ISBN 978-952-5726-02-2 (Print), 978-952-5726-03-9 (CD-ROM)
Proceedings of the 2009 International Symposium on Information Processing (ISIP'09)
Huangshan, P. R. China, August 21-23, 2009, pp. 167-170

A Spatial Data Management Method Based on Hybrid Peer-to-Peer Networks

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***Abstract*—Spatial data usually managed by many different custodians and need to be accessed by others. The trait of highly heterogeneous of data management nodes could be well utilized to meet the above application requirement. We use a hybrid peer-to-peer overlay of double layer to present a spatial data management method in distributed wide area network environments. The method fits well with the current spatial data management mechanism. It is provided with the capability of complex spatial query that are usually only supported in unstructured peer-to-peer networks, and it has the strength of effective querying and good scalability. We also introduce a spatial index based on Hilbert space filling curve. The results of simulation experiments show that the method is efficient.**

***Index Terms*—spatial data management, hybird peer-to-peer, spatial index, heterogeneous**

I. Introduction

In recent years, the rapid improvement in the ability of spatial data acquisition technology has caused explosive growth in the amount of spatial data that need to be managed, which make the massive spatial data management technology has been gradually not able to meet the requirements of current spatial production situation and future application on the aspect of storage capacity and access efficiency. With the development of computer networks whose widely used in the area of spatial information science, network-oriented distributed architectures are important development direction of future spatial information system.

As the rapid development of some new distributed systems based on p2p (peer-to-peer) technology and it has become the one application that occupies the most amount of Internet bandwidth among all the wide area network applications. Compared with the conventional centralized system, p2p has many merits as follows [1]. (1) It has no central control and can avoid the problem of a single point failure, and could provide good scalability. (2) It could provide the effective use of available resource of personal computers and existing servers, and does not need additional equipment to construct distributed massively spatial data management system, so we can achieve the good results of low cost and convenience deployment. (3) More importantly, in theory, the capacity of storage and processing in the architecture can be infinitely increased according to actual need. It can share bandwidth effectively among data manage nodes, thus save the cost of network bandwidth and improve the data transferring speed. So it is very suitable for those applications like spatial data management, which deal with data intensive and computation intensive task.

II. Related Works

As p2p technology has achieved great success in the field of data sharing in recent years, it has become one of the key techniques to construct new distributed systems. There are many related projects being developed at present, such as OceanStore [2], BitVault [3], and Granary [4].

OceanStore is the first project of data storage system based on p2p technology in the world. It is a global persistent data store designed to scale to wide area networks. It provides a consistent, highly-available, and durable storage utility atop an infrastructure comprised of entrusted servers for billions of users. It uses Tapestry that proposed by University of California, Berkeley for object location. Its semantic feature is very powerful, so it is very complicated during design and implementation.

BitVault is a content-addressable retention platform for large volumes of reference data that seldom-changing information and needs to be retained for a long time. It uses a large number of smart bricks as the building block to lower the construction cost. It organizes the bricks by use of peer-to-peer architecture. It uses XRing overlay network proposed by Microsoft Research Asia to construct system. The size of routing table can be self adaptive adjusted while the environment is changed in the overlay. It can build a broad tree index between nodes by the routing table. It has low deployment cost and good development prospects, but its energy cost is too high and there is no effective solution to the matter.

Granary is an Internet-scale storage service project, in which users pay for occupied storage space to the service provider, who scatters some storage servers throughout the Internet and ensures data's reliability, availability, security, and accessing efficiency. It has realized two important goals of p2p storage systems: flexible to various environments and effective data accessing. Some significant components are designed in adherence to these two goals, including the node-collection protocol PeerWindow and the object-index management algorithm PB-link Tree. It provides a public storage service on the

Sponsored by Natural Science Foundation of Hefei University China(No. 08KY005ZR and No. 08KY009ZR); Key Laboratory of Network and Intelligent Information Processing Hefei University

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Internet for users. There are many unsolved problems, and it is deployed in a campus scale at present.

The efficiency of spatial indexing in distributed wide area networks is relatively lower than local area networks because of the complexity of spatial semantics and spatial querying. In addition, the existence of a large number of dynamic nodes makes the situation more complicated. So p2p hasn't achieved the same success in the field of spatial data management as other application areas. But we still think the deployment of p2p technology in spatial data management is very promising.

III. DESCRIPTION OF THE METHOD

A. *Architecture*

P2P networks can be classified into three types according to their architectures, namely, unstructured, structured, and hybrid. Unstructured p2p has much superiority as its supporting complex query, simple configuration, and easy maintenance. Its disadvantages lie in bad scalability and inefficient of data query. While merits and demerits of structured p2p are just contrary to that of unstructured p2p. Spatial data management applications require the ability of powerful processing of spatial data querying and supporting complex query, so neither of the two architectures can completely meet the application requirements of spatial data management. While hybrid p2p strikes a good balance between the two former types. It considers and makes full use of the heterogeneous nature of management nodes. The design of load-balancing in accordance with the capability of nodes is in conformity with the current situation that there are significant heterogeneities in these spatial data management nodes within each organization and it also meet the demand of domain split management.

We use the double layer structure for the design of hybrid p2p. Its architecture is shown as Fig. 1. The nodes in this architecture can be divided into three types: normal nodes, index nodes, and manager nodes. Normal nodes are nodes that used only for general data accessing applications, don't have any special functions. Index nodes are used for preserving information about available manager nodes, searching state, and the current condition of the network architecture. The main function of manager nodes is processing the data querying request that launched by the normal nodes in the same virtual organization.

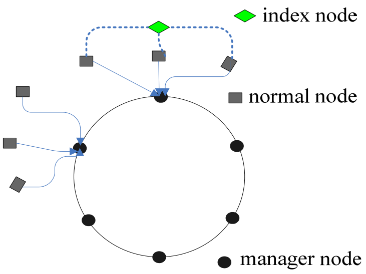

Figure 1. System architecture

The loading of manager nodes is very heavy and they need more resources of network bandwidth and computing. Sometimes one node in a virtual management domain belongs to a custodian is index node, as well as manager node, while the node is locate in inner layer. Here the outer layer is composed by many normal nodes and index nodes, which are served by the manager nodes in client/server fashion, while inner layer is constructed by some powerful nodes in distributed peer-to-peer fashion. These powerful nodes are selected by their comprehensive performance, and only one in each management domain.

B. *Routing Lookup Mechanism*

Here we use improved method based on Chord [5] that proposed by MIT as the basic distributed lookup protocol to search spatial data. Chord is a common distributed hash table based P2P overlay model. Its main function is as follows: given a key, it will be map to one node. It employs SHA-1 as consensus function to assign addresses for the key. The function support that each node store similar amount of key, and so load balancing is easy to realize.

The function assigns an m-bit identifier for each node and key. The identifier of a node is obtained by performs a hash computation on the address of the node, while that of a key is direct on itself. The digit number of the identifier is m, if it is large enough, and the probability that the identifiers of two nodes or keys are the same could be negligible. The identifiers of nodes and keys constitute a Chord ring with size of 2m. One key is assigned to the first node whose identifier is not larger than that of key in the identifier space. We call the node as the successor node of the key, denoted by successor . If identifiers are represented as a circle of numbers from 0 to 2m-1, then successor is the first node clockwise from k. Fig. 2 shows an identifier circle with m = 6.

C. *Distributed Spatial Indexing*

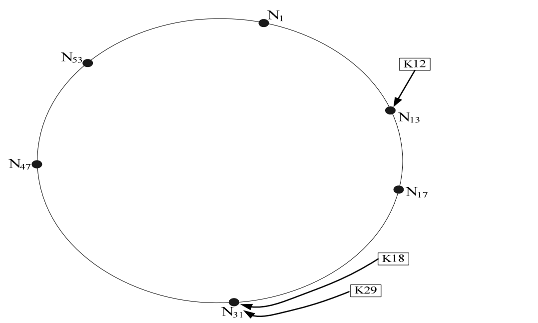

Figure 2. An identifier circle

For improving effectiveness of spatial querying in system, we need to build an indexing structure for all participated nodes. There are three steps in the construction process of the structure: (a) We use Hilbert space filling curve [6] to map multi dimensional spatial data down to a single dimension; (b) The index information can be range partitioned across the all manager nodes; (c) A distributed spatial indexing is build to serve the data accessing request.

In order to obtain a Hilbert space filling curve, an operator is given firstly, and then we can get a gradually refined one by recursive call a production rule to it. Its implementation is a gradual decomposition to continuous space. Its producing process is shown in Fig. 3.

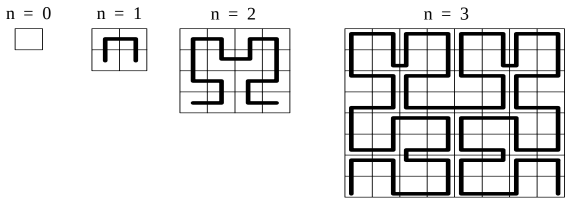

Figure 3. The formation process of Hilbert space filling curve

The algorithm for Hilbert ordering code is the binary digital operation based on the column number and row number of the raster grid where spatial object point being. So the complexity of the algorithm is O(ni2), here ni is the binary scale figure number of which row number and column number is maximum among that spatial object point located. The algorithm may formally be described as follows. For example, if we have two-dimensional data that consists of two 2-bit attributes. A two-dimensional data point (x, y) can be reduced to a single 4-bit value m, by interleaving the bits in x and y. Then a two-dimensional point (11, 01) would be mapped to the single-dimensional value 1011.

After multi-dimensional spatial data has been reduced to one dimension using Hilbert space-filling curve, then the indexing information about spatial data can be range partitioned across the networks, here each manager node manages spatial data in one contiguous range of single dimension values.

As the existence of the overlap of the bounding boxes in their directory of indexing information, which means that the needs to search several nodes during the processing spatial data query, and the query performance is seriously deteriorated. X-tree [7] is an excellent solution to this problem. The performance of hierarchical structure would be worse when the overlap increases, while the linear structure does not have such a problem. X-tree is a combination of a linear structure and a hierarchical structure, so it has the both advantages of hierarchy structure and linear structure. The indexing information about spatial data objects are kept on manager nodes, which can be used to avoid the inefficient directory structure split operation. The spatial data objects that may cause high overlap may be organized in linearly structure, while other data objects will be organized hierarchically in a dynamical manner as the same the original structure. It also recording its split history information for finds a minimal overlapping split scheme.

D. Query Processing Algorithm

If one node sends the request message to the system, the processing procedure of the spatial data accessing request is as follows. It will employ the local spatial indexing information to determine whether there are the target data objects on the node which launches to search. If there are, then the results are returned to the node, else the message will be forwarded to the manager node which manages the virtual domain include the launch node. Manager nodes that receive the messages of query then determine how to route the messages by local employ indexing information. As knowing all the MBR information stored on other manager nodes, so the manager node can make the decision that how to forward information. The query processing algorithm may formally be described as follows.

1: get one dimensional range by using Hilbert space-filling curve on multi-dimensional spatial querying window
2: get the consistent hash value of the range in the identifier space by call Chord arithmetic
3: send the querying message by use the frontal consistent hash value to their manager node
4: use DHT function lookup method to route the querying information
5: Each manager node that received querying messages search for its local spatial indexing information, and return the results that meet the query conditions
6: determine how to forward the message to other manager nodes base on spatial indexing information in their routing table
7: forward the message to other manager nodes may contain the target data objects

IV. Performance Evaluation

A. Experiment Setup

In order to evaluate the performance of the method provided in this paper in distributed wide area networks environment, extensive simulation experiments have been performed to compare the performance of the method with other methods. We performed our experiments on real world data sets of urban planning spatial data from one city.

These experiments are carried on a personal computer with CPU of Intel E4300 Core 2 Duo, memory of 1GB. At first there is only one custodian with some nodes in the system, and there are many custodians join into the system later and the size of the system reaches a certain level. We have the experiments repeated many times under the cases of different size, and the final result is the mean value of many repeated experiments results. We take the information about MBR to construct a spatial indexing structure on each manager nodes.

The size of spatial range queries accounts for the whole data distribution area in the range of 1%-3%. The location of spatial data query is randomly selected. We take these experimental results under the same experimental condition, and then the results are compared and analyzed comprehensively.

B. Simulator Implementation

We have implemented a simulator to verify the performance of the above method. The simulator has the core functions of our proposed method. It is structured into four main components: the generator of double layer architecture network, the component for routing lookup, the maintenance unit of spatial indexing structure, and the performance monitor. The generator of double layer architecture network can build double layer hierarchical architecture that we proposed. The component for routing lookup can support forward message in networks by employ above routing lookup algorithm; the maintenance unit of spatial indexing structure will builds our designed spatial indexing structure; the performance monitor will periodically collect the information of the node, and it can get the statistical result by using the collected information. For each spatial querying, a node is randomly selected as initiated node, and the above query processing algorithm will be implemented on this node. The performance monitor can get the result of response time for queries and the count of messages caused by these queries.

C. Experimental Results

We take the experiments of our proposed method and Chord with the same simulating peer-to-peer network environment, and then the results of comprehensive analysis and comparison between the two methods are taken. The comparison between the two methods about response time is shown in Fig. 4.

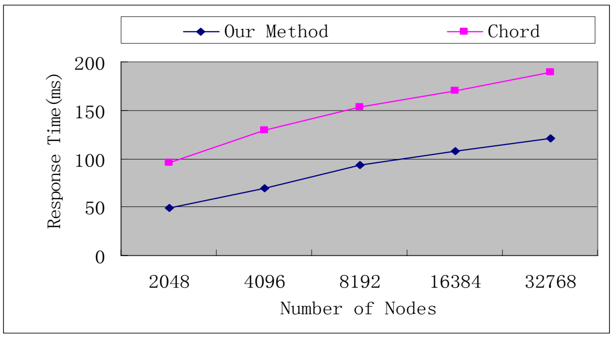

Figure 4. Response time comparison

Fig. 5 describes the comparative results of messages count caused by one spatial querying operation. The results show that our method can reduce the number of message count, especially under the condition of more participants. The results about response time and messages count are better in our method. This is mainly because that we have considered the heterogeneity of nodes, so its processing cost of querying in our method decreased significantly.

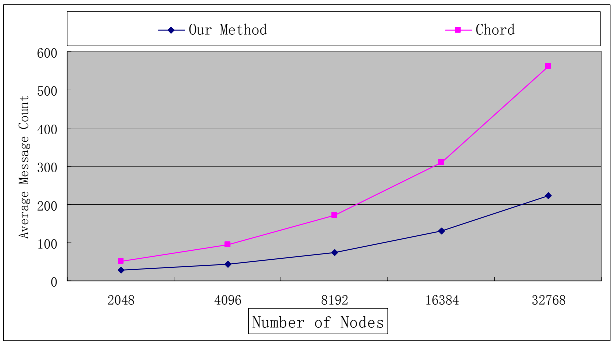

Figure 5. Message count comparison.

V. CONCLUSIONS

Rapid development of spatial data applications require an efficient management mechanism in distributed wide area networks environment to deal with their characteristics of heterogeneity, large scale, and dynamism. This paper proposed a hybrid peer-to-peer overlay of double layer to present a spatial data management method in distributed wide area network environments to deal with these challenges. The method fits well with the current spatial data management mechanism. It is provided with the capability of complex spatial query, and it has the strength of effective querying and good scalability. We also introduce a spatial index based on Hilbert space filling curve.The results show our method is efficient.

ACKNOWLEDGMENT

The research is supported by Natural Science Foundation of Hefei University China (No. 08KY005ZR and No. 08KY009ZR).

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