to geospatial professionals who plan to use Network GIS or are interested in the technical issues of Network GIS.

To answer these questions and to provide a systematic introduction of Network GIS, the rest of this Chapter is organized in the following manner: Section 16.2 describes the communication foundation of Network GIS, i.e., the underlying network infrastructure. Section 16.3 reviews basic GIS functions, discusses another critical issue of Network GIS, that is, how to distribute these functions over a network. Consequently, a flexible Network GIS framework is proposed. Section 16.4 introduces Distributed GIS as a new envision of Network GIS. Section 16.5 proposes taxonomy of Network GIS and discusses the usage of different types of Network GIS. Two examples of Network GIS are given in Section 16.6 to illustrate how Network GIS can be used in disseminating data/information and providing services. Finally, in Section 16.7, we present several research areas of Network GIS.

16.2 Network Infrastructure

Building a Network GIS depends on two critical issues: (1) the underlying network infrastructure on which the GIS functions are built, and (2) the distribution or allocation of GIS functions among different computers within a network. This section provides an overview of the first issue and describes the procedure of Network GIS communication.

A computer network connects computers located in different places by providing electromagnetic channels (wired or wireless) to exchange information. The information exchange process via the channels is very complex. The International Standard Organization (ISO) realized the complexity and the importance of developing an open network model to ensure the interoperability of different network devices and computers. Consequently, ISO proposed a 7-layer network model in the 1980s to formalize this complex process. This 7-layer network model is widely used in introducing network infrastructure (Jain and Agrawala, 1993; Tanenbaum, 1996). However, the most widely used network model is the TCP/IP 5-layer model (Murhammer et al., 1998; Stallings, 2000); TCP/IP stands for Transportation Control Protocol/Internetworking Protocol.

Figure 16.1 shows a typical Internet TCP/IP 5-layer model. The 5-layer model includes a physical layer, a network layer, an internet layer, a transport layer, and an application layer. The internet layer is not the Internet that refers to the global network. For simplicity, some scholars (Komar, 2002) also combine the lowest two layers as the network access layer. In general, an upper layer depends on the immediately lower layer by calling the interface provided by the lower layer to perform its tasks. This dependency is illustrated in Fig. 16.1 by the interfacing service provided to the upper layers by the lower layers. Each layer has its own protocol (a set of communication rules) for communicating with a peer layer on another computer, i.e. two layers at the same level in two computers use the same protocol. Because the two layers are at the same level, their communications are also labeled as peer or peer-to-peer communication. In this type of communication, the two layers do not communicate directly but through the lower layers or other devices except the directly connected physical layers. Most communications between two computers on the Internet will go though many other network devices, such as routers, which select routes for data to travel from a source to a destination. Routers route data units with specific volume size called packets from computer to computer. In this manner, a simplified network model is comprised of computers, network cables (or wireless devices) for exchanging electromagnetic signals, and routers for routing packets. Peng and Tsou (2003) provide a description of the ISO 7-layer and the TCP/IP 5-layer models. The following example illustrates how a Network GIS utilizes the network infrastructure and illustrates the functions of each layer using the 5-layer model.

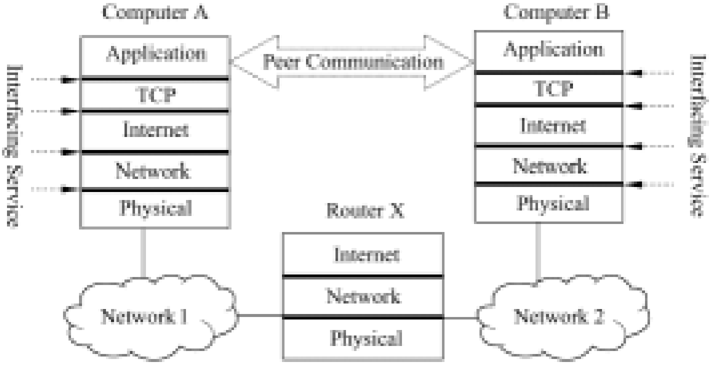

Figure 16.1 The Internet TCP/IP 5 layer model

If GIS α on computer A needs more data from GIS β which manages the spatial database on computer B, and the application layer protocol is HyperText Transfer Protocol (HTTP), α can call the data selection function of β through HTTP and will receive the response data. However, the above seemingly straightforward and simple communication procedure between α and β is actually a complex process as illustrated in Fig. 16.2 and involves the following steps:

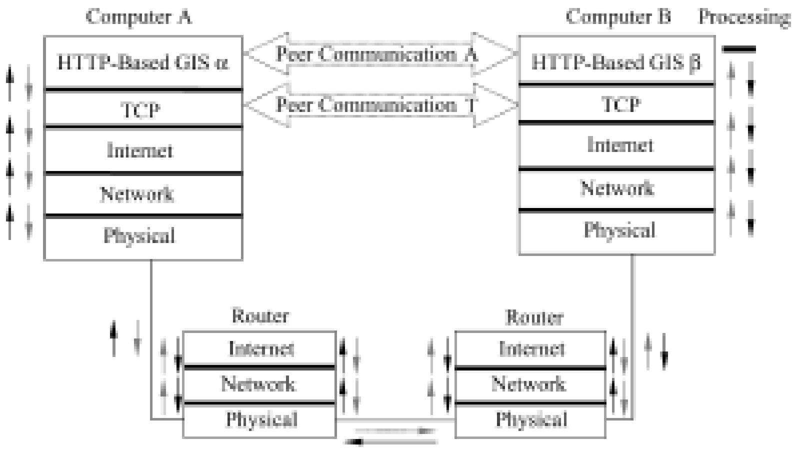

Figure 16.2 The communication procedure between two GISs in the Internet: The gray arrow shows the information flow of request from α to β, and the black arrow shows the response from β to α

(1) Data request information will be generated by α according to a GIS communication protocol, which is understandable to β. The data request information will be passed on to the application (HTTP) layer, which defines certain data format, interprets the data request information and transforms it to a data stream for passing to the TCP layer.

(2) The data stream is passed on to TCP layer by calling a TCP layer function provided to the application (HTTP) layer. The TCP layer ensures the end to end correct transmission of the data stream, i.e. the TCP layer on computer A will ensure the complete data stream reaches the TCP layer on computer B. The TCP layer will also divide the data stream into packets. Some priority and loss control functions can be added to this layer to ensure quality and level of service.

(3) The TCP layer will call the internet layer and pass the packets to the internet layer. According to the IP addresses of A and B, the internet layer will choose routes for the packets. The packets belonging to the same data stream may take different routes to travel from A to B because routes may involve various numbers of routers and other network devices, such as a firewall. Two routers are illustrated in this example; the internet layer may also divide packets into smaller packets called sub-packets, according to the data size restriction of

the internet protocol.

(4) The internet layer will call the network layer to send the packets/ sub-packets on computer A. The network layer will ensure error free exchange of packets/sub-packets between any two directly connected computers or routers.

(5) The network layer on computer A will call the physical layer to send electromagnetic signals, which have the digital data encoded. The physical layer on router X will receive the signals.

(6) The physical layer defines the electrical standards, such as number of pins for a port and electric voltages. These standards will ensure the direct communication between the two physical devices for transmitting signals with digital data encoded.

(7) The physical layer of router X will decode the digital data and pass them onto the network layer on router X for checking correctness. Router X's internet layer will reassemble the data into packets from sub-packets, and may divide the packets into sub-packets using different sizes according to different internet layer protocols.

(8) The 4th, 5th, 6th, and 7th steps will be repeated among A&X, X&Y, Y&B en route until packets reach computer B.

(9) The physical layer of computer B will receive signals from the physical layer of router Y and pass decoded digital data to the network layer.

(10) The network layer of computer B will check the correctness of the digital data and request the data again from router Y if the data are incorrect. Received digital data will be passed to the internet layer on computer B.

(11) The internet layer on computer B will assemble sub-packets into packets according to the same protocol used by the internet layer on router Y, and passes the packets to the TCP layer.

(12) The TCP layer will check the correctness and sequence of the packets, and assemble the packets into data stream, which will be passed on to the application layer. The application layer will interpret the data stream according to formats defined by HTTP. The interpreted data request information will be passed on to β.

(13) β will perform the data selection process on computer B as requested and generate datasets accordingly.

(14) The output datasets will be sent back to α in a similar procedure from step (1) to step (12).

Among the layers of the TCP/IP 5-layer model, the most upper two layers (TCP and application layers) are most frequently used in developing application software, such as GIS. For instance, HTTP is widely used in developing Web-based software. A better performance can be achieved by programming on TCP by calling Winsock or NetBIOS (Jones and Ohlund, 1999) directly (Yang, 2000). However, this method requires the developers to possess in-depth network knowledge; it is often used by system developers in developing commercial or system level software, such as ArcGIS. In general, the computer sending requests is termed a client while the computer responding is called a server in a network environment. In the research, design, and development of a Network GIS, only the two upper most layers, the server, and the client, are considered. All other network devices and functions will be provided by lower-level software and hardware, such as the operating systems.

16.3 Distributing GIS Functions

Another critical issue of building a Network GIS is how to distribute GIS functions over a network. This section introduces the GIS functions to be distributed, discusses how to distribute these functions, and proposes a flexible framework for Network GIS.

According to most widely accepted definitions of GIS (Worboys, 1995), a traditional GIS includes functions of capturing, storing, analyzing, and displaying spatial data. Practitioners' definitions of GIS (Tomlinson RH and Tomlinson R, 2003) may also include procedures, operating personnel, and spatial data. Although the procedures and operating personnel are not GIS functions, Network GIS is transforming some processes of procedures and capabilities of operating personnel into GIS functions. For example, if a driver needs a map from the mapping office to drive from LA to DC, the procedure could be:

(1) Call the mapping office to submit a map request.

(2) The mapping office will generate a route map according to the request.

(3) Someone will ship the map to the driver.

If the mapping office has a map server to generate the route map and the driver has a network connection to access the corresponding server, this procedure and the functions of calling and sending map could be automated and built into one system. Therefore, the procedure processes and the sending capabilities of personnel are transformed to the functions of a Network GIS.

By incorporating these transformed GIS functions, the functions of a GIS can be classified into six general technical areas according to the spatial data processing procedure (as illustrated in Fig. 16.3): data collection and input, data editing, data management, data access and integration, spatial analysis, and visualization/interaction. Data collection and input is collecting spatial data using manual, automatic, or semi-automatic methods, such as remote sensing, ground surveying, or digitizing from paper maps. Data editing includes checking data error, validating attribute data. Data management is performed through spatial databases, such as ArcSDE from ESRI or SpatialWare from MapInfo. Data access provides interfaces for a caller program to access and operate the spatial database. For example, Intergraph uses an Open DataBase Connectivity (ODBC) link to Microsoft Access database from GeoMedia. ESRI provides Spatial Data Engine to access its ArcSDE database (ESRI, 1997). GIS is distinguished from other information systems through its spatial analysis capabilities, such as selecting the shortest path, choosing a location to build a cell phone tower to serve a large area. The visualization and interaction functions are built to provide users with a displayed map, and users can perform selection, zoom, query on the map.

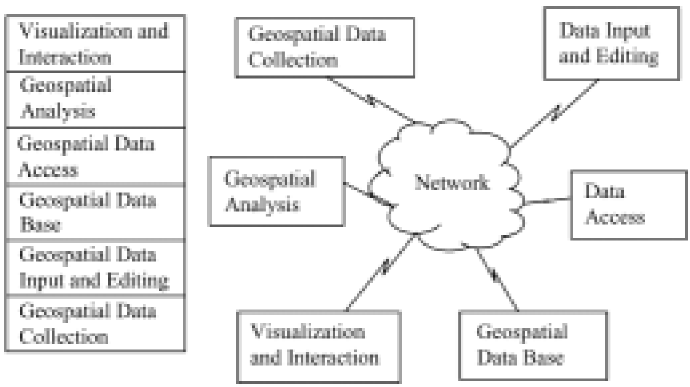

Figure 16.3 A traditional monolithic GIS (left) and a networked GIS (right) with different GIS functions distributed in a computer network. These functions can be allocated on two or more than two computers

In a traditional GIS architecture, these functions are all located within one computer. In a Network GIS, these functions will be allocated to different computers in a network to take advantage of the computing resources, and comply with the fact that datasets and users are widely distributed. The strategy of distributing GIS functions can be quite different according to specific project requirements and the long-term objectives of implementing a Network GIS. However, there are some basic principles in formulating these strategies:

(1) The data visualization interface and the system interaction should be accessed by users directly; therefore, the client (s) should host the data visualization interface and the user-interacting functions.

(2) The data management and databases should be allocated to a place that provides easy access to all clients and users with an acceptable performance; therefore, the server would be the ideal place to host the databases and data management.

(3) The data processing component has the greatest flexibility to be distributed to either the server side or the client side according to a specific application.

(4) Data collection often happens in fields, such as ground surveys. A mobile device could host this function and be equipped with a wireless connection to the server, so client can automatically update the database.

(5) The data access and integration function will be the connection between server and client or just inside the server according to the strategy taken in 3).

When data and data processing are all residing on the server, the data access and integration for linking the data and data processing will reside on server. If data and data processing are distributed on two computers, the data access and integration will be implemented on the two computers. This variation in data exchanged resulted from the data access and the integration strategies requires different protocols in Network GIS.

(6) The editing function resides mostly on computers which reside within the intranet or local network with the server. Network GIS could also automate this function by provide mobile or online update.

These general principles could help in strategic plan to allocate these six functions, but the implementation of Network GIS could be very complex. One aspect of this complexity is that these functions also include series of sub functions, which can also be allocated to different computers or be implemented all on one computer. For example, data visualization includes preparing data (coordinate transform, etc), visualizing data by symbolizing features, drawing image based on the symbolization, and displaying a drawn image. The display function of the visualized image can reside on the client side and all other functions can reside on the server side. This smaller client strategy is adopted by Mapquest (www.mapquest.com). On the other hand, we could put all visualization functions on the client side, and make the client bigger. This latter strategy is adopted by some commercial software, such as the Java client of ArcIMS (http://www.esri.com/software/arcims/index.html), and the ActiveCGM of GeoMedia WebMap (http://imgs.intergraph.com/products/default.asp?id=gmw&Submit=Go).

The smaller client strategy is ideal to implement simple functions or services with great speed, while the bigger client strategy can provide complex functions or more demanding services. The smaller or bigger client strategies are also referred as thin and thick client strategies respectively (Foote et al., 1998).

The adoption of thick or thin clients is dependent on the requirements, performance, and system-supporting infrastructure of a specific application. Mapquest, for instance, uses a thin client to let users submit queries and send only an image back to the client, through a web browser, while the Java version of ArcIMS includes a series of basic GIS functions, such as feature selection, feature querying, and display functions. According to the principles for distributing GIS functions, some GIS functions must be located on the server side but not on the client side, vice versa. But some functions can be located on either side. According to this principle, a flexible framework for building a Network GIS is illustrated in Fig. 16.4.

These strategies are based on the traditional client-server model. The rapid development of computing technology and computer networks also enable us to implement GIS among a number of computers in a network. This provides us another option to implement Network GIS. Instead of using client-server architecture, GIS functions can be implemented on different computers, and these computers can collaborate by serving as both server and client for a specific GIS

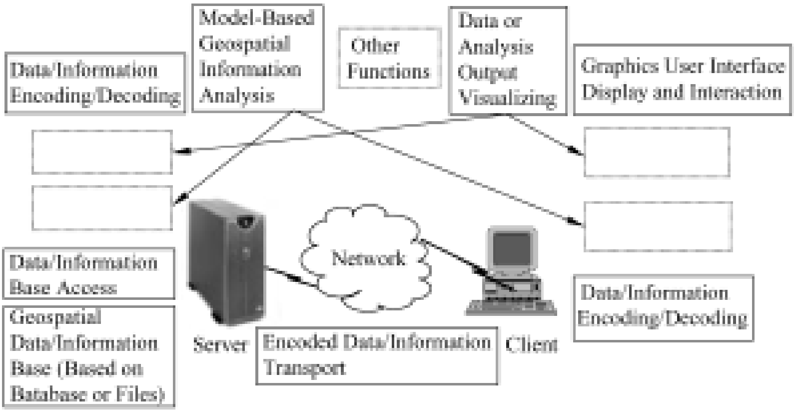

Figure 16.4 A flexible distributed GIS framework: the server side hosts data, provides data access interface; the client side displays the visualized data/output and interacts with users; data/information transmitted through the network will be decoded/encoded at both client and server side; model-based analysis, data visualizing, and other functions can be hosted at either server side or client side

task, which may require massive computing capability or data. Therefore, this implementation takes advantage of the distributed data and network computing power. The concept of agent-based GIS, peer-to-peer GIS (Li, 2003) and GridGIS are new research directions along this line.

16.4 Distributed GIS

By implementing GIS functions on two or more computers, the concept of Distributed GIS (DGIS) is introduced. This section provides an overview of this manifestation.

The basic idea of a Network GIS is to distribute GIS functions among different computers within a network. This idea of "distribution" gives Network GIS another name of DGIS. As its name implies, DGIS can be regarded as a GIS with its functions distributed at different places or on different computers. This definition emphasizes the distribution of all of the general six functions. According to this broad definition, almost all GISs are DGIS. Spatial data capturing, for instance, will be separated from the location where a computer hosts the processing of spatial data. This general definition can help us to manage a DGIS project by including the required personnel and procedures.

A more technical definition of DGIS similar to Network GIS would be a GIS that has functions distributed among different computers connected by a computer network. The functions could be hosting spatial data, accessing spatial data, analyzing spatial data, visualizing spatial data and providing interactions to users. In this definition, only the functions that can be implemented on computers or networks are considered, therefore, this definition is used for technical design, and implementation of DGIS (Yang and Wong, 2003).

In computer science, a distributed system is defined as “a collection of (probably heterogeneous) automata whose distribution is transparent to the user so that the system appears as one local machine”. (http://www.ditionary.com/) According to this definition, DGIS can be defined as an information system that allows the storing, accessing, analyzing, visualizing, and user interacting distributed within a network; while the system internal processing is transparent to users. For example, computer users can interact with a DGIS in selecting routes without knowing where the data are, who selects the routes, which computer did the visualization, but feel like all data and operations are in the computer in front of them.

This definition envisions a highly transparent DGIS, which requires implementing functions to replace some capabilities of professionals, and building each of the processing functions into a uniformly accessible component over the network (Li, 2000). There is no such type of DGIS yet. However, conceptually, this definition would help us to implement the general defined functions of GIS, including professional capabilities and procedures, into DGIS. This definition could also help us to envision a future distributed geospatial information service platform, such as peer-to-peer GIS or grid GIS.

16.5 Network GIS Taxonomy

Different manifestations of Network GIS are based on two facts: (1) the types of computer networks, and (2) the distribution of GIS functions. Network GIS could also be classified in these two ways.

In the first classification, if a Network GIS is implemented on the Internet, e.g., the mapquest system, then, the Network GIS can be regarded as an Internet GIS. If the network is an Intranet inside a company, university or department, the Network GIS can then be labeled as an Intranet GIS. If the client side of the GIS is implemented inside a Web browser, the Network GIS can be regarded as a WebGIS and a WebGIS can be an Intranet GIS or Internet GIS. However, some Internet GIS, such as ArcExplorer, are not WebGIS. As illustrated in Fig. 16.5, different types of Network GIS overlap. Mobile GIS (Braun, 2003; Spencer, 2000) has emerged and is regarded as Network GIS. ESRI, Trimble, and Tele Atlas (2003) defined mobile GIS as the movable devices with GIS and GPS functions. From this definition, a mobile GIS is not necessarily a Network GIS. However, if equipped with a wireless connection, a mobile GIS could become a wireless Network GIS.

With different functions distributed between servers and clients, the second classification divides Network GIS into two types (Foote, 1998). (1) a thin-client Network GIS with only a few functions, such as the display and interaction

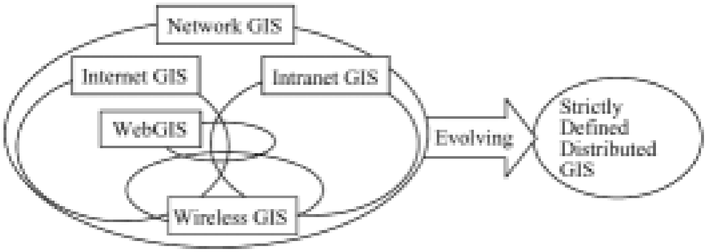

Figure 16.5 Network GIS taxonomy: different terms of network GIS refer to different implementations of distributed GIS: Network GIS is implemented in a network, which includes all kinds of GIS built on computer network; Intranet GIS is implemented in the Intranet. Internet GIS is implemented within an Internet. WebGIS is implemented inside a web browser. Distributed GIS is a future Network GIS with transparent characteristics that require more research and development

implemented on the client side. In this case, the server will handle functions related to data storage, processing, accessing, visualizing, and most interaction responses. (2) A thick-client Network GIS has most GIS functions implemented on the client computer, where the client can also communicate with the server for data and massive computing capability. In reality, we cannot just simply choose one from these two types. For example, we may need half of the functions to be implemented on the client computer while putting the other half on the server, or duplicate some functions on both server and client to improve performance. In this scenario, it would be flexible to implement GIS functions inside a component and make the internal system transparent to the component user (Brown, 1996; Li, 2000). This implementation of components could produce transparent components to help us in building the strictly defined DGIS.

Different applications require different types of Network GIS. For a department to share spatial data and GIS software, an Intranet GIS would be proper. Most GIS companies produce the Intranet GIS products, such as ArcGIS from ESRI and GeoMedia from Intergraph. If some data and software are used to build services for the public through the Internet, an Internet GIS is then proper. As such, ArcIMS from ESRI, GeoMedia Webmap from Intergraph would be proper to build Internet GIS. If in-field data update, collection, or validation is needed, mobile GIS will be a good choice. ArcPad from ESRI and Intelliwhere from Intergraph would be proper for this mobile GIS need. Wireless devices can be installed on the mobile devices to update the databases automatically if needed.

16.6 Examples of Network GIS

The Center for Earth Observing and Space Research (CEOSR) received funding from NASA through the Virginia Access-Middle Atlantic Geospatial Information

Consortium (VA-MAGIC) project (http://philler.scs.gmu.edu/vaccess/). In this project, we develop RS-oriented applications for the Mid-Atlantic region using datasets from NASA and other agencies. One of the applications is the hurricane Isabel web service, which collected and continues to disseminate satellite data and information about the hurricane. When hurricane Isabel hit the mid-Atlantic region in September, 2003, over 3,000 individual users accessed the website in one day to obtain information about this natural hazard. Another application is the Mid-Atlantic regional portal of geospatial information service that collects information from various government agencies, and provides high-resolution geospatial information services. The first example is a thin-client Network GIS because it provides only preprocessed static spatial data. The second example resembles more to a thick-client Network GIS because it provides more complex GIS functions. Both of them are Internet GIS and WebGIS since they all provide information within web browser and through the Internet.

The hurricane Isabel website is located at http://philler.scs.gmu.edu/vaccess/news/IsabelIndex.htm, and is a project integrating spatially referenced images, maps, and information from different Earth observing systems and/or sensors, such as Tropical Rainful Mesuring Mission (TRMM), GOES, Advanced Very High Resolution Radiometer (AVHRR), and Moderater Resolution Imaging Spectroradiometer (MODIS). Data from the National Hurricane Center, the Storm Center Inc., and a few other organizations are accessed through this web service to provide the hurricane information. The basic approach in developing this website service is shown in Fig. 16.6.

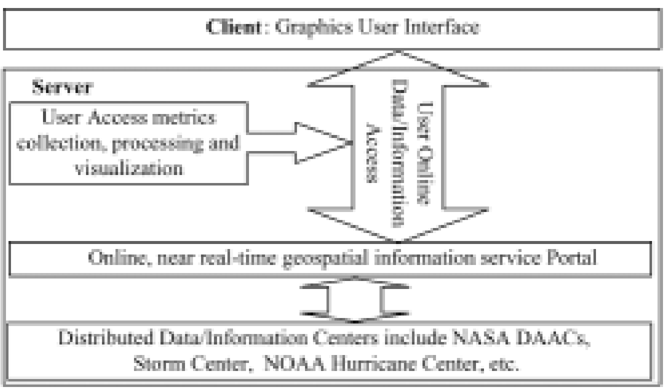

Figure 16.6 System architecture of the Hurricane Isabel Web Service

The Mid-Atlantic Regional Geospatial Information Service is a project supported by NASA, Intergraph, and USGS. The objective is to share data and information collected through VAccess-MAGIC (http://philler.scs.gmu.edu/vaccess/) and the SIESIP project (http://esip.gmu.edu/). The geographical coverage of these datasets ranges from the global level to the regional and local levels. Other spatial data provided by the Commonwealth of Virginia, NASA, NOAA, USGS, are utilized in the portal to build the services. GeoMedia WebMap (http://www.intergraph.com/gis/), a Network GIS software package from Intergraph, is adopted to provide GIS functions. The software framework is illustrated in Fig. 16.7. The dash-lined

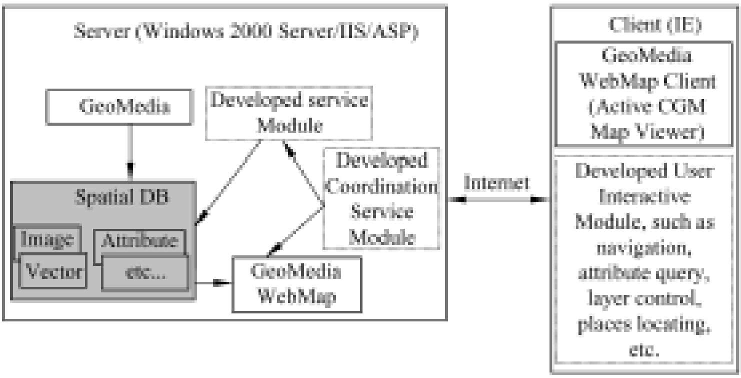

Figure 16.7 Software Framework for Mid-Atlantic Regional Geospatial Information Service System

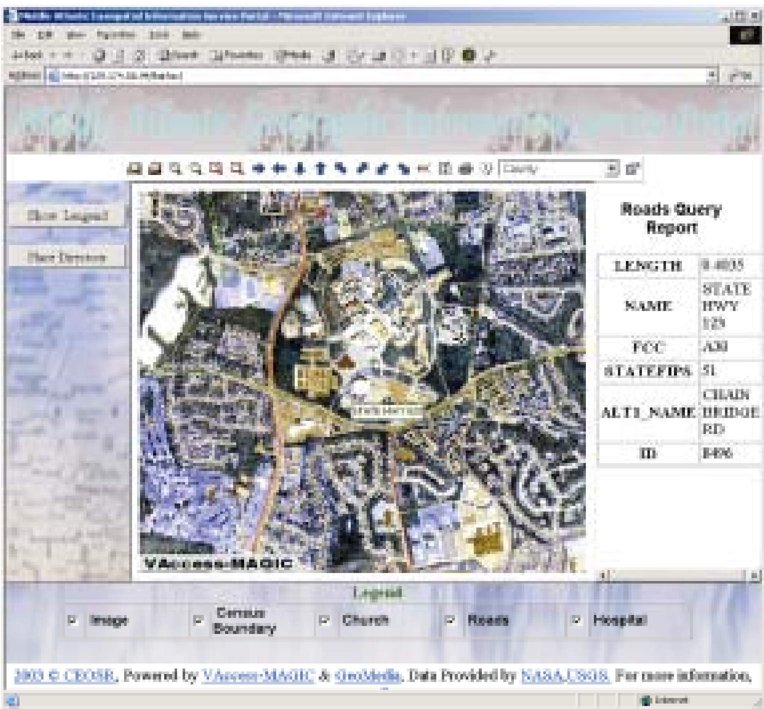

Figure 16.8 The GUI of Middle Atlantic Geospatial Information Service Portal

modules are developed to serve two functions: (1) to coordinate interactions between the GeoMedia products and the developed modules, and (2) to provide customized functions or services. The solid-lined white modules are software modules from Intergraph that are used for data management and web mapping. The gray modules refer to the data and information that CEOSR has collected through its various projects. The server side provides data, information, and services through the GeoMedia software and our developed modules. The client side provides visualization, interaction, and analysis functions to the users.

The portal provides users information about Fairfax county and Northern Virginia with online geographic information services. Users can explore the geographic environment of Northern Virginia by using the GIS functions provided online. Users can also use their background knowledge to design a customized map and print it out or use it in a document. The physical network supporting portal includes a DELL PowerEdge 4600 Server and a 100 Mbps network connection to the Internet. Users connected to the Internet through a 100 kbps+ connection can access the server with a good performance. The client-side interface is illustrated in Fig. 16.8. A detailed description of the system functionality can be found in the user manual (http://env.scs.gmu.edu/fairfax/utility/UserManual.htm).

16.7 Research Topics in Network GIS

Over the past ten years, Network GIS has been accepted and widely used in different disciplines from natural resource management (Kearns, 2003) to transportation (www.mapquest.com). However, to fully utilize the capability of Network GIS and build a completely transparent DGIS, the following issues should be addressed:

(1) The distribution strategy of geospatial information processing;

(2) Computational techniques for improving the overall performance;

(3) Proper protocols for effective transmitting of geospatial information;

(4) Interoperability of the data and software to enhance the transparency of DGIS;

(5) Adoption the peer to peer and grid computing infrastructures;

(6) Establishing a series of standards for measuring the quality and levels of services; and

(7) Geospatial knowledge discovery, management, and integration.

How should the geospatial information processing functions be distributed? Where should the sub functions be allocated? Where the data should be stored? Although answers to these questions will change according to specific applications, principles for guiding application developments should be established based on some criteria, such as performance and computing infrastructure.

The performance of distributed geospatial information processing is critical to both simple data dissemination and more complex functional geospatial information services. It requires more investigations on information extracting, compression, transmission, pre-fetching, pre-processing (Yang et al., 2004) and other computing techniques.

As illustrated in Fig. 16.5, where one puts the processing functions will also affect the data/information needs for transmitting. The variety in data/information transformed requires a set of protocols dealing with all levels of data from raw data to drawn images. These application level protocols (with respect to the network architecture) could be fundamental (with respect to Network GIS).

Interoperability research and implementation have been conducted for about ten years. Successes have been achieved in some projects, such as NSF funded Digital Library, ESRI's Geography Network, and NASA earth science data interoperability. However, there is a long way to go before we can fully integrate the data and sharing the processing module from different companies as envisioned by Buehler and McKeel (1996). Both government (such as GeoSpatial One-Stop), non-government organizations (such as OGC), and company efforts are needed.

Agent-based GIS (Tsou and Buttenfield, 1998; Luo, 1999) and Grid GIS (http://www.niees.ac.uk/events/GridGIS/) have been suggested as solutions for utilizing the power of massive networked computers. The implementation of agent-based GIS or Grid GIS will require a completely new design of the GIS according to computing environment of the agent or grid.

Online geospatial information service or Web Service becomes practical ways to gradually build DGIS (Tao and Yang, 2004). Levels of service, quality of service, and metrics for recording service performance (Stallings, 2002) are needed for providing effective and efficient web service and utilizing the power of massive networked computers.

The geospatial decision support system is based on geospatial information systems and disciplinary-based knowledge systems (Jankowski and Nyerges, 2001). The seamless integration of geospatial information and the decision support knowledge require investigations in spatial data mining and spatial knowledge discovery/management.

As an evolving field, Network GIS needs the contribution of various research and development related to computer networks and GIS. This chapter is only a general introduction. More detailed information can be found in related references. We believe that more literature will appear on this fast developing topic.

Acknowledgements

Research and developments discussed in this chapter are supported by NASA-funded Virginia Access—Middle Atlantic Geospatial Information Consortium (NASA NAG13-01009) and USGS-funded Building an Interoperable Web Mapping Portal for the Mid-Atlantic Region (03HQAG0146).

References

Braun P (2003) Primer on Wireless GIS, Urban and Regional Information Systems Association, http://www.urisa.org/store/primer_on_wireless_gis_qs.htm

Brown AW (1996) Foundations for Component-Based Software Engineering. In: Brown AW (ed) Component-Based Software Engineering. Los Alamitos, IEEE Computer Society Press, pp. 3 – 6

Buehler K and McKeel (eds) (1996) The OpenGIS Guide: Introduction to Interoperable Geo-Processing, Wayland, MA, OpenGIS Consortium, Inc.

Davis DE (2003) GIS for Everyone, 3rd edition. ESRI Press

ESRI, Trimble, and Tele Atlas (2003) What is Mobile GIS? http://www.esri.com/events/mobilegis/

ESRI (1997) Getting started with SDE, A ESRI white paper

Foresman T (1997) The History of GIS (Geographic Information Systems), Upper Saddle River, NJ: Prentice Hall

Foote, Kenneth E, Anthony PK (1997) WebGIS, NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u133/u133.html, posted July 13, 1998

GIS World (1996) Roger Tomlinson: The Father of GIS, GIS WORLD Interview, http://www.geoplace.com/gw/1996/0496/0496feat2.asp

Healey R, Dowers S, Gittings B, Mineter M (1998) Parallel Processing Algorithms for GIS. Bristol: PA: Taylor & Francis

Huang B, Jiang B, Lin H (2001) An integration of GIS, virtual reality and the Internet for Visualization, analysis and exploration of spatial data. International Journal of Geographic Information Science 15: 439 – 456

Jain B, Agrawala (1993) Open systems Interconnection. New York: McGraw-Hill

Jankowski P, Nyerges TL (2001) Geographic Information Systems for Group Decision Making: Towards a Participatory, Geographic Information Science. New York: Taylor & Francis

Jones A, Ohlund (1999) Network Programming for Microsoft Windows. Redmond, Washington: Microsoft Press

Kafatos M, Yang C, Wong D, Yang R (2003) Mid-Atlantic Geographic Information Service Center, VAGIS Conference 2003, Richmond, Oct. 27 – 28

Kearns FR, Kelly M, Tuxen KA (2003) Everything happens somewhere: using webGIS as a tool for sustainable natural resource management. Front Ecol. Environ. 1(10): 541 – 548

Komar B (2002) Teach Yourself TCP/IP Networking in 21 Days. Indianapolis, Indiana: SAMS pp. 39 – 40

Kreveld M, Nievergelt J, Roos T, Widmayer P (1997a) Algorithmic Foundations of Geographic Information Systems. Springer: New York

Kreveld MV, Roos T, Nievergelt J, Widmayer P, Nievergelt J (1997b) Algorithmic Foundations of Geographic Information Systems, Springer-Verlag

Murhammer M, et al. (1998) TCP/IP: Tutorial and Technical Overview. Upper Saddle River, NJ: Prentice Hall

Li B (2003) Peer-to-Peer sharing of cartographic data and software. In: Michael Peterson (eds) Maps and the Internet. Elsevier Science pp. 157 – 168

Li B (2000) A component perspective on geographic information services. Cartography and

Geographic Information Sciences 27: 75 – 86
Luo Y, Wang X, Xu Z (2003) Extension of spatial metadata and agent-based spatial Data navigation mechanism. In: Proceedings of the eleventh ACM international symposium on Advances in geographic information systems, pp. 102 – 109
Luo Y (1999) Study on Agent-based Distributed GIS. Unpublished PhD dissertation (in Chinese) (Beijing: Peking University)
OGC (1999) The OpenGIS Abstract Specification Topic 12: OpenGIS Service Architecture Version 4
O'Sullivan D, Unwin D (2002) Geographic Information Analysis. John Wiley & Sons
Longley PA, Goodchild MF, Maguire DJ, Rhind DW (1999) Geographical Information Systems. New York, John Wiley & Sons: pp. 1 – 20
Peng ZR, Tsou MH (2003) Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks. Hoboken, New Jersey: John Wiley & Sons, Inc. pp. 2 – 5
Peng ZR (1999) An assessment framework for the development of Internet GIS. Environment and Planning B-Planning & Design 26: 117 – 132
Plewe B (1997) GIS Online: Information retrieval, Mapping, and the Internet. Santa Fe: OnWord Press, pp. 6 – 14
Rogul D (2003) Geographical Information (GIS) Market Trends. Faulkner Information Services http://www.faulkner.com/products/faulknerlibrary/pdf/00016293.pdf
Spencer B (2000) Mobile GIS. Geo Solutions http://www.geoplace.com/asiapac/2000/0700/0700sol.asp
Stallings W (2002) High-speed Networks and Internets. Upper Saddle River, NJ: Prentice Hall
Stallings W (2000) Data and Computer Communications, 6th edition. Upper Saddle River, NJ: Prentice Hall
Sui DZ, Goodchild MF (2001) GIS as a media? International Journal of Geographic Information Science 15: 387 – 390
Tanenbaum A (1996) Computer Networks. Upper Saddle River, NJ: Prentice Hall
Tao V, Yang C (2004) Distributed Geographic Information Services. In: Rana S and Sharma J (eds) Frontiers of Geographic Information Technology. London: Springer
Tomlinson RF, Tomlinson R (2003) Thinking About GIS: Geographic Information System Planning for Managers. ESRI Press
Tomlinson R (1998) The Canada Geographic Information System. In: Foresman T W (ed) The History of Geographic Information Systems. Upper Saddle River, Prentice Hall: pp. 21 – 32
Tsou MH, Buttenfield BP (1998) An Agent-based, Global User Interface for Distributed Geographic Information Services. In: Proceedings of the 8th International Symposium on Spatial Data Handling, Vancouver, Canada, July, 1998 IGU: pp. 603 – 612
Wise S (2002) GIS Basics. Taylor & Francis: New York
Worboys M (1995) GIS: A Computer Science Perspective. Taylor & Francis
Yang C, Wong D, Yang RX, Li Q, Tao V, Kafatos M (2004) Performance improving techniques in WebGIS. International Journal of Geographic Information Sciences (in press)
Yang C, Wong D (2003) Distributed GIS, A course developed at George Mason University, website: http://philler.scs.gmu.edu/courses/dgis/
Yang C, Wong D, Kafatos M, Yang R (2003) PgGIS: A high performance WebGIS. Next

Generation of Geographic Information, Boston, Oct. 19 – 21, 2003. A patent application of this technology has been submitted and PgGIS is in the process of commercializing, website: http://env.scs.gmu.edu/pggis/map.html

Yang C, Kafatos M, Yang R, Qu J, and Wong D (2002) A geographic information service environment. In: Proceeding of GeoInformatics 2002 Nanjing, China, June 1 – 3, 2002, (CD-ROM publication)

Yang C (2000) Theory, Techniques and Implementation Methods of WebGIS. Unpublished PhD dissertation (in Chinese) (Beijing: Peking University)