The Development of and Prospects for Private Cloud GIS in China

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Abstract

The cloud geographical information system (GIS) has been an important development direction of GIS in recent years. To deploy GIS on cloud and enable users to enjoy the geographical information services at any time and any place is becoming a better choice in a GIS project nowadays. According to the different deployment modes and service objects, the cloud GIS can be classified into public cloud GIS and private cloud GIS, as well as hybrid cloud GIS. The clients of the private cloud GIS are usually small enterprises and schools. The private cloud GIS is the key to the popularity and innovation of the cloud GIS industry. China’s GIS/GNSS/RS industry has developed significantly in recent years, and demand for geographical information services has grown tremendously, thereby leading to a steady growth in the private cloud GIS sector. The article reviews the development process of the private cloud GIS in China. In addition, the platform construction and current focuses of research in China are explained. The prospect for the private cloud GIS in China is predicted at the end of the article. We hold the idea that the big data effect on the industry will become more apparent, and the targeted application of private cloud GIS will be clearer and more definite.

Key words: Private cloud GIS, Development, Prospect, China

1. Introduction

The idea of cloud computing can be traced back to 50 years ago, when the famous computer scientist John McCarthy predicted that “Computation may someday be organized as a public utility” (Dikaiakos et al., 2009). John McCarthy believed that along with the development of computing technology and popularization of computers, computing would one day be a kind of infrastructure like water and electricity, that are cheap, convenient, easy to get, and widely used in public. What once seemed as an impossible dream in the 1960s has finally come true nowadays.

Literally, “cloud computing” is the computing power from the cloud. The “cloud” here refers to the Internet in general and the “computing power” means the resources of data, computation, storage etc. It is called "cloud" because it has the characteristics of natural cloud: large-scale, fuzzy boundaries, elastic, really exist but cannot be touched directly. In general, cloud computing is a service mode. The way people use cloud computing is like using the electricity: there is no need to build power plants before using, and the only thing users need to do is turn on the power.

The National Institute of Standards and Technology (NIST) in America explained the cloud computing as a model of computing (Mell and Grance, 2011a). Cloud computing brings the distributed resources (such as servers, storage, applications, services, etc.) together as a shared resource pool, which people can use through the Internet (Mell and Grance, 2011a). China Academy of Telecommunication Research (CATR) thought the cloud computing is a kind of ICT (Information, Communication and Technology) resource that can be organized by the network (CATRMIT, 2012). Users can access and utilize the cloud computing with various forms of terminals via the Internet, such as personal computers, tablet computers, smart phones and so on.
Cloud GIS appeared in this background of cloud computing. GIS was created for storing, managing, analyzing and processing spatial data (Maguire et al., 1991). With the continuous improvement of spatial data accuracy and the variety of data acquisition methods in recent years, the big data era of spatial information has arrived (Lynch, 2008; Qiao, 2013). The increase in the amount of data means more time is required for data analysis. Moreover, part of the functions in GIS will lose effectiveness when handling big data. So improving the performance of GIS is becoming a challenge. Since cloud computing has inherent advantages in compute-intensive (Voorsluys and Buyya, 2012) and data-intensive (Rosas et al., 2014) applications, a combination of cloud computing and GIS will be a better choice when facing big data. The cloud GIS nowadays has become a new milestone in the development process of GIS.

According to the different deployment modes and service objectives, the cloud can be classified into public cloud and private cloud, as well as hybrid cloud (Letaifa et al., 2010). Different types of cloud GIS have different features and the pushers behind these cloud GIS are also different. The promoters of public cloud GIS are generally the leading enterprises of geographical information industry. Those enterprises need to establish public cloud GISs as their flagship products, such as ESRI's public cloud GIS product “ArcGIS.com”. Pushers of the private cloud GIS are usually small enterprises and schools, who have obvious industry characteristics and specific theme for use. As an extended product, the hybrid cloud GIS has the same pushers as public cloud GIS and private cloud GIS. So just in terms of development power, the private cloud GIS is the most promising product, and is the key to the popularity and innovation of the cloud GIS industry.

China, the world's largest developing country, has a considerable number of enterprises and research institutes. GIS in China has been applied to various industries (Chen et al., 2002; Hui, 2000), however, the development of the private cloud GIS is just beginning, which is the same as the global trend. The article reviews the development process of the private cloud GIS in China, and analyses the current status of development. A prospect of the private cloud GIS in China is given in the end of the article.

2. Development History

We hold the view that China's private cloud GIS has gone through three previous stages in the last 15 years: web GIS, grid GIS and public cloud GIS. Web GIS is a combination of GIS and the network (Karnatak et al., 2007). Web GIS is not apparently associated with cloud GIS, but its web-based service mode is a prototype of the latter to a certain extent. Grid computing is the basis of cloud computing (Foster et al., 2008), and correspondingly grid GIS is the predecessor of cloud GIS, which is the epitome of GIS in the distributed environment. Public cloud GIS is a pioneer in the development of the private cloud GIS. In the early years of cloud GIS, the infrastructure was inadequate, so a GIS built on a public cloud became the primary development goal, and set the scene for the private cloud GIS.

2.1 From Web GIS to Grid GIS

Web GIS developed rapidly in the early 2000s with the popularity of the Internet. The application mode of GIS is primarily terminal/host or client/server before web GIS, whereas web GIS brought forth a new mode of browser/server, which met the needs of geographical information sharing. The research of web GIS in China began in the late 20th century (early Chinese literatures appeared in 1997 (Zhang, 1997) ) and has continued into the 21st century.

The advantages of web GIS are obvious: a wider range of access for users, a more independent platform and the service costs are significantly reduced. Web GIS is widely applied in various industries because of these merits (Wang et al., 2004; Xia et al., 2011), and plays an important role in China's digital city construction (Chen et al., 2002). But there exist inevitable shortcomings of web GIS (Chen and Chen, 2011): it is not suitable for rapid calculation and is problematic when handling compute-intensive tasks.

The grid GIS made up for the drawbacks of web GIS. The progress from web GIS to grid GIS is enormous, even though the difference between them is only half a word in Chinese character. The bottom layer of grid GIS is a variety of distributed, homogeneous and/or heterogeneous computers that are connected through the Internet. These computers in the bottom layer are able to work together and support the GIS in the upper layers with powerful capacity of computing and storage. The study of grid GIS on the Chinese mainland became popular in 2002. Grid GIS was applied, for instance, in the fields of image processing (Shen et al., 2004), ocean data analysis (Xiao et al., 2009), and location-based mobile services (Tian et al., 2009).

2.2 From Grid GIS to Public Cloud GIS

Grid GIS has not achieved, in fact, the same scale of applications as web GIS. We think there are both technical and financial reasons. Firstly, Grid GIS is a typical distributed GIS, in which a traditional GIS task should be decomposed into multiple independent tasks and distributed to different computing nodes with task scheduling mechanisms. This would be technically challenging for most GIS administrators and users. Secondly, compared to web GIS which needs only a common computer to work, grid GIS is based on a cluster of computers. High construction cost of grid GIS is almost inevitable, and what is more serious is that the computing resources are always underutilized after construction.

The problem which grid GIS is facing is the same as the IT industry as a whole. Fortunately, the cloud computing revolution in the IT field has brought a new dawn to grid GIS. Cloud GIS is the GIS based on cloud computing with
advantages of on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service (Mell and Grance, 2011b). The search of cloud GIS in China began in 2009 and gradually increased afterwards. According to the different deployment modes, the cloud GIS can be classified into public cloud GIS and private cloud GIS. China’s cloud GIS research and applications are mainly concentrated on the public cloud GIS at the preliminary stage. Popular platforms in China include Amazon EC2, Google App Engine, and Microsoft Azure.

The study and application of the public cloud GIS in China started with the deployment of spatial data in cloud environment (Ge and Wang, 2009). As the public cloud itself was relatively young, its support for GIS was not widely available. In the initial study, Chinese scholars held the view that the support of Google App Engine for spatial data storage was poor, thus designed a data structure for storing and retrieving spatial information in cloud environment (Wang et al., 2009). In terms of service deployment, a research team from Wuhan University chose Amazon EC2, and deployed the Web Coverage Service (WCS) on it (Shao et al., 2011). In terms of application deployment, Peng Yue et al. deployed the China’s leading web GIS software called GeoSurf both on Google App Engine and Microsoft Azure (Yue et al., 2013). It is worth mentioning that a research group from Peking University thought the cloud GIS is rather a means of enhancing than a substitute for grid GIS (Ji et al., 2012).

2.3 From Public GIS to Private Cloud GIS

The public cloud has greatly reduced the difficulty of cloud GIS construction. However, with the increase in research, the drawbacks of the public cloud GIS became gradually apparent. Firstly, GIS administrators lost the capabilities of control and optimization to bottom layers after deployment of GIS on the public cloud. Secondly, high-accuracy and sensitive GIS data are not recommended to deploy on the public cloud for safety considerations. Thirdly, a lot of time will be wasted when big data is transmitted through the Internet from local disks to cloud. Lastly, the public cloud GIS was unable to take full advantage of local computing and storage resources. These defects of the public cloud GIS led to the development of the private cloud GIS.

The studies of the private cloud GIS in China are just growing in number in recent two years. Since the bottom layers of the private cloud GIS also need to be built, there appeared different choices of underlying architectures. The common cloud computing platforms (Bugnion et al., 2012; Wang et al., 2012) are mainly VMware, OpenStack, Eucalyptus, Nimbus, OpenNebula, Hadoop, etc. Hadoop is relatively frequently utilized in China (Zhou et al., 2012; Hao et al., 2013). In addition, there are also studies in which simple private cloud GIS platforms are established on Memcached (Fan et al., 2012).

3. Platform Construction

3.1 Commercial Private Cloud GIS

Major GIS vendors in the Chinese domestic market are mainly SuperMap, ESRI China, Zondy Cyber, GeoStar etc. Up to now, the technology implements by Chinese GIS vendors for private cloud GIS are mainly focused on the following three aspects (Ni and Chen, 2013):

- To design the software architecture of the cloud GIS platform and update the existing softwares, so that the softwares can be deployed on cloud computing environments.
- To work with public cloud providers and integrate their existing GIS systems with the IaaS solutions from public cloud providers, in order to gather experience for private cloud GIS by creating a public cloud GIS platform.
- To provide customers with a complete private cloud GIS solution from construction of the underlying data center to deployment GIS applications.

3.1.1 SuperMap: China's leading GIS vendor SuperMap began to support cloud computing with its product named SuperMap GIS 6R (2012). The new product SuperMap GIS 7C, which was launched in 2013, incorporated more aspects of cloud computing.

In the product SuperMap GIS 6R (2012), where R represents “Realspace”, users can directly access the base maps provided by Supermap cloud services. The product SuperMap Desktop .NET 6R (2012) is able to support Google Maps Engine and data sources. In order to be installed on the x64 servers that are commonly used in cloud computing environment, SuperMap iServer 6R (2012) was overwritten and compiled as a 64-bit version. Besides, the product SuperMap Objects Java/.NET 6R (2012) began to support multiple operating systems, such as UNIX, Linux and Windows.

SuperMap GIS 7C was released in 2013 at the SuperMap GIS technology conference. The letter C in the name represents Cloud, meaning the software in this version was better prepared for cloud computing. Three new products were introduced in the SuperMap GIS 7C: cloud portal for GIS, application server for cloud GIS and distribution server for cloud GIS.

- Cloud portal for GIS specifically refers to SuperMap iPortal 7C, which can be used to integrate and manage all kinds of GIS resources in the cloud.
- Application server for cloud GIS specifically refers to SuperMap iServer 7C, which is a development platform which can be utilized to develop both SOA applications and private cloud GIS systems.
• Distribution server for cloud GIS specifically refers to SuperMap iExpress 7C, which is a middleware between cloud and client sides. SuperMap iExpress 7C can also be used to create lightweight browser/server applications.

3.1.2 ESRI China: ESRI China is a branch of ESRI in China, and was established in 2003. ESRI China accounts for a considerable share of the Chinese GIS market. The product ArcGIS Server 10.1 released by ESRI China in 2012 was able to support cloud architecture. ArcGIS Server 10.1 adopted a new model, Site/GIS Servers, instead of the old model in the version of 10.0 and before. Each of the GIS Servers in this new model is equal, so the service will not stop even if shutting down any computing node. The new model of ArcGIS Server 10.1 is an ideal model for cloud GIS.

ArcGIS 10.2 was released in China in 2013, along with a brand-new product, Portal for ArcGIS 10.2 (Portal 10.2). Portal 10.2 can be used as a web-based portal, which is a collection of maps, services and applications, for the private cloud GIS. Portal 10.2 divided users by different groups, and organized resources and services for each group. In addition, ArcGIS 10.2 for Server is more suitable for cloud deployment after architecture optimization.

3.1.3 Other vendors: Zondy Cyber is a famous GIS vendor originated in China University of Geosciences (Wuhan). Zondy Cyber owns the famous series software named MapGIS. MapGIS K9 SP3 was launched by Zondy Cyber in 2011. Its highlight is the use of architecture which is suitable for cloud computing. In 2012, Zondy Cyber officially released its new solution for cloud GIS, MapGIS Internet GIS Sharing Server (MapGIS IGSS). Based on virtualized hardware, IGSS provides an on-demand spatial information data center using their so-called microcores.

GeoStar also derived from campus, Wuhan University in China. In terms of cloud GIS, GeoStar put emphasis on storage and management (GeoStar, 2011), and made a plan to develop a cloud-based geographical information services platform named GeoCloud. In the project of GeoCloud, GeoStar decided to deploy GeoGlobe SDK and the existing SOA-based GIS software on clouds.

### 3.2 Self-built Private Cloud GIS

The self-built private cloud GIS, usually based on open source cloud architectures, is another typical development direction. The self-built private cloud GIS enables researchers to understand, access, change, and optimize the bottom layers of cloud computing. For research and experimental purposes, the self-built private cloud GIS is often based on non-commercial architectures.

As an open-source infrastructure for distributed systems, Hadoop is often deployed on a cluster of virtual machines and plays an important role in self-built private cloud GIS platforms.

Researchers from Information Engineering University designed a Hadoop-based private cloud GIS in 2012 (Fan et al., 2013). Their architecture consists of four layers, namely, the physical layer, the cloud platform layer, the service layer and the application layer. Their private cloud GIS, making full use of HBase, HDFS and MapReduce, can be used to access and analyze large amounts of GIS data. Researchers from the Chinese Academy of Science (CAS) also designed a Hadoop-based private cloud GIS (Zhou et al., 2012), but the difference is that the architecture is divided into five layers: the hardware layer, the virtualization layer, the Hadoop layer, the Cloud GIS management layer and the Cloud GIS service layer.

Apart from Hadoop, Aneka has also been used in studies. Aneka is a cloud platform for developing applications, and a framework for developing distributed applications. Researchers from China University of Geosciences proposed an Aneka-based cloud GIS architecture, and deployed spatial data services (Wu et al., 2010). There are also studies which have built private cloud GIS platforms using distributed cache clusters based on Memcached (Fan et al., 2012). In a study from CAS, the private cloud GIS was established by Memcached and 30 physical computers (Fan et al., 2013).

There are few studies using a commercial GIS platform in construction of self-built private cloud GIS, for example, a cloud-based spatial decision support system from CAS (Liu, 2013). But in general, for research and experimental purposes, the architectures selected by self-built private cloud GIS are usually open source and non-commercial.

### 4. Current Focuses of Research

#### 4.1 Framework

Although the framework of the private cloud computing is relatively mature, the architecture of the private cloud GIS is not yet finalized. Cloud computing services comprise of three levels: Platform as a Service (PaaS), Infrastructure as a Service (IaaS) and Software as a Service (SaaS) (Luo et al., 2011). In which level should GIS combine with cloud computing? Researchers from China University of Geosciences believed GIS can be integrated with cloud computing at each level, and cloud GIS can be specifically divided into cloud GIS infrastructure services, cloud GIS platform services and cloud GIS application services (Wu and Wu, 2011). Some other scholars added cloud GIS data services (Peng et al., 2013) and cloud GIS content services (Peng and Wang, 2014) to the whole framework of cloud GIS, putting emphasis on the importance of GIS data.

To realize the functions of each service level, researchers from China University of Geosciences studied the on-demand self-service system architecture and designed a data flow (Diasse and Kone, 2011). Research fellows both from
Information Engineering University (Fan et al., 2013) and Chinese Academy of Science (CAS) (Zhou et al., 2012) studied the Hadoop-based implementation techniques of the private cloud GIS. Hadoop, being both reliable and sustainable (Wang, 2011), is an open source cloud computing framework from the famous Apache software foundation. The three key technologies, Hadoop Distributed File System (HDFS), Hadoop Base (HBase) and Hadoop MapReduce, in Hadoop framework can well support the research and development of the private cloud GIS. Except for Hadoop, the Aneka framework (Wu et al., 2010) and Memcached system (Fan et al., 2012; Fan et al., 2013) were also utilized.

The load balancing of the private cloud GIS is also a focus of research. Since the bottom layer of the private cloud GIS is a virtual or physical server cluster, it is necessary to distribute the tasks to each computing node according to load when large-scale and high-intensity service requests occur. Zhu Li et al. from Wuhan University proposed a content-based load balancing solution (Zhu et al., 2011), which use the genetic algorithm to balance the servers. Whereas Guo Mingqiang et al. put forward a task-based scheduling algorithm (Guo et al., 2013), which uses a content grid to aid the balancing of server loads. There is also research based on a quantum ant colony algorithm (Li et al., 2013), as well as software-based solutions (Wang, 2013) to achieve load balancing.

4.2 Data Deployment

Computing tasks for the private cloud GIS are usually data-intensive, so computational efficiency is crucial. An important foundation for improving the computational efficiency is a required deployment of spatial data. The spatial data deployment of the private cloud GIS should meet the following requirements. Firstly, in order to reduce the storage pressure of each computing node, the deployment should be distributed. Secondly, the spatial data should be interoperable and essential norms and rules should be formed. Thirdly, the management of the distributed data should be effective.

Researcher from Institute of Geographic Sciences and Natural Resources Research of CAS studied deployment architecture of distributed spatial data (Yin, 2011). In order to solve the problematic deployment and management of huge amounts of spatial data, they put forward a specific implementation of NoSQL database and distributed storage structure for vector spatial data. Wang Yonggang et al. studied the Hadoop-based storage and operation method of spatial data (Wang and Wang, 2010). Considering the amount of raster data is usually much larger than its vector counterpart in GIS, scholars from Chengdu University of Technology (Chen et al., 2012) put research emphasis on storage and display technologies of raster data in private cloud GIS. For the vector GIS data, the topology should be maintained correct in the process of distributed storage. A PhD student from Zhejiang University proposed a partitioning method based on grid-aided STR-Tree (Fang, 2011). The method is suitable for vector GIS data and its effect is satisfactory.

4.3 Algorithm Deployment

Compared to the traditional GIS algorithms based on a single server, algorithms for private cloud GIS are often based on a cluster of servers. This poses the issue of how to deploy the algorithm in the distributed environment and make an effective schedule. Cloud computing has the characteristic of elastic, but limited to the current virtualization technology, the unit of elasticity in actual research is mainly the whole virtual machine (Tang and Feng, 2014), which is not good news for the elasticity. It is necessary to improve the traditional algorithms in the private cloud GIS method.

The method to improve the traditional algorithms is mainly to overwrite the algorithms using parallel model. There are three major parallel modes (An and Chen, 2002): message-passing mode, shared storage mode and data parallel mode. The data parallel mode is popular in the research of the private cloud GIS algorithms in China. The commonly used data parallel mode is MapReduce. Yan Liu et al. proposed a spatial statistics method based on the MapReduce model, and utilized the method for clustering (Liu et al., 2010). Liu Yi et al. put forward a MapReduce-based parallel method to build tile pyramid of remote sensing images (Liu et al., 2013). In addition to using the MapReduce model, some other scholars designed a distributed file system by themselves (Rao et al., 2013), on which traditional GIS algorithms were realized.

5. Applications

So far, it has been reported that there are several industries, such as education, scientific research, e-government, urban construction, and electric power industry, which have introduced private cloud GIS and applied it to find a new way of working.

In the education sector, Beijing Union University (BUU) initially established China's first private cloud for higher education in 2013 (Qianlong, 2013). BUU is a distinctive university which consists of several sub-campuses all over Beijing, so the GIS resources of different colleges in BUU are also scattered. By establishing a private cloud GIS, BUU successfully unified its dispersed GIS resources. Tsinghua University in 2013 also began the construction of a private cloud GIS platform (Tsinghua, 2014), which will be used in the future as a basic platform for a project named "Campus as laboratory" in Tsinghua University.

In terms of smart areas (such as smart cities, smart campuses) construction, private cloud GIS is also beginning to play a role. Private cloud GIS in China has become an important foundation of these smart areas projects (Lin et al., 2010), and provides back-end storage and analysis services (Hu and Li, 2012). As part of smart city, the intelligent transportation industry also began to explore the use of private cloud GIS to
improve background services (Wan et al., 2014; Yiqin et al., 2011).

In addition, there are reports of private cloud GIS applications in e-government (Liang et al., 2011) and in the electric power industry (Liu, 2012).

6. Conclusion and Prospection

The impacts of science and technology on the times are sometimes surprising. The world's first public cloud services offered by Amazon began less than 10 years (Orna et al., 2013), yet cloud computing is used everywhere now. Great changes have taken place in the mode of geographical information service since about the year of 2008, when the GIS industry in China began to explore the combination of cloud computing. GIS with the cloud computing has gained new vitality. As a member of the world family of GIS, China has made superior progress in GIS in the last decade, along with the advancement of world science and technology.

In the course of development in the last decade, GIS in China has experienced several transformations: from web GIS to grid GIS, and then from grid GIS to the public cloud GIS, and lastly from the public cloud GIS to the present-day private cloud GIS. The emergence of the private cloud GIS met the needs of the times: firstly, although web GIS brought the convenient browser/server architecture, its performance was limited by the server; secondly, the construction cost of grid GIS was too high, despite a better performance; thirdly, the public cloud GIS compensated for the shortcoming of grid GIS, but its underlying layers cannot be accessed and optimized; and lastly, the private cloud GIS allows researchers and users not only to enjoy the benefits of cloud computing, but also to control the entire GIS project.

A number of excellent private cloud GIS platforms emerged in China in recent years. Typical representatives are ESRI China, SuperMap, Zondy Cyber and GeoStar etc. ESRI China is a well-known vendor in China, who launched the ArcGIS 10.1 and ArcGIS 10.2, both of which can be deployed in a cloud environment. SuperMap is a leading national GIS enterprise in China, and its products SuperMap GIS 6R/7C are able to be used to build a private cloud GIS. Zondy Cyber, GeoStar and other companies have also launched new products for the private cloud GIS. In addition to business platforms, there are many self-built private cloud GIS platforms, which are usually based on open source architectures. Because the bottom of the cloud is self-built, this kind of private cloud GIS platform will help researchers study the overall framework. Current researches of private cloud GIS in China focus on framework, data deployment, algorithms deployment etc. The private cloud GIS industry has taken shape in China. At present, there are already applications on education, scientific research, e-government, urban construction and power industry.

In the near future, Chinese private cloud GIS research will continue to focus on the framework, data, algorithms, etc.:

- For the research of framework, researchers will conduct more detailed studies of the way in which GIS and the private cloud are integrated. There are four service models for the private cloud GIS at present, namely cloud GIS infrastructure as a service, cloud GIS platform as a service, cloud GIS application as a service and cloud GIS data as a service. Perhaps there will be a new service model, while the existing service models will be more mature. Studies on load balancing will be more in-depth, and there will be more and better load balancing mechanisms.

- In terms of data, researches on the design of GIS data structure for a private cloud environment will be sustained. Since the quality and management mechanisms of GIS data deployment will directly affect the efficiency of data access, therefore the researches on the deployment and management of GIS data will increase.

- For the research of algorithm design, parallel mode, especially data-parallel mode, will be widely used. More and more traditional GIS algorithms will be transformed into a parallel mode, and are deployed in a private cloud GIS environment. It is foreseeable that the algorithm performance will be improved, since parallel algorithms can make more use of the private cloud GIS resource pool.

In the distant future, there will be more researches on high-speed storage and efficient analysis for big data, with the approaching era of big data. The private cloud GIS will play a greater role in big data scenarios of China. The market will be broader, and the private cloud GIS will be introduced to more industries, such as logistics, real estate, agriculture, economy, etc. For those industries that have introduced the private cloud GIS, the traditional GIS work pattern inside will more profoundly changed. It is foreseeable that the status of the traditional GIS service mode will be challenged.

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