Spat. Inf. Res. (2017) 25:89–97
DOI 10.1007/s41324-016-0080-4

An integrated architectural framework for geoprocessing in cloud environment

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Received: 3 October 2016 / Revised: 27 December 2016 / Accepted: 28 December 2016 / Published online: 5 January 2017

Abstract Spatial data infrastructure had ensured the availability of geospatial data over the local and global boundaries to be used in more flexible and efficient manner. With the enhancement in web service technologies the need of geoprocessing the geospatial data from various heterogeneous sources over the web, to produce valuable information is of great interest among research community. Towards this implementation of geoprocessing web, open geospatial consortium (OGC) has provided several web processing service standards for handling the geoprocess over the web. Most of the current existing geoprocessing web platforms inherit the capabilities of these web processing service standards and protocols define by OGC. However there exist several challenges that includes, growing intensity of data, high performance computing, real time data processing, and to provide robust, reliable, and cost effective geoprocess services to the end user. The future of geo-processing lies in the adoption of cloud computing to overcome the existing challenges. Characteristics of cloud computing including scalability, elasticity, pay-per-use, and self provisioning, offers a more reliable, on demand, and cost effective geoprocessing services to its end user. In this context the study makes an attempt to analyze the current state of geoprocessing services over cloud, with exiting GIS Cloud platform solutions in the literature to counter the challenges of GIS cloud. Furthermore, study proposes a design and architectural framework for geoprocessing over Cloud platform, based on OGC standards. The architecture includes developing geoprocessing service, and data management services as an essential part while storing/processing the geospatial data from heterogeneous sources. The architecture model including data management and geoprocessing can be bind together in a cloud platform to have an on demand service as per the requirement of end user.

Keywords Geographic information system (GIS) · Web processing services (WPS) · Web featured services (WFS) · Web mapping services (WMS) · Spatial cloud computing (SCC) · Spatial data infrastructure (SDI)

1 Introduction

Cloud computing and GIS both are the buzz words of new technological advancements achieved by the researchers. Cloud computing is widely adopted by various IT organizations and other fields for high performance computing, on demand service provisioning, and low cost solution for resource management; whereas, GIS provides a new trend in terms of processing and managing large amount of geographical spatial data. The growing challenges in GIS system, and overarching advantages of cloud computing has pushed many web based GIS organizations to adopt cloud platform.

The integration of software, hardware, and data to capture, manage, and display all forms of geographical

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referenced information is termed as Geographical Information System (GIS). A GIS system gives the freedom to user for analyzing and interpreting the data, so that it can reveal patterns, relationships, and trends. This analysis is very useful to solve the challenges of various fields such as land use, natural disaster, emergency management, mapping, and other [1]. Generally, GIS system is a large data intensive system that includes data acquisition and data processing from various sources. Each time a user's query request is processed for service, a high performance computing is needed repeatedly, and the same repeated with each new service request [2]. Even though to gain small information from a particular geographical area huge volume of data needs to be stored and processed. In such way any geographical application can cause the server overload due to high performance computing or larger data storage.

Although organization can have enough computing resources but it requires large amount of capital investment to fulfill the requirements. At the same time preprocessing of these spatial data from large geographical area is much time consuming, and needed more and more resource consumption as the time passes. Thus cloud computing can offer the scaling of resources to GIS, in which computational power can be supplied to the application as per need, multiple servers can be used for load balancing of GIS application at the peak hour of use as per need. The important outcome from this analysis suggest that a dynamic scaling of resources either for data storage, and a load balancing to upscale the computing power is must required for GIS system. Thus, cloud computing and GIS can be integrated with each other to provide a convenient platform for GIS application and can be termed as Geospatial Cloud or GIS based Cloud [3]. Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-service (IaaS) are the three service delivery models provided by cloud computing. Some latest researches concluded for geospatial cloud that under X-as-a-service (XaaS) service delivery model SaaS supports for GIS-as-a-service (GaaS), Application-as-a-service (AaaS), and Data-as-a-service (DaaS), depicted in Fig. 1 [4, 5].

The integrated GIS based cloud leverages several benefits to its end users; like on demand service provisioning of spatial data, imagery, processing, creating, managing, and analysis of maps in the public domain [6, 7]. Further it helps in processing of large volume of data, geospatial analysis, and supports for many client-rich GIS software application as a software-as-a-service model for geo-coding, mapping, and routing. Public safety and emergency management system, e-commerce and geo-targeted advertisement, web mapping, geo-earth observation analysis, geo referenced weather analysis, and social science are some of the applications of GIS based cloud.

2 Literature review

Over the period of last 20 years view of the GIS system expanded rapidly from traditional GIS system to desktop GIS, and then Web based GIS to grid computing based GIS. With the advent of Web 2.0 Web GIS came into existence that uses the functionalities of Internet to have public domain based access of GIS application to its end users [8, 9]. Web based GIS system had many advantages to its end users such as freedom of connecting large number of users, independent platform, and reduced cost. However, these web based GIS system are capable of handling large volume of users, but are incapable of fast processing, and managing the compute intensive task [10]. Further to enhance the capabilities of web based GIS Grid computing is identified [11]. The grid computing is based on distributed computing. The applications based on grid GIS are not much appreciated because of task decomposition and task scheduling algorithms of the GIS task. The grid computing needed multiple clusters of system to process the task, thus more resources are needed which increases the Grid GIS cost. The revolution of Cloud Computing in information technology field has changed the traditional GIS system and empowered it with more freedom to the end users. Rather to use a GIS software base, cloud computing has enabled the GIS applications to use anywhere and anytime with advantages of on demand service, broad network access, measured service, and resource pooling [12].

2.1 Review of geoprocessing over cloud

Geoprocessing is an important procedure to process the spatial data to find the useful information out of it and used in several GIS applications. The development of SDI and its enhancements had ensured the availability of geospatial data sharing across the geographical boundaries. In this context OGC has provided several standards and protocols including WPS, WMS, CSW, and WFS adopted for geoprocessing web. In [13, 14], authors have proposed geoprocessing as the major building block for Cyberinfrastructure and spatial data infrastructures (SDI). Deployment of geoprocessing over cloud can benefit its end user with more scalable, on-demand, and pay per use geoprocessing service [14, 15]. In [16, 17], authors have also emphasized on adoption of cloud computing for geoprocessing, to provide more scalable and on demand computing infrastructure.

Several researches have been reported in the literature for implementing geospatial processing in the cloud environment. In [18], author had presented a WPS implementation over cloud for evaluating the scalability of cloud

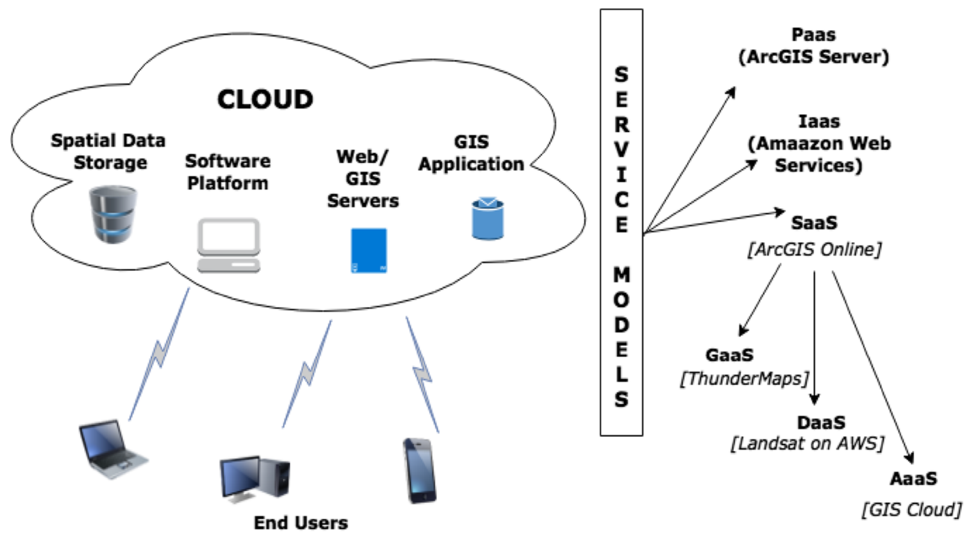


Fig. 1 Overview of cloud based GIS model

computing. The aforesaid study is limited only to web processing service specification. However, author had further implemented geoprocessing service over cloud platform using Amazon EC2 cloud platform based on XACML standard [14]. In similar kind of research, authors have provided a detailed study of integrating SDI over the cloud platform [19]. In this study OGC WPS implementation is used with Amazon Web services as a use case for public domain risk management system. In [20], author has implemented an OGC based WMS in the google app engine. Further authors had researched and discussed on security implications of cloud computing over geoprocessing by comparing several PaaS deployment solutions [21].

Most of these deployments have been done using public cloud solution and integrating various OGC standards. However, very few private deployment model and architecture are provided by the researchers for geoprocessing over cloud.

2.2 Review of GIS implementations and spatial data analysis in cloud

GIS Cloud is the cloud based GIS system of the new era to provide GIS services to end users. Internet network or intranet is used to access the cloud based GIS service to visualize and process the GIS data. Several research is available that provides an insight on cloud based GIS system, framework, and implementation. In [22], authors had provided the concept of GIS cloud, and features of GIS cloud such as, application infrastructure provisioning, technology infrastructure support, plummeting support and maintenance, reduced implementation cost, location independent resource pooling, and data visualization and presentation are discussed. Further, cloud based architecture for GIS application has been provided comprised of two components *GIS cloud interface and GIS server* [22]. However, the aforesaid study is limited to the discussion of architecture, as implementation is not discussed. The architecture presented in the study is loosely coupled as each of its component is dependent on one another, thus any component failure of the system can lead to failure of GIS server. Thus architecture lacks in terms of fault tolerance, robustness, and unavailability of database tier to manage and store processed spatial data.

Geospatial service comprises of two essential features data acquisition and geospatial processing to make a GIS system convenient and usable [7]. This research proposes an architectural model with design for web applications using geo-spatial standards. Research discusses a system design scenario, and further a UML sequence diagram is presented to represent the interaction among data acquisition and geospatial processing. Research provides a thorough insight on geospatial service in cloud with provided architecture and design scenario. However study lacks in design implementation and detailed analysis of spatial data management for geospatial service.

Spatial cloud computing (SCC) is another research dimension presented by several researchers in the field of GIS Cloud. In [23], author has proposed concept of SCC and compared with traditional models of GIS. The aforesaid study concludes the future aspects of SCC in terms of effectiveness, scalability, accessibility, elasticity, and processing. A comparative analysis has been done between Desktop GIS, and SCC, in terms of speed, accuracy, and easiness. However, the study is unable to provide analytics on cloud based SCC. Moreover, similar study has been carried out to provide a more detailed insight on SCC covering domain specific challenges of GIS such as intensive data management, computing resources, more generic data acquisition, and storage management by the authors in [15]. The study also discusses how cloud computing can offer a better solution to these challenges. Study recognizes cloud computing deployment models IaaS, PaaS, SaaS, DaaS as the solution to GIS challenges as; DaaS model can support implementation to data intensiveness, IaaS model support the processing resources, and SaaS can support concurrent access intensity. Further study explains how SCC challenges can be met based on several scenarios for data intensity, computing intensity, multi-access scenario. Implementation and its results are discussed with effectiveness, provided a better and complete understanding of SCC, with identification of research challenges and opportunities for SCC. A similar study has been carried out with propose geographic intelligence to the end user as a service, in [24]. Geographical intelligence is coined in the research for providing specific information by processing the geospatial data to the organization. The aforesaid study proposed a geo web based portal to visualize the data on the maps, and execute the spatial query over spatial data. The study lacks in providing the architecture for their implementation, and no privacy and security countermeasures are provided as geoportal works as a third party service provider for the organization.

Processing of large volume of geographical data such as satellite images and geographical areas is another challenge of GIS system. Therefore, spatial data management becomes an important challenge that needs higher amount of investment for data storage with better data management. In [22], research provides an insight on data storage and management focusing image spatial data, and presented cloud as the solution to spatial data storage. The aforesaid study lacks in explaining the complete processing model for spatial data storage, and data acquisition. Furthermore a more detail research has been conducted in the similar area and presented cloud as the solution model for satellite technology [25]. The research justifies the cloud as a solution for managing and processing the satellite spatial data, by proposing a data processing model as a cloud. A workflow analysis is presented to show how system will work under proposed model. Finally aforesaid study applied this proposed data processing model with image processing under remote sensing data. Experimental results explains proposed model have better results compare to traditional processing model. However study lacks in presenting a communication model for various components of the cloud architecture, and security risks associated with using traditional networking model for transferring data to processing system. A similar geospatial processing comparative study has been performed by the researchers to describe the challenges in cloud with regards to GIS such as how to store and access the spatial data on cloud?, how existing geo-processing function fits in cloud?, and dynamic scaling of computing resources [26]. However study lacks in proposing generic spatial data processing model that fits for most cloud based platform, as the study is done for specifically for AWS platform.

2.3 Review of GIS cloud applications

The benefits of GIS cloud are not limited to ease-of-use, efficient data management, computing resources, and on demand service, but is used in various fields including public safety and emergency management system, mapping and routing, geo-targeted advertisement, and many more.

For natural disasters and catastrophes a GIS based cloud based architecture model is proposed for emergency system [27]. The research discusses about the currents existing GIS solutions for emergency system focusing the earthquake, and discusses the current challenges of those systems, specifically managing spatial data. A detailed architecture is presented in the study, consisting of several layers as GIS cloud layer, GIS cloud application layer, GIS cloud management layer, cloud storage layer, GIS platform layer, and infrastructure layer. Microsoft windows azure platform is selected for the realization of the proposed architecture, a detailed workflow diagram is also presented to understand the flow process of the architecture. The major flaws in the study are, no comparative study has been done of proposed implementation with existing GIS application, cost effectiveness, and scalability. Similar study is done provided with architecture for emergency system, and implemented using Amazon cloud services [28]. The study lacks in the discussion of design case scenarios, comparative analysis, and interpretation of data acquisition and processing. In some more similar trends GIS based cloud application and architecture is proposed for road accidents [29], and collaborative GIS education [30].

3 Cloud based GIS and case study

GIS Cloud is future geographical information system, which is an integration of cloud services and GIS functionalities to have a wider range of applicability of geospatial services across the world, better ease of use, real time visualization, low cost solution, and variety of GIS application. GIS cloud can be defined as, hosted services over Internet for users of GIS or public users across geographical border accessing the maps. Services offered are such as mapping service, spatial data storage and access, spatial data visualization, spatial analysis with GIS applications, and management of information [3]. Cloud service delivery models, deployment models, and GIS applications are the main components of GIS cloud [31].

Cloud computing capabilities can support GIS system to have better data acquisition, and spatial data processing. GIS Cloud can also support dynamic scaling, resource pooling of network resources, databases and storage. The management of large volume of spatial data and processing of spatial data are the two major challenges of GIS system that needs much computing resources, therefore adoption of cloud infrastructure as a solution for computing resource can offer low cost GIS solution. A low cost GIS solution is big advantage for organizations dealing with processing of large volume of spatial data. Organizations like ESri, GIS have already migrated to cloud platform and benefiting from cloud service while providing on demand service to their end users. Proprietary solutions such as Amazon EC 2, Windows Azure, IBM Cloud, and open system solution such as Eucalyptus, Openstack, Open Nebula are few reliable and secure cloud service providers.

Cloud GIS overpowered, traditional GIS and Web GIS, with several benefits such as computing resource provisioning, support for technology infrastructure, reduced implementation cost, resource pooling, data storage and management, and support and maintenance [32]. However, GIS cloud can have few drawbacks such as data privacy and security because of security bottleneck in cloud computing.

Cloud computing has revolutionized most IT based organization, and other domains to migrate their business, core technologies into the cloud. GIS is also adopting the cloud technology to enhance the GIS system by utilizing the capabilities of cloud. ESRI is the leading company in cloud based GIS releases its web edition of ArcGIS software in 2012. Using the application user can store, process, and publish the data directly through the Internet, using the ESRI ArcGIS server [31]. Except ESRI, OpenGeo and GIS Cloud are two other systems which are very close to ESRI GIS Cloud. A case study has been done on all three GIS cloud system to analyze their architecture, features, services, and technologies to understand the need of GIS based Cloud. Table 1 represents the complete summary of the case studies, of all three Cloud based GIS system [33–35].

4 Design and proposed architecture

Data acquisition and data processing are the two main components of GIS system. Data acquisition refers to acquiring spatial data from various sources, to manage spatial data, and make available for data processing engine for processing. The geospatial information from various sources needs to be shared in interoperable manner, which is handled by Distributed Geospatial Service (DGS) [27, 39]. The interoperability in distributed system is best provided using Service Oriented Architecture [37]. The DGS services are a kind of web services that deals with, geospatial data, access to geospatial data in database, and processing of geospatial data. The geospatial data is handled by data service provider; however the geospatial processing, computing resources and services are provided by cloud service provider [38, 39]. Thus a common understandability between data provider and cloud service vendor is required. Evolution of semantic web has empowered geospatial data; based on Extensible Markup Language of semantic web Open Geospatial Consortium has introduced the Geographical Markup Language (GML) as a standard for geospatial data [40]. Geospatial data service is the main component of the GIS cloud based architecture; GML can be used for achieving the interchangeable data format. OGS has further provided several set of specifications for geospatial data provisioning, visualization, and service interface as; Web Feature Service (WFS) for geospatial data provisioning and output facilities, for production of mapping services as web mapping service (WMS), for geospatial registry services Catalog Service for Web (CSW), and web processing service (WPS) for processing the geospatial data [36, 41–43].

Open Geospatial Consortium has introduced these standards in such manner that it can fit in current IT trends, such as for integrating the geospatial data and services with web based distributed application, thus same standards can be implacable for cloud computing and adopted in this research [40]. To deploy any system over cloud, it should follow one of its standard service delivery models from IaaS, PaaS, and SaaS. For developing a better understanding of the system before migrating to cloud, demonstration of background phenomenon is needed to understand the requirements. Initially end user sends a query; to serve the user's query an application is needed, and to run this application software run time environment is required which itself runs over the operating system, and finally an infrastructure is required to run these platform environments. On the realization of the scenario it can be concluded that all three service delivery models are required to integrate the GIS system with cloud system.

As discussed GIS system requires processing of large volume of data efficiently, with on-demand-service in nature, thus requirements can be varied with the time. Cloud computing can handle this on demand service, with dynamic scaling of computing infrastructure for GIS. Infrastructure-as-a-service will fulfill these requirements of the GIS. To provide services and application a platform is needed, that is provided by PaaS cloud service delivery model. PaaS can be used for executing the services, replication, dynamic scaling, and load balancing for developers. Finally, the deployed services, and GIS application will work as SaaS service model for the end user.

Table 1 Comparative study of cloud based GIS system

Case study platform	Features	Key technologies and comments
ESRI in Cloud	Ease of use and fast deployment	Server used: ArcGIS
www.arcgis.com [33]	Low cost solution by using AWS	ARcGIS server deployed over Amazon EC2
	Greater availability	Scalability is achieved by creating multiple VM's using pre-installed ArcGIS server
	Internet based public GIS cloud	No centralized control with self load balancing
		Very close to the requirements of GIS based cloud system
OpenGeo Web Mapping [35]	Complete solution for Internet mapping	PostGIS spatial database over PostgreSQLis used for database to execute spatial and attribute queries
	Three different layers as storage, application, and support for existing framework	Server used: GeoServe
		GeoServe is used as application server that provides data visualization, data processing by WPS
		GeoExt/ExtJS framework is used for development
GIS Cloud	Easy data sharing and web publishing	PostGIS database is used
www.giscloud.com [34]	Improved GIS collaboration	HTML5 map engine
	Layered grouping	HTML5 canvas for web mapping
	Encrypted connection	
	Virtually unlimited storage and resource	

For the public access of the GaaS or SaaS (GIS application) network access model/Internet can be used. Thus as an integrated model it can be termed as GIS cloud, that fits in cloud service delivery models. Public/private cloud deployment can be selected with the same design, as cloud service provider or open source cloud vendor can be selected for implementation. The difference is of maintenance and support, in public cloud all service will be managed by cloud service provider whereas in private cloud it has to be performed by organization.

4.1 Design case scenario

To realize the GIS Cloud, a design scenario is demonstrated in which complete GIS system is migrated/deployed over cloud. OGC has provided several standards, while integrating the cloud services with GIS namely WFS, WPS, WMS, and CSW must need to be integrated in the system. The data service (WFS) management is a challenging scenario, as there can be multiple data providers with different geographical locations. In the scenario, when data service is available locally then it can be easily integrated with GIS service within the cloud. This is a typical design case when WFS, WMS, CSW, and WPS all are bounded in single cloud system providing GIS services. It is comparatively easy to implement and manageable.

However, most of the data providers are available beyond geographical borders, with multiple data providers and format. In this case the data service WFS resides outside of the cloud system and fetched the required data based on end user query and returned data is provided to WMS, WPS, and CWS services. Considering this scenario where organization and service vendors are residing over different geographical locations, each time a service is requested huge volume of data has to be transferred over computer network. To solve this all data service providers, organizations creates a cloud based central repository using IaaS deployment model, and the cloud based central repository will work as service provider and available to data services. Furthermore other service such as WMS, WPS, and CSW can be implemented using IaaS and PaaS, and bounded with their required WFS. Finally GIS application, web application can be deployed over this infrastructure to provide services to its end users. CSW service is included for searching desired data server and services. In this way elastic, dynamic scalable, and on demand GIS cloud is provided.

Figure 2 demonstrates the deployment of design scenario with GIS services on the cloud, based on design scenario. The request of user can be processed by corresponding service of GIS, such as user request maps from WMS with respect to layers with several parameters like size of image for analysis, then layer of maps with specific desired features is returned by the WFS or data service.

4.2 Architecture framework

The architecture of GIS Cloud is distributed multi layer architecture to meet the requirements, including dynamic scalability, resource pooling, and computing resources.

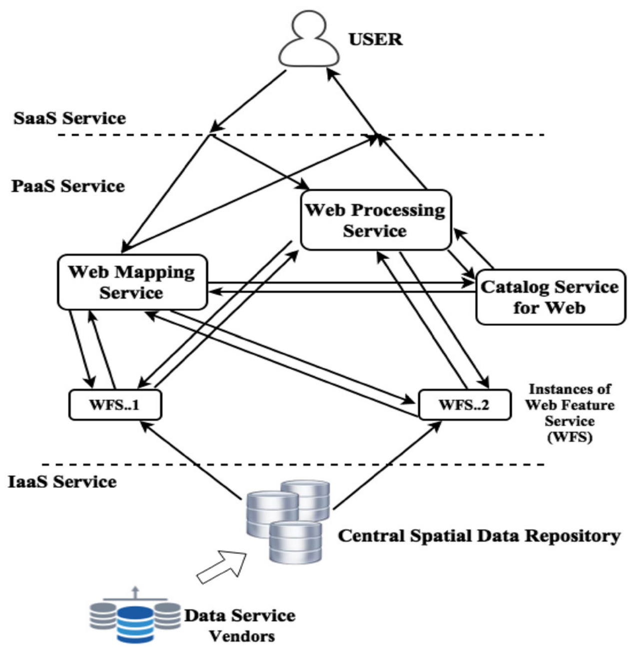


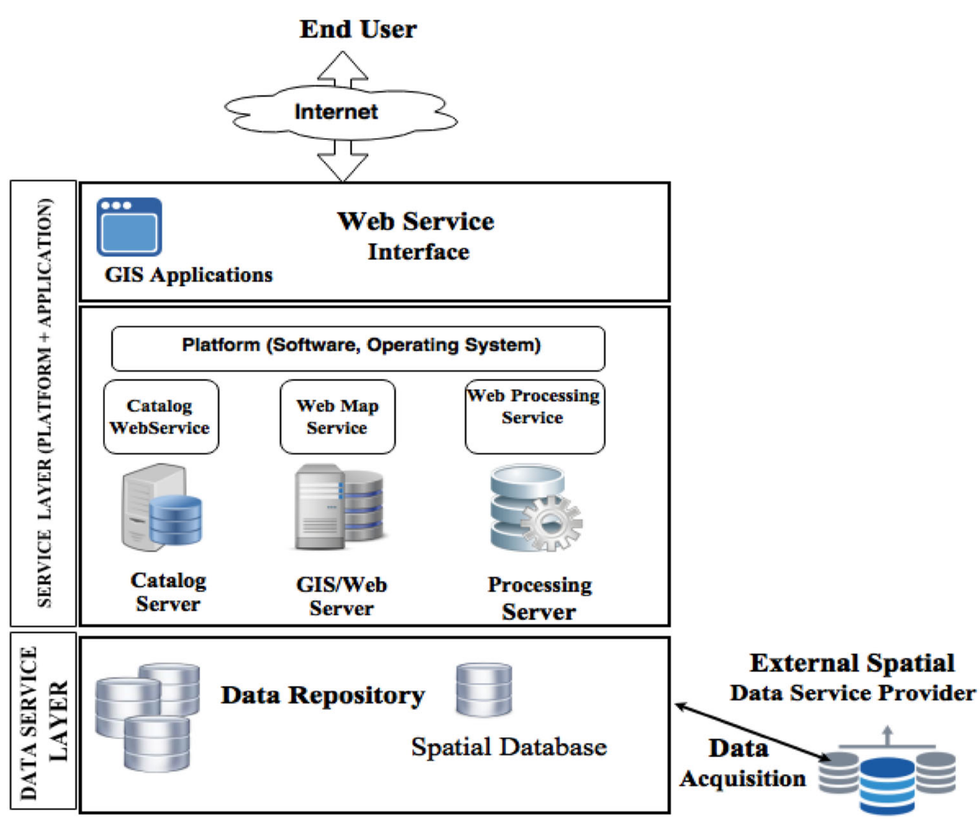
Fig. 2 Development of design scenario

Figure 3 represents the realization of architectural implementation of GIS cloud, which can be implemented either using private or public cloud deployment model. Open source software such as Openstack, Open Nebula, or proprietary solution such as Amazon EC2, Microsoft windows Azure, and IBM cloud can be used for implementation. GIS cloud architecture also depicts the implementation of OGC standards such as WFS, WPS, WMS, and CSW. Data service is an important geospatial system requirement that is implemented using centralized repository of spatial data collected from various organization and data vendors, and provides data services WFS to the other geospatial services.

The architecture of GIS based cloud system consists of two different layer as data service layer, and service layer. The architecture is explained as:

- Data Service layer consist of spatial data repository, and serves as data as a service to the other GIS services such as WPS, WMS, and CSW. Central data repository in data service layer is presented as a solution to the problems such as, multiple data service vendors are available with different geographical locations, security concerns of data, and direct access of data services from the service vendors may increase the processing time and cost. The centralized data repository resides inside the cloud as an IaaS, and serves as data service.
- Service layer is second layer works as a core layer of service for end users and developers to provide an interfacing between end user and data services. All the OGC standard GIS services WPS, WMS, CSW, and WCS are implemented as service over the cloud

Fig. 3 Architecture of GIS cloud



platform. The cloud platform itself provides infrastructure to the GIS services such as for catalog server, mapping server, processing server, and web server. Further, organization needs to focus on development of GIS application over the cloud platform to full-fill the requirements or services to the end user. However, the topmost sub-layer consist of SaaS comprises of GIS application which is accessed by end user using web browsers and network infrastructure and protocols.

- WMS, WCS, CSW, and WFS are the OGC standard GIS services included in the GIS cloud. In which WFS is solely used as data service interface especially for vector data with key operations such as GetCapabilities, DescribeFeatureType, and GetFeature. The CSW (catalog service for web) provides a service registry that is used for publishing the resource availability using metadata, and then end user sends a query for descriptive information about metadata in the registry to find the required resource or information.

5 Conclusion

Based on the available literature survey, and research this study provided design scenarios, and architecture for cloud based GIS. Study refines the present architecture found in literature and modified in more convenient manner to satisfy the requirements of GIS cloud. The study has tried to provide a detailed and thorough design and architecture for GIS Cloud by discussing several design cases, analysis of available cloud based GIS system, and with description and inclusion of OGC standards. Thus a more refined architecture is provided that included all GIS services, with more managed spatial data service by introducing centralize data repository inside the cloud. This centralized data repository is more useful while concerning about the data acquisition and spatial data management from various sources of data service provider. The provided architecture in Fig. 3 is capable of holding both public and private cloud deployment separately, with all GIS services and standards. The possible extension of the research is to provide an implementation using open source cloud and provide benchmark and recommendation for GIS cloud based on the provided architecture.

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