An Interest Filtering Mechanism Based on LoI

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Abstract. In large-scale DVE (Distributed Virtual Environment), data filtering is a critical factor to consider in connection with the real-time communications between simulators geographically separated. However, several existing data filtering mechanisms such as region-based, grid-based and hybrid ones result in limitations in computational complexity, filtering accuracy, or scalability. Aiming at providing an extensible filtering approach and reducing the overhead on both host and network, we propose an interest filtering mechanism based on LoI (Layer of Interest). The mechanism performs data filtering by means of multicast region publication, distributed receiver-side matching, and LoI-Based data filtering. We have implemented the mechanism into our RTI (Run-Time Infrastructure) software, and experiments are taken to demonstrate the effectiveness of it.

Keywords: DVE, Interest Filtering, DDM, LoI.

1 Introduction

DVE (Distributed Virtual Environment)[1], based on the technology of virtual reality and network, has become an important field in computer technology. As the continuous increment on the amount of entities, scalability becomes the main issue of the virtual environment. In order to lessen the heavy burden on network and hosts, data filtering mechanism should be taken into consideration.

DDM (Data Distribution Management) services in HLA(High Level Architecture) [2][3] implement data refinement by means of region matching. One critical issue in the data filtering mechanism is the computation of intersections between update and subscription regions. There are three main categories of approaches to perform this filtering process [4]: region-based, grid-based and hybrid method. Some other approaches such as agent-based filtering mechanism [5] and sorted-based matching algorithm [6] are also proposed. No matter how effective these mechanisms would exhibit, all of them have limitations in computational complexity, filtering accuracy, or scalability.

Aiming at reducing the complexity of computation, alleviating the problem of inaccurate matching, and providing an extensible filtering mechanism, we propose an interest filtering mechanism based on LoI. The mechanism performs region matching by means of multicast region publication and distributed receiver-side matching, which is propitious to the extensibility of the applications.

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2 Related Work

In this section, several existing filtering approaches are listed and summarized and their advantages as well as disadvantages are intensively analyzed. In the end, our previous research made by Zhou is presented for further discussion of our mechanism.

In region-based approach, an update region is checked with all subscription regions, and a connection between publisher and subscriber is established only if their regions overlap. A centralized DDM Coordinator is responsible for collecting all the region information and carrying out the matching process. MAK Technologies [8] has adopted this approach in DDM implementation of the MAK RTI [9]. Despite its simplicity in implementation, the approach brings large amount of computation overhead and cannot avoid recalculating matches when an update region changes. As [11] has announced, the region-based approach only favors a federation that efficiently manages the number of regions and region modifications.

In grid-based mechanism, update and subscription regions are assigned to one or more grid cells according to the region's covering ranges. Data distribution is determined by whether there are common coverage cells between the update region and subscription region. DMSO of DoD [10] implements their RTI Next Generation (RTI-NG) on the basis of grid filtering [11][12], and Azzedine Boukerche also proposes a filtering mechanism based on grid [13]. Grid-based mechanism greatly reduces the computational overhead by means of mapping regions to grid cells, but it has disadvantage in filtering accuracy, for irrelevant data may be received by the subscribers who are not interested in it.

The hybrid approach is proposed in order to reduce the computational complexity in region-based approach as well as irrelevant data transmission in grid-based approach. Pitch Technologies AB has adopted this approach in their pRTI [14]. Gary Tan and Azzedine Boukerche also proposed DDM implementation based on hybrid approach. In Gary Tan's design [15], a centralized DDM Coordinator is assigned to each cell, and all the regions cover this cell is delivered to it by means of point-to-point communication. The coordinator is responsible for matching regions and establishing multicast groups. In Azzedine Boukerche's Grid-Filtered Region-Based DDM [16], instead of a centralized coordinator for each cell, the grid cells are assigned evenly to the joined federates. The hybrid mechanism gets a balance between computation and accuracy. However, centralized coordinator or federate manager limit the scalability and point-to-point region delivery to the centralized node increase the network overload.

In our previous research, Zhou has proposed the concept of LoI to extend HLA and provide a mechanism of DDM implementation [7][17]. LoI is defined as an enumerate value to represent a particular degree for the interest on instance attributes. To perform the data distribution mechanism, five kinds of LoI variables are defined and two theorems based on the definitions are proposed and proved. The definitions and theorems are listed in Table 1 and Table 2. The two theorems give an effective approach in data filtering, which greatly reduce the irrelevant data transmission.

Table 1. Definitions of the LoI

Symbol	Definition
$P_m^{(i)}$	LoI of publisher over object class ***i*** with ***m***-size attribute set
$p_m^{(i,o)}$	LoI of local object instance ***o*** of object class ***i*** with ***m***-size attribute set
$\eta_j^{(i,o)}$	LoI of attribute update/reflect with ***j***-size attribute set of object instance ***o*** of object class ***i***
$S_k^{(i)}$	LoI of subscriber over object class ***i*** with ***k***-size attribute set
$s_l^{(i,o)}$	LoI of remote object instance ***o*** of object class ***i*** with ***l***-size attribute set

Table 2. Theorems of the LoI

Theorem	Description
Update Rule	A publisher can only send attribute updates of LoI $\eta_j^{(i,o)} \le p_m^{(i,o)}$
Reflect Rule	A subscriber can only receive attribute reflects of LoI $\eta_j^{(i,o)} \le s_l^{(i,o)}$

3 LoI-Based Interest Filtering Mechanism

In this section, we propose a hybrid interest filtering mechanism on the basis of LoI to perform data filtering in large scale DVE. The mechanisms on both grid filtering and region matching are improved comparing to existing hybrid approaches.

3.1 Outline Design

In order to avoid the disadvantage of centralized matching, we make our new mechanism carry out distributed matching on the receiver's side. Accordingly, multicast is adopted as the transmission strategy for the delivery of update region. The multicast groups are allocated in advance for each cell. Once the subscribers express their subscription region, they automatically join the multicast group that their regions cover and will send a request to all the publishers. In the next step, the publishers record related information for the requests and multicast their instances with update regions to multicast groups they cover periodically in the loop "heartbeat" thread. Then, on the subscriber's side, a region matching process based on LoI is made, and the feedbacks are sent back to the publisher. At last, the publisher route update data to multicast groups according to the feedback it receives. During this period, both the publisher and subscriber will perform data filtering in order to abandon irrelevant data packets. Fig. 1 shows an outline view of the mechanism.

At the publisher's side, a local instance list L_{local} is stored and updated in time, which contains all of the object instances that the publisher owns. For each object instance (I_k, $k \in N$, $0<k\le$ *size of* L_{local}) in the list, a group of fields are recorded, In which, $g_u^{(i,o)}$ represents the handle of multicast group that instance *o* of class *i* is bound to, and $f_u^{(i,o)}$ is a Boolean "dirty flag" identifying whether the update region of

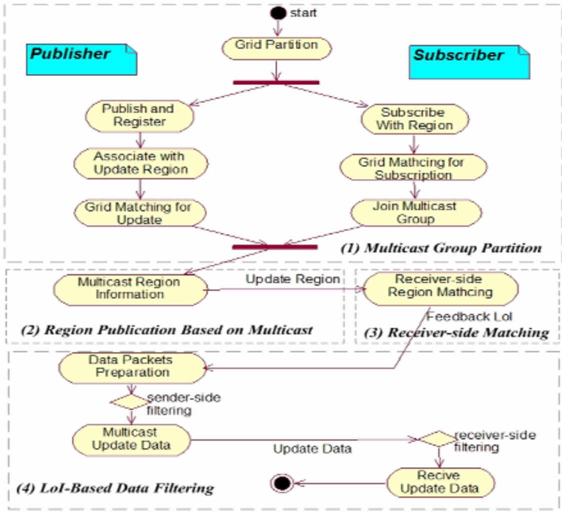


Fig. 1. Outline View of the LoI-Based Interest Filtering Mechanism

instance o has been changed without notifying others. At the subscriber's side, a similar remote instance list L_{remote} is preserved for each object instance the subscriber discovers. The following two definitions are needed for region publication by multicast.

– *Definition 1*: Let T denote an array for each multicast group that at least one of the publisher's local instances has been bound to. Each element in the array denotes the number of joined subscribers in the multicast group.

$$T = \{ T_i \mid T_i = \text{number of joined subscribers of the group } i, \quad 0 < i < \text{total number of multicast groups} \} \tag{1}$$

– *Definition 2*: Let r denote the count of multicast groups that at least one of the publisher's local instances has been bound to and at least one subscriber has joined.

$$r = \text{the size of } \{ T_i \mid T_i \in T, T_i > 0 \} \tag{2}$$

3.2 Multicast Group Partition

We assign multicast groups for grid cells before the initialization of simulation process in order to utilize the advantage of multicast to deliver both the region information and data packets. Fig. 2 shows a two-dimension 4×4 grid. For each grid cell C_{ij}, a multicast group M_{ij} as well as a characteristic coordinate (x_i, y_j) is assigned.

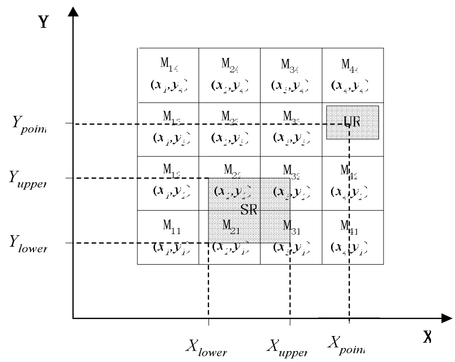


Fig. 2. Pre-assigned Multicast Groups and the Region Covering Mechanism

A subscription region with two dimensions can be denoted by the following two ranges, each on one dimension respectively: [X_{lower}, X_{upper}], [Y_{lower}, Y_{upper}]. A binary search is performed for each point in the subscription region to match the region with characteristics of grid cells. By this means, the subscribers can determine their multicast groups to join. After joining the multicast group, the subscriber should send a request with the corresponding multicast groups to all of the publishers, in order to trigger the region publication from the related publishers. When a subscriber cancels its interest on one region, it leaves the multicast group accordingly.

On the publisher's side, since update region is usually assumed small range of areas in real exercises, we consider it as a point when covering with multicast groups, as shown in Fig. 2. The algorithm to determine multicast groups then becomes covering cells with one point. The same binary search method is used as that of the subscription region. After determining the covered multicast group, the publisher then associates it with the related object instance in L_{local} by assigning $g_u^{(i,o)}$ with the group handle. The publisher should also record and update the values of T and r we previously mentioned after receiving requests from the subscribers. The two variables are to be used in the region publication period.

3.3 Region Publication Based on Multicast

The pre-assigned multicast group and determination of covered multicast groups for publishers and subscribers have got prepared for the region matching step. In this step, the publisher multicasts its update region to its covered multicast groups, where the related subscribers has previously joined and prepared to receive the update region information. An instance's information needs to be sent out for notifying others when any of the following situations occur:

– *Situation 1.* (required by subscribers) One or more subscribers have joined the multicast group that the instance is bound to. The variables T and r defined in 3.1 has recorded the situation. The related operation can be described as follows:

```
IF r > 0 THEN
    FOR each object o in L_local
        IF T[ g_u^(i,o) ] > 0 THEN multicast o to g_u^(i,o)
REPEAT
```

– *Situation 2*. (region changed) The instance's corresponding update region has been changed by region modifying services. The dirty flag variable $f_u^{(i,o)}$ in the local instance record can represent this situation, and operation for the situation is defined as:

```
FOR each object o in L_local that f_u^(i,o) ==true
        multicast o to g_u^(i,o)
REPEAT
```

– *Situation 3.* (object instance verification) A subscriber needs to know whether their discovered remote instances are still existing and valid in the federation execution on account of the consistency issue, so a periodically multicast of all the local instances is necessary even without any changes and requests. We define the operation as follows:

```
FOR each object o in L_local
        multicast o to g_u^(i,o)
REPEAT
```

We design our mechanism by assigning a periodically sending thread called "heartbeat" thread to all the publishers. The thread will multicast local instance information to related subscribers when any of the three situations occur. We choose a fixed time interval variable τ and make the heartbeat thread working as follows:

1. In every τ ms, do operation on *situation 1.*
2. In every 2τ ms, do operation on *situation 2.*
3. In a relatively long period (perhaps $10\text{-}15\tau$), do operation on *situation 3.*

This approach achieves a balance between simulation requirement and host overload. The accurate value of τ is adjustable according to the actual condition of network.

3.4 Distributed Receiver-Side Matching and Feedback

After receiving update region information from the multicast group, the subscriber will take a receiver-side matching to determine its $s_l^{(i,o)}$ (LoI of remote object instance). The LoI will be used for data filtering in the next step.

For convenience of discussion, we introduce our matching algorithm under the condition of 2 dimension (x,y) and 3 Layers (NO_LAYER, LAYER_VISION, LAYER_ABOUT). Fig. 3 shows the matching rules for the three layers. The auxiliary regions for LAYER_VISION and LAYER_ABOUT is introduced, the former is congruent with the original subscription region, while the latter is achieved by dividing each range of the former region with a constant value *EXTEND*. The two auxiliary regions indicate the rules for region matching. The subscriber performs

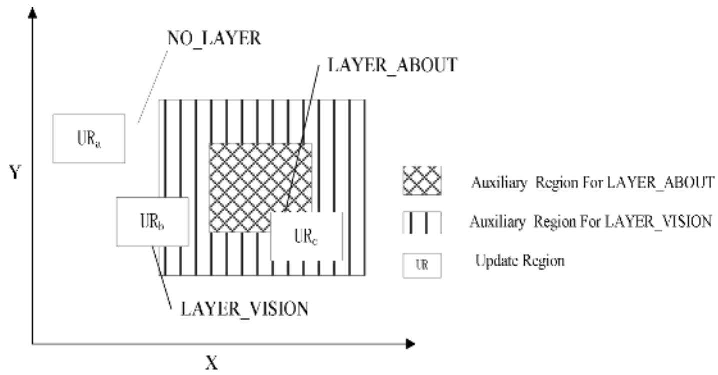


Fig. 3. Matching Rules for Three Layers

accurate matching for each pair of update region and subscription region, and for which the update region intersects with, the corresponding layer is returned. Otherwise, if no intersections occur, NO_LAYER is returned.

At last, the subscriber sends the $s_k^{(i,o)}$ back to the publisher for the sender-side data filtering. Meanwhile, it also preserves one copy of $s_k^{(i,o)}$ for each discovered instance o of class *i* in its L_{remote} in order to perform the receiver-side filtering.

3.5 Data Filtering Based on LoI

The aim of receiver-side region matching is to reduce the data transmission in data routing. During the data routing period, the publisher and subscriber will both take a filtering operation to discard irrelevant data. The following three steps are taken:

– *Step 1.* sender-side filtering

As discussed in [7], the publisher calculates $R_u^{(i,o)}$ according to the receiver-side feedbacks and its own $P_m^{(i)}$. Since $P_m^{(i)}$ contains necessary matching result of the subscriber, it becomes the measurement for sender-side filtering. According to the *Update Rule Theorem* mentioned in *Section 2*, the data packets whose $\eta_j^{(i,o)}$ is greater than or equal to $p_m^{(i,o)}$ will be discarded.

– *Step 2.* data routing in the network based on multicast

After sender-side filtering, the data packets reserved will be sent to the multicast group that the publisher holds. Multicast assures that all of subscribers interested in this data packet will receive it from their previously joined multicast groups.

– *Step 3.* receiver-side filtering

The sender-side filtering can hardly eliminate all the irrelevant data. Every subscriber checks data packets it receives by comparing $s_k^{(i,o)}$ with the $\eta_j^{(i,o)}$ attached in the update packets. Each instance *o* whose $s_k^{(i,o)}$is greater than $\eta_j^{(i,o)}$ will be discarded, as described in the *Reflect Rule Theorem* mentioned in *Section 2*.

4 Experiment and Result Analysis

In order to verify the new mechanism, we have implemented it into our HLA compatible RTI software-BH RTI. Experiments are carried out based on BH RTI within a tank war-game scenario as shown in Fig. 4. The experiment was taken on 2 PCs with 3.0 GHz Intel Pentium 4 CPU and 512 MB RAM on 100M Ethernet.

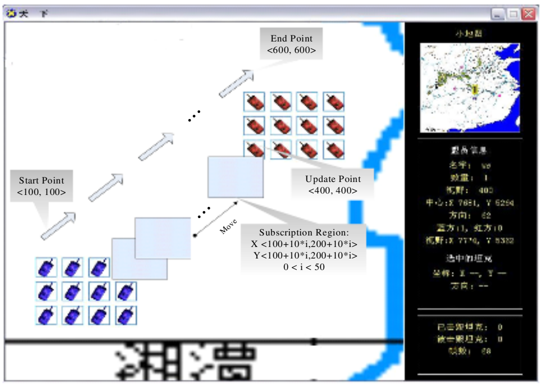
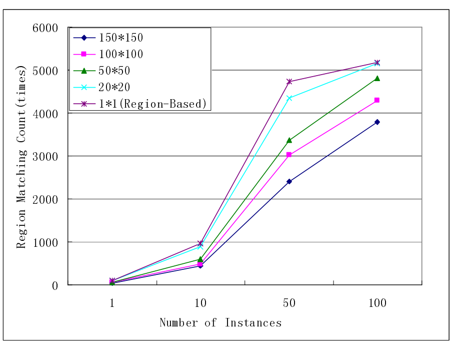


Fig. 4. Scenario of the Experiment

For comparison with the region-based approach, we record the region matching count (indicating load on hosts) at the receiver's side as well as the data transmission amount on the network (indicating load on the network). The results of experiment are based on different number of instances and grid cell divisions, as shown in Fig.5 and Fig.6. The region-based approach is indicated by 1*1 grid cells.



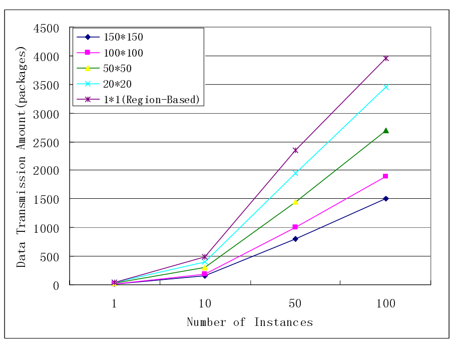


Fig. 5. Region Matching Count **Fig. 6.** Data Transmission Amount

As expected, the new interest filtering mechanism leads to less region matching count and data transmission amount on the network than the region-based approach. As the number of instances increases, the advantage becomes obvious enough to enhance the performance of both the hosts and network in large-scale DVE. We also conclude from the result that both the region matching count and data transmission amount are improved by the increase of grid cell.

The receiver side filtering is inevitable for accurate data reflection, as we analyzed in *Section 3.5 Step 3*. In large-scale DVE, the amount of data that the receiver filtered is also a factor to influence the load of hosts. We calculate the efficiency on receiving in our mechanism by means of dividing the data packages received by the packages eventually processed at the receiver's side. Results are shown in Fig. 7.

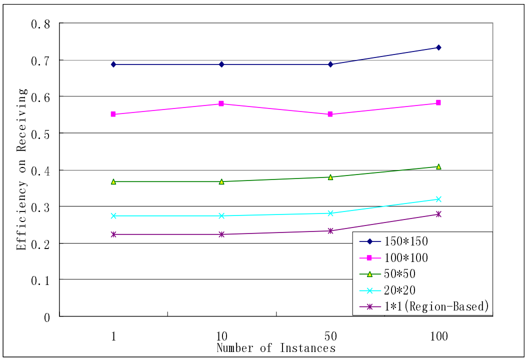


Fig. 7. Efficiency on Receiving

As the resolution of grid division increases, efficiency on receiving increases accordingly. When grid division reaches 150*150, nearly 70% of the packages received by the receivers are effective. That means only 30% of all the packages are to be filtered by the receivers. The resources of computation are greatly saved. The experiment also demonstrates that we may take higher resolution grid division in the scope of specific exercise in order to reduce unnecessary data transmission.

5 Conclusion

Data filtering is of vital importance in contributing a large-scale DVE. In this paper, an interest filtering mechanism based on LoI was proposed to implement data filtering in DDM Services and support for large-scale DVE. The mechanism adopts a distribute receiver-side region matching strategy and carry out data filtering based on LoI. We have implemented the mechanism in our RTI software. Experiment on region matching count, data transmission amount, and efficiency on receiving demonstrate that the mechanism is able to lessen the overhead of both hosts and network in large-scale DVE.

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