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A Layered Multicast Tree for Reliable Real-time Video Transmission of OMN

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Abstract

In order to guarantee the reliable real-time video transmission of overlay multicast network (OMN), a layered multicast tree with three-level is proposed based on NICE protocol to manage multicast service nodes. This solution can improve the data-transmitting efficiency, and minimize the redundant packets in OMN. Also, for the reliable video transmission in bandwidth-limited links of OMN, a QoS algorithm is analyzed by discarding the redundant frames of the video sequences according to the detected network condition. Finally, the performance test verifies the validity of proposed layered multicast tree for reliable video transmission.

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. 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[1-3].

Overlay Multicast Network (OMN) is emerging as a fundamental technique to solve the problems mentioned above. 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 [3]. But, the data-transmitting efficiency of OMN with overlay multicast is not as efficient as IP-based multicast, which can cause more link delays and width penalties. 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 transmitting delay may cause the video packets not to been decoded. So, how to scalably form an efficient overlay multicast tree is an important issue to be solved for reliable video transmission.

Also, the video stream needs occupy a great deal of network resources. The available network bandwidth is changing dynamically. When a large scale video stream is transmitted by a bandwidth-limited links of OMN, network congestion is caused easily, which can interrupt the transmission of video stream. So, how to adjust bit rates of video stream for reliable transmission is another issue to be solved.

On the basis of NICE protocol, a three-level layered multicast tree is proposed to improve the data-transmitting efficiency, and minimize the redundant packets in OMN. For the reliable video transmission in bandwidth-limited links of OMN, a QoS algorithm is carried out by discarding the redundant frames of the video sequences to reduce the output bit rates of video stream to match the network quality.

The rest of this paper is organized as follows: section 2 introduces the layered multicast tree including the algorithm of selecting multicast nodes; a QoS algorithm based on discarding the redundant frames is proposed in section3; then, we test this architecture in real practice; finally, we give the conclusions of the researches.

2. Layered multicast tree

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2.1. Classification of multicast tree for OMN

Overlay multicast is a unique feature of OMN because it is the underlying mechanism for multipoint video communication. The nodes in the overlay multicast tree can be logically organized into two topologies, namely, the control topology and the data topology. Control topology carries control data such as heartbeat messages, refresh messages, network probes and probed data while data topology comprises the actual data delivery paths to the multipoint destinations. According to the building sequence of two topologies, the multicast tree of OMN can be classified into three types: mesh-first, tree-first and layered approach [3].

For the mesh-first multicast tree, members distributedly construct a mesh as the control topology, and the control topology may assume a separate physical structure in the form of a mesh where the nodes in the topology possess higher connectivity, which make the multicast tree robust. But the entire control overhead is more. Also, in the control topology, nodes may not necessarily be the members of the multicast tree. The control topology can be seen as a superset of the data topology.

For the tree-first multicast tree, members directly construct an overlay tree topology for data delivery, and additional control links are monitored and maintained to allow quick recovery from member failures. It is suggested that the tree-first multicast tree adopt the tree structure for the data topology as it is simpler and more efficient than mesh-first tree.

In order to use the advantages of mesh-first and tree-first multicast trees, the layered multicast tree is carried out. The nodes form hierarchical structure which can achieve good scalability. At lower layer, nodes are partitioned into a set of multicast islands, whose centers are multicast service nodes (MSNs), and the cluster headers are located in upper layers of the control logic topology. Meanwhile the data topology is building. MSNs are organized into a multi-level layered logic topology for data delivery.

2.2. Proposed layered multicast tree for OMN

When video streams are transmitted in layered multicast tree, the video packets are delivered by MSNs from video source of the highest layer to receiving nodes of the lowest layer. The packet-transmitting delay from video source to receiving node becomes more while the degree of the tree increases. What's more, the video packets are delay-sensitive; the high delay may cause the video packets not to been decoded. In order to solve this problem, the layer of multicast tree is limited to 3. The structure of layered multicast tree based on NICE is shown as Figure 1.

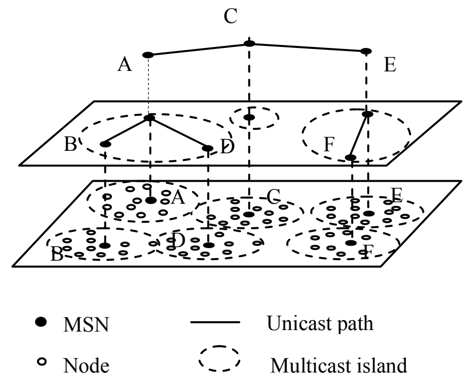

Figure1. The structure of layered multicast tree based on NICE

The top layer is consisted of video sources, which compress the real-time analogy signal to digital video stream. The middle layer is composed by MSNs, who is responsible to deliver the video packets form the source to the leaf nodes of multicast tree. Nodes in the ground layer are called leaf nodes of the multicast tree to decode received video stream. In this there-layer multicast tree, the frequent leaving and failure of leaf nodes do not affect the multicast tree infrastructure. So, the architecture is robust to the routing split caused by the frequently leaving and ungraceful leaving of leaf nodes in the multicast tree.

Because MSNs are used to forward packets in multicast tree, in order to reduce the data-transmitting delay as much as possible and make sure that the network loads are balanced. The selection (location) of the MSNs among network nodes is very important.

2.3. Algorithm for selecting MSNs

In order to reduce the data-transmitting delay and improve the efficiency of multicast tree as much as possible, the selection (location) of the MSNs is very important among network nodes. A selection algorithm with K-medoids and genetic algorithm were proposed in reference 4, which are the former research achievements of this paper.

The squared generalized weighting Euclidean distance was used to denote the distance between node and MSN. So, the distance between the jth node and the hth MSN was determined by the following formula

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

where $v_h (h = 1, 2, \cdots, c)$ denotes the hth MSN's property vector, and v_{ih} denotes the ith property value of v_h ; $w_i(i=1,2,\cdots,m)$ represents the ith property weight of network node $s_j(j=1,2,\cdots n)$, and s_{ij} denoted the ith property value of s_j

The objective function was defined as

$$J(U)=\sum_{h=1}^{c}\sum_{j=1}^{n}\left\|w_i(S_j-v_h)\right\|^2$$
$$=\sum_{h=1}^{c}\sum_{j=1}^{n}u_{hj}\sum_{i=1}^{m}[w_i(s_{ij}-v_{ih})]^2 \quad (2)$$

So, the problem of selecting optimal MSNs becomes to that of keeping the value of $J(U)$ minimal. The algorithm is the former research achievements of this paper and the detail of algorithm can be found in reference 4.

3. QoS algorithm by discarding frames

While the video packets are transmitted in layered multicast tree of OMN, the available network bandwidth changes dynamically, which influences the quality of services dramatically. For the reliable video transmission in bandwidth-limited links of OMN, a QoS algorithm by discarding redundant frames is proposed. By the algorithm, the video bit rates are adjusted by discarding the redundant frame in the video sequences according to the detected network condition, and guarantee the reliable transmission of the key frames to achieve to transmit important video streams efficiently under the bad network situation.

3.1. Dynamic link quality detection

The goal of detecting network's quality dynamically is to provide criterions for adjusting the bit rates of video streams. The video packets are transmitted with the protocol of UDP, and the real-time transport protocol (RTP) and the real-time transport control protocol (RTCP) are used to detect the network quality between MSNs and nodes. The packet loss rate is looked as an important parameter to reflect the network quality. So, we use the frame loss rates between MSNs and nodes to detect the network quality.

3.2. QoS algorithm

During the transmitting of video packets, the analogy video signal is compressed into digital video packets by the encoder. Then, the compressed video stream is transmitted to MSN, where the video sequence packets is filtered according to the different network qualities of service; after that, the filtered video packets are transmitted to relevant receiving nodes in low level of multicast tree.

According to the features of video encoding, the compressed video sequence consists of I frame, B frame and P frame, which forms a GOP (group of picture). I frame is the key frame, and the loss of key frames will cause video sequences not to been decoded. However, B frame and P frame can be discarded with certain algorithms in order to reduce bit rates of the video streams, and have less influence on the decoding quality. So, when there are less bandwidth available in network, B frame and P frame can been discarded selectively to guarantee the transmission of I frame according to the network condition.

Suppose that the video signal is compressed with H.264 algorithm by HKVison DS6004 encoder. The definitions of I frame, B frame and P frame are defined as Table 1.

Table 1. Definations of frames

	Frame type	Frame code
I frame	PktIFrames	0x0001
P frame	PktPFrames	0x0002
BBP frame	PktBBPFrames	0x0004
Audio frame	PktAudioFrames	0x0008

According to the definitions of frames, they are selected from the compressed video sequences firstly, and the redundant frames are discarded by the QoS scheme to adjust the bit rates of video streams, the frames. Finally, we obtain the adjusted video streams which meet the demand of network quality. The mechanism of QoS algorithm is shown as Figure 2.

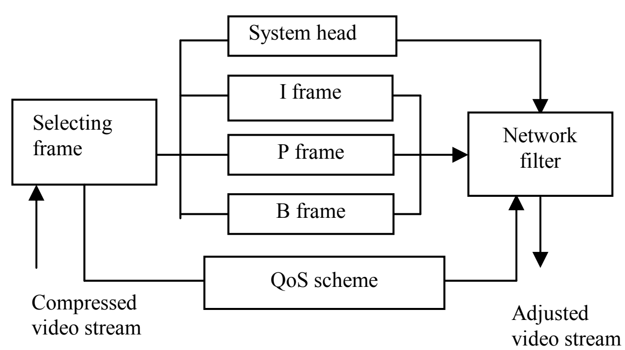

Figure 2. The mechanism of QoS by discarding frames

4. Performance tests

We have tested the performance of video transmission architecture in the real network. The testing conditions are as follows: the video source is located in the local network, where the maximized bandwidth is 100Mbps; and the encoder compresses 1 channels of video signal with the output bit rats of

256Kbps. And five MSNs are located in the network to build the layered multicast tree, where the maximized bandwidth is also 100Mbps. The number of total nodes of the lowest layer is 240.

The experiment results indicated: for the layered multicast tree without QoS algorithm, the frame loss rates increase greatly with more nodes joining the multicast tree and receiving video stream simultaneously. Because when there are more nodes receiving video streams, the redundant frames will occupy lots of network resources, and the network traffic is busy. So, the video frames loss rate improves rapidly. The loss of I frame may cause the video packets not to been decoded, and worsen the receiving video quality drastically. With the use of QoS algorithm, I frames of video streams are transmitted reliably as the key frames to achieve the reliable video transmission in bandwidth-limited links of OMN. With receiving no des increasing, the loss rate of I frames is shown as Figure 3.

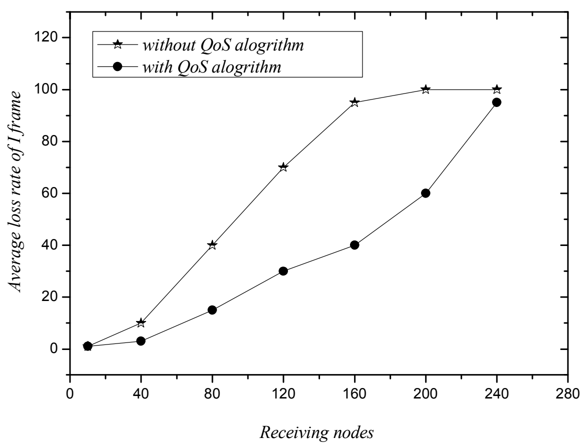

Figure 3. Relationship between average loss rate of I frames and receiving nodes

With the increasing of receiving nodes of joining the multicast tree, the average loss rate of I frame increased rapidly when the layered multicast tree deliver video packets without QoS algorithm, because the deliver efficiency of multicast tree is limited by the capability of MSNs in the middle layer of the architecture. But, with the use of QoS algorithm, the P or B frames are discarded when the receiving nodes increases. By this way, the output bit rates of video stream are reduced to meet the capability of MSNs, and to guarantee the reliable transmission of I frames

5. Conclusions

A layered multicast tree with three-level is proposed based on NICE. The architecture is robust to the routing split caused by the frequently leaving and ungraceful leaving of leaf nodes in the multicast tree. Meanwhile, a QoS algorithm based on discarding redundant frames of video sequence is carried out to reduce the bit rats of compressed video to guarantee the reliable video transmission in bandwidth-limited OMN. Finally, the performance test verifies the validity of the architecture.

6. Acknowledgements

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