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Practical Patching for Efficient Bandwidth Sharing in VOD Systems

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ABSTRACT

Recursive Patching is an efficient multicast technique for large-scale video on demand systems and recursively shares existing video streams with asynchronous clients. When Recursive Patching initiates a transition stream, it always makes a transition stream have additional data for the worst future request. In order to share a VOD server's limited network bandwidth efficiently, this paper proposes Practical Patching that removes the unnecessary data included in the transition stream. The proposed Practical Patching dynamically expands ongoing transition streams when a new request actually arrives at the server. As a result, the transition streams never have unnecessary data. Simulation result confirmed that the proposed technique is better than Recursive Patching in terms of service latency and defection rate.

Keywords: Bandwidth-sharing, Dynamic expansion, Multicast, Patching, Transition stream, VOD

1. INTRODUCTION

Video on Demand (VOD) is a critical technology for the multimedia applications such as home entertainment, electronic commerce, distance learning and digital video libraries[1]. In a typical VOD system, if a remote client requests a video that is stored on a VOD server, the server delivers the video data to the client. Since the network-I/O bandwidth of the VOD server is limited, the various multicast techniques such as Batching, Piggybacking, Patching, Transition Patching and Recursive Patching have been proposed to reduce communication traffic by sharing the same video data with asynchronous clients [1-5].

Simple Patching enables a new client to share future data, if it is possible, by caching an ongoing regular stream (R-stream) in the client's local buffer. Therefore, the server can serve the client by transmitting a new patching stream (P-stream), which is significantly shorter than the R-stream, on a new channel [1]. To reduce the amount of video data in a new P-stream for a new client, Transition Patching enables the client to share not only an ongoing R-stream but also an ongoing transition stream (T-stream) that has to patch the R-stream [4]. Recursive Patching shares ongoing T-streams recursively and achieves significant reduction of service latency compared with Transition Patching [5]. Recursive Patching and Transition Patching, however, have the problem that the T-stream should have additional data to support uncertain future requests that may arrive at the server within the transition window of the T-stream. That overhead can be offset only if such uncertain requests actually arrive at the server within the transition window of the T-stream.

This paper proposes a multicast technique called Practical Patching that can improve Recursive Patching. While Recursive Patching always initiates expanded T-streams, Practical Patching dynamically expands ongoing T-streams when the expansion is actually needed for a new request. The rest of this paper is organized as follows. Section 2 describes simple Patching, Transition

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Patching and Recursive Patching in detail. Section 3 introduces proposed Practical Patching, and section 4 describes the performance evaluation of the proposed technique in terms of defection rate and average service latency. Finally, section 5 describes some concluding remarks.

2. SIMPLE PATCHING, TRANSITION PATCHING AND RECURSIVE PATCHING

$v[t_1, t_2]$ is used to denote the video segment consisting of the video frames for a video that are played back at a client station during the period from time t_1 through time t_2, exclusive of time t_2. $skew(r_1, r_2)$ is used to denote the skew that is the time interval between the initiation of the stream for request r_1 and the initiation of the stream for request r_2. $D[t]$ is used to denote the video data needed to play back a video for t time units. It is assumed that the playback duration of a video is L time units. Simple Patching is motivated by the fact that a new client can join the latest ongoing regular multicast transmitting an entire video stream called the R-stream. Therefore, to reduce the amount of the data in the new stream for a new client, it tries to schedule and initiate a P-stream instead of a new R-stream. The P-stream is the beginning part of an entire video data. By using the P-stream and sharing the R-stream, it can service the new client without the latency, achieve true VOD service, thus has received considerable attention [5,6].

If a new request, r_n, for a video arrives and is scheduled at time t, simple Patching initiates an R-stream or a P-stream for it on a new channel as follows. If there is no R-stream for the same video, the server initiates a new R-stream of $v[0, L]$. However, if the latest R-stream for the same video is ongoing for request r_r and the time interval between current time t and the initiation time of the R-stream is less than or equal to rw called the size of the regular window, the server initiates a P-stream. That is, if $skew(r_r, r_n) \leq rw$, the server initiates a P-stream of only $v[0, skew(r_r, r_n)]$, which is the video data that the client has missed from the R-stream when he is scheduled. Otherwise, if $skew(r_r, r_n) > rw$, the server initiates a new R-stream. If a new request arrives at the server and can be scheduled within rw time units after the initiation of the R-stream for the same video, it is said that the request is within the regular window of the R-stream and it means that the client can be served with a P-stream.

If a new client is served with a P-stream, he caches the subsequent data from the latest R-stream while he downloads and plays back the P-stream. Therefore, it is assumed that a client station, which is served by a Patching-like multicast technique, has the download bandwidth enough to receive two streams simultaneously. After the client finishes playing back the P-stream, he plays the cached video data and keeps on caching the R-stream. Therefore, the maximum skew enabling a P-stream is the size of the client's local buffer. The detail algorithms at the server station and the client station for simple Patching were described in [1], and are omitted here.

As the skew of a new request to the latest R-stream gets bigger, the amount of the data in a P-stream gets larger. To reduce the data in the P-stream, Transition Patching [4] introduces a new stream called the T-stream. In addition to the regular window, it uses the transition window that is smaller than the regular window. The size of the transition window, tw, is the minimal interval between two consecutive T-streams. A T-stream is initiated to patch the latest R-stream and a P-stream is initiated to patch the latest R-stream or T-stream. Once a T-stream is initiated, it tries to initiate P-streams that have to patch the T-stream instead of the R-stream. It results in the reduction of the video data in the P-streams.

If new request r_n is out of the regular window of the latest R-stream for request r_r, then the server initiates an R-stream, else the server

initiates a P-stream or a T-stream as follows. If $skew(r_r, r_n) \leq tw$, a P-stream of $v[0, skew(r_r, r_n)]$ is scheduled as in simple Patching. If r_n is the first request that becomes out of the transition window of the R-stream, or $skew(r_r, r_n) > tw$, a T-stream of $v[0, skew(r_r, r_n)+2 \cdot tw]$ is initiated to patch the R-stream. The reason why the T-stream has the additional data for $2 \cdot tw$ time units will be discussed in section 3. Once a T-stream is initiated, the server tries to patch the T-stream instead of the R-stream. Thus, if r_n is within the transition window of the latest T-stream, then the server initiates a P-stream of *v[0, skew to the T-stream]* to patch the T-stream. However, if r_n is out of the transition window of the latest T-stream, the server initiates a new T-stream of *v[0, skew to the R-stream+2·tw]* to patch the R-stream.

Fig. 1 illustrates the difference between simple Patching and Transition Patching. Simple Patching schedules P-streams for requests r_2 and r_3, respectively. Transition Patching, however, schedules a T-stream for r_2 because there is no ongoing T-stream and $skew(r_1, r_2) > tw$. Later, because r_3 is within the transition window of the T-stream for r_2, or $skew(r_2, r_3) \leq tw$, r_3 is served with a P-stream of $v[0, skew(r_2, r_3)]$. While the client of r_3 downloads and plays back *v[0, 3]* from the P-stream, he caches *v[3, 6]* from the T-stream. When the client finishes playing back the P-stream at time 18, he releases the P-stream and begins to cache the R-stream. At the same time, the client plays back the cached *v[3, 6]*, and keeps on caching the rest of the T-stream. From time 21 through time 33, the client continues to play back and cache *v[6, 18]* in the T-stream while caching the R-stream. When the client finishes playing back the T-stream at time 33, he plays back and caches *v[18, L]* in the R-stream. In this way, the client of r_3 can play back the entire video data continuously by assembling *v[0, 3]* from the P-stream, *v[3, 18]* from the T-stream and *v[18, L]* from the R-stream, in turn, as in Fig. 1(c). As the number of P-streams that have to patch a T-stream increases, the total amount of the data in all streams in Transition Patching reduces compared with simple Patching.

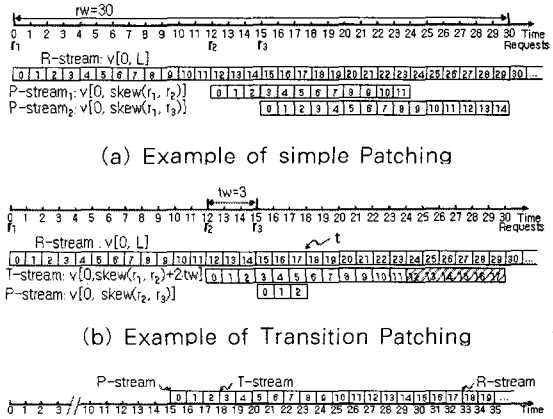


Fig. 1. Comparison between simple Patching and Transition Patching.

Recursive Patching enables a client to patch a series of T-streams on upper levels to reduce the video data in P-streams. In k-phase Recursive Patching (kP-RP), where $k \geq 2$, a client may receive an R-stream, a P-stream, or $(k-2)$ T-streams at maximum, but he is supposed to receive at most two streams at the same time. kP-RP uses $(k-1)$ window sizes: rw, tw_1, tw_2, ..., tw_{k-2}, where $rw > tw_1 > tw_2 > ... > tw_{k-2}$. rw is the size of the regular window, and tw_i is the size of the transition window on level i. 2P-RP corresponds to simple Patching using only rw. 3P-RP corresponds to Transition Patching that uses rw and tw_1 as the size of the regular window and the size of the transition window, respectively.

An R-stream, P-streams that have to patch the R-stream, and T_1-streams that have to patch the R-stream are scheduled in the same way as in Transition Patching with $tw=tw_1$. However, once the server initiates a T-stream on level i, T_i-stream, kP-RP recursively applies Transition Patching with $rw=rw$ and $tw=tw_{i-1}$ to the T_i-stream and the subsequent requests that arrive within the transition window of the T_i-stream. Therefore,

T_{i-1}-streams that have to patch the T_i-stream are initiated and kP-RP recursively applies Transition Patching with $tw=tw_{i-2}$ to the T_{i+1}-stream. In this recursive way, Recursive Patching tries to share T-streams on upper levels so as to reduce the video data in the P-stream that has to patch the T-streams. If a client is served with a P-stream being to patch the latest T_i-stream, he has to cache the latest T_i-stream, T_{i-1}-stream, ..., T_1-stream, and R-stream, sequentially. Fig. 2 shows the types of streams initiated by 4P-RP when it is assumed that every request arrives at the server every one time unit, rw=35, tw_1=11, and tw_2=3. R, T_1, T_2, and P represent the R-stream, the T_1-stream, the T_2-stream, and the P-stream, respectively. Each of requests arriving from 1 time unit to 11 time units is served with a different P-stream that has to patch the R-stream.

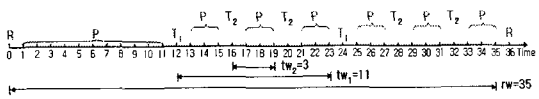


Fig. 2. Example of 4P-RP.

P2Cast [7] is an architecture based on a peer-to-peer approach and uses simple Patching to transmit a video stream. Unlike simple Patching, P2Cast makes clients buffer the video data to play back a server's role, and for each session, the server forms an application-level multicast tree over the unicast-only network. P2Cast usually outperforms multicast-based patching in terms of defection rate when clients can cache more than 10% of the beginning data of a video and the server's workload is high, but every client station in the same session is required to have a failure-tolerant capability.

3. PROPOSED PRACTICAL PATCHING TECHNIQUE

For the future requests that may arrive within tw_i time units after the initiation of a T_i-stream, Recursive Patching makes the T_i-stream have additional data for $2 \cdot tw_i$ time units in addition to *v[0, skew of the T_i-stream to the latest T_{i-1}-stream]*. The reason is that a small "waste" may actually lead to significant savings of bandwidth later [4]. Now, let us consider the amount of the video data in the T-streams by using Fig. 1(b). Because the P-stream for r_3 is scheduled later than the T-stream for r_2 by *skew(r_2, r_3)* time units, the client of r_3 has missed the R-stream more than the client of r_2 by *D[skew(r_2, r_3)]*. In addition, every client station can download at most two streams simultaneously in Patching-like systems. Hence, as long as the client of r_3 plays back the P-stream of *v[0, skew(r_2, r_3)]* on a channel and caches the T-stream on another channel, he cannot cache the R-stream simultaneously. When the client releases the P-stream at time t, he can begin to download the R-stream. After all, he has missed the R-stream more than the client of r_2 by *D[2·skew(r_2, r_3)]*. If the T-stream has the missed data, the client can download the missed data from the T-stream and play back the video continuously.

All requests that can be served with a P-stream that has to patch the T-stream must be within the transition window of the T-stream. The latest request among them is one arriving at the end of the transition window of the T-stream. The skew of the latest request to the T-stream is tw. Hence, Transition Patching always makes the T-stream have additional data of *D[2·tw]* in advance for the worst future request that may arrive at the end of the transition window of the T-stream. However, the overhead of *D[2·tw]* can be offset if there are P-streams that have to patch the T-stream.

Recursive Patching implies the problem as follows. If there is no request that has to patch the T_i-stream, the additional data will be complete waste. Although such a request, r_n, arrives, the data that has to be appended to the T_i-stream is not *D[2·tw_i]* but *D[2·skew of r_n to the T_i-stream]*. As long as request r_n does not arrive at the end of the transition window of the T_i-stream, *D[2·(tw_i-skew of r_n to the T_i-stream)]* is always waste.

Therefore, this paper proposes an efficient bandwidth-sharing technique called Practical Patching for VOD systems.

Proposed Practical Patching is a multicast technique for VOD services and can delete the unnecessary data included in T-streams. It initially schedules a T_i-stream of *v[0, skew of the current request to the latest T_{i-1}-stream]* with no additional data for the future requests. Then, when the server initiates a new P-stream or T_{i+1}-stream to patch the T_i-stream, k-phase Practical Patching (kP-PP) dynamically expands the latest T_i-stream, T_{i-1}-stream, ···, T_1-stream, which the new client has to patch. By expanding the T-streams when the expansion is necessary for the current request, Practical Patching can make every T-stream have necessary data.

To illustrate the correctness and implementation of proposed Practical Patching, Fig. 3 uses 3P-PP assuming that the minimum interval time between two requests is one time unit, rw=30, and tw_1=4. The first T_1-stream, which has to patch the latest R-stream, occurs when the skew of the current request to the R-stream becomes larger than tw_1 for the first time. It is sure that the minimum data of a T_1-stream is $D[tw_1+1]$. In Fig. 3(a), such a T_1-stream corresponds to one for request r_2. The arrival time of the latest request that can be served with a P-stream that has to patch the T_1-stream is (t_2+tw_1) time units, that is, time t_4. When the server schedules request r_4, it does not finish transmitting the T_1-stream. That is, whenever the server initiates a P-stream that has to patch a T_1-stream, it is still transmitting the T_1-stream on an assigned channel and has not released the channel yet. Therefore, the server can expand the T_1-stream as follows. When it schedules the new request, it calculates the additional data of the T_1-stream. It expands T_1-stream by modifying the end of the T_1-stream to *(current end point + (2· skew of the new request to the T_1-stream))* and appending the additional data to the T_1-stream. It continues to transmit the expanded T_1-stream on the current channel. The final streams that the server transmits are shown in Fig. 3(b). By expanding the T_1-stream before the transmission of the T_1-stream is completed, Practical Patching can make sure that the server can continuously transmit the expanded T_1-stream on the assigned channel. To append the additional data stored on the hard disk to the T_1-stream, the server has additional disk-I/O overhead. However, the additional data is the data already included in the T_1-stream of Recursive Patching. Moreover, if there is no new request, like request r_4, within the transition window of the T_1-stream, the expansion will never occur and Practical Patching can remove the disk-I/O for $D[2\cdot tw_1]$ included in Recursive Patching. Therefore, the disk-I/O overhead for the expansion in Practical Patching can be negligible.

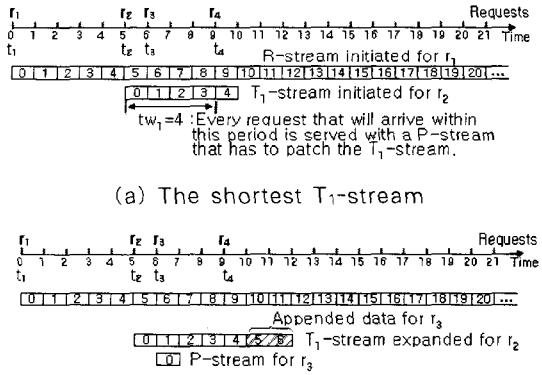
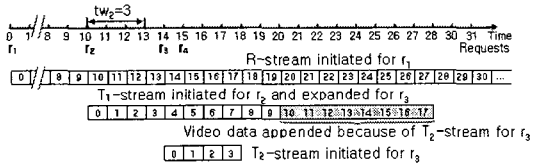


Fig. 3. Example of 3-phase Practical Patching.

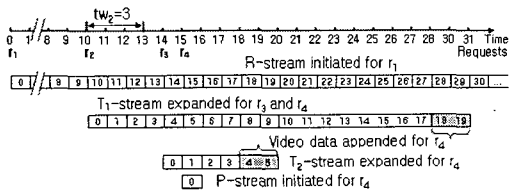
kP-PP, where $k \geq 4$, is more complex than 3P-PP because of recursion. If the server initiates a T_i-stream to patch the latest T_{i-1}-stream, the corresponding client station first plays back the T_i-stream and has to download the latest T_{i-2}-stream, T_{i-3}-stream, ..., T_1-stream, and R-stream, sequentially. If the T_i-stream is expanded for new request r_n by *D[2· (skew of r_n to the T_i-stream)]*, the time when the new client releases the T_i-stream and can begin to download another T-stream is delayed by *(2· (skew of r_n to the T_i-stream))* time units. Therefore, the server has to expand the latest T_{i-1}-stream, T_{i-2}-stream, ...,

T_1-stream, which the client has to download, by *D[2· (skew of r_n to the T_i-stream)]*.

Fig. 4 illustrates how to expand T-streams in 4P-PP with tw_1=9 and tw_2=3. When a P-stream of *v[0, 1]* is initiated for r_4 to patch the T_2-stream in Fig. 4(b), the client of r_4 has missed the T_1-stream more than the client of r_3 by *D[2·skew(r_3, r_4)]*. Therefore, the T_2-stream has to be expanded by *D[2·skew(r_3, r_4)]* to include the missed data. As the result of expanding the T_2-stream, the time when the client of r_4 can cache the R-stream is delayed by *2·skew(r_3, r_4)* time units, so the T_1-stream also has to be expanded by *D[2·skew(r_3, r_4)]]* to include the missed data in the R-stream. Finally, the expanded T_1-stream is *v[0, skew(r_1, r_2)+2·skew(r_2, r_3)+ 2·skew(r_3, r_4)]*. Using 4P-RP, a T_1-stream of *v[0, 10+2·9]* for r_2, a T_2-stream of *v[0, 4+2·3]* for r_3 and a P-stream of *v[0, 1]* for r_4 are initiated. Hence, for requests r_2, r_3 and r_4, the total amount of saved data in 4P-PP is *D[39-27]*, and the resource saving of 4P-PP over 4P-RP is about 30.8%.



(a) Streams when r_4 is about to be scheduled



(b) T-streams expanded for request r_3 and r_4

Fig. 4. Example of 4-phase Practical Patching.

As mentioned above, every T-stream in Practical Patching initially has the data necessary to the current request, and then the expansion of the T-stream occurs when a new request arrives at the server within the transition window of the T-stream. Therefore, every T-stream always has the video data necessary to server the real requests, and there is no waste data in the T-stream. At the worst case that a new request arrives at the end of the transition window of the T-stream, the T-stream becomes equal to the T-stream that is expanded in advance by Recursive Patching.

4. SIMULATION AND PERFORMANCE EVALUATION

This section presents experimental measurements in the simulation for performance evaluation of Practical Patching. The parameters used in the simulation are based on those in [4,5], and are listed in table 1. It is assumed that once a client starts watching a video, he sequentially watches it until the end of the video. Wong [5] has shown that the performance improvement of kP-RP over Transition Patching is getting less when k is getting larger and determined the sizes of a regular window and transition windows offline by exhaustive search. Since it is important to compare the performance of Practical Patching with that of kP-RP in the same condition, only one video is used and k and rw are fixed to 4 and 16 minutes as default values, respectively. In order to find the optimal pair, (tw_1, tw_2), the simulation was repeatedly performed varying the sizes of transition windows. As a result, it was observed that *(8, 4)* and *(4, 2)* minutes provided their own best service latency to 4P-RP when the mean inter-arrival time, m, was 20~90 and 5~10 seconds, respectively. The criteria for evaluation are the average defection rate and the average service latency that are commonly used to evaluate the performance of VOD services. The defection rate is the percentage of clients who cancel their own requests because waiting time is too long, or the value of dividing total number of requests by the number of canceled requests [1]. The service latency is defined as the waiting time from the time he requests a video through the time he can play back the video.

Table 1. Parameters used in the simulation.

Parameter	Values
Server bandwidth	12 channels
Length of the video	90 minutes(L)
Client's local buffer size	16 minutes(rw)
Number of requests	100,000 requests
Mean request inter-arrival time	5~90 seconds (Poisson distribution)
Defection time	10~90 seconds (Random distribution)

Fig. 5 and Fig. 6 show simulation results about the average defection rates and the average service latency of 4P-RP and 4P-PP varying m from 5 to 90 seconds. To show the performance improvement of 4P-PP over 4P-RP, the simulation uses $(8, 4)$ and $(4, 2)$ as (tw_1, tw_2) minutes, which are the optimal pairs in 4P-RP when m is 20~90 and 5~10 seconds, respectively.

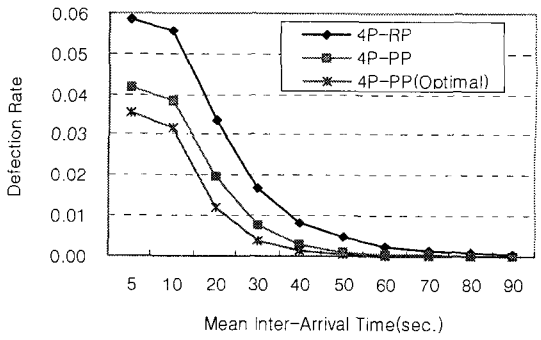


Fig. 5. Defection rate.

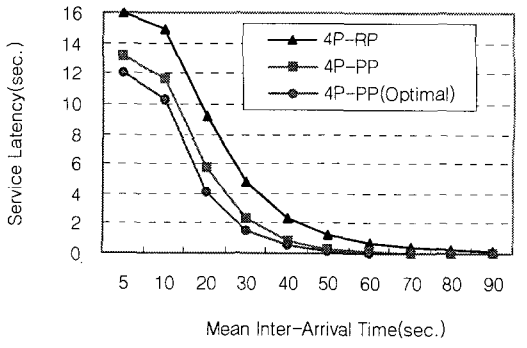


Fig. 6. Average service latency.

Proposed 4P-PP improves the defection rate by 63.6% and the service latency by 60.4% on average, respectively. The simulation result that provides the best performance in 4P-PP is also plotted. 4P-PP(Optimal) represents 4P-PP with $(tw_1, tw_2) = (4, 1)$, $(tw_1, tw_2) = (6, 1)$, and $(tw_1, tw_2) = (5, 1)$ minutes when m is 5~40, 50, and 60~90 seconds, respectively.

From the Fig. 5 and Fig. 6, we can see that the improvement percentage of 4P-PP over 4P-RP gets smaller as m gets smaller. The reason is as follows. As m gets shorter, the number of the requests that arrive within the transition window of a T-stream gets larger, and the waste data in the T-stream in 4P-RP gets less. From the simulation result, it is sure that proposed Practical Patching serves more clients with shorter service latency than Recursive Patching even under the condition that Recursive Patching provides the best performance. Moreover, 4P-PP can more improve the performance of the 4P-RP if the optimal pair (tw_1, tw_2) for 4P-PP is used.

Fig. 7 shows the simulation result about the average service latency of 4P-RP and 4P-PP varying the server bandwidth. In this simulation, m is fixed to 30 seconds and (tw_1, tw_2) is fixed to $(8, 2)$ minutes, which provides the best performance to 4P-RP.

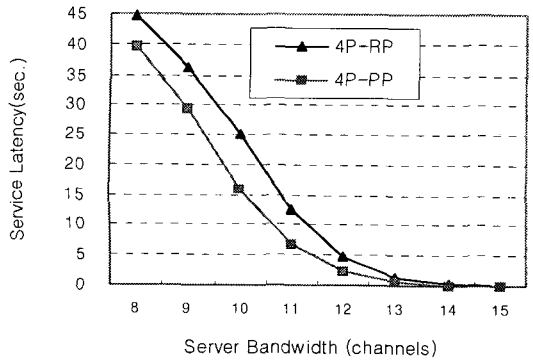


Fig. 7. Effect of the server bandwidth on latency when $(tw_1, tw_2) = (8, 2)$ min.

Fig. 8 shows the average service latency of 4P-RP and 4P-PP varying the sizes of transition windows when m and the server bandwidth are fixed to 30 seconds and 12 channels, respectively. Fig. 7 and Fig. 8 show that 4P-PP is always better than 4P-RP as expected.

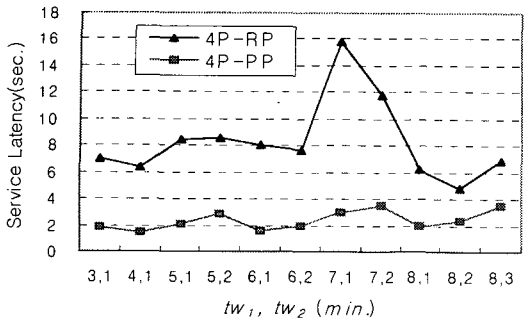


Fig. 8. Effect of the size of transition window on latency when m=30 sec.

5. CONCLUSION

This paper proposed Practical Patching that is a multicast technique to share a VOD server's limited network bandwidth efficiently. While Recursive Patching always makes T-streams have the additional video data for the worst request, Practical Patching dynamically expands the T-streams whenever such expansion is needed to serve a new request. The key of Practical Patching is that when the server is about to schedule a new request, the server is transmitting the T-streams, which the client of the request has to patch, on the already allocated channels. Therefore, the server does not have to worry about the allocation of a new channel to deliver the additional data as soon as it completes the transmission of the current T-stream. The server can expand the T-stream by modifying the end of the T-stream, appending the new additional data to the T-stream, and continuing to transmit the expanded T-stream on the current channel. Simulation results confirmed that Practical Patching could improve Recursive Patching in terms of defection rate and service latency in VOD systems. The future research will be to develop a formula to help determine the optimal sizes of the regular window and transition windows for Practical Patching.

6. REFERENCES

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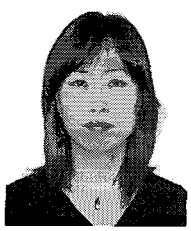

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