Experimental Demonstration of SVC Video Streaming using QoS-Aware Multi-Path Routing over Integrated Services Routers

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***Abstract*—We construct an experiment testbed using commercial routers and demonstrate QoS-aware multi-path SVC video streaming with it. The testbed consists of six integrated services routers (Cisco 2900 Series) that are configured using a mesh topology. To realize QoS-aware multi-path routing efficiently, we develop a centralized automatic NC&M system that monitors link status proactively, calculates the multi-path routing scheme for each streaming session, and communicates with the routers' control plane to adjust their routing policies. For each streaming session, when the NC&M finds a better multi-path routing scheme, it reconfigures the routers to invoke a path-switching. The experimental results indicate that the multi-path SVC video streaming scheme reduces the packet loss rate (PLR) from 3.33% to 0.62% for the base layer (BL) packets, and to 1.71% for the enhancement layer (EL) packets. Additional experiments on video playback quality, video playback peak signal-to-noise ratio (PSNR), and delay jitter also verify that the multi-path scheme outperforms the single-path one significantly and utilizes the network resources more efficiently.**

***Index Terms*—Multi-path routing, Scalable video coding (SVC), Video streaming, Cisco integrated services routers**

I. Introduction

Recently, various applications have emerged on the Internet and pushed the network traffic to grow exponentially. Consequently, it has been a consensus that the Internet service needs to transform from the best-effort model to an integrated one, which should consider multiple quality-of-service (QoS) parameters jointly [1]. However, due to the heterogeneity of networks and clients, fluctuations of bandwidth, and many other challenges, service providers still have difficulties to deliver QoS-guaranteed services to anywhere, at any time, especially for high-throughput and jitter-sensitive video applications, such as video-on-demand and teleconferencing.

In the network layer, routing and forwarding were originally designed for transmitting data packets over a single path based on routing tables, which were built according to hop-count or propagation delay. A single routing path in today's bandwidth-limited Internet may have difficulty to satisfy the bandwidth requirement of video streaming applications [2]. To this end, multi-path routing was proposed to aggregate network bandwidth resources more efficiently [1]–[4]. The discussion in [1] suggested that multi-path video streaming usually provides a more cost-effective solution than setting up a single path for the total streaming capacity. Moreover, the path diversity associated with multi-path routing can support better protection and faster restoration.

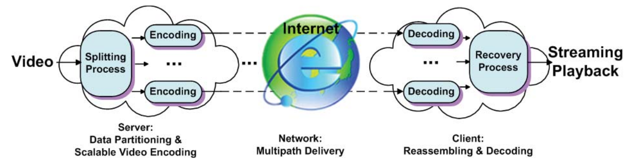

Fig. 1. Video streaming framework by integrating SVC and multi-path routing.

Scalable video coding (SVC) [5], [6] is the scalable extension of H.264/AVC that supports spatial, temporal and quality scalability. Specifically, SVC codec encodes a video into several substreams with a layered structure, including one base layer (BL) substream and a few enhancement layer (EL) ones. By decoding the BL substream, a streaming client can playback the video with the lowest quality, while the more additional EL substreams it collects, the better playback quality it will perceive. This property, in conjunction with a multi-path routing strategy, leads to a promising framework for video streaming in bandwidth-limited networks, as shown in Fig. 1. To optimize the design of this framework, previous works have investigated a few subjects, including adaptive data partitioning [7], [8], video-specific multi-path routing [9]–[11], rate allocation and packet scheduling [12], [13], peer-to-peer and multi-source streaming [14]–[16], protection and restoration [17]. The systematic studies in [18], [19] discussed the overall framework design of multi-path SVC video streaming. Moreover, researchers have tried to apply this framework over various network infrastructures, including wireless ad-hoc networks [20], multi-media sensor networks [21], in-door 60 GHz radio networks [22], and IEEE 802.11e wireless local area networks (LANs) [23]. However, most of these previous works are theoretical investigations with only simulation results. In order to make this framework practical, it is essential for us to build network testbed and collect realistic experimental data.

In this work, we build an experiment testbed using commercial routers and use it to demonstrate QoS-aware multi-path SVC video streaming. The testbed consists of six integrated

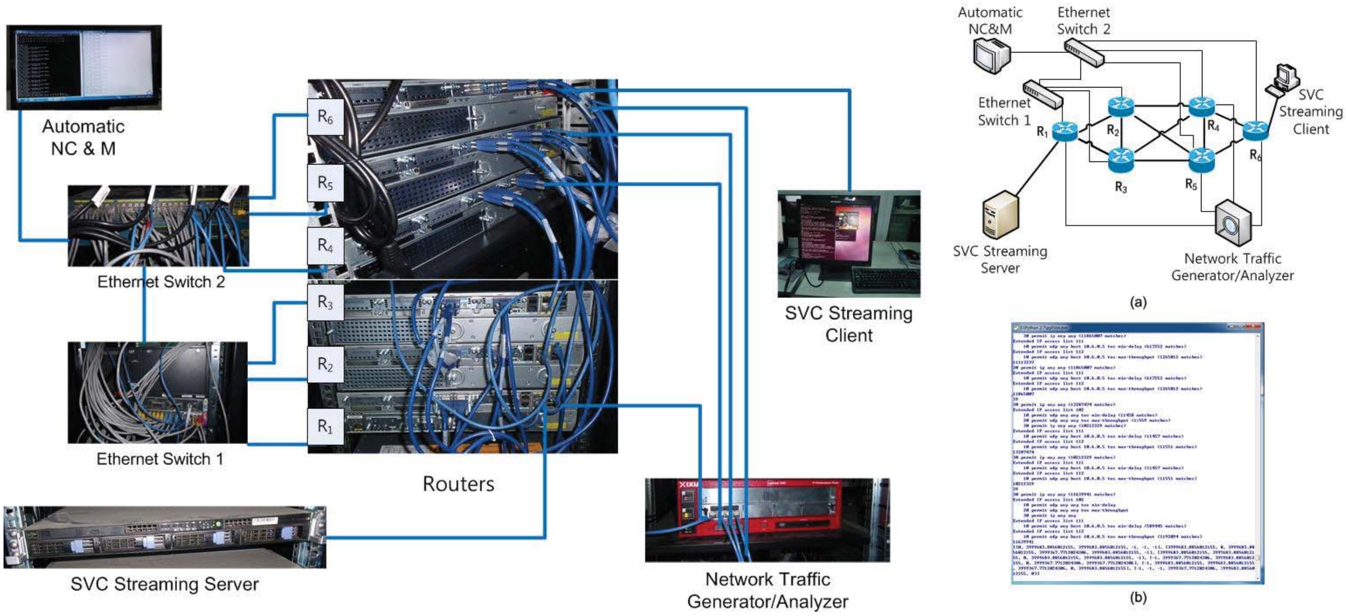

Fig. 2. Network testbed setup for multi-path SVC video streaming, (a) network topology, and (b) user interface of the NC&M system.

services routers (Cisco 2900 Series) that are configured using a mesh topology. In order to realize QoS-aware multi-path routing efficiently, we develop a centralized automatic network control and management (NC&M) system that monitors link status proactively, calculates the multi-path routing scheme for each streaming session, and communicates with the routers' control plane to adjust their routing policies. Our implementations of SVC streaming server and client are based on open-source softwares, which are modified to support video distributions over multiple routing paths. The background traffic is inserted into the testbed using a stand-alone traffic generator (IXIA XM2), to simulate bandwidth fluctuations in realistic networks. For each streaming session, when the NC&M finds a better multi-path routing scheme, it reconfigures the routers to invoke a path-switching. The experimental results indicate that the multi-path SVC video streaming scheme achieves better performance than the single-path one, in terms of packet loss rate, video playback peak signal-to-noise-ratio (PSNR), and delay jitter, and hence utilizes the network resources more efficiently. Therefore, our experimental demonstration verifies the effectiveness of multi-path SVC streaming and indicates a possible road-map to realize it.

The rest of the paper is organized as follows. Section II discusses the overall experimental setup. The operation principles of the network elements in the testbed are explained in Section III. Section IV shows the experimental results. Finally, Section V summarizes the paper.

II. Network Testbed Setup

Fig. 2 shows the network testbed setup for experimental demonstration. The video distribution network consists of six integrated services routers (Cisco 2900 Series). As shown in Fig. 2(a), the routers are connected to form a mesh topology. In order to emulate a bandwidth-limited network environment, we configure them to have a link capacity of 4 Mbps. The automatic network control and management (NC&M) system, whose user interface is shown in Fig. 2(b), runs on a personal computer (PC) with a 3.10 GHz Intel Core CPU and 4.0 GB RAM. This PC is connected with all routers, *i.e.*, $R_1 - R_6$, through two switches (Cisco Catalyst Series), both of which are placed here only to provide the connection between the NC&M and routers, thus are transparent to our experiments. For simplicity, we assume that there is only one pair of streaming server-client in the setup, and they are connected to routers R_1 and R_6, respectively. The rack-mounted server runs Linux with a 2.40 GHz Intel Xeon CPU and 32 GB RAM. The client is based on a common personal computer with a 2.20 GHz Intel Core CPU and 4.0 GB RAM, and it also runs Linux. The stand-alone traffic generator/analyzer's (IXIA XM2) output ports are connected with routers R_1, R_4 and R_5 to insert background traffic into the testbed, and its input port is connect with R_6 to collect traffic for analyzing.

Fig. 3 shows the logic infrastructure of the network testbed. The actual multi-path SVC streaming is accomplished in the data forwarding plane, where each router examines the Internet protocol (IP) headers of input packets and forwards them according to a preset routing policy. For the same SVC streaming session, base layer (BL) packets and enhancement layer (EL) packets are distinguished based on different type-of-service (ToS) values in their IP headers. Hence, packets belonging to different SVC layers can be routed over multiple paths, even though their source and destination IP addresses are the same. In order to implement this scheme, we modify the routing and forwarding features on the routers and develop a new control plane scenario. The automatic NC&M system monitors

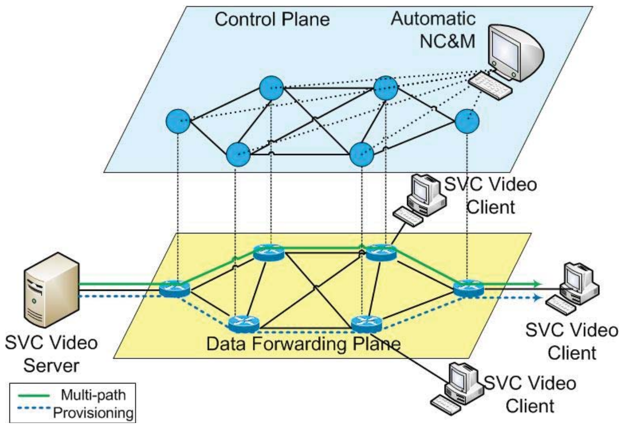

Fig. 3. Logic infrastructure of the network testbed.

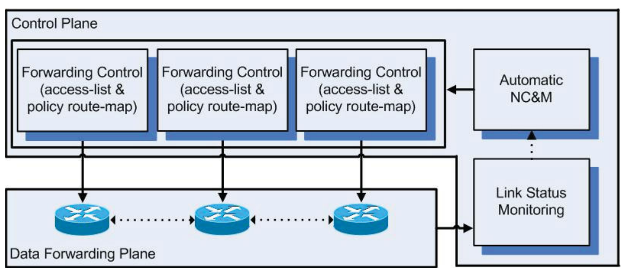

Fig. 4. Operation principle of the control plane.

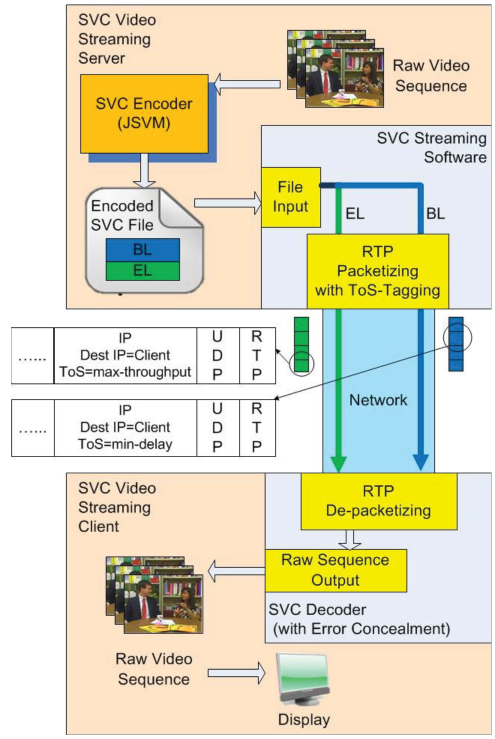

Fig. 5. Operation principle of the SVC streaming system.

the link status proactively and calculates routing paths for each streaming session. Thus, the routing is conducted by the NC&M system in a centralized manner. This scheme is more efficient than the fully distributed routing performed by each router. When the number of streaming sessions or/and the network size is/are extremely large, we can upgrade the NC&M system to be based on cloud computing and leverage the cloud's computation power for the routing tasks [24]. The NC&M then configures the routers to implement the routing strategies. On the routers, the new forwarding feature will send streaming packets to the next hops according to the new strategies.

III. Operation Principles

Fig. 4 shows the operation principle of the control plane. The link status monitoring module establishes communications with the routers using the network configuration (NETCONF) protocol. After obtaining the link status, the NC&M system calculates multi-path routing strategies for the streaming sessions, using a multi-path routing algorithm similar to that in [19]. New routing strategies are then configured into the routers through NETCONF sessions. Specifically, the access-lists and policy route-maps are configured to enforce our new routing strategies on each router. The access-list matches streaming packets with specific combinations of source and destination IP addresses and ToS values. The policy route-map then directs the router to forward these matched packets according to the multi-path routing strategies from NC&M. The streaming server and client softwares are developed based on open-source ones, which are modified to accommodate the requirements of multi-path SVC video streaming. Fig. 5 illustrates the detailed operation principle of the streaming server and client. On the server side, the Joint Scalable Video Mode (JSVM) module is responsible for SVC transcoding. When a streaming session starts, the server encapsulates the BL and EL data with corresponding RTP/UDP/IP headers and sets the ToS field to predefined values. The client buffers received packets for reordering and decoding. All reconstructed frames and relevant logs are stored for performance analysis.

IV. Experimental Results

We combine 8 copies of the MPEG standard test sequence "Paris" [25] in common intermediate format (CIF) resolution (352×288), and make a 320 s (8000 frames) video sequence. The video is then encoded to SVC with the JSVM software. The bit-rate of the SVC's BL is 500 Kbps, while the EL's bit-rate is variable as $0.5 - 0.9$ Mbps. The network traffic generator/analyzer (IXIA XM2) inserts dummy packets into the testbed to make the background traffic fluctuate within $0.2 - 2.5$ Mbps on each link.

Fig. 6 shows the experimental results on packet loss rates (PLRs). For the multi-path scheme, we plot the PLRs of both BL and EL packets. The PLR from single-path SVC streaming is also shown as reference. It can be seen that for most of the time points, the PLR of BL from the multi-path scheme is significantly lower than that from the single-path scheme. This

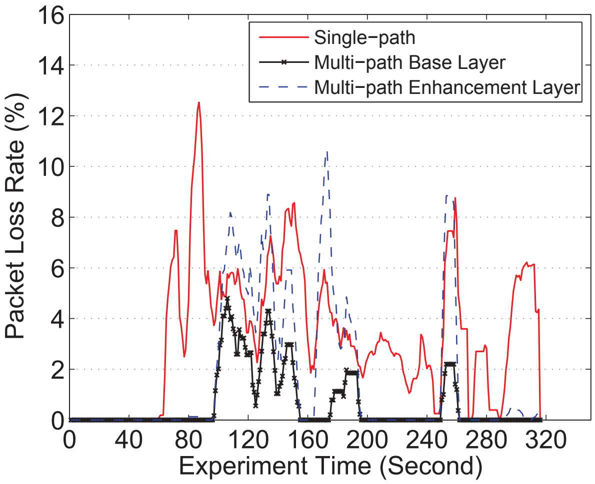

Fig. 6. Comparisons of packet loss rates from the SVC streaming using single-path and multi-path routing.

Fig. 7. Snapshots of video playback on the streaming client, (a) single-path scheme, and (b) multi-path scheme.

verifies that the multi-path scheme we implemented can adapt with bandwidth fluctuations in a better way. For the whole streaming session, the average PLR of the single-path scheme is 3.33%, and the average PLRs of the BL and EL packets in the multi-path scheme are 0.62% and 1.71%, respectively. It is interesting to observe that for the multi-path scheme, the BL packets' PLR is much lower than that of the EL ones. This is because that our implementation of the QoS-aware multi-path SVC streaming tries to serve the BL packets with a higher priority. When the end-to-end bandwidth is not sufficient to transmit both BL and EL substreams, we sacrifice the EL substream to ensure BL transmission. Hence, in this situation, even though the video quality can decrease due to the absence of the EL, the playback is still smooth since the video decoder receives sufficient BL packets. While for the single-path scheme, packets can be dropped during the congestions, regardless of which SVC layer they belong to.

Fig. 7 shows the snapshots of video playback on the streaming client. It can be seen clearly that the single-path scheme imposes severe playback quality degradation. While for the multi-path scheme, no noticeable playback quality degradation can be observed. For the single-path scheme, when link congestion happens on the single routing path, both BL and EL suffer severe packet loss. While in the multi-path scenario, the SVC video streaming is achieved over two different paths, the PLR of BL is reduced significantly and the video playback on the client maintains smooth. Fig. 8 shows the experimental results on jitters. Here, we define jitter as the delay difference between two adjacent received packets. We observe that the jitters from the multi-path scheme are smaller than those from the single-path scheme for most of the time. However, we can also see a few jitter peaks in the plot of the multi-path scheme due to path switchings. As the packets are transmitted over different routing paths before and after a path switching, the jitter can be as high as 7.2 *msec*. For the whole streaming session, the average jitter of the single-path scheme is 4.6 *msec*, while the average jitter of the multi-path scheme is reduced to 3.8 *msec*.

Fig. 9 illustrates the experimental results on peak signal-to-noise ratios (PSNRs). Specifically, we evaluate the luminance component's peak signal-to-noise ratio (Y-PSNR) values of all reconstructed frames. Y-PSNR reflects the difference between the original frame and the reconstructed one. The results indicate that due to network congestions, the single-path scheme suffers from severe PSNR degradations after streaming the video for 60 *s*. While the multi-path scheme maintains high PSNR for most of the streaming time, and ensures smooth video playback. But as it takes certain time for the NC&M system to response to a sudden bandwidth decrease, we can still see low PSNR values in the plot of the multi-path scheme.

V. Conclusion

In this paper, we built an experiment testbed using commercial routers and demonstrated QoS-aware multi-path SVC video streaming with it. The testbed consisted of six integrated services routers (Cisco 2900 Series) that were configured using a mesh topology. The experimental results indicated that the multi-path SVC video streaming scheme could reduce the packet loss rate (PLR) from 3.33% to 0.62% for the base layer (BL) packets, and to 1.71% for the enhancement layer (EL) packets. Additional experiments on video playback quality, video playback peak signal-to-noise ratio (PSNR), and delay jitter also verified that the multi-path scheme could outperform the single-path one significantly and utilize the network resources more efficiently.

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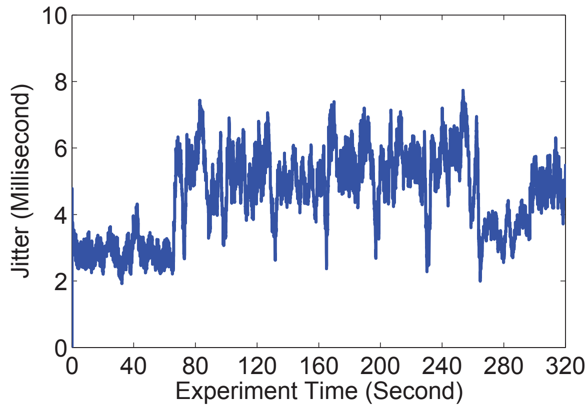
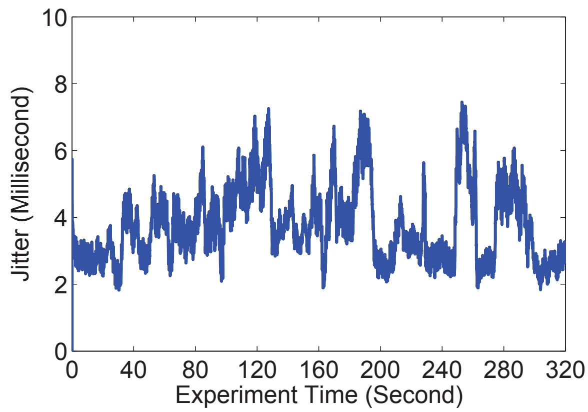


(a) Single-path scheme



(b) Multi-path scheme

Fig. 8. Experimental results on jitters

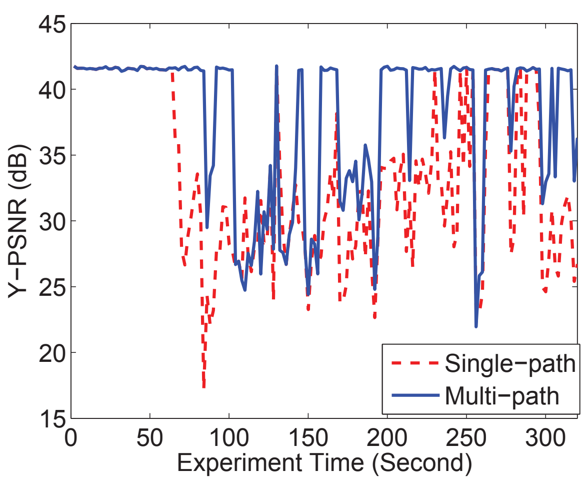


Fig. 9. Experimental results on PSNRs.

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