The Roles of Web Feature Service and Web Map Service in Real Time Geospatial Data Sharing for Time-Critical Applications

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Abstract

This research examines current open standards, protocols and technologies capable of resolving the issue of real time spatial data sharing for time-critical applications. Focusing on investigating the role of Web Feature Service (WFS) and Web Map Service (WMS), this research has developed a solution for the real time geospatial data sharing at feature level over the Web. Specifically, for instant remote data access and exchange, the OGC (OpenGIS Consortium) WFS is used to access and manipulate feature-level data through the Web, and the OGC WMS is used to deliver maps in a standard image format (SVG, PNG, JPEG, etc) from heterogeneous databases. A prototype has been implemented to query, extract, create, delete, update and map geographic features stored in web accessible OGC simple feature datastores for transportation emergency applications. The prototype results show that the OGC WFS and WMS play important roles in real time geospatial data sharing and exchange from heterogeneous sources at feature level for time-critical applications. WFS and WMS eliminate time-consuming data translation and facilitate reuse of existing geospatial data over the web.

1. Introduction

Many time-critical applications, such as emergency response, location-based services, real time traffic management and environmental monitoring, need instant access to diverse data to make quick decisions and take instantaneous actions. Imagine the following several scenarios: a terrorist is bombing an airport near a big city, and mass casualties require immediate medical response; a serious vehicle incident is happening on a highway, and police need to quickly find out the incident location for traffic management; a fire is occurring in a residential area, and fireman have to determine the environmental situation of the residential area right away to develop suitable rescue strategies; --- All of these scenarios require a rapid, effective and efficient response. Timely, accurate geographic information from easily accessible databases is fundamental to the quick response and emergency services dispatch. They are dependent upon access to complete and up-to-date geographic information from a variety of providers. But it is often difficult to obtain even basic geographic information promptly. The problem is not necessarily that the geographic information has not been captured. The problem is accessing and combinng geographic information from different sources in a timely manner. If the above situations involve more than one spatial database and these spatial databases are incompatible, it will be difficult or time-consuming to retrieve the needed geographic information. The issue of how to acquire data rapidly from different sources and integrate the heterogeneous spatial data for analysis becomes very important for the time-critical applications where decisions must be made quickly.

The development of World Wide Web (WWW) and the Internet provides a way to quickly access various geodatabases. The Internet has become an immensely valuable information resource and been widely recognized recently as an important means to quickly disseminate information and acquire spatial data from diverse sources (Crowder 1996; Greenwood 1997; Green and Massie 1997; Plewe 1997; Rohrer and Swing 1997; Craig 1998; David et al. 1998; Doyle et al. 1998; Carver 2001; Zhu 2001; Pundt and Bishr 2002; Peng and Tsou 2003). Many commercial Internet GIS programs, such as ESRI's MapObject IMS and ArcIMS, AutoDesk's

MapGuide, Intergraph's Geomedia WebMap, MapInfo's MapXtreme, GE SmallWorld's Internet Application Server and ER Mapper's Image Web Server, are developed to offer better tools for data sharing over the web (Zhang et al. 2003). With these Internet GIS programs the Internet can be used to download data for viewing, analysis or manipulation (Peng and Zhang 2004a; Peng and Zhang 2004b; Zhang et al. 2003). The WWW offers the benefits of flexibility, ubiquity, and reduced costs and risks of obsolescence and isolation (Anderson and Moreno 2003). The WWW has more significant influence on time-critical applications, which usually require integrating data quickly from various sources and downloading data online instead of delivering data on CD or other means so as to greatly reduce data-collection time.

Although the development of the WWW and many of the aforementioned Internet GIS programs provide proprietary ways to allow users to quickly access, display and query spatial data over the web (Plewe 1997; Green 1997; Stand, 1997; Su et al. 2000; Kowal 2002), issues still exist that prevent decision makers from quickly integrating the heterogeneous spatial data. Two issues obviously block time-critical applications to quickly acquire and integrate spatial data over the web: One is the heterogeneity of existing GIS systems and the other is the file-level data sharing systems over the web.

Currently, several commercial desktop GIS software systems dominate the geographical information (GI) industry, such as ESRI ArcInfo and ArcView, Smallworld GIS, Intergraph GeoMedia, MapInfo professional, Clark Lab Idrisi, etc. It is unlikely that all GIS applications will use the same software (Tarnoff 1998). Different vendors have their own proprietary software designs, data models and database storage structures. Thus, geographical databases based on these designs cannot communicate without data conversion. In order to exchange information and share computational geo-database resources among heterogeneous systems, conversion tools have to be developed to transfer data from one format into another. Two problems arise in sharing heterogeneous spatial data through data conversion: (1) Data become inaccurate after data conversion. This is crucial because accurate and up-to-date information is a basic and essential requirement of time-critical applications. Inaccurate information after data conversion may lead to wrong decisions. (2) A lot of time has to be wasted on data conversion. Not to mention that a lot of time and money have to be spent on developing data conversion tools. Thus, while time-critical applications require a rapid, effective and efficient response, data conversion will delay the response. Although commercial Internet GIS programs offer better tools for fast data sharing over the web, like the desktop GIS software systems these Internet GIS programs also have the problems of proprietary software designs, data models and database storage structures. Thus, mapping and geoprocessing resources distributed over the web by these Internet GIS programs cannot be shared and interoperated. It is difficult for time-critical applications to share the geospatial data in real time over the web without data conversion because of the heterogeneity of existing desktop and internet GIS systems. Data sharing facilitated by the advances of network technologies is thus hampered by the incompatibility of the variety of data models and formats used at different sites (Choicki 1999; Zhu 2001). The importance of building true interoperable distributed geographic information systems to share data is becoming imperative (Doyle 1997; OGC 1998; Ackland 1999; Bennett 2000; Zhu 2001; Zhang et al. 2003). Data interoperability is especially important for time-critical applications in terms of real-time data sharing and decision making.

The second important issue blocking time-critical applications from quickly acquisition and integration of spatial data over the web is that most prior research and professional practices have been focused on web data sharing at the file-level; to share and exchange geospatial information users must request whole datasets or data files from different data sources via online downloading (Peng 2005). There are several problems with the file-level data sharing systems (Peng 2005): First, file-level data sharing usually requires data integration such as data conflation due to differences in semantics, data model and data format. But data conflation is a tedious, subjective, and often error-prone process for consolidating differences between two or more data files. Second, data updated from one source at the file-level cannot be automatically propagated to other related data or applications. Data sharing at the file-level usually causes latency of data updates. This causes problems to time-critical applications that need real-time data access to the most up-to-date information. Third, file-level data sharing makes it difficult to provide feature-level data search, access, and exchange in real time over the web. Some time-critical applications must download a whole data file for analysis even they need only several features of the file instead of the whole file or have interest in a small area of the file. This will largely increase the time of acquiring and analyzing data and affect the speed of decision-making. Therefore, although file-level data sharing and data integration are useful, they are insufficient to meet the demand of time-critical applications that need real-time access and exchange of the most up-to-date feature-level data.

The use of open standards, protocols and technologies offers the potential to overcome the aforementioned interoperability and file-level data sharing problems and therefore facilitate feature-level spatial data sharing over the web in real time. Efforts to develop standards for spatial data sharing and exchange over the web have been under way for several years (David et al. 1998; Peng and Zhang 2003a; Zhang et al. 2003). There are active interests from researchers, practitioners, and vendors in exploiting open standards for sharing spatial data over the web and realizing the goal of data interoperability (Herring 1999; Kottman 1999; Shekhar et al. 2001; Zhu 2001; Smith, et al. 2002; Anderson and Moreno 2003; Peng and Zhang 2003a; Zhang et al. 2003; Evans 2004; Di 2004; Probst et al. 2004; Peng 2005). However, little has been published to investigate the combined use of open standards of the OGC Web Map Service (WMS) specification and the Web Feature Service (WFS) specification in attempting to solve data interoperability and file-level data sharing issues.

This study aims to examine current open standards, protocols and technologies capable of resolving the two issues of data interoperability and file-level data sharing to achieve real time spatial data sharing over the web for time-critical applications. Focusing on investigating the role of OGC WFS and WMS, this research has developed a solution for real time web sharing of geospatial data from heterogeneous sources at feature-level for time-critical applications. A prototype has been implemented to query, extract, create, delete, update and map geographic features stored in web-accessible OGC simple feature datastores for transportation emergency applications. It proposes legacy data sharing among various agencies by providing web services.

2. A Framework for Real Time Geospatial Data Sharing

The solution of this study to real-time feature-level geospatial data sharing over the web for time-critical applications uses OGC web services. Figure 1 shows the framework of this solution. For instant remote data access and exchange, the OGC WFS is used to access and manipulate feature-level data through the web and the OGC WMS is used to deliver maps in a standard image format (SVG, PNG, JPEG, etc) from heterogeneous databases. This approach ensures basic conditions for interoperability by using standard exchange mechanism between diverse spatial data sources connected over the web.

The main advantages of this approach are interoperability and feature-level data sharing. Using this approach, time-critical applications and organizations can deploy spatial data and geo-processing capabilities over the web in real time so that mapping and geoprocessing resources distributed over the web can be shared and integrated and information from diverse sources with incompatible data formats can work together transparently across the web. Many existing proprietary legacy databases can be used and shared based on this approach. It can reduce investments to different applications programs and organizations by avoiding overlapping or repeatedly creating same data. Because this approach allows users to access data at the feature level from distributed sources, it can largely reduce the time spent on data acquiring and integrating by time-critical applications, which may only need a few of features in a small area to make decision. Further, because WFS uses GML to represent features and the XLink in GML can link or associate spatial features from different sources, the update in one data source can be immediately reflected or propagated in other related data sources or applications.

The solution is based on some open standards and has the potential to be a way of getting to data interoperability. The detailed related knowledge for this solution is discussed in the following sections.

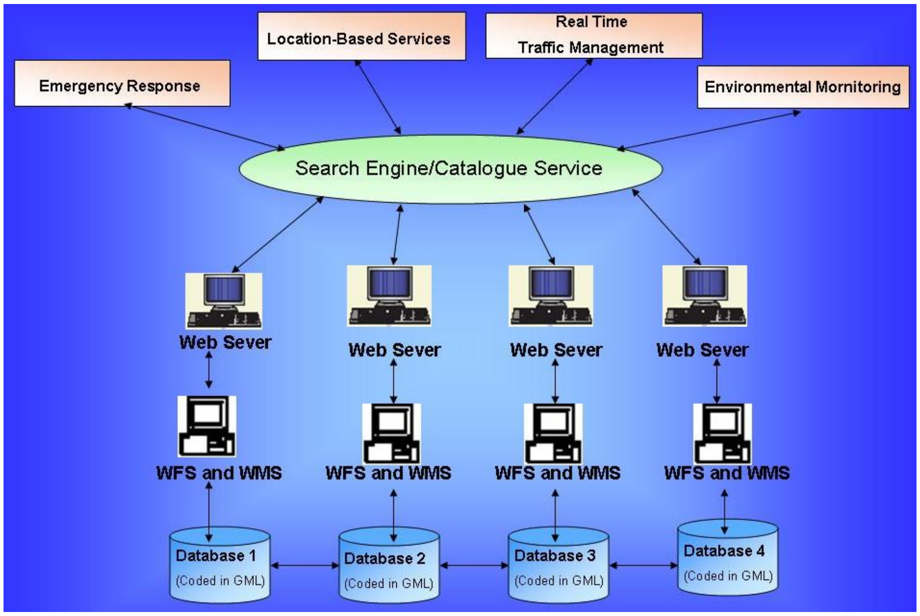

Figure 1. A framework of real time geospatial data sharing for time-critical applications

2.1 Interoperability and Open Standards

Interoperability plays an important role in time-critical applications. Time-critical applications will be seriously hampered without the real-time ability to quickly visualize patterns of activity and understand the multilayered, location-based context of emergency situations. Interoperability is necessary for time-critical applications to fully exploit huge existing geographic information and make a rapid, effective and efficient response. Within the context of OpenGIS Consortium Inc. (OGC), interoperability refers to “software components operating reciprocally to overcome tedious batch conversion tasks, import/export obstacles, and distributed resource access barriers imposed by heterogeneous processing environments and heterogeneous data” (McKee and Buehler 1998; Brodeur et al. 2003). Because many systems are based on closed or proprietary interfaces it is difficult to find a good means to realize interoperability (Lowe 2002). Standardization is seen as a way to achieve interoperability and a solution to solve problems arising from syntactic, structural, and semantic heterogeneity between data sources (Brodeur et al. 2003; Zhang et al. 2003). Currently many researchers agree that adopting open standards is an important approach to realize interoperable geographic information systems and share spatial information in real time over the web (Anderson and Moreno 2003; Peng and Zhang 2004a; Zhang et al. 2003; Evans 2004; Di 2004; Probst et al. 2004; Peng 2005).

Open standards are specifications developed and/or approved under a published consistent process and fair environment. Many organizations such as World Wide Web Consortium (W3C), ISO/TC 211 and OGC, are dedicated to developing and promoting the adoption of open standards to achieve interoperability and reduce data duplication. W3C provides the information technology baseline standards, ISO/TC 211 develops abstract but detailed baseline standards, and OGC focuses on the implementation-oriented standards that fit into the abstract frame set by the ISO/TC211 (Kresse 2004).

Now many vendors and open source projects are adopting the open standards developed by W3C, ISO/TC 211 and OGC. The rapid development and adoption of the open standards has provided a stable foundation for making GIS interoperable. The recent development in web services further makes the construction of interoperable GIS possible. With web services it becomes possible for time-critical applications to acquire and integrate spatial data from heterogeneous sources in real time over the web.

2.2 Web Services and OGC Web Services

With demands for geospatial interoperability and adoption of the open standards, GIS are evolving from a traditional client-server architecture to a web service architecture. In the web service architecture the web is used for delivering not only data but also geo-processing functionality that can be wrapped in interoperable web services (Anderson and Moreno 2003). The emergence of web services provides the interoperable capability of cross-platform and cross-language in the distributed net environment (Jia et al. 2004). In fact, web service is a kind of self-contained and self-described software components that can be discovered and invoked by other software components through the web. In the web services view, every different system or component offers some services for others, and every system does its job by just calling or combining suitable services over Internet (Cömert 2004).

Within the broader context of web services, OGC web services deal with geographic information on the Internet. OGC web services provide a vendor-neutral interoperable framework for web-based discovery, access, integration, analysis and visualization of multiple online geospatial data sources. OGC web services represent an evolutionary, standards-based framework that enables seamless integration of a variety of online geoprocessing and location services [OGC Interoperability Program White Paper 2001]. Examples of OGC web service standards include WFS, WMS, Web Coverage Service (WCS), Catalogue Service (CS) (Figure 2). WFS is an OpenGIS implementation specification (OGC document 02-058 2002) that allows a client to retrieve, query, and manipulate feature-level geospatial data encoded in GML from multiple sources. The OGC WMS specification is capable of creating and displaying maps that come simultaneously from multiple heterogeneous sources in a standard image format (OGC document 04-024 2004). WCS provides access potentially detailed and rich sets of geospatial information, in forms that are useful for client-side rendering multi-valued coverages, and input into scientific models and other clients (OGC document 03-065r6 2003). CS provides catalogues for OGC web services and supports the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects. (OGC document 04-021r2 2004). With the OGC web services technologies, users can 'wrap' existing heterogeneous data into a web service and enable many potential clients to use the service (Figure 3).

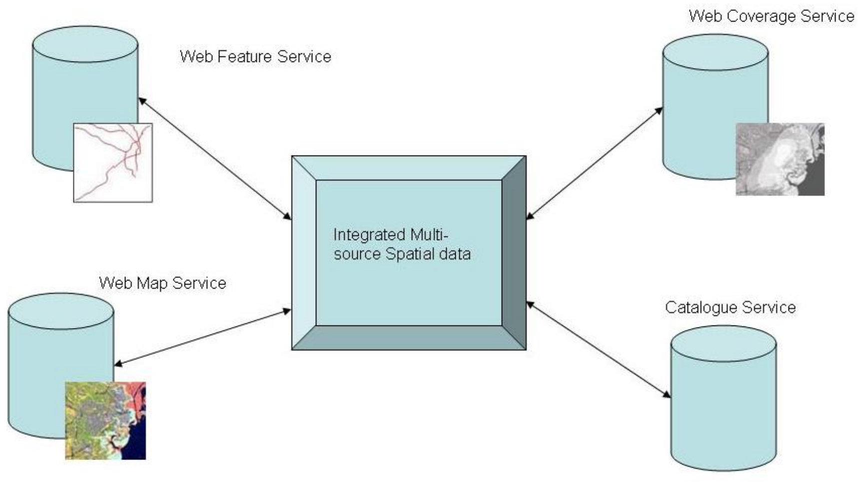

Figure 2. Illustrating OGC web services

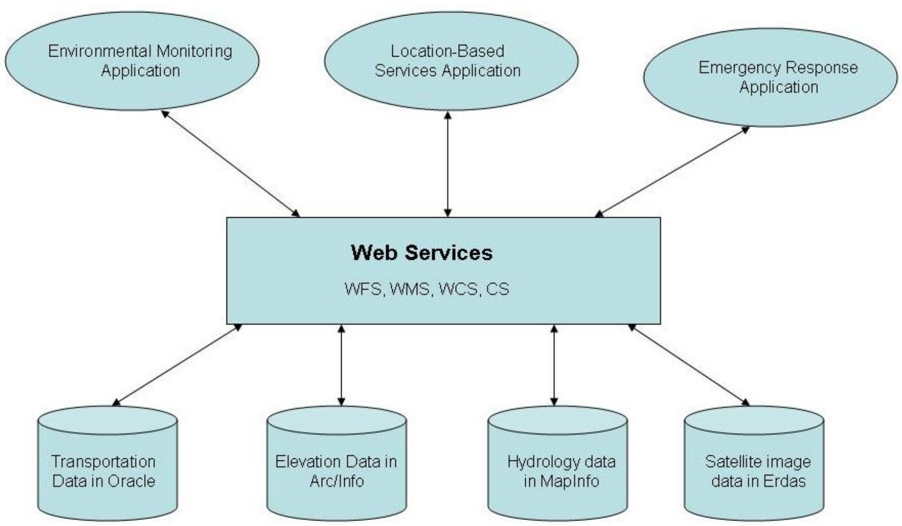

Figure 3. Sharing heterogeneous spatial data through web services

2.2.1Web Feature Service

WFS is an OGC specification for describing data manipulation operations at the feature level on OpenGIS simple features (e.g., points, lines, and polygons) (OGC document 02-058 2002). WFS is written in XML and uses GML to represent features. The database (or datastore in OGC's term) used to store geographic features can be in any format. But it should be opaque to client applications. Users can send a request in XML to a WFS server; WFS, which connects with various formats of databases, processes the requests and sends the response in XML back to users. WFS uses a subset of XPath expressions for referencing properties and uses HTTP as the distributed computing platform.

To support transaction and query processing at feature level on datastores, five operations are defined in OGC WFS: *GetCapabilities; DescribeFeatureType; GetFeature; Transaction and LockFeature*. *GetCapabilities* describes the capabilities of the WFS server, such as which feature types it can service and what operations are supported on each feature type; *DescribeFeatureType* informs the structure of any feature type upon a request; *GetFeature* retrieves feature instances; *LockFeature* processes a lock request on one or more instances of a feature type for the duration of a transaction; *Transaction* services transaction requests like *create*, *update, and delete* operations on features.

With transaction operations, WFS can create, delete, and update features over the web in real time. This capability provides the potential to conduct spatial analysis, modeling, and other operations on the web based on spontaneous access to distributed geospatial data at the feature level. The following is a simple example of creating an instance of feature type BUILDING by using the *create* capability:

```
<?xml version="1.0"?>
<wfs:Transaction
version="1.0.0"
service="WFS"
xmlns="http://www.uww.edu/zcr"
xmlns:gml="http://www.opengis.net/gml"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:wfs="http://www.opengis.net/wfs"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.uww.edu/zcr
            http://www.uww.edu/wfs/cwwfs.cgi?
     request=describefeaturetype&amp;typename=BUILDING.xsd
            http://www.opengis.net/wfs ../wfs/1.0.0/WFS-transaction.xsd">
<wfs:Insert>
<BUILDING>
<WKB_GEOM>
          <gml:Polygon gid="1"
              srsName="http://www.opengis.net/gml/srs/epsg.xml#4326">
            <gml:outerBoundaryIs>
              <gml:LinearRing>
                  <gml:coordinates>-38.76 , 17.26, -37.45, 18.38 ...</gml:coordinates>
              </gml:LinearRing>
            </gml:outerBoundaryIs>
        </gml:Polygon>
     </WKB_GEOM>
     <ID>150</ID>
     <NAME>HYER</NAME>
     <COLOR>gray</COLOR>
    <AGE>25</AGE>
  </BUILDING>
</wfs:Insert>
</wfs:Transaction>
```

With the five operations, WFS can query and extract data at the feature level. It is this feature-level data manipulation that allows users to download only the interested feature data instead of the whole dataset and makes WFS valuable for time-critical applications, because it can greatly reduce the time of data access and integration and significantly improve the speed of decision-making. The following is an example that a WFS fetches a specific instance of the feature type PERSON identified by the feature identifier “Z123”:

```
<?xml version="1.0" ?>
```

```
<wfs:GetFeature
service="WFS"
version="1.0.0"
outputFormat="GML2"
xmlns:zcr="http://www.uww.edu/zcr"
xmlns:wfs="http://www.opengis.net/wfs"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/wfs ../wfs/1.0.0/WFS-basic.xsd">
    <wfs:Query typeName="zcr: PERSON">
        <ogc:Filter>
            <ogc:FeatureId fid="Z123"/>
        </ogc:Filter>
    </wfs:Query>
    </wfs:GetFeature>
```

Users also can select several features that are located in a small area of interest. The following is an example that a user gets the BUILDING feature located in the small area [-55.345, 46.657, -54.278, 47.265] in a big city:

```
<?xml version="1.0" ?>
<GetFeature
version="1.0.0"
service="WFS"
handle="Query01"
xmlns="http://www.opengis.net/wfs"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:gml="http://www.opengis.net/gml"
xmlns:zcr="http://www.uww.edu/zcr"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/wfs ../wfs/1.0.0/WFS-basic.xsd">
<Query typeName="zcr:BUILDING">
        <ogc:Filter>
            <gml:Box>
                    <gml:coordinates>-55.345, 46.657, -54.278, 47.265</gml:coordinates>
            </gml:Box>
        </ogc:Filter>
    </Query>
</GetFeature>
```

Furthermore, because WFS uses GML to represent features, it can associate two or more database resources by the Extensible Linking Language (XLink) technology in GML and point to specific spatial feature elements by the XML Pointer Language (XPointer). By associating two or more database resources, it is possible that the data updated at one source can be automatically updated in other closely associated data sources. In the following example, the city data is associated with its components of street, building and lake data by using XLink.

```
<gml:FeatureCollection>
   <gml:featureMember xlink:type="simple"
       xlink:href="http://www.uww.edu/zcr/street.xml"/>
    <gml:featureMember xlink:type="simple"
       xlink:href="http://www.uww.edu/zcr/building.xml "/>
    <gml:featureMember xlink:type="simple"
       xlink:href="http://www.uww.edu/zcr/lakes "/>
</gml:FeatureCollection>
```

Through the XLink function, when the transportation department in a city updates its street data, the related city data will also be automatically updated. This can avoid latency of data update caused by data sharing at the file level. Within a file-level data sharing system, data updated in one department usually cannot be made available immediately to other departments because data file delivery or downloading is infrequent. But through the XLink technology, WFS makes automatic and immediate data update become possible over the web.

2.2.2 Web Map Service

The OGC WMS is based on the OGC WMS specifications and ISO/TC211 specification (ISO 19128). It is capable of creating and displaying maps that come simultaneously from multiple sources, which that may be remote and heterogeneous in standard image formats such as Scalable Vector Graphics (SVG), Portable Network Graphics (PNG), Graphics Interchange Format (GIF) or Joint Photographics Expert Group (JPEG) (OGC document 04-024 2004). It provides three operation protocols: *GetCapabilities*; *GetMap and GetFeatureInfo*. *GetCapabilities* allows a client to instruct a server to expose its mapping content and processing capabilities and return service-level metadata; *GetMap* enables a client to instruct multiple servers to independently craft "map layers" that have identical spatial reference system, size, scale, and pixel geometry. The client can then display these overlays in a specified order and transparency such that the information from several sources is rendered for immediate human understanding and use; *GetFeatureInfo* enables a user to click on a pixel to inquire about the schema and metadata values of the feature(s) represented there (For a detailed discussion, please see OGC Web Map Service Specification at http://www.opengis.org/specs/?page=specs).

Through WMS, users can submit requests in the form of Uniform Resource Locators (URLs) by using a standard web browser. For example, users can use the following URLs to instruct the server to expose its mapping content and processing capabilities: http://172.16.1.33:8080/geoserver/wms?request=GetCapabilities. Unlike WFS allowing users to access specific feature datastores in GML, which is only concerned with the representation of geographic data content and does not specify how data should be presented, WMS permits users to display spatial data and produce maps. A SLD (Styled Layer Descriptor)-enabled WMS can allow users to map feature data from a WFS using user-defined symbols. WMS employs open standard HTTP as the distributed computing platform and uses open standard XML to convey service metadata, descriptions of error conditions, or information about particular features shown on a map. WMS can access WFS feature-level query results by piping them to a portrayal engine for dynamic map styling. WMS itself also provides parameters and functions to allow users to query and integrate data in a small area from diverse sources. For time-critical applications, on the one hand WMS can be used directly to integrate data from multiple heterogeneous sources in standard image formats for the display purpose; on the other hand, it can map the feature-level data acquired from a WFS server, which communicates with users in the GML format.

3. A Prototype Implementation

A prototype for real time transportation management application has been implemented based on the framework (Figure 1) using the aforementioned OGC web feature services and web map services. The main purpose of this prototype is to develop an interoperable data sharing system on the Internet to allow transportation agencies to access the most up-to-date information for real time traffic management. While traditionally users must download the whole data files over the web even they only use a small part of the datasets for their tasks, this data sharing system allows users to download and integrate feature-level data in a small area. Figure 4 illustrates the architecture of the implemented prototype.

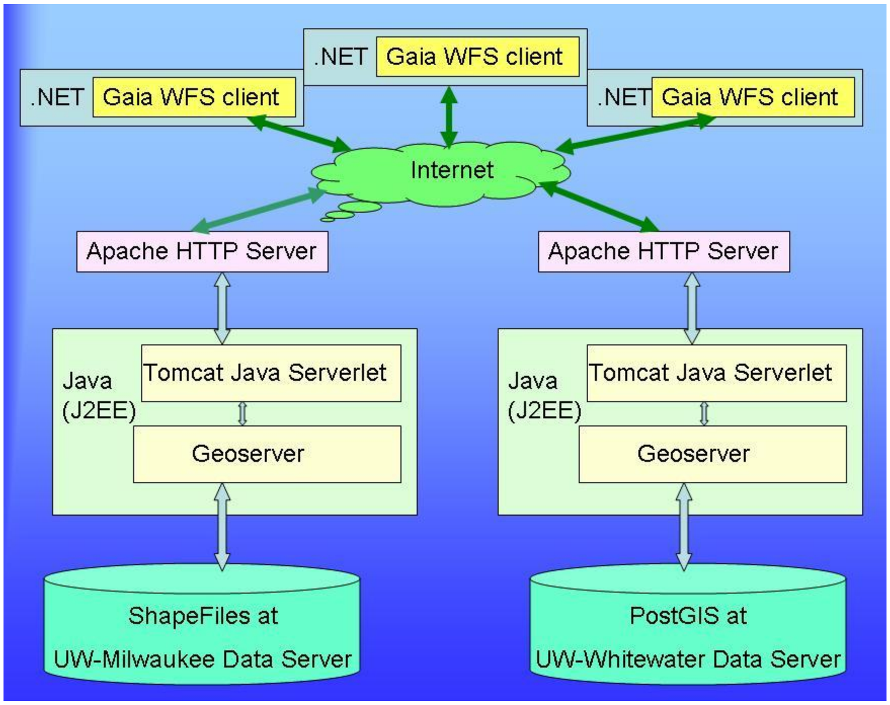

Figure 4. Architecture of the implemented prototype

The open source software Geoserver (version 1.2.3) (http://geoserver.sourceforge.net/html/index.php) is installed to provide web feature services and web map services. Geoserver is developed with a full implementation of the OGC WFS and WMS specifications. Java 2 Platform, Enterprise Edition (J2EE) is used as the supporting environment for GeoServer. Apache HTTP server is employed as a web server. Tomcat is chosen as a java servlet container, which provides web developers with a simple consistent mechanism for extending the functionality of a web server and for accessing existing web applications. Gaia (version 1.1.04) software (http://www.thecarbonproject.com/products/gaia.html) is served as a WFS and WMS client to provide graphic interface for users to use web feature services and web map services. Gaia is an OGC compliant client and it is capable of handling raster maps and GML features from any WFS or WMS server. It is developed based on Microsoft .Net framework version 1.1 environment. Through Gaia, users can view spatial data from multiple sources and it also provides some basic GIS display functions such as *zoom in*, *zoom out*, *pan* and *switch* or *restack* different data layers. All of the software tools used in this prototype and their supporting environments are open-source, and can be downloaded for free.

Two WFS servers and two WMS servers are built in this implemented prototype. One WFS server and WMS server are located in a computer at the Department of Urban Planning, University of Wisconsin-Milwaukee (http://129.89.71.203:8080/geoserver/wfs? and http://129.89.71.203:8080/geoserver/wms?). The other WFS server and WMS server are deployed in a computer at the Department of Geography and Geology, University of Wisconsin-Whitewater (http://140.146.96.217:8080/geoserver/wfs? and http://140.146.96.217:8080/geoserver/wms?). The original data in the UW-Milwaukee computer are ESRI Shapefiles. The original data in the UW-Whitewater computer are stored in an open source PostGIS database. These two different data formats are chosen just for test purpose.

The data used come from the Waukesha Transit Trip Planning Project, an online bus trip-planning website for the City of Waukesha, Wisconsin, which is available at http://metro-trip.ci.waukesha.wi.us/waukesha/. The data of bus routes, streets and landmarks/facilities are located in the UW-Milwaukee computer. The data of bus stops are located in the UW-Whitewater computer.

3.1 Some Experimental results

Through the implemented prototype, data providers can publish different proprietary format data, such as Shapefiles and PostGIS, straight to the web by using WFS and WMS. Users can directly access these heterogeneous data sources without having to know specifically who might provide the data they want and what format the data is. They need not contact data providers in email or mail to get some files and convert the files into a format they need to start the task. Figure 5 displays bus routes data (original Shapefile format) extracting from the WFS server in UW-Milwaukee and bus stops data (original data in PostGIS) acquiring from the WFS server in UW-Whitewater together.

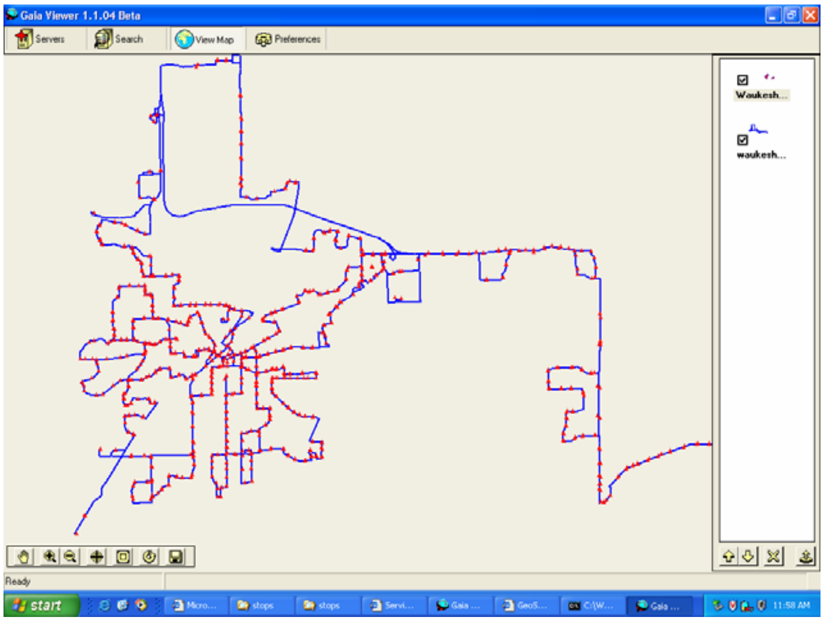

Figure 5. Integrate routes data and bus stops data together from two heterogeneous data sources through the web.

In the implemented prototype, users can search for and download feature-level spatial data over the web in the real time. Users can query, extract, create, delete, update and map geographic features using WFS. Figure 6 is an example of querying one route segment feature in GML format over the web by WFS. Figure 7 is its according SVG graphic map displayed by WMS. Figure 8 illustrates how to query and integrate several features in a small area from both UWM and UWW servers.

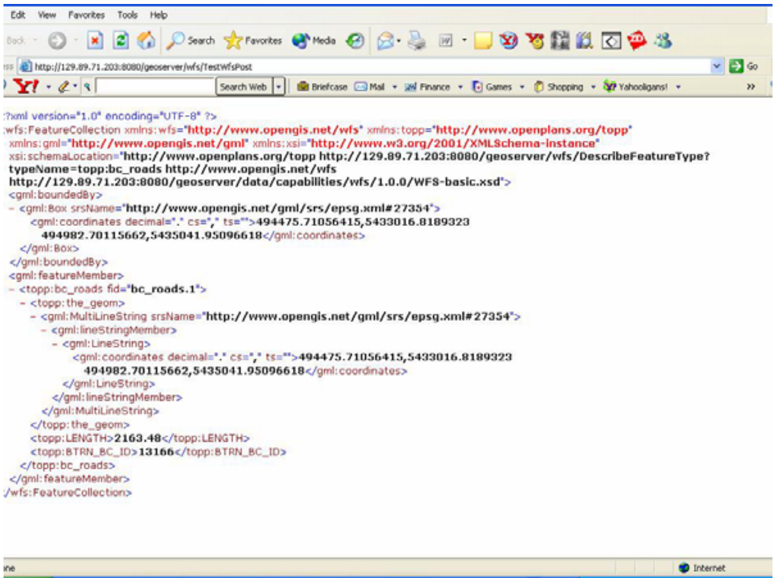

Figure 6. Query one route segment in GML format over the Web

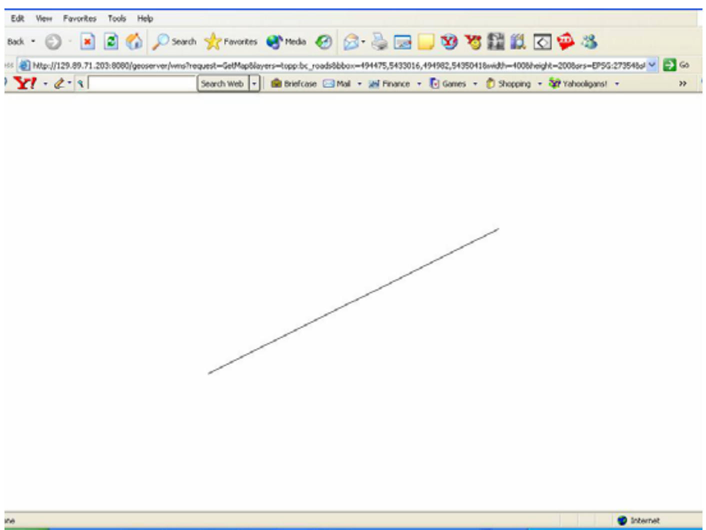

Figure 7. The according SVG graphic map of the queried one route segment feature

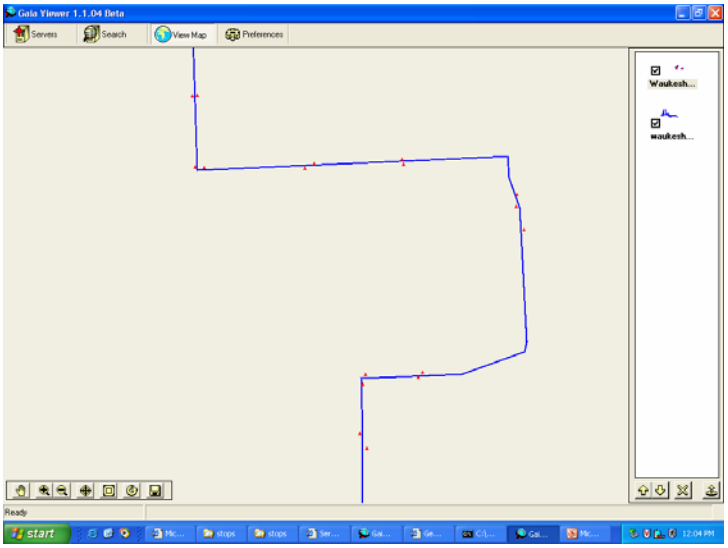

Figure 8. Query and integrate several features from both WFS servers

4. Discussions

In order to reduce duplication of efforts among agencies, make geographic data more accessible to the public and increase the benefits of using available data, a framework of real time geospatial data sharing for time-critical applications is proposed by using OGC WFS and WMS. From the results of an implemented prototype based on the proposed framework, it is found that the approach has many advantages in facilitating time-critical applications:

First, it supports multiple time-critical applications. With the proposed framework, heterogeneous information can be accessed by different programs on different platforms via the internet. An application or program can use its preferred software and data types. An organization is not locked into a single vendor because of a previous investment. The organization is also not restricted to use the same data format.

Second, the approach allows spontaneous access to a feature in different datasets that are located in different data servers, and permits users to exchange data at feature level, while current commercial Internet GIS programs cannot. This provides a foundation for time-critical applications to instantly access diverse remote data over the web. Sharing and exchanging data at feature level in real time are especially important for time-critical applications, because they can largely reduce the time spending on data-acquiring processes and offer an emergency response team the ability to directly search for and access all feature-level information in the distributed internet environment.

Third, this approach can make different time-critical applications access various formats of spatial data and services and therefore eliminate the time wasted on converting data. It give users the capability to easily and dynamically publish and exchange data in an open, non-proprietary industry-standard format on the web, thus maximizing the re-use of geospatial data, eliminating time-consuming data conversion and reducing associated costs. It bridges the gaps among different data sources, vendors, databases and formats. Databases based on this framework could be easily re-used in the future. Data developed at a local scale could be readily integrated into those at a regional or global scale in the future, and data developed for one application could be readily integrated with data developed for another application. Furthermore, this framework reduces users' requirements for local data storage, and creates new opportunities for businesses that maintain online sources of data and information.

Fourth, this approach can allow users and key decision makers to quickly access the most accurate and up-to-date geospatial data over the web. Feature changes can be updated from one source to another without human intervention in the framework. This framework has the potential to link geospatial data in a distributed environment. That is, geospatial data at one location can be dynamically related to data elements at another location, and an update at one database can be automatically reflected in another related database, an ultimate goal of data sharing.

Finally, this approach can improve communication among different departments and reduce the planning cycles for different departments to develop new programs. Spatial information created in one department can be available to others immediately, and all independent systems can communicate quickly and effectively, regardless of data formats.

While this approach has the aforementioned advantages, it still has some limitations to be resolved such as semantic interoperability issues. The proposed approach can only lead to technical interoperability by adopting OGC web services. Different data producers and service providers may develop different data schemas and the same basic feature types may be named and described differently. For example, "house" and "building" may refer to the same feature type but are called differently by different organizations. This kind of semantic heterogeneity problems is not the focus of this paper. Semantic issue may be the most difficult one and has been discussed in recent literature (Egenhofer 1999; Smith and Mark 2001; Cruz et al. 2004). Many researches have been conducted to find a way to resolve semantic issue in GIS such as using ontology technologies (Bayer and Onsrud 2004; Hong 2004). But geospatial semantic web technologies are still in their initial research stage. How to automatically convert geospatial data to user-specific geospatial information and knowledge by using a service-oriented architecture is one of major research issues in geospatial semantic web. Some other issues, such as where users can find OGC web services, scalability, and security, also need to be further investigated.

5. Conclusions

This research examines current open standards, protocols and technologies capable of resolving the issue of data integration and dissemination. A solution is proposed for searching, accessing, extracting and visualizing network spatial data at feature level in real time over the web from distributed sources with different GIS formats. A prototype system has been implemented as a test-bed for the proposed solution. The results of the prototype shows that the OGC WFS and WMS may play important roles in real time geospatial data sharing and exchange from heterogeneous sources at feature level for time-critical applications. They can allow users to download only interested features of a data file instead of the whole data file, disseminate and update spatial data in a timely, accurate manner. They also can eliminate time-consuming data translation, reduce integration requirements and associated costs, and facilitate reuse of existing geospatial data over the web. With WFS and WMS, individual organizations can leverage disparate data from multiple sources, regardless of vendor brands, formats, or platforms, and thus realize complete data sharing. People in different departments may work together more efficiently, making better decisions and avoiding duplication of effort.

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