HotStreaming: Enabling Scalable and Quality IPTV Services

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ABSTRACT

HotStreaming is an overlay peer-to-peer based IPTV system. It consists of three major technical components: *partnership formation*, *video segment request scheduling*, and *multiple description code*. This system is, to our best knowledge, one of the pioneering, if not the first, IPTV systems that *integrate innovations in overlay networking and video coding* for optimal user experience. In this paper, we focus our discussions on the partnership formation and multiple description code components, the core innovations on the networking and video coding sides. The preliminary experimental results indicate that HotStreaming is promising and significantly enhances the state of the art. In particular, the proposed partnership formation scheme is able to achieve one-order-of-magnitude better stability.

Categories and Subject Descriptors

J.7 [**Computers in Other Systems**]: Consumer Products, C.2.4 [**Computer-Communication Networks**]: Distributed Systems – *distributed applications*, I.6.4 [**Simulation and Modeling**]: Model Validation and Analysis, H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems – *video*, E.4 [**Coding and Information Theory**]: Data compaction and compression

General Terms

Algorithms, Performance, Design, Reliability, Experimentation, Human Factors.

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Keywords

IPTV, video broadcast, video streaming, error recovery, overlay peer-to-peer network, multiple description code

1. INTRODUCTION

With the rapid advances in multimedia entertainment, broadband network, and semiconductor manufacturing technologies, high-speed multimedia wireless communication is coming of age. According to a September 21, 2005 report from Northern Sky Research[1], the IPTV market is estimated to exceed 7 billion US dollars in 2010 and when the infrastructure is in place, the market will move quickly into retail business and will draw revenues from household subscribers. Another market research from Multimedia Research Group[2] reports a similar trend. In particular, the amount of IPTV subscribers is estimated to expand from 1.9 to 25.3 million worldwide by 2008 and the revenue to climb from 472 million Euro in 2004 to 5.35 billion Euro in 2008.

Despite the positive prospective of IPTV, the key to the successful deployment of IPTV services lies in the quality of services (QoS), a lesson we learned from the VoIP development. Skype[3], MSN[4] and Yahoo Instant Messenger[5] all provide free VoIP services. Skype stands out, having 3.5 to 4 million active users at any one time[6], because of the substantially better voice

[1] http://www.tekrati.com/T2/Analyst_Research/ResearchAnnouncementsDetails.asp?Newsid=5837

[2] http://www.dmeurope.com/default.asp?ArticleID=6683

[3] http://www.skype.com/

[4] http://www.msn.com/

[5] http://messenger.yahoo.com/

[6] http://www.voipplanet.com/solutions/article.php/3580131

quality. We think the challenge of meeting the QoS demand of the users is the same to all real-time multimedia applications, including IPTV. Our objective in this work is to develop a scalable networking and video coding platform for quality video broadcasting over the Internet. *HotStreaming*, the proposed IPTV system, takes 1) the *overlay peer-to-peer (overlay p2p)* networking approach, with which the system can exploit the resources, such as storage and bandwidth, available among the peer users to minimize the need of server infrastructure, and 2) the *multiple description coding (MDC)* approach, with which the heterogeneous peer users can flexibly subscribe to streams of different resolutions and enjoy the best quality their available resources permit.

There are three major technical components in the design of HotStreaming: the *partnership formation*, *video segment request scheduling*, and *multiple description code*. The partnership formation determines for each user the group of partner peers to request the video segments. The video segment request scheduling algorithm determines for each user at each point in time the specific segments and the ordering to request. The multiple description code determines the encoding and playback strategy for satisfying user perception. As far as we know, HotStreaming is one of the pioneering, if not the first, IPTV systems that *integrate innovations in both overlay networking and video coding* for optimal user experience.

In this paper, we focus our discussions on the partnership formation and multiple description coding components of HotStreaming. The partnership formation component is essential for the overlay P2P based video broadcasting. In this overlay P2P network paradigm, a video stream is divided into segments. These video segments are delivered from peer users to peer users. More specifically, a user chooses a number of peers to form a partner group. From these partners, the user receives the video segments. To these partners, the users may also ask for retransmissions of the lost segments. A user might also be chosen by other peers in the network to be their partners. How the partner and consumer relationship is built impacts the efficiency and stability of the network. In fact, load balancing and stability of the partnership relationship in the presence of peer dynamics, i.e., joining and leaving the network randomly, are the main design considerations in the partnership formation component of HotStreaming. Results from the simulation show that, relative to the one used in the state of the art [6], the two partnership formation schemes of HotStreaming are able to reduce the instability of the P2P partnership by 52% and 89% respectively, and the stability gain is achieved without compromising the system load balance.

MDC is the component that impacts the user perception of the video. One simple example is to code the odd frames based on the previous odd frames and the even frames based on the previous even frames. As opposed to coding the frame-to-frame differences as in MPEG4, we code the interleaving frame differences. Then the two sub-streams can be transmitted separately over the network and played back with synchronization at the receiver. Such a design is more fault tolerant than conventional video coding. When one sub-stream is lost due to network congestion, the decoder can still independently play the remaining sub-stream with controlled degradation. Perceptual quality and flexibility are the main design considerations of the MDC component. Results from the preliminary experiments indicate that the proposed scheme is able to achieve good perceptual quality.

2. RELATED WORK

The distribution of TV video over IP is a quasi-reliable multicast problem in nature. Solutions at the network layer have long existed. Multicast routing protocols such DVMRP [1] and PIM-SM [2] are all documented as IETF RFCs and widely implemented in the commercial routers. Reliable multicast solutions at the network layer such as SRM [3] has also been proposed early in 1997. The problem with the network-layer solutions is deployment. All routers in between the multiple senders and receivers need to run the necessary mechanisms to work.

To get around the deployment problem, recent work, such as the mechanism described in [4], proposes to implement multicast at the application level. Quasi-reliable multicast mechanisms such as ZigZag [5] and CoolStreaming [6] also exploit the deployment flexibility at the application level. Our HotStreaming system is closest in spirit to CoolStreaming but we are different in the design of the partnership formation mechanism and in the use of video coding scheme.

3. PPARTNERSHIP FORMATION

In partnership formation, each receiving users obtains a partner list. It is the partners who serve the video segments to the receiver. Users may leave and join the overlay peer-to-peer network dynamically. The reliability of the transmission will be affected when the partners leave the network. Therefore, when the event of partners leaving the network is detected, substitute partners will be selected to cover for the job of video segment transmission.

The partner list is adjusted by the low frequency peer advertisements. The partner list is intended to capture the candidate partners who are alive and preferred by the receiving peer. Each peer advertises its existence in its peer advertisements in a controlled random fashion. Other peers receiving the advertisement decide in a controlled random fashion as well whether to select the peer sending the advertisement as a partner. A balanced and robust partnership formation policy can help achieve both load balance and stability. In this part, we investigate gossip-based partnership mechanism and propose possible improvements.

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3.2 Gossip-Based Partnership

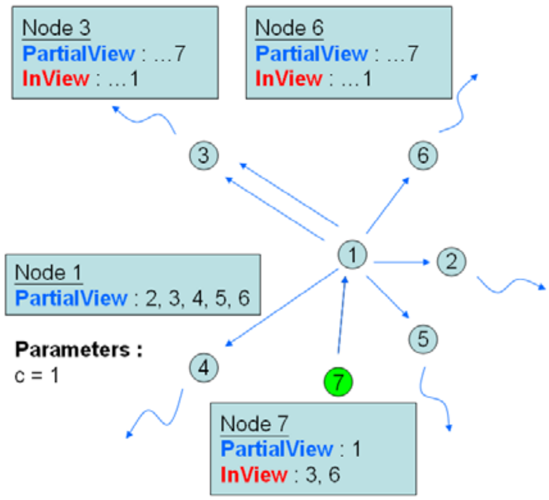

Figure 1. Node 7 enters the system and chooses node 1 as the contact node.

SCAMP (Scalable Membership protocol) [7] is the state-of-the-art peer-to-peer partnership protocol operates in an unstructured and fully decentralized manner. SCAMP is the mechanism that Coolstreaming, a prominent overlay P2P based TV broadcasting system. In SCAMP, when a peer node joins the SCAMP system at the first time, it adds the contact node in its partial view, the data structure that each peer node keeps track of the partner peers. The contact node will advertise this newly joined peer node to all its partner nodes and c additional nodes randomly selected from its partial view. These advertisements are also referred to as subscription messages and the process of a new node joining the system is illustrated in Figure 1. The PartialView list tracks the partner peers and the InView list tracks the consuming peers.

When a peer node receives the subscription message, the peer node has a probability of 1/(1+M) to add the advertising node to its partial views, where M is the size of partial view. Otherwise, the subscription message will be randomly forwarded to a node in its partial views. Entries in the partial views will expire and each peer node re-advertises the subscriptions periodically to refresh the expiration timer of its entries in other peer nodes. This is also the mechanism that peer nodes update their partner list as other nodes join and leave the system dynamically.

Peer nodes in a steady SCAMP system will remain steady and the sizes of the partial views will converge which leads to a balanced video segment serving load for each node. SCAMP is, however, vulnerable when the network is dynamic. In the presence of node dynamics, SCAMP system can be often disconnected which results in video interruption and overall network instability. When a node discovers that there are no more nodes in the partial or in view lists, it leaves and re-joins the network. To improve the stability, we propose two preferential random schemes for the subscription message advertising and partner selection.

3.3 Improved Preferential Gossip Partnership

In SCAMP, subscription forwarding and partner selection processes are pure random. This although achieve in good load balancing property, the network can be unstable in dynamic environments. Some nodes might be isolated and disconnected, i.e., have no partners or not a partner of any other node, from the major part of the network. To minimize the time duration the nodes are isolated and the number of isolated nodes, we propose two preferential random policies. The first one is to allow preferential random forwarding of the subscription messages, referred to as the Preferential Random Forwarding approach. When each node re-subscribes itself, partners with larger partnership are favored and have a higher chance to be chosen as the targets. To balance the partnership, the subsequent forwarding of the subscription messages will be sent to partners with smaller partnership. The other policy is to allow preferential selection of partners. In SCAMP and Preferential Random Forwarding, a node is selected as a partner when its subscription is received by the probability 1/(1+M). In this further improvement, referred to as the Preferential Random Selection approach, a peer with small partnership size (e.g. less than 5) selects all nodes from all subscriptions it has received until reaching the default partnership size limit.

3.4 Experimental Setup

We use ns-2 [8] simulator to simulate 1000 overlay peers using SCAMP, Preferential Random Forwarding and Preferential Random Selection schemes. The overlay peers join and leave the network using an exponential on-off distribution. Both on and off periods have a mean value that equals 250 seconds. At the initialization phase, all nodes finish joining the network before the first 5000 seconds. The subscription advertisement cycle is set to 128 seconds and we run each simulation for 75000 seconds.

3.5 Experimental Results

Figure 2 show the distributions of the time the connected network becomes disconnected and the time the disconnected network comes back connected. Both Preferential Random Forwarding and Preferential Random Selection schemes take a longer time to enter the disconnected state from the connected state. The Preferential Random Selection outperforms especially in preventing frequent and sudden the system disconnection. We can also observe that Preferential Random Forwarding and Preferential Random Selection schemes have fewer numbers and shorter periods of disconnections than SCAMP.

Table 1 shows the statistics of the network stability due to the three schemes, including the Connected Time and Disconnected Time are the amount of time that the overlay network being in connected and disconnected state respectively. Disconnected Node (N) shows the average number of nodes that are partitioned from the main cluster when the network is disconnected. Let S be the ratio of Disconnected Time to the Total Time. We are able to derive the instability index for each scheme by the multiple of N and S. The instability index represents the how serious the network can be, spatially and temporally, interrupted using different partnership formation schemes. As we can see, the instability of the P2P partnership is reduced by 52% and 89% respectively with the Preferential Random Forwarding and Preferential Random Selection improvements.

Table 1. Normalized network stability statistics of three schemes

	SCAMP	Pref. Random Forwarding	Pref. Random Selection
Connected Time (sec)	50640	57760	66820
Disconnected Time (sec)	19040	10320	2760
Total Time (sec)	69680	68080	69580
Disconnected Node (N)	2.85236	2.46696	2.24358
Instability (N*S)	0.77940	0.37395	0.08899

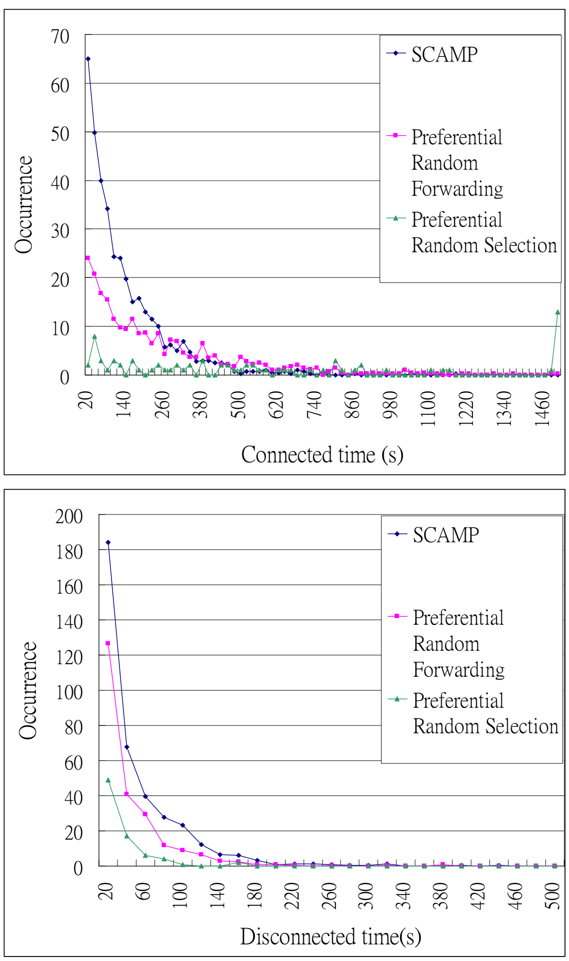

Figure 2. Histograms of the time network goes connected → disconnected and disconnected → connected

Figure 3 show that the partnership size, i.e., the out-degree, and the consumer-ship size, i.e., the in-degree, of SCAMP are generally load balanced but the partnership equilibrium falls at a smaller value which might not be able to keep the network connected under the exponential dynamics. In Preferential Random Forwarding, the in- and out-degrees show a slight growing trend but negligible. In the Preferential Random Selection improvement, the in- and out-degrees remain load balanced. In particular, both the in- and out-degrees show a higher concentration at a higher mean value which helps improving the network stability. The in-degrees, however, show a slight higher variance, which is the cost the scheme pays for the gain at out-degree balance and stability.

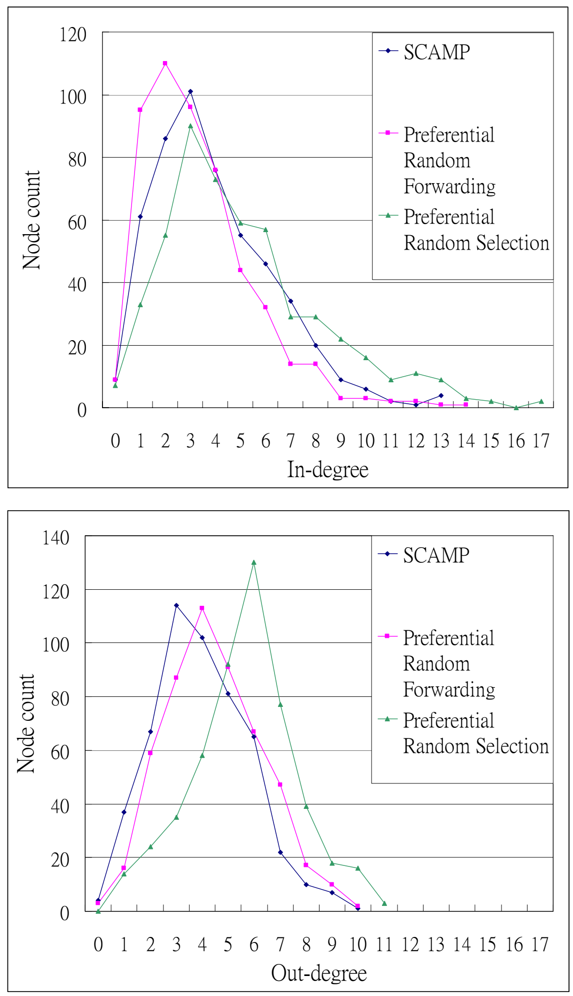

Figure 3. In-degree and out-degree distributions

4. Multiple Description Code

The multiple description codec is a critical component of HotStreaming that directly influences the user satisfaction. We decompose video streams in the temporal dimension for diversity gains. One simple example is to code the odd frames based on the previous odd frames and the even frames based on the previous even frames. As opposed to coding the frame-to-frame differences as in MPEG4, we code the interleaving frame differences. Then the two sub-streams can be transmitted separately over the network and played back with synchronization at the receiver. Such a design is more fault tolerant than conventional video coding. When one sub-stream is lost due to network congestion, the decoder can still independently play the remaining sub-stream with controlled degradation.

Based on the concept described above, we propose a new coding scheme named MDC-STHI (Spatial Temporal Hybrid Interpolation) [9], consisting of four streams as shown in Figure 4. Streams E_f and O_f represent the even and odd streams, respectively, encoded from the original full-size video. E_q and O_q denote the down-sampled version encoded at a lower bit rate. Our implementation uses 2:1 down sampling in each dimension of the video frame, resulting in one quarter of the original resolution. While E_q and O_q require extra bits to encode, we will show in the next section that the combination of the four streams has many desirable features for video streaming in P2P networks such as HotStreaming.

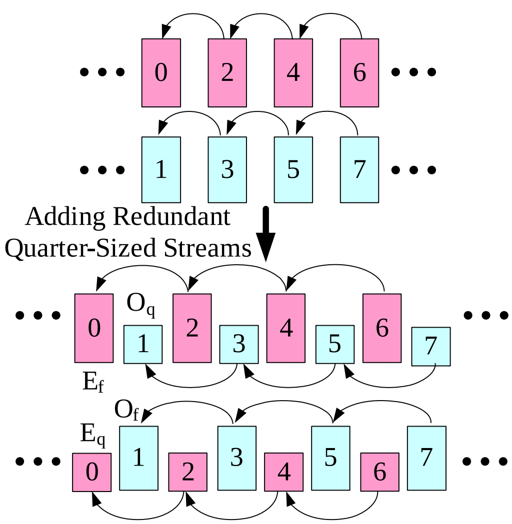

Figure 4. Video Streams in MDC-STHI

Figure 5 illustrates a possible P2P networking scenario using MDC-STHI. Generally, Internet users with various computational capabilities are connected through networks of different bandwidths, and in a P2P environment like HotStreaming, they may be randomly grouped as peers for video streaming. In Figure 5, the number of circles indicates roughly the amount of resources at the node. Thus, N3 has enough bandwidth and computing power to retrieve both streams E_f+Oq and O_f+Eq from N1 and N2. In turn, N4, N5, and N6 can receive appropriate combinations of streams from N3 according to their available resources. For example, N4 may retrieve only Eq or Oq from N3 because it uses a mobile device with a narrowband wireless connection and a small-sized screen that best displays quarter-sized videos. On the other hand, N6 can accommodate all streams from N3 and may further distribute the video streams intelligently to other peers. Compared to other MDC designs, MDC-STHI offers superior flexibility for P2P video streaming as the four streams are independently encoded and a node may adaptively deliver suitable combinations according to the peers' capabilities.

The combination of E_f+O_q or O_f+E_q pose an interesting challenge as it contains two streams of different resolutions. During transmission, the bits from O_q may piggyback in the same IP packet with E_f of the previous frame, and vice versa for O_q. This saves the overhead and ensures same time arrival of adjacent frames. We also developed an innovative hybrid interpolation scheme for such combinations, fully explained in [9].

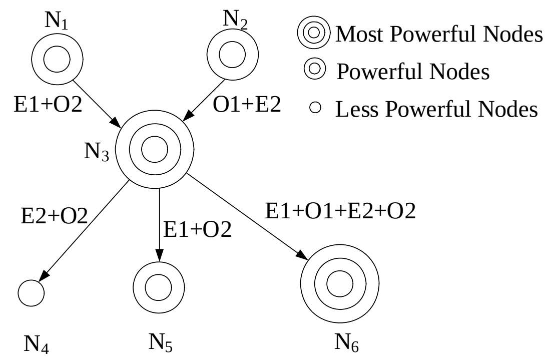

Figure 5. MDC-STHI over a P2P network

4.1 Experimental Setup

We use four CIF-sized (360x288) sequences and one D1-sized (720x480) sequence in our experiments. All test sequences are encoded with only I and P frames with I frame interval being 30 frames. For CIF-sized sequences, the bit rate for each full-sized stream is 750 kbps, and that for each quarter-sized stream is 300 kbps. For the D1-sized sequence, the bit rate for each full-sized stream is 1500 kbps, and 600 kbps for each quarter-sized stream. We set the precision of the weight value to 1/3, so the quantized weight value can be represented with 2 bits if no compression is applied. The transmission of weight information therefore requires only about 1% of the total bandwidth. We simulate the scenario where one description stream is lost or deliberately omitted due to bandwidth limitation, and only the full-sized even frames and quarter-sized odd frames are available. This means that E_f and O_q are interpolated to produce a full-sized video sequence.

4.2 Experimental Results

The PSNR values of interpolated odd frames are shown in Figures 6-9. The red curve is the result of hybrid interpolation, and the green and orange ones, respectively, are the results of spatial and temporal interpolation. From these figures, we can conclude that the weight information does improve the overall video quality. We also show the frames from different interpolation methods for the D1-sized Football sequence in Figures 10-13, and the perceptual quality is also better with the proposed hybrid interpolation scheme.

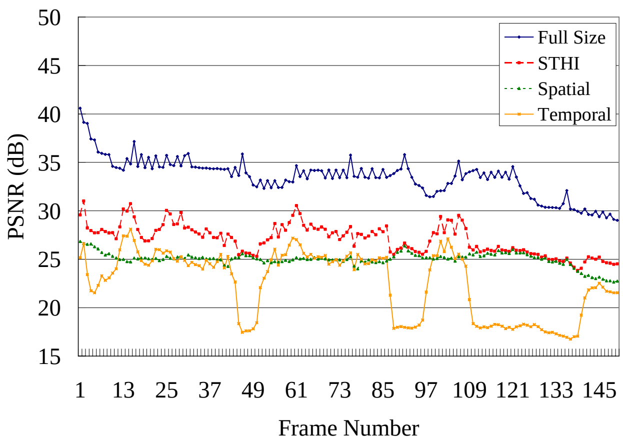

Figure 6. The PSNR values of the CIF-sized Stefan sequence

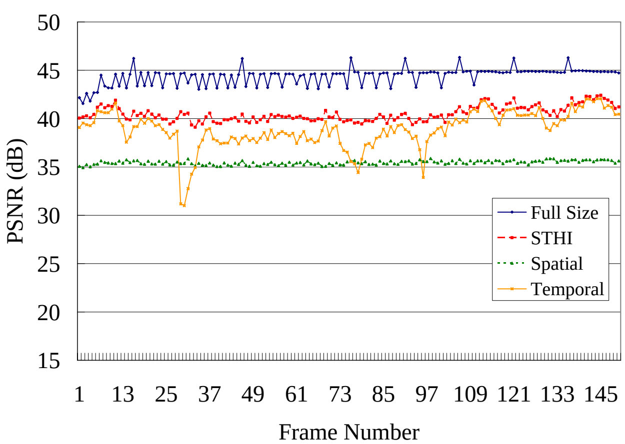

Figure 7. The PSNR values of the CIF-sized Mother and Daughter sequence

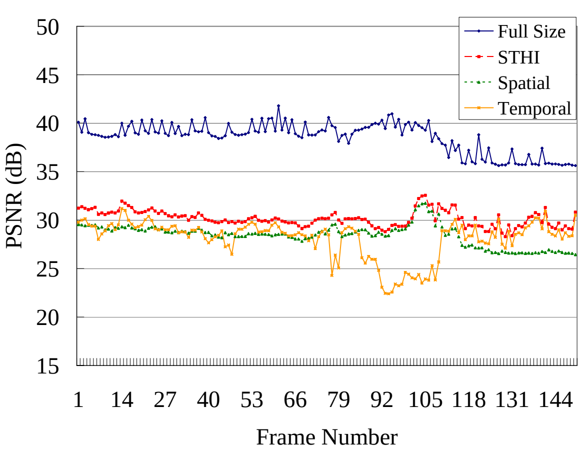

Figure 8. The PSNR values of the CIF-sized Foreman sequence

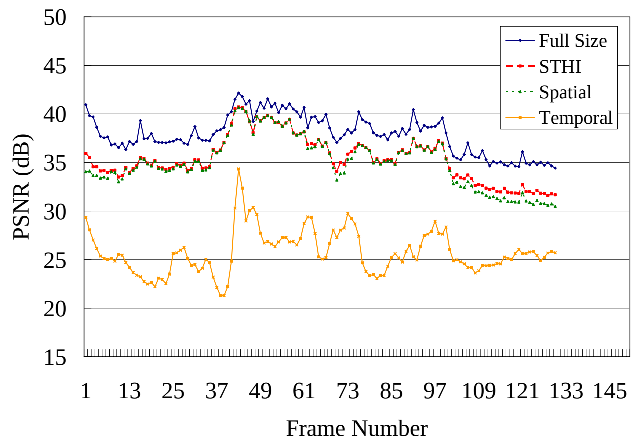

Figure 9. The PSNR values of the D1-sized Football sequence

Figure 10. The 121st frame of the full-sized odd stream

Figure 11. The 121st frame of the weighted interpolated odd stream

Figure 12. The 121st frame of the spatially interpolated odd stream

Figure 13. The 121st frame of the temporally interpolated odd stream

5. CONCLUSION AND FUTURE WORK

The preliminary experimental results indicate that the partnership formation and the multiple description code components are promising and show significant improvements. The core designs of the networking and video coding parts, although promising, are not yet tightly integrated. The major future work lies in the third component, video segment request scheduling. This is also where the networking and coding sides of the system fuse. The video segment request scheduling algorithm determines for each receiver, at each point in time, the specific segments, the ordering to request, and the partner to request the segment from. The mechanism in the state-of-the-art CoolStreaming [6] is rather heuristic and naïve: A node will request first the segment with very few copies remaining in the partners. In our view, the solution seems impractical for heterogeneous networks. Our premise is to allow each node in a heterogeneous network to request segments of particular resolutions or temporal streams based on the available resources in the partnership and itself. As a result, the system is able to better utilize the resources of the system and achieves better overall user satisfaction.

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