SEAMLESS CHANNEL TRANSITION FOR PYRAMID-BASED NEAR-VOD SERVICES

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ABSTRACT

Periodic broadcasting is known as an efficient technique for delivering popular videos by reducing bandwidth requirement for transmitting streaming video to simultaneous viewers. The channel transition problem is a noticed issue to be concerned about the variability of popularity of video and resource management in periodic broadcasting. In this paper, we approach a general seamless channel transition scheme for pyramid-based broadcasting protocols and present the Stairway Channel Transition (SWCT) scheme. Compared to the existing schemes that are only designed for dedicated broadcasting protocols, our design possesses more flexibility, while it does not reduce the performance of the original protocols.

1. INTRODUCTION

Periodic broadcasting is an efficient technique to reduce the bandwidth requirement for transmitting streaming video to simultaneous viewers in near Video-on-Demand (VoD) services. In a periodic broadcasting system, the number of broadcasting channels is due to the allowable startup latency, not the number of requests. Thus, it is more suitable for distributing hot video programs. Many periodic broadcasting techniques have been proposed, such as Pyramid Broadcasting [1], Fast Broadcasting (FB) [2], Skyscraper Broadcasting [3], Staircase Broadcasting (SB) [4], Harmonic Broadcasting [5], Pagoda Broadcasting [6] and many other variations.

The *channel transition* problem is noticed as an important component of the resource management for the periodic broadcasting of *multiple* videos. To reflect the "level of hotness", the startup latency of a popular movie should be shortened to satisfy a large number of clients. If a movie is no longer popular, part of the assigned channels can be released for other movies. A channel transition scheme named Seamless Fast Broadcasting (SFB) was proposed in [7], and another seamless transition scheme over Staircase Broadcasting (SSB) was presented in [8].

To design seamless channel transition schemes for various broadcasting schemes is still an open question. The frameworks of SFB and SSB are dedicated to their respective FB and SB protocols, and not suitable for other protocols. Otherwise, SFB and SSB sacrifice some performance of the original FB and SB in trade of the seamless property. In this paper, we approach a general seamless channel transition scheme for pyramid-based broadcasting protocols. Unlike SFB and SSB, our Stairway Channel Transition (SWCT) scheme is appropriate for a set of pyramid-based broadcasting protocols. It does not modify the original protocols and thus keeps the performances of these protocols.

The rest of this paper is organized as follows. Section II introduces several previous researches related to our work. In Section III, we introduce our SWCT scheme and illustrate several examples. Comparisons between transition schemes are presented in Section IV. Finally a conclusion is given in Section V.

2. RELATED WORKS

2.1 Pyramid-based Broadcasting Protocols

Most of the present broadcasting schemes can be classified as Pyramid-based, Harmonic-based, or Pagoda-based protocols [9]. Pyramid-based protocols divide the video into several segments of equal or different sizes. These segments are broadcasted in individual channels of equal bandwidth. The Pyramid Broadcasting, Skyscraper Broadcasting, and Fast Broadcasting are representative Pyramid-based protocols. The enhanced mirrored-pyramid broadcasting (EMPB) [10] is altered from FB. The detail introductions of these pyramid-based protocols are omitted here.

2.2 SFB and SSB

The common concept of SFB and SSB is to rebuild a multiple relationship among various segment lengths corresponding to different channel allocations. However, the implementations of these two schemes are quite different. The SFB employs a strategy named "data padding" to enlarge the original video to be of suitable size, and a factor α is defined as the number of minimum allocated channels. Under the design of SSB, neither data padding nor factor α are needed, but unused channels will not be immediately released.

3 THE STAIRWAY CHANNEL TRANSITION SCHEME

The first idea of SWCT was from the study of the channel transitions in FB and we had announced it in [11].

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Meanwhile, the Flexible Periodic Broadcast (FPB) [12] is similar to our SWCT in concept but uses the Fibonacci series as the video segmentation scheme and a different design of ending rules for old channels. By our further observation, we found that our scheme is also suitable for several other pyramid-based protocols.

In the following introduction, L is the length of the broadcasted video. This video may be divided into N segments named $S_1, \ldots, S_N$. The number of current allocated channels is k, and the length of the (first) segment is d, which is also the startup latency. Other notations are clarified as below:

$S_{i,j}$: the j^{th} block in segment S_i. In some broadcasting protocols, video segments are not equal-sized but composed by blocks in equal size. A sequence of consecutive blocks from a block to the last block before the sequence repeats will be mentioned as a "cycle" in the rest of the paper.

C_i: the i^{th} old channel, i.e. the channel broadcasting old segment(s).

C_j': the $_j{}^{\text{th}}$ new channel, i.e. the channel broadcasting new segment(s).

T_a: the starting time of the channel transition.

$T_E(C_i)$: the ending time of the old channel C_i.

$T_S(C_j')$: the starting time of the new channel C_j'.

$T_R(S_i)$: the received time of the segment S_i.

$T_P(S_i)$: the played time of the segment S_i. $T_R(S_1)=T_P(S_1)$ since S_1 is always received and played immediately.

d: the length of an old segment.

d': the length of a new segment.

m: the number of channels to be released or added.

k': the number of allocated channels after the channel transition.

We verify if a pyramid-based broadcasting protocol can perform the SWCT scheme by the following procedure:

Step 1: Identify the minimum/maximum client buffer requirements in this protocol, as shown in Fig. 1. The minimum cases are trivial. The maximum cases occur when $T_P(S_{i,j})=T_R(S_{i,j})$+(cycle length)-$d$ in C_i. Define each $T_S(C_j')$ by letting $T_S(C_1')=T_R(S_1)$ in the minimum case. Define the "last cycle" and each $T_E(C_i)$ in old channels by letting $T_a= T_R(S_1)$ in the maximum case. Note that the leading block of the last cycle in C_i is not necessarily $S_{i,1}$. This can be easily certified by checking all the block rotations in the last cycle and discovering that all the buffer requirements are the same, as shown in Fig. 1(d).

Step 2: Decide the correspondence between C_i and C_j' with m modified channels, i.e. find the mapping g so that $j=g(i,m)$ or $i=g^{-1}(j,m)$. Rewrite each $T_S(C_j')$ to $T_S(C_{g(i,m)}')$.

Step 3: Check if $T_S(C_{g(i,m)}')-T_E(C_i)\geq 0$ for all i. If the answer is positive, this broadcasting protocol can perform an m-channel transition with SWCT; otherwise, find out the restriction if possible.

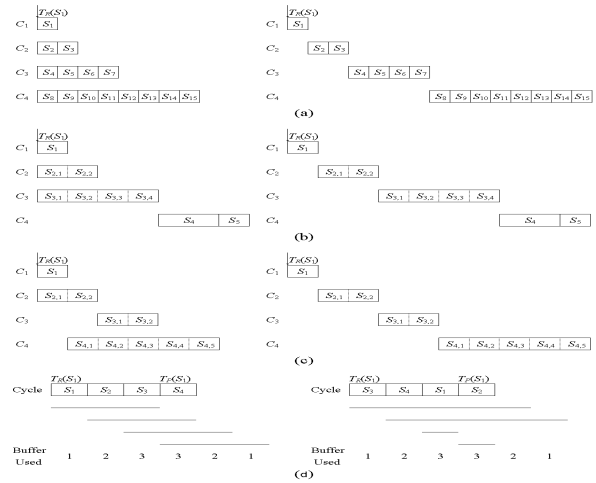

Fig. 1. Client buffer requirements: maximum case (left) and minimum case (right). (a) FB. (b) EMPB. (c) Skyscraper broadcasting. (d) Block rotation does not influence the buffer requirement.

Step 4: If the inequality in Step 4 is obviously constant, m can be any number smaller than k; or we must repeat Step 1 ~ Step 4 for checking all possible m.

Step 5: Repeat Step 1 ~ Step 4 again for both the negative and positive channel transitions.

In following discussion, we will demonstrate SWCT examples over EMPB, and Skyscraper Broadcasting protocols.

3.1 SWCT over EMPB

In EMPB, all the segments can be divided into blocks with equal length (precisely, the length d of S_1). By viewing each block in EMPB as a segment in FB, all the transition rules follow the SWCT over FB discussed in [12]. The only difference is that the last cycle in C_k should starts at $T_E(C_{k-1})$, not T_a. According to the Step 1 mentioned above,

$$T_E(C_1)=T_a,$$
$$T_E(C_i)=T_E(C_1)+(2^{i-1}-1)\cdot d,\ 2\leq i\leq k-1,$$
$$T_E(C_k)=T_E(C_1)+(2^{k-1}-2)\cdot d, \text{ and}$$
$$T_S(C_j')=T_S(C_1')+(2^{j-1}-1)\cdot d',\ 2\leq j\leq k',$$

where $d=L/(3\cdot 2^{k-2}-2)$, $d'=L/(3\cdot^{2k-m-2}-2)$ (in the negative transition) or $L/(3\cdot^{2k+m-2}-2)$ (in the positive transition).

In the negative transition with m channels released, the new channel C_j' succeeds the old channel C_{j+m} for all j, $1\leq j\leq k-m$. According to Step 2 and 3, we can ensure that the negative SWCT over EMPB does not cause any overlaps between old and new channels. The positive case also follows FB by letting the new channel C_{i+m}' succeeds the old channel C_i. For all i, $1\leq i\leq k-1$, the verification process is similar to that in [11]. For $i=k$,

$$T_S(C_{k+m}') - T_E(C_k)$$
$$=(2^{k+m-1}-1)\cdot d' - (2^{k-1}-2)\cdot d$$
$$=d\cdot(2^{k+m-1}-1)(3\cdot 2^{k-2}-2)/(3\cdot 2^{k+m-2}-2) - (2^{k-1}-2)\cdot d$$

$=d\cdot((3\cdot2^{k-2}-2^{k-1})(2^{m+1}-1)+2^{k-1}-2)/(3\cdot2^{k+m-2}-2)\geq 0,$

given that $m\geq 1$, and $k\geq 3$; therefore the positive SWCT is also feasible over EMPB. Fig. 2(a) and 2(b) demonstrate the negative and positive examples with k=4 and m=1 respectively.

3.2 SWCT over Skyscraper Broadcasting

For the limitation of space, we do not describe the detailed design process but the main difference compared to the SWCT over FB/EMPB.

The main difference between the negative SWCT schemes over Skyscraper and FB/EMPB, as in Fig. 2(a) and Fig. 3(a), is that C_i' succeeds C_i, $1\leq i\leq k\text{-}m$, and C_{k-m+1} to C_k are released rather than C_1 to C_m, which is similar to the FPB in [12]. The reason is that $2^m\cdot d>d'$ and therefore $T_S(C_1')\text{-}T_a$ could not be bounded by d' if we let C_j' succeeds the C_{j+m} as the cases in FB/EMPB.

Unfortunately, $T_S(C_{i+m}')\text{-}T_E(C_i)$ is not always a non-negative value in the positive channel transition. We check all the instances within $k\geq 2$ and $k+m\leq 20$ (the startup latency is less than 1.5 seconds by using twenty channels for a 120 minutes video). Among the total 171 cases, 38 cases cause overlaps. However, a positive channel transition only fails when both of following conditions are fulfilled.

1) The number k of originally allocated channels is odd.
2) The number m of increased channels is odd.

Even when the channel transition fails, overlaps only occur in odd channels. The example is demonstrated in Fig. 3(b). This phenomenon retrieves the feasibility for performing positive SWCT in Skyscraper Broadcasting. The solution is to let the (C_{2j}, C_{2j+1}) be the basic unit for a channel transition, i.e. the server will always increase or decrease even number of channels in a channel transition, as shown in Fig 2(c). The number of basically allocated channels for a video is three (C_1, C_2 and C_3). This solution restricts the elasticity of a channel transition, but results in no overhead.

4 SIMULATION RESULTS AND DISCUSSIONS

The comparison between SFB, SSB, and our SWCT are given in this section. We address three issues including startup latency, buffering space requirement, and channel release delay.

4.1 Startup Latency

Suppose the server does not support any unicast for the instantaneous playback in [12]. The comparison of startup latencies is listed in Table II. The SFB and SSB divide the video with adapted strategies, thus increase the latencies. Our SWCT scheme does not modify the structures of original protocols and therefore keeps the same latencies.

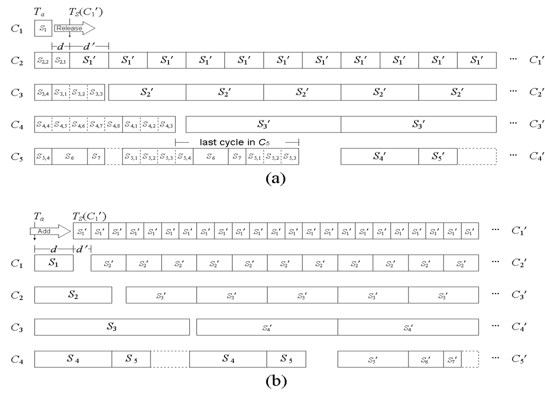

Fig. 2. SWCT over EMPB. (a) Negative channel transition. (b) Positive channel transition.

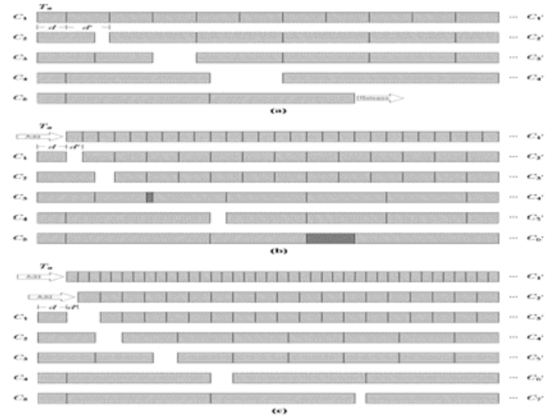

Fig. 3. SWCT over skyscraper broadcasting. (a) Negative channel transition. (b) Overlaps in the positive channel transition. (c) Our solution.

Among all the broadcasting protocols with seamless channel transition capability, the FB with SWCT possesses the shortest startup latency. The performance of SFB improves as α increases; however, a larger α means fewer "available free channels" in the system. The startup latency in EMPB with SWCT will be close to the one in SSB when k>5. The FPB and Skyscraper Broadcasting with SWCT have inferior latency performance due to the smaller numbers of video segments within the same available channels.

4.2 Buffering Space Requirement

Fig. 4 is the evaluation of maximum buffering space requirements in different protocols. The FB with SWCT does not require extra buffering space and outperforms SFB regardless of the value of α. The EMPB with SWCT effectively reduces the buffer requirement of FB and performs even better than FPB. The SSB inherits the buffer-reducing feature of staircase broadcasting and requires least buffering space. The zigzag curve for Skyscraper with SWCT reflects the variation of the ratio between the size of the last video segment and the total video length.

TABLE II.
Comparison of startup latencies for a 120-min video using *k* channels (second). The SWCT scheme is applied to FB, EMPB, and Skyscraper protocols

k	2	3	4	5	6	7	8	9
SB, FB	2400	1028.6	480	232.26	114.29	56.69	28.24	14.09
EMPB	n/a	1800	720	327.27	156.52	76.6	37.9	18.85
Skyscr	2400	1440	720	480	266.67	184.62	112.5	80.9
SSB.	2400	1200	600	300	150	75	37.5	18.75
SFB	n/a	1028.6	514.29	257.14	128.57	64.29	32.14	16.07
SFB	n/a	n/a	480	240	120	60	30	15
FPB	2400	1200	654.55	378.95	225	135.85	82.76	50.70

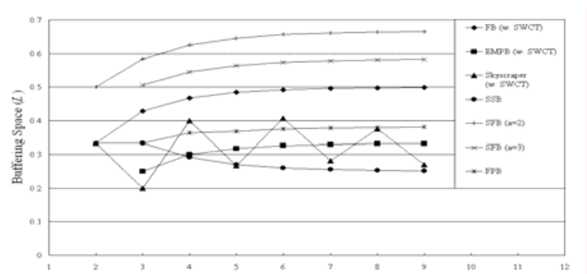

Fig. 4. Comparison of buffering space requirement for a 120-min video using *k* channels.

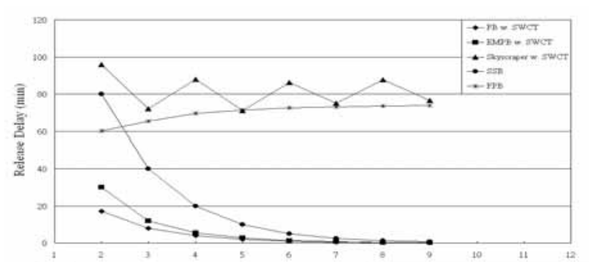

Fig. 5. Comparison of channel release delay for the negative channel transition from *k*+1 channels to *k* channels of a 120-min video.

4.3 Channel Release Delay

The SSB, FPB, and our SWCT do not add or release all the modified channels immediately. Clients will not be aware of this kind of delay, but the server should consider it for the channel scheduling. The channel release delay is more critical than channel adding delay because a free channel can be reserved for later use, but a used channel can not be released ahead. As shown in Fig. 5, the FB and EMPB with SWCT bring much less channel release delay than SSB, while the release-last strategy causes high channel release delay for the FPB and skyscraper broadcasting with SWCT.

5 CONCLUSION

In this paper, we approach a general seamless channel transition scheme for Pyramid-based broadcasting protocols. A verification procedure is proposed and a set of pyramid-based protocols have been proved suitable for our SWCT scheme. Our scheme does not change the structures or reduce the performance of the original protocols. The system manager should choose a favorable protocol in accordance with the tradeoff among the startup latency, buffering space requirement, and the channel release delay. All the channel allocation or playback policy in [8] and [12] are also suitable for our scheme, but designing improved policies will be our future work.

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