An Interest Management Architecture by ALM and Region Partition for Large-Scale Distributed Virtual Environment

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***Abstract*—Large-Scale Distributed Virtual Environments (LSDVEs) must deal with the challenge of supporting a large number of users interacting on the Internet while keeping the communication among the parties synchronous and highly reactive. Interest Management is widely used to filter unnecessary messages in such systems. However, the lack of deployment of IP Multicasting over the Internet and other problems introduced by the division of virtual environment should be considered. We present an interest management architecture that supports a large number of users on the Internet by dividing the virtual environment into multiple adjacent hexagonal regions. In the architecture, messaging among entities is based on a multi-server communication infrastructure by the Application Layer Multicasting (ALM). And each region is mapped to an ALM tree with a master node constructing the overlay tree and managing nodes that lie in its region. The interest area of each entity is composed of two parts: the inner hexagon and outer hexagon. By the two parts, inter-region as well as intra-region interaction is supported to maintain a continuous view without increasing too much traffic. In addition, the buffer borderlines near the boundaries are introduced to reduce the number of connections and disconnections that occur when a node frequently moves at the boundary of the regions without affecting the messaging of the entities and modifying the partition structure.**

***Index Terms*—Interest Management, Large-scale Distributed Virtual environment, Application Layer Multicasting, Peer-to-Peer, Hexagonal Region Partition**

I. INTRODUCTION

Large-Scale Distributed Virtual Environments (LSDVEs) aims at supporting a large number of users interacting over a wide area network such as internet. In addition, such systems also need to support awareness, real-time communication, data consistency and reality [1]. To achieve those objectives, the common request for such systems is capable of transmitting a large number of messages in speed. Maybe it is possible to simulate a few entities over small network. However, when simulating a lot of entities over the Internet, the capacity is seriously bounded by at least two key limitations: network bandwidth and host performance [2][3], which will lead to more problems. At present, defense ministries and military and aviation simulation companies are in constant need of overcoming server bottlenecks and the lack of deployment of IP Multicasting in order to make their training environments fully deployable on the Internet in a scalable manner [4]. The end-to-end delay and scalability are two important performance factors for LSDVEs. Precise coordination among the parties is defined through the end-to-end delay where the parties are connected to an intranet or to the Internet from geographically distributed location. It has been recommended that the end-to-end delay should be within 100 ms [5]. Other Studies have lowered the condition to 200 ms as an acceptable delay [6]. When there are large numbers of users, scalability becomes the most important challenge in DVE. The basic definition of scalability is the ability of the system to withstand an increase in the number of users it supports, without degrading the overall performance and interactive experience.

It is unable to solve the above problems only depending on improving network speed and processing power. We must take measures from the aspect of the software itself, and Interest Management is one of the key technologies to resolve such problems. By Interest Management, lots of unnecessary messages can be filtered among irrelevant entities, so as to decrease the whole virtual environment's network burden. However, the lack of deployment of IP Multicasting over the Internet and other problems introduced by the division of virtual environment should be considered.

Most DVE (Distributed Virtual Environment) systems use IP Multicasting to realize communication for Interest Management, such as NPSNET, DIVE, MASSIVE and etc. In these systems, some Areas of Interest (AOI) are defined by certain rules, and each AOI is mapped to a multicast address. Only entities who are interested in the AOI can receive messages by joining in its multicast

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group, while those who are not interested in it receive no message. Although achieving good results in Intranet environment, the pre-mentioned methods are not readily deployable on the Internet. Reasons include scalability, the fact that IP Multicasting is designed for a hierarchical routing infrastructure and does not scale well in terms of supporting large numbers of concurrent groups, the deployment hurdles caused by manual configuration at routers and Internet Service Providers' unwillingness to implement IP multicasting, marketing reasons due to the undefined billing at the source (content provider) and receivers, and many other obstacles [17]. To overcome the practical lack, an alternative has been proposed to shift multicast support from the networking layer to the end systems and proxies. This is Application Layer Multicasting (ALM).

Dividing the simulation into multiple regions is needed for interest management; however, such division also introduces other problems, such as inter-region interaction and the "bouncing" problem [4]. Some proposed architecture, such as Knutson et al's P2P Support for Massively Multiplayer Games [7] and Limura et al's Zoned Federation of Games Servers [8] offer a discrete view of the nodes: a node is only interested in the region it is in. This approach simplifies the design and makes it more scalable and robust. However, in reality, some nodes should have a continuous view of the virtual world; i.e. be able to "see" nodes in other regions. Thus, the inter-region interaction must be supported by the LSDVEs without increasing too much communicating traffic. Besides, when a node frequently moves at the boundary of the two regions, more connection and disconnections are created and seriously degrade system performance, which is called the "bouncing" problem [4].

In this paper, we present an Interest Management Architecture for LSDVEs, aimed at supporting a large number of users on the Internet. It divides the virtual environment into multiple adjacent hexagonal regions in order to manage the interest of the entities. Messaging among entities is based on a multi-server communication infrastructure by ALM, which combines the merits of both peer-to-peer and client-server infrastructure and overcomes the lack of IP Multicasting. The interest area of each entity is composed of two parts: the inner hexagon and outer hexagon. By the two parts, inter-region as well as intra-region interaction is supported to maintain a continuous view without increasing too much traffic. In addition, the buffer borderlines are introduced to resolve the "bouncing" problem.

The road map of the paper is as follows. The related work is outlined in Section 2. The proposed Interest Management Architecture is covered in Section 3. Section 4 describes the simulation prototype and the evaluation of our mechanism is discussed in Section 5. The conclusion and future work follow in Section 6.

II. RELATED WORK

In literature, there are some methods directed for interest management in large-scale DVE systems. We broadly divide them into two categories. One is the spatial model based on aura, focus and nimbus [9], and the other is region partition. DIVE [10] and MASSIVE [11] belong to the former while NPSNET [12] and SPLINE [13] to the latter. In some systems both are applied, such as WAVE [14].

The spatial model uses different levels of awareness between objects based on their relative distance and mediated through a negotiation mechanism built upon the concepts of aura, focus and nimbus [15]. However, it does not scale well for large numbers of entities, because it requires significant processing resources. Also, as each packet is associated with a custom set of destination hosts, the model cannot take advantage of the packet distribution efficiency provided by multicasting [16].

The region partition is less precise than spatial model, but it is a more scalable way, and can be implemented easily by making the best of multicasting. For example, NPSNET is such a typical system which divides the virtual world into a lot of hexagonal cells. One participant is associated with seven cells that represent its AOI. Hence, it is also a member of seven network multicast groups. The participant's host listens to all seven groups but sends messages only to the one associated with the cell in which it is located. Generally, most of the systems using region partition are based on IP multicasting. Although they achieve good results in the Intranet environment, they are not readily deployable on the Internet.

Some DVE systems only support intra-region interactions, such as DIVE and WAVE, while some support inter-region interactions as well as intra-region interactions, such as NPSNET, SPLINE and MASSIVE. But when the participants interact with other participants in neighbor regions, they must get information of all the participants in neighbor regions. They receive the information that they are not interested in. This degrades the scalability of the system.

Ref. [4] presents a collaborative virtual architecture based on ALM which can be easily deployed on the Internet. To support a large number of users, it divides the virtual environment into multiple adjacent hexagonal zones. The inter-region interactions are also managed by the hybrid node based on one entity's visibility, which decreases unnecessary message propagation. In addition, the introduction of a buffer zone between adjacent zones reduces the number of connections and disconnections that occur when a node frequently moves at the boundary of the zone. However the ways of supporting inter-region interactions and reducing the number of connections and disconnections are too complicated.

III. PROPOSED INTEREST MANAGEMENT ARCHITECTURE

Many aspects must be considered when designing the Interest Management approach for LSDVEs. From the functional aspect, communication architecture, transport protocol, method of region partition and data distribution management both for inner regions and intra regions should be considered. Meanwhile, the performance should also be raised, including improving scalability, reducing end-to-end delay and lessening the impact of the "bouncing" problem, etc. In this section, we will present our interest management architecture and discuss how its design best satisfies these requests in multi-user virtual environments and solves the issues discussed in the previous section.

A. Communication Infrastructure

1．Multi-Server Network Structure Based on ALM

Currently, about four network structures are mainly adopted by DVE. They are peer-to-peer structure based on unicast, peer-to-peer structure based on multicast, client-server structure, and multiple severs structure. The first one has a small delay, while needs more bandwidth. The second one can save bandwidth, while can't deploy well on the Internet. The third one overcomes the deficiency of peer-to-peer structure, while the server becomes a bottleneck which makes scalability hard and introduces serious delay. The last one makes up the shortage of simple client-server structure, while also introduces more serious delay and makes the management more complicate.

ALM not only overcomes the lack of IP Multicasting, but also well supports the Interest Management depending on its multicast mode. The differences between IP Multicasting and ALM are demonstrated in Fig. 1. In Fig. 1 (a), the routers are responsible for replicating and forwarding the messages to finally reach the end-hosts. In Fig. 1(b), the end-hosts are responsible for such replication and forwarding, with no concern on what is happening in the routers. Since routing information is maintained by an application of the end-host rather than at routers, it is more scalable than IP Multicasting. Also, ALM does not require any special infrastructure support, so it is fully deployable on the Internet. However, the disadvantages of ALM are more bandwidth and delay (compared to IP multicasting) for the sake of supporting more nodes and scalability. But ALM-based algorithms have shown "acceptable" performance penalties with respect to IP Multicasting and other practical solutions. [4][17]

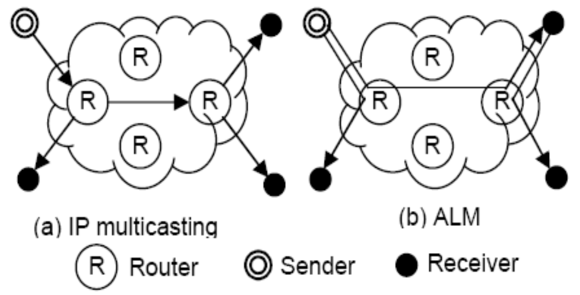

Figure 1. Multicasting Concepts

In practice, nodes in ALM communicate by P2P network structure. Therefore each node can contribute its bandwidth to the overall capacity, which decreases the delay. However, it is much better for the server to realize the information maintenance of all participating nodes in DVE, the establishment of ALM tree and the messaging management. Thus we design a multi-server network structure based on ALM, which combines the merits of both the P2P and client-server structure. Its network structure is shown in Fig. 2. In the structure, there are two kinds of servers: the master server and the region server. The master server is exclusive in the system and fulfills the following tasks. Firstly, it manages all users' basic information and supplies registration, login and logout service for them. Also, it dynamically maintains every entity's occupied region. When one entity moves inside of one region, its occupied region doesn't change, and when moves from one region to another, its occupied region changes. Besides, it is responsible for the management and assignment of region servers. The region server is multiple in the system. And each non-empty region is allocated one region server to connect and manage the nodes that lie in the region and construct the ALM overlay tree. In Fig. 2, two regions' ALM trees are shown, the real lines indicate the physical connection (LAN or Internet); whereas the broken lines with arrowheads indicate the network overlay of ALM tree.

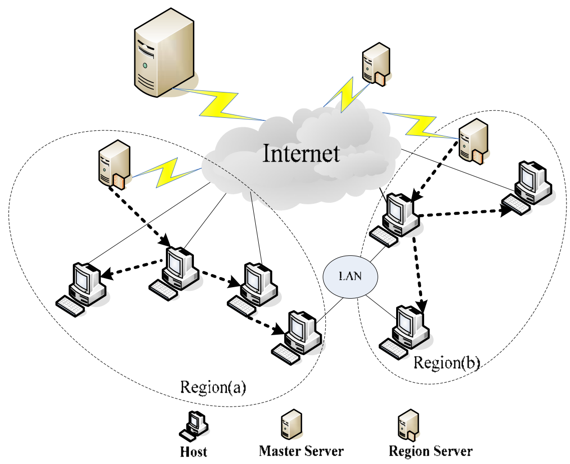

Figure 2. The multi-server hybrid network structure based on ALM

2．Underlying Transport Protocol

Two transport protocols available are TCP and UDP over Internet. It is necessary to choose suited protocols for different kinds of messages in DVE. Generally, the static 3D data are always kept in the host and should not be considered. What should be considered focus on the dynamic data, such as update messages and interactive messages. The update messages describe the change of entities' position, speed and orientation, which are continuous, plentiful and real-time. But for DVE system, losing one of such frequent messages every now and then does not hamper the performance significantly since the state synchronizes itself with the next messages, as long as losses are not for longer periods. It is therefore best for our protocol to use UDP since it is fast and satisfies the objective. The interactive messages mainly focus on the command and event information which requires both guaranteed and real-time delivery, thus Acknowledgement-based reliable UDP is suitable for such key messages. Although TCP takes care of such reliability, it imposes unnecessary overhead on performance, but can be used for users' login and register operation.

B. Interest Management

Based on the above proposed communication infrastructure, we design the interest management model by hexagonal region partition. The interest area of each entity is composed of two parts: the inner hexagon and outer hexagon. By the two parts, inter-region as well as intra-region interaction is supported to maintain a continuous view without increasing too much traffic. Each hexagonal region is mapped to an ALM tree, and the intra-region and inter-region interaction are all managed by the master node in the tree which is the region server supplied by systems. In addition, data filtering based on the leaves' focus can decrease much more traffic. At last, the buffer borderlines are introduced to solve the "bouncing" problem.

1．Region Partition

The hexagon has been widely used in DVE applications and adopted by AOIM papers. We also use it to partition the environment, which is shown in Fig. 3. The dots denote the entities in the regions. The hexagons are much better than other shapes, such as the squares and triangles. Since they are regular shapes, which makes it possible to have a multiple region layout without any gaps. Also, considering a node with a radius of visibility, the maximum number of different zones covered at a time is a 3 , as opposed to 4 for squares and 6 for triangles (Fig. 4)[4][16].

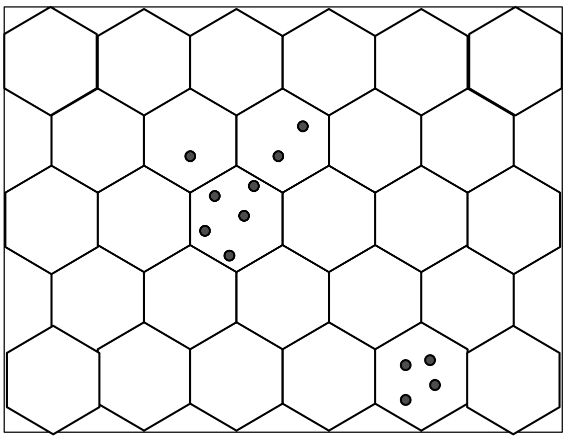

Figure 3. The hexagonal region partition

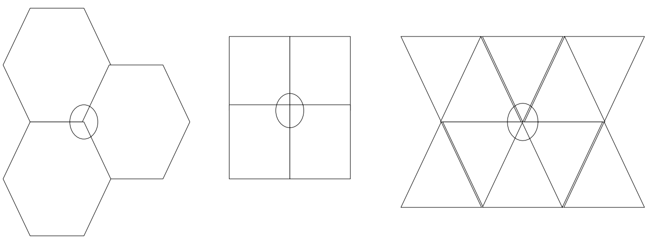

Figure 4. Number of zones covered by a visibility circle in a hesagon, square, and triangle layout

2．ALM Overlay Tree

Each non-empty hexagonal region is mapped to an ALM overlay tree, and gets allocated a special node, called the master node as well as the root node of its tree. The master node constructs and maintains the ALM overlay tree and manages the nodes that lie in its region. Other nodes are the child nodes, whose levels in the tree are decided by their network performance. In some systems, the master node is also a user node in the region [7]. Being a user creates a problem when the master node has to switch zones itself and a reelection process needs to take place. The mater node in our method is a special server which is the region server described in the above section to enhance the performance, although it is a cost for dedicating a region server for each non-empty region.

Fig. 5 gives an example of a three-level ALM tree containing ten nodes. On the one hand, the master node manages the nodes inside the region it is responsible for. It accepts the requests from users joining in the region, and sends a response to the joining node containing a list of potential parents whose uploading bandwidths are suitable. Then the new-joining node selects the best parent based on the end-to-end delay from those selected potential parents. When a node leaves, the master node also takes charge of adjusting its ALM tree without much cost. Since, when a node switches form one zone to another, only its children will have to reconnect, and the tree remains stable. In Fig. 5, when the node 2 leaves, only node 4 and 5 will have to reconnect (sub-tree of node 4 remains intact). On the other hand, except for the leaf nodes, other nodes in the ALM tree also need to transmit messages to one's sub-nodes in the P2P manner, thus more hosts contribute their bandwidth.

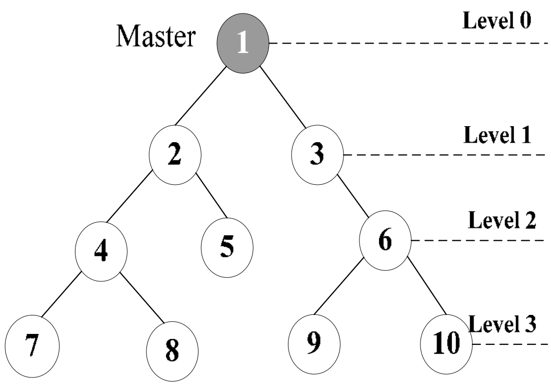

Figure 5. P2P-based ALM overlay tree

3．Communication With Interest

The interest area of each entity is composed of two parts: the inner hexagon and outer hexagon, which are shown in Fig. 5. The inner hexagon is the region where the entity resides. The communication with the entities in the same region is called intra-region interaction. The outer hexagon which is denoted by broken line in Fig. 6 shows its interest in the entities of adjacent regions. Since when the entity's visibility is larger or it is near the boundary of its region, its area of interest will be across its own region. Thus, to maintain a continuous view, this inter-region interaction is needed. Although in some DVE systems, the entity's area of interest are the region where it resides and the adjacent six regions and should receive messages of all the entities in seven regions, which increases unnecessary traffic. We divide the six adjacent regions into twelve small regions, and generally the entity is really interested in the more adjacent six small regions. In Fig. 6, the area of interest of Entities in the region 1 contains region 1 itself and the outer hexagon's six small regions, i.e. the inner hexagon and outer hexagon.

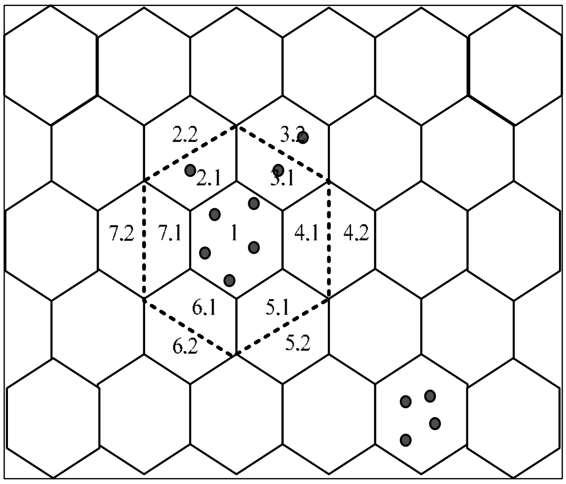

Figure 6. Area of Interest composed of the inner hexagon and outer hexagon

（1）Intra-Region Interaction

In the ALM tree, the node only needs to directly send messages to its sons and the master node. Then the son nodes transmit messages to its sub-tree's nodes according to the overlay of its sub-tree, and the mater node is responsible for transmitting messages to the tree's other nodes according to the overlay of the ALM tree. For example, in Fig. 5, if node 4 produces an update message, it needs to directly send it to the node 7 and 8 as well as the master node 1, while the other nodes, except for the sub-tree of 4, will receive the message from node 1 depending on the ALM overlay tree. If the node 7 has sub-nodes, they will receive the update message by node 7. The transmitting process is shown in Fig. 7, where the real lines with arrows denote direct delivery by node 4 and the broken lines with arrows denote indirect delivery by node 4.

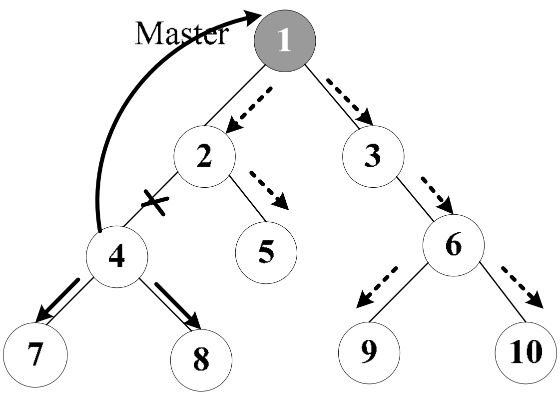

Figure 7. Delivery of node 4's messages

（2）Inter-Region Interaction

The master nodes of adjacent regions control the inter-region interaction. First, the master nodes of six adjacent regions are responsible for transmitting the messages of the entities in the outer hexagon to central region's master node. Then the central region's master node delivers them to its sub-nodes by the ALM overlay tree. If the node in the central region produces an update message, the master node of the central region also needs to send it to the correct adjacent master nodes based on the node's position in the environment. For example, in Fig. 8, if one entity in the central region produces an update message, the master node in the central region must deliver it to the three master nodes in adjacent regions with gray background as well as its own region's nodes.

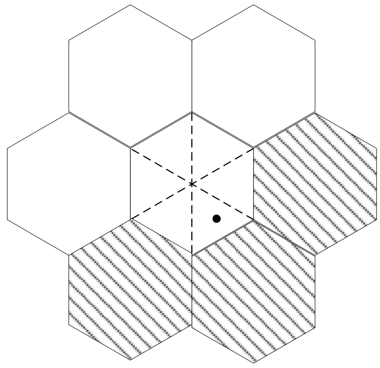

Figure8. Inter-region interaction by master nodes of adjacent regions

（3）Filtering by the Leaf Nodes' Focus

A simple filtering policy proposed in Ref. [4] is also used in our scheme to avoid unnecessary message propagation. In the ALM tree, it might be impractical for each node to get all of its peers' messages depending on the size of the hexagonal region, and unnecessary messages can be filtered based on the leaf nodes' focus or visibility, which is shown in Fig. 9(a). Since not all the messages received from the up levels need to be delivered to leaves because the leaves don't need to deliver messages but only receive messages. The parent can decide whether or not to forward the messages based on the focus interest of the leaf nodes. Thus, every parent node containing leaf nodes can be called Filtering Capable Node (FCN). The FCN is one that can filter out specific messages based on the interest of its descendents. However, not all messages will be filtered out because know about the interest of the nodes two levels below it(not direct descendents). Any node that has a leaf is considered a FCN, which is shown in Fig. 9(b).If the ALM tree is binary tree or the number of its levels is small, this method can efficiently decrease the whole communication burden in the system.

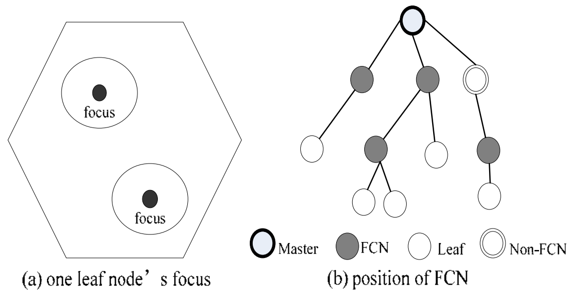

Figure 9. Message filtering inside one region

C. Buffer Borderlines

In a military simulation, for example, a tank unit might often be moving back and forth at the boundary of two regions. Also, a FPS avatar might recurrently enter and leave a combat region to shoot and avoid to be shot respectively. An entity frequently moving around the boundary is called the "bouncing" problem shown in Fig. 8(I), which can bring serious cost to system, such as more connections and disconnections, complicate messaging of the entity itself. In practice, it is needless to disconnect primary region when crossing the boundary justly. Thus the buffer borderlines paralleled with the boundaries are introduced to postpone disconnecting and connecting. For example, in Fig. 10(II), the broken lines a and b are the buffer borderlines. In Fig. 10(II), when an entity moves from A to B, it doesn't carry out the actions of disconnecting and connecting immediately, but postpone these actions until it crosses the buffer borderline b. Such postponing approach won't influence the messaging of the entity, since the area between b and the boundary in B belongs to the entity's area of interest in our interest management approach. The distance between b and the boundary can be an overall variable and adjusted according to the special need by the system. It is a simple way without modifying the partition structure.

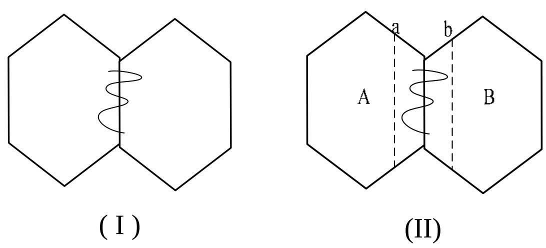

Figure 10. Buffer borderlines in hexagonal regions to resolve the "bouncing" problem

IV. SIMULATION PROTYPE

We implemented a simple war simulation prototype by VC++. An open source 3D graphics rendering engine OGRE (Object-Oriented Graphics Rendering Engine) and a graphics library OpenGL are used in the prototype to simulate the graphical virtual world and the avatar model. The virtual world is divided into multiple hexagonal regions; intra-region and inter-region interaction are realized using our proposed interest management architecture. A master server and multiple region servers are supported in the prototype. Application is composed of three parts: the master server, the region server and the client. A new user should download the client program and install it before joining in the virtual world. This client program renders the static 3D model of the system in the local host, thus, only dynamic messages should be transmitted during the simulation. Fig. 11 represents a snapshot of the application, where the current user is around the house with other users represented by the same avatar model and three airplanes flying in the sky.

Figure 11. Snapshot of the simulation application

V. PERFORMANCE EVALUATION

First of all we evaluate the end-to-end delay about both intra-region and inter-region interaction. Seven adjacent regions with many entities are arranged, and the end-to-end delays of every level's entities in the central region are observed in 2 minutes. Results are shown in Table 1. The source of message is selected among entities both in the central region and the adjacent region, and the end-to-end delays between the selected sources to all levels' nodes are tested. From the table, we can see that if the ALM tree is limited in 3 levels, the end-to end delays both for intra-region and inter-region interaction are smaller than 200ms, which satisfies the request of DVE. But, at the fourth level the delay is unacceptable. Therefore the levels of ALM trees should be restricted. We also find that whether the nodes are from the same ISP or LAN affects the end-to-end delay. Thus it is better for the nodes to select the parent from the same ISP or LAN, which can be guaranteed in our approach because the new-joining node selects the parent with the smallest end-to-end delay. Besides, the performance is better since the delay of inter-region interaction is almost equivalent to intra-region interaction by our communication mechanism.

Table 1. Average end-to end delay about intra-region and inter-region interaction

Source of message	Delay(ms) average at level 1	Delay(ms) average at level 2	Delay(ms) average at level 3	Delay(ms) average at level4
in the region	52.2	90.4	147.4	202.5
Out of the region	71.5	108.2	158.9	215.7

Introducing buffer borderlines near the boundary is also tested. 30 regions and 120 users are deployed. Hexagons have a radius R, and entities move with a maximum speed of 2.4R/hour. The number of joins of all nodes is counted every 5 minutes on the master server in two cases: without buffer borderlines and with buffer borderlines. Results are shown in Fig. 12, which indicates that our method of introducing buffer borderlines to solve the "bouncing" problem works well.

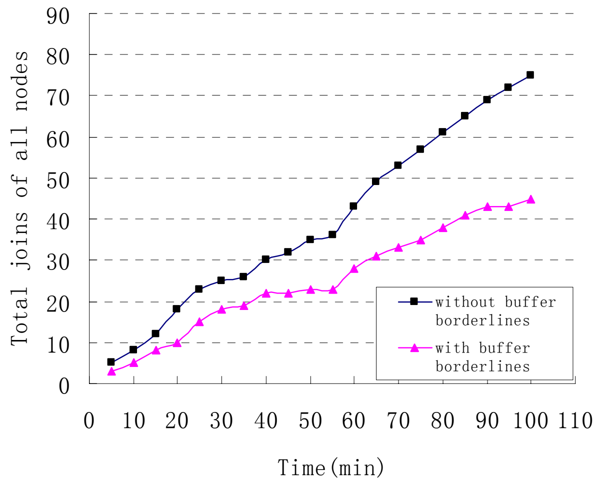

Figure 12. Total Joins of all nodes with buffer borderlines vs. without buffer borderlines

VI. CONCLUSIONS

We have proposed an enhanced Interest Management Architecture that enables interaction in more scalable manner for the large-scale distributed virtual environments over the Internet. The Application Layer Multicasting is used in conjunction with the client-server structure to overcome the disadvantages of IP Multicasting and combine the merits of both peer-to-peer and client-server infrastructure. Scalability is achieved by dividing the world into multiple adjacent hexagonal regions in order to properly organize the entities and efficiently manage their liaison. In the Architecture by ALM and hexagonal region partition, some problems introduced by division of virtual world are considered. First, to maintain a continuous view, the inter-region interaction is supported without increasing too much communication overhead. Besides, the problem of a node frequently bouncing in and out at the boundary of two zones is solved by introducing buffer borderlines near the boundaries. At last, the simulation prototype is given and the evaluation of the architecture is discussed.

Our future work will focus on designing and implementing the dynamic assignment and load balancing techniques of region servers. Since allocating a region server to every non-empty region is wasting. The region with few entities and too many entities should be considered to adopt different ways. Besides, the effective of ALM tree in the Interest Management Architecture should also be improved to support more levels.

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