A Multicast Island Partitioning Model of OMN Based on Fuzzy Recognition

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Summary

In order to partition nodes into the nearest MIs (Multicast Islands) in overlay multicast network (OMN), a MI partitioning model is designed. The model uses RTT (Round Trip Time) of links and the network-accessing frequencies of nodes as properties to partition nodes to the nearest MIs, whose centre are called MSNs (Multicast Service Nodes). Also, the similarity degree between nodes and relevant MSNs and the objective function of MI is designed under fuzzy condition. Then, an optimal fuzzy recognition matrix is calculated and analyzed including its algorithm. Finally, results from the simulation verify the feasibility and validity of the model.

Key words:

Multicast island; Partitioning model; Overlay multicast network; Fuzzy recognition

1. Introduction

For Current Internet based on the Best-Effort unicast content delivery mechanism, it is difficult to transmit large-scale, multi-point content with large receiver sets, especially for multi-channel real video streams. IP multicast has been regarded as an efficient delivery mechanism over Internet [1-3]. Compared with the point-to-point unicast delivery protocol, IP multicast is inherently bandwidth-efficient and scaleable. However, as a router-dependent multicast service, IP multicast has not widely adopted by most commercial ISPs because of deployment, network management, and support for higher layer functionality, and thus large parts of the Internet are still incapable of native multicast more than a decade after the protocols were developed [2].

Overlay Multicast Network (OMN) is emerging as a fundamental technique to solve the problems mentioned above [3]. On the basis of current Internet with the Best-Effort unicast content delivery mechanism, it builds an application level multicast (ALM) architecture by having the end users (nodes) to self-organize into logical overlay networks for packet delivery. According to organizing manners of nodes, the OMN can been classified into two types: host based or infrastructure (proxy) based [3]. In the host based multicast, the OMN is constructed by end-users , and the data duplication, multicast data forwarding, and group members' management and other functions are all achieved at these end-users in the groups. In proxy based multicast, some nodes are strategically deployed within the network. Then, according to the applications' requirement, these nodes autonomously form overlay multicast trees to provide multicast service. Obviously, compared with the host based multicast, latter has a higher stability and can easily provide QoS service to real-time multicast streams of multimedia applications such as audio and video conferencing [3].

Regarding to the real-time transmission of video streams, the transmitting delay should be minimal because of the stronger relevance between video sequence packets. The high delay may cause the video packets not to been decoded. In order to guarantee the high quality video transmission within OMN, extensive researches have been carried on [4-6]. Most of the researches focus on designing efficient routing protocols to achieve to minimize the video packet transmitting delay, while the physical topology information is seldom considered. The logic transmission routing path in the OMN is possibly circuitous in the physical topology level. In this case, overlay network routing algorithm certainly cannot give the very good solution to minimize the video packet transmitting delay.

Yeo[3] reviewed the current OMN model, and gave a comparative insight into their performance, then got the conclusion that different OMN architectures could cause the varieties of network delay when forwarding multicast data. Tree-based OMN architectures, being more topology aware, are better able to exploit underlying network topology for efficient data distribution, and to minimize the packet transmitting delay in maximum degree.

Enlightened from the conclusion, a tree-based OMN architecture is established, which is shown in Fig. 1. MSNs are strategically deployed within the network to build a proxy-based multicast Infrastructure. Aimed to minimize average latency of the entire overlay multicast tree and improve the data-transmitting efficiency, we design a MI partition model to partitioning receiving nodes to the nearest MSN for data forwarding. The MSN and its group members construct Multicast Islands (MIs). When video sequences are transmitted by OMN, the last hop has an important effect on the average latency of the entire

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overlay multicast tree. So we focus on the partition of leaf nodes to simplify the research.

The rest of this paper is organized as follows: Section 2 introduces the design of MI partition model, including definitions of similarity degree between nodes and MSNs and the objective function of MI, then calculates then optimal MI partitioning matrix under fuzzy condition; Section 3 simulates the partition model, and the results verify the feasibility and validity of the model; Finally, conclusions are carried out in section 4.

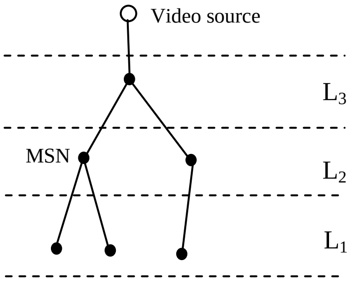

Fig. 1 A tree-based OMN architecture

2. Design of MI Partitioning Model

2.1 Problem Formulation

To construct a proxy-based overlay multicast tree, the first is to deploy fixed MSNs within network, then MSNs are taken as the clustering headers, and a model is designed to partition the nodes into MIs. The purpose of the MI partition model is to partition the node to its nearest MSNs to minimize the average delay of entire multicast tree, meanwhile, to improve the data delivery efficiency in OMN. So, according to the characteristics of real-time video transmission, we take RTT between nodes and MSNs and node's network-accessing frequencies as properties of nodes.

2.2 Similarity Degree and Objective Function

Suppose that there are *n* network nodes with *m* dimensions to been partitioned into *c* MIs, and the MI is specified by the corresponding MSN. Let $x_j\,(j=1,2,\cdots,n)$ be a property vector of *m* dimension in order to denote the *j*th network node. Let x_{ij} denote the *i*th property value of x_j where $i=1,2,\cdots,m$, and $j=1,2,\cdots,n$.

In OMN, according to the requirement for link delay and received image quality, the nodes property weight vector is defined as

$$W=(w_1,w_2,\cdots,w_m)^T\subset R^m\,,\quad \sum_{i=1}^{m}w_i=1 \qquad (1)$$

Where $w_i\,(i=1,2,\cdots,m)$ represents the *i*th property weight of x_j.

The squared generalized weighting Euclidean distance is used to denote the distance (similarity) between nodes and MSNs. So, the distance between the *j*th node and the *h*th MSN is determined by the following formula

$$\left\|w_i(s_j-v_h)\right\|^2=\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2 \qquad (2)$$

Where v_h denotes the *h*th MSN's property vector, and v_{ih} denotes the *i*th property value of v_h, and s_j is the normalized form of x_j to eliminate the influences caused by different dimensions of the property value. The mapping relation between s_j and x_j is determined by the following formula

$$x_{ij}\to s_{ij}=\frac{x_{ij}-x_{i\min}}{x_{i\max}-x_{i\min}} \qquad (3)$$

For fuzzy recognition, the same network node does not belong exclusively to a MI. So, we use the degree of membership u_{hj} denotes the ratio that the *j*th node belongs to the *h*th MSN. Meanwhile, to reasonably express the diverse distances between the measured node and corresponding MSNs, we take u_{hj} as the weight of the distance between the *j*th node and the *h*th MSN. So, the similarity degree of the *j*th node and the *h*th MSN is defined by the following formula

$$d(s_j,v_h)=u_{hj}^k\left\|w_i(s_j-v_h)\right\|^2=u_{hj}^k\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2 \qquad (4)$$

Where *k* is any real number greater than 1, and the degree of membership matrix $U=[u_{hj}]_{c\times n}$ used to represent the degree of membership between nodes and MSNs has the properties that

$$0\le u_{hj}\le 1\,,\ \sum_{h=1}^{c}u_{hj}=1\,,\,0<\sum_{j=1}^{n}u_{hj}<n \qquad (5)$$

Where $1\le h\le c$, and $1\le j\le n$, and *c* is the total number of MSNs, and *n* is the total number of network nodes.

So, under the fuzzy condition the objective function of MI partitioning model is defined by the sum of the similarity degree of measured nodes to the MSN. That is

$$J_k(U)=\sum_{h=1}^{c}\sum_{j=1}^{n}d(s_j-v_h)=\sum_{h=1}^{c}\sum_{j=1}^{n}u_{hj}^k\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2 \qquad (6)$$

Obviously, the fuzziness coefficient *k* is used in the objective function $J_k(U)$, but how to determine the value should been studied. Through researches and simulations, Bezdek[7] found that the objective function is optimized where *k*=2. In this paper, we choose 2 as the value of *k*, so the objective function is revised as

$$J_2(U)=\sum_{h=1}^{c}\sum_{j=1}^{n}d(s_j-v_h)=\sum_{h=1}^{c}\sum_{j=1}^{n}u_{hj}^2\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2 \qquad (7)$$

2.3 Calculating the Optimized MI Partitioning Matrix

After what have been analyzed above, we find that the objective of the fuzzy partitioning model is to minimize the objective function $J_2(U)$ through finding the appropriate degree of membership matrix U^*, namely the optimal MI partitioning matrix.

There are *n* network nodes with *m* dimensions to compose the pattern space. Let $S=\{s_1,s_2,\cdots,s_n\}^T\subset R^{m\times n}$ denote the normalized feature vector set. According to Eq.6, the *Lagrange* function can be constructed as follows

$$L_2(u_{hj}^*,\lambda)=J_2(U^*)+\sum_{j=1}^{n}\lambda_j(1-\sum_{h=1}^{c}u_{hj}^*) \tag{8}$$

Let $\dfrac{\partial L_2(u_{hj}^*,\lambda)}{\partial u_{hj}^*}=0$, and then calculate the optimal MI partitioning matrix

$$\frac{\partial J_2(U^*)}{\partial u_{hj}^*}+\sum_{j=1}^{n}\lambda_j\frac{\partial(1-\sum_{h=1}^{c}u_{hj}^*)}{\partial u_{hj}^*}=0 \tag{9}$$

So,

$$u_{hj}^*=\frac{\lambda_j}{2\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2} \tag{10}$$

$$\lambda_j=\frac{1}{\sum_{k=1}^{c}\dfrac{1}{2\sum_{i=1}^{m}[w_i(s_{ij}-v_{ik})]^2}} \tag{11}$$

Then, the optimal MI partitioning matrix is defined by the following formula [8][9]

$$u_{hj}^*=\frac{1}{\sum_{k=1}^{c}\dfrac{\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2}{\sum_{i=1}^{m}[w_i(s_{ij}-v_{ik})]^2}} \tag{12}$$

3. Simulation Results

In order to be generalized, the properties of 20 network nodes including the link delays between nodes and MSNs and the network-accessing frequencies of nodes are created randomly as listed in Table 1. Let $delay_j(h)$ indicate data-transmitting RTT between the *j*th node and the *h*th MSN, and let f_j denote the network-accessing frequency of the *j*th node, so $d_f(j)=1/f_j$ is defined to measure the accessing distance of the *j*th node to corresponding MSNs. The larger f_j implies that the *j*th node request the video more frequently. To improve the network efficiency and reduce the $delay_j(h)$, let the node with larger f_j be nearest to the MSN. So, according to Eq.4, the similarity degree of the *j*th node and *h*th MSN is determined by following formula

$$d(s_j,v_h)=u_{hj}^2[w_1^2d_f^2(j)+w_2^2delay_j^2(h)] \tag{13}$$

Table 1: Property values of network nodes(created randomly)

node	*f*	*delay (1)*	*delay (2)*	*delay (3)*	*delay (4)*
n1	19	287	110	128	311
n2	16	137	199	254	27
n3	4	68	28	103	154
n4	20	109	25	201	46
n5	9	270	143	325	72
n6	3	170	86	2	188
n7	25	35	317	121	296
n8	17	72	99	156	101
n9	13	250	275	80	140
n10	23	240	80	26	246
n11	27	208	30	155	117
n12	13	250	275	80	140
n13	10	50	111	59	89
n14	6	56	109	21	164
n15	31	265	146	299	58
n16	15	154	229	81	306
n17	9	98	269	268	206
n18	26	2	85	94	312
n19	16	30	270	25	92
n20	12	210	168	141	46

With Eq.3, the values in Table1 are firstly normalized. Let w_1 and w_2 be the weigh of f_j and $delay_j(h)$, and $w_1=w_2=0.5$. When $c=4$, the nodes can been fuzzily recognized with MI optimal partitioning matrix defined by Eq.12. The nodes partitioning results are shown in Fig. 2.

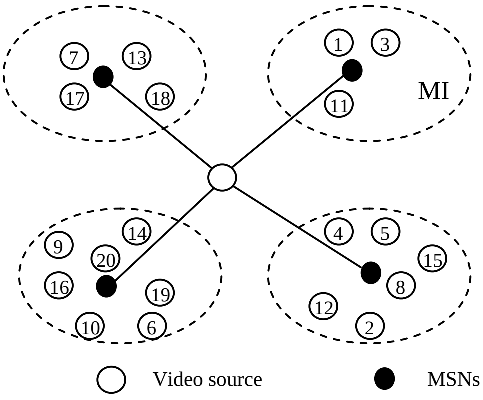

Fig. 2 Results of partitioning nodes into MIs

The purpose of partitioning nodes into MIs is to achieve a maximized similarity degree between the group nodes and their MSNs. The quality of partitioning results can bee verified by the objective function. Under the same network condition, the less the objective is, the better the partitioning quality is. Using the network nodes listed in

Table 1 to simulate the basic network infrastructure, supposing that there are 10 nodes joining the multicast tree which is constructed by MSNs each time randomly, then, the node is partitioned by the fuzzy MI partitioning model into the nearest MI. In order to verify the feasibility and validity of the fuzzy MI partitioning model presented in this paper, we compared the partitioning quality of this model with that of K-Means MI partitioning model [10]. The results are shown in Fig. 3.

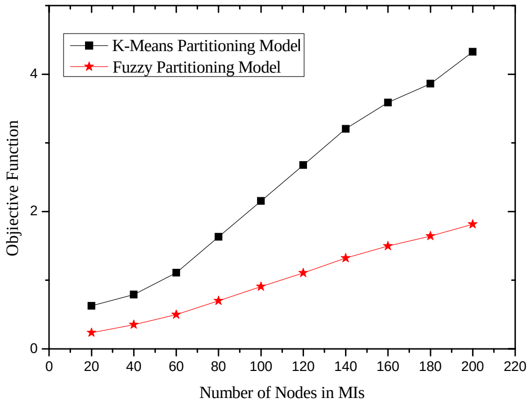

Fig. 3 Simulation results of K-Means partitioning model and fuzzy partitioning model

In the K-Means MI partitioning model, the similarity degree between the *j*th node and *h*th MSN is denoted by squared weighting Euclidean distance, which is formulated as

$$d'(s_j, v_h) = u_{hj}[w_1^2 d_f^2(j) + w_2^2 delay_j^2(h)] \qquad (14)$$

The objective function is defined by the following formula

$$J_1(U) = \sum_{h=1}^{c}\sum_{j=1}^{n} u_{hj}[w_1^2 d_f^2(j) + w_2^2 delay_j^2(h)] \qquad (15)$$

Where $u_{hj} = \begin{cases} 1 & d'_{hj} = \min\{d'_{kj}\} \\ 0 & d'_{hj} \neq \min\{d'_{kj}\} \end{cases}, 1 \le k \le c, 1 \le j \le n$

When the nodes join the multicast tree, the partitioning models will classify them to the nearest MI. As shown in Fig. 3, the values of the objective function of the fuzzy MI partitioning model is less than those of the K-Means partitioning model, which means the quality of partitioning nodes into MIs by the fuzzy MI partitioning model is better than that of the K-Means partitioning model. Moreover, with the increasing of nodes joined the multicast tree, the increasing rate of the objective function values of the fuzzy MI partitioning model is less than that of K-Means partitioning model. All of those results verify the validity and feasibility of the fuzzy partitioning model, and prove that the fuzzy partitioning model is better than the K-Means partitioning model when they are used to partition nodes into MIs.

4. Conclusions and Discussion

For large-scale, multi-channel real video streams' transmission, the final purpose of building an OMN is to minimize the entire network delay, and to forward data efficiently to avoid the network congestion caused by redundant data delivery in the logic link. A fuzzy MI partitioning model is proposed to partition the nodes into the nearest MIs. From the results of simulations, we verify the validity and feasibility of the model.

Because of the instinct characteristics of clustering algorithm, the model is sensitive to the initial MSNs. Therefore, in the practical application, according to the physical network architecture, we can achieve to enhance the model partitioning precision by selecting different MSNs for several times as needed.

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