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Development of New Generations of Mobile GIS Systems Using Web Services Technologies: A Case Study for Emergency Management

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Abstract: This study aims to address utilization of Web Services technologies for development of Mobile GIS systems, to provide interaction between mobile client devices and servers in a loosely coupled manner. For many mobile GIS applications, such as emergency management, in which access of mobile clients to different servers is required in order to use their data and functionalities, developers are faced with different challenges. One of the most important issues relates to the nuances among different mobile devices that make each mobile device require its own specific server designation and implementation. To solve the problem, utilization of Web Services technologies for development of Mobile GIS systems is proposed. In order to address and investigate the proposition a case study on emergency management was conducted. The results of the case study show that with such a proposition, a mobile GIS client can easily access to different Web services and use their data and functionalities, requiring no specific server designation for specific mobile client. It is shown that simultaneous utilization of mobile GIS and Web services can considerably improve emergency management, by providing emergency workers and managers with up-to-date spatial data describing a current emergency situation and also different GIS functionalities required for better in-field decision-making.

Key words: Mobile GIS systems, wireless communication, web services technologies, spatial service sharing

INTRODUCTION

Emersion of concepts such as ubiquitous computing has leaded to development of new type of geospatial information system, which is known as mobile GIS. Mobile GIS refers to the access and use of GIS data and functionalities through mobile and wireless devices. Currently, mobile GIS and relevant technologies, techniques and applications are widely under research and investigation. Various explanations and examples are available, e.g., Derekenaris *et al*. (2001), Montoya (2003), Casademont *et al*. (2004), Yuna *et al*. (2006), Toninelli *et al*. (2007) and Yin *et al*. (2006).

The most important challenge of designers for development of mobile GIS applications is the restricted resources of mobile devices (Kupper, 2005). In fact, designers can no longer count on adequate amount of memory, processing power, etc. in mobile devices. Additionally, the number and type of mobile devices is increasing and designers must concern on the affects of nuances among mobile devices.

Locating and executing business logic on remote servers is a solution for mobile devices limitations, particularly memory and processing resources. There are also, many applications requiring client-server architecture, in nature, to provide users with access to data, functionalities and services which are provided by different servers and data providers. Emergency management, Natural Resource Management and Location Based Services (LBS) can be named as some examples of such applications.

Considering emergency management as a sample, according to the SDI conceptual model for emergency management developed by Mansourian *et al*. (2006) and also a further interoperable system architecture for emergency response proposed by Mansourian and Taleai (2008), each of the emergency management organizations should update some parts of spatial data describing current emergency situations during their emergency response operations. They should also provide spatial services and functionalities required for better decision-making. These spatial data, services and functionalities should be shared to be accessible for wider emergency management community for a coordinated and knowledge-based emergency response. Using such up-to-date spatial data, functionalities and services which are

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accessible to emergency workers via mobile GIS, they can make the best in-field decision for any operation. Mobile GIS is also a proper tool for in-field data collection to update organizations data servers.

In such applications, due to the nuances among different mobile devices, each mobile device requires its own specific server designation and implementation. This situation makes mobile GIS not to be applicable in practice. Developing mobile GIS systems using Web services technologies is a proposed solution to the problem.

Web services are key technologies allowing the application's business logic, or some parts of that, to run on remote servers, independent of the mobile device's computational resource limitations. Further more, Web services provide a variety of mobile devices with effectively access to the same functionality or business logic on remote servers. By locating and executing business logic on remote servers, the developers can focus on just developing user interfaces, which are the gateway between the user and the business logic, with respect to the specific mobile devices' characteristics. By implementing Web services on the servers of emergency management organizations, client applications on the hand-held devices of emergency workers can access the services of different organizations to use different functionalities and data which are provided by other organizations.

In the context of an ongoing research project in K.N. Toosi University of Technology, a prototype mobile GIS system for emergency management has been designed and developed, based on Web services technologies. In this study the outcomes of the project is depicted and the proposition is investigated.

MATERIALS AND METHODS

This study was conducted in the context of a research project numbered PM/2251 granted to the authors from K.N.Toosi University of Technology, Iran, in August 2007. Here, describes the main technologies and frameworks utilized for development of the studying system.

Web services technologies: Web services technologies are realization of a software design pattern called service-oriented architecture (SOA). From the SOA point of view software architecture is composed of services (Zimmermann *et al*., 2004). The services are applications which present piece of functionality that fulfill users (human or software package) needs and requirements. SOA is a conceptual architecture for implementing services with the following characteristics (Cerami, 2002):

- Loosely coupled
- Self-describing
- Standard-based
- Dynamic discoverable

The service is generally, implemented as a course-grained, discoverable software entity that exists as a single instance and interacts with applications and other services through a loosely coupled, message-based communication model. The service is a software entity that is available over the Internet or private (intranet) networks; uses a standardized messaging system; is not tied to any one operating system or programming language; is self-describing via a common grammar; and is discoverable via a simple find mechanism (Cerami, 2002).

Figure 1 shows 3 major roles in SOA: Service providers which implement their services and publish them on the internet/networks; Service requesters that utilize the available services to fulfill their requirement; and Service registries which are directories for services and service providers can publish their services by registering them in it and service requesters can search for appropriate service in it. SOA works based on a publish-find-bind model.

Web services are implemented using a collection of standards. These standards, when considered together, form what is widely referred to as the Web services protocol stack. Figure 2 shows the seven distinct layers of the Web services stack, which are grouped into three levels (Marks and Werrell, 2003). Each level indicates a level of maturity for the layers it contains. These levels represent a framework that can be used to evaluate the maturity of Web services standards today and can also be used to monitor how Web services standards progress over the medium to long term.

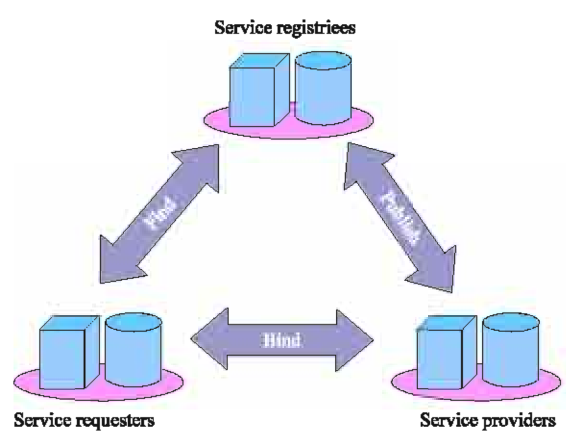

Fig. 1: Web services major roles

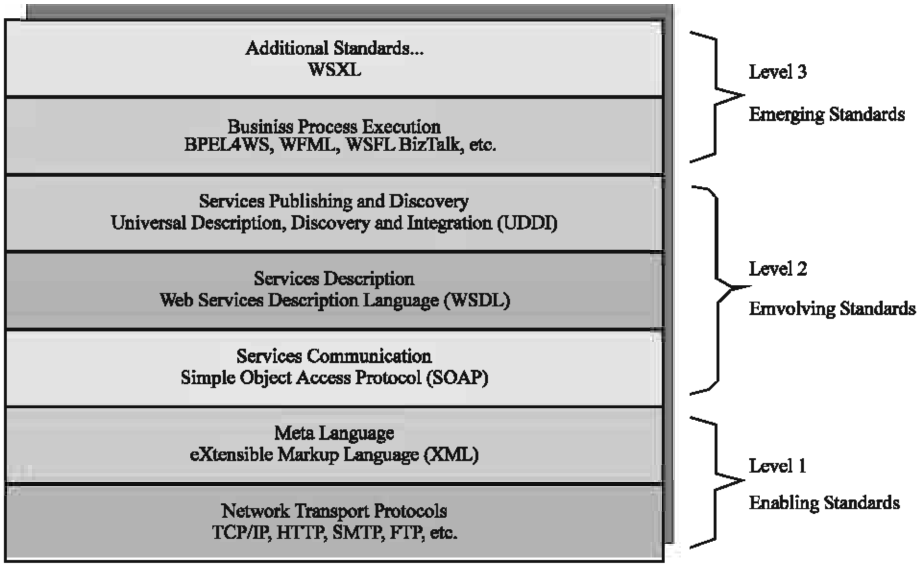

Fig. 2: Web service protocol stack (Marks and Werrell, 2003)

The enabling standards level contains network transport protocols and meta-language layers. The layers within the enabling standards level contain well-defined and accepted standards and protocols that are widely used to support mission-critical business application such as TCP/IP, HTTP and XML.

The evolving standards level contains layers for SOAP (Simple Object Access Protocol or Service-Oriented Access Protocol), WSDL (Web Service Definition Language) and UDDI (Universal Description, Discovery and Integration) which all together form the core standards for deployment of Web services. The services communication layer uses SOAP as a lightweight protocol for exchange of information in a decentralized, distributed computing environment. SOAP is an XML-based protocol that allows communication between multiple computer architectures, languages and operating systems. The service description layer is where WSDL is used as a common XML framework for describing a Web service. A WSDL document describes a set of messages in terms of what they contain and how they are exchanged. In addition to describing the message contents, WSDL defines where the Web service is available and what communication protocol is used to talk to the service. In other words, the WSDL file defines all the information required to invoke a Web service. The UDDI specification defines a data structure standard for describing organizational entities and the services they provide using XML (Service Publishing and Discovery Layer). UDDI provides high-level business information that complements the information contained in a WSDL document (Apte and Mehta, 2002).

The emerging standards level has the least well-defined capabilities. This level represents proposed standards that are promoted by individual vendors, have not yet gained broader endorsement or acceptance in the wider Web services community and have not been adopted as open standards for development by key standards bodies such as the W3C and OASIS.

There are many examples of implementation and utilization of Web services technologies such as: Wang *et al*. (2004), Oh and Fox (2007), Murakamia *et al*. (2007), Votisa *et al*. (2008) and Gyimesi (2008). In order to develop a Web service environment, there are two development lines with respect to service providers and service requesters. Service providers in order to implement and publish their own Web services should first develop the core functionality of the services. During the first step, service providers may develop the core functionality from scratch or they may connect to an existing legacy system or application. At the next step, they should develop a service wrapper for the core functionality. This usually could be a SOAP service wrapper. Such capabilities are provided in the most of software development platforms such as Microsoft Net framework of Microsoft and J2EE of Sun Microsystems. Service providers present a service description as a WSDL document afterward. Then, they need to deploy the services on some Web servers over the internet. Finally, service providers need to publish the existence and specifications of their new service. This usually means publishing data to a global UDDI directory or perhaps a private UDDI directory specific to their company.

In a web service environment, in order for service requesters to exploit the published Web services, those services relevant to the requirements should be first identified and discovered. So, this first step usually involves searching the UDDI for services. Once appropriate services have identified, the next step is to locate a service description as a WSDL document. Third, service requesters must create a client application. Finally, they should run the client applications to actually invoke the Web services.

General architecture of mobile GIS for emergency management: Variety of different architectures is possible when developing mobile Web services applications. Considering the requirements of emergency management, appropriate architecture of mobile GIS system for emergency management is suggested as Fig. 3. Figure 3 shows the block diagram architecture of the system.

The architecture is composed of 6 main components as follow:

- Hand-held device
- Wireless network
- Position determination components
- Gateway
- Internet
- Server

In the architecture of Fig. 3, hand-held devices are used by emergency workers to interact with the system. The hand-held device is a part of system which mobile GIS client application should be installed and run on it. The mobile GIS client application presents a front-end user interface that presents information to emergency workers and captures their input data. Position determination component refers to the component that determines the location of hand-held device in real time. The hand-held devices exploit the wireless network, the gateway and the internet to interact with mobile GIS Web services, which are installed and run on the server. The server is a computer which is used by the organization to deliver data and functionalities to the client applications. The server is connected to the internet. The internet is also connecting to the wireless network thorough the gateway which is a translator between these two types of network. Each of mentioned components is briefly described as follow:

Hand-held device: The hand-held devices are different from desktop or laptop computers. They have limited display monitor and data manipulation facilities such as mouse and keyboard. Mobile devices are two major categories: PDAs/Pocket PCS and smart phones. Smart phones are mobile phones with some extra computer-liked functions such as accessing and surfing the Web, data upload and download, etc. In contrast to smart phone, PDAs/Pocket PCS are small and restricted resources computers which use some light weight operating systems such as Microsoft Windows CE, Palm OS or Symbian's EPOC. Currently, these two types of hand-held devices are converging to each other as sometime it's hard to distinguish them from each other. A hand-held device in order to be useful for an emergency management mobile GIS system should have the ability to connect to a Web-based server through a wireless network.

Position determination components: Position determination components refer to the components that determine the location of a mobile devices in real time. Two approaches are used to compute a mobile user's position, which are hand-held based and network based. Some hybrid approaches are used as well, where measurement and computations are split between the terminal and the network (Pashtan, 2005). Three of the best methods which can provide emergency management with accurate positioning are the observed time difference of arrival (OTDOA), uplink time difference of arrival (U-TDOA) and Global Positioning System (GPS).

Server: Server is another component of a emergency management mobile GIS system. In fact involving organizations in emergency management should have

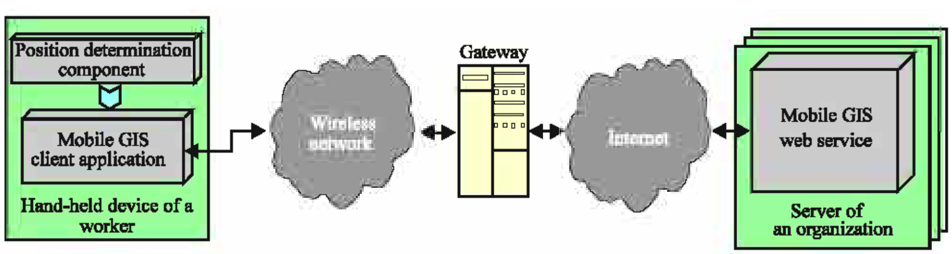

Fig. 3: Overall architecture of the prototype mobile GIS system for emergency management

some Web services to interact with mobile GIS client applications of emergency workers. These services work on server computers of the organizations.

Wireless Network: Wireless network is the underlying infrastructure of the mobile GIS system for emergency management. Thorough the wireless networks, the gateway and wired network, hand-held devices of emergency workers can communicate with servers.

Wireless networks have evolved across the time. According to Kupper (2005) that investigates different generations of wireless networks, 2.5, 3 and 4 G of wireless networks are the proper media to implement mobile GIS application for emergency management. However, it should be noted that mobile GIS works in a much more challenging wireless network environment than the wired network environment. At least, currently 2.5 and 3 G wireless networks which are available and operational have some restrictions including limited bandwidth, connection latency, unstable connectivity, etc.

Any wireless data network can be used as the infrastructure to access the Web. However, considering the low bandwidth of the wireless networks and small screen and user-interface of hand-held devices, the Web content should be mobilized. Nowadays, several standards and specification have developed for the wireless Web, including C-HTML (Compact HTML), Web Clipping, HDML (Hand-held Device Market Language), WAP (Wireless Application Protocol), XHTML, etc. that can be used for accessing Web thorough the wireless networks.

Internet: Internet is considered as another component of the mobile GIS system. It connects server computers of the organizations, involved in emergency management to the wireless network.

Gateway: The gateway is a piece of middleware that links the wireless network to the internet. It basically gives the wireless network the ability to access the internet contents. The gateway (e.g., Web gateway service or WAP gateway service) acts as an interpreter, which translates the internet content for mobile devices and vice versa.

Design and development of a prototype mobile GIS system for emergency management: As a part of the research, a prototype mobile GIS system was developed, using Web services technologies, in order to investigate integration of mobile GIS and Web services technologies. The prototype system was developed for emergency management.

From a software architecture point of view, the system has two main groups of software packages: mobile GIS client applications and mobile GIS Web services. It is obvious that organizations involved in emergency response, may develop some mobile GIS Web services and some mobile GIS client applications, based on their own requirements. Since, there are several applications required for emergency management, in this research, a prototype system based on a predefined scenario and application was developed, that satisfied fire organization. Based on the scenario, fire organization as one of the participating organizations in emergency response is going to present following functionalities to its firefighters in the operation area:

- The ability to view a map that contains buildings, road network and important buildings such as gas stations, hospitals, schools, etc.
- The ability to determine a firefighter's location and showing the location on the map to him/her.
- The ability to present up-to-date spatial data about the burning area to the firefighter in the field.
- The ability to update the database of fire organization after finishing an operation.
- The ability to use the municipality data about the closed roads.
- The ability to find optimum path from current location to the burning area, based on usable roads.

In order to develop a prototype system based on described functionalities the system was split into three distinct packages:

- Mobile GIS client application: Provides firefighter with an interface to interact with the system;
- Firefighting Web service: Is a web service, which is responsible for delivering information about burning area to firemen. Also, the service is responsible for receiving the information of firefighter about their finished operations and updating the database of fire organization by that information.
- Road network Web service: A web service, which is located at the municipality and is responsible to distribute the information about closed roads during an emergency. It also provides users with optimum path finding analysis.

In fact many challenges exist for developing the mentioned packages: (i) the Web services have to provide information and functionalities for mobile devices over the wireless network and (ii) the mobile GIS client application have to be run over a restricted resource hand-held device.

The first problem relates to the wireless network. As mentioned earlier, a variety of wireless networks are available now, each of which has unique characteristics that make it appropriate for specific applications. Meanwhile, mobile GIS system should address many issues with respect to wireless network characteristics including (Kupper, 2005):

- Network coverage: Mobile devices do not have network connectivity everywhere at all times.
- Latency: Wireless network connections are slow and some are slower than others. Few wireless connections achieve their advertised bandwidth and also there are still errors in connections that increase the latency.
- Power: Wireless networks consume power at a voracious rate. For every bit of information transmitted or received, an amount of power is consumed.
- High costs: Wireless usage rates are expensive. Other than fixed costs of an enterprise WLAN, wireless network access involves a service provider who may charge by the minute, by the amount of bandwidth used, or through a flat rate.

Considering the mentioned issues, most mobile applications today adhere to one of the two distinct possibilities (Chatterjee and Webber, 2004):

- Systems in which client applications require an always on network connectivity and
- Systems that function properly without the wireless network at all, but simply synchronize their data through a network-connected PC.

In general, both of these systems fail to satisfy the requirements of emergency worker in the defined scenario. Mobile GIS client applications, based only on offline synchronization capabilities, do not leverage wireless connectivity to provide real-time access to the most up-to-date information of the organizations. On the other hand, Mobile GIS client applications that heavily use the wireless network provides real-time access while decreasing application latency and increasing usage costs. Therefore, in this research an intermediate approach was adopted to develop the proper system for emergency management. This intermediate approach has following characteristic:

The mobile GIS client application is designed in the way that it can handle some of the requirements of the emergency workers, independent of Web service of fire organization. The client application has most of the important data about the operation area including buildings, road networks and important. The client application also is capable of showing the workers current position on the map using an intrinsic GPS receiver of the hand-held device. The application also has simple GIS functionalities such as zoom, pan, identify etc. The mobile client with these functionalities can provide emergency workers with some part of information in different situations without the need to a wireless connection to the firefighting or municipality services.

The mobile GIS client is capable of using firefighting Web service to retrieve the information about burning area and show this information on the map. Additionally, emergency workers can update the database of fire organization thorough the mobile GIS application and firefighting Web service. These functionalities are accessible only if the connection to wireless network is established and worked in a proper manner.

The mobile GIS client also is capable of using road network Web service of municipality to show the closed roads on the map. This functionality is accessible only if the connection to wireless network is established and worked in a proper manner as well.

The firefighting Web service uses transactions in order to update databases of fire organization. Therefore, if the connection between the server and the client is broken the database will not affect and the user should start over database updating; as there is no real means of saving information prior to a transaction completing.

Another problem for developing mobile GIS systems is that hand-held devices have limited resources dictated by their power and size constraints. Therefore, for developing the mobile GIS system, the simple functionalities are implemented at the mobile GIS client application and the more complex ones such as network analysis are implemented at the Web services.

Microsoft Net Framework and Sun Microsystems' Java 2 Enterprise Edition (J2EE) provide excellent platforms for developing Web service applications. In addition, Microsoft Net Compact Framework (CF) and Java 2 Micro Edition (J2ME) are two famous platforms for developing mobile applications. In this research, Microsoft Net Framework is used to develop the firefighting Web service and the road network Web service. Microsoft Net CF is also used to develop the mobile GIS client application. C# is exploited as programming language for developing the system.

The Microsoft Net Framework is an integral Microsoft Windows component for building and running the next generation of software applications and Extensible Markup Language (XML) Web services. The Net Framework consists of two main parts: the Common

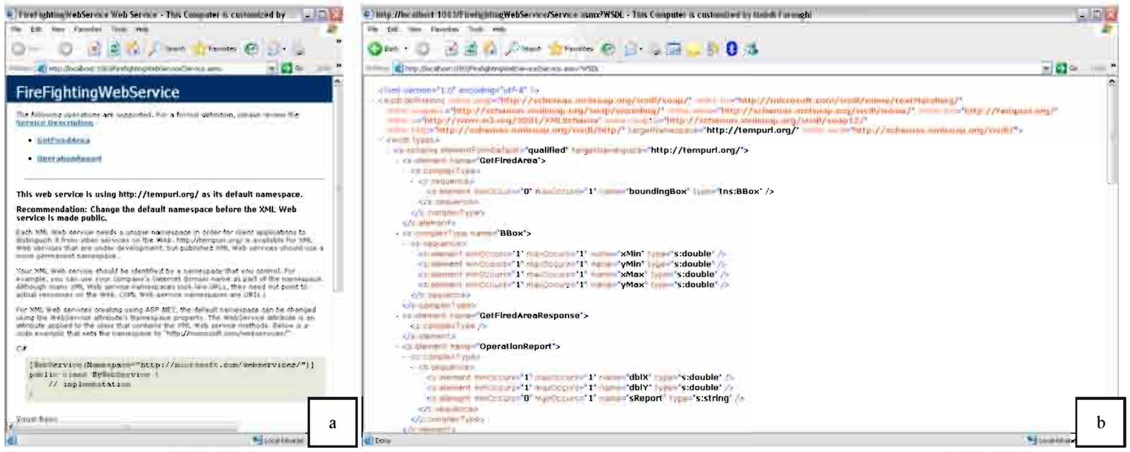

Fig. 4: Firefighting Web service. a: general information about the Web service generated by Net Framework; b: WSDL document of firefighting Web service

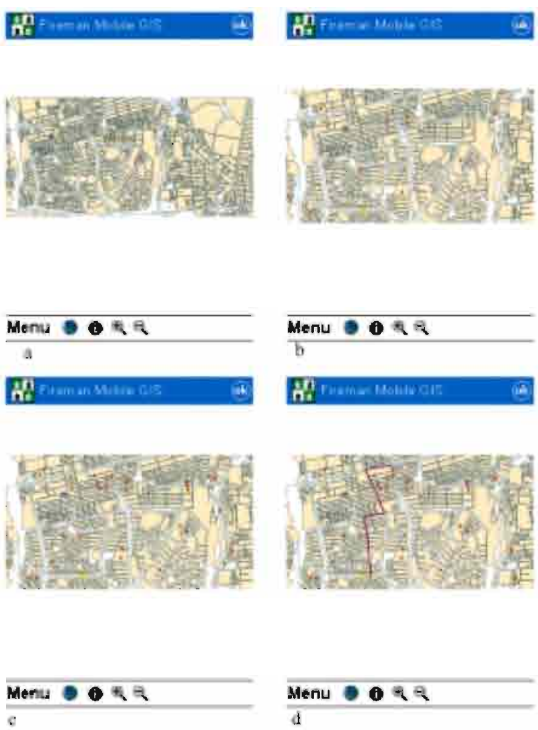

Fig. 5: Mobile GIS client application

Language Runtime (CLR) and a unified set of class libraries, including ASPNet for Web applications and Web services, Windows Forms for smart client applications and ADONet for loosely coupled data access. The Microsoft Net Compact Framework is the smart device development framework for Microsoft Net, bringing the world of managed code and XML Web services to devices. The Net Compact Framework is a rich subset of the Net Framework, thus providing the same benefits as the Net Framework. But the Net Compact Framework is designed specifically for resource-constrained devices, such as PDAs and smart mobile phones. The Net Compact Framework greatly simplifies the process of creating and deploying applications to mobile devices while also allowing the developer to take full advantage of the capabilities of the device.

Firefighting Web service presents Get Fired Area() and Operation Report() functions. The Get Fired Area() can be used by mobile GIS client application to retrieve the burning area of a specific zone. The zone is introduced to the Firefighting Web service by drawing a bounding box. The Get Fired Area() returns an XML file which contains spatial and non-spatial information about burning areas. The Operation Report() can be used to update the database of fire organization by mobile GIS client application. The Operation Report() returns a Boolean variable which indicate if the update transaction is finished successfully. Fig. 4a illustrates the required information about the firefighting Web service that is generated by Net Framework. Fig. 4b shows the WSDL document of the firefighting Web service.

The road network Web service presents Get Closed Points() and Optimum Path() functions. The Get Closed Points() gets the bounding box parameters, specified by the mobile GIS client and returns spatial and non-spatial information about closed point on the road network within the area. The Optimum Path() can be used for determining the optimum path based on the user inputs (start and end points on the network) and closed roads constrains. The Web service returns an XML file, which contains the spatial information about the optimum path.

The mobile GIS client application presents zoom, pan, identify and some other simple functionalities to firefighter. Figure 5a shows the simple map of the client application which contains building and network layer of an area in Tehran city (Between Shahrak Ghods and Vanak Sq.). Figure 5b shows a map of client application in which burning area is marked. The information about burning area is retrieved from firefighting Web service using SOAP messaging mechanism. Figure 5c shows the information about closed roads which is retrieved using Get Closed Point() function of road network Web service. Fig. 5d illustrates optimum path between the current location of firefighters and a burning area. As Fig. 5d shows, the optimum path is determined with respect to closed roads.

DISCUSSION

Mobile GIS can be exploited as a tool, which provides emergency workers with the ability to update required data for emergency management, particularly in response phase. Also, mobile GIS with the ability to access required spatial data can support in-field decision making of emergency worker.

Considering the specific characteristics of hand-held devices and wireless networks as well as requirements of emergency workers, in this study Web services was suggested as the appropriate technologies that can facilitate the development of suitable mobile GIS system for emergency management. Web services allow a part of mobile GIS system's business logic to run on servers, independent of the mobile device's computational resource limitations. Web services provide a variety of mobile devices with effectively access to the same functionality or business logic on remote servers. By implementing Web services on the servers of emergency management organizations, client applications on the hand-held devices of emergency workers can access the services of different organizations and therefore use different functionalities and data which are provided by other organizations.

In order to evaluate the usefulness of using Web services technologies for developing mobile GIS system for emergency management, a general architecture for mobile GIS system for emergency management was proposed and a prototype system based on the proposed architecture was developed. The prototype system was developed based on a defined scenario for firefighters in fire organization. Using the developed system, firefighters can access to some basic functionalities and data of the area. Additionally, they can access up-to-date data about burning area from the Web service of fire organization. They can access to the most up-to-date data about closed roads using the Web service of municipality. The Web service of municipality also provides firefighters and emergency workers of other organizations with the ability to find the shortest path to a destination with respect to the open and closed roads during the emergency.

The development of prototype system shows that using Web services technologies as underlying technologies for developing mobile GIS system for emergency management can effectively improve the quality and applicability of the system.

CONCLUSION

From the results of the case study, it can be concluded that using Web services technologies, new generations of mobile GIS systems can be developed in which irrespective of mobile devices specifications, applications at the server side can be designed and implemented. Mobile clients can also easily access the servers, data and functionalities and use them via just a specific mobile device interface. Utilizing Web services technologies are new in developing mobile GIS systems and therefore more research and experiments are needed to test these technologies. Also, in future investigations, integration of Web services technologies with recent activities of international standard organizations such as OGC in the context of geospatial Web services and Open LS should be considered for developing mobile GIS systems.

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