Fine-Grain Layered Multicast based on Hierarchical Bandwidth Inference Congestion Control

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***Abstract*—This paper presents an approach to facilitate the bandwidth inference congestion (BIC) control in a fine-grain layered multicast for multimedia delivery. One-way delay trend detection has been shown to be effective in explicitly or implicitly estimating the end-to-end available bandwidth. By using a hierarchical layered probe in combination with the delay trend detection scheme, we propose a congestion control protocol for fine-grain layered multicast of 3-D wavelet based scalable video streaming over heterogeneous networks.**

I. INTRODUCTION

Multimedia communication over (wired or wireless) IP networks has become increasingly important due to the explosive growth of the Internet. Scalability at bitstream level is an important feature for multimedia delivery over networks with differing channel capacity, display resolution, and dynamically changing available bandwidth. The scalable video coding scheme intends to encode a video signal once but enables different receivers to decode the video by receiving part of the bitstream depending on the available bandwidth and the target resolution [3]. MPEG-4 fine-grain scalability (FGS) provides a scalable video coding scheme based on hybrid motion compensation and bit-plane DCT coding [10]. However, in order to avoid the drifting problem, it sacrifices the coding efficiency by using base layer only in motion compensation. To improve the coding efficiency , several efficient scalable video coding schemes by using motion-compensated temporal filtering (MCTF) have been proposed to achieve the scalability and solve the drifting problem encountered in the close loop hybrid coding systems [1][3].

Layered Multicasting with scalable video coding scheme enables efficient distribution of real-time multimedia streaming over heterogeneous networks [4]. In a layered multicast system, the server divides a scalable bitstream into different layers and each layer is disseminated by a separate IP multicast group. According to the available bandwidth, each receiver joins some groups from the base layer to higher enhancement layers. Rate control issues are necessary in layered multicast in order to protect packet losses on a lower layer and to assure fair bandwidth allocation among competing layers at a congested link. Since the multimedia communication is delay-sensitive, reliable connection-oriented TCP transport is not appropriate. Various rate-based protocols have been proposed for UDP transport to adapt to the network dynamics and to achieve TCP-friendliness. Packet losses and round-trip delays are widely used to detect congestion in these protocols [8].

Several receiver-driven layered multicast protocols have been proposed to achieve improved intra-session fairness in which each receiver gets the quality of video commensurate with network bandwidth availability and end-system processing load [9][11]. ThinStreams architecture has also been proposed to de-couple network control and video codec to prevent excessive congestion in network [5]. A BIC control protocol for multimedia layered multicast has been proposed in [8], where each receiver uses one-way delay trend detection to estimate the end-to-end available bandwidth and uses the delay trend in the decision of joining additional layers. In this paper, based on the BIC control protocol, we propose a hierarchical BIC control protocol to achieve a fine-grain layered multicast. This new scheme enables a receiver to join the suitable coarse layers quickly and provides the ability of receiver to reach the optimal fine-grain layer after the hierarchical sub-layered probes. By combining with the scalable wavelet video coding based on MCTF, we propose a framework to achieve the efficient scalable video transmission over the heterogeneous networks.

II. SCALABLE VIDEO CODING WITH MCTF

Three-dimensional (3-D) wavelet scalable video coding technique has been proposed recently. It has the embedded coding characteristics and the ability to achieve continuous rate scalability. The 3-D wavelet video coding proposed in [3] applies the MCTF transform along with the temporal axis. Fig. 1 is an example of 3-D wavelet transform tree in which the temporal wavelet transform is applied first followed by the spatial domain wavelet transform. A simple case to apply the temporal wavelet transform is to use the Haar filter. For each pair of image A and B, the lowpass frame (L) and highpass frame (H) are respectively calculated by

$$L(m,n)=\frac{1}{2}\left[B(m,n)+A(m+\tilde{k}(m,n),n+\tilde{l}(m,n)\right], \quad (1)$$

and

$$H(m,n)=A(m,n)-B(m+k(m,n),n+l(m,n)). \quad (2)$$

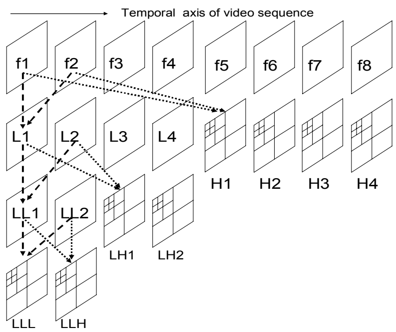

Figure 1. The 3-D wavelet decomposition with 3 levels of a temporal wavelet transform [3].

$[k(m,n),l(m,n)]$ is the forward motion vector from frame A towards frames B and $\left|\tilde{k}(m,n),\tilde{l}(m,n)\right|$ is the backward motion vector form B towards A [3].

After the 3-D decomposition of video sequence, several methods have been proposed to encode the coefficient of the 3-D wavelet transform. 3-D Embedded Subband Coding with Optimized Truncation (3-D ESCOT) uses a fractional bit-plane coding to encode each subband independently [2]. This feature makes it very easy to achieve frame-rate scalability and resolution scalability for the coded video stream. Moreover, it uses the context-based adaptive arithmetic code and global rate-distortion optimization to achieve high compress efficiency.

III. DELAY TREND DECTECTION AND BIC CONTROL

In recent years, the one-way delay trend detection techniques have been proposed to estimate end-to-end available bandwidth. However, various error sources may distort the measured delay trend. Instead of trying to estimate the absolute available bandwidth, [7] provides a delay trend detection method to enable a receiver to judge whether the available bandwidth is at or higher than the target layered bit rate. By applying the delay trend detection to multimedia layered multicast, [8] proposes a BIC control protocol for multimedia applications based on a cumulative layered multicast transmission. Before proposing our hierarchical BIC control for fine-grain layered multicast, we will give a brief overview of delay trend detection and BIC control for multimedia layered multicast in this section.

A. Delay Trend Model

The delay trend model has been proposed to estimate the end-to-end available bandwidth. By sending a probe at a fixed-rate and analyzing the one-way delay trend, the receiver can test whether it's available bandwidth at the probe rate. Suppose there are N links between the sender and the receiver. Let C_i denote the channel capacity of link i, $i=1,2,\ldots,N$. Assume M packets have been sent during the probe at a predefined bit rate (R_p) from time t_1 to t_2, and the size of each packet is S_m, $m=1,2,\ldots M$. Let $T_i[t_1,t_2]$ be the cross traffic through link i between t_1 to t_2. The end-to-end available bandwidth between the sender and the receiver was defined as

$$B_{ava}[t_1,t_2] = \min_i \left(c_i - \frac{T_i[t_1,t_2]}{t_2 - t_1}\right). \qquad (3)$$

The one-way delay of packet m, D_m, can be calculated by

$$D_m = \sum_{i=1}^{N}\left(\frac{S_m}{C_i} + d_i^m + \sigma_i\right), \qquad (4)$$

where d_i^m is queuing delay of packet m and σ_i is the processing delay at link i. Since $\sum_{i=1}^{N}\frac{1}{C_i}$ and $\sum_{i=1}^{N}\sigma_i$ are constant for all packets. The delay D_m is dependent on the packet size, S_m, and the sum of queuing delay, $\sum_{i=1}^{N} d_i^m$. If all the packet sizes are the same, the delay trend is relative to the trend of queuing delay. If packet sizes are different, the delay trend is affected by trends of packet size and queuing delay. According to the proposition in [7], if the probing bit rate R_p is higher than the available bandwidth, $\sum_{i=1}^{N} d_i^m$ will have an increasing trend. Otherwise, no trend will happen. This scheme [7] proposed a Fullsearch algorithm to calculate the delay trend, D_{trend}.

$$D_{Trend} = \frac{\sum_{m=2}^{M}\sum_{l=1}^{m-1} I(D_m > D_l)}{\frac{M(M-1)}{2}}, \qquad (5)$$

where $\boldsymbol{I}(D_m>D_l) = 1$ if $D_m>D_l$, otherwise $\boldsymbol{I}(D_m>D_l) = 0$. The value of delay trend, $D_{trend,}$ is between 0 and 1. Whether the delay trend happens is decided by comparing D_{trend} to a given threshold. Equation (5) can also be used to calculate the trend of packet size, S_{trend}, by replacing D_m with S_m. According to D_{trend} and S_{trend}, a decision rule to decide whether the end-to-end available bandwidth can reach the probing bit rate [7].

B. BIC Congestion Control for Layered Multicast

Based on the end-to-end available bandwidth estimation, a bandwidth inference congestion control scheme for multi-layered multicast has been proposed in [8]. Suppose a multimedia multicast system has L layers (each layer is designated as a multicast group). A receiver at layer k will receive layer 1 to layer k. In order to allow a receiver to join an upper layer, the server periodically sends the packets of layer $k+1$ into layer k, $k=1,2,\ldots,L-1$. After the probing period, receivers at layer k can perform the delay trend detection to decide whether they have the enough available bandwidth to join layer $k+1$. After the probe of layer k, the server can proceed to start the probe of layer $k+1$. When a receiver detects the packet loss rate is greater than a predefined threshold, the receiver will leave current layer. Fig. 2 shows an example of a 4-layer multicast, where the server probes form layer 1 to layer 3 circularly.

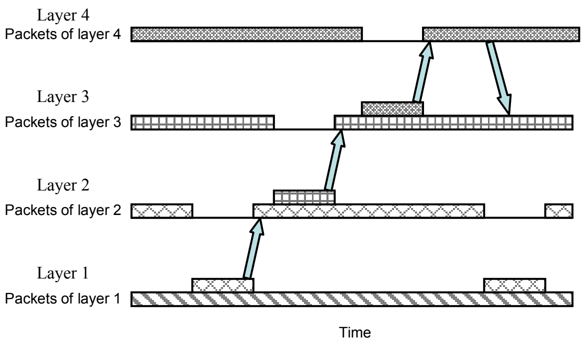

Figure 2. An example of multi-layer BIC with *L=4*.

The arrows show a receiver form layer joins layer 2, 3 and 4 after 3 probes, and then it leaves layer 4 because of the packet loss.

IV. HIERARCHICAL BIC CONTROL SCHEME FOR FINE-GRAIN LAYERED MULTICAST

In the BIC control for layered multicast scheme described in previous section, the (bitrate) scale of layers can not be too small; otherwise it will take a long time to reach its optimal layer when its available bandwidth has a large increment. However, the motivation of scalable video coding is to support the fine-grain scalability. The coarse-grain multicast system will restrict the scalability. In this paper, we propose a hierarchical BIC framework to achieve the fine-grain layered multicast system. Suppose a multicast system consists of N coarse layers, $\{L_i, i=1,2,...,N\}$. Each coarse layer can further be divided into M sub-layers, where $M=2^P$. Denote $L_{i,j}$ as the jth sub-layer in the ith coarse layer and $B_{i,j}$ as the cumulative rate up to layer $L_{i,j}$. A receiver at layer $L_{k,m}$ will receive packets form coarse layer 1 to $k-1$ and sub-layer 1 to m in coarse layer k. In the hierarchical BIC for fine-grain layered multicast, the server periodically sends the probing packets for coarse layers 1,2,…, and N-1. When the coarse layer k is being probed, packets of $L_{k,j}$, j=1,2,…,M and $L_{k+1,1}$ will be sent to layer $L_{k,1}$. All the receivers at coarse layer k, i.e., layers $L_{k,j}$, j=1,2,…,M, will receive the packets at the probing bitrate $B_{k+1,1}$. The receivers then use the delay trend detection to decide whether their end-to-end available bandwidth is at or higher than the probing bitrate $B_{k+1,1}$. If a receiver at $L_{k,m}$ detects its available bandwidth to be higher than the probing bitrate, it will join the layers up to $L_{k+1,1}$. Otherwise, it will stay at its original layer $L_{k,m}$. According to this probing scheme [8], each coarse layer will be probed in turns.

At each coarse layer k, after it has been probed and stabilized, the server will wait a duration T and then start the hierarchical sub-layer probe in this coarse layer k. The motivation of hierarchical sub-layer probe is to enable receivers to approach its optimal fine-grain layer closer to its actual available bandwidth. In the first step of sub-layer probe at coarse layer k, the sever sends the probing packets at the bitrate of medium sub-layer $B_{k,2^{p-1}+1}$ by sending packets of $L_{k,j}$, j=1,2,…, $2^{p-1}+1$, into layer $L_{k,1}$. Hence, receivers at sub-layer 1 to $2^{p-1}+1$ will receive the probing packets at bitrate $B_{k,2^{p-1}+1}$. According to the delay trend detection, they can adjust whether they have the available bandwidth to join the medium sub-layer $L_{k,2^{p-1}+1}$, or stay at their original sub-layer. At the second step, server will send the probing packets at the bit rates of first quarter and third quarter sub-layer, $B_{k,2^{p-2}+1}$ and $B_{k,3\times 2^{p-2}+1}$, at the same time. At this probing duration, the packets of sub-layer 1 to $2^{p-2}+1$ will be sent into sub-layer 1 and the packets of sub-layer $2^{p-1}+1$ to $3\times 2^{p-2}+1$ will be sent to sub-layer $2^{p-1}+1$. The receivers then decide whether they can join the first or third quarter sub-layers, $L_{k,2^{p-2}+1}$ and $L_{k,3\times 2^{p-2}+1}$, according to their delay trend detection results. This hierarchical sub-layer probing scheme repeats until the sever probes the bit rates of all even sub-layer $B_{k,j}$, j=2,4,…,M , by sending the packets of even-layers into odd-layers through the probing duration. Fig. 3 is the structure of Hierarchical BIC control for fine-grain layered multicast with the number of sub-layers $M=2^3$. The arrows with solid lines represent the probes of coarse layers. The arrows with other lines represent the hierarchical sub-layered probes. After the probe of coarse layers, the server probes the hierarchical sub-layers in three probing durations at different probing layers.

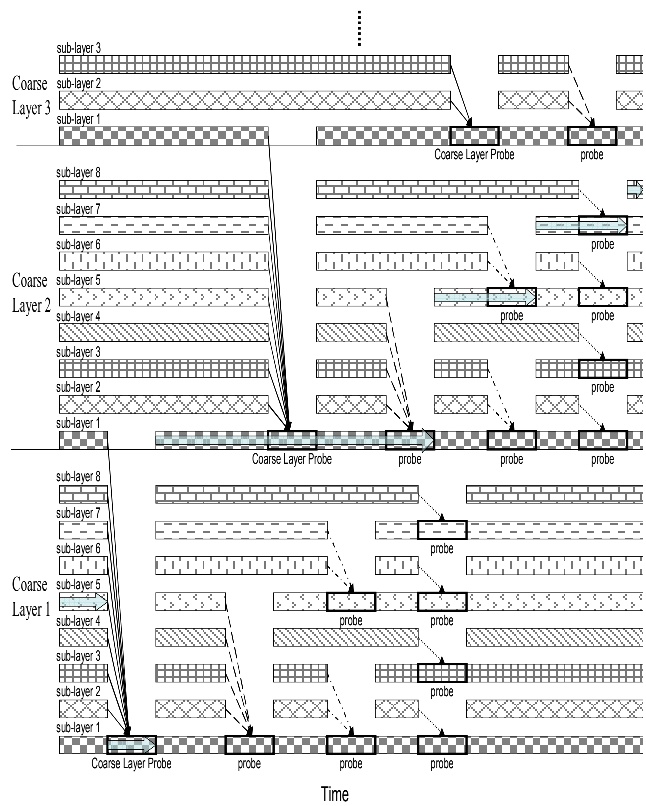

Figure 3. The hierarchical BIC control for fine-grain layered multicast structure. The number of sub-layers $M=2^3$. ⟹ represents a receiver switching layers in the hierarchical probing scheme.

V. SIMULATION AND DISCUSSION

According to the multi-resolution nature of wavelet transform, wavelet video coding can easily support the temporal, SNR, and spatial scalability. Furthermore, since the 3-D ESCOT uses a fractional bit-plane coding to encode each subband independently, we can further divide each coarse layer into fine-grain layers. According to the scalability of scalable video coding, we design a fine-grain layered multicast streaming structure with six coarse layers of different temporal, SNR, and spatial resolutions. The bit rates of coarse layers are 64, 128, 256, 512, 1024, 2048 Kbps respectively. Each coarse layer is further divided into eight fine-grain layers. We use the ns-2 network simulator [6] to simulate this fine-grain layered multicast. The probing size is 50 packets and the size of each packet is 512 bytes. In our simulation topology, we use four receivers with different bandwidth and round-trip time as shown in Fig. 4.

The layer subscription of Receiver 3 is shown in Fig. 5. The solid line is the layered multicast subscription result of Receiver 3 by using the BIC control scheme. In the beginning, Receiver 3 rapidly changes the layer subscription and then stays at its optimal coarse layer 5 at bit rate 512 Kbps. The dashed line is the result by using our proposed fine-grain layered multicast scheme. After the probe of coarse layers, server uses the hierarchical probing scheme to probe the sub-layers. According to the probing of fine-grain layers, Receiver 3 joins sub-layer 5, 7 and 8 in turns. After the hierarchical sub-layered probes, Receiver 3 reaches its optimal fine-grain layer at bitrate 960 Kbps which is very close to its maximum available bandwidth and then steady stays at this bitrate.

Since the join or leave of coarse layers affect the temporal, SNR, or spatial resolution, we should increase the threshold of delay trend analysis to avoid the frequent join and leave. However, the changing of sub-layer will only affect the fractional bit-plane which is less sensitive to human vision. Therefore, we can reduce the threshold of delay trend in sub-layer probe to enable receivers to pursue its optimal fine-grain layers quickly according to the variation of available bandwidth.

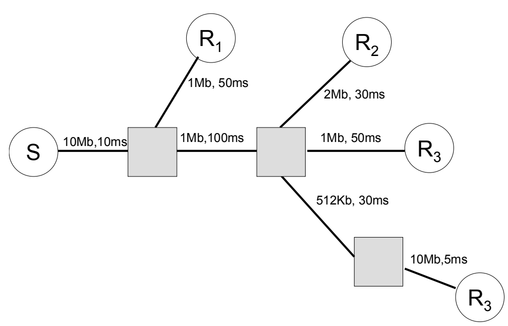

Figure 4. The simulation topology.

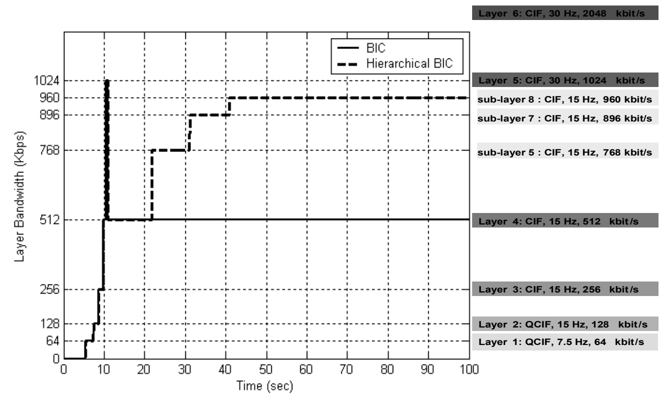

Figure 5. Layer subscription for Receiver 3.

VI. CONCLUSIONS

In this paper, we present a new architecture for using delay trend detection with hierarchical layered-probe for bandwidth inference congestion control of fine-grain layered multicast. According to the probes of coarse layer and sub-layer, a receiver can rapidly adapt to its optimal fine-grain layer according to the changing dynamics of available bandwidth. Facilitated by the 3-D wavelet scalable video coding, we propose a framework of fine-grain layered multicast to achieve an efficient scalable multimedia streaming scheme over heterogeneous networks.

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