Research on Multicast Reliability in Distributed Virtual Environment

Yanjun Long  
Network Information Center of Yongzhou Vocational Technical College, Yongzhou Hunan, China  
Email: zgledu@163.com

Jianquan Ouyang  
College of Information Engineering of Xiangtan University, Xiangtan Hunan, China  
Email: oyjq@xtu.edu.cn

Abstract—This paper proposes a novel multicast reliability algorithm in distributed virtual environment. Firstly, architecture of the distributed virtual environment system is made up of three layers, which are 1) Layer 1 is made up of distributed virtual environment server, which can transmit information from internet to clients, 2) Layer 2 is constructed by clients, which are connected to a specific server and can only solve a specific task, and 3) Layer 3 are tasks which should be solved by the distributed virtual environment system. Afterwards, the multicast problem of distributed virtual environment can be converted into a tree network with several nodes, of which the key issue is how to obtain a multicast strategy with the maximum reliability satisfying several constraints. Then, a multicast reliability algorithm for the distributed virtual environment system is present by finding key nodes and key paths in the tree network. Finally, experiments are conducted by both the performance evaluation metric “average cost” and “blocking probability” to demonstrate the effectiveness of the proposed algorithm.

Index Terms—Multicast Reliability, Distributed Virtual Environment, Key Node, Key Path

I. INTRODUCTION

Virtual environment, also known as virtual reality, represents the future of computer interface, which is fully immersive interactive interface. Currently, virtual environment technology has been successfully applied in many areas of medical, military, aerospace, robotics, manufacturing, construction, education and entertainment. When the virtual reality technology is integrated with network technology, a distributed virtual environment technology can be used. In addition, distributed virtual environment is a kind of software architecture, which can support real-time interaction of users around the world. Particularly, distributed virtual environment is a set of network interconnection technology of virtual environment systems to run simultaneously on a computer. Distributed virtual environment has the following three characteristics [1][2].

(1) Space sharing. The virtual space of distributed virtual environment is available for all participants to feel living in the same places. This shared space is available for users to communicate with each other in public places, and it must be guaranteed to all participants in the data and attributes entirely consistent.

(2) Characterization sharing. After each participant comes into the shared space, he becomes to be a virtual person, also known as avatars. When the participants come into the shared space of virtual environment, they can see the distribution of other substitute, and can still see the new substitute to enter and leave the scene.

(3) Time-sharing. In a virtual environment, participants are able to see each other's behavior in a timely manner. In other words, the distributed virtual environment should support the mode of real-time interaction.

With the rapid development of computer technology, network technology, and virtual reality technology, distributed virtual environment performs as an important area of computer science theory and applications and it has made great progress. In order to make the users to share the same time and space in the same distributed virtual environment, different techniques and methods are used to improve the system's consistency and scalability. However, as the scale of virtual environments is increasing, and the interactive features of virtual environment task is getting stronger, these techniques and methods can not meet users’ requirement. In the aspects of time sharing and space sharing, distributed virtual environment faces two major challenges: the first one is information filtering capabilities to further improve the system and the second one is to increase the system interactivity. In order to improve the interactivity of the system, the time and space sharing technology should be improved in the following areas: 1) improving the behavior of the system reproduction accuracy and consistency, 2) consistency control to operate on the same object at the same time support different user, 3) making the system with the task adaptive capacity, 4) providing with suitable reproduction accuracy and consistency according to users engaged in different types of tasks, 5) making the system with the ability of network bandwidth adaptive to select the most important information which are transmitted according to the current bandwidth [3].

Distributed virtual environment is designed based on the traditional virtual environment, so that it can support the function of human interaction. Therefore, virtual
reality technology has five characteristics, which are 1) the shared virtual workspace, 2) the behavior of the pseudo-entity realism, 3) support for real-time interaction and shared clock, 4) a plurality of users communicate with each other in various ways, 5) resources information sharing, and allowing the user to manipulate the object in natural environment. On the other hand, distributed virtual environment system is implemented by combining distributed system with the VR system, which mainly consists of four basic components, including 1) the virtual environment display device, 2) interactive control equipment, 3) processing systems, and 4) data network [4].

As is illustrated in Wikipedia, multicast is the delivery of a message or information to a group of destination computers simultaneously in a single transmission from the source in computer networking. Copies are automatically created in other network elements, such as routers, but only when the topology of the network requires it.

Multicast is most commonly implemented in IP multicast, which is often employed in Internet Protocol (IP) applications of streaming media and Internet television. In IP multicast the implementation of the multicast concept occurs at the IP routing level, where routers create optimal distribution paths for datagrams sent to a multicast destination address. Multicast reliability is a very important problem in distributed virtual environment, therefore, in this paper we study on a novel multicast reliability model for distributed virtual environment.

The main creativity of this paper can be illustrated in the following:

1. We propose a three-layer structure based distributed virtual environment system which could keep high multicast reliability.

2. Three important concepts (“Important node”, “Key node”, and “Key path”) are proposed to describe the main points problem in distributed virtual environment system.

3. A novel multicast reliability algorithm for the distributed virtual environment system through seeking key nodes and key paths in the tree network.

II. RELATED WORK

Distributed virtual environments can simulate the behavior and activities of users who interact with each other in a virtual world based on a large-scale computer network. In the following section, we will survey related works about distributed virtual environments.

Lu et al. points out that 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. Then, they 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 [5].

Bouras et al. introduces virtual objects’ attributes and proposes two approaches that exploit these attributes in order to handle workload assignment and communication cost in DVE systems. Both approaches take into account scenario-specific aspects of DVE systems, such as the impact that entities’ attributes have on each other and the way this impact can affect the system’s state. These scenario-specific aspects are then combined with quantitative factors of the system, such as workload, communication cost, and utilization [6].

Bouras et al. conducts distributed virtual environments again recently in paper [7]. In this paper, the authors present a simulation modeling tool, named STEADiVE for networked servers distributed virtual environments that could be used by designers for evaluating the performance of their approaches under different scenarios and system settings. The validation of the simulation modelling tool has showed that it achieves high accuracy in representing a real DVE system.

Deng et al. conducted a formal analysis of this problem and discuss two efficient delay adjustment schemes to address the problem. Afterwards, the experimental results show that the proposed schemes can significantly improve the performance of the load balancing algorithm with neglect able computation overhead [8].

Duong et al. concentrated on the interactivity-constrained server provisioning problem, whose goal is to minimize the number of distributed servers needed to achieve a prespecified level of interactivity. The authors proposed several computationally efficient approximation algorithms for solving the problem. The main algorithms exploit dependencies among distributed servers to make provisioning decisions. Then, the authors conducted extensive experiments to evaluate the performance of the proposed algorithms [9].

Zhou et al. proposed a novel distributed total order consistency approach with two control algorithms to ensure events are delivered in the identical order. The experimental results demonstrate that through the approach, the processes could effectively maintain the total order delivery with small control overhead [10].

Duong et al. designed a multi-objective approach to the zone mapping problem, in which both the total number of clients without QoS and the migration overhead are considered. To this end, the authors proposed several new algorithms based on meta-heuristics such as local search and multi-objective evolutionary optimization techniques [11].

Morillo et al. proposed the experimental characterization of P2P DVEs. The results show that the saturation of a given client has an exclusive effect on the surrounding clients in the virtual world, having no noticeable effect at all on the rest of clients. Nevertheless,
the interactions among clients that can take place in this types of systems can lead to the temporal saturation of an unbounded number of clients, thus limiting the performance of P2P DVEs [12].

Tang et al. investigated update scheduling algorithms to make efficient use of network capacity and improve consistency in DVEs. The proposed approach is to schedule state updates according to their potential impacts on consistency. In DVEs, the perceptions of participants are affected by both the spatial magnitude and temporal duration of inconsistency in the virtual world. The algorithms can be used on top of many existing mechanisms such as dead reckoning [13].

Belmonte et al. studied on how to manage virtual reality devices as federate resources in a virtual world using the HLA-RTI standard architecture. This approach has been used as a framework to build simulators for training workers in civil engineering [14].

Wang et al. proposed a new methodology for Grid computing - to use virtual machines as computing resources and provide Virtual Distributed Environments (VDE) for Grid users. It is declared that employing virtual environment for Grid computing can bring various advantages, for instance, computing environment customization, QoS guarantee and easy management. A light weight Grid middleware, Grid Virtualization Engine, is developed accordingly to provide functions of building virtual environment for Grids [15].

Haase et al. analyzed the challenges of such an adaptive SoC. It is shown that many of the requirements for an adaptive FPGA-realization are met by the SDVM, the scalable dataflow-driven virtual machine which has been successfully implemented and tested on a cluster of workstations. The SDVM has evolved to a virtualization layer for multicore-FPGAs, now called SDVM (R). This virtualization layer allowed a transparent runtime-reconfiguration of the underlying hardware to adapt to the changing system environment [16].

Chan et al. proposed a distributed sound rendering architecture for real-time sound rendering in a distributed virtual environment with moving observers and sound sources. This paper also proposed the distributed prioritized sound rendering method to improve the rendering performance while preserving the perceptual quality. The new architecture has the advantages that it is based on low cost PCs and is scalable [17].

Van et al. present a novel approach of dividing the virtual world into even smaller parts called microcells. Critical in this approach are the algorithms that manage the microcell allocation over the available servers. These algorithms Must face a number of challenges and have as a central goal to keep the load experienced by the servers below a given threshold. Particularly, the authors present a number of algorithms that determine the microcell allocation and runtime adaptations of the microcell allocation to optimize the deployment [18].

Wang et al. proposed a novel method for constructing distributed scene graphs with high extensibility. This method can support high concurrent interaction of clients and implement various tasks such as editing, querying, accessing and motion controlling [19].

Multicast reliability is an important problem in distributed virtual environment related research, the main work of which are listed as follow.

Xu et al. proposed a reliable ODMRP (R-ODMRP) for preferable throughput and especially suited for high-speed MANET, which includes packet acknowledgement, lost packet recovery, secure authentication and QoS based packet delivery. With the exploration of active network, R-ODMRP constructs the multicast routing based on the cluster, establishes a distributed mechanism of the acknowledgment and recovery of packet delivery. Along with cluster key distributed in one cluster, this protocol can authenticate the consistency of multicast source and receivers depending on local security strategy [20].

Micanti et al. present a packetization strategy for the reliable electronic distribution of Digital Cinema (DCinema, DC) content. A reliable multicast protocol is used to send high definition DC video contents to multiple receivers, allowing them to correctly acquire the entire stream. NORM (NACK Oriented Reliable Multicast) is chosen as multicast protocol, because of the guarantees offered on the reliable transmission of data. The target result is to send reliably DC contents, by exploiting a number of multicast-enabled heterogeneous networks, such as fiber, satellite, WiMAX, and so on [21].

As is well known that distributed virtual environment have becoming a hot research, the reasons are lied in the following two aspects. Firstly, the emergence of distributed virtual environment is a huge challenge to the traditional computer environment. The earliest computer environment aims to support a single-user to complete a task. With the proposal of the concept of the Computer Supported Cooperative Work (CSCW), computer environment begins to aims at multiple users to complete a task collaboratively. Particularly, these environments are either character-oriented or graphics-oriented. Distributed virtual environment is not only designed for multiple users to complete a task and type interface, but also provides a fully immersed user experience. Secondly, the research field of distributed virtual environment is related to computer science research areas, including: Computer Supported Cooperative Work, Human-Computer Interaction, Virtual Reality, Artificial Intelligence, and Multimedia Technologies and so on. As distributed virtual environment is interdisciplinary, more and more researchers put themselves in the field of distributed virtual environment related research.

As is shown in Fig.1, we give the architecture of the distributed virtual environment system, which is made up of three layers structure. The first layer is made up of distributed virtual environment server, which can transmit information from internet to clients. The second layer is constructed by clients, which are connected to a specific server and can only solve a specific task. The third layer are tasks which should be solved by the distributed virtual environment system.
To explain the above distributed virtual environment system in detail, we illustrated the internal structure of it in Fig.2, which is made up of DVS server and client and are connected through network through TCP/IP stack.

III. MULTICAST RELIABILITY SCHEME IN DISTRIBUTED VIRTUAL ENVIRONMENT

A. Problem Statement

Based on the architecture of distributed virtual environment system shown in Fig.1, the multicast problem of which can be converted into a tree network with $n$ nodes. Then, information of distributed virtual environment system can be transmit from root node to leave node. In this tree, the edge $E_{uv}$ has a reliability value $r_{uv}$, which represents the reliability degree to transmit useful information from node $u$ to node $v$. Hence, the reliability of multicasting information is important in this communication mode. The key issue is how to obtain a multicast strategy with the maximum reliability, satisfying the above constraints. The formal description of the proposed problem is shown as follows.

\[
\max \prod_{E_{uv} \in T} r_{uv}^{l(v)} \quad (1)
\]

where $l(v)$ denotes the number of leave nodes in the subtree with node $v$ as the subtree root.

Afterwards, using the intermediate node, we could re-defined the above problem. All the nodes in the tree network can be classify into $k+1$ node sets ($N_0, N_1, \ldots, N_k$), and the root node is belonged to set $N_0$. Adding the intermediate nodes in the proposed tree network can enhance the reliability of the distributed virtual environment system. The whole multicasting process can be illustrated by the following steps:

1. The root node $N_0$ issue a message to its sub-layer node in $N_i$ and each leaf node is located in $N_i^c$ or located in the descendants which belonged to $N_i$.
2. For $2 \leq i \leq k-1$ ($i$ refers to the id of time period)
3. If the node in $N_{i+1}$ is not a leaf node then
4. Send information to the sub-tree of the given node
5. End if
6. Each intermediate node can receive the information from only one other intermediate node
7. End for
Next, we will study on how to enhance the reliability for the above multicast process. Particularly, we can convert the reliability enhancing problem to the information transmitting cost minimizing problem, which can be formally described as follows.

\[ \text{Min } \sum_{e \in E} \text{cost}(E_{uv}) \]  \hspace{1cm} (2)

where \( m \) refers to the number of nodes in the graph, and \( \text{cost}(E_{uv}) \) denotes the cost of information transmitting through the edge \( E_{uv} \).

B. Multicast Reliability Algorithm

To achieve the target which is denoted in Eq.2, in this sub-section, a multicast reliability algorithm for the distributed virtual environment system is proposed. Before giving the multicast reliability algorithm, some concepts should be defined in advance.

Definition 1 (Important node): For the given network tree, the important node denotes the node which has the sum of in-degree and out-degree larger than a predefined threshold value.

In this paper, the predefined threshold value is set to three.

Definition 2 (Key node): For the given network tree, the key node denotes the node which satisfy the following two conditions:
1) the node is belonged to the important node;
2) the node’s degree is equal to one.

Definition 3 (Key path): For the given network tree, the key path denotes the path which connect two key nodes.

Based on the above three definitions, the multicast reliability algorithm is given as follows.

Algorithm: Multicast reliability algorithm for the distributed virtual environment system

Input: All the nodes in the tree network \( (N_0, N_1, \ldots, N_k) \), and the root node is belonged to set \( N_0 \).

Output: The reliability multicast scheme for the proposed network.

(1) For each node \( n_j \) in the tree \( (N_0, N_1, \ldots, N_k) \)
(2) If the required reliability of node \( n_j \) is not satisfied
(3) Add node \( n_j \) into node set \( S \)
(4) If node set \( S \) is empty
(5) Goto to step 17
(6) Else find out the key node and key path in the given network.
(7) End if
(8) End for
(9) While node set \( S \) is not empty
(10) Choose a node \( n_j \) in \( S \)
(11) Remove the edges which are connected by node \( n_j \) to obtain a sub-tree.
(12) For each edge in the sub-tree
(13) Set information transmitting cost value of each edge zero
(14) Finding the edge with the least const value
(15) Add the edge in to the reliability multicast scheme
(16) End for
(17) Return the reliability multicast scheme

IV. EXPERIMENTS

To test the performance of the proposed algorithm, we design a series of experiments to make performance evaluation with comparison to other methods, which are 1) RMX \([22]\), 2) RMF \([23]\), and 3) AG \([24]\). The algorithm is denoted as MR-DVE in the following parts.

In our experiments, three parameter are tuning to make evaluation, including: reliability level \( r \), network scale \( T \).

In the experiment 1, the average cost is used as the performance evaluation metric. Firstly, we test the performance for different methods when reliability level and network scale is changing, and the results are shown in Fig.3 and Fig.4.

In the experiment 2, the blocking probability is used as the performance evaluation metric. We test the performance for different methods when reliability level and network scale is changing, and the results are shown in Fig.5 and Fig.6.

From the above experimental results, it can be seen that for both the performance evaluation metric “average cost” and “blocking probability”, our proposed algorithm-MR-DVE has lower average cost and blocking probability values.

The reasons lie in the following aspects:
(1) Analyzing the RMX method \([22]\)

The RMX approach splits a large heterogeneous reliable multicast session into a number of multicast data groups of co-located homogeneous participants. A collection of application-aware agents-Reliable Multicast proxies organizes these data groups into a spanning tree using an overlay network of TCP connections. However, the computing cost of this method is not considered. Hence, the computing speeding and accuracy is not satisfied.

(2) Analyzing the RMF method \([23]\)

RMF is a scalable reliable multicast algorithm that was first developed to support wb, and this approach is based on the fundamental principles of application level framing (ALF), multicast grouping, and the adaptivity and robustness in the TCP/IP architecture design. However, the algorithm of key nodes searching of this paper in not efficient enough, therefore, the performance of which is less than our method.

(3) Analyzing the AG method \([24]\)

AG is a scalable method to improve packet delivery of multicast routing protocols and decrease the variation in the number of packets received by different nodes. The proposed protocol works in two steps. In the first step, any suitable protocol is used to multicast a message to the group, on the other hand, in the second step, the gossip protocol tries to recover lost messages.
Fig. 3 Average cost for different schemes with the reliability level changing.

Fig. 4 Average cost for different schemes with the network scale changing.

Fig. 5 Blocking probability for different schemes with the reliability level changing.

Fig. 6 Blocking probability for different schemes with the network scale changing.
However, AG has not tried to improve upon the efficiency and scalability of MAODV itself. Particularly, AG would not work if the links are unidirectional. Hence, the performance of AG can not be satisfied.

4) Analyzing the method proposed in this paper (MR-DVE)

Different from the above methods, in this paper, the architecture of the distributed virtual environment system is made up of three layers: 1) Layer 1 is made up of distributed virtual environment server, 2) Layer 2 is constructed by clients, which are connected to a specific server and can only solve a specific task, and 3) Layer 3 are tasks which should be solved by the distributed virtual environment system. The proposed three-layer distributed virtual environment system can keep high multicast reliability.

On the other hand, the performance of our method performs better than other methods, because our method introduces three important concepts, which are 1) Important node, 2) Key node, and 3) Key path, and then we propose a multicast reliability algorithm for the distributed virtual environment system through seeking key nodes and key paths in the tree network.

Hence, we can know that our algorithm can provide reliability multicast service for the distributed virtual environment systems.

V. CONCLUSIONS

In this paper, we study on how to satisfy reliable multicast requirement in distributed virtual environment. Firstly, three-layer architecture of the distributed virtual environment system is given. Based on the given three-layer architecture, the multicast problem of distributed virtual environment can be converted into a tree network with several nodes, by seeking key nodes and key paths in the tree network. Experimental results show the effectiveness of our approach comparing other methods.

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