SVC or MDC? That's the Question

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***Abstract*—Multi-rate video scalable codecs, SVC and MDC, provide as plausible solutions to deal with heterogeneous environment of Internet. They, however, also give rise to a wide debate over which one is more efficient supporting P2P IPTV systems. Our goal in this work is to resolve the debate by providing a quantitative comparison of P2P IPTV systems given different choices of coding schemes and P2P network formations. The answer is rather subtle. MDC-based systems, though outperform SVC-based ones under certain network formation with bottleneck in terms of network throughput, suffer from a lower level of perceptual quality in terms of PSNR due to the coding inefficiency. The results drawn from this paper can be provided not only a lesson to the design of large-scale heterogeneous P2P IPTV systems but also as a strong evidence that a poor choice of codec at the higher level might over shadow the network-level designs and the codec and network formation components ought to be co-designed for optimal user experience.**

Keywords-Thin stream problem, Membership formation, Multi-rate coding, IPTV.

I. INTRODUCTION

In view of reducing server load and avoiding a single point of failure, the peer-to-peer (P2P) paradigm has surpassed the traditional client-server solutions for contents delivery over the internet. Proven as an efficient solution for large-scale, multi-party content delivery, the P2P model is getting to encroach the current tendency toward video-broadcasting applications known as P2P IPTV, such as PPStream [1] , PPLive [2] and CoolStreaming [3]. However, the Internet's intrinsic heterogeneity makes real-time video broadcasting a complicated and challenging problem. The solution tends to be suboptimal with single-rate video distribution, because there is no single target rate good for diverse peers.

Local resources of user devices such as CPU power, available memory and hard disk space contribute partly to the heterogeneity. In order to penetrate services utterly from HDTV flat-panel displays, portable multimedia players (PMPs), to 3G mobile devices with different bandwidth connectivity provided by advent development in optical and wireless communication like Wi-Fi, 3G, or WiMax, people engaging in video compression bring up a new term – "multi-rate video". In fact, in a typical P2P network, the video segments are acquired from multiple member (providing) peers. This, originally designed for robust connectivity in P2P networks, creates redundancy and is in favor of solutions with multi-stream, multi-rate video distribution.

Aiming at achieving different levels of compression efficiency, rate scalability, and error-resiliency, there are two flavors of multi-rate coding schemes proposed to maximize the display quality while meeting diverse bandwidth and latency constrains: Scalable Video Coding (SVC) [5] and Multiple Description Coding (MDC) [6].

A. *Scalable Video Coding (SVC)*

Several tools supporting the most significant scalability modes has been adopted in part of established video coding standard including MPEG and H.263+ [7, 8]. Scalable Video Coding is a recent amendment to ISO/ITU Advanced Video Coding (H.264/AVC) standard, which guarantees graceful degradation in bit rate and format and provides video services with lower temporal or spatial resolution by transmitting or decoding partial bit streams. SVC organizes the compressed file into a Base Layer and multiple Enhancement Layers, which carry additional information to enhance quality, resolution or frame rate. The base layer is the essential layer provides basic quality and can be decoded independently of other enhancement layers. In the other words, only that there is the prior presence of base layer, can consequentially introduced first enhancement layer, second enhancement layer, and so on be decoded, which implies there is interdependency between each layers. Therefore, the rate scalability can be achieved by combining spatial (resolution), quality (SNR) and temporal (frame rate) scalability types at each level. More information about SVC can be found in [9].

B. *Multiple Description Coding (MDC)*

MDC has been proposed as an alternative to SVC. In contrast to SVC, MDC is a form of data partitioning, which fragments single video stream into multiple independent descriptions. Each description carries partial information of original data and guarantees a basic level of reconstruction quality. With more additional descriptions received if the bandwidth affords, the quality can thus further be improved. For no priority between each description, an arbitrary subset of descriptions can be decoded, which not only processes bit rate adaptation but also consolidate error-resilience over unreliable channel with unavoidable packet loss and congestion [10].

Available bandwidth between the peers contributes also to the heterogeneity. There are strategies proposed to deal with bandwidth heterogeneity, such as P2P network formation algorithm according to the distribution of peer's capacity and degree [4]. These protocols can exploit network heterogeneity and provide better quality of video streaming service by connecting to the high capacity-to-degree-ratio neighbors, which shortens the network diameter and thus reduces transmission delay without the support of IP multicast.

A number of P2P IPTV systems are proposed using various multi-rate, multi-stream video codec, as well as various P2P network formations. A major debate arising is the use of SVC vs. MDC for P2P real-time video broadcasting. The existing comparisons are qualitative. Our goal in this work is to resolve the debate by providing a quantitative comparison of P2P IPTV systems given different choices of multi-rate, multi-stream video encoding schemes and P2P network formations.

We find that the answer is rather subtle. MDC-based systems outperform SVC-based ones in terms of network throughput. In other words, the amount of video data delivered by MDC-based systems is higher. However, the decoded video sequence of MDC-based systems shows a lower perceptual quality than that of the SVC-based ones. This indicates that MDC-based systems will provide a lower level of user satisfaction in the end. The lesson, more importantly, is that it is likely premature to draw conclusions about a multimedia streaming system based on a network-level evaluation. For multimedia systems, it is essential to evaluate not only the amount of the content delivered in time but also the quality of the content received. In this study, the compression efficiency of SVC reverses the system performance at the user level. To our surprise, the advantages of P2P network formation mechanism can be well-overshadowed by the use of an inefficient video codec.

The rest of this paper is organized as follows. Section II describes related work, and Section III addresses the problem definition we'd like to discuss. Section IV presents the simulation setting for overlay topology, membership formulation, streaming content codec, and scheduling scheme. The experimental results are shown in Section V and finally the conclusion summarize in Section VI.

II. BACKGROUND

Characteristics of the two coding schemes, SVC and MDC, are very distinct in terms of interdependency. When they are applied to video streaming over packetized Internet, the performance of systems is determined by the system architecture and the scenario of packet transmission scheduling. Though, the SVC standard has just become mature recently. There are few performance comparisons between MDC and LC (Layered Coding), the predecessor of SVC, reported in the literature. The applications of MDC and LC are not limited to P2P-based multimedia systems. In [11], the authors compared MDC and LC for multicasting real-time transmission by simulation under different protocols and network topologies. The paper pointed out that MDC outperforms LC over a broad range of scenarios including networks with no feedback support, networks with long RTTs and applications with low latency requirements. This is especially evident if the base layer packets are lost, which indicates that reliable transmission of base layer is necessary for LC to perform well. Therefore, in [12], this paper applied ARQ-based error protection and FEC-based error protection to both LC and MDC. In that way, error-resilience capability of LC has been improved and has almost equivalent performance as MDC up to 10% loss rates. In [13], LC outperforms MDC when rate-distortion optimized scheduling of the packet transmission over multiple network paths is employed. In [14], the paper gave an overall comparison between LC and MDC in a peer-driven video streaming system via analytically and simulation by changing the peer connect probability and the peer replacement time in case of disconnection to represent the stability in the P2P network. As expected, results are coherent to the previous works, because LC requires a lower bit rate to reach the same level of video quality. LC is more efficient than MDC in more reliable network.

For P2P IPTV systems in particular, there are several works selecting appropriate content representation for streaming session. The earlier innovation providing MDC in P2P streaming is brought by CoopNet, project of Microsoft Research [15]. CoopNet constructs multiple, diverse distribution trees to provide redundancy in network paths and uses MDC to provide redundancy in data. However, it adopts the P2P model as means of relieving the server load. The Peer-to-Peer Receiver-drIven MEsh-based Streaming, PRIME [16], adopting also MDC coding, further solve the problems of bandwidth bottleneck and content bottleneck in MDC-based P2P streaming systems. Moreover, in [18], the authors further extend MDC scheme with spatial-temporal hybrid interpolation (STHI) to adjust streaming traffic according to the bandwidth and device capability of each peer and point out that another strong distinction between MDC and SVC is that thin stream is more likely to occur for layered streaming in a dynamic P2P streaming network.

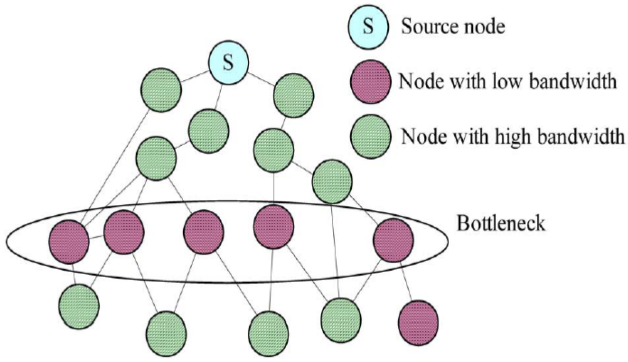

Figure 1: Topology of a P2P network with bottleneck [18]

Compared to MDC, SVC is not quite mature in this application field, recently, the system proposed in [17] organized a set of reliable complementary multicast trees combined with prioritization mechanism to support SVC by transmitting base-layer first and then the enhancement layers according to the level of network congestion. Another architecture *SVCP2P* [23] was also implemented. With the assistance of the central servers, *SVCP2P* is able to deal with the more complicated scheduling algorithm met in SVC scheme. Furthermore, some work such as Co-SVC-MDC [24] attempts to incorporate both the MDC and SVC coding schemes.

III. Problem Definition

The coding scheme not only affects the coding efficiency, but also the overall system performance when implemented as part of a P2P IPTV streaming system. For instance, the coding nature of SVC adds more complexities to system design than MDC does due to its layer dependency. The major drawback deploying layered coding in P2P the network environment is that peers might leave unexpectedly and peer connections should be intentionally arranged such that the connection bandwidth gradually decreases from the source going downstream to the leaves. Otherwise, the thin connections in the middle of the distribution P2P network will prevent downstream peers from fully utilizing its bandwidth. This is referred to as the thin stream problem [18].

In this work, we investigate how different network structures formed by peer connections with bandwidth heterogeneity in P2P IPTV systems interact with different coding schemes, SVC and MDC, and what quality the receiver peers enjoy. We execute simulations and further simplify the problem as streaming two kinds of coding schemes with two and four quality-leveled scalable video under three different network structures. They represent dynamic connections between high and low bandwidth peers: two extreme network cases, with and without the bottleneck, and one generalized cases. To quantify those problems, we apply throughput to analyze performance. Considering not only from networking but also user perception, another metric Peak Signal-to-Noise Ratio, PSNR, for objective video quality assessment is used as an approximation to user perception of quality.

IV. Simulation Model

We use network simulation tool ns-2 [19] for the evaluation. A P2P IPTV system consists of several fundamental components, from bottom up, *A. overlay topology*, *B. membership formulation*, *C. the codec of streaming contents* and *D. scheduling scheme.* The specific settings used in our experiments will be detailed below.

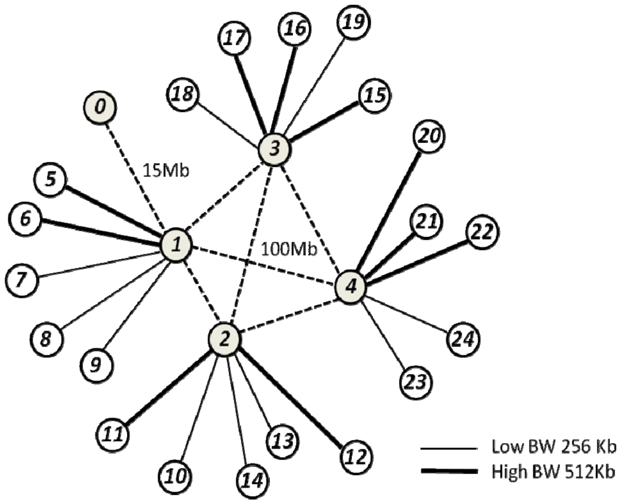

Figure 2: the topology in our simulation

A. Overlay Topology

We build a mesh overlay over a small-scale transit-stub topology network with 25 nodes. There are 4 fully-connected nodes serving as the transit nodes. Each transit node connects to 5 stub nodes as shown in Fig. 2. Node 0 is the node where the source peer resides. The other stub nodes are the nodes where the receiving peers reside. The links between each node is duplex and with four kinds of bandwidth: 100Mbps between transit nodes, 512Kbps for half of the stub nodes, 256Kbps for the other half of the stub nodes, and 15Mbps for the source node. Furthermore, we assign the delay between the transit nodes to be 30ms and the delay between transit to stub nodes to be 10ms.

Note that the topology is simple and small. It may not resemble the topology that any actual P2P IPTV system spans but can represent a snapshot of a small neighborhood formulation within the streaming duration. Though, our goal is to resolve the debate and compare the MDC- and SVC-based systems in particular cases. We find it easy to create P2P membership formulations on such a topology and such that different network situations can be conveniently generated. In addition, we do not take cross traffic and packet losses into consideration to leave the study of these other factors in the future work. However, it's not hard to imagine that the cross traffic might degrade the SVC-based system performance more due to a lower level of robustness to losses, especially those at the base layers.

B. Membership Formulation

In order to examine how different bandwidth distributions, (a result of different P2P membership formation strategies) impact the performance of P2P IPTV streaming, we generate three distinct membership formation scenarios. Peers that are closer to the source are referred to as the upstream peers and the farther ones are the downstream peers. The three scenarios are as follows. *1) Upstream with higher bandwidth peers and downstream with lower bandwidth peers (H2L):* This is the best case in distributing scalable video in P2P IPTV systems. There is no bottleneck prohibiting the segments from propagating between peers and scale down properly with the level of bandwidth available. *2) Upstream with lower bandwidth peers and downstream with higher bandwidth peers (L2H):* On the opposite, this is the worst case when the peer has all members with low bandwidth as providers. *3) Random connection (RAN):* Consider P2P IPTV systems in operation. The overlay networks tend to be mesh based for better robustness and load balance [20]. The random connection case is set to reflect the popular use of mesh P2P networks.

C. Streaming Content Codec

The latest codec standard H.264/AVC provides higher coding efficiency than previous standards such as MPEG4. We thus adopt H.264 as a comparing base to encode MDC and SVC streams. Using JSVM [21], utility software, we generate two videos from *foreman* sequence with a frame rate of 30 fps for MDC and SVC. In our setting, we propose two cases for comparison, 2 streams and 4 streams cases, to emphasize how codec scheme matters.

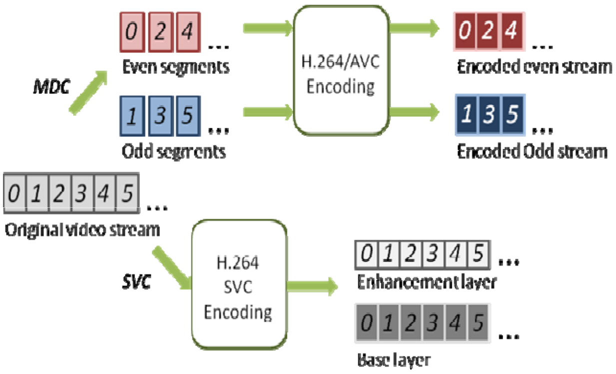

Figure 3: The flow chart of encoding process for MDC and SVC by H.264 in our scenario

1) Two Streams Case

In 2 streams case, the process is illustrated in Fig. 3. For MDC, video is divided into even stream and odd stream, which is the most familiar temporal MDC method called ODD-EVEN-MDC or splitstream [22]. The elegance of this scheme lies in the fact that from an encoder point of view it is extremely simple and very nicely handles temporal propagation destroyed pictures. For SVC, we encode the video into a base layer and one enhancement layer. The data rate of the compressed video streams and the average PSNR of the reconstructed video sequence are listed in Table I. The average bit rate for one description or one layer is set around low bandwidth link value, which is also half of high bandwidth link. The reconstructed video PSNR from MDC and SVC with respect to streaming time is shown in Fig. 4.

TABLE I. AVERAGE BIT RATE AND THE RECEIVER-SIDE AVERAGE RECONSTRUCTED PSNR FOR MDC AND SVC IN 2 STREAMS CASE

MDC				SVC			
Bit rate (Kbps)		PSNR		Bit rate(Kbps)		PSNR	
Even(E)	212	E, O	30.35	Base(B)	204	B	33.40
Odd(O)	212	E+O	34.96	Enhancement(E)	174	B+E	37.48

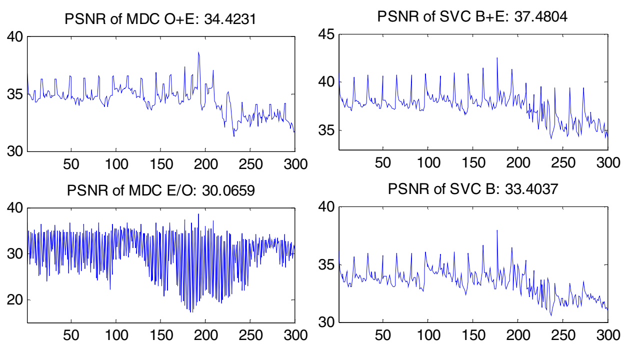

Figure 4: PSNR of *foreman.cif* with respect to streaming time deconstructed from partial or full description/layer in MDC/SVC case. MDC is on the left side, and SVC is on the right side. Lower figures indicate there are only one base layer or one description (Even/Odd) received and deconstructed. Upper figures indicate when all descriptions/layers received. The average PSNR is denoted in each figures' title.

2) Four Streams Case

Furthermore, we extend the multi-rate video to 4 streams. Here in order to make MDC and SVC more comparable, we add temporal scalability in first two streams avoiding quality degradation resulting from frame repetition of MDC. The frame repetition effect can be obviously reflected in Fig. 4 and Fig. 5 by the periodic sudden drop in PSNR every separated frame if only partial MDC descriptions received. The encoding process is similar with that in Fig. 3 but with slight difference. For MDC, we divide the whole video sequence into four equal-sized streams according to the frame's order and encode separately. For one or two descriptions received, display the video with frame rate of half original; while for more than tree descriptions received, reconstruct video with original frame rate. For example, if only one description is received, repeat frame once to create half frame rate video, which is 15 frames per second. On the other hand, for SVC, the first two layers are encoded with half original frame rate with incremental quality. And so does the two higher layers, however with full frame rate.

TABLE II. AVERAGE BIT RATE AND THE RECEIVER-SIDE AVERAGE RECONSTRUCTED PSNR FOR MDC AND SVC IN 4 STREAMS CASE

MDC			SVC		
Number of Descriptions	Bit rate (Kbps)	PSNR	Number of Layers	Bit rate (Kbps)	PSNR
1	123.5	28.72	1	115.8	31.57
2	247.0	34.84	2	219.9	33.66
3	370.5	31.78	3	345.8	33.83
4	494.0	34.84	4	507.2	34.85

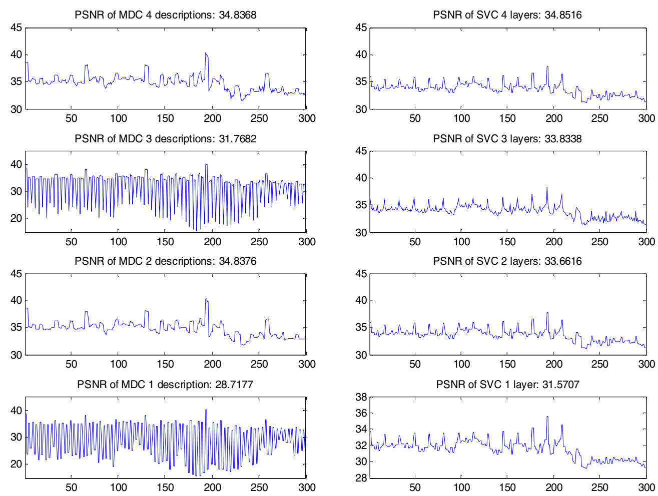

Figure 5: PSNR of *foreman.cif* with respect to streaming time reconstructed from partial or full description/layer in 4 streams MDC/SVC case. MDC is on the left side, and SVC is on the right side. Left side of figure indicates there is one incrementally to four descriptions received and decoded. While right side of figure indicates the result of sequentially received from base layer to the third enhancement layer, which is the forth layer.

Similarly, the data rate for four descriptions/layers video streams and the average PSNR of the reconstructed video sequences are listed in Table II. The reconstructed video PSNR from MDC and SVC with respect to streaming time is shown in Fig. 5.

D. Scheduling Scheme

The design of scheduling scheme will also influence the performance of the P2P live streaming system. Here, we formulate our scheduling as follows. At first, each peer acquires its members' buffer maps and records the union of the available segments and the respective owners. According to the estimated bandwidth between the peer and each of its members, the peer decides which segment can be requested from which owner under the constraint that the segment can arrive before the playback time. Concerning load balancing, for each available segment, the peer randomly chooses a feasible owner to download the segment. Estimated bandwidth is obtained from the total segment size previously requested divided by the round trip time. In order to avoid fluctuation in estimated bandwidth, we smooth the estimated bandwidth by taking the exponential weighted average of the current estimation and the previous ones. For parallel processing, we take four segments together into consideration in one round of scheduling. Among all feasible combinations, the one leading to the best video quality will be selected. For SVC, the combinations should exclude those without base layer or not sequentially dependent enhancement layers within one segment.

V. Experimental Results

A. Evaluation Metrics

At the network level, we examine the *throughput* of data streamed to each peer. We also capture the perceptual quality of video by *PSNR* in order to evaluate the performance between MDC and SVC at the user level. By comparing results using both metrics, we discover subtle differences between MDC- and SVC-based P2P IPTV systems.

B. Simulation Results

There are three membership formulations mentioned above in our simulation: *1) Upstream with higher bandwidth peers and downstream with lower bandwidth peers (H2L)*, *2) Upstream with lower bandwidth peers and downstream with higher bandwidth peers (L2H),* and *3) Random connection (RAN).* The results are summarized in Table III. In general, the throughput of MDC-based system is higher than its SVC-based counterpart. The PSNR, however, shows an opposite trend. In that, SVC-based system tends to provide a higher perceptual quality.

To explain the results, characteristics of MDC and SVC should be pointed out. Recall the streams summarized in Table I. They are generated by controlling the data rate and PSNR so that they can be as comparable as possible. First of all, the compression efficiency difference can be observed. Even and odd streams separation somewhat degrade the compression efficiency from motion estimation. As a result, the data rate of MDC is unavoidably higher than that of SVC when a certain PSNR should be reached. Moreover, PSNR of reconstructing only one description in MDC is worse than that in base layer because only half information is provided and thus comparing to the original video, error increases on the half part of missing frames, which is shown in lower left block in Fig. 4. Second, the property of dependence and independence between layers and descriptions also makes a different. Because of taking advantage on dependence between layers, the data rate of an enhancement layer is less than an independent MDC description. However, only on the existence of base layer can the enhancement layer be reconstructed.

TABLE III. 2 Streams Case: Receiver-Side Average Throughput and PSNR in Three Membership Formulation Cases

case	codec	Upstream peers		Downstream peers	
		PSNR	Throughput(kbps)	PSNR	Throughput(kbps)
H2L	MDC	34.42	424.0520	30.97	265.0900
	SVC	35.60	378.6320	33.49	208.5150
L2H	MDC	30.26	224.8194	31.80	296.8822
	SVC	33.71	225.0905	33.54	212.8770
RAN	MDC	32.66	339.2722	31.15	259.7911
	SVC	34.74	308.8404	34.35	278.3066

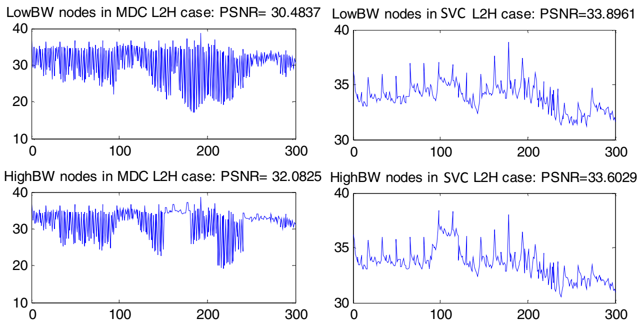

Figure 6. The PSNR of foreman.cif over streaming time with respect to upstream peers and downstream peers. MDC is on the left-side column and SVC is on the right-side column. The first row is the average PSNR received by upstream peers with low bandwidth and the second row is, on the other hand, downstream peers with high bandwidth.

Although SVC has a higher coding efficiency, it fails to utilize the network bandwidth effectively. Indeed, MDC and SVC perform rather differently in the L2H scenario. See Fig. 6. The plot on the lower right indicates the average PSNR over time received by the downstream (higher bandwidth) peers. Comparing to the plot on the upper right which illustrates the average PSNR measured at the lower bandwidth peers upstream, the downstream peers although with higher network capacity can only request the same or less data from their suppliers. It is because the bandwidth constraint at the upstream peers. To meet the time constraint, it only allows one layer of the video from the source, and the dependency between layers in SVC inherently forces the requested layer to be base layer. As a result, the throughput observed at the downstream peers does not truly reflect the available bandwidth of the downstream peers.

In the L2H scenario, the SVC coding scheme suffers from the thin stream problem. In that, a low resolution or partial video is received by a peer even if the peer has enough bandwidth for a full video. P2P networks are dynamic by nature. Peers are on and off spontaneously. To cope, most P2P networks are designed to discover changes, thus changing the network connections, on a regular basis. Layered coding scheme is not compatible with P2P network formulation not taking bandwidth and proximity to the source into consideration [18].

On the other hand, MDC, the left column in Fig. 6 shows distinct behavior from the SVC case. As mentioned in SVC, the upstream peers in MDC also have their bandwidth limitation from receiving more than one description in live streaming, so they request either an even or an odd description. However, surprisingly, the downstream peers can exploit the independency between the descriptions and collect both the even and odd descriptions from different upstream peers in time before playback. Therefore, when MDC runs into the thin stream problem, it still has a chance better utilizing upstream peers' bandwidth to provide higher PSNR.

Looking back to another two cases, we find that throughput in MDC is higher than SVC, nevertheless, average PSNR in SVC is higher than MDC, which means, SVC can provide better quality under less data rate. In the case one, H2L, both MDC and SVC fully make use of their bandwidth. Consequently in the streaming results, upstream peers thus gain all video segments and downstream peers only receive partial of them. And in the other random case, the scheduling results depend on the peer's bandwidth and the video segments its members possess.

TABLE IV. 4 STREAMS CASE: RECEIVER-SIDE AVERAGE NUMBER OF DESCRIPTIONS/LAYERS, THROUGHPUT AND PSNR IN THREE MEMBERSHIP FORMULATION CASES

case	codec	Upstream peers			Downstream peers		
		Number of Descriptions	PSNR	Throughput (kbps)	Number of layers	PSNR	Throughput (kbps)
H2L	MDC	3.715	34.84	494.0096	1.969	32.38	234.6546
	SVC	3.820	34.85	507.2072	1.969	33.16	249.4248
L2H	MDC	1.860	34.84	247.0048	2.609	32.78	341.9818
	SVC	2.182	33.68	232.5171	1.698	32.73	179.3516
RAN	MDC	2.773	34.66	364.3321	2.406	32.36	299.4933
	SVC	3.000	34.28	385.5986	2.315	33.48	299.4411

From the summarized results of 4 streams case in Table IV, it shows more comparable values in PSNR and in throughput between MDC and SVC under whatever the membership formulation case is. Again, referring to Table II, in this 4-stream codec scheme setting, PSNR shown in the second level of MDC is higher than that in the third level due to using the half frame rate video as a comparison base. In addition, if any frame repetition involves in the reconstruction process in MDC, like level1 and level 3, the PSNR thus decreases. For SVC, PSNR improves incrementally as the layer number and thus the bit rate grows obviously more in the second and third enhancement layer to provide full frame rate video. That shows the good granularity property of SVC.

As a help to clarify the results, we add another parameter *number of descriptions/layers* here in Table IV. Looking at the L2H case we interested most, we find the same conclusion as that in 2 streams case that the downstream peers using MDC do possess richer throughput as well the number of descriptions. In such situation, higher throughput somehow compensates the lower coding efficiency of MDC. More different descriptions get chance to penetrate the bottleneck and reconstruct into a higher quality video segment, reflecting in the values of PSNR. The Fig. 7 illustrates the PSNR over streaming time of upstream and downstream peers respectively in L2H case.

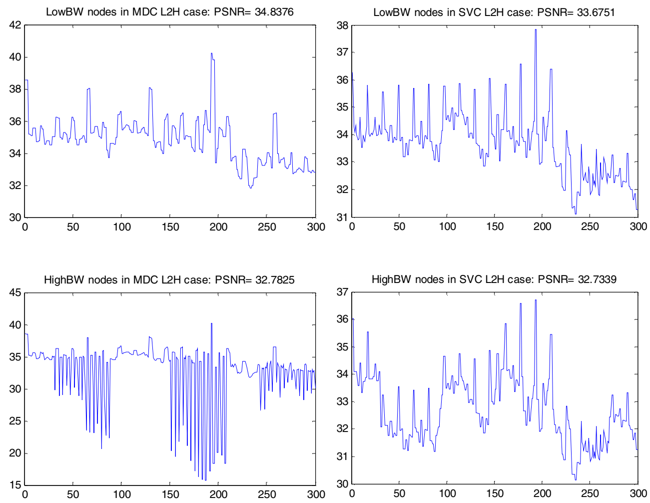

Figure 7. The PSNR of *foreman.cif* over streaming time for 4 streams case with respect to upstream peers and downstream peers. MDC is on the left-side column and SVC is on the right-side column. The first row is the average PSNR received by upstream peers with low bandwidth and the second row is, on the other hand, downstream peers with high bandwidth.

VI. CONCLUSION

In this paper, we pointed out the critical difference, interdependency, between MDC and SVC two scalable codec when coming into diverse P2P network formations. Dependence between each layer improves coding efficiency, however, imposes restrictions on the flexibility conflicting with highly dynamic P2P method.

Our simulation results shows that there is no apparent gap between SVC and MDC when there is no bottleneck existing. All peers can well utilize their bandwidth to get the best video quality they deserve. On the other hand, when the network happen to reorganize when some peer leave unexpectedly or after a swarming cycle that the high bandwidth peer have no comparable downlink attached, the deficiency in quality will be exposed. In this condition, MDC still has chance to survive, trying to collect even and odd segments from distinct members respectively both with low bandwidth. Though network throughput in MDC-based systems outperforms peers with high bandwidth blocked by the bottleneck in SVC-based ones. The latter still enjoy the higher quality or PSNR than those in MDC. That is, the higher coding efficiency of SVC somewhat compensate for its less redundancy.

REFERENCES

[1] [Online]. Available: http://www.ppstream.com/PPStream

[2] [Online]. Available: http://www.pplive.com/PPLive.

[3] X. Zhang, J. Liu, B. Li, and T.-S. P. Yum, "DONet/CoolStreaming: A data-driven overlay network for live media streaming," in *Proc. IEEE INFOCOM*, Miami, FL, Mar. 2005, vol. 3, pp. 2102–2111..

[4] Kin-Wah Kwong; Tsang, D.H.K., "Building Heterogeneous Peer-to-Peer Networks: Protocol and Analysis," *Networking, IEEE/ACM Transactions on* , vol.16, no.2, pp.281-292, April 2008.

[5] Schwarz, H.; Marpe, D.; Wiegand, T., "Overview of the Scalable Video Coding Extension of the H.264/AVC Standard," *Circuits and Systems for Video Technology, IEEE Transactions on* , vol.17, no.9, pp.1103-1120, Sept. 2007.

[6] Goyal, V.K., "Multiple description coding: compression meets the network," *Signal Processing Magazine, IEEE* , vol.18, no.5, pp.74-93, Sep 2001.

[7] ISO/IEC (1998) Information technology – coding of audiovisual objects: Visual (MPEG-4). JTC1/SC29/WG11, Tokyo, Final Committee Draft 14496-2

[8] Telecom. Standardization Sector of ITU (1998) Video coding for low bitrate communication. ITU-T Recommendation H.263 version 2

[9] A. Kouadio, M. Clare, L. Noblet and V. Bottreau, "SVC – a highly-scalable version of H.264/AVC" , EBU TECHNICAL REVIEW – 2008 Q2.

[10] Yao Wang; Shunan Lin, "Error-resilient video coding using multiple description motion compensation," *Circuits and Systems for Video Technology, IEEE Transactions on* , vol.12, no.6, pp.438-452, Jun 2002.

[11] Singh R, Ortega A, Perret L, Jiang W (2000) "Comparison of multiple description coding and layered coding based on network simulations," In: Proc. visual communications and image processing, San Jose, CA. SPIE, 3974:929–939.

[12] Yen-Chi Lee; Kim, J.; Altunbasak, Y.; Mersereau, R.M., "Performance comparisons of layered and multiple description coded video streaming over error-prone networks," *Communications, 2003. ICC '03. IEEE International Conference on* , vol.1, no., pp. 35-39 vol.1, 11-15 May 2003.

[13] Yen-Chi Lee, Joohee Kim, Yucel Altunbasak, Russell M. Mersereau, "Layered coded vs. multiple description coded video over error-prone networks," Signal Processing: Image Communication, Volume 18, Issue 5, May 2003, Pages 337-356, ISSN 0923-5965, DOI: 10.1016/S0923-5965(02)00138-8.

[14] Yanming. Shen, Zhengye Liu, Shivendra S. Panwar, Keith W. Ross, Yao Wang., "Peer-Driven Video Streaming: Multiple Descriptions Versus Layering," *Proc. IEEE ICME*, Amsterdam, The Netherlands, 2005.

[15] Padmanabhan, V.N.; Wang, H.J.; Chou, P.A., "Resilient peer-to-peer streaming," *Network Protocols, 2003. Proceedings. 11th IEEE International Conference on* , vol., no., pp. 16-27, 4-7 Nov. 2003.

[16] Magharei, N.; Rejaie, R., "PRIME: Peer-to-Peer Receiver-drIven MEsh-Based Streaming," *INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE* , vol., no., pp.1415-1423, 6-12 May 2007.

[17] Baccichet, Pierpaolo; Schierl, Thomas; Wiegand, Thomas; Girod, Bernd, "Low-delay peer-to-peer streaming using scalable video coding," *Packet Video 2007* , vol., no., pp.173-181, 12-13 Nov. 2007.

[18] Meng-Ting Lu; Jui-Chieh Wu; Kuan-Jen Peng; Huang, P.; Yao, J.J.; Chen, H.H., "Design and Evaluation of a P2P IPTV System for Heterogeneous Networks," *Multimedia, IEEE Transactions on* , vol.9, no.8, pp.1568-1579, Dec. 2007.

[19] Advances in Network Simulation, Lee Breslau; Deborah Estrin; Kevin Fall; Sally Floyd; John Heidemann; Ahmed Helmy; Polly Huang; Steven McCanne; Kannan Varadhan; Ya Xu; Haobo Yu; The VINT Project, IEEE Computer, Vol. 33, No. 5, pp. 59-67, May 2000

[20] Magharei, N.; Rejaie, R.; Yang Guo, "Mesh or Multiple-Tree: A Comparative Study of Live P2P Streaming Approaches," *INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE* , vol., no., pp.1424-1432, 6-12 May 2007.

[21] "The TML project web-page and archive," http://kbc.cs.tu-berlin.de/stewe/vceg/.

[22] Castro, M., Druschel, P., Kermarrec, A.M., Nandi, A., Rowstron, A., Singh, A., "Splitstream: high-bnadwidth multicast in cooperative environments", Proc. Of the 19th ACM symposium on Operating systems principles. (2003) 298-313.

[23] X. Lan, N. Zheng, J. Xue, X. Wu, and B. Gao., "A peer-to-peer architecture for efficient live scalable media streaming on Internet", In Proc. of ACM Multimedia'07, pages 783–786, Augsburg, Germany, September 2007.

[24] Chung-Ming Huang; Chung-Wei Lin; Chia-Ching Yang; Chung-Heng Chang; Hao-Hsiang Ku; , "An SVC-MDC video coding scheme using the multi-core parallel programming paradigm for P2P video streaming," *Computer Systems and Applications, 2009. AICCSA 2009. IEEE/ACS International Conference on* , vol., no., pp.919-926, 10-13 May 2009